Fifth Study Conference on BALTEX

Kultuurivara
Kuressaare, Saaremaa, Estonia
4 - 8 June 2007

Conference Proceedings

Editor: Hans-Jörg Isemer

Jointly organized by
Estonian Maritime Academy
Marine Systems Institute at Tallinn University of Technology
Estonian Meteorological and Hydrological Institute
GKSS Research Centre Geesthacht GmbH

Conference Committee

Franz Berger, German Weather Service, Germany

Jüri Elken, Marine Systems Institute at Tallinn University of Technology, Estonia

Hans-Jörg Isemer, GKSS Research Centre Geesthacht, Germany

Daniela Jacob, Max-Planck-Institute for Meteorology, Germany

Sirje Keevallik, Estonian Maritime Academy, Estonia

Friedrich Köster, Danish Institute for Fisheries Research, Denmark

Joakim Langner, Swedish Meteorological and Hydrological Institute, Sweden (Chair)

Walter Leal, TuTech Innovation GmbH, Germany

Andreas Lehmann, Leibniz Institute of Marine Sciences, Germany

Juha-Markku Leppänen, HELCOM, Finland

Anders Omstedt, Göteborg University, Sweden

Jozef Pacyna, Norwegian Institute for Air Research, Norway

Jan Piechura, Institute of Oceanology PAS, Poland

Dan Rosbjerg, Technical University of Denmark

Markku Rummukainen, Swedish Meteorological and Hydrological Institute, Sweden

Bernd Schneider, Baltic Sea Research Institute Warnemünde, Germany

Benjamin Smith, Lund University, Sweden

Timo Vihma, Finnish Meteorological Institute, Finland

Hans von Storch, GKSS Research Centre Geesthacht, Germany

Ilppo Vuorinen, University of Turku, Finland

Preface

The science and implementation plans for BALTEX Phase II (2003-2012) are in place since 2004 and 2006, respectively. Therefore, the 5th Study Conference on BALTEX is a first possibility to review how these research plans have been adopted and implemented by the research communities at national and international levels. About 2/3 of the more than 120 papers presented at the Conference contribute to meeting the new objectives of BALTEX Phase II, which are related to climate and climate variability research, water management issues, and air and water quality studies. This appears to be a clear indication that the development of BALTEX into a broader environmental research programme focussed on the Baltic Sea and its huge catchment area is well underway.

For the first time, the Conference is conducted in co-operation with other organisations and programmes, which have a dedicated activity profile in areas where BALTEX research is contributing to, including HELCOM, the Baltic Marine Environment Protection Commission; LOICZ (Land-Ocean Interactions in the Coastal Zone), a core-project of the International Geosphere-Biosphere Programme (IGBP); the INTERREG IIIB Project ASTRA (Developing Policies and Adaptation Strategies to Climate Change in the Baltic Sea Region); the European Union's Sixth Framework Programme (FP6) Integrated Project ENSEMBLES (Ensemble-based predictions of climate changes and their impacts); and the FP6 Network of Excellence EUR-OCEANS (Network of Excellence for Ocean Ecosystem Analysis). The Conference will therefore offer a forum for exchange of ideas and planning of future joint initiatives and projects.

Timing and location of the Conference follow the BALTEX tradition: The conduction of international BALTEX Conferences on Baltic Sea islands in three years intervals. Following previous BALTEX Study Conferences on Gotland (1995), Rügen (1998), Åland (2001) and Bornholm (2004), the BALTEX community is assembling on the Estonian island of Saaremaa now in 2007 with the Cultural Centre *Kultuurivara* of the island's capital Kuressaare as the Conference venue.

This proceeding volume contains abstracts of all papers, both oral presentations and posters, given at the Conference. They are ordered according to the Conference sessions and the Conference programme.

The Conference was jointly organised by the Estonian Maritime Academy, the Marine Systems Institute at Tallinn University of Technology, the Estonian Meteorological and Hydrological Institute and the International BALTEX Secretariat at GKSS Research Centre Geesthacht, Germany. We thank Edith Kallaste and Kelly Otsman at Reisiekspert Ltd in Tallinn for local preparations of the Conference.

Geesthacht, June 2007

Hans-Jörg Isemer
Editor

Partners

HELCOM
Baltic Marine Environment Protection Commission

LOICZ
Land-Ocean Interactions in the Coastal Zone

ASTRA
Developing Policies and Adaptation Strategies
to Climate Change in the Baltic Sea Region

ENSEMBLES
Ensemble-based Predictions of Climate Changes
and their Impacts

EUR-OCEANS
European Network of Excellence
for Ocean Ecosystems Analysis

Sponsors

Estonian Maritime Academy

Marine Systems Institute
at Tallinn University of Technology

Estonian Meteorological and Hydrological Institute

SIDA - Swedish International Development
Cooperation Agency

GKSS Research Centre Geesthacht, Germany

Contents

Author Index

The World Climate Research Programme: Achievements and Future

Vladimir Ryabinin

Joint Planning Staff for WCRP, c/o WMO, 7 bis, Avenue de la Paix, Geneva, CH-1211 Switzerland
E-mail vryabinin@wmo.int

1. Achievements

In 2005 the WMO/ICSU/IOC WCRP celebrated its 25th anniversary. During 2004 - 2005 a lot of effort was invested into critical analysis of what the WCRP had achieved during quarter of a century of its existence and what and how needed to be done in the future. The thinking was summarized in a document entitled "Coordinated Observation and Prediction of the Earth System", which constituted the WCRP Strategic Framework for the years 2005-2015.

The document lists several specific achievements of the completed and ongoing WCRP projects, which include the development of the now operational ENSO observing system in the tropical Pacific and Indian Ocean, capability of meaningful seasonal prediction mostly associated with predictability originating from the tropics, unprecedented surveys of the global oceans and the Arctic, to name only a few. WCRP has worked both through its highly focussed projects, which produced major specific outcomes, and also acted as a think tank and facilitator of climate science development, especially in the area of atmospheric, oceanographic and coupled climate system observation, modelling, and data assimilation and reanalysis. A question remains though whether similar achievements could be reached and deliverables generated without the existence of a programme like the WCRP? The author tends to think that the knowledge that has been generated and exchanged within the climate research community, the drive that the projects like TOGA and WOCE relayed to the climate science, the guidance on model development, data assimilation and verification that came from the joint WCRP/WMO Commission for Atmospheric Sciences Working Group on Numerical Experimentation, the coordination of model runs for climate prediction provided by WCRO JSC / CLIVAR Working Group on Coupled Modelling do create the critical level of difference. Without WCRP, the climate science and assessments like IPCC reports would not be the same.

2. Thoughts about the future

At present the WCRP experiences certain difficulties. The programme structure based on projects is not fully optimised for integrating the results achieved by these projects. Many international programmes and organisations, and the WCRP is not an exception, operate under the principle of "zero nominal growth", which, due to inflation, in reality means less and less capacity. It has become therefore more and more difficult to allocate resources to meetings of experts and other coordination and support activities. In addition to this, the climate warming is now "unequivocal", and there is less and less to prove about its origin, so the decision makers to some extend feel that the role of the WCRP and similar programs may have been accomplished.

In terms of scientific challenges, there is still very much remained to do, and given below are several potential issues for consideration. They are based on personal views of the author, which have been forming under the strong influence of expressed thoughts of great WCRP thinkers. Nevertheless the statements below do not represent endorsed or official recommendations by the WCRP. By no means they can be considered complete.

Despite the significant progress in climate modelling, the ranges of uncertainty in climate prediction by WCRP models in the IPCC TAR and AR4 (2001 and 2007) remain nearly the same. For example, for the A2 scenario the models predict surface warming from 1.6^{o}C to 5.5^{o}C in TAR and from 2.0^{o}C to 5.5 in AR4. Six years of research resulted in narrowing the interval by approximately one/tenth. In the future, it will be important to include in the model runs all essential feedbacks and processes existing in the climate system, so that the only factors of uncertainty, apart from natural differences in models, would be due to the impact scenarios. Studying the relevant processes, learning how they "work" and can be either parameterised or expressed explicitly in models, perfecting the models and making them more comprehensive and all-encompassing remains a very important task for WCRP, and it requires a lot of international coordination. We need further progress in cryospheric and hydrological studies, understanding of and representation in models of interaction between clouds, radiation, and aerosols, impact of clouds on atmospheric chemistry, better understanding of marine biology and biogeochemistry, changing vegetation, and modes of variability and processes in the higher atmosphere. Addressing all these problems requires full strength of the Earth System science. Nevertheless, the problems in the traditional to WCRP "physical domain" of the natural sciences are far from being exhausted. The WCRP experience in meteorological modelling and numerical weather prediction (NWP), and, particularly, in model validation will help to quantify uncertainties in biogeochemical and biological models.

NWP is an operational activity and is highly optimised. Most of NWP operations are done in a well-defined sequence and are precisely documented. NWP research benefits very strongly from the rigorous estimation of forecast error and associated diagnostics. Climate prediction and research are much less organised and optimised than NWP. There is no scheduled subscription to many types of available satellite data. Only a fraction of satellite observation data flow is systematically used. Not all data sets have an error estimate and are available to science community. There is certain degree of duplication of effort. It seems that there must be a potential for considerably better organisation of the climate research and prediction activities. The WCRP Coordinated Enhanced Observing Period may serve as a prototype of such better organisation of the business. Better synchronised observation of the Earth System, validation of observations at a series of high standard reference sites, systematic production of required data records, which would be consistent with other records and have an estimate of accuracy, – these development would benefit climate research very significantly. WCRP should be able to facilitate such optimisation.

At a recent follow-up workshop to the International Conference on Arctic Research Planning (Copenhagen, 11-145 November 2005), one of the breakout groups was considering development of modelling and observations in cold climate regions. An idea emerged in the discussions that improved organisation of both terrestrial modelling and observations could follow watershed boundaries, which in such regions were controlled by geomorphology and soil (permafrost) distribution. This idea may lead to a general recommendation that new regional initiatives could follow the same principle whereas observations, regional model domain selection could be defined in accordance with hydrological considerations. In principle, a similar approach may be applied to regional oceanographic projects in marginal seas. Obviously, many existing regional projects like BALTEX, already follow such approach in their work. It is therefore more important that new regional projects consider its usefulness as well.

Predictability at longer than seasonal and interannual scales originates not only from the “physics” but is also associated with other domains of the Earth System. It is therefore expected that WCRP will cooperate more and more with the International Geosphere – Biosphere Programme and its projects. A potential merger of the programmes is being considered. Prediction of monsoons, long-term anomalies of temperature and precipitation, higher and lower intensity of tropical cyclones remains largely in the physical domain but according to the WCRP Task Force on Seasonal Prediction even seasonal forecasts need to be viewed on the background of longer-term climate change. WCRP is embarking on an effort to address also decadal prediction, which essentially deals with multi-year or decadal modes at atmospheric variability. So far, predictability exploited in seasonal forecasting schemes is the one related to tropical processes and mechanisms such as the El Nino – Southern Oscillation. Little is known firmly about the existence and nature of predictability of climate that would be related to processes in mid- and high- latitudes. Long-term feedbacks due to sea-ice- and snow cover anomalies, as well as other potential factors increasing predictability need to be explored very intensively.

The Earth System Science Partners work together in several ways. They organise major Open Science Conferences on Global Change, cosponsor some projects (e.g. WCRP and IGBP share the project “Surface Ocean – Lower Atmosphere Study” together with SCOR and CAGCP), organise joint projects (e.g. at present there are four joint projects on global carbon, water systems, food security, and human health). In addition, they undertake Integrated Regional Studies (IRS). Capacity and experience developed by the GEWEX Continental Scale Experiments (CSEs, now Regional Hydroclimate Projects) should represent considerable interest in this context to the ESSP. BALTEX is one of the most advanced CSEs. Not only it conducts comprehensive and coordinated measurements and regional modelling that would be typical to a GEWEX-type project. The scope of its activities is much wider. BALTEX develops a holistic look at the region of the Baltic Sea, reviews environmental changes occurring in it and their linkages to global processes, and helps to support the implementation of the a regional convention (HELCOM). It follows from the extremely positive experience by BALTEX, that former GEWEX CSEs have the potential of fulfilling the role of ESSP IRS.

3. Conclusions

Recent assessments have shown that the “cost of the climate change issue” is comparable in economic terms with significant fraction of national GDP. Most of the return on investment comes from mitigation of negative consequences of the climate change and adaptation to them. It should be realised, however, that the current uncertainties in climate predictions are very high, and a lot of resources will still be required to reduce them to a level enabling well informed specific decisions, both at the global and regional scale.

In order to be even more successful in the future, WCRP needs to achieve the following:

- continue fundamental research on climate predictability and anthropogenic climate change, role of oceans in climate, hydrological cycle, cryosphere and atmosphere including stratosphere;
- focus efforts on cross-cutting (for WCRP projects) issues like seasonal and decadal prediction of climate, monsoons, and climate extremes;
- achieve advances in understanding of chemistry - climate interactions and their inclusion in models and future emission scenarios;
- start addressing issues of adaptation to climate change and mitigation of its consequences;
- develop comprehensive regional activities;
- effectively and efficiently interact with other global change programmes;
- develop partnerships with relevant key players; and
- be proactive in promoting the WCRP and demonstrating convincingly to decision makers and general public its role for the coordination and facilitation of global change research and major assessments.

GEWEX Coordinated Energy and Water Cycle Observations Project (CEOP)

John Roads

Scripps Institution of Oceanography, Univ. CA, UCSD-0224, La Jolla, CA 92093, jroads@ucsd.edu

Abstract

When the Global Energy and Water-cycle Experiment (GEWEX) began in 1988, its lead scientists recognized that global data sets needed to be evaluated at regional scales (Sorooshian et al. 2005). At the same time, significant improvements were being made to land surface models as a result of regional experiments being carried out by the GEWEX International Satellite Land Surface Climatology Project (ISLSCP) and and the International Geosphere-Biosphere Programme (IGBP). As a result of the convergence of GEWEX interests for a regional test bed, the need to scale up ISLSCP land surface studies to larger geographical areas, and the desire of the International Association of Hydrological Sciences (IAHS) to involve hydrology more actively in climate research, the concept of a continental scale hydrologic experiment was developed in 1990 and a group of international experts recommended the Mississippi River Basin as an initial focus area. Subsequently several other Continental Scale Experiments (CSEs), including BALTEX (BALTic sea EXperiment) were developed.

GEWEX established the GHP (ca.1994) to coordinate these CSEs (Lawford et al. 2004). The Coordinated Enhanced Observing Period (‘*CEOP’*) was part of the initial GHP strategy to coordinate the diverse GEWEX CSE activities to understand and model the influence of continental hydroclimate processes on the predictability of global atmospheric circulation (Stewart et al. 2001a,b, Leese et al. 2001). *‘CEOP’* was eventually moved from GHP and GEWEX (ca. 2001) by the World Climate Research Programme (WCRP) to become “an element of WCRP initiated by GEWEX” (Koike 2004). ‘*CEOP’* continued to be strongly supported by GHP and soon many GHP science activities became actively entrained within ‘*CEOP’*, in part through data management and modeling activities and in part through parallel science working groups.

Now, initially ‘*CEOP’* was a pilot experiment, designed to intensively study a limited time period, 7/1/2001-12/31/2004, a period when many CSEs had corresponding intensive observation periods and a time when many of the new Earth Observing Satellites were providing a wealth of new information (Lawford et al. 2006). With the demonstrated uniqueness of ‘*CEOP’* Phase 1 and advent of ‘*CEOP’* Phase 2, which will extend the time period and enhance the science agenda, it has now become clear that ‘*CEOP’* will contribute to the scientific objectives of GEWEX and integrated data management activities of WCRP for a much longer term. As a result, GEWEX, in full agreement with the GHP, and with ‘*CEOP’*, is now merging GHP and ‘*CEOP’* to form a new entity, tentatively designated the **Coordinated Energy and water cycle Observations Project (CEOP)**. This formal merger is meant to enhance the efforts of both GHP and ‘*CEOP’* and not lose sight of any of the GHP strategic goals or any of the ongoing GHP science work.

Information about the new CEOP (Roads et al. 2007) and the role of BALTEX will be provided at the Conference.

References

Koike, T., 2004: The Coordinated Enhanced Observing Period – An initial step for integrated global water cycle observations. WMO Bull., 53, 115-121.

Lawford, R., R. Stewart, J. Roads, H. Isemer, M. Manton, J. Marengo, T. Yasunari, S. Benedict, T. Koike, S. Williams, 2004: Advancing global and continental scale hydrometeorology: Contributions of the GEWEX Hydrometeorology Panel (GHP). *Bull. Amer. Soc.*, 1917-1930

Leese (and others) 2001: CEOP Implementation Plan. http://monsoon.t.u-tokyo.ac.jp/ceop/Implement.html

Lawford, R., M. Bosilovich, S. Eden, S. Benedict, C. Brown, A. Gruber, P. Houser, T. Meyers, K. Mitchell, J. Roads, M. Rodell, Sorooshian, S., Tarbley, D., S. William, 2006: US Contributions to the Coordinated Enhanced Observing Period, Bull. Amer. Soc., July 2006.

Roads, J., S. Benedict, T. Koike, R. Lawford, S. Sorooshian, 2007: Towards a new Coordinated Energy and water-cycle Observations Project (CEOP): Integration of the Coordinated Enhanced Observing Period (formerly known as *‘CEOP’**) and the GEWEX Hydrometeorology Panel (GHP). CEOP Project Office, 9 pp.

Sorooshian, S., R. Lawford, P. Try, W. Rossow, J. Roads, J. Polcher, G. Sommeria, and R. Schiffer, 2005: Water and energy cycles. : Investigating the links. WMO Bull., 54, 58-64.

Stewart, R.E., J. Leese and T. Koike, 2001a: CEOP science plan and overall strategy, GEWEX project office, 13 pp.

Stewart, R.E., J. Leese, T. Koike and R. Lawford, 2001b: CEOP implementation beginning. BAHC/GEWEX News Joint Issue, 3-4.

Common Research Interests for LOICZ and BALTEX in the Baltic Sea Area

Jozef M. Pacyna, Chair of the LOICZ SSC

Norwegian Institute for Air Research (NILUL), Instituttveien 18, P.O. Box 100, NO-2027 Kjeller, Norway.
E-mail: jp@nilu.no

1. LOICZ mission and objectives

The world's coastal zone forms a variable, multi scale boundary between land and ocean highly valued by human societies. Since 1993 Land-Ocean Interactions in the Coastal Zone (LOICZ) (www.loicz.org) is a core project of the International Geosphere-Biosphere Programme (IGBP) on Global Change of ICSU studying this heterogeneous, relatively small but highly productive, dynamic and sensitive area of the earth's surface. Since 2003 while working on its first decade synthesis LOICZ I transitions into LOICZ II which is expected (with a life time until at least 2012) to be the key research contributor dealing with multiple scale transboundary processes of global coastal change including the human dimensions. LOICZ II will therefore have a new position in the Earth System Science Partnership of the IGBP, IHDP, WCRP and DIVERSITAS.

Consequently in early 2004, LOICZ II has come under the wings of a second parent, the International Human Dimensions Programme for Global Environmental Change, IHDP. The joint sponsorship formalizes a major shift from biogeochemical cycling in the coastal zone into a broader charge of studying human-environment interactions in the global coast. The LOICZ II focus will be centered on 4 characteristics / activities:

1. LOICZ is global;
2. LOICZ aims to provide a broader context for the coastal zone outside of traditional natural and social science boundaries. This inherently means to make LOICZ the major reference point for coastal change and use scenarios providing the underlying typologies, which capture the multiplicity of scales of forcing functions (Drivers) and institutional and human dimensions of state change, impact and response;
3. LOICZ provides a synthesis across disciplines and geography and across the global, regional, national and local scale;
4. LOICZ can visualize different outputs to be communicated beyond the immediate peer group, i.e. it can evolve to a portal for both Earth Systems Science questions and multiple stakeholder groups beyond the purely scientific arena;

LOICZ specific goals include:

1. To contribute to Earth System science by researching the relevance and impact of global change on coastal systems – a global-scale commitment.
2. To make scientific knowledge on the scales of coastal change and the options for sustainable use available to policy makers, managers and stakeholders – an issue driven commitment.
3. To develop a research framework for interdisciplinary analysis of existing information, and generation of new research, integrating biogeochemical, biophysical and human components of coastal systems.
4. To provide within this research framework, a flexible infrastructure able to respond to new research demands that includes and integrates disciplines of natural and social sciences.
5. To develop a framework for science dissemination, outreach and capacity building that encourages participation by scientific and non-scientific communities at local, national, regional and global scales.
6. To provide a global platform to facilitate and coordinate international, regional and national coastal research initiatives, that improves the design and implementation of observation and research networks.

LOICZ II science themes are as follows:

Theme 1: Vulnerability of coastal systems and hazards to society sets the stage for the subsequent themes which address the wider coastal domain. It considers the hazards to humans from coupled human-ecosystem change, carrying capacities and vulnerability issues, including the risk of degrading the sustainability of coastal goods and services.

Theme 2: Implication of global change for coastal ecosystems and sustainable development focuses on conflicting spatial, temporal and organizational issues of coastal change, land and sea use, and how these exert pressures on coastal systems and influence natural resource availability and sustainability.

Theme 3: Human influences on river basin-coastal zone interactions considers river basin drivers/pressures that influence and change the coastal domain. The whole water continuum is considered as a single system. Processes of material transport to the ocean, and human influences due to activities in the Exclusive Economic Zone (EEZ), are considered through links to Themes 2 and 4.

Theme 4: Biogeochemical cycles of coastal and shelf waters focuses on the cycling of carbon, nutrients and sediments in coastal and shelf waters, and their exchange with the ocean. This recognizes the vital and changing benthic processes of coastal waters that influence shelf ecosystems and global chemical cycles.

Theme 5: Towards coastal system sustainability by managing land-ocean interactions integrates across the other four themes, and provides a platform for considering coastal zone development and management (including resource users) in the context of "strong" and "weak" sustainability options.

LOICZ Topics include:

Topic 1: What are the implications of ecological and economic change for patterns of land and sea use?

This topic encapsulates much of the content of Themes 1, 2 and 5 of the LOICZ science plan. The ecosystem approach (underlying 'ecosystem based management') regards humans to be an integral part of current natural systems. There are large numbers of deterministic and stochastic models that examine various facets of the natural environment, and similarly large numbers of models dealing with human social systems. However, there have been very few attempts to couple them together into a single socio-ecological system that consider the system to consist of an assemblage of interdependent life forms - including humans - and their non-living habitats and resource base, the integrity of which is highly dependent upon human decisions.
Work within this topic focuses on:

(1) Conceptual modelling
LOICZ explores how models can incorporate dynamic interpretations of data and source empirical data to populate models.

(2) Quantitative models
Mechanistic or stochastic models operate at various different scales and levels of complexity and this topic explores how scale affects system properties requirements for data as well as mixed methodology approaches to accommodate the entire scale of systems.

Topic 2: What are the effects of changes to the flow of freshwater and materials to estuaries and shelf seas?

This topic encapsulates much of the content of themes 3 and 4 of the LOICZ science plan, 1) examining the changes in loads associated with human activities in coastal watersheds as well as other human-induced effects, and 2) examining the response of coastal and shelf ecosystems to these changes. To the extent that we can extend or develop LOICZ approaches to apply to coastal governance, activities under this topic will also address theme 5 of the LOICZ science plan.
Runoff, groundwater flows, nutrient and sediment loads are all affected by human activity and especially human-induced changes in climate and landuse. These may be addressed using a variety of relatively simple analytical tools, including nutrient accounting approaches and large-scale hydrologically based models. Several activities are proposed to extend existing approaches either geographically or methodologically, to permit estimation of nutrient loads, their uncertainty and variation.
The response of coastal and shelf systems has been addressed in LOICZ I by estimating the metabolism of coastal and shelf ecosystems using the LOICZ budget methodology. This methodology will be refined and extended under LOICZ II, and specifically in an attempt to address issues of coastal sustainability and governance.

Topic 3: How can comparative analysis inform the improvement of the governance of human activities in changing coastal ecosystems?

This question integrates across the five themes of the LOICZ Science Program. It addresses the primary goal of LOICZ II: "to provide knowledge, understanding and prediction to allow *coastal communities* to assess, anticipate and respond to the interaction of global change and local pressures in determining coastal change". A coastal community is defined to include policy makers, managers and stakeholders. The term "coastal ecosystems" embraces large marine ecosystems (LMEs), coasts and their associated watersheds.
The approach will be to select sites for an analysis of success factors in bridging between ecosystem science and governance. The analysis will focus upon successes and failures in instigating the changes in human behavior (institutions, markets and civil society) that mark the implementation of a coastal ecosystem management initiative. In all cases the analysis will examine coastal governance within the context of the next larger system – a watershed, a Large Marine Ecosystem or geographic region.

2. LOICZ and BALTEX together in the Baltic Sea region

Major subjects of cooperation between LOICZ and BALTEX are described in the BALTEX II (2003 – 2012) Science Framework and Implementation Strategy. This document focuses on research addressing two main objectives of BALTEX II:

- climate variability and change, and
- gradual extension to water and quality studies.

LOICZ, through its European contribution from the ELOISE (the EU European Land-Ocean Interaction Studies) framework http://www2.nilu.no/eloise) of more than 60 projects has collected a wealth of data on coastal zone structure and functioning in the Baltic Sea region. A number of models were developed to study the impacts of socio-economic changes in major European catchments on the water quality in the coastal areas, also the Baltic Sea coasts. These data and models form the basis for cooperation between LOICZ II and BALTEX II also within the remaining BALTEX II objectives on:

- energy and water cycles in the Baltic Sea basin,
- further development of tools and models for water management, and
- interactions with decision makers in the Baltic Sea region.

A cross-cutting issue of capacity development, including education is another very important area for cooperation between the two projects. LOICZ II is ready to share with BALTEX II its experience in teaching university course on coastal zone management, such as the Erasmus Mundus Programme on coastal zone. The ELOISE experience in developing information digests for academia and policy makers along major coastal zone research subjects can also proposed when building within BALTEX II various procedures of education and outreach at the international level.

Perfomance of an Ensemble of RCMs over the BALTEX Area from the Inter-Continental Transferability Study (ICTS)

B. Rockel[1], B. Geyer[1], R. W. Arritt[3], J. McGregor[6], W. J. Gutowski Jr.[3], C. G. Jones[4], I. Meinke[2], D. Paquin[5], J. Roads[2], E. S. Takle[3], U. Willén[7]

[1]GKSS Research Centre, Geesthacht, Germany, Burkhardt.Rockel@gkss.de
[2]Scripps Institution of Oceanography, UCSD, La Jolla, CA USA, [3]Iowa State University, Ames, IA USA, [4]Université du Québec à Montréal Canada, [5]Ouranos, Canada, [6]CSIRO, Australia, [7]SMHI, Sweden

1. Introduction

In 2001 an initiative started to bring together the continental scale experiments within GEWEX (Global Energy and Water Experiment, http://www.gewex.org/) in a coordinated experiment (CEOP, http://www.ceop.net/). The main time period of the first phase of this experiment was October 2002 to December 2004. During this time period data from reference sites, global analyses of the main weather centres around the globe, and satellite date were collected and stored in three central data archives for free access to the scientific community.
Controlled numerical simulations of regional climates are currently being conducted over locations having fundamentally different climate regimes (e.g., tropical, midlatitude, polar). In particular, ICTS (http://icts.gkss.de/) contributes continuous multiple regional simulations to the CEOP model archive and in turn uses the CEOP global analyses, in situ, and satellite data to evaluate these regional simulations.
Presently seven centers with eight models (seven RCMs and one GCM, see Table 1) are actively contributing to the ICTS.

Model	Institute
CLM	GKSS Research Centre (Germany)
CRCM	Ouranos (Canada)
GEM-LAM	RPN/MSC and University of Quebec (Vanada)
MM5	Iowa State University (U.S.)
RCA3	Rossby Centre, SMHI (Sweden)
RegCM3	Iowa State University (U.S.)
RSM	ECPC (U.S.)
C-CAM	CSIRO (Australia)

Table 1. Participating models and institutes in ICTS

2. Model Setup

For ICTS seven computation areas were defined over the different RHPs (Regional Hydrology Projects, formerly known as Continental Scale Experiments) (Figure 1). MAGS (Mackenzie GEWEX Study), GAPP (GEWEX Americas Prediction Project), LBA (Large-Scale-Biosphere-Atmosphere Experiment in Amazonia) and LPB (La Plata Basin), BALTEX, AMMA (African Monsoon Multidisciplinary Analysis), GAME (GEWEX Asian Monsoon Experiment), and MDB (Murray-Darling-Basin Water Budget Project).
The horizontal resolution of the regional models was chosen to be 50 km. The simulation period is from July 1999 to December 2004. This covers the three observation periods of CEOP phase 1. Driving data for the RCMs are from the National Center for Environmental Prediction (NCEP) Department of Energy (DOE) Reanalysis II and the European centre for Medium range weather Forecast 40-year reanalysis (ERA40). Additional simulations on selected regions with higher horizontal resolution are under discussion for future simulations.
Time series of several surface and atmospheric quantities are stored as 3 hourly MOLTS (Model Output Location Time Series) for CEOP reference sites (red dots in Figure 1). Gridded data common 0.5x0.5 degree grids are stored as daily mean time series (rectangles in Figure 1).

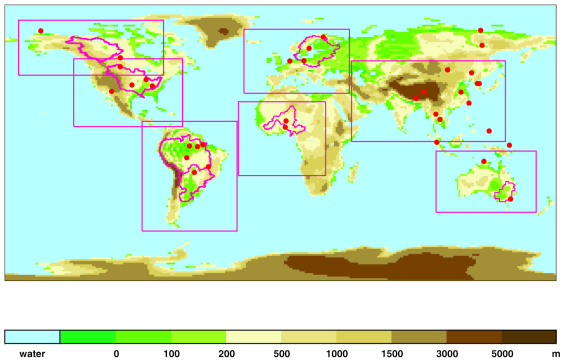


Figure 1. ICTS model domains.

3. Simulations

The main focus of the data analysis is on the CEOP phase 1 EOP-3 and EOP-4 (October 2002 – December 2004) which covers two annual cycles. Latest results from the ICTS simulations will be presented. The main focus in the first part of the presentation will be on the performance of the RCMs regarding the energy and water cycle over the BALTEX catchment area in comparison to observations (e.g. reference sites) and global model analysis data. In the second part a comprehensive overview of the results for the other RHPs will be given.
Snap shots of first results are in Rockel et al. (2005) and Takle et al. (2007).

References

Rockel, B., I. Meinke, J. Roads, W.J. Gutowski, Jr., R.W. Arritt, E.S. Takle, C. Jones, The Inter-CSE Transferability Study, *CEOP Newsletter,* No. 8, 2005.

Takle, E.S., J. Roads, B. Rockel, W.J. Gutowski Jr., R.W. Arrit, I. Meinke, C.G. Jones, and A. Zadra, Transferability intercomparison: An opportunity for new insight on the global water cycle and energy budget, *Bull. Amer. Soc.*, in print, 2007

BALTEX Contribution to GEWEX:

Independent Estimates of the Water and Energy Budgets in the Baltic Sea Region?

Daniela Jacob

Max-Planck-Institute for Meteorology, Bundesstrasse. 53, 20146 Hamburg, Germany (daniela.jacob@zmaw.de)

1. Introduction

BALTEX was launched in 1992 as a Continental-scale Experiment (CSE) of the Global Energy and Water Cycle Experiment (GEWEX) within the World Climate Research program (WCRP). GEWEX (http://www.gewex.org) has been initiated to observe, understand and model the hydrological cycle and energy fluxes in the atmosphere, at land surface and in the upper oceans. The goal of GEWEX is to reproduce and predict, by means of suitable models, the variations of the global hydrological regime, its impact on atmospheric and surface dynamics, and variations in the regional hydrological processes and water resources and their response to changes in the environment. While GEWEX phase I concentrated on determination and modeling of the global hydrological cycle and energy fluxes, GEWEX phase II now investigates possible changes in the Earth's energy budget and water cycle.

Intensive studies of specific hydrological region are carried out within the Continental-scale Experiments (CSE), like BALTEX.

2. Water and energy budget synthesis (WEBS)

During the past several years, GEWEX CSEs began to develop water and energy budget synthesis, which were build on global and regional modeling efforts to complement observations. Major achievements have been made to determine uncertainties in the water cycle and energy fluxes, see for details: http://ecpc.ucsd.edu/projects(ghp/WEBS .

Now, one goal is to determine the accuracy of available global re-analyses data sets, using budgets derived from observations. Two time periods are under investigation: 1996 to 2000, and a longer period starting in the early 80s.

3. GEWEX-related Milestones for BALTEX Phase II

BALTEX phase can directly contribute to GEWEX with a number of activities in objectives 1 to 3. Here we focus on objective 1, related to better understanding of the water and energy cycles, for which four milestones are planned, see BALTEX phase II: Science Framework and Implementation Strategy.

By the end of 2008, independent estimate of the water and energy budgets over land and sea, based on observations, re-analyses products and model results, should be completed for the time period 1980 to 2005. They will serve as input to GEWEX CSE-related activities.

4. Working group activities

During the last year a new working group has been established, to achieve the budget as a contribution to GEWEX as mentioned above. This core group initiates, collect and synthesizes studies of budgets, to analyze and understand the variability of the water and energy budgets on different time periods, 1999-2003, 1980-2005, 1960-2000 and 1900-2100.

For the analysis observations, as well as modeling results will be taken into account and the BALTEX phase I idea to determine the so-called **BALTEX box**, will be used. If possible, sums of precipitation, evaporation and runoff will be calculated for the land part fraction of the Baltic Sea catchments area and for the area of the Baltic Sea itself (except for runoff).

A first synthesis from the literature and several modeling experiments will be presented, including ERA15, ERA40 and regional model results driven by ERA40 and ERA15 performed within the ENSEMBLES project.

Investigation of the Water and Energy Budgets in the BALTEX Area, as Simulated in a Regional Climate Model

Petter Lind[1] and Erik Kjellström[1,2]

[1]Department of Meteorology, Stockholm University, SE-10691 Stockholm, peli0688@student.su.se
[2]Swedish Meteorological and Hydrological Institute, SMHI, SE-60176 Norrköping, Sweden

1. Introduction

The main goal of the Global Energy and Water Experiment is to improve the knowledge of the water and energy budgets on a global, regional and local scale. Quantifying the various storage and flux components and thereby closing the water and energy cycle has not yet been estimated successfully (e.g. *Roads,* 2002 and *Hagemann et al.,* 2005). This is partly due to the lack of reliable observations of precipitation and evaporation (*Roads,* 2002). A major aim in GEWEX and related projects is therefore to improve the models ability to reproduce the water and energy budgets accurately, and an important key feature in this aspect is to compare model results to observations.

The best closure may be achieved using a reanalysis system. Ruprecht used the NCEP/NCAR reanalysis data to evaluate the water budget in the BALTEX area (*Ruprecht et al.,* 2003). The results did not, however, close the water budget, and the proposed reasons for the imbalance were twofold. Firstly, the amount of rainfall was underestimated in the BALTEX region, which led to too large values of evaporation minus precipitation. The second problem was the large errors in mass budget terms in mountain areas, which could be due to the coarse resolution, and thus a too smooth topography. Another dataset is the ECMWF reanalysis ERA40 (*Uppala et al*., 2005). It has been shown that ERA40 reproduces observed features of the precipitation distributions in the BALTEX area while evaporation is partly overestimated (*Hagemann et al.,* 2005).

In order to more accurately reproduce the water and energy budget in a specific region, regional models with higher resolution may be used. In this study we analyze results from dynamical downscaling of ERA40-data with the regional climate model RCA3 (*Kjellström et al.,* 2005) in the BALTEX area.

2. The regional model

RCA3 is a regional climate model that includes a description of the atmosphere and its interaction with the land surface. It includes a land surface model (*Samuelsson et al.,* 2006) and a lake model, PROBE (*Ljungemyr et al.,* 1996). Given realistic boundary conditions (i.e. reanalysis products like ERA-15 and ERA-40) RCA3, and its predecessor RCA2, have been found to reproduce regional scale climate conditions of standard variables like 2m-temperature, precipitation and wind speed (*Jones et al*., 2004, *Kjellström et al*., 2005).

3. Experiment description

RCA3 is used in an experiment that covers the time period from January 1961 to August 2002 Lateral boundary conditions, sea-surface temperatures and sea-ice conditions are taken every six hours from the ERA40 dataset. The ERA40-data was downloaded on a 2^{o} horizontal resolution and with 60 vertical levels of which we used levels 13-60 covering the vertical domain between the surface and 10 hPa. The ERA40-data was interpolated both horizontally and vertically to the RCA grid. In the experiments RCA3 runs at approximately 50x50 km horizontal resolution and 24 levels in the vertical with a time step of 30 minutes. Additional details about the experiment and results of it can be found in *Kjellström et al. (2005)*.

4. Observational data sets and method of analysis

The present-day climate in the model is evaluated against different observational data sets. In comparison to earlier studies with RCA3 the analysis includes more data sets and now looks more specifically into the BALTEX area. Some of the datasets that will be used are; the Global Precipitation Climatological Project (GPCP, *Adler et al.*, 2003), the CPC Merged Analysis of Precipitation (CMAP, *Xie and Arkin*, 1997) and the Mesoscale Analysis from the Swedish Meteorological and Hydrological institute (MESAN, *Häggmark et al*., 2000). The latter is a product derived through a meso-scale assimilation of synoptic observations with an operational short-range weather forecast model. Data from MESAN are available at 22x22 km horizontal resolution with a 1-hourly temporal resolution.

To study the water cycle in the BALTEX area, vertically integrated water budget components are computed and analyzed in the budget equation, both for the various observational datasets (including now also ERA40 and MESAN), and compared to RCA3 results. The full budget equation relates the total (atmospheric plus surface) water change with time to atmospheric moisture convergence, precipitation, evaporation and surface runoff. An example of model output that will be scrutinized can be seen in Figure 1 showing summer mean precipitation minus evaporation in parts of northern Europe.

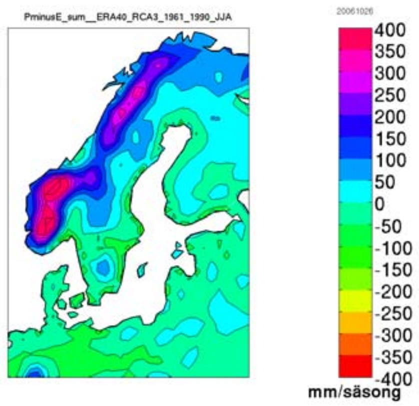


Figure 1. Precipitation minus evaporation during summer (June-August), for the time period 1961-1990. Unit: mm per three months.

A similar budget calculation will be performed for the energy budget. Here, the budget terms include the sensible and latent heat fluxes, net short and long wave radiation, ground heat fluxes and storage terms. The spatial and temporal changes in the budget components will be analyzed in terms of annual means, seasonal cycles and inter-annual variability.

5. Preliminary results

The reanalysis-driven experiment is compared to the ERA40 dataset itself. It is therefore to be expected that the RCA3 results should not diverge too much from this reanalysis experiment, but as the resolution differs, and because of different representation of several parameterizations in the global and regional models, and also due to the lack of data assimilation in the regional model, some deviations are unavoidable.

RCA3 has been shown to reproduces the seasonal mean values in specific geographical regions better than ERA40, especially at the Norwegian Atlantic coast (*Kjellström et al.*, 2005). In all high-altitude areas RCA3 simulates more precipitation than what is given by ERA40 as a consequence of the higher horizontal resolution. But, differences between the two datasets are not restricted to mountainous areas. One other example of an improvement in the RCA3 results as compared to ERA40 can be found in Figure 2 illustrating the seasonal cycle of precipitation over the Baltic Sea.

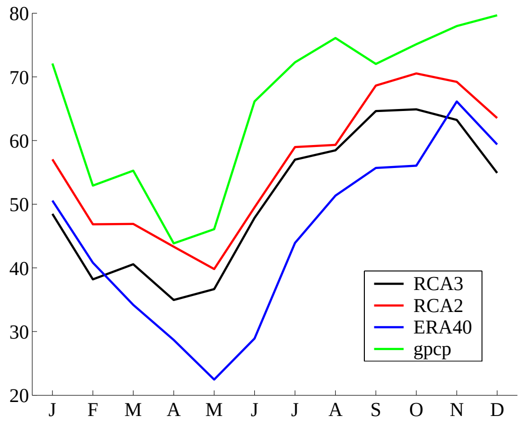


Figure 2. Seasonal cycle of precipitation over the Baltic Sea including Kattegatt in RCA3 and RCA3, both forced with ERA40, ERA40 and as observed by GPCP.

6. Concluding remarks

RCA3 has previously been shown to reproduce main features of the climate in regions like the BALTEX area. This applies both for averages over years and seasons, but also for higher variability on the synoptic scale. We therefore trust that the model can provide important additional information about the components constituting the heat and water budgets in the BALTEX areas. In a companion paper (*Kjellström and Lind*, 2007) we investigate the climate change signal in these budget terms in a couple of regional climate change experiments.

References

Adler, R.F., G.J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, and P. Arkin, 2003. The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present). *J. Hydrometeor*., 4,1147-1167.

Førland, E. J. & Hanssen-Bauer, I., Increased Precipitation in the Norwegian Arctic: True or False?, Clim. Change, 46, 485-509, 2000

Hagemann, S., Arpe, K. And Bengtsson, L., Validation of the hydrological cycle of ERA-40, *ERA-40 Project Report Series (ECMWF)*, No. 24, 2005

Häggmark, L., Ivarsson, K-I., Gollvik, S. and Olofsson, P-O., Mesan, an operational mesoscale analysis system, *Tellus*, 52A, 2-20, 2000

Jones, C.G., Ullerstig, A., Willén, U. and Hansson, U., The Rossby Centre regional atmospheric climate model (RCA). Part I: Model climatology and performance characteristics for present climate over Europe, *Ambio*, 33, pp. 199-210, 2004

Kjellström, E., Bärring, L., Gollvik, S., Hansson, U., Jones, C., Samuelsson, P., Rummukainen, M., Ullerstig, A., Willén U. and Wyser, K., A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). SMHI Reports Meteorology and Climatology No. 108, SMHI, SE-60176 Norrköping, Sweden, 54 pp., 2005

Kjellström, E., and Lind, P. Changes in the water and energy budgets in the BALTEX area in future warmer climates. Submitted to the fifth study conference on BALTEX, Kuressaare, Saaremaa, Estonia, 4-8 June 2007

Ljungemyr P., Gustafsson N. and Omstedt A., Parameterization of lake thermodynamics in a high-resolution weather forecasting model. *Tellus*, 48A, 608–621, 1996

Roads, J., Closing the water budget, *GEWEX Newsletter*, 12, 1, pp. 1-2 and 6-8, 2002

Ruprecht, E. and Kahl, T., Inv of the atmospheric water budget of the BALTEX area using NCEP/NCAR reanalysis data, *Tellus*, 55A, 426-437, 2003

Samuelsson, P., Gollvik, S. and Ullerstig, A., The land-surface scheme of the Rossby Centre regional atmospheric climate model (RCA3). *Report in Meteorology 122*, SMHI. SE-601 76 Norrköping, Sweden, 2006

Uppala, S. M., P.W. Kållberg, A.J. Simmons, U. Andrae, V. da Costa Bechtold, M. Fiorino, J.K Gibson, J. Haseler, A. Hernandez, G.A. Kelly, X. Li, K. Onogi, S. Saarinen, N. Sokka, R.P. Allan, E. Andersson, K. Arpe, M.A. Balmaseda, A.C.M. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, S. Caires, F. Chevallier, A. Dethof, M. Dragosavac, M. Fisher, M. Fuentes, S. Hagemann, E. Holm, B.J. Hoskins, L. Isaksen, P.A.E.M. Janssen, R. Jenne, A.P. McNally, J.-F. Mahfouf, J.-J. Morcrette, N.A Rayner, R.W. Saunders, P. Simon, A. Sterl, K.E. Trenberth, A. Untch, D. Vasiljevic, P. Viterbo and J. Woollen, The ERA-40 Re-analysis, *Q. J. Roy. Meteorol. Soc.*, 131, 2961-3012, 2005

Xie, P., and P.A. Arkin, 1997: Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. Bull. Amer. Meteor. Soc., 78, 2539 - 2558.

The Contribution of the BALTEX In-situ Reference Sites to CEOP

Frank Beyrich [1], Wolfgang Adam [1], Fred Bosveld [2], Jani Poutiainen [3] and Tarja Savunen [3]

[1] German Meteorological Service (DWD), Meteorological Observatory Lindenberg / Richard-Aßmann Observatory, Lindenberg, Germany, (email: frank.beyrich@dwd.de)
[2] Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
[3] Finnish Meteorological Institute (FMI), Helsinki, Finland

1. Introduction

The Coordinated Enhanced Observing Period (CEOP) has been developed and implemented within the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP) with the fundamental aim to establish an integrated global observing system for the water cycle which responds to both scientific and social needs of the human society. The CEOP implementation strategy includes the collection, central archiving and management of

- data from the full spectrum of available experimental and operational satellites (e.g., NOAA-AVHRR, TRMM, LandSat, Terra, Aqua, EnviSat, ADEOS-II),
- model output products from leading numerical weather prediction and climate modelling centres around the world, and
- comprehensive land surface / atmosphere data sets collected at a number of world-wide distributed reference sites.

During the first phase of CEOP data have been collected over a time period of two consecutive full-year cycles (October 2002 to December 2004).

2. The BALTEX reference sites in CEOP

The in-situ reference sites contributing to CEOP have been nominated by the various Continental Scale Experiments (CSEs) within GEWEX with BALTEX representing the European continental-scale water cycle studies. Three sites from the BALTEX study area submitted the full spectrum of data sets defined for CEOP, namely Sodankylä (Finland), Cabauw (The Netherlands), and Lindenberg (Germany). These sites represent different major climate and vegetation regions in the BALTEX study domain (see Table 1).

Table 1
BALTEX in-situ reference sites for CEOP Phase 1

	Sodankylä	Cabauw	Lindenberg
Location	67.4°N, 26.7°E	52.0°N, 4.9°E	52.2°N, 14.2°E
Elevation	179 m	-1 m	73 m
Climate	sub-arctic	temperate, dominating marine influence	temperate, transition from marine to continental influence
Vegetation	boreal forest	mainly grassland	mixed farmland / forest

The Lindenberg data sets comprise measurements from two stations in the area around the Meteorological Observatory Lindenberg / Richard-Aßmann Observatory representing the two dominant types of land use, namely farmland and forest (note that the co-ordinates given in Table 1 correspond to the Lindenberg – Falkenberg low vegetation site).
Data sets were submitted from the in-situ reference sites to the CEOP Central Data Archive (CDA) which is managed by the Earth Observing Laboratory (EOL) of the National Center for Atmospheric Research (NCAR) (see at http://www.eol.ucar.edu/projects/ceop/dm/). They include

- standard surface meteorology and radiation data
- soil temperature and soil moisture profiles
- energy fluxes
- tower profile data
- high-resolution radiosonde data.

All data are quality-controlled according to procedures implemented at the institutions of the data providers, and they are available in a common data format.
Upon request, additional data could be made available from the European reference sites such as profiles of mean atmospheric state variables measured with ground-based remote sensing systems (e.g., wind profiler, microwave radiometer profiler), cloud parameters (from ceilometer or cloud radar measurements) or additional radiation and aerosol parameters (UV radiation, aerosol optical depth). These data are not part of the CEOP data sets, they are not available for each of the sites, and the formats have not been harmonized.

3. Data example

An example of the annual cycle of both mean climate variables and energy fluxes for the three BALTEX-CEOP reference sites has been recently presented in Beyrich et al. (2006). They have shown that the temperature and global radiation curves for Sodankylä are mainly governed by the high latitude, while smaller differences between Cabauw and Lindenberg have to be attributed to the decreasing marine influence when moving from The Netherlands to Eastern Germany. Larger differences could be noticed for the turbulent energy fluxes. In addition to deviations in the absolute values, significant differences also exist between the sites concerning the partitioning of the available energy between the sensible and latent heat fluxes. This is illustrated in Figure 1 showing the annual cycle of the Bowen ratio (i.e., the mean ratio between the sensible and latent heat fluxes) for the different measuring sites.
From Figure 1, it becomes obvious that the variability of the Bowen ratio (Bo) during the period from March till October is most pronounced at Sodankylä. High values specifically occur during early spring when there is still snow at the surface resulting in low values of evaporation. Moreover, low sun elevation angles cause effective heating of the crown region of the needle-leaf trees resulting in increased turbulent transport of sensible heat. A slight dominance or at least the same magnitude of H when compared with LE can also be found for the measurements from the Lindenberg forest station during spring.

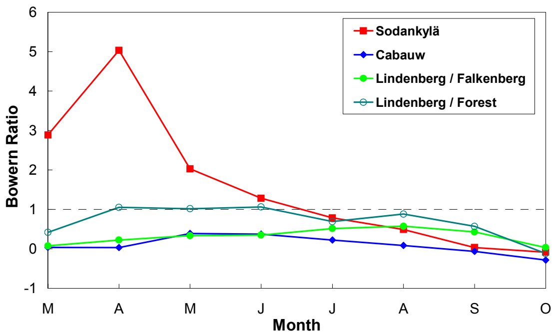


Figure 1. Monthly mean values of the Bowen ratio (Sensible devided by latent heat flux) at the CEOP reference sites Sodankylä, Cabauw, and Lindenberg during the period March till October 2004

On contrary, LE is dominant over H (Bo < 1) for the Cabauw and Lindenberg - Falkenberg measurements during most of the vegetation period. The soil at Cabauw is well supplied with water throughout most of the year resulting in the lowest Bo values, while drying of the soil and decreasing plant activity results in a gradual increase of Bo from April to August at Lindenberg - Falkenberg.

Interannual variability of the sensible and latent heat fluxes over the three-year period 2003 – 2005 at Lindenberg – Falkenberg is illustrated in Figure 2. The Figure clearly shows the dominance of LE over H during all of the time. Depending on the general weather situation, the flux magnitudes show an opposite tendency for the single years. Latent heat fluxes in summer were lowest during the hot and dry year 2003 and highest during the wet summer of 2005. It should be remarked that the precipitation sum over the period May till September was 134 mm, 234 mm, and 312 mm for the three years, respectively. On contrary, the highest summertime sensible heat fluxes were recorded in 2003.

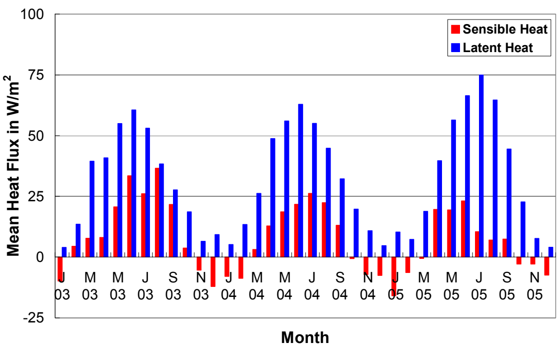


Figure 2. Monthly mean values of sensible and latent heat fluxes at the CEOP reference site Lindenberg – Falkenberg during the period 2003-2005

4. Perspectives

In the meantime, phase 2 of CEOP has been approved by the GEWEX and WCRP science panels. This phase 2 will cover the period 2007 –2010. Collection of satellite, model, and in-situ data has started on January 1^{st}, 2007 at the different centres, agencies and institutes contributing to CEOP. The three BALTEX reference sites, Sodankylä, Cabauw, and Lindenberg, will continue in supporting CEOP through their data delivery to the CDA for this phase 2. Based on the achievements of the first phase, CEOP will be an important integrative effort of the WCRP and has become a relevant component of the Integrated Global Observing Strategy – Partnership (IGOS-P), and a key element of the Global Earth Observation System of Systems (GEOSS).

References

Beyrich, F., and W. Adam: A note on the use of CEOP reference site data for comparison with the output of global models: The Lindenberg example. *CEOP-Newsletter* **6**, 6-7, 2004.

Beyrich, F., W. Adam, F. Bosveld, T. Savunen, and J. Poutiainen: BALTEX reference sites have completed the data delivery for CEOP phase 1. *BALTEX-Newsletter* **9**, 11-14, 2006.

Comparison of Air-Sea Fluxes in the Uncoupled and Coupled BALTIMOS System

Philip Lorenz[1], Daniela Jacob[1] and Andreas Lehmann[2]

[1] Max-Planck-Institute for Meteorology, Bundesstr. 53, 20146 Hamburg, Germany (philip.lorenz@zmaw.de)
[2] Leibniz Institute of Marine Sciences (IFM-GEOMAR), Kiel, Germany

1. Introduction

Within the framework of DEKLIM/BALTEX, a fully coupled regional climate model system for the Baltic Sea region, called BALTIMOS, was developed. It consists of components for the atmosphere (Regional climate model REMO; *Jacob et al.* 2001; *Jacob* 2001), the ocean (Baltic Sea Ice Ocean Model BSIOM; Lehmann and Hinrichsen, 2000) and the hydrology (LARSIM; *Bremicker* 2000).
BALTIMOS shows a good performance (e.g. *Lehmann et al.* 2004). Nevertheless, in comparison to observations the amplitude of the annual sea surface temperature (SST) cycle simulated by the coupled BALTIMOS system show an underestimation within the Baltic Sea, associated with reduced sea-ice.
These deviations in the evolution of SST do not show up in the uncoupled BSIOM model, the ocean component of BALTIMOS. For detecting the mechanisms leading to these differences, a comprehensive comparison of air-sea fluxes computed by the BALTIMOS system against those used in the stand-alone ocean model BSIOM has been performed and analyzed.

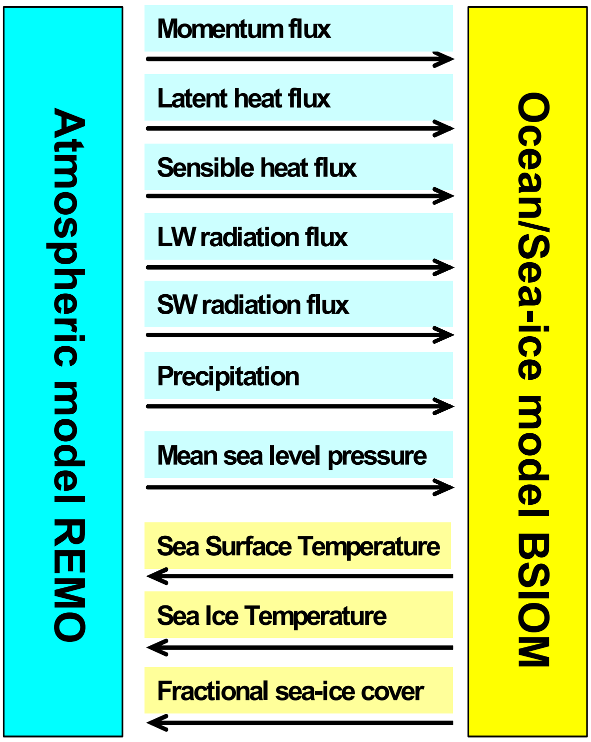


Figure 1. Coupling interface REMO-BSIOM within BALTIMOS.

2. Air-Sea fluxes in BALTIMOS and BSIOM

Figure 1 shows the coupling interface between REMO and BSIOM. Within the atmospheric component REMO the air-sea net fluxes for momentum, sensible and latent heat, short- and long wave radiation, and additionally precipitation and mean sea level pressure are calculated and passed to the ocean component BSIOM. The ocean model returns updated values of sea surface temperature, ice surface temperature and fractional sea ice coverage.
The stand alone BSIOM model calculates the air-sea fluxes by bulk formulas from meteorological data. As input data the gridded meteorological dataset from synoptic stations provided by the BALTEX Hydrological Data Centre at SMHI has been used.

3. Comparison of air-sea fluxes

For this study a stand alone BSIOM simulation as well as a coupled BALTIMOS simulation have been performed covering the years 1999-2006. Daily means of all air-sea fluxes as well as surface temperatures and ice evolution has been recorded at the high resolution of the BSIOM grid (~5km). Area means of these quantities for different parts of the Baltic Sea have been calculated. Comprehensive statistics of these area values have been performed for both experiments and compared against each other. The results of this analysis will be presented.

References

Bremicker, M.: Das Wasserhaushaltsmodell LARSIM: Modellgrundlagen und Anwendungsbeispiele, Freiburger Schriften zur Hydrologie, Band11, 2000

Jacob, D., U. Andrae, G. Elgered, C. Fortelius, L. P. Graham, S. D. Jackson, U. Karstens, Chr. Koepken, R. Lindau, R. Podzun, B. Rockel, F. Rubel, H.B. Sass, R.N.D. Smith, B.J.J.M. Van den Hurk, X. Yang: A Comprehensive Model Intercomparison Study Investigating the Water Budget during the BALTEXPIDCAP Period, Meteorology and Atmospheric Physics, Vol.77, Issue 1-4, pp. 19-43, 2001

Jacob, D.: A note to the simulation of the annual and interannual variability of the water budget over the Baltic Sea drainage basin, Meteorology and Atmospheric Physics, Vol.77, Issue 1-4, pp. 61-73, 2001

Lehmann, A. and Hinrichsen, H.-H.: On the thermohaline variability of the Baltic Sea, J. Marine Systems, Vol. 25, Issue 3-4, pp. 333-357, 2000

Lehmann, A., Lorenz, P. and Jacob, D.: Modelling the exceptional Baltic Sea inflow events in 2002-2003, Geophysical Research Letters, 31, L21308, doi:10.1029/2004GL020830, 2004

Advances in Weather Radar Based Quantitative Precipitation Measurements for the Purposes of Climate Research

Jarmo Koistinen[1], Timo Kuitunen[1], and Daniel Michelson[2]

[1]Finnish Meteorological Institute (FMI), Helsinki, Finland. jarmo.koistinen@fmi.fi
[2]Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden.

1. Introduction

The development of weather radar applications in Europe has been a scientific and socio-economic success story during the past 30 years. During this period, national efforts have increasingly become an international cooperation. European interaction is consolidated by several exchange programmes of real-time and near real-time radar data among neighboring countries for operational and R&D purposes (e.g. NORDRAD and CERAD). Within the framework of BALTEX, the BALTRAD network and BALTEX Radar Data Centre (BRDC) at SMHI have provided harmonized datasets since the start of the BRIDGE campaign in 1999 (*Koistinen and Michelson* 2002). Today BALTRAD comprises the operational C-band weather radar networks in Norway, Sweden, Finland, Estonia, Denmark, and Poland, with renewed data feeds expected soon from e.g. Germany.

Products generated at BRDC represent the most frequent application of weather radars: quantitative precipitation estimation (QPE). The main objective in such activities is to develop precipitation fields for the purposes of research and services in the fields of meteorology (diagnosis, forecasting and climatology) and hydrology (especially warnings and mitigation of floods). The advantage of weather radars compared to conventional gauge networks is the availability of measurements in real time, which exhibit typically 100 times better time resolution and 10 000 times better spatial resolution than national gauge networks. High resolution facilitates the derivation of precipitation rates and accumulations from small areas and short time periods.

On the other hand, the absolute accuracy of radar based QPE is not very good in a randomly-selected location at surface level. Still, even semi-quantitative precipitation estimates are valuable for many climatological applications, e.g. in the validation and downscaling of spatial and temporal precipitation patterns provided by satellites, NWP and climate models. Much work has been devoted recently in the quality control (QC) of radar based QPE, i.e. removal of systematic biases and random errors from the radar estimates of surface precipitation and quality diagnostics of the final products. Such optimization denotes often integration of multi-source data e.g. from radars, satellites and ground-based measurements.

The purpose of this paper is to give an overview of present challenges and solutions in weather radar based QPE. Significant and less significant QC procedures and methodologies applicable in the BALTEX region are shown. As an example of climatological applications statistics of a very large sample of area-intensity probabilities of rainfall in Finland will be presented.

2. Recent advances in the quality assurance of radar based QPE

Up to these days, in most cases, the users of radar products must have accepted the data without any additional information which could indicate the quality or accuracy of the product in general not to speak of pixel by pixel quality indicators. Luckily the European weather radar community has taken this issue seriously e.g. in COST 717 (*Michelson et al.* 2005) and Eumetnet OPERA (*Huuskonen* 2006). The aim is to agree on common quality measures, which is a challenging task as quality is a multi-dimensional parameter of a radar measurement. The first dimension is the classical accuracy of the measured or estimated quantity, i.e. bias and random error, which can be at least estimated as a function of time and space (before and after possible correction steps). The second dimension is the probability of various phenomenal occurrancies in a measurement bin, such as e.g. presence of hail or bright band, birds, insects, sea clutter, severe attenuation, complete beam overshooting. In such classification of scattering targets, new data processing methodologies, such as fuzzy logic (*Peura et al.* 2006), and modern hardware technologies, e.g. polarization diversity (*Ryzhkov and Zrnic* 2006), appear quite promising. The third dimension is the application i.e. which quantities are used, and in which way, in the user application, and additionally which are the specific user requirements for the first two dimensions.

A fundamental factor in any radar application and QC is the availability of measured data. The stability of modern radar hardware and software as well as high processing speeds of radar signals and wide bandwidths of telecommunication lines have facilitated full real-time operational use of the measured 3D polar volumes of Doppler and reflectivity data. In optimal cases, the average long-term availability can exceed 99 % including all maintenance breaks.

Not until the paper of *Joss and Waldvogel* (1990) was generally accepted was it realised that the main bias in QPE in the European climate is the sampling difference between a radar measurement high above the ground level and the actual precipitation rate at ground. This is a direct implication of the fact that the average vertical profile of reflectivity (VPR) exhibits a negative vertical gradient. Thus, without a proper adjustment of the sampling difference by applying a correction for the effects of the VPR, large biases exist in QPE. This is especially valid in the precipitation of temperate and cold climates where the negative vertical reflectivity gradient is typically larger than in the warm climates. For example in Finland, at the range of 200 km from the radars, the average bias in radar estimates of precipitation at ground level due to the VPR effects is -8 dB in rainfall and -17 dB in snowfall. The conclusion is that without a proper VPR adjustment scheme like that by *Koistinen et al.* (2003) or equivalent methods based on gauge adjustment (e.g. *Michelson and Koistinen* 2000) radar data are invalid at distant ranges to fulfill the accuracy requirements of QPE for the purposes of e.g. BALTEX.

The longer the measurement range is, the larger is the probability that a radar does not detect any precipitation due to total beam overshooting, or due to partial beam overshooting and increasing minimum detectable dBZ. Such cases appear as spurious echo free areas in radar measurements and can't be corrected by any factor. This kind of bias is severe when radar products are applied in the validation of precipitation measured or modeled with other tools. Robust methodologies to diagnose such areas are expected to appear soon.

The selected sources of inaccuracy show convincingly that any "blind" use of radar products for climatological and water cycle studies contains major quality and accuracy risks unless a proper professional QC scheme has been applied. It is to be expected that factors of inaccuracy will be provided in near future in conjunction with the ordinary radar based precipitation products applied e.g. in BALTEX.

3. An example of climatological use of quality-controlled radar data

When the challenge of QC and accuracy can be solved to an acceptable level, radar measurements provide several orders of magnitude larger data samples than gauges. The implication is that extremely rare events can be detected in the data, i.e. reliable probability estimates of the order of 1/100 000. From the socio-economic point of view, extreme events are the most devastating ones especially if the frequency of them will increase due to the climatic change. Downscaling the relatively large-scale precipitation events provided by the climate models, according to radar-based precipitation climatologies, may help in estimation of future occurrence of mesoscale extreme events. In this study we present cumulative density functions (CDF) of rainfall for accumulation periods varying between 1 minute and 24 hours and areas of 1 km^2 – 1024 km^2. The data set covers six summers from seven Finnish weather radars. As is evident from the discussion above, such a dataset, which contains roughly 1.5 x 10^{11} measurements, must pass a very critical stepwise QC process before the statistics can be presented. It is expected that such a large sample is most valuable climatologically, especially at the high end of the CDF. Probability distributions of rainfall intensity and accumulation are the basis of hydraulic and hydrological planning of construction structures needed in heavy rain and flood mitigation.

References

Huuskonen, A., 2006: EUMETNET OPERA: Operational programme for the exchange of weather radar information. *Proceedings, 4th European Conference on Radar in Meteorology and Hydrology*, Barcelona, p. 371-374.

Joss, J. and Waldvogel, A., 1990: Precipitation and hydrology, in: Radar in meteorology: *Battan memorial and 40th Anniversary Radar Meteorological Conference*, Boston, edited by Atlas, D., pp. 577–606, AMS.

Koistinen J. and Michelson D.B., 2002: BALTEX Weather Radar-based Products and their Accuracies. *Boreal. Env. Res*. 7 (3). p. 253-263.

Koistinen, J., Pohjola, H., and Hohti, H., 2003: Vertical reflectivity profile classification and correction in radar composites in Finland, in: *31st Conference on Radar Meteorology*, Seattle, pp. 534–537, AMS.

Michelson D.B. and Koistinen J., 2000: Gauge-radar network adjustment for the Baltic Sea Experiment. *Phys. Chem. Earth (B)* 25 (10-12). p. 915-920.

Michelson, D., Einfalt, T., Holleman, I., Gjertsen, U., Friedrich, K., Haase, G., Lindskog, M., and Jurczyk, A., eds., 2005: *Weather Radar Data Quality in Europe: Quality Control and Characterization*. EUR 21955, COST Office, Luxembourg. 87 pp.

Peura, A., Koistinen, J., and Hohti, H., 2006: Quality information in processing weather radar data for varying user needs. *Proceedings, 4th European Conference on Radar in Meteorology and Hydrology*, Barcelona, p. 563-566.

Ryzhkov, A., and Zrnic, D., 2005: Radar polarimetry at S, C, and X bands. Comparative analysis and operational implications. *Preprints, 32nd Conference on Radar Meteorology*, Albuquerque, NM, AMS (on a CD-ROM).

Estimating Climate Trends Using GPS

Tobias Nilsson, Jan Johansson, Martin Lidberg and Gunnar Elgered

Onsala Space Observatory, Chalmers University of Technology, Onsala, Sweden, tobias.nilsson@chalmers.se

Introduction

Climate trends calculated using weather models are uncertain due to changes in the observing systems which have occurred during the last 40 years [*Bengtsson et al.,* 2004]. Thus it is important to develop observing systems with high long-term stability. One possibility is to use Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS). One attractive feature of this system is that the measured parameter is time, a quantity which can be monitored with high accuracy.
The signals transmitted from the GPS satellites are delayed in the neutral atmosphere. Part of this delay is caused by water vapor, and this part is closely related to the Integrated Precipitable Water Vapor (IPWV). In geodetic processing of GPS data this excess delay is normally estimated. Hence it is possible to use these results to infer estimates of the IPWV. The IPWV estimated using GPS has shown to have a root-mean square (RMS) accuracy of 1–2 mm.
Some GPS networks have now been operational for over a decade. For example, the Swedish geodetic reference network SWEPOS has been acquiring data since August 1993. Hence, we can by using data from such networks get relatively long time-series of IPWV in order to study climate trends *[Gradinarsky et al., 2001]*.

GPS data processing

In order to obtain the IPWV from the raw GPS observations a processing is made where the atmospheric excess propagation path is estimated together with other unknown contributions to the observations. These include satellite positions and satellite clock errors. One strategy to handle these satellite errors are to estimate them in the processing of the GPS data. This requires that data from several GPS receivers must be processed together in what is normally called a Network Solution. Another strategy is to use satellite orbits and clocks estimated from e.g. a Network Solution and process every station individually. This is called Precise Point Positioning (PPP).
In this work we will use both strategies and compare the results. For the Network Solution we use the GPS processing software GAMIT *[King 2002]*, while for the PPP solution we use the GIPSY OASIS-II software *[Webb and Zumberge 1993]*.

SWEPOS and other GPS networks

The SWEPOS network consists of 21 geodetic GPS stations distributed all over Sweden. The GPS antennas of these stations are mounted on concrete pillars placed on solid bedrock and are protected by radomes. These stations have been operating since 1993.
SWEPOS also contain a number of simplified reference stations. These typically have their antennas mounted on rooftops. Most of the simplified stations have been constructed in the last few years. In total there are around 100 simplified stations, mostly in the southern and the eastern parts of Sweden (see Figure 1).
In addition to the SWEPOS stations we also have access to data from the geodetic GPS networks in Finland, Denmark and Norway, as well as data from some other GPS stations in northern Europe.

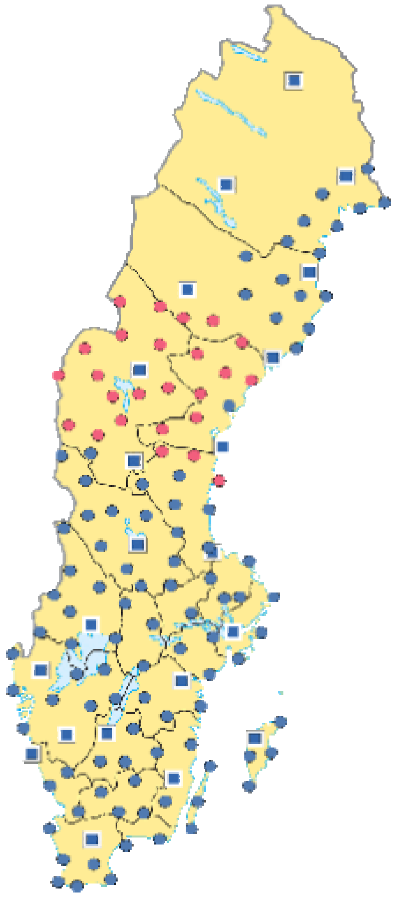


Figure 1: The Swedish GPS reference network SWEPOS. Blue station symbols indicate operational GPS sites. The squares denote the original 21 "geodetic" sites build on solid bedrock. The circles denote the additional reference stations often mounted on top of buildings. The red circles are sites in the planning stage.

Water Vapor trends

We will investigate the trend in the IPWV estimated from the stations of SWEPOS as well as other sites in the Nordic countries. We will compare the results from the GIPSY and the GAMIT data processing and investigate sources of the possible differences in the results. As an example, the water vapor trends in Sweden for the period 1997–2005 using the GAMIT results are shown in Fig. 2. The trend are however dependent on what time-period that are used to obtain them. For example, *Gradinarsky et al. (2002)* obtained significantly more positive trends. *Gradinarsky et al. (2002)* also detected different trends for summer and winter, this we will investigate further. The IPWV trends will be compared to trends estimated using other techniques, for example radiosondes and the water vapor radiometer at Onsala Space Observatory.
We will also investigate how for example the change of type of protective radome affects the results. In SWEPOS most radomes were changed to a different type in 1996, and

we will investigate what impact these changes have had on the IPWV estimated using the two different processing strategies.

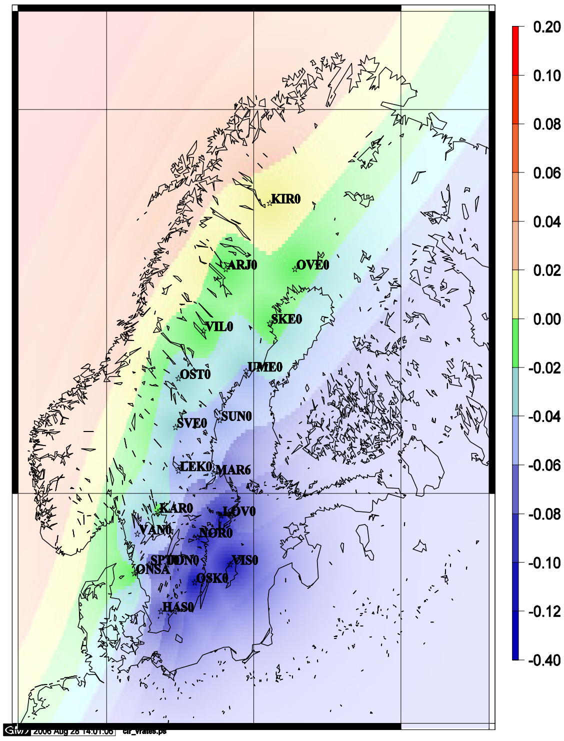


Figure 2. The IPWV trends for the SWEPOS geodetic stations for the period 1997-2005.

References

Bengtsson, L., S. Hageman, K. I. Hodges, Can climate trends be calculated from reanalysis data, *J. Geophys. Res.*, Vol. 109, No. D11111, 2004

Gradinasky, L. P., J. M. Johansson, H. R. Bouma, H.-G. Scherneck, G. Elgered: Climate monitoring using GPS. *Phys. Chem. Earth*, Vol. 27, 335-340, 2002

King R. W., Documentation for the GAMIT GPS analysis software, *MIT internal report*, 2002, http://www-gpsg.mit.edu/~simon/gtgk/GAMIT.pdf

Webb, F. H., Zumberge: An introduction to the GIPSY/OASIS-II, *JPL Publ.* D-11088, Jet Propul. Lab. Pasadena, California, 1993

Observations and Modeling of a Cold-Air Outbreak over the Gulf of Finland

Lorenzo Claveri[1], Timo Vihma[1], Hannu Savijärvi[2] and Bengt Tammelin[1]

[1] Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland; Lorenzo.Claveri@fmi.fi
[2] University of Helsinki, Department of Atmospheric Sciences, Helsinki, Finland

1. Introduction

Cold-air outbreaks are frequent phenomena over the Baltic Sea in winter. During a cold-air outbreak, the thermal stratification is typically stable over the land and sea ice, but unstable over the open sea. The turbulent surface fluxes can reach several hundreds of Watts per square meter, and shallow convection develops over the sea. Under small fetches it often develops as roll-convection, and changes to cell-convection with increasing fetch. The convection often results in cloud formation and heavy snowfall. Over the narrow Gulf of Finland, cold-air outbreaks are also associated with large coastal gradients in the wind speed, air temperature and air moisture.

Cold-air outbreaks have been studied especially over the U.S. Great Lakes and downwind of the Arctic sea ice edge. Cold-air outbreaks over the Baltic Sea have been addressed by, e.g., *Andersson and Gustafsson* (1994), *Gustafsson et al.* (1998), and *Vihma and Brümmer* (2002). There has, however, seldom been a good mesoscale network of observations available for detailed monitoring of mesoscale processes. In this study, we will present observations and model results of a cold-air outbreak over the Gulf of Finland, Baltic Sea, from 15 to 25 January 2006. The MM5 model simulations are validated against observations of the Helsinki Mesoscale Testbed: data are utilized from 17 weather stations, including a station with frequent rawinsonde soundings. The MM5 simulations are also compared against analyses of the ECMWF model.

2. Observations

The Gulf of Finland is 60 to 120 km wide and some 400 km long, and oriented in WSW-ENE direction (195-75°). The gulf is surrounded by relatively flat land areas, the surface elevation within 100 km of the coast being mostly less than 100 m. There are several in-land, coastal, archipelago, and lighthouse weather stations, and we selected 17 of them to be applied in this study. The selection was made on the basis of the representativeness of the station in conditions of easterly winds: stations with the wind measurement affected by trees, buildings or tower structures were not included in the study.

During the study period until 17 January, 2006, the weather was warm with near-zero temperatures and small thermal differences between the sea and atmosphere and horizontally between the stations (Figure 1). The wind turned rapidly to ESE in the night between 16 and 17 February, 2006, and the air temperatures started to decrease. At the longitude of 25°E, the rapid decrease in air temperature occurred about 24 h after the turning of the wind. In the inland stations, the temperature decreased by 18 K in 24 h, while at the stations in the middle of the gulf, the simultaneous decrease was about 13 K. The cold period lasted for six days, during which the synoptic-scale wind conditions remained almost stationary, the large-scale geostrophic wind being from ESE. The air temperatures in the middle of the gulf remained at -12 to -15°C, while the temperatures inland ranged from -18 to -25°C. The sea surface temperature, measured at Harmaja, dropped gradually from 3 to 0°C. In the beginning of the cold period, there was sea ice only in the easternmost parts of the Gulf of Finland, but by the end of the cold period, the sea ice edge had advanced approximately 100 km further to the west. The end of the cold period was very rapid. In the night between 22 and 23 January, the wind turned back to southwest, and the air temperatures increased rapidly close to zero. In Helsinki, the temperature increased from -21.0 to -8.5°C in 2 hours.

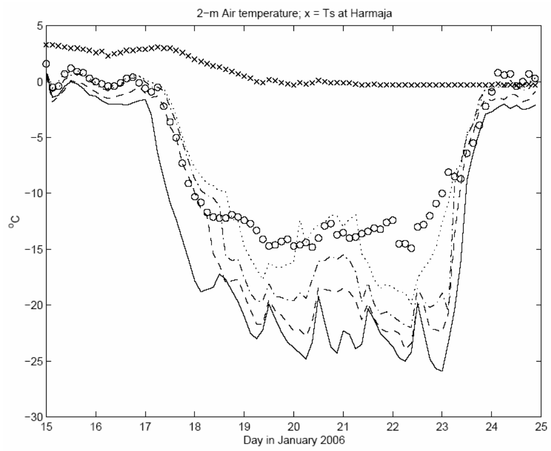


Figure 1. Time series of 2-m air temperature at five stations (solid line: over land 100 km north of the coast, dashed line: 20 km north of the coast, dot-dashed line: at the coast, dotted line and circles: over the Gulf of Finland) and the sea surface temperature in the northern part of the gulf (crosses).

3. Model Experiments

The model applied was MM5, which is a three-dimensional, multinested, nonhydrostatic, terrain-following σ-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation. In the present study we have applied the Polar version of MM5 developed at the Ohio State University. The initialial and boundary conditions were based on the ECMWF Operational Analyses with the resolution of about 25 km with 6 hours intervals. For the analyses presented here, MM5 was configured with two nested domains. The inner domain, centered on the Gulf of Finland, was a 100 × 100 element grid with a grid spacing of 3 km. The outer domain, which was used to provide improved lateral boundary conditions to the inner domain, was configured as 80 meridional grid points by 80 zonal grid points with a grid spacing of 9 km. The model was run with the vertical resolution of 52 σ levels, 10 of them in the lowermost 2-km layer. MM5 contains seven different PBL schemes to represent the boundary layer processes. For this simulation with high vertical resolution, a local 1.5-oder-closure scheme was applied. The simulation was made for a 10-day period. Nudging with the operational analyses of the ECMWF was applied every three hours using four-dimensional data assimilation.

4. Results

The observed and modeled evolution of air temperature at the northern coast of the Gulf of Finland is shown in Figure 2.

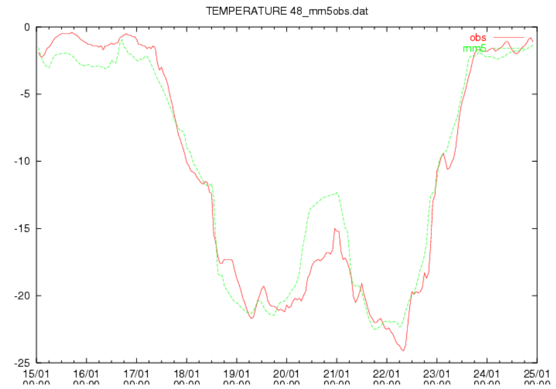


Figure 2. Time series of the observed and modeled air temperature at the height of 48 m at Kivenlahti, northern coast of the Gulf of Finland.

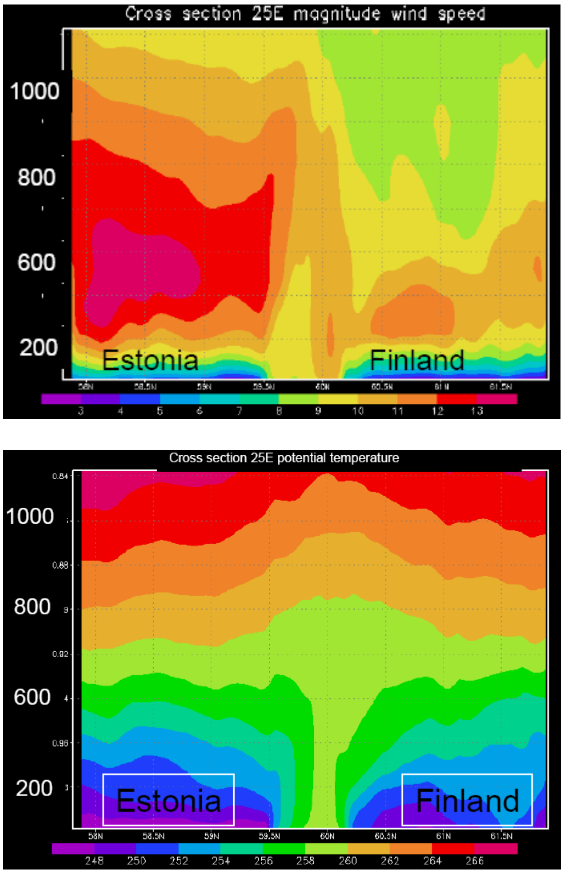


Figure 3. Cross sections of mean wind speed (above) and potential temperature (below) for the period 15-25 January, 2006, along longitude 25°E.

The model results (Fiugure 2) are promising also during the cold period, when there was a large temperature gradient at the coast, and the stratification changed from unstable over the sea to very stable over the land. The largest overestimation of the air temperature is related to a shift in the location of the coastal front, which was maintained by the convergence line of a land-breeze cell. The formation, strength and location of the convergence line is very sensitive to the geostrophic wind direction.

The case also included formation of convective snow bands aligned along the gulf, and the model results were in good agreement with radar data (not shown).

The simulated wind field included two low-level jets (Figure 3). Over Finland, the situation was baroclinic in the ABL with cold air to the right of the wind vector. Accordingly, close to the surface, the wind speed increased with height, as the effect of surface friction dominated over the effect of baroclinicity, but above the core of the LLJ, the baroclinicity dominates resulting in wind speed decreasing with height. This is a well-known situation. Over the Estonian coast, the situation was very interesting: in the ABL, cold air being to the left of the wind vector, the geostrophic wind increased with height, and there was a deep layer of winds exceeding 12 m/s. Higher up, from 1 km upwards, the temperature field was, however, opposite: the cold air had advanced further over the sea, and there was accordingly cold air to the right of the wind vector, resulting in wind speed decreasing with height. Hence, there was a jet also over the Estonian coast, but it extended much higher than at the Finnish coast.

5. Conclusions

The model results agreed reasonably well with observations although the coastal gradients in wind speed and air temperature were very large. A high horizontal resolution was therefore needed for successful simulation of the case. Accurate modeling of cold-air outbreaks and related coastal mesoscale variations in wind, air temperature, air humidity, and precipitation are needed for several reasons. In coastal regions, the spatial variations are often so large that they are essential for the weather forecasts for the public. In addition, the spatial variations are important for operational services for navigation and aviation. Coastal variations in the ABL are essential for oceanographic applications, for example for understanding and modeling coastal upwelling, the wave field, as well as sea ice dynamics and thermodynamics. Detailed knowledge of spatial variations in the wind field is needed also for planning of coastal and offshore wind farms. Improved understanding on the mesoscale processes in various flow situations is also needed to better parameterize the unresolved coastal subgrid-scale variability in climate models. For all the above-mentioned aspects, it is important to understand how much benefit can be obtained by high-resolution modeling compared to resolutions typically used in operational and climate models.

References

Andersson, T. and Gustafsson, N., Coast of departure and coast of arrival: two important concepts for the formation and structure of convective snowbands over seas and lakes', *Mon. Wea. Rev.* **122**, 1036–1049.

Gustafsson, N., Nyberg, L., and Omstedt, A., Coupling of a High-Resolution Atmospheric Model and an Ocean Model for the Baltic Sea, *Mon. Wea. Rev.* 126, 2822– 2846, 1998.

Vihma, T. and B. Brümmer, Observations and modelling of on-ice and off-ice flows in the northern Baltic Sea, *Bound.-Layer Meteorol.,* 103, 1-27, 2002.

Recent Advances in the Physical Oceanography of the Gulf of Finland

Kai Myrberg, Tarmo Soomere, Matti Leppäranta, Alexei Nekrasov

Finnish Institute of Marine Research, Erik Palménin aukio 1, PL 2, 00561 Helsinki, Finland, kai.myrberg@fimr.fi
Institute of Cybernetics at Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia, soomere@cs.ioc.ee
Division of Geophysics, University of Helsinki, Box 64 (Gustaf Hällströmin katu 2), 00014 Helsinki, Finland
Russian State Hydrometeorological University, 98 Malookhtinsky prospekt, 195196 St.Petersburg, Russia

1. Introduction

The Gulf of Finland (hereafter denoted as the GoF) is an elongated sub-basin with a mean depth of 37 meters only in the north-eastern extremity of the Baltic Sea. The studies of the physical oceanography of the GoF started already in the late 1890's by Admiral Makarov. Regrettably, after the World War II no research covering the entire Gulf was possible until the 1990's. The results from the early studies up to the middle of the 1990's were reviewed by *Alenius et al*. (1998).

We make an attempt to review the main *updates* in the knowledge of the physical oceanography of the Gulf of Finland during 1996-2006, with a minimum reference to earlier knowledge or items concerning the whole Baltic Sea. This time interval starts from the Estonian-Finnish-Russian Year of the Gulf of Finland 1996, a milestone of joint studies of this area that has separated two worlds since the 1940s. The output of the studies that were carried on during the whole decade and included extensive analyses using historical and recently-collected data sets, numerical modelling tools, and introducing of new theoretical concepts, eventually contributed to another milestone – the declaring the Baltic Sea as a particularly sensitive sea area by the IMO in the end of 2005, the status becoming effective from July 2006. The overview is based on more than 100 papers published in international peer-reviewed journals. Owing to restrictions for the extended abstract, references to the source papers as well as information spread in the form of non-published reports have been omitted.

2. Hydrography

The western end of the Gulf is a direct continuation of the Baltic Sea Proper, whereas the eastern end receives the largest single fresh water inflow to the Baltic Sea; the River Neva. These features combined with extremely complex geometry of the gulf result in a strong east-west salinity gradient and a stratification that is highly variable in both space and time. The hydrography of the GoF is characterized by large temporal and spatial variations in both salinity and temperature. There is evidence that the sea-surface temperature of the GoF has risen about 0.5–0.8 degrees during the last 15–40 years.

A key issue that has improved the accuracy of simulations of the processes in the GoF during the last years is the refinement in the circulation models' resolution both in the horizontal and vertical directions. Three-dimensional models of the gulf are implemented with a horizontal resolution down to 1 mile. Nested-grid approaches are often applied where the output from a large-scale low-resolution model is used to obtain the boundary conditions in the high-resolution local models. The reason for paying special attention to the horizontal resolution is that the baroclinic Rossby-radius (R_1) is very small: the typical values of the R_1 are 2–4 km, this being less than a half of the analogous values in the Gotland Deep. Also, R_1 has a large spatial and temporal variability; consequently, the mesoscale water motions are extremely complex here. The key features of the hydrography such as the surface salinity and temperature as well as the vertical salinity and temperature distribution are modelled with a reasonable accuracy in the scientific high-resolution three-dimensional models. However abrupt changes e.g. due to upwelling are still a challenge for the models. Another partly open question is whether the use of non-hydrostatic models in the simulations of the GOF dynamics would improve the results.

3. Marine meteorology and air-sea interaction

The remarkable features of the marine meteorological conditions of the GoF are wind anisotropy and the non-homogenous patterns of atmospheric temperature due to the highly variable surface roughness and heat exchange between the sea and atmosphere. The major progress in understanding the meteorological conditions in the GoF has become possible due to availability of long-term data from Kalbådagrund, a caisson lighthouse in the central part of the GoF (59º58'N, 25º37'E) at a distance of 29 km from the Finnish and 37 km from the Estonian coast. The wind speeds on the open sea are considerable larger than those estimated from the coastal data or from the older lighthouse data. The differences are only partly related to the warm and windy conditions in 1990s. The wind data observed at the northern coast of the gulf adequately represent the open-sea wind properties but those recorded at the southern coast at cases do not match the open-sea wind properties even qualitatively.

The open-sea wind regime of the GoF is a superposition of south-western and north to north-west winds (dominating in the entire northern Baltic Proper), and more local west and east winds blowing along the gulf. The mean wind speed in severe long-lasting storms in the GoF is by 2–3 $m\ s^{-1}$ less than in the Baltic Proper. Unlike to the wind regime in the Baltic Proper, the directional distribution of strong winds in the GoF often poorly agrees with the analogous distribution for all winds. This means that the strongest winds may blow from directions from which winds are relatively infrequent. The frequent and relatively strong afternoon surface winds along the GoF coasts during summer can be explained as an evidence of downstream meanders of the geostrophic flow caused by its interplay with sea breeze and the geometry of the gulf. The expected rise of the annual mean temperature over Finland, including the GoF, may substantially modify the properties of the air-sea interaction processes.

4. Water and energy balance on sea surface

GoF receives river water 112 km^2/a mostly in the east flowing into the whole Baltic Sea. This corresponds to 10 % of the volume of the basin. The atmospheric net contribution is very small. Considerable new evidence has been also obtained about details of the monthly mean heat fluxes based on the open-sea meteorological data. The all-year surface heat balance is dominated by the radiation balance, which is normally positive in April–September, peaking to 200–250 $W\ m^{-2}$ in the summer months. In winter the high albedo of the ice lowers the incoming solar radiation, and mild winters the balance has turned positive in March already. Sensible and latent heat fluxes are important in fall and winter when the winds are strong and also stratification of the atmospheric surface layer is unstable. From November until ice formation the turbulent losses are together at –100 W m^{-2} even larger than the net radiation losses.

5. Water dynamics

A traditional, but idealized, view of the GoF circulation is that the mean circulation is cyclonic with an average velocity of a few cm/s. However, at long time-scales the circulation is intrinsically baroclinic due to the pronounced horizontal buoyancy gradients and sea-surface slope mainly created by the permanent fresh water supply to the eastern part of the Gulf. At shorter time scales wind stress at the sea surface plays a dominant role. The Gulf is large enough to experience the effects of the earth's rotation as well.

The patterns and the persistency of the currents simulated with the use of the high-resolution models deviate to some extent from the classical analysis. A cyclonic mean circulation generally is discernible but both the mean and instantaneous circulation patterns contain numerous quasi-permanent mesoscale features such as eddies, fronts or jets. The radius of eddies typically exceeds the internal Rossby radius. Their composition apparently is also affected by the complex bathymetry. The surface-layer flow pattern is characterized mainly by an Ekman-type drift. Strong and persistent currents in the easternmost part of the Gulf are caused by the voluminous runoff from the River Neva. A relatively persistent flow along the whole gulf towards the Baltic Proper exists in some subsurface layers northwards from the gulf axis. Generally, baroclinic instability is expected to lead to disintegration of such flow; however, a relatively gently sloping bottom at the Finnish coast stabilizes the flow to some extent. Multi-layer flows have also been detected for several bays at the southern coast of the GoF. The week-scale and month-scale variability of coastal currents along the Estonian coast is at times interpreted in terms of coastally trapped (edge) waves.

There only exist a few observational studies of mesoscale eddies, for example, an observation of an eddy formed after the rapid splitting of the eastward downwelling jet to the offshore cyclonic and the inshore anticyclonic branch. The diameter of the eddy was estimated to be 15–20 km, about 4 times the internal Rossby-radius of deformation.

The simulations performed during the latter decade also correctly represent both long-term and mesoscale features of the water exchange between the GoF and the Baltic Proper. The outflow in a specific sub-surface layer slightly north of the axis of the Gulf is highly persistent as well as the inflow adjacent to the Estonian coast (that is visible at all depths). A noticeable transport into the gulf takes place at the Finnish side in a thin surface layer. The magnitudes of the in- and outflow strongly depend on the time period in question because of a large role of mesoscale dynamics in this area.

A highly interesting phenomenon of the reversal of the classical estuarine deep-water transport pattern (the events when the salt wedge is being exported from the gulf, potentially accompanied by large halocline variations and high intra-halocline current speeds) occur for some sequences of south-westerly wind events. This feature suggests that the near-bottom layers of the GoF rather actively react to the wind forcing, a reasoning which considerably modifies the traditional concept of the partially decoupled lower layer dynamics. There are still many interesting challenges connected with the entrance area of the GoF. The multitude of processes (such as high internal wave activity and frequent production of strong eddies and topographically controlled local currents) in this area makes the modelling of the water exchange processes extremely challenging.

The smallest values of the water residence time are found in the inflow regions and at river mouths. The highest water ages were encountered in the outflow regions. The oldest bottom water in the GoF is found to be about 8.3 years old. Since a number of eddies, fronts and cyclonic circulation cells seem to be quasi-stationary, the water age distribution has a pronounced horizontal variability.

On of the most interesting features of the water dynamics in the whole Baltic Sea is the quasi-permanent salinity front at the entrance of the GoF that has attracted several multidisciplinary field studies. Its dynamical background can be explained by the existing cyclonic mean circulation in the GoF that causes a strong gradient between the in- and outflowing water to/from the GoF. The front is typically oriented in the SW–NE direction, approximately parallel to the bottom slope. Its intensity and geometry respond to the wind pattern to a large extent.

Upwelling in the Gulf of Finland is usually triggered by alongshore winds although the complex-shaped coastline and many islands in the GoF are favourable for upwelling for wind from any direction. Statistical analysis of a 10-year time series of modelled vertical velocity demonstrated that the persistency of upwelling is up to 30–50 % along certain parts of the Finnish coast. The typical extension of a single upwelling event is 10–20 km offshore and about 100 km alongshore. Their lifetime is from several days up to several weeks. Major effects of upwellings are observed in a 5–10 km broad zone but gradually the nutrient-rich waters are spread to offshore whereas its dynamics can be strongly affected by the fresh-water forcing. The difference between the upwelled and surrounding surface water can be up to 10° C whereas the horizontal gradient may reach 1° C/km^{-1}. Usually a wind event with a duration of about 60 h is required, corresponding to a wind impulse of the order of 4000–9000 kg m^{-1} s^{-1}. Upwellings apparently are particularly important in development of the late-summer cyanobacterial blooms; so far this component of biological production is poorly quantified.

6. Water level

The sea-level changes in different time-scales in the GoF are affected by (i) relative land uplift and changing (ii) the wind regime, (iii) the air pressure patterns, and (iv) the density of sea water. The strongly anisotropic wind climate of the Baltic Sea is one of the main factors in forming the local wave climate and sea level variations whereas the corresponding anisotropic wave regime apparently contributes to the forming of the above-described specific features of the vertical structure of water masses at the entrance of the GoF.

The prevailing westerly winds cause an eastwards rising surface slope to take place within the Baltic Sea. The largest variation of sea water level in the whole Baltic Sea occurs at the closed eastern end of the GoF. The total range of historical extremes exceeds 5 m whereas the highest storm surge reached 4.21 m in Sankt Petersburg. The NAO index nearly perfectly correlates with the detrended annual mean sea level along the Finnish coast. The latter decade presented further evidence to the feature that the relative magnitude of the land uplift with respect to the water level along the northern coast of the GoF apparently has changed around year 1960.

Remarkable aperiodic interannual sea level variability over 2 to 6 years (with an amplitude of 10–20 cm at

Stockholm) has been documented during the previous decade. Its main cause probably is the variation of east–west directed wind forcing over the Danish Sounds. The dominant component of the sea level variation is the annual cycle, about 50–80 % of which is imported into the Baltic Sea from the North Sea as well. Its half-range was about 10 cm during the first half of the 20th century, increased rapidly by about 75 % in the 1970s–1980s, and decreased to around 13 cm in the end of the century at the northern coast of the GoF. The average range of the sea level variation at the southern coast of the GoF seems to be somewhat smaller where the relevant amplitudes vary between 9.5 and 12 cm.

The mid-range Baltic Sea level variability (periods from 2 days to several years, partially based on data from the northern coast of the GoF) has a significant spatial coherence: all variations from periods of 6 months up to about 10 years have an almost identical geographical pattern and, most probably, have a common origin. The whole Baltic Sea level acts either as a quarter-wave-length (with a node at the southern Baltic Sea) or a half-wave-length oscillator for these periods; these regimes basically coincide for the GoF. Horizontal long-term variations of the sea level are mostly caused by variations of the local wind climate and by the basin-scale salinity variation. The sea level in the large river mouths (e.g. Narva River) is frequently higher than in the rest of the sea; yet there is no considerable difference in correlations between the stations located in the large river mouths and other stations; thus the sea level variability due to the river runoff thus is almost completely accounted for by the mean field. The temporal and spatial correlation radii of the sea level data from the southern coast of the GoF are about 10 days and 200–400 miles, respectively. Simple stochastic models correctly reproduce, at least, 90 % of the sea level data from the Estonian coast.

The sea level of the GoF in February-March has increased during the latter decades; a minor decrease during April-October and an increase in November-January can be noticed as well. The seasonal maximum of sea level in terms of monthly means has been shifted from the end of September to the end of October.

The annual standard deviation of the sea level has largely increased in the 1960s–1970s. The higher sea levels are more probable than the low levels, which is a common feature at all the sites along the Finnish coast. In particular, the annual maximum values of water level have significantly increased on the Finnish coasts during the latter half of the 20th century. The January storm in 2005 set new sea level maxima at many sites of the GoF but the sea level reached a relatively modest value of 230 cm in Sankt Petersburg. An interesting feature is that the overall variability of the Baltic Sea water level has increased even more than its local variations, thus large-scale phenomena rather than local storms have caused these changes.

Current scenarios for the coming 100 years predict an increase in global mean sea level from 0.1 to 0.9 m. Although the uncertainties in the scenarios are large, in most cases the rise in water level is expected to balance the land uplift at the northern coast of the GoF and the past declining trend of the relative sea level is not expected to continue. The southern and eastern coasts of the GoF may experience relative water level rise. There exist suggestions that the seemingly increasing storminess (expressed as a statistically significant increasing trend of the number of storm days over the last half-century) in the eastern Baltic Sea has already caused extensive erosion and alteration of depositional coasts. The areas with considerable risk are an important recreation site Narva-Jõesuu and the Sillamäe dumping site of the former uranium enrichment plant.

7. Surface waves

The basic advances in surface wave studies in the GoF area during the last decade are based on (i) the implementation of contemporary spectral wave models that adequately represent the sea state even in such a challenging place for wave modellers as the Gulf of Finland, (ii) the improvement of the quality of atmospheric models accompanied with the above-mentioned availability of high-quality marine wind data, and (iii) the directional wave data from the central part of the GoF.

Directional wave statistics is now available for selected ice-free periods in the beginning of the 1990s and more or less continuously from November 2001. The highest waves were measured on 15 November 2001 (H_s=5.2 m off Helsinki). Very long waves, with peak periods up to 12 s occurred in the GoF on 9 January 2005.

A specific feature of the GoF is that the average wave directions are often concentrated in narrow sectors along the gulf axis although the wind directions are more evenly spread. This phenomenon is attached to the slanting fetch conditions in which the wind direction is oblique to the gulf axis. Shorter waves are usually aligned with the wind, while somewhat longer and higher waves that often dominate the wave field propagate along the gulf axis.

Operational wave models of the Baltic Sea based on the model WAM cycle 4 have been implemented at the turn of the millennium with a typical spatial resolution of 5–9 nautical miles while the scientific models use resolutions of a few miles. Yet the operational models reasonably forecast wave conditions even in the most extreme storms. Owing to relatively short wavelengths in the GoF, the WAM model gives reasonable results until the depth of about 5 m and as close to the coast as 200–300 m in the bays adjacent to the GoF. The 'memory' of wave fields is relatively short, i.e. the changes in wind properties are fast reflected in the wave field properties. As a consequence, the wave fields in several sub-basins of the GoF mimic the changes of the open-sea wind properties and reveal significant seasonal and spatial variability that apparently reflects an analogous variability in the GoF.

Probably the most intense fast ferry traffic in the world crosses the central part of the gulf. The wakes from fast ferries (defined as large ships sailing at speeds close to the phase speed of long waves for the particular water depth) form a considerable part of the total wave activity in certain subbasins, in particular in Tallinn Bay. Wakes from fast ferries frequently contain highly nonlinear and at times solitonic waves; for that reason the ship wave groups may have substantial remote influence and ship-wave-induced near-bottom orbital velocities may be by a few tens of % larger than expected from the linear wave theory. The leading wake waves from large high-speed vessels frequently have the heights about 1 m and periods of 10–15 s. Such waves occur extremely seldom in natural conditions in Tallinn Bay and may cause unusually high near-bottom velocities at the depths of 10–30 m. The daily highest ship waves mostly belong to the annual highest 1–5 % of wind waves. The annual mean energy of ship waves in the coastal area of Tallinn Bay forms about 5–8 % from the total wave energy (6–12 % during the spring and summer seasons) and about 18–35 % (27–54 % during spring and summer season) from the wave energy flux (wave power). The influence of ship wakes, identified with the use of optical measurements, extends to a depth of at least 15 m and usually lasts about 6–15 minutes but is limited to a water layer with a thickness of about 1 m near seabed. About 10,000 kg of sediments per metre of the affected sections of the coastline may be brought into motion by ship wakes annually. The total loss of sediments could be several hundred litres per metre of coastline.

8. Ice conditions

Sea ice is present in the GoF for 4–5 months each winter, through December to April. In mild winters only the eastern part freezes but normally the basin becomes fully ice covered. In the beginning of the winter the freezing front progresses from Neva Bay westward along the northern coast, and consequently the ice season is more severe toward east and north. On the Estonian coast the heat inflow from the Central Baltic Sea and southerly to south-westerly wind help to keep to area ice free. The asymmetry of the ice conditions is also caused by the coastal morphology supporting a wide fast ice zone on the coast of Finland.

The maximum annual thickness of coastal fast ice is 30–80 cm, increasing toward east. Congelation ice appears to be dominant formation type in the stratification of the ice sheet. Snow-ice amounts to 10–30 %, and frazil ice proportion is small but it is not known how small. The brackish ice of the Baltic has a fine scale structure similar to sea ice. The ice crystals have irregular boundaries and the brine entrapment is significant, the salinity of the ice being 0.5–2 ‰ in winter. According to observations, the fresh water ice type occurs only at river mouths, where the salinity of the water is less than about 1.5 ‰.

Outside the fast ice zone there is the drift ice zone with a highly nonlinear mechanical behaviour. Ice thinner than about 20 cm normally drifts with the wind and currents. The theoretical free drift speed is then a useful approximation, giving the speed of 2 % of the wind speed. Indeed it is observed that southerly and northerly winds open wide leads on the lee side. Easterly winds push the ice out of the GoF, while westerly winds pack the ice toward the eastern end. In the presence of compressive drift pressure ridges form. The largest mapped ridges have been 6–8 m thick, but it is quite likely that larger ones exist, in particular at the eastern fast ice boundary between at Kotka–Vyborg longitudes.

When the ice becomes thicker than 50 cm, as is the case in cold winters such as 1987, the wind forcing can no more overcome the yield stress of the ice, and the GoF ice cover may be stationary in the middle winter up to two months. When the thickness of ice is within 20–50 cm, it has restricted mobility. Displacement are typically smaller, and the length scale of the motion increases so that islands and shoals lock the drift into the fast ice zone. A good example is Gogland, which locks the more eastern ice pack.

It is clear that the sea ice has a remarkable influence on the oceanography of the GoF. Ice formation and melting influence the stratification of the waters, in particular the freshening of the surface layer in spring is important. But more drastic is the nonlinear dynamical behaviour of the drift ice. Thick ice cuts the transfer of momentum from the wind to the water body, and the circulation becomes weak as forced only by boundary fluxes at the ice edge.

Dynamic-thermodynamic sea ice models have been developed for the GoF, as a part of a full Baltic Sea model or as a local fine resolution model. The evolution of the ice conditions can be rather well predicted, the main problems being the ice mechanics in the near-fast ice boundary zone. Also there is a large change in the quality of ice across the basin, from thin pancake ice in the west to heavily ridged pack ice in the east, which requires good advection schemes from numerical models.

There are long time series available for the coastal ice conditions in GoF; longest one dates back to 1829 (ice break-up at Helsinki). During the 20th century, the variability of the dates of freezing and ice break-up has been about three months, but only the latter one shows significant trend toward shorter ice seasons, as much as 15–20 days per hundred years. In the maximum annual ice thickness a decreasing trend has been found.

9. Optics

The Baltic Sea and GoF waters are ‘turbid oceanic coastal waters’ in Jerlov’s classification. Out from the near-shore zone, the transparency of the water or the Secchi depth is presently 4–7 m with no large differences between basins. During the last 100 years the Secchi depth has decreased in GoF, the average coming from 8 m down to 5 m. In the same proportion the euphotic depth of the GoF waters has come down, being about 1.5 times the Secchi depth.

Direct irradiance measurements have been made mainly at coastal sites in GoF. There the transparency is below 5 m due to the larger amount of suspended matter. Measurements show attenuation coefficient as about 1 m^{-1} for total light level and as 2–3 m^{-1} at 380 nm wavelength corresponding to high level of yellow substance.

Optical remote sensing methods have been employed to map the quality of the GoF water. The optical complexity of the waters, in particular the mixed influence of yellow substance and suspended matter, cause limitations to the identification of optically active substances from remote sensing data. Therefore the methods have been successful mainly in identifying algae blooms due to their strong signal. However, this method has future promises for identifying different types of water in the basin.

Acknowledgements

This study was supported by the Estonian Science Foundation (Grant 5762) and partially in the framework of the MC RTN SEAMOCS (MRTN-CT-2005-019374) and the Eco-Net project “Wave Current Interaction in Coastal Environment.” A large part of the underlying paper was written during the visits of one of the authors (TS) to the Centre of Mathematics for Applications in the framework of the MC TK project CENS-CMA (MC-TK-013909). The third author (ML) is supported by Maj and Tor Nessling foundation (Project ‘Oil spill model for winter conditions in the Gulf of Finland’).

References

Alenius P., Myrberg K., Nekrasov A., Physical oceanography of the Gulf of Finland: a review, *Boreal Env. Res.*, 3, 97-125, 1998.

Modeling the Pathways and Ages of Inflowing Salt- and Freshwater in the Baltic Sea

H.E. Markus Meier

Swedish Meteorological and Hydrological Institute, Norrköping, Sweden, e-mail: markus.meier@smhi.se

1. Introduction

Although the circulation of the Baltic Sea has been studied intensively in earlier publications, there are still many open questions connected to pathways and time scales of inflowing salt- and freshwater in the various subbasins. Due to the large temporal and spatial variability the investigation of the mean large-scale circulation of the Baltic Sea is only with the help of models possible.

To analyze the time scales of the circulation the concept of age distribution and transit time (Bolin and Rodhe, 1973) is used which has been applied earlier to the Himmerfjärden estuary (Engqvist, 1996), the Gulf of Finland (Andrejev et al., 2004), the Gulf of Bothnia (Myrberg and Andrejev, 2006), and the entire Baltic (Meier, 2005). In these studies a passive tracer was added to the model variables to characterize the average age of sea water in the reservoir with prescribed values at the lateral open boundaries or at the sea surface. For instance, Meier (2005) found for the period 1903-1998 mean ages of the bottom water of 1 year at Bornholm Deep, 5 years at Gotland Deep, and 7 years at Landsort Deep. For the whole Baltic a maximum age of about 11 years appeared in the bottom water at Landsort Deep. In his study the age of sea water is the time elapsed since a water particle left the sea surface. The mentioned studies have in common that the age of sea water is estimated from the equation of the age of pure water. Hence, it is not possible to distinguish between different water masses.

In the present study the concept of age is refined. A high-resolution simulation for 1980-2004 was performed using an eddy-permitting three-dimensional circulation model. In the model various water masses were marked with passive tracers and the associated ages of the specific water masses were calculated. The aim is to better understand the large-scale circulation and related time scales.

2. Methods

In this study a new version of the Rossby Centre Ocean model (RCO) (Meier et al., 2003) was used to perform a multi-year long, high-resolution simulation for the Baltic Sea. RCO is a Bryan-Cox-Semtner primitive equation circulation model with a free surface and open boundary conditions in the northern Kattegat. It is coupled to a Hibler-type sea ice model with elastic-viscous-plastic rheology.

The model domain covers the Baltic Sea including Kattegat. In the present study, RCO was used with a horizontal resolution of 2 nautical miles and with 41 vertical levels with layer thicknesses between 3 and 12 m. Minimum and maximum depths amount to 6 and 250 m corresponding to 2 and 41 levels, respectively.

As the layer thicknesses of the vertical grid are too large to resolve the bottom boundary layer (BBL) accurately, a BBL model is embedded to allow the direct communication between bottom boxes of the step-like topography (see Meier et al., 2004).

In the new version of RCO, a flux-corrected, monotonicity preserving transport (FCT) scheme following Gerdes et al. (1991) is embedded.

A model simulation for 1980-2004 is performed. RCO is started from rest on 26 May 1980 with initial temperature and salinity observations from May 1980. At the open boundary in the northern Kattegat hourly sea level observations from the Swedish tide gauge station Ringhals are prescribed. In case of inflow, temperature and salinity at the open boundary are relaxed towards observed climatological mean data. In case of outflow, a radiation condition is utilized. Also the freshwater inflows of the 29 largest rivers of the Baltic catchment area are considered. Monthly mean discharges are calculated from a large-scale hydrological model. The atmospheric forcing is derived from three-hourly gridded observations of sea level pressure, geostrophic wind components, 2 m air temperature, 2 m relative humidity, precipitation, and total cloud cover.

To track specific water masses concentrations of passive tracers and associated age concentrations are calculated following the studies by Delhez et al. (1999) and Deleersnijder et al. (2001). The initial tracer and age concentrations are set to zero. At the open boundary in Kattegat the same radiation conditions as used within RCO for temperature and salinity are utilized. In case of inflow, at the open boundary the concentrations of the tracers and associated ages are relaxed to zero, with a time scale of one day. At the sea surface no flux boundary conditions are used.

The sources of the following water masses are marked with passive tracers:

1. inflowing water at the entrance sills independently of salinity,
2. inflowing water with salinities larger than 17,
3. warm intermediate inflow water with salinities both larger than 8.95 and smaller than 14.3 and with temperatures larger than 11°C,
4. inflowing freshwater from the river Neva,
5. inflowing freshwater from the river Kalixälv,
6. inflowing freshwater from all rivers.

On 26 May 1980 the tracer and age concentrations were set to zero. As at the end of the almost 25-year long simulation in December 2004 the tracer concentrations are not in steady-state, a 96-year spin-up experiment was performed with four-times repeated atmospheric and hydrological forcing. The aim was to calculate quasi steady-state age distributions based upon the climate variability for 1980-2004.

3. Selected results

In Figures 1 and 2 5-year mean ages at the end of the 96-year spin-up experiment are shown. The associated tracers mark either inflowing water at the Darss Sill and at the Drogden Sill (case 1, Fig.1) or freshwater from all rivers (case 6, Fig.2).

In the first case there are pronounced vertical and horizontal age gradients between the lower layer and the upper layer and between the Baltic entrance area and the Bothnian Bay in the north, respectively. At the sea surface of the Bornholm Basin, Gotland Basin, Bothnian Sea, and

Bothnian Bay the mean ages amount to 26-30, 28-34, 34-38, and 38-42 years, respectively.
Largest mean ages of more than 30 years associated to the freshwater of the rivers (case 6) are found in the central Gotland Basin and Belt Sea. At the bottom the mean ages are largest in the western Gotland Basin and amount to more than 36 years. In the Baltic proper vertical gradients of ages associated to the freshwater inflow are smaller than in the case of inflowing saltwater from Kattegat indicating an efficient recirculation of freshwater in the Baltic Sea. More results of this study will be presented at the conference (see also Meier, 2007).

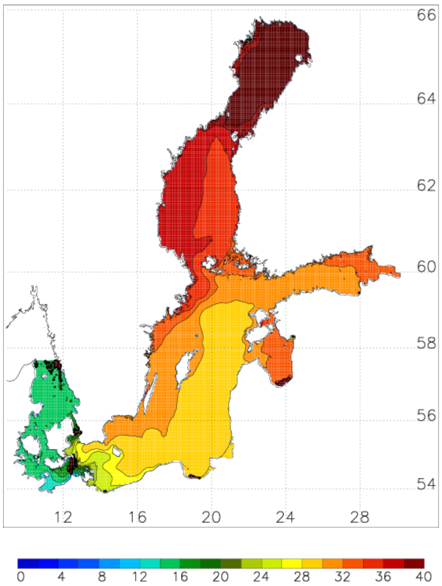


Figure 1. Mean age (in years) at the sea surface for the last 5 years of the 96-year spin-up related to the tracer marking inflowing water at the Darss and Drogden sills.

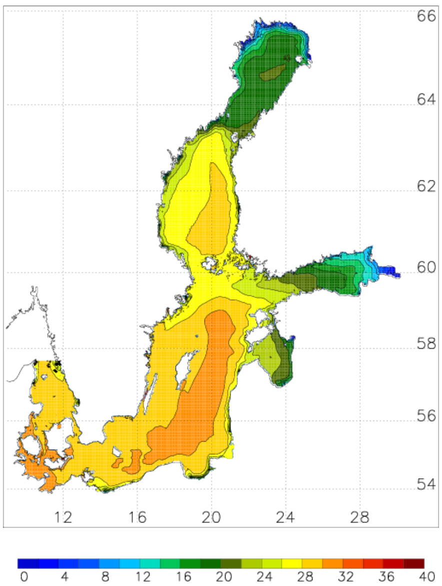


Figure 2. As Fig.1 but the ages are related to the tracer marking freshwater from all rivers.

Conclusions

The main conclusions of this study are:

1. The implementation of the BBL model improves simulations of the multi-annual variability in the Baltic Sea.
2. The implementation of the FCT advection scheme enables the investigation of the pathways and ages of Baltic water masses generated at spatially limited sources on long time scales (e.g. the calculation of ages in steady-state).
3. The calculation of steady-state ages of inflowing water from the Kattegat and from the rivers requires at least 100-year simulations because maximum ages of more than 30 and 40 years are found, respectively. Using the method of repeated integration of a time slice with atmospheric and hydrological forcing from the period 1980-2004 plausible age distributions are calculated. Due to the high ages the Baltic Sea is vulnerable to eutrophication and to the enrichment of long-lived pollutions.

References

Andrejev, O., K. Myrberg, and P.A. Lundberg, Age and renewal time of water masses in a semi-enclosed basin - application to the Gulf of Finland, Tellus, 56A, 548-558, 2004

Bolin, B., and H. Rodhe, A note on the concepts of age distribution and transit time in natural reservoirs, Tellus, 25, 58-62, 1973.

Deleersnijder, E., J.-M. Campin, and E.J.M. Delhez, The concept of age in marine modelling: I. Theory and preliminary results, J. Mar. Sys., 28, 229-267, 2001.

Delhez, E. J.M., J.-M. Campin, A.C. Hirst, and E.Deleersnijder, Toward a general theory of the age in ocean modelling, Ocean Modelling, 1, 17-27, 1999.

Engqvist, A., Long-term nutrient balances in the eutrophication of the Himmerfjärden estuary, Estuarine, Coastal and Shelf Science, 42, 483-507, 1996.

Gerdes, R., C. Köberle, and J. Willebrand, The influence of numerical advection schemes on the results of ocean general circulation models, Clim. Dyn., 5, 211-226, 1991.

Meier, H. E.M., Modeling the age of Baltic Sea water masses: Quantification and steady state sensitivity experiments, J. Geophys. Res., 110, C02006, 2005.

Meier, H.E.M., Modeling the pathways and ages of inflowing salt- and freshwater in the Baltic Sea. Estuarine, Coastal and Shelf Science, accepted, 2007.

Meier, H. E.M., R. Döscher, and T. Faxén, A multiprocessor coupled ice-ocean model for the Baltic Sea: Application to salt inflow, J. Geophys. Res., 108(C8), 3273, 2003.

Meier, H.E.M., R. Döscher, B. Broman, and J. Piechura, The major Baltic inflow in January 2003 and preconditioning by smaller inflows in summer/autumn 2002: a model study, Oceanologia, 46, 557-579, 2004.

Myrberg, K., and O. Andrejev, Modelling of the circulation, water exchange and water age properties of the Gulf of Bothnia, Oceanologia, 48(S), 55-74, 2006.

Testing a New Swell-Dependent Drag Coefficient in a Process Oriented Ocean Model

Björn Carlsson, Anna Rutgersson and Ann-Sofi Smedman

Department of Earth Sciences, Meteorology, Uppsala University, Sweden
Bjorn.Carlsson@met.uu.se

1. Introduction

Normally one can assume the classic Monin-Obukhov theory (MOST) in the atmospheric surface layer. At sea MOST is valid as long we have wind driven waves, i.e. growing sea. However, it has been shown when swell is present, i.e. when sea waves travel faster than the wind, this is not the case, e.g. in *Smedman et al.* (1999). The turbulence structure is changed and the wind can even be driven by the waves when swell has the same direction as the wind. These findings have also been supported by large-eddy simulations by Sullivan et al. (2004).
Surface stress can be described by the drag coefficient, $C_D = (\tau/\rho)/U_{10}^2$, where τ is surface stress, ρ the air density and U_{10} the wind speed at 10 m. The neutral counterpart is C_{DN} and can be calculated using the atmospheric stratification. The drag coefficient has been found to decrease when the swell and wind have the same direction and increase when the swell direction is opposite the wind. These findings are also shown in Drennan et al. (1999)
New parameterisations of the neutral drag coefficient are thus developed and tested in an oceanographic model to investigate the importance of including swell effects when modelling the ocean. The mixing depth and the current velocity are parameters that possibly could be affected, since those properties are determined by the surface stress through the turbulence in the ocean surface layer.

2. Ocean model

The PROBE-Baltic model is a process oriented oceanographic model set up for the Baltic Sea, dividing it into 13 coupled basins. For each basin, properties such as temperature, salinity and velocity are area averaged but well resolved in the vertical, allowing good profiles. The model is driven by river runoff, meteorological forcing from ERA40 data (1958-2001) and SMHI 1°x1° gridded data set (2002-2004) and by water-levels in North Sea. For more details, see e.g. *Omstedt and Axell* (2003) and *Omstedt and Hansson* (2006).
The analysis in this study is focused on the Eastern Gotland Basin, but the other basins and the Baltic Sea as whole would follow the same pattern.

3. Parameterisation

Measurement data was taken from the small island Östergarnsholm east of Gotland in the Baltic Sea. Open-ocean conditions are present when the wind comes from the sector 50-220°. For more details about this site and the instrumentation, see for example Smedman et al. (1999). The data was used to develop new parameterisations in the presence of swell, using information from wind speed and angle between the swell and the wind. Swell is defined when the wave age, $c_p/U_{10} > 1.2$, where c_p is the phase velocity of the dominant waves. Figure 1 shows the parameterisations tested in the PROBE-Baltic model. The full curve describes the neutral drag coefficient during growing/mixed sea and the dashed curves during swell for four different angles between dominant waves and wind. The importance of the angle increases as the wind speed decreases.
The model was run with three different descriptions of the drag coefficient. The reference run is with swell excluded. The two remaining runs include and assume following (0°) and counter (180°) swell, respectively, for all wind speeds below 6 m/s. These runs are chosen for a sensitivity study of the swell effect

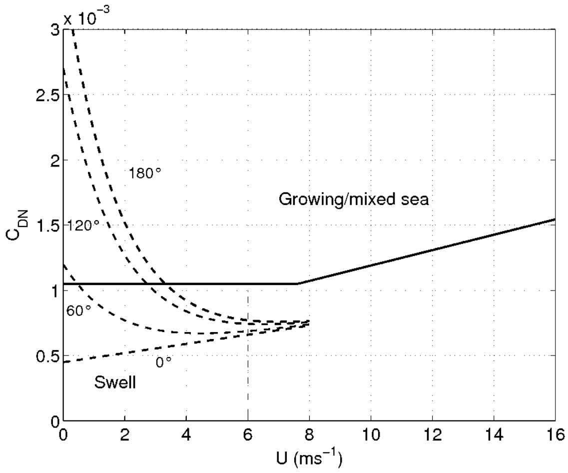


Figure 1. The new parameterisation of the neutral drag coefficient for growing/mixed sea conditions (full line) and swell (dashed curves) for different angle between waves and wind. Vertical line displays the boundary between swell and growing/mixed sea used in the in the model.

4. Results

A 5-day period with low winds was analysed. In figure 2 the time series of wind speed and calculated surface stress are shown. The surface stress is reduced compared to the reference run (full curve) when assuming following swell (dashed-dotted) and slightly enhanced at low wind speeds when counter swell is assumed (dashed). In some situations (not shown here) the assumption of following swell can more than halve the stress and counter swell could more than double the stress, compared to the reference run. The maximum difference never exceeds 0.03 N/m^2 since the stress is already small at the low wind speeds.
Regarding the current velocity, four profiles from the first part of the period in figure 2 are shown in figure 3. The speed (left) typically decreases and veers (right) clockwise with depth. The reference run is denoted by (o). As the stress is reduced during following swell (+) the current speed is lower near the surface. The opposite is true when the counter swell (x) enhances the stress (at low wind speeds). The profiles differ at larger depths as well, both in speed and direction. There are thus significant swell effects on the current profiles.

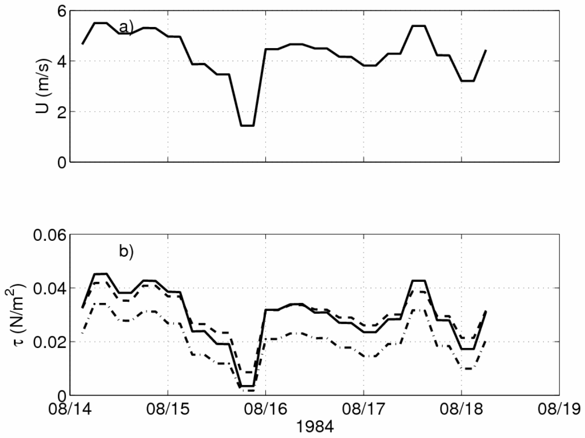


Figure 2. Period showing wind speed and corresponding modelled surface stress. Lines represents swell excluded, dashed-dotted curve are with following swell assumed and dashed are with counter swell assumed.

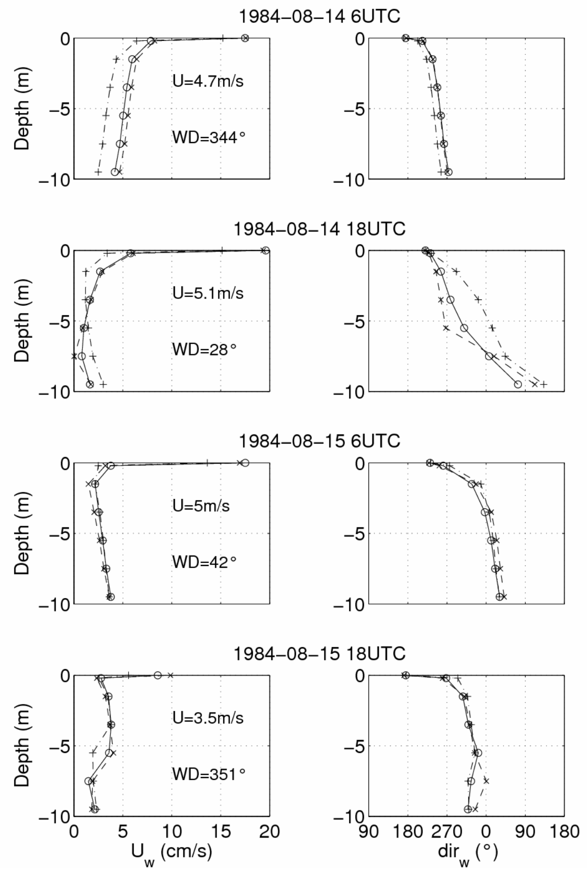


Figure 3. Current profiles of speed (left) and direction (right) during two days of low winds. (o) is with swell excluded, (+) is with following swell assumed and included and (x) is with counter swell assumed.

However, during this situation the mixing-depth was not affected. This depth is mainly governed by the turbulent mixing of the ocean surface layer and is most likely more influenced by high-wind situations than the low-wind situations when swell is present.

The 40 year mean surface stress was not very much changed, as swell becomes important only at low wind speeds when the surface stress already is small. If assuming following swell the mean stress was reduced by 2% and assuming counter swell the reduction was 0.5%. Looking only at low-wind situations the relative effect is significantly larger.

5. Conclusions

A new formulation of the drag coefficient which takes into account the effects of swell is presented. This new parameterisation is used to study the swell effects on surface stress, current velocity and mixing depth in an oceanographic model. A reference run, with swell excluded, and two swell runs, assuming only following and counter swell, respectively, for a sensitivity study of the swell effects, were run for about 40 years by the PROBE-Baltic Model. The results were analysed both on the climatic scale and for a limited swell case study.

The findings are:

- During periods of low winds, the relative changes in stress and current velocity are large.
- Climatic mean effects on surface stress and current velocity are small. The mixing depth of the surface layer is not affected.

References

Drennan W., H. Graber and M. Donelan, Evidence for the Effects of Swell and Unsteady Winds on Marine Wind Stress, *J. phys oceanogr.*, Vol. 29, p. 1853-1864, 1999

Drennan W. and H. Graber, On the wave age dependence of wind stress over pure wind sea, *J. Geophys.Res.*, Vol. 108, Vol. 108, No. C3, 2003

Larsén X. G., V. Makin and A.-S. Smedman, Impact of waves on sea drag: Measurements in the Baltic Sea and a model interpretation, *The global atmosphere and ocean system,* Vol. 9, No. 3, pp. 97-120, 2003

Omstedt A. and L. Axell, Modeling the variations of salinity and temperature in the large Gulfs of the Baltic Sea, *Continental Shelf Res.*, Vol. 23, 265-294, 2003

Omstedt A. and D. Hansson, The Baltic Sea ocean climate system memory and response to changes in water and heat balance components*, Continental Shelf Res.*, Vol. 26, 236-251, 2006

Smedman A.-S., U. Högström, H. Bergström, A. Rutgersson, K. Kahma and H. Pettersson, A case study of air-sea interaction during swell conditions, *J. Geophys.Res,*, Vol. 104, No. C11, pp. 25833-25851, 1999

Sullivan P., J. Edson, J. McWilliams and C.-H. Moeng, Large-eddy simulations and observations of wave-driven boundary layers, *AMS Symposium on Boundary Layers and Turbulence*, Vol. 16, 2004

How do we know that Human Influence is Changing the Climate in the Baltic Sea Region?

Hans von Storch and Jonas Bhend

Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany, hvonstorch@web.de

1. The BACC report

When the Assessment of Climate Change for the Baltic Sea Basin (BACC) was "invented" during a BALTEX meeting in Roskilde in September 2004, a key questions was to what extent the scientific community would actually *know* or merely *claim* that anthropogenic climate change would take place in the Baltic Sea basin. To find out, a systematic survey was conducted in the published literature about the state of knowledge. A voluntary group of about 80 scientists from 12 countries has reviewed and assessed the published literature on climate change in the Baltic Sea region. Now, in 2007, the assessment is available (*BACC-group*, 2007; *von Storch* et al., 2007).

For temperature, it was stated: "In the past century here has been a marked increase of temperature of more than 0.7 ^{o}C in the region…. Consistent with this increase in mean and extreme temperatures, other variables show changes, such as increase of winter runoff, shorter ice seasons and reduced ice thickness on rivers and lakes in many areas. These trends are statistically significant but they have not been shown to be larger than what may be expected from natural variability. In addition, no robust link to anthropogenic warming, which on the hemispheric scale has been causally related to increased levels of greenhouse gases in the atmosphere in 'detection and attribution' studies, has been established. However, the identified trends in temperature and related variables are consistent with regional climate change scenarios prepared with climate models. Therefore, it is plausible that at least part of the recent warming in the Baltic Sea basin is related to the steadily increasing atmospheric concentrations of greenhouse gases. Efforts are needed which systematically examine the inconsistency of recent trends with natural variability, circulation changes as well as the consistency with elevated greenhouse gas concentrations as a potential cause." For precipitation, wind speed and salinity, among others, no statements concerning anthropogenic signals are made.

2. Different approaches for assessing quality of changes

A variety of methods are in use to assert the quality of changes, if they are just coincidental or systematic. The principal problem is displayed by Figure 1. Depending on the fantasy of the analyst, the data show oscillations, a trend or a regime shift (in the sense of a break point). The best explanation is, however, that the series shows irregular low-frequency variability, with a tendency towards smaller values in later years than during some decades in the first third of the series.

Obviously, fitting statistical models, such as that of a break point or of a linear or non-linear trend is not really providing the needed answers. There are two reasons, one is: Even stationary time series with red or even long memory may show intermittently such behavior. The other is – how would we know that the behavior in the window of documented changes extends into the future?

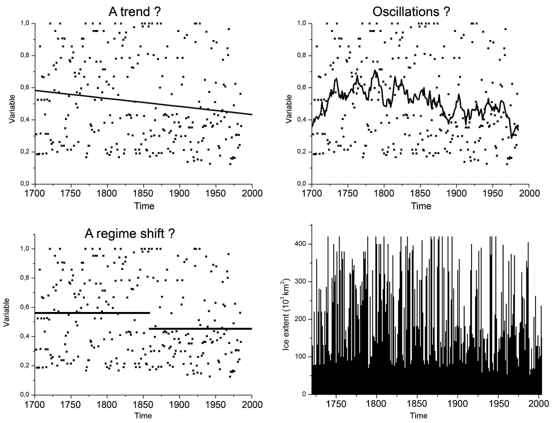


Figure 1. Difficulty to interpret a times series, as to whether it goes along with oscillations, a regime shift or a trend (after *Omstedt*, pers. comm.; also *BACC-group*, 2007)

3. Testing significance of trends

To solve the first problem, many ask – is the break point or the trend "statistically significant"? This is a well defined statistical procedure, which is in very many cases erroneously administered because of sheer incompetence. The problem is that often people implicitly operate with a null hypothesis, which is to be rejected, that a series of randomly drawn numbers have constant mean values. In that case the data have no memory, and the application of a procedure based on this assumption requires data which are serially uncorrelated. They are in most cases not. Thus in many cases the supposedly "significant" trend are technically not statistically significant.

But, even when the test is done correctly, what does the acceptance of the alternative hypothesis "there is a nonzero trend" imply? It implies, if we would repeat to collect the same data in a parallel world, we may expect to see again a trend. It does not imply that the trend will continue into the future.

An example is the annual cycle – when we test temperature variations from May through July on the Northern Hemisphere, we likely will reject the null hypothesis of no trend; and indeed, when we again examine the temperature series from another year, we will again see a temperature rise during that time. However, this finding does not imply that the trend will continue into September, October and so forth.

A major problem with "significant trends" is that the mathematics behind the word "significant" are not understood but are blended with the lay term "significance" (meaning – relevance).

In case of BACC, the literature screened contained a number of statistical analyses of trends, some of which were correct, others not.

4. The detection problem.

In fact, when considering a time series, which contains a trend, we do not need to do a significance test, except if we think that our data exhibit some uncertainties due to the observational process. Otherwise we know that the time series has a trend, with some given slope, during the interval. There is no uncertainty about it. The uncertainty we are interested is – is this slope larger than what we may expect as part of the natural climate variability to happen without increasing greenhouse gas concentrations?
This is the "detection problem" (Hasselmann, 1979, 1993). Statistically it means that we consider naturally occurring trends as being drawn from a random variable with a distribution function F(p), with p representing probability. Detection means to reject the hypothesis that recent trends T are sufficiently rare under the null hypothesis, e.g., T > F(95%).

5. Arguments, why a trend should be maintained in the future.

Statistics can hardly help us to decide if a trend will continue into the future. When talking about the future, we are in most cases leaving the statistical area of quantifying the risk of incorrect assessments. Instead we are entering the field of plausibility.
When we have convinced ourselves that a recent trend or adopted regime is related to some process, which in itself is predictable, then the trend or regime will continue if this process will prevail to act. This is a physical argument, not a statistical argument.

6. Attribution

The process of assigning a plausible cause for observed changes is named "attribution" (e.g., IDAG, 2005). This is usually a second step after a successful detection. A number of different candidate causes, which may be responsible for the change, which was found beyond the range of normal variations, is screened how well it fits the observed changes. Eventually that mix of causes is adopted as "best explanation" which describes the past changes best.
The famous assessment of the 3rd Assessment Report of the IPCC (*Houghton* et al. , 2001) that about 2/3 of the global warming since the middle of the 19th century would be due to elevated greenhouses gases, has been obtained is this way.
For the Baltic Sea catchment, the BACC initiative found no efforts to formally detect non-natural changes; also no efforts to objectively assign anthropogenic and natural factors to the observed warming in the region.

7. Consistency arguments

In view of the failure of the scientific community to rigorously address the abnormality of the recent warming in the Baltic sea region, and its possible causes, the BACC assessment offered a consistency argument, which is quoted in Section 1 of this extended abstract – namely: The recent warming during the industrial period in the Baltic Sea region is consistent with the global scale changes of air temperature. The latter, however, underwent a rigorous "detection and attribution"-analysis with the result that, first, the recent warming was beyond the range of natural variability and, second, that the best explanation of the recent warming was to relate 2/3 of it to elevated levels of greenhouse gases (e.g., IDAG, 2005).
We have now begun another line of consistency analysis. We ask if the most recent trends are consistent with what contemporary regional climate models envisage as the response to elevated GHG concentrations. In this way, we offer the possibility to falsify the hypothesis of a presently observable anthropogenic signal. A possible outcome of our analysis is "no falsification" of the hypothesis "trend is man-made". Our method can not discriminate the plausibility of different forcing-effects but merely assess the consistency of recent changes with an a-priori assumed mechanism, in particular increased levels of GHGs in the atmosphere. Obviously, a regular "detection and attribution" analysis is more informative, but our method is applicable also in cases of considerably less data and without reference to sometimes hardly available estimates of natural variability.
Of course, this rests on the assumption that our contemporary models are good enough for projecting anthropogenic climate change. We believe that they are, but we have to acknowledge that a conclusive proof of that assumption is not possible at this time.
If recent trends fails to be consistent with the expected trend, then in principle three reasons may be thought of - the model is insufficient (e.g., the expected signal is false), the natural variability overwhelms the signal, or more than the expected mechanism is at work, for instance decreasing concentrations of industrial aerosols in parallel to an increase of GHG gases.
A first case study, dealing with winter precipitation amounts in the Baltic Sea region, is offered by Bhend and von Storch (2007) at this conference.

References

Bhend, J. and H. von Storch, Towards the detection of a human induced climate change in Northern Europe, IBS Publication No38, pp. 29-30, 2007

Hasselmann, K., On the signal-to-noise problem in atmospheric response studies. B.D. Shaaw (Ed.) *Meteorology over the tropical oceans*, pp 251-259, Royal Met. Soc., Bracknell, Berkshire, England, 1997

Hasselmann, K.: Optimal fingerprints for the detection of time dependent climate change. *J. Climate* 6, 1957 – 1971, 1993

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson, *Climate Change 2001: The Scientific Basis*. Cambridge University Press, 881 pp, 2001

IDAG, Detecting and attributing external influences on the climate system. A review of recent advances. *J. Climate* 18, 1291-1314, 2005

von Storch, H., A. Omstedt and H.-J. Isemer,: BALTEX assessment of climate change for the Baltic Sea basin (BACC). In: Filho, Mannke and Schmidt-Thone (eds) *"Information, communication and education of climate change – European perspectives"*, 2007, submitted

BACC Group: *Assessment of climate change for the Baltic Sea basin*, Springer-Verlag, in press

Towards the Detection of a Human Induced Climate Change in Northern Europe

Jonas Bhend and Hans von Storch

Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany, jonas.bhend@gkss.de

1. Introduction

During the last years, many studies concluding a human influence on the observed climate change on global to sub-continental scales have been published, for instance *Hegerl et al* (1996) and *Stott* (2003). However, as a consequence of the increasing variability on smaller spatial scales (*Stott et al., 1996*), and due to uncertainties in the expected pattern and intensity of the response to anthropogenic forcing, the magnitude of the human influence on regional climate change in Europe is still a matter of debate. Hence, this study aims at analyzing the similarity of patterns of observed trends and predicted changes due to anthropogenic forcing and further aims at discussing the consequences for future detection and attribution studies.

2. Data

Anthropogenic climate change patterns have been estimated from an ensemble of climate change simulations run with the Rossby Centre regional Atmosphere Ocean model (RCAO) of the Swedish Metrological and Hydrological Institute (SMHI, *Räisänen et al., 2004*). The ensemble consists of two scenario runs (SRES A2 and B2) and two control runs for the respective driving global models (ECHAM and HadAM). The anthropogenic climate change pattern has been defined as the difference between scenario and control run mean.

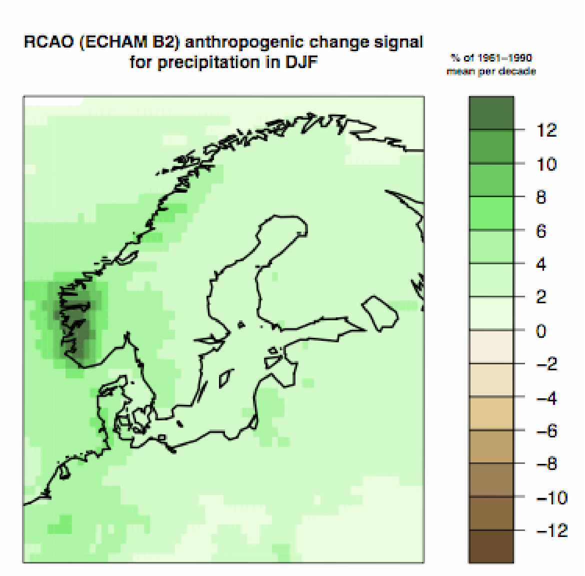


Figure 1. Anthropogenic change signal for precipitation in winter (DJF) according to the simulation driven with the ECHAM model forced with the SRES B2 emission scenario.

In addition, these possible climate change patterns have been compared using pattern correlation methods (*Santer et al.,* 1993) to trends in several observational data sets such as the gridded observations of the Climatic Research Unit (CRU, *Mitchell and Jones, 2005*). Long and homogeneous observations with high temporal resolution are still rare, and thus we use seasonal means as indicators of climate change. For the sake of brevity, we focus on wintertime (DJF) precipitation. Nevertheless, the results for the remaining seasons as well as for seasonal mean temperature will be discussed shortly in section 5 and 6.

3. Anthropogenic climate change signals

The regional climate model simulations agree on an increase in precipitation in winter (e.g. figure 1), which is more pronounced on the west coast than over the more continental parts of northern Europe. However, the exact spatial pattern and the magnitude of the rate of change in mean precipitation depend strongly on the driving global model used. For a comprehensive analysis of the RCAO climate change simulations please refer to *Räisänen et al.* (2004).

4. Observed trends

A consistent increase in northern Scandinavian wintertime precipitation is found in the observations (e.g. figure 2). The observed increase in precipitation is strongest over the southern Baltic and southern Norway. This feature is robust to the choice of trend length (not shown).

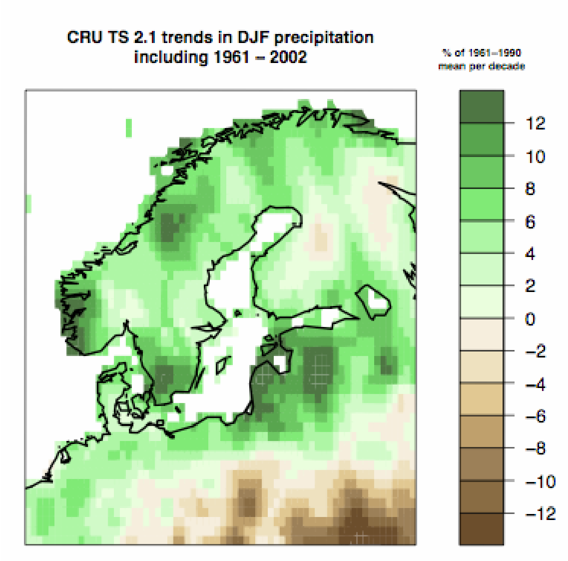


Figure 2. Trends in observed winter (DJF) precipitation according to the CRU TS 2.1 data set (in units of percentage change of 1961-1990 mean).

According to various studies such as those by *Wanner et al.* (2001) and *Hurrell and van Loon* (1997), a large part of the climate variability in northern Europe is attributable to the North Atlantic Oscillation (NAO). Additionally, a pronounced increase in wintertime NAO from the sixties, when the NAO prevailed in its negative phase, to the mid-nineties, with predominantly positive values of the NAO index, has been observed. Consequently, a large amount of the observed trend could be due to changes in the NAO, which, in turn, are probably due to natural variability.

Thus, additional analyses have been carried out in order to estimate the influence of the NAO on the observed trends. Using linear regression and the NAO index of *Jones et al.* (1997), the NAO signal has been estimated and removed from the observations.
After removing the NAO signal, the trends in the observations are significantly reduced (changes in the NAO account for about 50% of the trends in wintertime temperature and precipitation). In addition, the trend pattern exhibits slight changes as well (figure 3).

5. Similarity of observed and predicted patterns

First, we find good correspondence between the observed trends and the anthropogenic climate change scenarios for both temperature and precipitation for all seasons except for autumn.
Second, it is found that the observed trends in precipitation are much more pronounced than the changes due to human influence as simulated by the models. Assuming, that the scenarios are correct, a large amount of the observed trends in wintertime precipitation is caused by natural forcing. After removing the NAO signal from the observations, the magnitude of the remaining trends is much closer to the rates of change in the anthropogenic climate change scenarios, but the similarity of the patterns is also reduced slightly. Above findings hold true for temperature as well, however, the difference in magnitude between observed and simulated changes in temperature is much smaller.
Furthermore, the differences between the individual anthropogenic change simulations are generally larger than the differences between the best matching ensemble member and the observations.

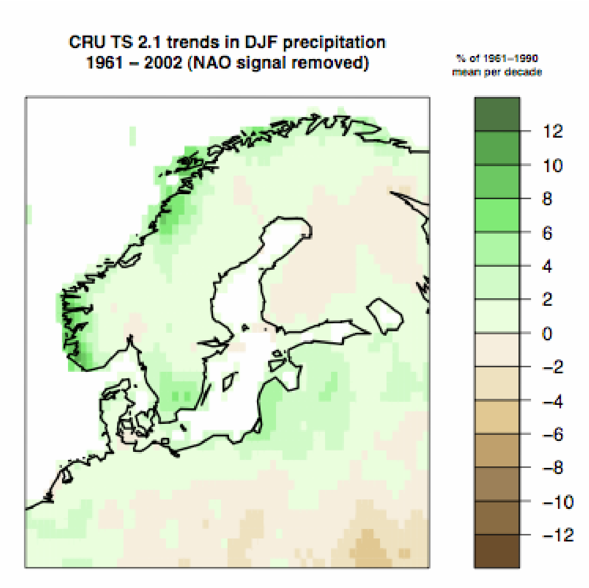


Figure 3. Trends in observed winter (DJF) precipitation after the removal of the NAO signal (data and units according to figure 2).

6. Conclusions

The results presented above illustrate a striking similarity between the observed patterns of change in seasonal means and the anthropogenic climate change scenarios derived from an ensemble of regional climate model simulations. A possible attribution of the observed changes to anthropogenic forcing is further supported when analyzing observations of which the NAO induced variability has been removed. Additionally, these results illustrate the potential of seasonal mean precipitation for future detection and attribution studies. However, proper detection and attribution is still hindered by the dominance of natural variability in northern Europe and by the similarity of the patterns of natural variability and the patterns of predicted changes due to anthropogenic forcing.

References

Hegerl, G. C., H. von Storch, K. Hasselmann, B. D. Santer, U. Cubasch, and P. D. Jones, Detecting greenhouse-gas-induced climate change with an optimal fingerprint method. *Journal of Climate*, 9, 10, pp. 2281–2306, 1996

Hurrell, J. W. and H. van Loon, Decadal variations in climate associated with the North Atlantic Oscillation, *Climatic Change*, 36, pp. 301-326, 1997

Jones P. D., T. Jonsson, and D. Wheeler, Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland, *International Journal of Climatology*, 17, pp. 1433-1450, 1997

Mitchell, T. D. and P. D. Jones, An improved method of constructing a database of monthly climate observations and associated high-resolution grids, *International Journal of Climatology*, 25, pp. 693-712, 2005

Santer, B. D., T. M. L. Wigley, and P. D. Jones, Correlation methods in fingerprint detection studies, *Climate Dynamics,* 8, pp. 265-276, 1993

Stott, P. A., Attribution of regional-scale temperature changes to anthropogenic and natural causes, *Geophysical Research Letters*, 30, 14, pp. 1728, 2003

Stott, P. A. and S. F. B. Tett, Scale-dependent detection of climate change, *Journal of Climate*, 11, 12, pp. 3282–3294, 1998

Räisänen, J., U. Hansson, A. Ullerstig, R. Doscher, L. P. Graham, C. Jones, H. E. M. Meier, P. Samuelsson, and U. Willen, European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios, *Climate Dynamics*, 22, pp. 13-31 2004

Wanner, H., S. Brönnimann, C. Casty, D. Gyalistras, J. Luterbacher, C. Schmutz, D. B. Stephenson, and E. Xoplaki, North Atlantic Oscillation – concepts and studies, *Surveys in Geophysics*, 22, pp. 321-382, 2001

Precipitation Pattern in the Baltic Sea Drainage Basin and its Dependence on Large-Scale Atmospheric Circulation

Jaak Jaagus

Department of Geography, University of Tartu, Vanemuise 46, 51014 Tartu, Estonia, jaak.jaagus@ut.ee

1. Introduction

Precipitation is a climatic variable that has the highest variability in space and time. Therefore, it may produce remarkable damage on natural environment as well as on human activity.

Usually, spatial and temporal distribution of rainfall seems rather random. But using detail statistical analyses, general regularities of precipitation regime reveal.

Principal component analysis PCA (or analysis of empirical orthogonal functions) is a multiple exploratory technique that has been widely used in climatology for analysis spatio-temporal variability of climatic variables and for regionalisation of precipitation patterns. It allows to derive some main factors (components) from a huge amount of empirical data and to analyse the peculiarities of their spatial and temporal variability.

In the previous study, a regionalisation scheme is composed for precipitation in Europe (Jaagus, 2006). It was based on 5 to 5 degree gridded monthly and seasonal precipitation data derived from the global land precipitation dataset created by the Climatic Research Unit, University of East Anglia (Hulme, 1992). Using principal component analysis and gridded precipitation data during the period 1900-1996, European precipitation regions were defined.

The first principal component defined two main regions with opposite fluctuations. The first one covers the major part of central, eastern and northern Europe including the whole Baltic Sea drainage basin. The Mediterranean region is the second one, which precipitation fluctuations are in an opposite phase comparing with the central and northern Europe.

The objectives of this study are (a) to create a regionalisation of the Baltic Sea drainage area based on precipitation regime using PCA, (b) determine long-term trends in precipitation in different regions, and (c) to analyse relationships between large-scale atmospheric circulation and precipitation regimes at these precipitation regions.

2. Material and methods

Gridded monthly precipitation totals are obtained from the dataset created by the Climatic Research Unit, University of East Anglia (Hulme, 1992). The grid density has been higher than in the previous study. The 2.5 x 3.75 degree dataset was used. All together, there was 44 grid points on the territory of the Baltic Sea drainage basin. The period 1900-1996 was used. Data matrix consists of 44 variables (grid cells) for 97 years and 12 months (or 4 seasons) every year.

The following characteristics of large-scale atmospheric circulation were used

- frequency of the main circulation forms W, E and C according to the Vangengeim- Girs classification;
- frequency of zonal (Z), meridional (M) and half-meridional (HM) circulation groups according to Hess and Brezowsky (Grosswetterlagen);
- Arctic oscillation (AO) and North Atlantic oscillation (NAOPD – using data from Ponta Delgada, NAOG – data from Gibraltar) indices;
- North Atlantic oscillation (NAOT), East Atlantic (EA), East Atlantic Jet (EAJ), Polar/Eurasia (POL), East Atlantic/West Russia (EAWR) and Scandinavia (SCA) teleconnection indices (only for the period 1950-1996)

A rotated PCA using varimax normalised rotation was applied. Distinguishing of precipitation regions in the Baltic Sea drainage basin after PCA followed a series of stages. Loading maps were composed for each significant component. A component was found for every grid cell, which has the highest correlation, i.e. loading with precipitation at that cell. Every component distinguishes one precipitation region – covering the grid cells, which have the highest correlation with this component. Finally, a map of precipitation regions was drawn.

PCA and the regionalisation procedure was applied for sequential monthly, for sequential seasonal and for separated seasonal precipitation (spring – MAM, summer – JJA, autumn – SON, winter DJF).

Trend analysis was made by the use of linear regression of time series of scores of the principal components. Trends on the $p<0.05$ are considered significant. The detected trends were interpreted so that a significant change in precipitation has occurred in the regions that have the highest correlation with the corresponding component.

Relationships between precipitation and scores of separated seasonal precipitation and seasonal values of atmospheric circulation characteristics were analysed using correlation coefficients.

3. Regionalisation

Applying rotated PCA, a regionalisation scheme for precipitation in the Baltic Sea region was composed (Figure 1). Sequential monthly precipitation values were used. This analysis derived areas with similar fluctuations, emphasising seasonal variations of precipitation.

All together six precipitation regions were detected, which are significantly different from each other. The southern region covering the territories of Poland, Belarus, Lithuania and the Kaliningrad district of Russia is characterised by precipitation maximum in spring and summer and minimum in autumn and winter, comparing with the other regions of the Baltic Sea drainage basin.

Second well distinctive precipitation region is situated east from the Baltic Sea embracing central and eastern parts of Latvia, Estonia and Finland, and south-western Russia. In this region, precipitation maxima occur in summer and autumn, and minima in winter and spring.

Eastern coast of Sweden and western coasts of Finland, Estonia and Latvia belong to the third precipitation region, southern Scandinavia (Denmark, southern Sweden, Oslo area in Norway) to the fourth, northern Scandinavia to the fifth and Scandinavian mountains to the sixth one.

These regions are not all the same if to use sequential seasonal precipitation values and precipitation during separate seasons. Results of PCA for precipitation of the sequential seasons show that the southern region remains the same but the southern Scandinavian and the Baltic coastal regions present one region. Another large precipitation region consists of the northern Scandinavian region and the northern part of the eastern region.

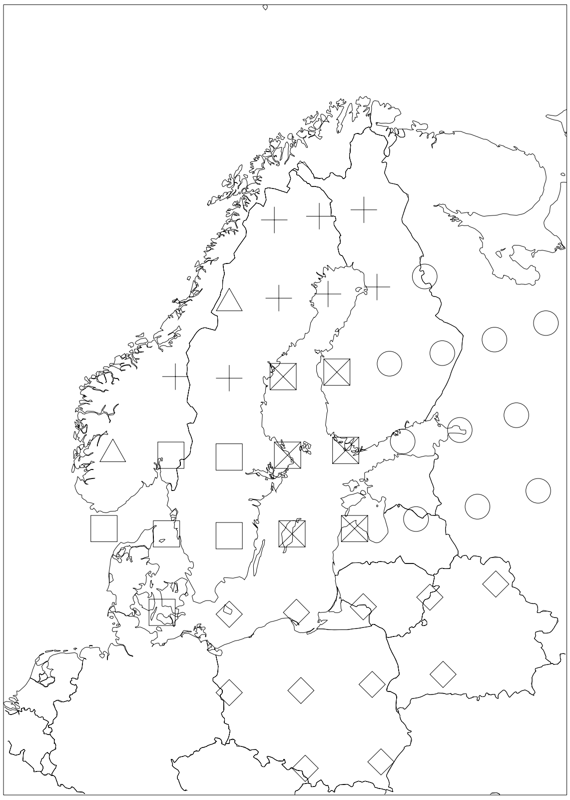


Figure 1. Precipitation regions in the Baltic Sea drainage area.

PCA of the separate seasons demonstrates the following peculiarities. The southern region is the most clearly expressed in autumn and winter. In spring, it is divided into the western and eastern parts. The eastern region is clearly present in spring. During the other seasons, it is divided into northern and southern parts. The Baltic coastal region can be noticed better in spring and summer.

4. Trend analysis

Long-term changes in precipitation are analysed using time series of scores of the principal components. A significant increasing trend was detected in the northern Scandinavian region, i.e. in the northern Sweden and northern Finland. The trend persists in case on sequential monthly and seasonal time series of precipitation. The significant trend is evident in all seasons except summer, which had no trends at all. The highest increasing trends in time series of scores of precipitation at this region were observed in winter and spring (Figure 2). In winter, the increase in precipitation has been typical practically on the whole territory of Sweden.
Decreasing trends reveal in the southern region. But they were insignificant in all seasons. On the rest of the Baltic Sea drainage basin there have not been any significant changes in precipitation during 1900-1996.

5. Correlation between atmospheric circulation and precipitation

Relationships between large-scale atmospheric circulation and precipitation are analysed using correlation between variables of circulation and scores of principal components at different precipitation regions. Generally, the highest correlation revealed in case of winter precipitation. Some statistically significant correlations have found also for spring and autumn but not in summer. It can be assumed that summer rainfall is mostly induced by convective eddies and not by atmospheric circulation.

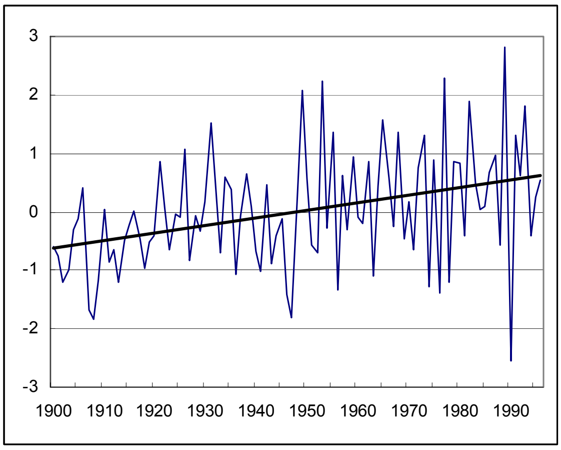


Figure 2. Time series of scores of the sixth principal component of spring precipitation representing northern Sweden and northern Finland.

Characteristics of zonal circulation, such as NAO and AO indices, and frequencies of the zonal circulation form W (Vangengeim-Girs) and zonal circulation group Z (Hess-Brezowsky) have a highly significant correlation with scores of precipitation in the Scandinavian mountains, Lappland and, of less magnitude, in Finland, north-western Russia and Estonia. Besides, Arctic oscillation (AO) index has the highest correlation (Figure 3).
Characteristics of meridional circulation (frequency of the circulation form E and meridional circulation group M, Scandinavian teleconnection index SCA) have negative correlations.

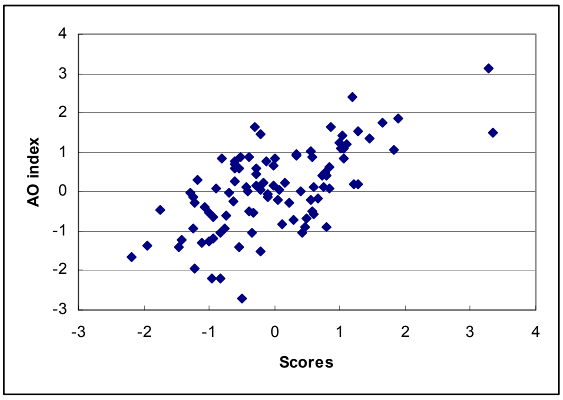


Figure 3. Scatter plot of AO index and scores of the fourth principal component of winter precipitation representing Scandinavian mountains and Lappland.

References

Hulme, M., A 1951-80 global land precipitation climatology for the evaluation of General Circulation Models, *Climate dynamics*, 7, 57-72, 1992.

Jaagus, J., European precipitation regions and their relationships with atmospheric circulation, *EMS Annual Meeting Abstracts*, Vol. 3, 2006, ISSN 1812-7053.

Long-Term Temperature, Salinity, and Sea Level Records from the Baltic Sea Entrance

Kristine S. Madsen[1,2] and Niels K. Højerslev[1]

[1] University of Copenhagen, Niels Bohr Institute, Juliane Maries Vej 30, 2100 Copenhagen OE, Denmark (ksm@fys.ku.dk)
[2] Danish Meteorological Institute, Lyngbyvej 100, 2100 Copenhagen OE, Denmark

1. Introduction

The Baltic Sea is experiencing climate changes. To understand these changes, detailed measurements of previous conditions are of high value, and since the natural variability in the area is large, long data records are necessary. This study focuses on the only open boundary of the Baltic Sea, the transition area to the North Sea. Measurements of temperature, salinity and sea level have been conducted throughout the last century from a dense network of lightships and tide gauges in the transition area (cf. Figure 1), and many of these high quality data have now been digitalized. This ongoing study analyses the long-term variations in data and derived parameters, giving new detailed insight to the conditions in the Inner Danish Waters.

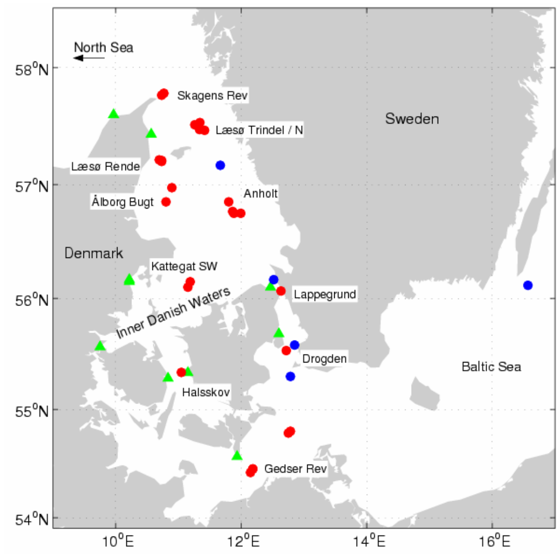


Figure 1. The study area, and indication of the positions of tide gauges (green) and Danish (red with names) and Swedish (blue) lightships. A cluster of dots indicate that the same ship has been moved to neighboring positions.

2. Data

The Danish lightship records have been digitalized by the Danish Meteorological Institute (DMI) from 1931 and onwards, giving 9 unique long-term records with daily measurements of temperature and salinity in 5 meter intervals from the Inner Danish Waters, as well as two records from the Skagens Rev ship in Skagerrak and the Vyl ship in the eastern North Sea. The measurements generally ended in the late 1970'es or 1980'es, though the surface measurements at Drogden are continued, now by a permanent station. Also, the digitalization of Drogden goes back to 1900. The Swedish lightship records are also being digitalized as a part of the SHARK project, starting from year 1923, and here 4 ships are located in the study area and one south of Öland in the southern Baltic Sea. For this project, data from 9 Danish tide gauges are used. The data records start around year 1900, and generally the quality of the measurements is high, but special attention need be paid to changes in the reference level of the measurements, instrument changes and long period Saros tides.

3. Preliminary results

The 15 year running mean temperature records from the lightships are shown in Figure 2. A clear temperature change is seen throughout the century at the Drogden station. It can be split up in a warming period from 1900 to about 1945, a slightly cooling or stagnant period until 1980, and a strong warming trend from 1980 onwards. There is a high degree of correspondence between the measurements from the different ships, and so the other ships generally support the observations made at Drogden. However, there is some indication that the recent warming may have started earlier than 1980. These findings resemble the global results found in IPCC (2001).

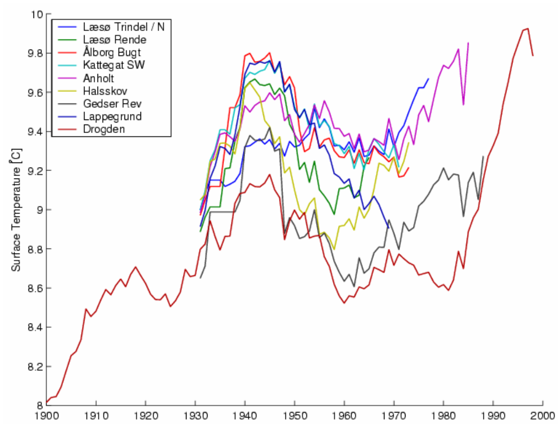


Figure 2. 15 years running mean temperature from 9 Danish lightships.

Temperature variations will give changes in the steric effect. Figure 3 gives an example of the integrated thermal expansion calculated for a water column at Halsskov. The summertime steric effect depends on water depth, at this station the depth is 20 m, and the steric effect is 6-8 cm. The wintertime steric effect is close to 0 and almost the same from year to year.

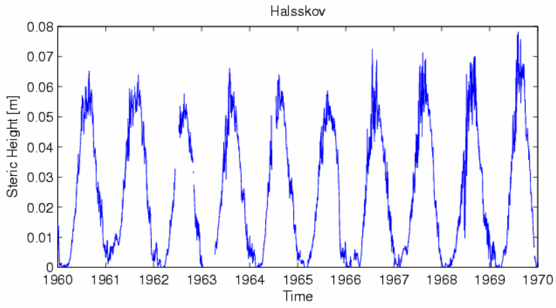


Figure 3. Steric height [m] for the time period 1960-1970 calculated for a water column from temperature measurements made by the Halsskov lightship.

Acknowledgments

Data for this project have been provided by DMI and SMHI's Swedish Ocean Archive (SHARK)

References

IPCC: *Climate Change 2001, The Scientific Basis*, Report Prepared for IPCC by Working Group 1, WMO, UNEP, University Press of Cambridge, 2001

Air Mass Seasonality and Winter Season Cold Air Masses in Latvia

Anita Draveniece

Latvian Academy of Sciences, Akademijas laukums 1, Riga LV 1050, Latvia
E-mail: int@lza.lv

1. Seasonality of air mass frequency over Latvia (1990-2000)

The frequency of air masses over Latvia was analyzed in relation to twelve landscape seasons: pre-winter, mid-winter, late winter, pre-spring, early spring, full spring, pre-summer, early summer, high summer, late summer, early autumn, full autumn. Each season may be distinguished by a definite amount of solar radiation, distinctive state of heat and water balance, phenological state of vegetation, and a distinctive occurrence of different air mass types and their particular "association". *Krauklis and Draveniece* (2004) showed that during each season these variables show a particular combination of numerical values and a distinctive landscape pattern.

Identification of air masses was performed following air mass back trajectory and the thermal properties of air masses using twice daily radiosounding data (Riga, partly Liepaja) and classified following *M.Geb's* (1981) classification. The duration of frontal passage was excluded from the air mass statistics.

The annual cycle of Latvia's air mass frequency may be divided into two periods with transition periods between them. The P+A period (October to mid-April) from full autumn to early spring, is the time of arctic and subpolar air masses. The mean frequency if oceanic and transformed subpolar air masses (mP and xP) slightly exceeds 30% and these alternate with cold air masses – oceanic arctic (mA), transformed arctic (xA) and continental subpolar air (cP). During the time from June to August or from early summer to late summer ($Ps+S_p$ period), warmed subpolar and mid-latitude air masses prevail. This period may be distinguished by the highest, however below 10%, yearly occurrence of subtropical air masses, while the mean frequency of oceanic and transformed subpolar air masses (mP+xP) is between 30-36% and arctic air doesn't arrive at all (Figure 1). The spring transitional period (mid-April to mid-May), the time from full spring until pre-summer, is unsettled in terms of dominant air masses, while the autumn transitional period (end of August to end of September) sees a reduction in temperate subpolar and warm mid-latitude $Ps+S_p$ air masses, and cold oceanic arctic and continental subpolar air masses (mA+cP) expand their influence, yet the frequency of the latter air is still slightly under 20%.

Winter (period of negative net radiation) in Latvia lasts on average for four months (end of October to end of February), and encompasses three landscape seasons: pre-winter (end of October to end of November), midwinter (beginning of December through third decade of January) and late winter (third decade of January to end of February). These seasons are dominated by air masses of subpolar or subarctic and arctic origin.

2. Pre-winter, midwinter and late winter typical air masses

During pre-winter the winter air masses gain the upper hand over warmer air, and during the 11-year period arctic air masses (xA, mA) and subpolar continental cP air comprised altogether on average 40%. Sleet and slush occurred almost each year. Pre-winter is known for establishing of first snow cover, which lasts for at least one, but commonly several days. Forming of permanent snow cover is not typical for pre-winter, yet in November 1998 the snow cover lasted for 23 days, and actually was a continuous snow cover. Falling of snow often occurs in oceanic arctic air, arriving behind the cold front. The xA air is the coldest air mass in pre-winter. It may produce only light snow, if any, and the air temperature at nighttime may fall below -10°C. For instance, in the middle of November 1994, while the city (Riga) heat-island effect prevented the minimum here from falling below -7°C, minima near -13°C were recorded in the eastern part of Latvia.

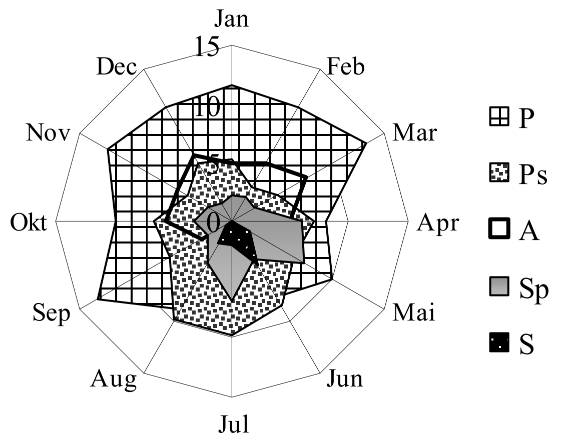


Figure 1. Monthly mean frequency (number of days) of air mass types in Riga (1990-2000): arctic (A), subpolar (P), warmed subpolar (P_s), mid-latitude (S_p) and subtropical (S) air.

During midwinter the occurrence of temperate/warm oceanic subpolar mP air and transformed subpolar xP air was on average 34-38% . Similarly to pre-winter, the frequency of oceanic subpolar mP air, which usually brings warming of weather and even thaws, was high at 21-24% (fronts excluded). With regard to snow cover, a distinction should be made among the subtypes of arctic air. In the 1990s the coldest cA air was identified only in the last week of December 1996. The temperature minimum over snow covered territories dropped to -30º to -36ºC. The xA air affected Latvia each January, yet it was not identified each December. The xA air brings the customary severe winter weather, when the daily average temperatures may fall to -25° or -26°C. The two latter air mass types normally don't bring precipitation.

With an exception of the extremely warm February 1990 with only a couple of days of mA air, in late winter the frequency of arctic air masses is slightly higher. Frosts are common and, although rarely, the cA air may affect Latvia. February 1994 was such a really cold month, with a minimum of –29.4°C on the coldest day in Riga and even lower (-33°C) elsewhere in Latvia as a result of cA air. Late winter shows an increased occurrence of transformed maritime air masses. The reason for this is xA air, which is more frequent at this time than in any other month because a short period of anticyclonic weather often occurs in early February. The anticyclones often form over Northern Europe in maritime air of arctic origin, which gradually is transformed into xA air and brings severe frosts in cold Februaries.

It should be noted that the studied 11-year period did not include any winter with an extended inflow of cA air because 1987/1988 was the start of a period of relatively mild winters. January 1987 is known to be the coldest on 100-year record. An unusually cold outbreak of cA air from the north-east brought near record low January temperatures (-37°C) and a record long period of very low (-25° to -30°C) temperatures.

3. Changes in arctic air mass frequency during winter season (1958-2000): preliminary findings

With the purpose to assess whether the results obtained by the air mass analysis for 11-year period could be generalized, time series of temperature and pseudopotential temperature at the 850 hPa level for the years 1958 to 2000 (Riga) were created and tested. Application of a polynomial regression model and the non-parametric Mann-Kendall test showed that considerable air temperature changes have occurred in two winter months. The changes in temperature (January) and pseudopotential temperature (November), supposedly, might result from slight variations in air mass thermal characteristics or the changes in monthly air mass categories.

With the purpose to test the latter assumption the frequency of arctic air masses, particularly continental arctic cA and transformed arctic xA air masses, was detected during a 42-year period. The frequencies of all arctic air mass types (cA, xA, mA) together showed great variations: from 13 days (1972/73) to 63 days during 1962/63 winter season.

The frequency of oceanic arctic air alone varies greatly from season to season, yet these air masses are indispensable for Latvia's winter (Figure 2). Apart from this the occurrence of transformed arctic air, which usually comes with northerly and north-easterly airstreams and is a cold air mass in all seasons (September till first half of May) in Latvia, has been on average twice less – 12 days per season, and in comparison to mA air shows greater frequency variations from season to season. Transformed arctic air xA uses to arrive after a series of cyclones, when a concluding ridge of high pressure may develop in the oceanic arctic air over Scandinavia and then it is transformed into xA air, which is drier and colder. In winter the daily temperatures may decrease to -25°C and even below -30°C at night; the skies are clear or partly cloudy.

The coldest and an infrequent continental arctic cA air, which comes to Latvia with north-easterly or easterly airstreams occurs only in winter (December to early March). Since it originates over the Arctic basin and Siberia, where snow and ice cover chills the lower layers and forms a marked temperature inversion up to 850 hPa, it is bitterly cold (≤-40°C). The lack of moisture causes cloudless weather without precipitation. Over the studied period a continuous influence of the very cold cA air has lasted no longer than 7 days.

The Mann-Kendall test was applied separately to each arctic air mass type (cA, xA and mA), at a significance level of $p<0.05$. A statistically significant trend (normalized test statistic -2,19) was found for the occurrence of continental arctic cA air. Although not significant, a slight decrease in oceanic arctic and transformed arctic air has been detected, too.

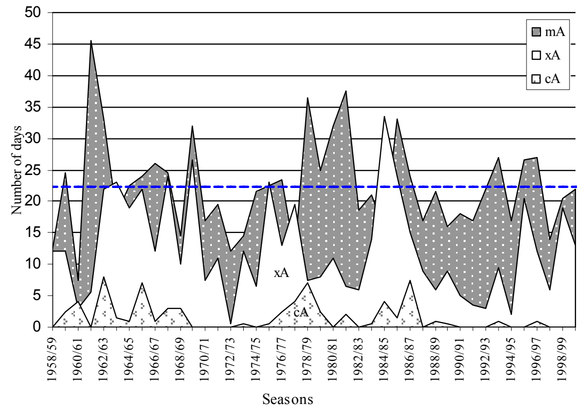


Figure 2. Winter (November-February) season frequencies of oceanic mA, transformed oceanic xA and continental arctic cA air masses in Riga (1958-2000). Blue dashed line – mean frequency of mA air masses over 42-year period.

The preliminary finding is consistent with the results of snow cover study by *Draveniece et al.* (2006), which showed an oscillating character of the variability of snow cover and detected a decreasing trend in continuous snow cover duration using linear regression analysis.

The presented preliminary findings still would need to be studied in greater detail, adjusted and better interpreted from a geographical viewpoint.

References

Draveniece, A., Briede, A., Rodinovs, V., Kļaviņš, M., Long Term Changes of Snow Cover in Latvia as Indicator of Climate Variability. *Proceedings of the Latvian Academy of Sciences, Section B*, **60** (2/3), 85–91, 2006

Geb, M., Climatological basis of air mass determination for central Europe, *Beilage 50 81 zur Berliner Wetterkarte*, pp. 32, 1981

Krauklis, Ā., Draveniece, A. Landscape seasons and air mass dynamics in Latvia. *Ģeogrāfiski raksti/Folia Geographica*, **X**, pp. 16-48, 2004.

Modelling the Baltic Sea Ocean Climate on Centennial Time Scale; Temperature and Sea Ice

Daniel Hansson and Anders Omstedt

Göteborg University – Earth Sciences Centre, Box 460, 405 30 Göteborg, Sweden. E-mail: daniel@gvc.gu.se

1. Introduction

The Baltic Sea has undergone large and sometimes rapid climate change in the past ranging from a generally cold little ice age to a generally warmer present. The little ice age ended in 1877 in the Baltic Sea region and the temperature has since increased more than 0.7°C over the past century. This directly impacts the maximum ice extent as it is dependent on the mean winter air temperature. Omstedt and Hansson (2006) found that the Baltic Sea will become fully ice covered when the mean winter air temperature is -6°C or below and completely ice free if the temperature rises above +2°C. Still, the range of the natural variability is not fully understood. It is of great interest to understand how the Baltic Sea will respond to future climate change, whether caused by natural variability or in combination with anthropogenic influences.

2. Data and methods

Recent breakthroughs in climate research related to the Baltic Sea have made meteorological datasets on centennial timescales available. These datasets originate from high quality station data from 1893 and onwards and gridded multi-proxy reconstructions spanning the period 1500-2001. Using a process oriented coupled basin model we here investigate whether or not these datasets are suitable as forcing when modelling horizontally and vertically integrated water temperature and maximum ice extent of the Baltic Sea.

3. Results

The results are encouraging and are in good agreement with independently measured and historical data used as validation (Hansson and Omstedt, 2007). The results indicate that the 20th century was the warmest century in the region with the least maximum ice extent of the last 500 years. On a decadal time scale, the 1990s, 1930s, and 1730s were the warmest decades and comparable in terms of both water temperature (Figure 1) and maximum ice extent (Figure 2). The warm period during the 1730s give rise to some questions if this period really was as warm as the results indicate. This could be an artifact of poor instrumental readings during the first years of available instrumental records. However, maximum ice extent observations from this time period do support the model results to some extent. Nevertheless and even though different climate forcing mechanisms may operate on the climate system today compared to over the last half millennium, it cannot clearly be stated that the region is experiencing climate change outside the natural limits of the past 500 years.

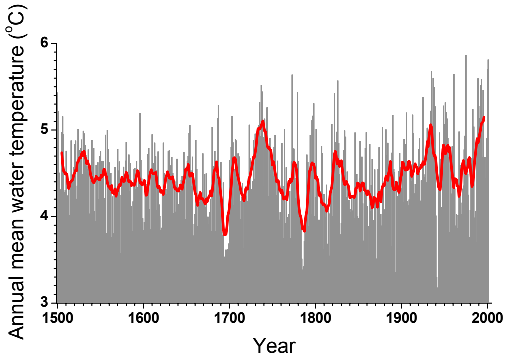


Figure 1. Modelled horizontally and vertically integrated water temperature (grey is yearly and red is decadal mean) in the Baltic Sea over the time period AD1500 to AD2001. The warming in the 1730s is of comparable magnitude to the late 20th century warming.

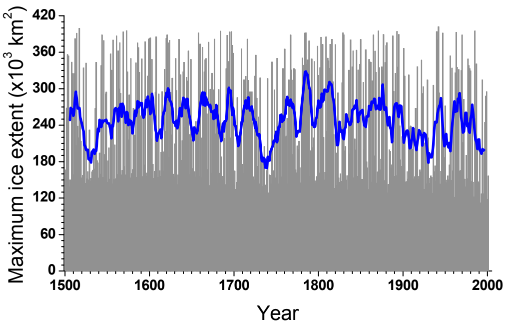


Figure 2. Modelled maximum ice extent (blue is yearly and blue is decadal mean) in the Baltic Sea over the past 500 years. Large variations have occurred over time and a minimum of ice extent was reached during the 1730s and the 20th century.

References

Hansson D., Omstedt A., Modelling the Baltic Sea ocean climate on centennial time scale; temperature and sea ice, *Submitted*, 2007

Omstedt A., Hansson D., The Baltic Sea ocean climate system memory and response to changes in the water and heat balance components, *Continental Shelf Research*, Vol. 26, Issue 2, pp. 236-251, 2006

Trends of Temperature and Salinity of the Baltic Sea for the Period 1969-2005 and Long-Term Variability of Winter Water Mass Formation

Andreas Lehmann, Hans-Harald Hinrichsen, Sarah Febiri[1] and Giesela Tschersich[2]

[1]Leibniz-Institute of Marine Sciences at the University of Kiel, Germany, alehmann@ifm-geomar.de
[2]Federal Maritime and Hydrographic Agency Hamburg, Germany

1. Introduction

The annual warming trend for the Baltic Sea basin surface air temperature has been shown to be 0.08 °C/decade which is somewhat larger than the trend for the entire globe (1861-2002), which is about 0.05 °C/decade. A marked warming in the last decades of the 20th century started around 1980 (Fig. 1). For the period 1980-2004, the low-passed filtered temperature time series shows an increase of about 1°C for the Baltic Sea catchment area. Detailed analysis of sea surface temperature data for the period 1990-2005 also show positive trends for the central basins of the Baltic Sea *(Siegel et al*., 2006, *Lehmann* & *Tschersich*, 2006). The analysis of *Siegel* et al. and *Lehmann* & *Tschersich* has been extended to the exceptional year 2006. Additionally, monthly averaged temperature and salinity profiles obtained from the ICES hydrographic data base for the period 1969-2005 have been analyzed to investigate corresponding trends in the deep basins of the Baltic Sea. Further, an analysis of the variability of winter water mass temperatures in the deep Basins of the Baltic Sea, and the relationship to surface temperatures during the formation of the winter water is presented.

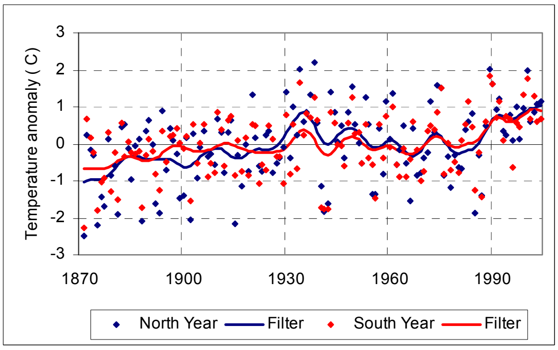


Figure 1. Annual mean temperature for the Baltic Sea catchment 1874-2004, calculated from 5° by 5° latitude, longitude box averages taken from the CRU dataset based on land stations. Blue line represents mean temperatures of the area to north of 60°N, red line to the south of that latitude. The dots represent individual years, and the smoothed curves highlight variability on timescales longer than 10 years (with courtesy from BACC Poster 'Detection of Past and Current Climate Change 1) Atmosphere: Temperature and precipitation, Fig.1.)

2. Trends of temperature and salinity

The trend analysis of SST NOAA-satellite data reveals a temperature increase for the Baltic Sea in the range of 0.2-0.9 °C/decade. The corresponding air temperature trend for 1980-2000 is about 0.5°/decade. Furthermore, the comparison of seasonal trends of air temperature anomalies with corresponding trends of SST reveals high agreement. Thus there is a close relationship between the warming of air temperatures and the corresponding increase in SST. However, satellite derived temperature data represent only the very surface of the ocean. Furthermore, SSTs can be biased due to high cloud cover and to uncertainties in the water vapor correction. Taking this into account we made an analysis of temperature and salinity profiles of the Arkona, Bornholm, and Gotland Basins from the ICES hydrographic data base (1969-2005, Fig. 2). For the sea surface temperature (0-5 m) am average increase of about 0.5°C/decade resulted. For the total water column the unweighted spatial average results in 0.26°C/decade.

Contrary, the surface salinity decreased by about 0.2 PSU/decade, and for the unweighted spatial average of the total water column salinity decreased by about 0.13 PSU/decade.

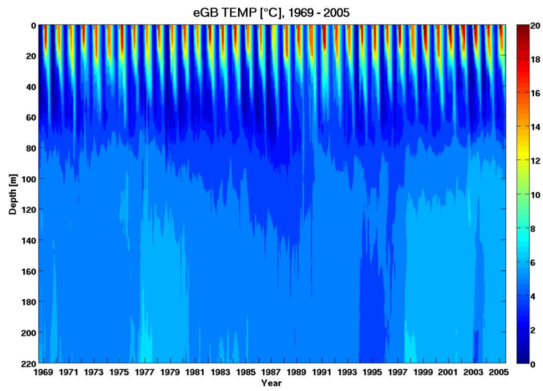


Figure 2. ICES hydrographic data base: Temperature evolution in the eastern Gotland Basin for the period 1969-2005.

3. Variability of winter water mass formation

The thermal stratification of the upper water layers in the Baltic Sea varies seasonally in response to the annual cycle of solar heating and wind-induced mixing. In winter, the stratification down to the halocline is almost destroyed by convection and strong wind mixing. Monthly averaged temperature profiles obtained from the ICES hydrographic data base are used to study long-term variability (1950 to 2005) of winter water mass formation in different deep basins of the Baltic Sea east of the island of Bornholm (Fig.2). Besides strong inter-annual variability of deep winter water temperatures, the last two decades show a positive trend. Strong positive correlations of winter surface temperatures to temperatures of the winter water body located directly above or within the top of the halocline were obtained until autumn months (Fig. 3). This strong coupling allows sea surface temperatures in winter to be used to forecast the seasonal development of the thermal signature in

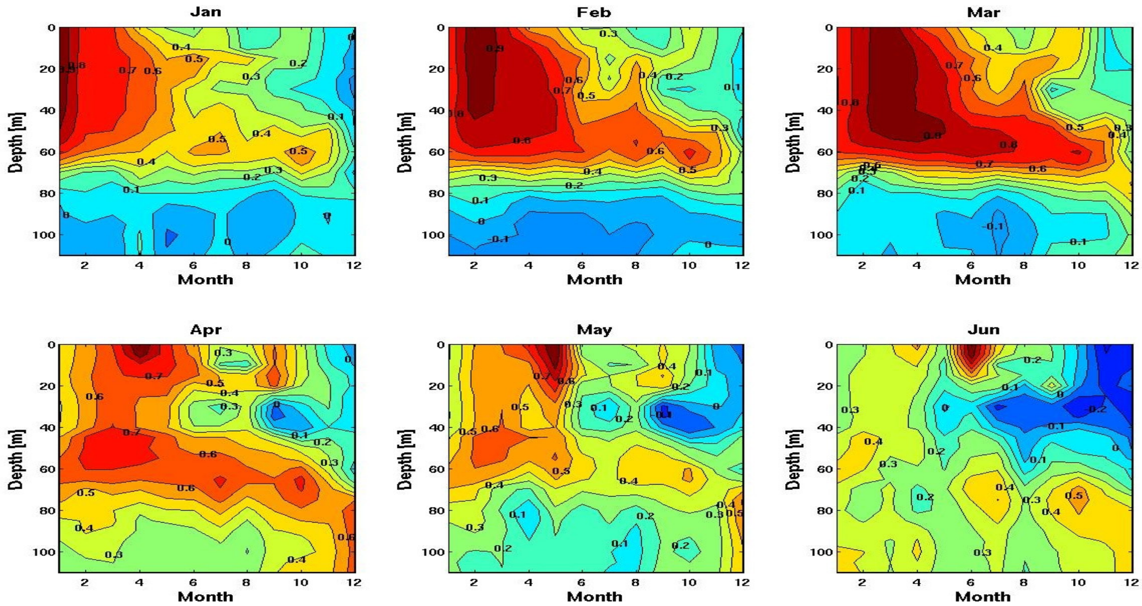


Figure 3. Profiles of correlations coefficients of surface temperature for specific months (Jan-Jun) with deep water temperature in the eastern Gotland Basin.

deeper layers with a high degree of confidence. The most significant impact of winter sea surface temperatures on the thermal signature in this depth range can be assigned to February/March (Fig. 3). Stronger solar heating during spring and summer results in thermal stratification of the water column leading to a complete decoupling of surface and deep winter water temperatures. From the trend analysis and the coupling of winter surface temperatures with deeper layers, increasing winter temperatures will automatically result in a warming of deeper layers above and within the halocline. Based on laboratory experiments, temperature-dependent relationships were utilized to analyze inter-annual variations of biological processes with special emphasis on upper trophic levels (e.g. fish egg mortality rates as well as stage specific developmental rates of zooplankton species).

References

Siegel, H. Gerth, M., Tschersich, G., Sea surface temperature development of the Baltic Sea in the period 1990-2004, *Oceanologia*, 48, 119-131, 2006

Lehmann, A., Tschersich, G., Trends in sea surface temperature of the Baltic Sea since 1990, *BALTEX Newsletter*, No. 9, 7-9, 2006

Stagnation Periods and Deepwater Inflow Dynamics: An Analysis of Measurements in the Baltic Sea During the 20th Century

Erik Gustafsson and Anders Omstedt

Göteborg University, Department of Earth Sciences, Box 460, SE-405 30 Göteborg, Sweden. E-mail: erikg@gvc.gu.se

Inflow of dense, oxygen-rich water through the Danish straits is a critical factor for the Baltic Sea ecosystems. In some of the deeper pools, periods with stagnant bottom water is a naturally occurring phenomenon as a result of a strong salinity stratification and a restricted water exchange. Nonetheless, since more regular measurements of oxygen concentrations began about a hundred years ago, we seem to experience generally larger areas of stagnant bottoms and for extended periods of time. Human activities in the catchment area of the Baltic Sea are known to have increased the inputs of nutrients above the natural loading. It's however not clear to what extent the eutrophication is responsible for the aggravated oxygen conditions in the deepwater, and to what extent this situation may be a result of changes in the inflow dynamics. The main purpose of this study is to investigate the interaction between inflow and oxygen dynamics, and whether or not the inflow dynamics has actually changed during the last century.

A first prerequisite for an inflow to occur is of course a positive sea level difference across the Danish straits. Initially, the inflowing water consists of rather low saline Belt Sea water, and the inflow has to continue for a sufficient period of time for this buffer volume to be replaced and then allow water of higher salinity to enter. The neutral buoyancy level of the inflowing water will depend on the stratification of the deepwater, which in term is determined by the rate of diffusion, i.e., how much the deepwater density has decreased since the last inflow. The halocline region of the Baltic Sea is generally well ventilated, whereas inflows to the deeper parts are more sporadic. The fact that the halocline is situated well below the sill levels in the entrance means that inflowing water will experience a decreased salinity due to entrainment of surrounding low saline water. The result is that the mix of high saline Kattegat water and low saline Baltic Sea water seldom is dense enough to replace the deeper waters of the Baltic.

A stagnation period is characterised by a decreasing density due to diffusion. As a result of the mineralisation of biological material, the oxygen concentration decreases as well, in some cases until depletion – which may lead to formation of hydrogen sulphide. This is of course dependent on depth; as mentioned above the halocline region (~ 60-100 m depth) is generally well ventilated, whereas deeper parts may be stagnant for long periods. Based on observations, the longest stagnation period we know is between 1983 and 1993, when no major inflow was realised (see Figure 1). It's however important to understand that the oxygen situation in the stagnant pools isn't a good indicator of the general state of the Baltic Sea. During the period mentioned above, erosion of the halocline related to deepwater diffusion resulted in decreasing areas of anoxic bottoms. This is a consequence of the fact that the deep basins constitute a very small percentage of the total bottom area – the mean depth of the Baltic Sea is about 60 m. Thus, a stagnation period is something that occurs mainly in the deeper deepwater of the pools whereas numerous inflows ventilate the upper deepwater in the meantime.

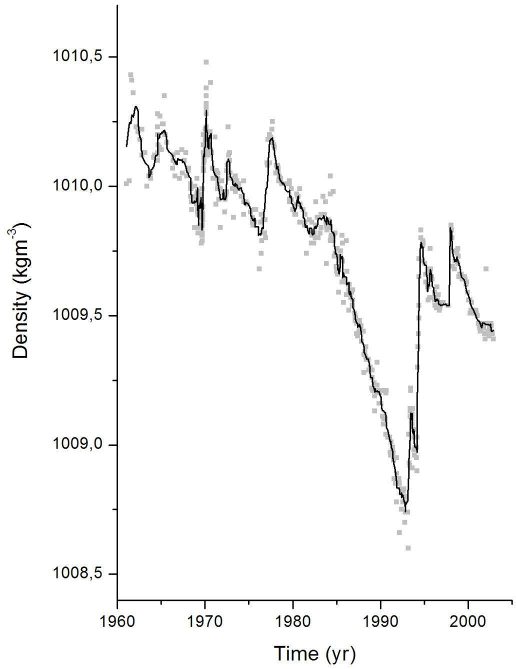


Figure 1. Development of the density at BY15 during the years 1960-2003 at 225 m. depth.

It's possible to define three (at least) prerequisites necessary to be fulfilled to break a stagnation period: 1. A sufficiently long period of positive sea level difference across the straits. 2. High salinity in the inflowing Kattegat surface water – which is coupled to the freshwater input to the Baltic Sea. 3. Sufficient diffusion in the deepwater. This presentation will characterise these three factors.

Trends, Long-Term Variations and Extremes of the Northern Baltic Proper Wave Fields

Tarmo Soomere

Centre of Nonlinear Studies, Institute of Cybernetics at Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia, soomere@cs.ioc.ee

1. Introduction

Several cases of extremely rough wave conditions at the turn of the millennium (*Kahma et al*. 2003) and ferocious winter storms in 2004/2005 (*Suursaar et al*. 2006, *Soomere et al*. 2006) have reinforced the discussion as whether the wave conditions in the Baltic Sea have become rougher compared to the situation a few decades ago. On the one hand, *Orviku et al*. (2003) argue that the apparently increasing storminess in the Baltic Sea has already caused extensive erosion of depositional coasts. On the other hand, the changes in the wave climate (*WASA Group* 1995) have been found marginal, at least, until the mid-1990s.

Although a number of numerical wave studies have been performed in the Baltic Sea conditions and there exists a large pool of high-quality wave data, adequate long-term simulations or analysis of the Baltic Sea wave fields are still missing. In this study, an attempt is make to establish the basic features of the long-term variations of wave conditions based on two time series of wave properties.

2. Measurements at Almagrundet 1978- 2003 and observations at Vilsandi 1954-2005

Probably the longest instrumental wave recordings in the northern Baltic Sea have been performed at Almagrundet in 1978–2003. This record contains the roughest instrumentally measured wave conditions (significant wave height 7.8 m) in this area until December 2004. The site is partially sheltered from the dominating south-western winds. Therefore the data may give a slightly biased picture of the open-sea wave properties (*Kahma et al*. 2003); however, they eventually reflect the changes of the long-term wave patterns (*Broman et al*. 2006).

A valuable source of long-term wave information form visual observations. Information from ship-based visual observations has been widely used for the purposes of the global wave statistics (*Hogben et al*. 1986). *Gulev and Hasse* (1999) show that even the wave climate changes estimated from data observed from merchant ships are consistent with those shown by the instrumental records. Much less use has been made from visual observations from the coast. Such data always contain an element of subjectivity, usually have a poor spatial and temporal resolution, inadequately reflect waves for several wind directions, may give a distorted impression of extreme wave conditions, have many gaps caused by inappropriate weather conditions or by the presence of ice, etc.

Yet the visual wave data are one of the few sources for detecting the long-term changes of the wave climate. Their basic advantage is the large temporal coverage. For example, recently digitised data from wave observations from the coast of the island of Vilsandi cover 52 years 1954-2005 (*Soomere and Zaitseva* 2007) and thus form the longest available wave data set in this area. This time interval evidently is long enough to extract long-term features of the changes in the overall wave activity. The quality of the data is acceptable and the average wave properties at the site, the appearance of the distribution of wave heights, the joint distribution of wave heights and periods as well the seasonal variation of wave heights (based on daily mean wave conditions) match those extracted from the Almagrundet data (*Soomere and Zaitseva* 2007, *Broman et al*. 2006). No corrections have been made in their analysis to compensate for missing values, for the uneven distribution of data, or for ice cover in the analysis below (except for using all available observations at each day for the estimate of the daily mean wave height at Vilsandi which was important in order to homogenize the data set). The wave heights in 1954–57 (Fig. 1) probably are overestimated (*Soomere and Zaitseva* 2007). However, the qualitative behaviour of the mean wave height in 1954–1957 apparently reflects a decrease of the wave activity during these years.

3. Linear trends of annual mean wave heights

The Almagrundet data for the years 1979–95, the data from which were found to be the most reliable, show a linear rising trend of 1.8% per annum in the average wave height. The correlation coefficient between the trend line and the measured wave data is about 0.66. Such a trend follows the general tendency of the wind speed to increase over the northern Baltic Sea (*Broman et al*. 2006, among others). The increase in wave heights at Almagrundet, however, is more intense than analogous trends for the southern Baltic Sea or for the North Sea, which are estimated as less than 1% per year (*Vikebo et al*. 2003, *Gulev and Hasse* 1999). It is comparable with the analogous trend reported by *Bacon and Carter* (1991) for the North Atlantic.

A fast increase in the annual mean wave height occurred in 1979–1995 at Vilsandi as well (Fig. 1). The increase rate is as high as 2.8 % per annum at Vilsandi, with a reasonably high correlation coefficient (R^2=0.44).

The Almagrundet data from the turn of the century were initially considered as doubtful (*Broman et al*. 2006). It was argued in that the large variation of the wave heights in 1995–2003 years did not match the analogous variation of the annual and monthly mean wind speed at Utö although the wind data from this island well represent the wind conditions in the northern Baltic Proper. *Soomere and Zaitseva* (2007) show that the Almagrundet data from 1995–2003 are in good agreement with the Vilsandi data. Consequently, both the data sets probably reflect the changing wave situation in these years. The fast decrease of the annual mean wave height both at Almagrundet and at Vilsandi suggests that the above trend only existed during 1.5-2 decades and has been replaced by a decrease of the overall wave activity.

4. Quasiperiodic variation of wave heights

The most important conclusion from Fig. 1 is that no simple trend exists in the long-term variation of the annual mean wave height at Vilsandi. The formal trend is indistinct, about 0.1% per annum, with a fairly small correlation coefficient (R^2~0.006).

Instead, a quasiperiodic variation of the overall wave activity can be identified. Subsequent periods of high or low wave activity are separated by about 25 years. The wave heights were relatively large in 1965–1975 and at the end of the 1990s. The wave activity fast decreased starting from the end of the 1990s. The sea was comparatively calm in the end of the 1950s and in the middle of the 1980s.

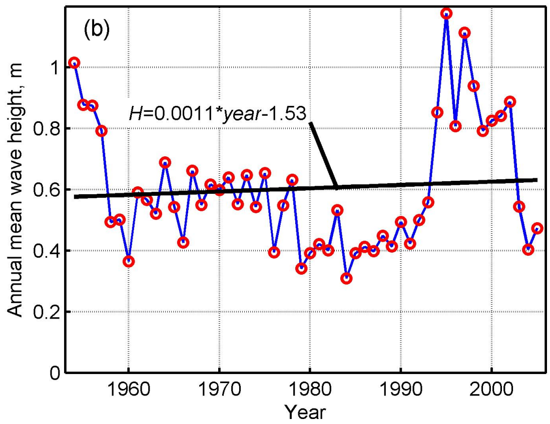


Figure 1. Annual mean wave height at Vilsandi in 1954-2005 (From *Soomere and Zaitseva* 2007).

5. Extremes and annual mean wave heights

Since the beginning of waverider measurements in the northern Baltic Proper in 1996, the significant wave height has exceeded 7 m only four times there (*Kahma et al*. 2003, *Soomere et al*. 2006). This happened twice in December 1999, again twice in three weeks during the 2004–05 winter storms (once in December 2004 (see *www.fimr.fi*), and once on 9 January 2005 during windstorm Gudrun). The significant wave height probably exceeded this threshold in January 1993 and on at least two occasions in the 1980s. The 1984 January storm was probably the most ferocious and long-lasting one until Gudrun in January 2005. Another storm in January 1988 was weaker. A strong storm that established the pre-Gudrun water level records along the northern coast of the Gulf of Finland took place in January 1975. It apparently created very rough seas; unfortunately no reliable wave data are available from this event.

Therefore, extremely strong storms with significant wave heights close to or exceeding 7 m seem to occur roughly twice a decade. The Almagrundet data (which does not cover windstorm Gudrun) suggests that, in general, neither the frequency nor the intensity of extreme wave storms has increased during the last thirty years. This is consistent with the observation that the number of active cyclones has not radically changed during recent decades.

An interesting feature is that all the listed events (except the January 1984 storm) took place after periods with relatively low wave activity. In other words, they occurred after autumns and early winters that had predominantly nice weather. This coincidence may be explained by relatively high sea surface temperatures after fine weather periods; however, it is worth of a further study.

6. Discussion

The central and somewhat surprising outcome is that no clear trend of an increasing wave activity can be identified in the northern Baltic Proper. Instead, variations of the wave fields apparently are quasiperiodic, with a period about 25 years. Since the instrumentally measured or numerically modelled time series of wave parameters usually are shorter, a number of contradictory trends may be reported depending on which phase of the long-term variability the data reflect.

It is intuitively clear that a larger wind speed generally causes a greater wave activity. The match of the Utö wind data and the wave data from Almagrundet in 1979–1995 is clearly identifiable. Quite surprisingly, the rapidly falling trend of the annual mean wave height both at Almagrundet and at Vilsandi after 1998 does not match the Utö wind data (*Broman et al*. 2006). This mismatch is a highly interesting feature. Secular changes in the dominating wind directions may affect the coastal wave heights; however, the match of the wave properties at the opposite coasts suggests that certain other properties of the wind fields (such as the duration of winds from different directions or changes in wind patterns related to shifts of the trajectories of cyclones) may play an important role in the forming of the Baltic Sea wave fields.

This study was supported by the Estonian Science Foundation, Grant 5762, the MC RTN network SEAMOCS (MRTN-CT-2005-019374), MC ToK project CENS-CMA (MC-TK-013909), and the Eco-Net network "Wave-current interactions in coastal environment."

References

Bacon S., Carter D.J.T., The wave climate changes in the North-Atlantic and North Sea, *Int. J. Climatol.*, **11**, 545–558, 1991.

Broman B., Hammarklint T., Rannat K., Soomere T., and Valdmann, A., Trends and extremes of wave fields in the north–eastern part of the Baltic Proper, *Oceanologia*, **48** (S), 165–184, 2006.

Gulev S.K., Hasse L., Changes of wind waves in the North Atlantic over the last 30 years, *Int. J. Climatol.*, **19**, 1091–1117, 1999.

Hogben N., Da Cunha N.M.C., and Oliver G.F., *Global Wave Statistics*, Unwin Brothers, London 1986.

Kahma K., Pettersson H., and Tuomi L., Scatter diagram wave statistics from the northern Baltic Sea, *MERI – Report Series of the Finnish Institute of Marine Research*, **49**, 15–32, 2003

Orviku K., Jaagus J., Kont A., Ratas U., and Rivis R., Increasing activity of coastal processes associated with climate change in Estonia, *J. Coastal Res.*, **19,** 2, 364–375, 2003.

Soomere T., Behrens A., Tuomi L., and Nielsen J.W., Unusual wave conditions in the northern Baltic Sea during windstorm Gudrun in January 2005, *Geophys. Res. Abstr.,* **8**, Paper 028512006, 2006.

Soomere T., Zaitseva I., Estimates of wave climate in the northern Baltic Proper derived from visual wave observations at Vilsandi, *Proc. Estonian Acad. Sci. Eng*., **13**, 2007 (in press).

Suursaar Ü., Kullas T., Otsmann M., Saaremäe I., Kuik J., and Merilain M., Hurricane Gudrun and modelling its hydrodynamic consequences in the Estonian coastal waters, *Boreal Env. Res*. **11**, 143–159, 2006,

Vikebo F., Furevik T., Furnes G., Kvamsto N.G., and Reistad M., Wave height variations in the North Sea and on the Norwegian Continental Shelf 1881-1999, *Continental Shelf Research*, **23**, 251–263, 2003.

WASA Group, *The WASA project: changing storm and wave climate in the northeast Atlantic and adjacent seas?* GKSS Report 96/E/61, Geesthacht 1995.

Current and Expected Changes in River Ice Regimes within the Russian Part of Baltic Drainage Basin

Valery Vuglinsky

State Hydrological Institute, 2nd Line 23, 199053, St.Petersburg, Russian Federation, E-mail:vvuglins@vv4218.spb.edu

1. Introduction

Ice river regime determines the conditions of river use in winter time and it is an important factor at the establishment of the dates for navigation, duration and carrying capacity of ice routes across rivers, etc. Investigations show that ice regimes in the rivers within the Russian part of Baltic drainage basin were subject to significant changes during the last 20-25 years because of a stable positive trend of winter air temperatures. The period 1950-1979 was taken for comparison; during that time winter air temperatures were close to climatic norm. Preliminary computations were also made on possible changes in the ice regimes in rivers within the study territory for the next 5-10 years.

2. Methodology.

Two methodological approaches were applied to estimate the past and future changes. The first approach is based on a comparison of averaged characteristics of ice regimes for 1950-1979 and 1980-2000 to determine the gradients of these changes and use this gradient for future assessments. The second approach is based on the establishment of correlation between ice regime characteristics and winter air temperatures for the study periods with its future use with the account of prognostic values of winter air temperature.

3. Results

It has been established that mean river ice cover duration in the last twenty years within the territory under consideration became 2-10 days shorter, if compared with the previous 30-year period, because of later ice-on and earlier ice-off (Fig.1). In accordance with the forecasts of spring and autumn air temperatures, this tendency would be observed in 2010-2015, too. Changes in river ice cover duration at the level of 2010-2015 could consist -10-15 days.

The maximum ice cover thickness on the rivers on the Russian part of Baltic drainage basin during the last 20 years was thinner by 2-7 cm on the average. Moreover, a positive tendency towards a thinner maximum ice cover

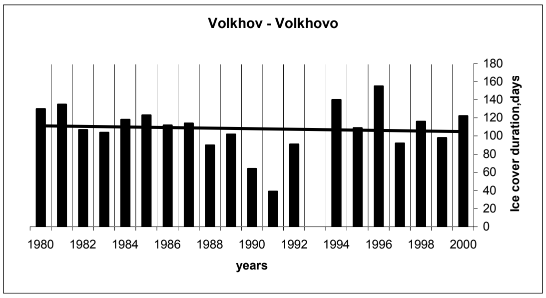


Figure 1. Tendencies towards changes in ice cover durations in the Volkhov river

thickness on the rivers of this region was observed for the whole 50-year period.. According to the prognostic assessments before 2010-2015 it may be by 5-7 cm thinner.

The above changes in ice regimes on the rivers within the Russian part of Baltic drainage basin require an adaptation of different economic branches related with water use in winter time.

References

Vuglinsky V.S. Peculiarities of ice events in Russian Arctic rivers. *Hydrological Processes*, 16, pp 905-913, 2002

Vuglinsky V. Specific features of ice events in large Russian rivers discharging to the Arctic ocean. *Proceedings 1st CliC International Science Conference*, Beijing, China, pp 280-281, 2005

Vuglinsky V.S., Gronskaya T.P. Changes in river and lake ice regime within Russian territory and their concequences for economy, *Modern problems of hydrometeorology*, pp.229-244, 2006 (in Russian)

Simulation of Runoff in the Baltic Sea Drainage Basin During the Past Millennium

Jonas Olsson[1], L. Phil Graham[1], Jörgen Rosberg[1], Sara-Sofia Hellström[1], Erik Kjellström[1], and Ronny Berndtsson[2]

[1]Research and Development, Swedish Meteorological and Hydrological Institute (jonas.olsson@smhi.se)
[2]Department of Water Resources Engineering, Lund University

1. Introduction

Climate models are usually used to produce scenarios for future climate. However, another possible use of these models is to reproduce the climate that occurred in the past. The aim of such exercises is generally to estimate the past range of variability of different variables. This is important especially for putting recent climate extremes in to a proper historical perspective.

At Rossby Centre, SMHI, such a so-called paleosimulation covering the Baltic Sea drainage basin and surrounding areas, has recently been performed. The simulation covers three time periods between years 1000 and 1929. The simulation was performed with the regional climate model RCA3, developed at the Rossby Centre. RCA3 takes boundary conditions from a simulation with the global model ECHO-G, with forcings representing the past climate.

The aim of this study was to reconstruct the runoff to the Baltic Sea during the past millennium. This was achieved by feeding reconstructed precipitation and temperature from the ECHO-G/RCA3 output into the hydrological HBV model, set up for the Baltic Sea drainage basin.

2. Climate model data

The global model ECHO-G was used to simulate climate variations during the past millennium (e.g., *von Storch et al.*, 2004). In ECHO-G, the atmospheric model ECHAM4 (*Roeckner et al.*, 1999) is coupled with the ocean model HOPE-G (*Wolff et al.*, 1997) The present simulation was based on reconstructed forcing from three major external variables, estimated from ice core data: (*i*) annual global concentrations of CO_2 and CH_4, (*ii*) volcanic radiative forcing, and (*iii*) solar radiative forcing. These estimates were combined with sunspot observations. *Gouirand et al.* (2006), e.g., compared model simulated data for Scandinavia with reconstructed temperature time series and found a reasonable agreement.

The ECHO-G output was downscaled in to the Baltic Sea drainage basin by the regional model RCA3 (*Kjellström et al.*, 2005), for three periods: 1000-1199, 1551-1749, and 1751-1929. In this study, RCA3 was coupled with the lake model FLAKE. The downscaling increased the horizontal resolution from 3.75º in the ECHO-G output to 1º in RCA3. The RCA3 model was evaluated in a perfect boundary experiment during 1961-1990. For temperature good agreement was found, whereas the precipitation was somewhat overestimated in some parts of the region (*Moberg et al.*, 2006). For the past climate experiment, RCA3 data were compared with reconstructed and historical temperature series. Some differences in the temperatures and their frequency distribution was found for summer and autumn, whereas winter and spring were more accurate (*Moberg et al.*, 2006).

To summarize, the downscaled results from the experiments in combination with observations from the 20th century indicate the following concerning the Swedish temperature and precipitation climate for the 20th century. The temperature was unusually high, at least in a 500-year context. The amount of precipitation during the period since 1970 was unusually large. The simulated climatic variability during the 20th century agrees rather well with recorded data.

3. Hydrological model application

The hydrological HBV model (e.g., *Lindström et al.*, 1997), set up for the Baltic Sea drainage basin (HBV-Baltic; *Graham*, 1999), was used to reconstruct the runoff to the Baltic Sea during the past millennium. The HBV model is a catchment-based, conceptual, and semi-distributed rainfall-runoff model that has been used worldwide in catchments of sizes ranging from a few up to more than 100 000 km². It includes routines for snow accumulation and melt, soil moisture, storage routing, runoff response, and evapotranspiration.

Graham (1999) set up, calibrated and evaluated the HBV model for the Baltic Sea drainage basin for the period 1980-1994. Good performance was achieved, as measured by a Nash-Sutcliffe efficiency, R^2, reaching 0.84 for daily runoff to the Baltic Sea in an independent verification period (1986-1994). In this study, the same set-up was used, and Figure 1 shows the sub-basins considered.

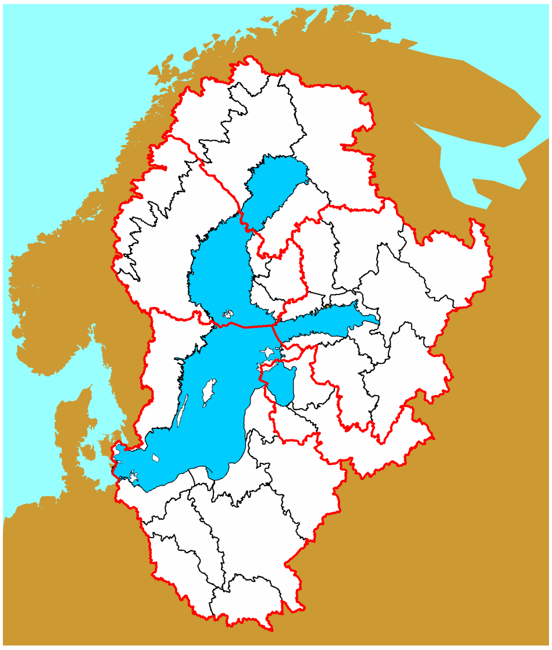


Figure 1. Principal basins (red lines) and sub-basins used in the HBV model set-up for the Baltic Sea.

4. Adjustment of precipitation and temperature

Before the hydrological model application, precipitation and temperature in the RCA3 output were adjusted to fit the observations used in *Graham* (1999). As these observations start in 1980 (and are now updated to 2005) and the RCA3 data end in 1929, the climate database from the Climate Research Unit (CRU) at University of East Anglia (*Mitchell et al.*, 2004) was used in an intermediate step. The CRU data were available for the period 1901-2002. All data sets have a daily time resolution.

The adjustment was done by sub-basin specific monthly correction factors, multiplicative in the case of precipitation and additive in the case of temperature. To calculate the factors, the gridded RCA3 outputs for the period 1901-1929 and CRU data for the periods 1901-1929 and 1980-2002 were interpolated into daily spatial sub-basin averages, to conform to the observations in *Graham* (1999). In the first step adjustment, monthly sub-basin averages for 1980-2002 observations and CRU data were compared, yielding the correction factors required to make the CRU data conform to observations. In the second step, corrected CRU data in the period 1901-1929 were compared with RCA3 data for the same period. This gave the total correction required to make the RCA3 data conform to the observations.

Concerning the precipitation correction factors, these turned out to be large for the southernmost sub-basins in Germany and Poland. This was expected since the area is close to the boundary of the experiment where the output is known to be uncertain. The average adjustment required for the rest of the sub-basins is shown in Figure 2. Except for June and July the correction is below 1, i.e., the RCA3 precipitation is overestimated, in line with previous evaluation. In June-July a minor increase in precipitation is required. On average over the year precipitation is reduced by a factor 0.82. It can be noted that the percentage of dry days in the RCA3 data agrees well to the observations, ~15%.

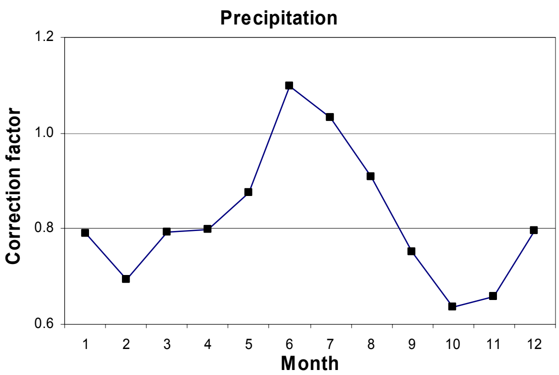


Figure 2. Average precipitation correction factor.

Regarding the temperature correction factor, the uncertainty at the boundary is not as obvious. Even so these sub-basins were omitted, and the average correction for the remaining sub-basins is shown in Figure 3. Except for March and April negative correction is required, i.e., RCA3 temperatures were overestimated. Generally, however, the correction required is rather limited, mostly within ±1ºC. On average over the year temperature is reduced by 0.55 ºC.

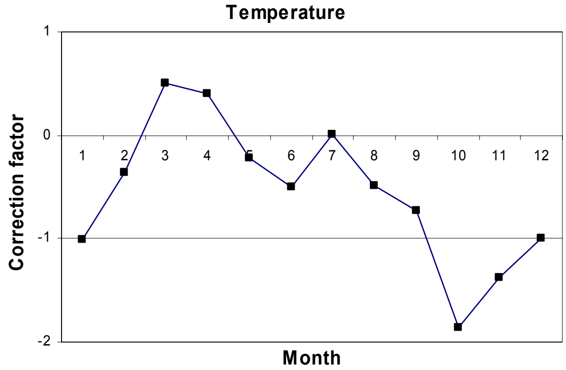


Figure 3. Average temperature correction factor.

5. Concluding remarks

The correction of the RCA3 data required does not appear to be very large, which has increased our confidence in the simulated precipitation and temperature. The correction was applied to all three simulation periods (1000-1199, 1551-1749, and 1751-1929) and HBV simulations are currently being performed. Runoff generated directly in the RCA3 model indicates that river flow may have been higher in these periods than in the 20th century in the southern part of Sweden, but not in the northern part (*Moberg et al.*, 2006). Evaluation of the HBV simulations will show whether this finding is accurate, and generally increase our understanding of the past runoff climate in the Baltic Sea drainage basin.

References

Gouirand I, et al., Climate variability in Scandinavia for the past millennium simulated by an atmosphere-ocean general circulation model, *Tellus*, 59A, doi:10.1111/j.1600-0870.2006.000207.x, 2006.

Graham L.P, Modelling runoff to the Baltic Sea, *Ambio*, 28, pp. 328-334, 1999.

Kjellström E, et al., A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA). RMK 108, SMHI, 601 76 Norrköping, Sweden, 2005.

Lindström G, et al., Development and test of the distributed HBV-96 model, *J. Hydrology*, 201, pp. 272-288, 1997.

Mitchell T D, et al., A comprehensive set of highresolution grids of monthly climate for Europe and the globe, Tyndall Centre for Climate Change Research, W. Paper 55, Univ. East Anglia, UK, 25 pp.

Moberg A, et al., Climate in Sweden during the past millennium, TR-06-35, SKB, Box 6854, 102 40 Stockholm, Sweden, 2006.

Roeckner E, et al., Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle, *J. Climate*, 12, 3004-3032, 1999.

von Storch H, et al., Reconstructing past climate from noisy data, *Science*, 06, pp. 679–682, 2004.

Wolff J-O, et al., The Hamburg Ocean Primitive Equation Model, Tech. Rep. 13, DKRZ, Hamburg, 98 pp, 1997.

Climate Simulations of the Past Millennium with the Global Model ECHO-G: Results for the Baltex Area

Eduardo Zorita, Sebastian Wagner, Fidel Gonzalez-Rouco* and Hans von Storch

GKSS Research Centre, Geesthacht, Germany (eduardo.zorita@gkss.de) and *Universidad Complutense, Madrid

1. Introduction

Climate reconstructions of the past few millennia may provide useful information of the amplitude of climate variations at centennial timescales and help to put the recent 20th century global warming into the perspective of natural climate variations. Several simulations covering all or parts of the past millennium have been conducted with the global climate model ECHO-G driven by estimations of past external forcing (*Storch et al.*, 2004; *Zorita et al.*, 2005). Here, the main results of the simulated climate in the Baltex area will be presented. The simulations differ only in their initial conditions, and thus allow for a rough estimation of the internal variability at multidecadal and regional timescales, which is presently poorly known.

2. Climate model and simulations

The global coupled climate model ECHO-G consists of the spectral atmospheric model ECHAM4 and the ocean thermodynamic/dynamic sea ice model HOPE-G. Both sub-models were developed at the Max-Planck-Institute of Meteorology in Hamburg. In the present setup, the atmospheric model has a horizontal resolution of T30 (approx. 3.75 x 3.75 degrees) and 19 vertical levels.
The ocean model HOPE-G has an effective horizontal resolution of approximately 2.8 degrees with 20 vertical levels. In the tropical regions a grid refinement is employed with decreasing meridional grid-point separation, reaching a value of 0.5 degrees at the Equator. This increased resolution allows for a more realistic representation of ENSO events. The climate model is flux-adjusted to avoid climate drift. The flux adjustment is held constant in time and its global average is set to zero.
Note that the resolution of both atmosphere and ocean models is too coarse to reasonably resolve the Baltic Sea. The results of the simulations cannot, therefore, be interpreted at small regional scales. Here, the emphasis will be put on larger-scale climate patterns of relevant for the Baltex region.
The model was driven by the following external forcings: total solar irradiance, volcanic forcing, and well-mixed greenhouse gases. The solar forcing was derived from the data provided by *Crowley* (2000) through transforming effective solar forcing to Total Solar Irradiance (TSI) units to drive the model. There still exists a large uncertainty in the amplitude of past TSI at centennial timescales. In this simulation the Crowley data were re-scaled so that the differences between the Late Maunder Minimum (1680-1710) and present (1960-1990) are 0.3 % of the TSI. The volcanic net radiative forcing was translated to changes in an affective solar constant. The volcanic forcing is thus implemented in this simulation as a global annual reduction in the solar constant. The values provided by Crowley already take into account an e-folding time in the years following a volcanic eruption. The concentrations of atmospheric carbon dioxide and methane were derived from ice-core measurements. Concentrations of N2O were used as in previous scenario experiments with this model: fixed 276.7 ppb before 1860 and the historical evolution from 1860 to 1990 AD adjusted from Battle et al. (1996). Figure 1 shows the past forcings used in all simulations together with the global temperature response in two of them.

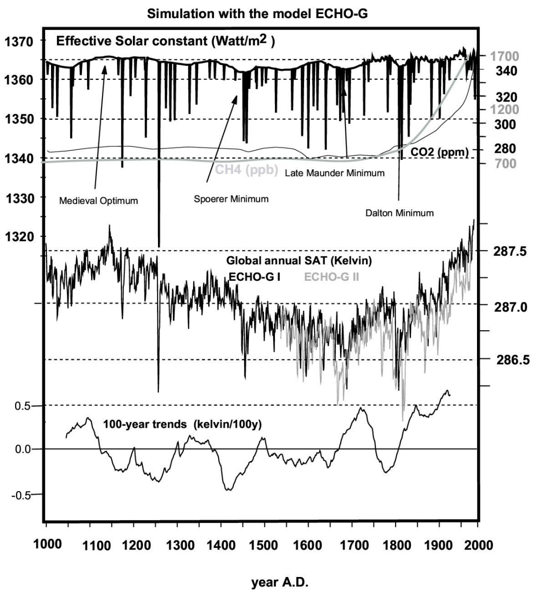


Figure 1. External forcing used in the climate simulations (upper panel), global temperature response in the simulations starting in 1000 A.D. and 1500 A.D. (middle panel) and 100-year running temperature trends (lower panel)

3. Comparison with climate reconstruction

In general the simulated global and Northern Hemisphere air temperature agrees with the reconstructions that indicate large temperature variability at multidecadal and centennial timescales, e.g. derived from boreholes or from dendroclimatological methods designed to preserve low-frequency variability. The simulations clearly indicate temperature deviations larger than reconstructed by *Mann et al* (1999).
On regional scales, the agreement with long early-instrumental records and some long temperature reconstructions is remarkable. For instance, Figure 2 shows a comparison between simulated grid-point values and the Central England temperature record and a summertime Alpine temperature reconstructions. A reasonable agreement is also found between modeled and reconstructed summer Alpine temperature (not shown) (*Büntgen et al*, 2006).

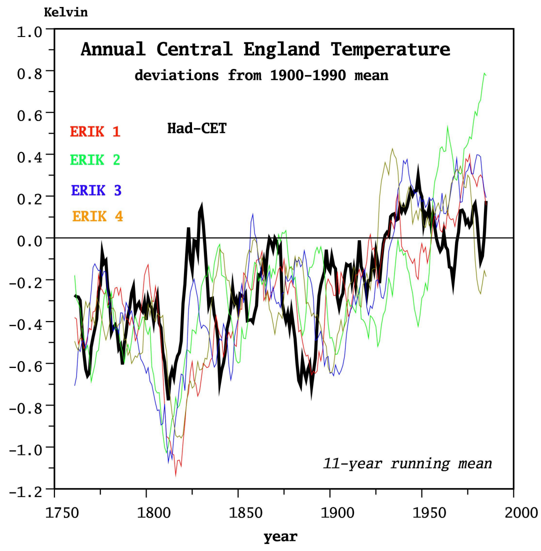


Figure 2. Observed and simulated (grid-point values) records of the Central England annual mean mean temperature

4. North Atlantic Oscillation

The simulated evolution of the North Atlantic Oscillation index in past millennium and in the last 250 years is displayed in Figure 3.

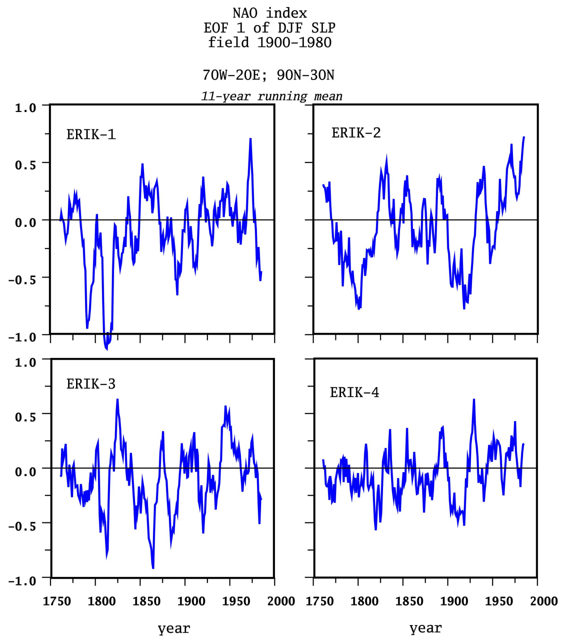


Figure 3. The simulated North Atlantic Oscillation Index in four simulations with the global model ECHO-G in the period 1750-1990.

At centennial timescales the NAO index seems to follow a similar evolution as the globally averaged temperatures, i.e. also following the external forcing. At shorter timescales, for instance multidecadal, clear deviations among the simulations can be observed, indicating that the internal variability of NAO at these timescales is larger than the possible influence of the external forcing. The modeled NAO, however, clearly responds to the external forcing when this forcing is strong enough, as in the last decades of the 21rs century under scenario A. This result may indicate that the observed evolution of the NAO in recent centuries does not necessarily has to be explain by the effect of external forcing, either natural or anthropogenic.

5. Air temperature in the Baltic Sea region

Figure 4 shows the simulated evolution of the annual mean air temperature averaged in n extended Baltic Sea area in the period 1000-2100 in one of the simulations.

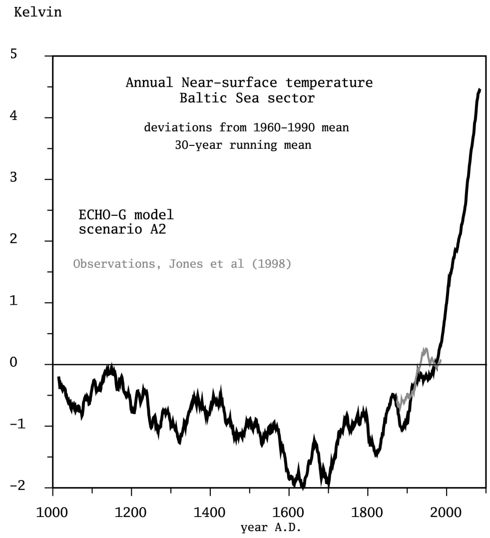


Figure 4. Simulated mean annual near-surface air-temperature in an extended Baltic Sea region in the past millennium and in the 21st century. Observational record is also included.

The simulated temperature shows one maximum around 1150 A.D. possibly corresponding to the so called Medieval Warm Period, followed by a temperature decrease with and clear temperature minima around 1700 A.D., which also corresponds to the Little Ice Age and Late Maunder Minimum periods. The temperature Medieval Warm Period reaches roughly the same level as in the late 20th century. The projected temperature increase in the 21ts century, however, clearly stands out of the range of natural variability simulated by the model.

References

Büntgen, U., D.C. Frank, D. Nievergelt, and J. Esper, Summer temperature variations in the European Alps, A.D. 755-2004. J. Climate 19, 5606-5623, 2006.

Crowley, T.J., Causes of climate change over the past 1000 years. Science 289, 270-277, 2000.

Mann, M.E.,R. Bradley, and M. K. Hughes, Northern Hemisphere temperatures during the past millennium; inferences, uncertaintes a, and limitations. Geophys. Res. Lett., 26, 759-762, 1999.

Storch, H. von, E. Zorita, J. M. Jones, Y. Dmitriev. F. González and S. F. B. Tett, Reconstructing past climate from noisy data. Science 306, 679-682, 2004.

Zorita E. , F. González-Rouco, H. von Storch, J.P. Montavez and F. Valero, Natural and anthropogenic modes of surface temperature variations in the last thousand years. Geophys. Res. Lett. 32, L08707 (2005).

Towards Policies and Adaptation Strategies to Climate Change in the Baltic Sea Region

Prof. Dr. Walter Leal Filho and Franziska Mannke

TuTech Innovation GmbH, Harburger Schloßstr. 6-12, 21079 Hamburg, leal@tutech.de

1. Abstract

This paper introduces the project "Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region" (ASTRA) and discusses the role of policies in fostering mitigation and adaptation strategies in the Baltic Sea Region.

2. Introduction

The problems originated by climate change are becoming clearer and clearer each year. In addition to even hotter summers, winters with little snow and an increase in floods, our climate is changing and science needs to do something about it. The main objective of the project "Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region" (ASTRA), which is funded by the Interreg IIIB Programme (Baltic Sea) of the European Commission, is to assess regional impacts of the ongoing global change in climate and to develop strategies and policies for climate change adaptation.

First, the project will use scientific knowledge from climate modelling and climate impact research, as well as geomorphological and geological investigations to assess the effects of climate change impacts on both natural and socio-economic systems. The study will address threats arising from climate change in the BSR area, such as extreme temperatures, droughts, forest fires, storm surges, winter storms and floods. As a first step, the recent winter storm (January 8-9, 2005) and related national, regional and local effects and responses will be studied as a starting example of the various challenges climate change poses to the region.

Second, adaptation strategies for regional planning purposes will be developed. In WP 1 climate change impacts and vulnerability of regions are studied in several regional and local case studies focusing on single effects as well as on socio-economic sectors. Entry points and integration to existing planning processes and methods will be identified.

Third, a special attention to risk awareness will be addressed through intensive dissemination exercises, such as regional conferences and workshops in the countries around the BSR (WP 2 Dissemination). Transferring the impact results from WP 1 into adaptation strategies and policies is the main objective of work package 3. Finally, policy recommendations for climate change adaptation will be delivered for different spatial scales from the local to the national and the BSR level.

The ASTRA shall further develop the successful results of the BSR Interreg IIIB SEAREG project which assessed the impacts of future sea level rise in several case study areas in the Baltic Sea Region (BSR).

3. Aims of the project and activities

The main objective of ASTRA is to develop a dynamic trans-national approach to mitigate climate change effects within spatial planning mechanisms, which can be implemented by the partners in the Baltic.

Awareness-raising is also a very important issue, because even though climate change is mentioned frequently in the media, the awareness among local stakeholders and decision makers is still low.

First of all, the winter storm in January 2005 and related national, regional and local effects and responses will be studied as an illustrative example of the various challenges climate change poses to the region. Secondly, awareness of climate change and the need for adaptation to its effects is raised among different stakeholders in the countries around the Baltic Sea in conferences and workshops, integrating scientists, planners and decision makers. Thirdly, climate change impacts and vulnerability of regions will be pointed out in several regional and local case studies and the effect on socio-economic sectors are illustrated. Finally the case study areas will be discussed in seminars and on conferences to create a transparent view on how different regions in different countries are affected by climate change and how they can adapt to it or mitigate the impacts.

As a result of the project, concrete mitigation and adaptation strategies will be developed together with decision makers, adaptation strategies around the Baltic will be reviewed and policy recommendations will be presented, based on the experiences of the SEAREG and ESPON project, providing a basis for a joint Baltic adaptation strategy.

4. The role of policies

ASTRA focuses on the development of policy recommendations and guidelines for adaptation to climate change in the Baltic Sea Region. As a first step a policy document was prepared, which provides basic information on the matter of policy-making and in which way it can enhance adequate action in the field of climate change (CC). The document also aims to create a common understanding of ASTRA partners on the role of policy-making in addressing issues related to climate change1. It describes, therefore, the challenges, decision-makers and planners are confronted with, when addressing climate change impacts and developing adaptation strategies.

Furthermore, it opens up first ideas how to integrate climate change adaptation into existing policies. Besides, it points out exemplarily existing policies in the field of adaptation strategies in the Baltic Sea Region (BSR). All ASTRA project partners were invited to comment the paper and to extend the given examples by own views, specific examples and/or experiences. In this manner, the draft paper provides an overview on the perception and handling of climate change impacts in the Baltic Sea Region.

Sector	Increased average temperature	Increased precipitation	Extreme weather events (Storms, droughts)
Health Sector	Physiological and behavioural adaptation types may change - weaker protection against cold peaks of climate; increase of living organisms in natural waters Health problems for elderly and weak people, increase of ozone concentration, increase of living organisms in natural waters, increased pollen in air	Potential cases of death Potential cases of death	Potential cases of death Potential cases of death
Forestry	Operability of forests reduced as a result of a shorter period of frozen ground positive aspects: lengthened growing season, increased productivity ; negative effects: occurrence of diseases and pests, droughts	Deprivation of crop	Deprivation of crop
Agriculture		Increased danger of erosion and floods positive aspects: lengthened growing season, increased productivity ; negative effects: occurrence of diseases and pests, droughts	Deprivation of crop
Water management	Water shortage, changes in the seasonal distribution of runoff	Increase in precipitation, changes in the seasonal distribution of runoff	Flooding of the sewage system, pollution of drinking water supply Flooding of the sewage system, pollution of drinking water supply
Energy sector	Problems with the cooling down of nuclear power plant, droughts endanger bio mass production		power outages, broken electric power poles and lines; wind power production endangered by heavy storms, downed trees
Tourism sector	Shorter season for skiing holidays, fewer winter sport areas		
[CARTER, KANKAANPÄÄ 2004; Federal Environmental Agency 2005]			

Figure 1. Sectors affected by climate change impacts in the BSR.

As shown in Figure 1, impacts of climate change affect a range of sectors in different ways. It should be noted that some sectors are not only affected by climate change impacts, but are also responsible for causing climate change. Agriculture, for example, is affected by changes in growing seasons, plant productivity, occurrence of diseases and pests, water resources and new crops. At the same time the agricultural sector itself has an impact on climate through emissions of greenhouse gases (*Carter and Kankaanpää* (2004). Private households are affected by the increasing risk of storms or floods, at the same time their daily life style (extensive car use, travelling by plane) has a significant impact on the concentration of greenhouse gas in the atmosphere. Therefore, there exists no simple polluter-pays-principle when addressing climate change but a complex structure of causes and impacts. Mitigation and adaptation strategies have to be adjusted to the characteristics and needs of different sectors.

5. Conclusions

The work performed within the framework of ASTRA aims at taking all effects of climate change that affect the spatial development into account in order to elaborate adaptation and mitigation strategies together with spatial planners and other stakeholders. This is important to many Baltic cities since they are also vulnerable to the effects of global warming such as floods and at the same time depend on stable climate conditions for trade. Finally the project is useful in ensuring a broad awareness and adaptation strategies among inhabitants to prevent the adverse effects of climate change and to ensure a stable development of cities and regions.

References

Carter, T.R.; Kankaanpää, S. (Eds.): *Adapting to climate change in Finland: Research Priorities.* Proceedings of the FINADAPT seminar, Finnish Environment Institute (SYKE), Helsinki, 14. November 2003, FINADAPT Working Paper 1, Finnish Environment Institute Mimeographs 318, 42 pp, Helsinki, 2004.

The ENSEMBLES and the BALTEX Projects

Markku Rummukainen[1], Chris Hewitt[2] and Daniela Jacob[3]

[1]SMHI, SE-601 76 Norrköping, Sweden (Markku.Rummukainen@smhi.se); [2]Met Office, Hadley Centre for Climate Prediction and Research, Fitzroy Road, Exeter, Devon EX1 3PB, United Kingdom; [3]Max-Planck-Institute for Meteorology, Bundesstrasse 53, D-20146 Hamburg., Germany.

1. The ENSEMBLES project in a nutshell

The ENSEMBLES (contract number GOCE-CT-2003-505539) is a 5-year Integrated Project, running since September 2004, under the European Commission's 6th Framework Programme, Sub-Priority ”Global Change and Ecosystems”. The long name of the project is “Ensembles-based Predictions of Climate Changes and their Impacts”. It is structured around 10 Research Themes. These concern global and regional climate model systems, global and regional climate projections, understanding climate processes, model evaluation, impact studies, emission scenarios, user interaction, and coordination. There is an emphasis on Europe, but also on more global topics. The around 70 participating institutes and universities aim to:

- Develop an ensemble prediction system for climate change based on global and regional Earth System models and to produce, for the first time, an objective probabilistic estimate of uncertainty in future climate at the seasonal to decadal and longer timescales
- Quantify and reduce the uncertainty in the representation of physical, chemical, biological and human-related feedbacks in the Earth System (including water resource, land use, and air quality issues, and carbon cycle feedbacks)
- Maximise the exploitation of the results by linking the outputs of the ensemble prediction system to applications such as agriculture, health, food security, energy, water resources, and insurance

Even though ENSEMBLES and BALTEX at first glimpse might seem rather different, they do have a number of potential collaboration areas (cf. BALTEX 2004, ENSEMBLES 2007).

2. Collaboration areas between the ENSEMBLES and the BALTEX projects

A major collaboration area is the regional climate and impact science building on global climate change simulations.

The ENSEMBLES coordinated global and regional climate model simulations offer enhanced starting points for regional climate system studies for the Baltic Sea region. As has been discussed by, e.g., Rummukainen et al. (2004), the characteristics and quality of the global climate model simulation underlying regional climate change studies can have a major influence on the results. In addition to employing latest global and regional climate models in a coordinated fashion, the ENSEMBLES project targets evaluations of the relative performance of the models. In the regional climate model studies, the foundation for model “ratings” will be based on a type of hindcast studies, in which the lateral and sea surface forcing is taken from the ERA-40 data. Various metrics of model performance, ultimately to construct model weighting schemes, are being tested. Among the suggestions are metrics based on physical consistency, but also measures of major importance for impact studies. Thus, regional climate system studies in the context of BALTEX can add to the regional evaluation of climate models in the ENSEMBLES. Herein, the advanced BALTEX efforts on the regional energy and water cycles, including on the hydrology of the surrounding land surfaces are especially interesting.

Even with expected improvements in global and regional climate model simulations, including higher resolution, the set-up of the ENSEMBLES regional climate models does not as a rule feature coupled ocean components. As has been see by Kjellström and Ruosteenoja (2007), this can be a serious limitation, depending on the characteristics of the sea surface temperature and sea ice data in the underlying global climate model simulation that provides boundary conditions for regional climate modeling.

The ENSEMBLES climate simulations, possibly enhanced by special BALTEX modeling studies, mean of course also a wealth of cases to be put through impact models. The usefulness of climate scenario ensembles for hydrological impact studies has been nicely illustrated by Graham et al. (2007), in the frame of the recent PRUDENCE project (Christensen et al. 2007). The ENSEMBLES project has a range of impact studies lined up as well, some of which with very concrete linkages to the BALTEX aims. In addition, the probabilistic methodologies underway in the ENSEMBLES, seeking ways of propagating all the information from global climate models first to the regional ones and then to impact models and subsequently to information made available for stakeholders.

Lastly, the projects share also the aim of wanting to interact with stakeholders. Pooling the data should facilitate this as such, but, importantly, the BALTEX can become a valuable avenue for the ENSEMBLES to reach out for the regional decision-makers and users, such as HELCOM.

3. What now?

The first batch of ENSEMBLES global climate simulations is now becoming available. (A second set, based on new model versions geared towards so-called Earth System representation, is expected towards the end of the project.) The regional climate simulations are underway. Already finished are two sets of hindcast-type experiments that are based on the ERA40. These sets differ in terms of model resolution, the first being on 50 km and the second on 25 km. As mentioned above, these runs will be the base of relative (and absolute) model performance analyses and model weighting. The ENSEMBLES regional climate change simulations will be done using the system of regional climate models designed with the help of the performance analyses. The climate change runs will be made in a transient fashion, i.e. as continuous simulations from around 1950, extending up to 2050 or 2100, on 25 km resolution. These runs will be conducted during 2007, to be followed by a range of impact studies. In 2008, the ENSEMBLES will also finalize a new observations-based data base for the European land region, which might be of interest for the BALTEX community.

References

BALTEX. BALTEX Phase II (2003-2012): Science Framework and Implementation Strategy. International BALTEX Secretariat Publication No. 34, 92 pp. 2006

Christensen, J.H., Carter, T., Rummukainen, M. and G. Amanitidis. Evaluating the performance and utility of regional climate models: the PRUDENCE project. *Climatic Change,* 81, Supplement 1, in press, 2007.

ENSEMBLES, http://www.ensembles-eu.org/ (follow "Documents" and then "Description of Work") 2007.

Graham, L.P., S. Hagemann, S. Jaun and M. Beniston. On interpreting hydrological change from regional climate models. *Climatic Change,* 81, Supplement 1, in press, 2007.

Kjellström, E. and K. Ruosteenoja. Present-day and future precipitation in the Baltic Sea region as simulated in a suite of regional climate models. *Climatic Change,* 81, Supplement 1, in press, 2007.

Rummukainen, M., S. Bergström, G. Persson, J. Rodhe and M. Tjernström. The Swedish Regional Climate Modelling Programme, SWECLIM: A review. *Ambio,* 33, 4-5, pp. 176-182, 2004.

Changes in the Water and Energy Budgets in the BALTEX Area in Future Warmer Climates as Simulated in a Regional Climate Model

Erik Kjellström[1,2] and Petter Lind[1]

[1]Department of Meteorology, Stockholm University, SE-10691 Stockholm
[2]Swedish Meteorological and Hydrological Institute, SMHI, SE-60176 Norrköping, Sweden, Erik.Kjellstrom@smhi.se

1. Introduction

The main goal of the Global Energy and Water Experiment is to improve the knowledge of the water and energy budgets on a global, regional and local scale. This includes model development and evaluation of their performance in present-day climate (e.g. *Hagemann et al.*, 2005; *Lind and Kjellström*, 2007).

Another obvious use of the climate models is to investigate the simulated climate change signals in a future climate influenced by a enhanced greenhouse effect. An effort has been made to summarize information from various projections on climate change in the BALTEX area in the Assessment of Climate Change for the Baltic Sea Basin (BALTEX, 2006).

The climate models show a future climate that is warming more than the global average. Geographical details show that the largest increases in temperature during winter are found in the northern area of the basin while the seasonal cycle of warming is less clear in the south. For precipitation there is a clear increase in the simulations in the entire area except in the southernmost parts during summer (BALTEX, 2006).

2. The regional model

RCA3 is a regional climate model that includes a description of the atmosphere and its interaction with the land surface. Originally RCA stems from the numerical weather prediction model HIRLAM. It includes a land surface model (*Samuelsson et al.,* 2006) and a lake model, PROBE (*Ljungemyr et al.,* 1996). RCA3 in its present form builds on the previous version RCA2 which is described in *Jones et al.* (2004). Further documentation of RCA3 can be found in *Kjellström et al*. (2005).

3. Experiment description

RCA3 is used for 3 climate change experiments in which the time period 1961-2100 is simulated. Lateral boundary conditions and SSTs are updated every six hours from either of two global coupled atmosphere-ocean general circulation models, these are: the ECHAM4/OPYC3 (*Roeckner et al.,* 1999), and the ECHAM5/OM1 (*Roeckner et al.,* 2006) both developed at DKRZ, the Deutsches Klimarechenzentrum GmbH, and the Max-Planck Institute for Meteorology in Hamburg.

Future greenhouse gases and the radiative effect of sulfur aerosols is accounted for in terms of equivalent CO_2 concentrations following the A2, A1B and B2 emission scenarios from the Special Report on Emission Scenarios (SRES) by the Intergovernmental Panel on Climate Change (*Nakićenović et al.,* 2000). The A2 and B2 scenarios were used with ECHAM4 boundary conditions and the A1B scenarios with ECHAM5 boundaries. For further details of the application of the forcing conditions in the ECHAM4 experiments see *Kjellström et al.* (2005).

In the experiments RCA3 is run at approximately 50x50 km horizontal resolution and 24 levels in the vertical with a time step of 30 minutes.

4. Investigating the simulation of the control climate

Given realistic boundary conditions RCA has been found to reproduce regional scale climate conditions (*Jones et al.*, 2004, *Kjellström et al.*, 2005). In these studies reanalysis products like ERA-15 and ERA40 were used to provide boundary conditions. In a companion paper (*Lind and Kjellström*, 2007) we demonstrate how RCA3 forced by ERA40 manages to reproduce energy and water budgets in the BALTEX area. Here, we show how RCA3, given boundary conditions from the control periods of the AOGCMs, reproduces these budgets. This is done by looking at vertically integrated water budget components in comparison to observational data sets (cf. *Lind and Kjellström,* 2007).

5. The transient climate change experiments

Here we investigate how the climate change signal is manifested in terms of the water and energy budgets of the BALTEX region. All three scenarios shows an increasing precipitation in the BALTEX area in the future climate in all seasons except in the southern parts where precipitation is projected to decrease during summer. In Figure 1 we exemplify this by showing the change in seasonal mean precipitation with time in one of the scenarios area averaged over the Baltic Sea.

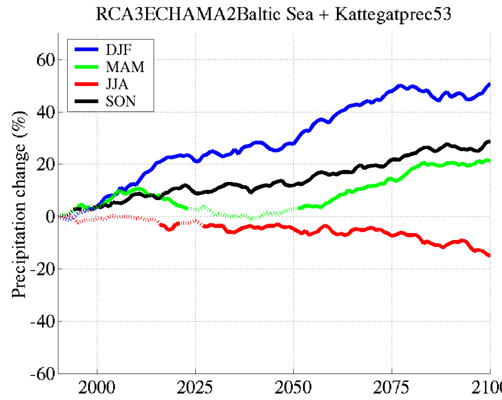


Figure 1. Transient climate change in the simulated seasonal precipitation area-averaged over the Baltic Sea and Kattegatt in the RCA3ECHAM4A2 simulation. Full line means that the change compared to the natural variability is statistically significant as compared to the natural variability in the control period (1961-1990), see details in *Kjellström et al.* (2005).

The increase in precipitation is larger than the corresponding increase in evaporation due to the higher temperatures and consequently the water balance at the surface is positive for large parts of the area. In the south, the decrease in precipitation during summer together with increasing evaporation leads to a drier situation with decreasing water availability, seen also in the annual mean (Figure 2).

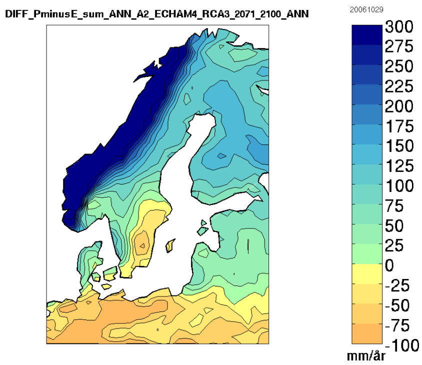


Figure 2. Change in annual mean P-E (precipitation minus evaporation) in one scenario at 2071-2100 compared to 1961-1990.

6. Summary and concluding remarks

The present paper deals with simulated future changes in the water and energy budgets of the BALTEX region. We intend to investigate the climate change signal in three different emission scenarios where the regional model has been forced by boundary data from two GCMs. Such a small set of experiments will of course only cover a very limited range of possible outcomes for the region but may still provide some information about uncertainties associated with emissions and choice of boundary data.

References

BALTEX, Assessment of Climate Change for the Baltic Sea Basin: The BACC Project. International Baltex Secreteriat. Report No. 35, ISSN 1681-6471, 2006.

Hagemann, S., Arpe, K. And Bengtsson, L., Validation of the hydrological cycle of ERA-40, *ERA-40 Project Report Series (ECMWF)*, No. 24, 2005

Jones, C.G., Ullerstig, A., Willén, U. and Hansson, U., The Rossby Centre regional atmospheric climate model (RCA). Part I: Model climatology and performance characteristics for present climate over Europe, *Ambio*, 33, pp. 199-210, 2004

Kjellström, E., Bärring, L., Gollvik, S., Hansson, U., Jones, C., Samuelsson, P., Rummukainen, M., Ullerstig, A., Willén U. and Wyser, K., A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). SMHI Reports Meteorology and Climatology No. 108, SMHI, SE-60176 Norrköping, Sweden, 54 pp., 2005

Lind, P. and Kjellström, E., Investigation of the water and energy budgets in the BALTEX area, as simulated in a regional climate model. Submitted to the fifth study conference on BALTEX, Kuressaare, Saaremaa, Estonia, 4-8 June 2007

Ljungemyr P., Gustafsson N. and Omstedt A., Parameterization of lake thermodynamics in a high resolution weather forecasting model. *Tellus*, 48A, 608–621, 1996

Nakićenović, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., et al., 2000. Emission scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, 599 pp.

Roeckner, E., Bengtsson, L., Feicther, J., Lelieveld, J. and Rodhe, H. 1999. Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle. *J. Climate 12*, 3004-3032.

Roeckner, E., R. Brokopf, M. Esch, M. Giorgetta, S. Hagemann, L. Kornblueh, E. Manzini, U. Schlese, and U. Schulzweida, Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 atmosphere model, J. Climate, 19, 3771-3791, 2006.

Samuelsson, P., Gollvik, S. and Ullerstig, A., The land-surface scheme of the Rossby Centre regional atmospheric climate model (RCA3). *Report in Meteorology 122*, SMHI. SE-601 76 Norrköping, Sweden, 2006

Transient Simulations of Future Runoff to the Baltic Sea for the 21st Century

L. Phil Graham

Swedish Meteorological and Hydrological Institute, SE-601 76 Norrköping, Sweden
e-mail: phil.graham@smhi.se

1. Introduction

This paper focuses on the large-scale hydrological response to projected changes in climate over the Baltic Sea basin. Regional scale projections of future climate change over the Baltic Sea basin have been performed for the full period of the 21st century. These were used in a hydrological model to produce projections of future "hydrological change," for total river inflow to the Baltic Sea. This fills in the gaps of previous studies that looked only at climate change impacts at the end of the 21st century. Now, in addition to assessing hydrological change in the distant future, changes in the near future can be assessed. Trends for the northern drainage basins of the Baltic Sea show generally increasing annual river flow over the coming century, while southern areas show little annual change or decreases. The seasonal variability in river flow is projected to decrease in most basins, with the exception of the Baltic Proper to the far south.

2. Climate model simulations

This study uses continuous long-term climate simulations, often referred to as "transient simulations" that cover the full period of the 21st century. Results shown here use simulations from the Rossby Centre Regional Atmospheric Model, RCA3 (Kjellström et al., 2005). The simulations cover a 140-year time period from 1961 to 2100. For these simulations, the radiative forcing of the climate system is based on observed concentrations of greenhouse gases until 1990 and on the IPCC SRES B2 and A2 emissions scenarios for the remaining time period.

The RCA3 simulations were performed using a horizontal grid resolution corresponding to about 50 km. Global forcing at the regional model boundaries came from the coupled atmosphere-ocean general circulation model (GCM) ECHAM4/OPYC3 (Roeckner et al., 1999). Lateral boundary conditions and sea surface temperatures were updated every six hours from the GCM. The ECHAM4/OPYC3 simulation used a horizontal grid spacing of 2.8° (T42 spectral resolution).

3. Hydrological model simulations

Hydrological modeling was performed with the HBV-Baltic Model, which does a reasonable job of representing the large-scale hydrology of the present climate (Graham, 1999). It has been used in previous studies evaluating both the present and future hydrology of the Baltic Basin (e.g., Graham et al., 2006; Graham, 2004; van den Hurk et al., 2002). For present climate simulations, it uses meteorological observations from the synoptic station network covering the Baltic Sea basin, currently for the period 1980-2005 (updated once a year).

Due to biases in results from climate models for the present climate—precipitation in particular—the simulated climate variables must be adjusted before being used in hydrological models (as well as other impacts models). Variations on the delta approach have typically been used. This adds the change in climate to an observational database that is used as input to the hydrological model to represent the future climate. More recently, scaling approaches (sometimes referred to as bias correction) have been applied (e.g. Lenderink, et al., 2007; Graham et al., 2007). A scaling approach can be argued to be more desirable as it is a more direct application of results from the climate models. However, if biases in the climate model are large, it adds its own distortion to the climate change signal.

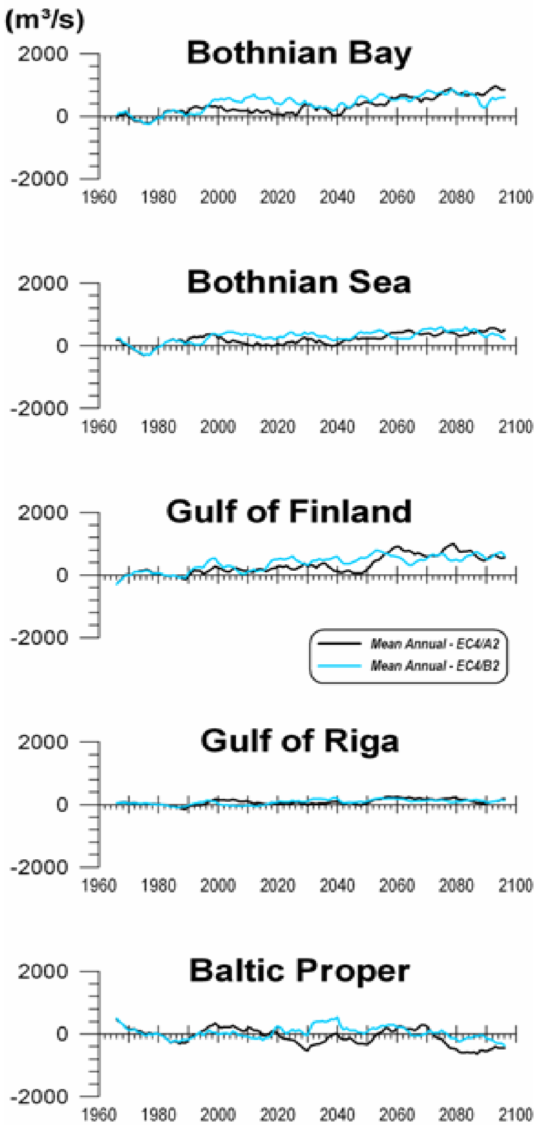


Figure 1. Mean annual change in river flow. Shown are 10-year running means of deviation from the simulated mean river flow for the period 1961-1990, using the RCA3 simulations forced by ECHAM4/OPYC3, both A2 and B2.

Use of a scaling approach is necessary for continuous climate simulations, such as the transient simulations used here. In these simulations, precipitation was compared to the available record used in HBV-Baltic, 1980-2005. Looking at long-term means for the same period in the climate simulations, scale factors for annual precipitation were determined. These scale factors were applied to daily precipitation from RCA3 for the full simulation period, which was then input to the hydrological model. Scaling for temperature was performed in the same way, except that monthly scale factors were determined.

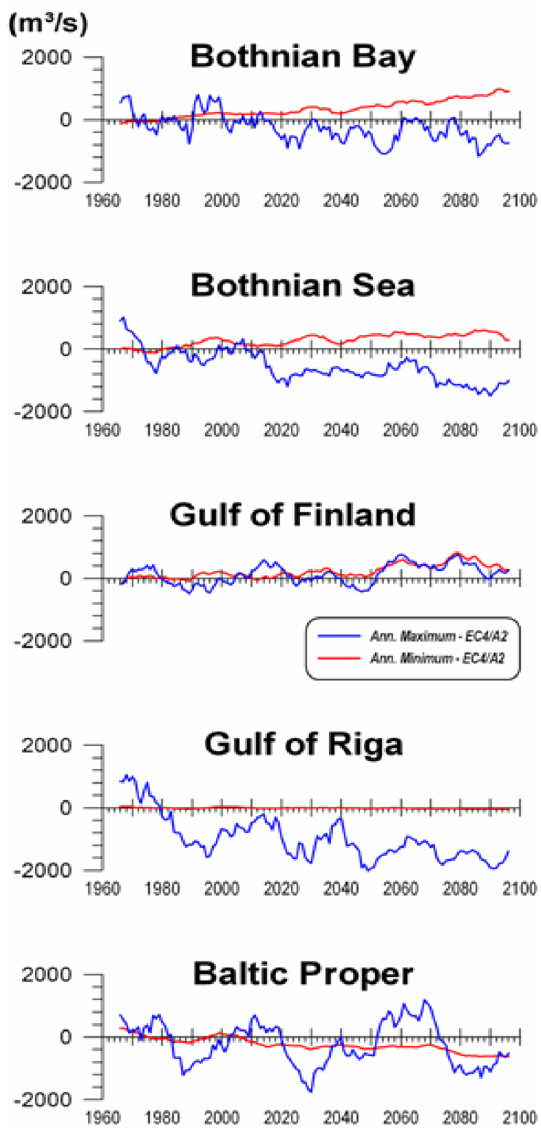


Figure 2. Change in annual maximum and minimum river flow. Shown are 10-year running means of deviation to the simulated mean maximum and minimums for the period 1961-1990 using the RCA3 simulation forced by ECHAM4/OPYC3 A2.

4. Results

Figure 1 shows change in annual river flow and Figure 2 shows change in annual maximum and minimum river flow. Both show 10-year running means over the full simulation period 1961-2100. River flow in the north is generally shown to increase, while flow in the south decreases. This is in agreement with previous studies that focused on the latter part of the 21st century. However, these results add details of projections for mid-century. Of note is that the B2 scenario shows increased river flow exceeding that of the A2 scenario for much of the mid-century.

Figure 2 gives an indication for coming trends in the variability of river flow. For the north, low flows are projected to increase, while high flows show a decrease. In other words, there is less seasonal variability in river flow. Further south, low flows show a decreasing trend, while no obvious trend is present for high flows. This indicates possible periods of water scarcity, but perhaps little change in flooding, compared to present climate conditions.

5. Conclusions

The first hydrological assessment using continuous, transient climate simulations has been performed for the Baltic Basin. This 140-year period includes the entire 21st century and provides new detail to projected hydrological impacts for the near future. However, even though methods for transferring the climate change signal from climate models to hydrological models have improved, they still add their own uncertainty to the assessment. This is under continuous development.

References

Graham, L.P., Modeling runoff to the Baltic Sea. *Ambio* 28, 328-334, 1999.

Graham, L.P., Climate change effects on river flow to the Baltic Sea. *Ambio* 33, 235-241, 2004.

Graham, L.P., Hagemann, S., Jaun, S. and Beniston, M., On interpreting hydrological change from regional climate models. *Climatic Change*, (in press), 2007.

Kjellström, E., Bärring, L., Gollvik, S., Hansson, U., Jones, C., Samuelsson, P., Rummukainen, M., Ullerstig, A., U., W. and Wyser, K., *A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3)*. SMHI Reports Meteorology and Climatology, No. 108, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden, 54 pp, 2005.

Lenderink, G., Buishand, A. and van Deursen, W., Estimates of future discharges of the river Rhine using two scenario methodologies: direct versus delta approach. *Hydrol. Earth Sys. Sci.* (in press), 2007.

Roeckner, E., Bengtsson, L., Feichter, J., Lelieveld, J. and Rodhe, H., Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle. *J. Climate* 12, 3004-3032, 1999.

van den Hurk, B.J.J.M., Graham, L.P. and Viterbo, P., Comparison of land surface hydrology in regional climate simulations of the Baltic Sea catchment. *J. Hydrol.* 255, 169-193 2002.

Precipitation Extremes under Climate Change in the Baltic Area as Simulated with a Regional Climate Model

Ole Bøssing Christensen

Danish Meteorological Institute, Lyngbyvej 100, DK-2100 Copenhagen Ø, Denmark. E-mail: obc@dmi.dk

1. Background

In recent years, the resolution of regional climate models has been increased to a point where extremes of precipitation are much better described than before.

At the DMI, time slice integrations in the PRUDENCE setup (http://prudence.dmi.dk, Christensen and Christensen (2007)) have been performed with the HIRHAM regional climate model in 50km, 25km and 12km resolution.

We will compare precipitation extremes as simulated in the different resolutions, validate against observation and present projections of climate change and the effect on model resolution on these.

2. Results

The effect of resolution on extremes indices, in particular for daily precipitation, will be presented. We will show results for the whole of Europe but concentrate on results for the Baltic Basin.

Fig. 1 shows the 10-year return value of daily precipitation for late summer (July, August, September) in 3 different resolutions. The values generally increase with increased resolution, and a problem with convective precipitation not reaching inland from the sea is gradually solved, as a larger fraction of convective precipitation is explicitly resolved in higher resolution.

In Fig. 2 we show average return values for an area around Denmark. The gridded data have been pooled, hence the high theoretical return times on the x-axis.

It is again illustrated how extremes increase with increased resolution. Comparisons with the observation-based curve in this figure show that the higher resolution gives more realistic results. It should be noted that the observations are land-points only, whereas all model data have been calculated by pooling both land and sea points from a sub-grid rectangle covering Denmark. Therefore the observational values should have been higher.

Aggregation of daily 12km grid cell values into 50km cells of course decreases extremes. However, it can be seen that the aggregated high-resolution data are more realistic than the data from the 50km simulation.

There is a clear climate change signal in the extreme precipitation. This signal is significantly larger than the simulated change of average annual precipitation.

3. Conclusion

The added value of very-high-resolution regional simulations is not just a question of more realistic spatial patterns. The effect of high resolution is evident in the realism of extreme precipitation events. Hence, high resolution will be a valuable tool in investigations where high-intensity precipitation events are important.

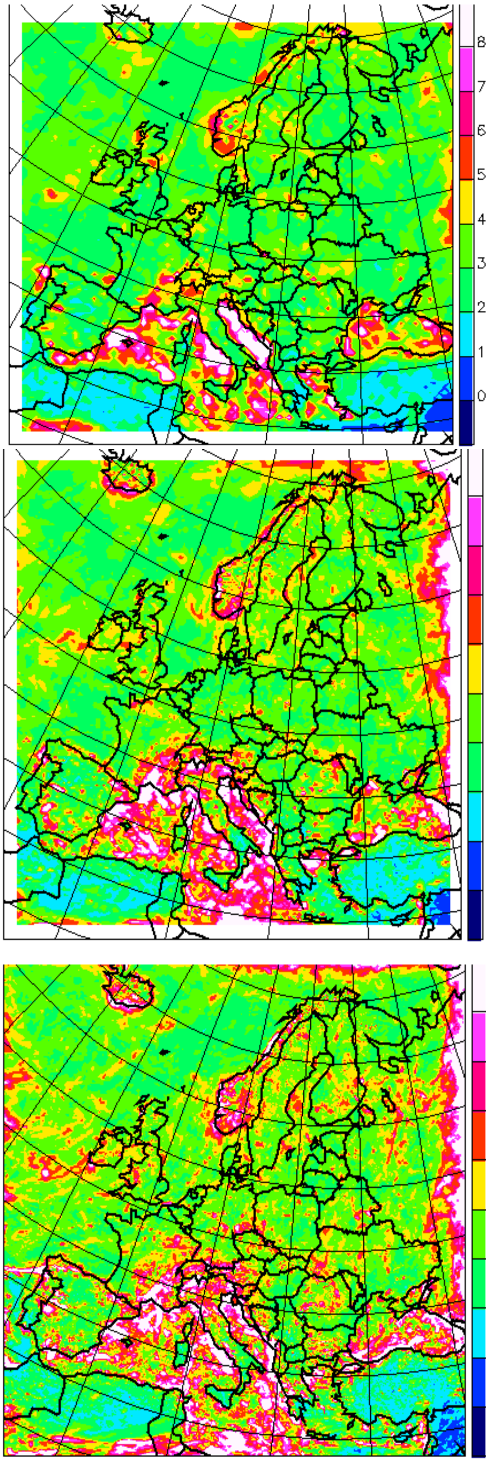


Figure 1: Ten-year return value of daily precipitation (mm/day) in the months July, August, September for the PRUDENCE control simulation with HIRHAM. Upper panel: 50km resolution; middle panel: 25km resolution; lower panel: 12km resolution.

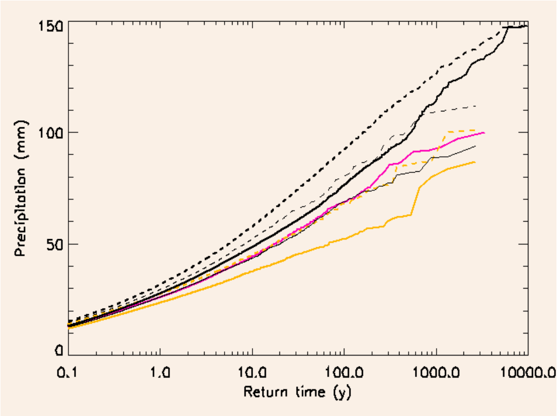


Figure 2: Average return values of daily precipitation over Denmark for current climate (full lines) and future climate (dashed lines). Thick black: 12km resolution; thin black: 12km aggregated to 50km; orange: 50km simulation; purple: 10km gridded observations.

References

Christensen, J. H., and O. B. Christensen, A summary of the PRUDENCE model projections of changes in European climate by the end of this century, *Climatic Change*, in press, 2007

Decadal Variability of the Hydrological Cycle in the Baltic Sea Region

Daniela Jacob and Philip Lorenz

Max-Planck-Institute for Meteorology, Bundesstrasse. 53, 20146 Hamburg, Germany (daniela.jacob@zmaw.de)

1. Introduction

During BALTEX phase I the focus was mainly on process understanding and modeling of the water and energy cycles of the Baltic Sea basin. This focus is carried on in BALTEX phase II, objective 1. In addition, within objective 2 climate variability, climate change since 1800 and future climate projections are introduced to the BALTEX activities. Both objectives are linked through the variability of the hydrological cycle, which is strongly influenced by the large scale flow from the Atlantic. However, local and regional processes are able to modulate the hydrological cycle.

To understand possible changes in the hydrological cycles due to the changing climatic conditions, decadal variability during the past 100 years has been studied. Furthermore possible changes in the future will be discussed.

2. REMO experiments

Validation as well as climate change projection experiments have been carried using the regional climate model REMO (*Jacob et al.*, 2001; *Jacob*, 2001). For this study the regional model domain defined within the ENSEMBLES project with a horizontal resolution of 0.44° (~50km) has been used. It covers whole Europe on a rotated coordinate system (figure 1).

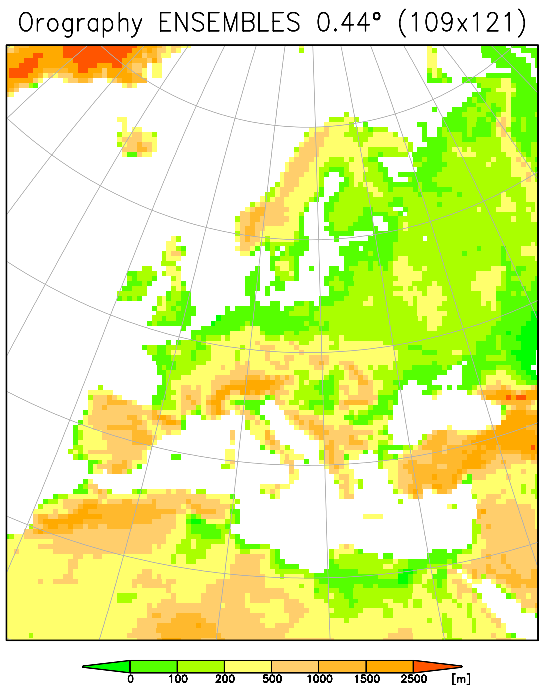


Figure 1. REMO model domain with orography [m].

Firstly, two validation experiments have been performed, one using the ECMWF ERA15 dataset for initialization and lateral boundary forcing, (1979-2002; from 1994 onwards operational analysis from ECMWF), and the other one using the ECMWF ERA40 dataset (1958-2002).

Secondly, climate change projections have been computed, which were all initialized and driven at the lateral boundaries with data from coupled global climate change experiments simulated by the ECHAM5/MPIOM model system (Max-Planck-Institute for Meteorology):

- Three realizations of a control run (1950-2000)
- Three realizations of a climate change run (2000-2100) for the SRES A1B emission scenario
- One realization of a climate change run (2000-2100) for the SRES A2 and for the SRES B1 emission scenario, respectively.

3. Analysis of the decadal variability in the hydrological cycle

For the analysis of the decadal variability of the hydrological cycle, decadal area sums of precipitation, evaporation and runoff have been calculated for the land part fraction of the Baltic Sea catchments area and for the area of the Baltic Sea itself (except for runoff). Additionally changes in mean soil wetness were taken into account; however, these are rather small.

With these values it is possible to calculate residual budget values like total runoff into the Baltic Sea, or net transport of Baltic Sea water through the Kattegat (under the assumption the mean sea level in the Baltic Sea doesn't change significantly). As an example the calculated decadal values of simulated run-off into the Baltic Sea and net transport through the Kattegat is shown in figure 2 for an A1B member on the REMO 0.44° horizontal resolution.

An analysis of the decadal variability and its possible future change will be presented for several budget quantities of the hydrological cycle for the Baltic Sea region.

References

Jacob, D., U. Andrae, G. Elgered, C. Fortelius, L. P. Graham, S. D. Jackson, U. Karstens, Chr. Koepken, R. Lindau, R. Podzun, B. Rockel, F. Rubel, H.B. Sass, R.N.D. Smith, B.J.J.M. Van den Hurk, X. Yang: A Comprehensive Model Intercomparison Study Investigating the Water Budget during the BALTEXPIDCAP Period, *Meteorology and Atmospheric Physics*, Vol.77, Issue 1-4, pp. 19-43, 2001

Jacob, D.: A note to the simulation of the annual and interannual variability of the water budget over the Baltic Sea drainage basin, *Meteorology and Atmospheric Physics*, Vol.77, Issue 1-4, pp. 61

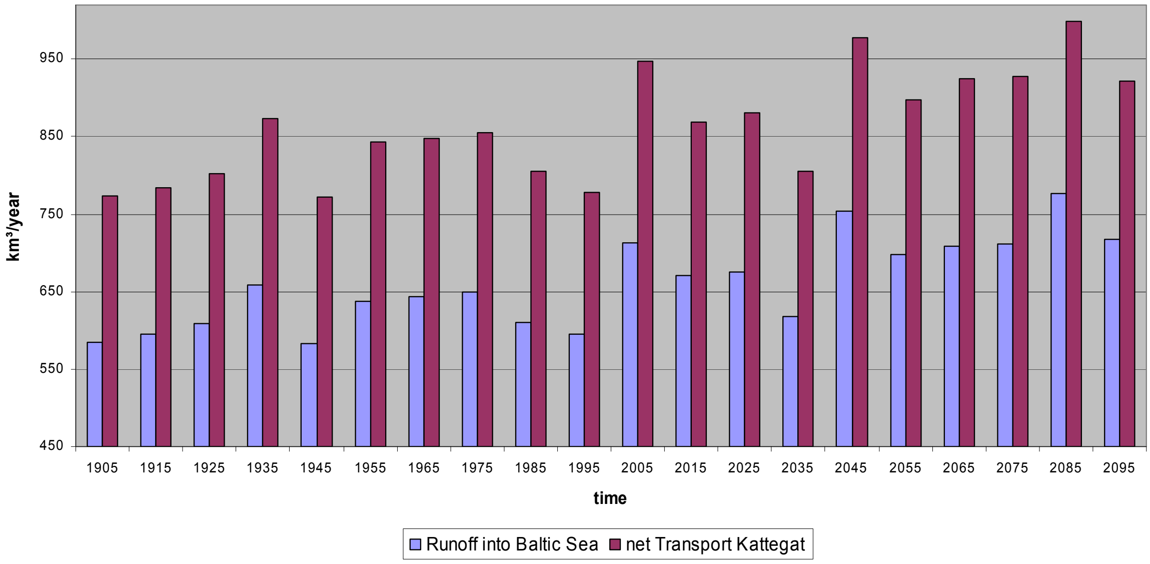


Figure 2. Calculated decadal values of simulated run-off [km³/year] into the Baltic Sea and net transport [km³/year] through the Kattegat for 1900 to 2100 (REMO 0.44° / A1B).

Prolonged Periods with Little Rain During Summer in Finland – Observations and Future Projections

Kirsti Jylhä, Tiina Kilpeläinen, Ari Venäläinen, Seppo Saku, Heikki Tuomenvirta, Kimmo Ruosteenoja and Andrea Vajda

Finnish Meteorological Institute, P.O. Box 503, FIN-00101 Helsinki, Finland; e-mail kirsti.jylha@fmi.fi

1. Introduction

Dry spells, or prolonged periods with little rain, decrease surface and ground water level, thereby having adverse effects on the environment and various sectors of the society, e.g., agriculture, hydropower generation and forestry. Summer 2006 in Finland was exceptionally dry, with less than 25% of the average precipitation sum in the vicinity of the Bothnian Bay and in the Helsinki metropolitan area. At the station Helsinki Kaisaniemi during June-August, it rained only 35 mm, the smallest summer rainfall amount ever recorded since the onset of the precipitation measurements there in 1845. Among numerous consequences of the wide-spread drought, the risk of forest fires in Finland and the surroundings was larger than usually.

The objective of our study is three-fold. First, the average dry interval (*DI*) between two successive rain events in summer is examined based on measurements with a continuously recording rain gauge. Second, we assess 10-year return levels for durations of spells with only a small amount of precipitation (*DS10*). Third, multi-model mean projections for changes in the average summer maximum number of consecutive dry days (*CDD*) are presented, discussing the level of agreement between the models.

This work contributes to climate change adaptation studies in Finland within a national research programme. In parallel, we have also examined the impact of climate change on forest fire risk (*Vajda and Venäläinen* 2006) and heavy precipitation (*Tuomenvirta et al*. 2006) in the Baltic Sea catchment.

2. Material and methods

Rainfall data used to examine *DI* were collected with a Fuess recording rain gauge at the weather station Helsinki Kaisaniemi in May-September during the period 1951-2000. Daily precipitation sums calculated from the data were closely correlated with those based on standard precipitation observations at the same station, with a correlation coefficient of about 0.97, which proves the data quality to be good enough for climatological analysis.

Daily observations at twelve stations in Finland were utilized to examine *DS10*. In this paper we discuss results for the Helsinki Kaisaniemi station based on observations in 1958-2006. We considered several thresholds (10, 25, 50, 100, 200 mm) of the accumulated precipitation sum and picked out the longest spells that started between the 1st of May and the 30th of September to achieve these thresholds. The 10-year return levels were assessed applying the so-called "peak over threshold" (POT) approach, assuming the Generalized Pareto distribution. The calculations were performed with the so-called eXtremes software (*Katz et al.* 2005).

Relative changes in June-August *CDD* by the end of the 21st century were estimated on the basis of experiments performed with seven regional climate models (RCMs) in the EU FP5 project PRUDENCE (*Christensen et al.* 2006). All the RCMs regionalized information from the HadAM3H general ciculation model (GCM), applying the IPCC-SRES A2 radiative forcing scenario. Details of the projections were subject to differences in RCM design and random effects due to internal climate variability. To alleviate their influence, we consider here multi-model means, but we also examine the regional pattern of the level of agreement between the RCMs. The sea areas were masked out, mainly because of a rather unrealistic future climate over the Baltic Sea in summer in most of the model runs, arising from a very large increase in the Baltic sea surface temperatures (SST) in the driving GCM system (see *Kjellström and Ruosteenoja* 2006).

3. Results

According to the observations, the average duration of a single dry interval in Helsinki in summer is about 21 hours. However, *DI* decreases rapidly from early to late summer, with a mean of 32 hours in May and 16 hours in September. Deviations between the five decades considered were large but no temporal trend could be found. In summers of the 1970s and 1980s *DI* was clearly shorter than during the previous two decades and the subsequent one. The longest dry spell took place in 1960, lasting 32 days and 22 hours.

The 10-year return level for the duration of a period with a precipitation sum of only 10 mm is in Helsinki 45 day, with an uncertainty range of 39-53 days (Figure 1). On the other hand, we can estimate that on average once in a decade there is a period of 100 days with not more than 50-80 mm of precipitation. As a comparison, the average precipitation amount in Helsinki in 1971-2000 was 642 mm annually and 189 mm in June-August.

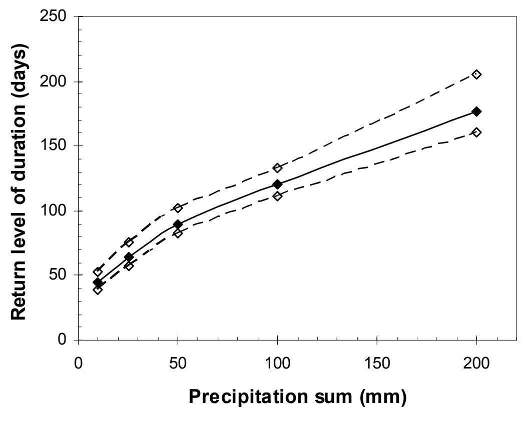


Figure 1. 10-year return levels *DS10* (in days) for durations of spells with only a small amount of precipitation in Helsinki Kaisaniemi, as a function of the precipitation thresholds (in mm). The solid line gives the maximum likelihood estimates and the dashed lines depict the 90% confidence interval.

On the southern and western coast of the Baltic Sea, all seven RCMs agreed on an increase in the 30-year mean of the summer maximum number of consecutive dry days by the end of this century (Figure 2a). The multi-model mean change in *CDD* ranged from 40-70% in Germany (and even higher westwards) to less than 20% in Lithuania and central Scandinavia (Figure 2b).

Around the Gulf of Finland and to the east of the Gulf of Bothnia, about half of the models suggested an increase in *CDD* and the rest a decrease or no change (Figure 2a). In general, *CDD* had a tendency to decrease with increasing summer mean precipitation (*P*). For the area-average of *CDD* in Finland, the largest decrease (-9%) was projected by a model run with prescribed sea and lake surface temperatures and the highest increase (14%) by a model run employing an alternative Baltic SST forcing. However, no simple relation could be found between the sign of the change and the procedure used in the experiments for the Baltic SST. The spread among the RCMs partly resulted from differences in model formulation but also from random noise. Because of the disagreement on the sign of the change (and a low signal-to-noise ratio), wide areas in Figure 2b are not shaded with colour.

4. Discussion

Based on observations during many decades, we have discussed here durations of short-term dry weather and long-term periods with little rain at a single station. A further study on the latter, utilizing information at several other stations as well, is currently going on. Return periods longer than 10 years are also being examined.

In our study for *CDD*, we considered the uncertainty due to differences in RCM formulation and experimental design, including also diversities in the Baltic SST forcing. It should be emphasized, however, that additional sources of uncertainty in future climate projections, arising from deviations between the lateral boundary conditions of the driving GCMs and uncertainties in future emissions, can be much larger than the contribution from differences in RCMs. In this particular case, we found (not shown) that in the driving HadAM3H experiment the projected change in the June-August mean precipitation in Finland by 2071-2100 was 10% (and 1% for *CDD*). By coincidence, this increase in *P* is very close to our results for the corresponding multi-model mean change in *P*, based on a set of 19 GCM simulations conducted for the Fourth Assessment Report of the IPCC (not shown). This suggests that our results for *CDD,* presumably covering only a small fraction of the whole uncertainty range, might still be rather typical. However, this conclusion should be confirmed by studying *CDD* on the basis of several GCM experiments.

References

Christensen J.H., Carter T.R., and Rummukainen, M., Evaluating the performance and utility of regional climate models: the PRUDENCE project, *Clim. Change,* 2006 (in press).

Katz, R.W., G.S. Brush, and Parlange, M., Statistics of extremes: Modeling ecological disturbances. *Ecology,* 86(5), pp. 1124–1134, 2005.

Kjellström, E., and Ruosteenoja, K., Present-day and future precipitation in the Baltic Sea region as simulated in a suite of regional climate models, *Clim. Change,* 2006 (in press).

Tuomenvirta, H., K. Jylhä and T. Kilpeläinen, Extreme precipitation events in the Baltic Sea catchment - observations and future projections. In: Jania, J. and Kundzewicz, Z.W. (eds.): Extreme hydrometeorological events in Poland and their impacts - European context. Warsaw, 7– 9 December 2006. Faculty of Earth Sciences, University of Silesia, pp. 82-84, 2006.

Vajda A. and Venäläinen A., The impact of climate change on forest fire risk in Scandinavia and Baltic region, In 5th International NCCR Climate Summer School Abstracts, Switzerland, 2006.

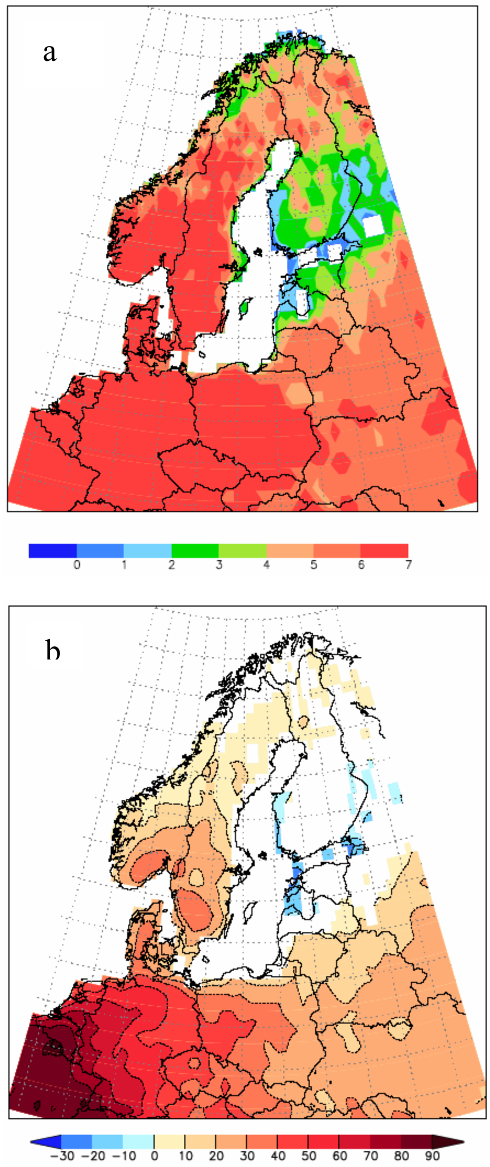


Figure 2. Projected changes in the 30-year mean of the summer (JJA) maximum number of consecutive dry days (*CDD*) by 2071-2100, compared to 1961-1990, based on PRUDENCE RCM simulations with A2 radiative forcing scenario. a) The number of models indicating a positive change. b) Multi-model mean change (%); in white land areas three out of seven models disagree on the sign of the change.

Acknowledgements

This work was financed by the Finnish ministries of Transport and Communications, the Environment, and Agriculture and Forestry.

Future Wave Climate of the Baltic Sea - Projections with Winds from the Regional Climate Model RCA3 of the Rossby Centre

Barry Broman

Swedish Meteorological and Hydrological Institue, Rossby Centre, SE-601 76 Norrköping, Sweden
E-mail: Barry.Broman@smhi.se

1. Introduction

Blowing of the wind generates waves. The size - as given by the significant wave height – is depending on the wind speed, the length over sea where wind is acting fetch –and the duration. An empirical nomogram of these factors has been constructed, and can be found in WMO (1998)
Hs = F(W,F,D) where Hs is significant wave height (m), W is wind speed (m/s), F is fetch (m)and D is duration (s). Significant wave height is defined as the mean of the 1/3d highest waves during a time interval. Earlier has a dataset been calculated for the 25 year period 1980-2004, *Meier et al* (2006). The results from this have been compared to measurements at some locations with fairly good results. With this experience it was interest in finding out the future evolution of the wave climate.

2. Data

A database of fetches has been constructed for the Baltic in the range long 8-30 deg and latitude 54-66 deg wit a resolution of 20'*10' (longitude,latitude). For every grid point there is distance to the shore in 8 directions. Wind is coming from results from runs of RCA3, the regional climate model of Rossby Centre. *Kjellström et al* (2206). From the same model there are also output about ice. For every grid point the ice concentration is used to give no waves if it is greater than 50%.

3. Results

The results will be given as statistical maps with mean, maximum and some percentiles for different time periods and compared with the 25 year period 1980-2004. The figure below shows an example of an outcome but in this case from results of one monthly maximum 2006 for the operational wave model at SMHI.

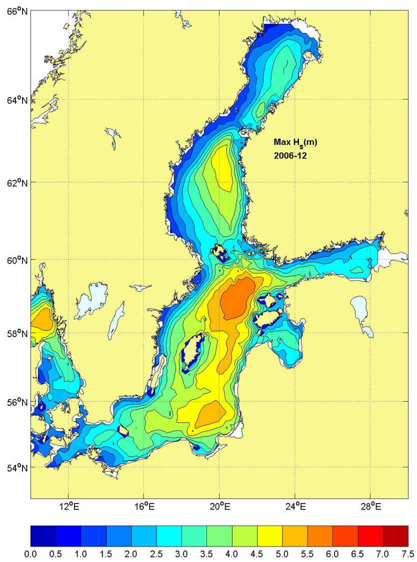


Figure 1. Example of ouput from op.model

References

WMO-No.702 1998, Guide to Wave Analysis and Forcasting (second edition)

Broman Barry, Meier H.E.Markus, Modeling waves in past and future climates of the Baltic Sea, *5 th Balic Sea Science Congress*, Abstracts, pp. 72-73, 2005

Meier H.E.Markus, Broman Barry, Kallio Hilka & Kjellström Erik, Projections of future surface winds, sea levels, and wind waves in the late 21st centuary and their application for impact studies of flood prone areas in the Baltic Region, Geological Survey of Finland, Special Paper 41,pp.23-43.

Kjellström, E., Bärring, L., Gollvik, S., Hansson, U., Jones, C., Samuelsson, P., Rummukainen, M., Ullerstig, A., Willén U. and Wyser, K., 2005. A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). Reports Meteorology and Climatology, 108, SMHI, SE-60176 Norrköping, Sweden, 54 pp.

Climate Change Impact on the Baltic Sea Ecosystem: The HELCOM View on Future Co-Operation with BALTEX

Juha-Markku Leppänen

Helsinki Commission, Juha-Markku.Leppanen@helcom.fi

The HELCOM Assessment of Climate Change in the Baltic Sea Area, which was adopted by HELCOM in March 2007, is a perfect example of co-operation and dialogue between a scientific community and environmental policy makers.
The report is based on the comprehensive BALTEX/BACC Assessment, which integrates available knowledge of historical, current, and expected future climate change.
Currently HELCOM is finalising the HELCOM Baltic Sea Action Plan, which aims at holistic actions, addressing eutrophication, biodiversity, maritime activities, and hazardous substances. When HELCOM is setting targets for good ecological status, this should be in line with prevailing physiographic, geographic, and climatic conditions. Thus e.g. the effects of climate change have to be taken into account as "a shifting background".
The adopted joint BALTEX/BACC/HELCOM Assessment has a comprehensive chapter "Climate-related Change in the Baltic Marine Environment" which is dealing with projected changes in the physical and chemical conditions, nutrient inputs, chemical contaminants, and potential climate-related changes in the Baltic marine ecosystem.Even though the last topic included bacteria, phytoplankton, zooplankton, benthos, fish, marine mammals and seabirds, it was still considered as "preliminary" and to be amended when more hard facts are available. The result of the previous co-operation with more than 80 scientists from 12 countries coordinated by BALTEX/BACC was so excellent that HELCOM hopes for future co-operation to assess even better the impacts of future climate change on the Baltic Sea ecosystem. The best available science based advice is in the core of the Baltic Sea Action Plan. Therefore HELCOM does not want to restrict the topics of co-operation to climate change and is expecting new ideas by the Conference.

Climate Change and Land Ecosystems of the Baltic Sea Basin – Knowledge Gaps and Research Priorities

Benjamin Smith

Geobiosphere Science Centre, Lund University, Geocentrum II, 22362 Lund Sweden. Ben.Smith@nateko.lu.se.

1. Ecosystem impacts of climate change

Scientific knowledge of the ecosystem impacts of recent climatic and environmental change across the Baltic Sea region was synthesised as part of the Baltex Assessment of Climate Change for the Baltic Sea Basin – BACC. For the terrestrial environment, it could be concluded that climate change during the last 30-50 years has already given rise to measurable changes in both the structure and functioning of the ecosystems. Robust indicators of change include the advancement of spring phenological phases in certain plant species, changed migratory patterns and behaviour – for example in migratory birds – upslope displacement of the alpine treeline, and increased land-surface greenness as plants and ecosystems adjust to improved growth conditions and a richer carbon supply.

Many of the current trends may be expected to continue for at least some decades into the future, as atmospheric CO_2 concentrations continue to rise, and the climate continues to warm. However, future projections are intrinsically uncertain: for many impact types, current trends could be broken or reversed due to system-internal feedbacks, shifts in controlling processes, non-climatic drivers and structural transformations. Uncertainty in the future trajectories and regional patterns of biologically-significant climate variables, such as rainfall and cloudiness, can likewise propogate to the ecosystem impacts.

2. Uncertainties and research needs

Several areas of major uncertainty were identified with respect to future ecosystem changes across the Baltic Sea catchment area. These fall into three main categories; firstly, limitations to current understanding of the mechanisms by which species and ecosystems respond to climate change; secondly, factors with a potential to modify climate responses that are difficult to characterise because of their episodic or species-specific nature – for example, impacts of pests, pathogens and climatic extremes; and thirdly, sensitivities to non-climatic covariates of climate change, such as land use, forest management, agricultural practices, pollutant deposition rates and technology development. The further elucidation and constrainment of these uncertainties constitute fertile ground for research, especially as many of them surround ecosystem functions of sectoral or societal importance: forest growth, net carbon emission, water quality, habitat conservation. The following key questions for research are proposed:

- How will the distribution and abundance of pests and pathogens respond to climate change, and what consequences will this have for the functioning of natural and managed ecosystems?
- Given current greenhouse gas emissions scenarios, their associated socio-economic storylines, and the changes in climate and ecosystem functioning they are expected to lead to, what are the likely trajectories and spatial patterns of land use change within the Baltic Sea region? What consequences will these, in turn, have for species distributions, carbon sequestration, water runoff and land-sea nutrient fluxes?
- How will changes in hydrology, soil thermal dynamics, biogeochemistry, microtopography and vegetation affect the contribution of extant peatland areas to greenhouse forcing, not forgetting the carbon exports of these areas to the Baltic Sea?
- What changes in disturbance regimes will result from future climate variability, especially extreme events like storms, spring temperature backlashes, extended drought periods or a succession of extreme summers? What will be the consequences for ecosystems, taking into account feedback mechanisms such as insect pest outbreaks and herbivore pressure in forests? What will be the consequences for water quality in lakes and land runoff?

RCM-Downscaled Climate Indices Requested by the Swedish Government Climate and Vulnerability Inquiry Committee: An Overview and some Remarks

Lars Bärring

Rossby Centre, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden. lars.barring@smhi.se

1. Introduction

About two years ago the government initiated an official inquiry committee on climate and vulnerability, <http://www.sou.gov.se/klimatsarbarhet/> (in Swedish only). The committee is to assess effects and impacts of projected future climate changes on the Swedish society and environment, and to evaluate present day vulnerabilities to climate variability and climate extremes. The inquiry thus has a wide frame of reference in that all societal sectors and environmental aspects are to be included, and the resulting conclusions should include an assessment of the measures and resources required for various adaptations options.

SMHI is involved in this work at several levels, of which an important one is to provide climate scenario information to all working groups. In addition to the standard set of annual, seasonal and monthly means/accumulations of temperature, precipitation, etc. this information includes future scenarios for the Baltic Sea (Meier, 2006, Meier et al., 2006) and hydrological scenarios for the three major Swedish lakes (Bergström et al., 2006).

A major contribution is the production of a wide range of climate indices (indices of climate extremes). Taking an unorthodox approach, we allowed free requests (within practical and possible limits) from the members of the committee working groups on the basis of the general and vague information that "...regional climate models does not only produce climate averages but do simulate the evolution of 'weather conditions' over time...". Examples of some previously defined climate indices were drawn from the *MICE/PRUDENCE/ STARDEX* project consortium and from the European Climate Assessment (*ECA*). Based on this, the working groups compiled a long shopping list of climate indices.

2. Climate indices

Some of the requested climate indices followed established concepts and/or were specified in enough detail to be directly calculated. However, a few ideas for indices were expressed in rather conceptual terms of possible impacts. Within the limited time available, these requests could only as first order approximations be transformed into simple climate indices. The variables (Table 1) used for calculating the indices were either calculated online in the model or in the post-processing step. All variables are in the form of daily summary statistics (mean, sum, maximum, minimum, etc.). From this data, a range of indices were calculated by forming annual, seasonal or monthly statistics that result in one value per year for each gridcell. These statistics could be for example:

a. maximum running sum/mean for a fixed period,
b. count of days above/below some threshold,
c. first/last date when some conditions occurred,
d. longest consecutive period for some weather condition,
e. degree-days for heating, cooling and vegetation growth,
f. vegetation period, start, end and length,
g. combination of several variables and conditions, of which some are rather imaginative, e.g. a 'slippery day index' and a 'mould index'.

Table 1. The basic variables used for calculating the climate indices.

Variable	Explanation	Unit
Precip	Daily precipitation amount	mm
Rainfall*	Daily total rainfall	mm
Snowfall	Daily total snowfall (unit is mm water)	m
Evap	Daily total evaporation	mm
PminusE*	Daily total of precip. minus evap.	mm
T2m	Daily mean 2m temperature	ºC
T2min	Daily minimum 2m temperature	ºC
T2max	Daily maximum 2m temperature	ºC
Tsurf	Surface temperature	ºC
SnowCover*	Gridcell average snow cover	fraction
SnowDepth*	Gridcell average snow depth	cm
SnowWeq	Gridcell average snow water equivalent	m
LakeIce	Thickness of lake ice	cm
W10m	Daily mean 10m wind speed	m/s
GustWind	Daily maximum 10m gust wind speed	m/s
W70m	Wind speed at 70m	m/s
SunHours	Accumulated sum hours	hours
SWdown	Surface downward shortwave radiation	W/m^2
LWdown	Surface downward longwave radiation	W/m^2
Cloudbase	Daily minimum cloudbase height	m
PrecipMax	Maximum precipitation intensity	mm/h

* Calculated 'off-line' or otherwise post-processed from the basic model output.

3. Regional climate model runs

All indices were calculated based on daily data from several model runs (Table 2). For all indices, except the percentiles based on the W70m winds, one index value was calculated for each year in a time period and then averaged to form the final index value for the period. One of the run (ECHAM5/A1B) was recently completed and not possible to include in the deliveries to the Committee and will thus be used mainly for comparison purposes in the final assessment.

Table 2. Overview of the RCM simulations.

Model	RCAO (Jones et al., 2004)	RCA3 (Kjellström et al, 2005)
Simulation	time slice	transient runs
Analysis period(s)	1961-1990 2071-2100	1961-1990 1991-2005* 2011-2040 2041-2070 2071-2100
Forcing data GCM/SRES	ECHAM4/A2 ECHAM4/B2 HadAM3H/A2 HadAM3H/B2	ERA40/ ECMWF oper.* ECHAM4/A2 ECHAM4/B2 (ECHAM5/A1B)

* The run for the period 1991-2005 (15 years) is forced by ERA40 extended with ECMWF operational analysis data.

Recently, SMHI published a facts sheet (Alexandersson, 2006) comparing temperature and precipitation observations for the two periods 1961-1990 and 1991-

2005. This document shows a clear shift towards warmer and wetter conditions during the last 15 years. The indices were calculated for the same two periods using an RCA3 run forced by ERA40 extended with ECMWF operational analysis data. While these two data sources are not homogeneous, this RCM run is still an attempt to follow up on the observational study to provide background material that is consistent with the climate scenarios. In total, about 12000 maps were produced, including both 'absolute' and difference maps in a variety of combinations of monthly/seasonal/annual × time periods × RCM version × forcing GCM/SRES. This number of maps is quite stunning and the total information volume seems intractable, even though some 200 persons are involved in the Committee working groups, and no one peruses all of them.

4. Example results

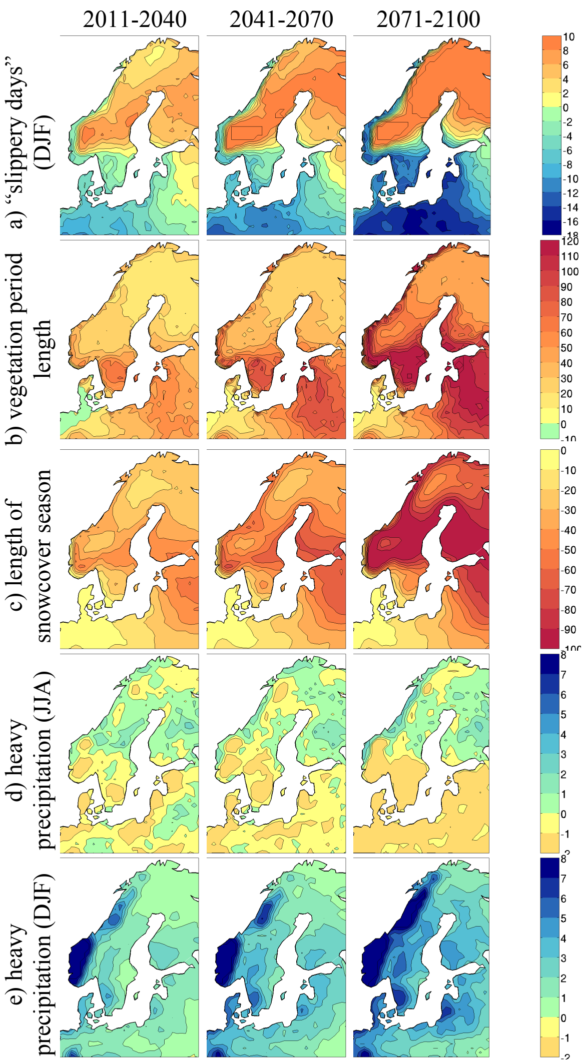


Figure 1. Some example of climate indices based on the RCA3 transient run with lateral boundary conditions taken from the ECHAM5/A1B (Roeckner et al, 2006). All maps presented as differences from the baseline period 1961-1990. The unit of all maps is *[change in number of] days*.

5. Concluding remarks

The material is still under evaluation (Bärring et al., in prep.) and the full set of maps is available from the SMHI website <www.smhi.se>. However, some general conclusions can be drawn:

- Some indices based on thresholds (e.g.spells or number of days above/below a threshold) can be sensitive to bias that otherwise may be regarded as small or acceptable. It depends on how far out in the tail of the frequency distribution the threshold is.
- Differences between two time-slices of such indices are normally robust (if the index does not 'saturate', i.e. reaches a minimum/maximum).
- From an impact point of view, it has been a most useful exercise for the group members to start thinking in quantitative terms about how and in what ways weather and climate actually sectors.
- Experts and professionals not used to climate model data often find it difficult to transfer experience based on point measurements to gridcell data.
- From a model development point of view, it has been a most useful exercise. We have gained a lot of insight in what data are likely to be of interest in the future, and where even small biases may become problematic.
- While some indices are rather simplistic in relation to the specific problem they are intended address, they still provide first order attempts that point toward opportunities for developing better online parameterisations or offline impact models.

References

Alexandersson H. and Edquist E.: Klimat i förändring. En jämförelse av temperatur och nederbörd 1991-2005 med 1961-1990. *Faktablad*, No 29. SMHI, Norrköping, Sweden,2006.<http://www.smhi.se/sgn0102/n0205/faktablad_klimat.pdf>.

Bergström S., Hellström S.-S. and Andréasson J. Nivåer och flöden i Vänerns och Mälarens vattensystem - Hydrologiskt underlag till Klimat- och sårbarhetsutredningen. *Reports Hydrology,* No. 20. SMHI, Norrköping, Sweden, 2006.

Jones C. G., Willén U., Ullerstig A. and Hansson, U. The Rossby Centre regional atmospheric climate model Part I: Model climatology and performance for the present climate over Europe. *Ambio,* 33, 4-5, pp. 199-210. 2004.

Kjellström E., Bärring L., Gollvik S., Hansson U., Jones C., Samuelsson P., Rummukainen M., Ullerstig A., Willén U. and Wyser K., 2005. A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). *Reports Meteorology and Climatology,* No.108. SMHI, Norrköping, Sweden, 54 pp. 2005.

Meier H. E. M. Baltic Sea climate in the late twenty-first century: a dynamical donwscaling approach using two global models and two emission scenarios. *Climate Dynamics,* 27, pp. 39-68, 2006.

Meier H. E. M., Kjellström E. and Graham L. P. Estimating uncertainties of projected Baltic Sea salinity in the late 21st century. *Geophys. Research Letters,* 33, pp. L15705, doi:10.1029/2006GL026488. 2006.

Roeckner, E., Brokopf R., Esch M., Giorgetta M., Hagemann S., Kornblueh L., Manzini E., Schlese U., and Schulzweida U. Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 atmosphere model, *Journal of Climate*, 19, 3771-3791, 2006.

Impact of Climate Change on the Baltic Sea Ecosystem

Kari Eilola and H. E. Markus Meier

Swedish Meteorological and Hydrological Institute, Norrköping, Sweden, e-mail: kari.eilola@smhi.se

1. Introduction

The impact from future climate changes on the physical conditions of the Baltic Sea and the dynamics of the deepwater inflows have been investigated in several studies (e.g. *Meier*, 2006; *Meier et al.*, 2006). Budget-models have been used to simulate also the post-industrial (1950-1988) nutrient conditions of the Baltic Sea (*Wulff and Stigebrandt*, 1989). 3-D ecosystem model simulations based on about 10-year response times have been used to investigate the ecosystem response to nutrient abatement strategies and to simulate the state of the Baltic Sea a century ago (*Neumann and Schernewski*, 2005; *Schernewski and Neumann*, 2005). However, so far the impact of climate changes on the biogeochemical cycling of nutrients in the Baltic Sea has not been investigated and the response of the marine ecosystem is unknown (BALTEX Assessment of Climate Change for the Baltic Sea Basin - BACC, http://www.gkss.de/baltex/BACC/).

In this study projections of the Baltic ecosystem for the end of the 21st century will be presented. For this purpose a high-resolution 3D coupled biogeochemical-physical ocean model has been developed to investigate the Baltic Sea response to climate variations and anthropogenic activities on time scales of 100 years (*Eilola and Meier*, 2006). The ecosystem model provides information about:

- nutrient cycling and biomass production,
- budgets, transports, sources and sinks,
- water quality and sedimentation of organic matter,
- temporal and spatial development of algae blooms,
- occurrence of harmful algae blooms.

2. Methods

The model system is based on the Swedish Coastal and Ocean Biogeochemical model (SCOBI) (*Marmefelt et. al.*, 1999; 2000; 2004; *Eilola et al.*, 2006; *Eilola and Sahlberg*, 2006) (Fig.1) and the Rossby Centre ice-ocean circulation model (RCO) (*Meier et al.*, 2003; *Meier and Kauker*, 2003).

For the period 1902-1998 we used reconstructed atmospheric forcing data (*Kauker and Meier*, 2003). Projections of the future marine ecosystem are performed based upon the assumption that future variability of the physical processes will not change. Global coupled Atmosphere-Ocean General Circulation Models (AOGCMs) are typically too coarse to resolve regional scales of interest for climate change impact studies. Therefore, a high resolution limited area model (RCAO) has been run with lateral boundary data taken from two GCM simulations, HadAM3H (Hadley Centre, U.K.) and ECHAM4/OPYC3 (Max Planck Institute for Meteorology, Germany). Six 30-year long time slices have been simulated at the Rossby Centre (Räisänen et al., 2004). Two control simulations represent the recent climate (1961-1990) and four scenario simulations represent the climate of the late 21st century (2071-2100). Thereby, two different emission scenarios of anthropogenic greenhouse gases are assumed (SRES A2, B2). To minimize model biases of the global and regional climate models, the so-called delta-change technique is applied, i.e. the 30-year monthly mean changes of the forcing functions for the Baltic Sea model will be calculated from the time slice experiments and added to the observed forcing of our reference period 1902-1998. Driven with this future forcing the coupled RCO-SCOBI model is integrated. The same dynamical downscaling approach as applied in this study has been used earlier to calculate physical variables like water temperature, sea ice, sea level, and salinity (*Meier*, 2006; *Meier et al.*, 2006). For the present climate climatological nutrient loads are used. We assume that in future climate the nutrient concentrations will be unchanged and estimate the riverborne nutrient fluxes using the changing flows calculated with a large-scale hydrological model for the entire Baltic catchment area (*Graham et al.*, 2006). The deposition of nitrogen from the atmosphere is assumed to be unchanged.

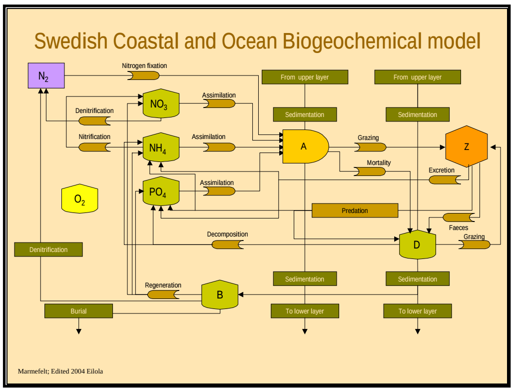


Figure 1. The SCOBI model contains nitrate (NO3), ammonium (NH4), phosphate (PO4), autotrophs (A1, A2, A3), zooplankton (ZOO), detritus (DET), and oxygen (O2). Hydrogen sulfate (H2S) is included as negative oxygen. The sediment (B) contains nutrients in the form of benthic nitrogen (NBT) and phosphorus (PBT). The sediment module includes sediment re-suspension and aggregated process descriptions for oxygen dependent nutrient regeneration, denitrification and adsorption of ammonium to sediment particles as well as permanent burial of organic matter.

3. Results

The scenario simulations suggest that global warming may cause:

- increased water temperatures of the Baltic Sea,
- reduced sea ice cover,
- increased winter mean wind speeds causing increased vertical mixing,
- increased river runoff causing reduced salinity (Fig.2).

These changes may have more or less pronounced effects on the functioning and the structure and productivity of the marine ecosystem and the water quality of the Baltic Sea since these are very much controlled by the physical processes and by the nutrient loads from land and atmosphere.

The model system is validated with special emphasis on temperature and salinity variations, cyanobacterial blooms, and effects from deepwater renewal on hydrogen sulfate and oxygen conditions. The results show that the model may capture the major characteristics of oxygen dynamics in the Baltic Sea (Fig.3) which is crucial for a good description of the nutrient dynamics.

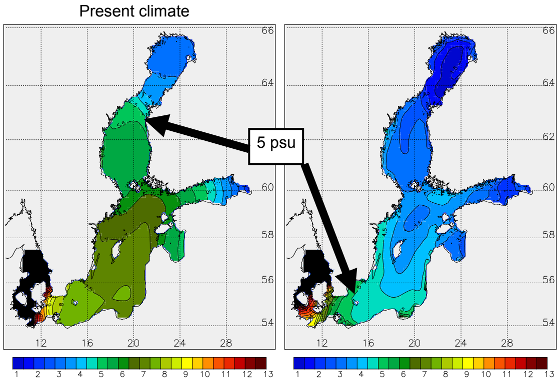


Figure 2. Sea surface salinity (in psu). (a) Climatological data by *Janssen et al.* (1999) and (b) projection with the largest salinity change in 2071-2100 (RCAO-ECHAM4/A2). In (b) projected changes were added to climatological data. Salinities larger than 13 psu are shown in black. The figure is adopted from *Meier et al.* (2006).

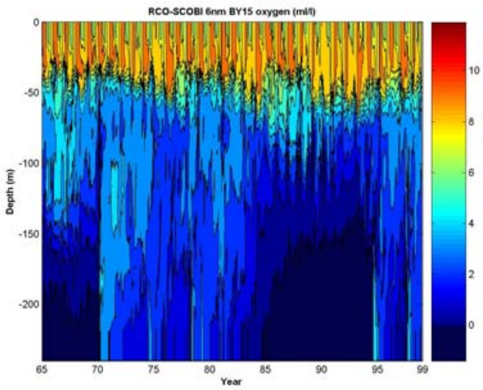


Figure 3. Oxygen (in ml/l) as function of depth and time at Gotland Deep during the last 39 years of the control run.

In this presentation we will discuss the impact of changing climate on the Baltic Sea ecosystem with focus on the nutrient and oxygen dynamics based upon our scenario simulations. The impact from climate change on the late-winter excess dissolved inorganic phosphorus in the surface layer and the inter-annual variability of cyanobacterial blooms will also be studied. Further, the impact on the variability of deepwater oxygen and phosphate concentrations and the sediment pools of the Baltic Sea will be discussed.

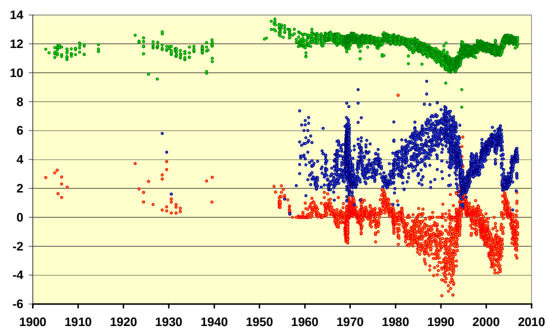


Figure 4. Gotland Deep data from 1903 to 2006 in the depth range 150m to 190m (SMHI SHARK data base). Green, blue and red dots indicate salinity (psu), phosphate (μmol/l) and oxygen (ml/l), respectively.

References

Eilola, K., and M. Meier, Implementation of a high-resolution 3D ecosystem model for local and regional climate studies in the Baltic Sea. BALTEX Newsletter No:9. GKSS, Geestacht, Germany, 2006.

Eilola, K., and J., Sahlberg, Model assessment of the predicted environmental consequences for OSPAR problem areas following nutrient reductions, SMHI Reports Oceanography No.83, 2006.

Eilola, K., Almroth, E., J. Naustvoll, P. Andersen and B. Karlson, Modelling the dynamics of harmful blooms of *Chattonella* sp. in the Skagerrak and the Kattegat, ICES CM 2006/E12, ICES Annual Science conference., 2006

Graham, L.P., S. Hagemann, S. Jaun, and M. Beniston, On interpreting hydrological change from regional climate models, *Climatic Change*, 2006, accepted.

Janssen F, Schrum C, Backhaus J, A climatological dataset of temperature and salinity for the North Sea and the Baltic Sea. *Deut Hydrogr Z Supplement* 9, pp 245, 1999

Kauker, F., and H.E.M Meier, 2003, Modelling decadal variability of the Baltic Sea: 1. Reconstructing atmospheric surface data for the period 1902-1998, *J. Geophys. Res*., 108(C8), 3267, 2003

Marmefelt, E., B. Arheimer, and J. Langner, An integrated biochemical model system for the Baltic Sea. Hydrobiologia, 393, 45-56, 1999

Marmefelt, E., B. Håkansson, A.C. Erichsen, and I. Sehested Hansen, Development of an ecological model system for the Kattegat and the southern Baltic. SMHI Reports Oceanography No.29, 2000

Marmefelt, E., H. Olsson, H. Lindow and J. Svensso, Integrerat kustzonssystem för Bohusläns skärgård, SMHI Reports Oceanography, No. 76, 81 pp, 2004

Meier, H.E.M., Baltic Sea climate in the late twenty-first century: a dynamical downscaling approach using two global models and two emission scenarios. Clim. Dyn., 27, 39-68, doi:10.1007/ s00382-006-0124-x., 2006

Meier, H.E.M., and F. Kauker, Modeling decadal variability of the Baltic Sea: 2. Role of freshwater inflow and large-scale atmospheric circulation for salinity. J. Geophys. Res., 108(C11), 3368, doi:10.1029/2003JC001799, 2003

Meier, H.E.M., Döscher, R. and Faxén, T., A multiprocessor coupled ice-ocean model for the Baltic Sea: Application to the salt inflow. J. Geophys. Res. 108(C8), 3273. 06-0124-x., 2003

Meier, H.E.M., E. Kjellström, and L.P. Graham, Estimating uncertainties of projected Baltic Sea salinity in the late 21st century, Geophys. Res. Lett., Vol. 33, No. 15, L15705, doi: 10.1029/2006GL026488, 2006

Neumann, T., and G. Schernewski, 2005, An ecological model evaluation of two nutrient abatement strategies for the Baltic Sea, *J. of Mar. Sys*., Vol. 56, 195-206, 2005

Räisänen, J., U. Hansson, A. Ullerstig, R. Döscher, L.P. Graham, C. Jones, H.E.M. Meier, P. Samuelsson, and U. Willén European climate in the late twenty-first century: regional simulations with two driving global models and two forcing scenarios, *Clim. Dyn*., 22, 13-31, 2004.

Schernewski, G., and T. Neumann, The trophic state of the Baltic Sea a century ago: a model simulation study, *J. of Mar. Sys*., Vol. 53, 109-124, 2005.

Wulff, F., A. Stigebrandt, A time-dependent budget model for nutrients in the Baltic Sea, *Global Biogeochem. Cycles*, Vol.3, No1, 63-78, 1989.

Methods for Assessing the Impact of Climate Change on Nutrient Flows from Catchments

Heikki Kaipainen, Ämer Bilaletdin, Tom Frisk and Arto Paananen

Pirkanmaa Regional Environment Centre, P.O.Box 297, FIN-33101 Tampere, Finland. heikki.kaipainen@ymparisto.fi.

1. Introduction

Climate change will have great impacts on meteorological and hydrological regime and so it will also affect nutrient flows from catchments. Quantitative assessment of this phenomenon has become possible when mathematical models have been developed for describing the different processes connected to climate change. However, relatively few research projects have produced this kind of estimations. One of them was presented by *Inkala et. al* (1997).

Pirkanmaa Regional Environment Centre participated in the NUTRIBA project within the Baltic Sea Research Programme of the Academy of Finland (BIREME 2003) in which estimations of the development of phosphorus and nitrogen flows through the River Kokemäenjoki to the Baltic Sea was estimated. The work has continued within the ASTRA project with special emphasis on climate change.

2. The modelling procedure

The modelling system consists of three parts. The runoff model used to simulate daily discharges from catchments was WSFS (*Vehviläinen* 1994) which was developed in the Finnish Environment Institute. Phosphorus transport from catchment is simulated using statistical CATCHLOAD model *(Bilaletdin et al*. 2005). Discharges and phosphorus loadings were used as input data to the river and lake models. To assess the concentration and transport and retention processes of phosphorus in the river and lake system, a one-dimensional advective-diffusive compartment model was constructed. The inlet and outlet of the each lake and river section compartments were linked advectively to other compartments.

The changes in meteorological parameters for climate change scenarios were taken from the Rossby Centre regional climate model RCAO run with global models HadAM3H and ECHAM4/OPYC3. Two emission scenarios used were A2 and B2 from the IPCC. (*Ruosteenoja* 2006) In other words, a total of four scenarios projected to the period 2071–2100 were calculated in addition to reference data set from the 30-year-period of 1961–1990 representing the present climate.

3. Description of the case study area of the river Kokemäenjoki

The study area, Kokemäenjoki river basin, is the fourth largest catchment in Finland with a total surface area of 27 000 km^2 and an average water discharge of 230 m^3 s^{-1} (Fig. 1). Nutrient loading was modelled in an area that covers 26% of the entire Kokemäenjoki river basin. This area was considered to have the major effect on nutrient loading into the estuary.

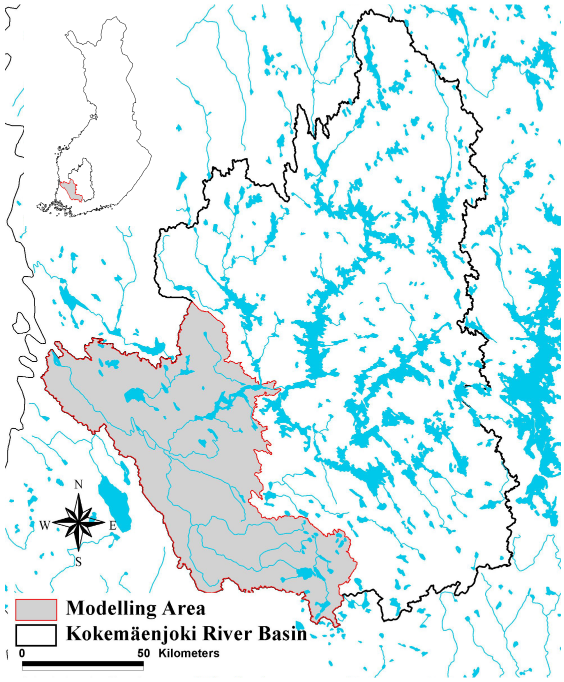


Figure 1. Modelling area and the boundary of Kokemäenjoki river basin.

4. Preliminary results

According to the scenario simulations, the seasonal dynamics of the phosphorus loading will change. In summer months (Jun-Oct) loading will slightly decrease and rest of the year loading would increase up to 100 % depending on the selected scenario (Fig. 2). Annual loading sums will increase regardless which model or emission scenario is used.

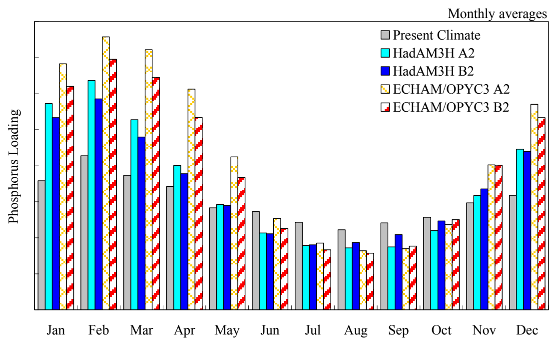


Figure 2. Monthly average phosphorus loadings from the 30-year period with different scenarios at the outlet of Kokemäenjoki river basin.

5. Conclusions

Quantitative assessment of the impact of climate change on nutrient flows requires modelling procedure. The effects can be increasing or decreasing depending on the situation and they are by no means self evident. The uncertainty of the predictions depends on the uncertainties in predicting the climate change itself. There is also uncertainty due to inaccuracy of the data used and the calculation algorithms of the different models. In the case study of the river Kokemäenjoki the effects seem to be the same magnitude and direction than in the previous studies e.g. The Finnish Research Programme on Climate Change (*Bilaletdin et. al*. 1996).

References

Bilaletdin, Ä., Frisk, T., Vehviläinen, B., Kallio, K., Huttunen, M. & Kaipainen, H. 1996. Model-ling the effects of climate change on nutrient transport from large drainage basins. In Roos, J. (Ed.): The Finnish Research Programme on Climate Change - Final Report. Publications of the Academy of Finland 4/96:173-178.

Bilaletdin, Ä., Frisk, T. and Kaipainen, H. 2005. A dynamic phosphorus transport model – CATCHLOAD: the case study of Lake Burtnieks, Latvia. In: River Basin Management III. Brebbia, C.A. and Antunes do Cormo, J.S. (eds.) WIT Press, Southampton, pp. 359-368.

BIREME 2003. Baltic Sea Research Programme. The Academy of Finland, Newsletter 1/2003, 12 pp.

Inkala, A., Bilaletdin, Ä & Podsetchine, V. 1997. Modelling the effect of climate change on nutrient loading, temperature regime and algal biomass in the Gulf of Finland. Boreal Environment Re-search, Vo. 2, No. 3, pp. 287 – 301.

Ruosteenoja, K., Jylhä, K. and Tuomenvirta, H. 2005. Climate scenarios for FINADAPT studies of climate change adaptation. FINADAPT Working Paper 15, Finnish Environment Institute Mimeographs 345, Helsinki, 32 pp.

Vehviläinen, B. 1994. The watershed simulation and forecasting system in the National Board of Waters and Environment. Publications of the Water and Environment Research Institute. National Board of Waters and Environment. No. 17.

Perpetrator, Victim and Free-Rider – the Ambivalent Role of Tourism and Recreation for the Climate Change

Ralf Scheibe

University of Greifswald, Institute of Geography and Geology, Makarenkostraße 22, D – 17487 Greifswald, ralf.scheibe@uni-greifswald.de

1. Tourism and its role for climate change

Whenever there is spoken about climate change in the Baltic Sea Region the discussion is focused on the sciences mostly. The reasons and causers of the calamity are to be pointed out quickly: the emission of greenhouse gases by industry and traffic. Both sources are bound to reduce the CO_2-emission – often with doubtful success. On the other hand the role of the victim is occupied by the agriculture regularly: We all know the pictures of the withered farmland or grape-vines destroyed by hail. However, one of the most important economic sectors is forgotten systematically: the tourism. For the following paragraphs it shall include recreation in general, too. Tourism and recreation are signed by a very ambivalent role in the game of climate change: They are perpetrators, victims and free-riders at the same time.

2. Recreation causes climate change

Of course tourism and recreation appear as perpetrators: They induce (needless) traffic and require additional electric power and fresh water supply normally. For all that tourism grows continuously: The latest annual report of the World's Tourism Organization WTO shows that the number of tourists has increased about 4.5 per cent in 2006 compared to 2005. The popularity of exotic destinations like Australia, Oceania and Africa rises even more rapidly – these destinations can be reached only by plane with an exorbitant output of greenhouse gas. The trend up to a second or even a third holiday trip every year is evident in the industrialized countries. The low cost airlines make it easy more and more.

Although the awareness of health grows; the demand after nature-orientated forms of recreation like water sports, hiking, climbing and cycling grows continuously. But the suitable destinations like lakes, glaciers and woods are away from urban agglomerations regularly - indoor facilities are even rare. Most of the places of excursions are to be visited individually by car systematically. And there is a second reason therefore: Recreation needs special equipment more and more; a surfboard or diving gear can be transported by public passenger traffic hardly. Most of the trendy nature sports like scuba diving, windsurfing and skiing induce more individual traffic than other purposes of the being all together.

3. Disadvantages of the climate change for tourism and recreation

But tourism is a victim of the climate change, too. Touristy infrastructure like camping grounds and yacht harbors has been directly destroyed by hurricanes and tornados year after year. We all know it from TV pictures from the Caribbean and Northern America, but the last years show the reality of those occurrences here in Middle Europe, too. It is no secret that the number of extreme occurrences like heavy thunderstorms has increased during the last decade.

The indirect influence of the climate change on tourism is even more manifold. Normally non domestic species e.g. *Teredo navalis* endanger infrastructure like coastal protection groins and wooden piles in yacht harbors. The naval heritage under water – beloved destinations for wreck divers and marine archaeologists – is threatened, too. Other "alien" species like dangerous jellyfishes make beaches and shallow water areas unusable. The rising sea level threatens touristy destinations partially or at all. The costs to strengthen the infrastructure of tourism and coastal protection increase rapidly and have to be seen together with the growing importance of the Baltic Sea as a touristy destination e.g. with more than 300,000 yacht moorings with an increasing degree of comfort (and susceptibility).

The consequences of the climate change do not apply only the summer holiday infrastructure. We all know that the classic Scandinavian winter sport destinations seem to become unattractive due to lost of snow and the heavy rainfalls in winter times. Snow guns could equalize the lost of snow, but they need – what a vicious circle - additional electric power and water supply.

4. The benefits for tourism and recreation

But there is hope of the benefits going on with climate change in the Baltic Sea Region, too. Tourism and recreation could profit from climate change at the expense of other classic touristy destinations: While the Mediterranean and Caribbean become more and more unattractive by hot and dry touristy peak seasons, the short summer of the countries around the Baltic Sea will be extended up to six or eight months. It means an extended income of two or three months for the touristy suppliers! One of the main problems – the short touristy season without a second of the winter sports – could be solved of its own volition. The attractiveness for wellness and health spas could increase due to the healthy climate. The increasing number of persons of higher age would demand such offers.

Especially water sports could benefit from the warmer and dryer summers: Due to the poor ice coverage leisure boots can stay in water the whole year and have to be only slipped to renew the bottom painting. Kite-surfers enjoy the waves of the probable summer storms. Hobby fishers and scuba divers are enthusiastic about the new variety of fish species.

5. The need of interdisciplinary work

Fortunately, the BALTEX community can supply strong and resistance facts and scenarios of the climate change for the next 100 years. But climate change overlays with other effects e.g. of the socio-economic change: the excess of age, the ongoing transformation process of the economies of former socialist countries in Eastern Europe and others. Engineers, planners, tourism managers and last but not least insurance agencies need a lot of all-embracing information - BALTEX has the overview and the details about the natural background – an extension to the applied sciences would be desirable.

Adaptation to Climate Change in Water Management – Baltic Sea Basin

Zbigniew W. Kundzewicz

Research Centre for Agricultural and Forest Environment, Polish Academy of Sciences, Bukowska 19, 60-809 Poznań, Poland, zkundze@man.poznan.pl
Potsdam Institute for Climate Impact Research, Telegrafenberg, D-14412 Potsdam, Germany, zbyszek@pik-potsdam.de

1. Introduction

In the global system, everything is connected to everything else. The climate and freshwater systems are interwoven in a complex way, so that any change in one of these systems induces a change in the other.
Hydrological variables of primary importance in water management, such as river discharges, water levels in rivers, lakes, and ground; and soil moisture are controlled by the climate-driven precipitation, evaporation (dependent on climate-driven temperature, radiation, humidity, and wind speed), snowmelt and glacier melt.

2. Climate change impacts on water resources

There has been an increasing body of evidence of the ongoing global warming. A discernible warming has been observed and the future warming is likely to be considerably faster, depending on scenarios of the socio-economic development and on the mitigation policy (curbing the greenhouse gas emissions).
Long-term trends in precipitation have also been observed in many regions. Projected precipitation changes differ regionally, yet are model- and scenario-specific and loaded with high uncertainty. Mean annual precipitation is likely to increase in the North, including much of the Baltic Sea Basin. However, intensity of rainfall events is projected to increase even in regions where the mean annual precipitation is likely to decrease.
Ongoing climatic and non-climatic changes have already influenced water resources in a discernible way and even stronger changes are projected for the future. Warming leads to changes in seasonality of river discharge in catchments where much winter precipitation falls as snow; winter flows increase, with peaks coming earlier, and summer flows decrease. Ongoing reduction of European glaciers will gradually lead to decrease of glacier contribution to river discharge. Decreasing groundwater recharge is projected over many areas.
The negative impacts of climate change on freshwater systems are likely to outweigh its benefits. Where runoff is projected to decline, the value of the services provided by water resources will be reduced. The beneficial impacts of increased annual runoff in other areas may be tempered by negative effects of increased precipitation variability, cf. *Kundzewicz & Mata* (2007).
Despite the progress in evaluating uncertainties (e.g., in ensembles-based studies), quantitative projections of changes in precipitation, river flows and water levels remain largely uncertain, with main sources of uncertainty being: scenarios, climate models, downscaling, hydrological models, available data.

3. Adaptation: notions and concepts in water management perspective

One can interpret adaptation as adjustment in natural or human systems in response to actual or expected changes, which moderates harm or exploits beneficial opportunities. Taxonomy of adaptation distinguishes several concepts of classification, such as: anticipatory (proactive; adaptation to ongoing changes) or reactive (to projected changes); autonomous (spontaneous) or planned; private or public, etc.
In general, Europe has a high adaptation potential in socio-economic terms due to strong economic conditions, high GDP, stable, well-trained population with capacity to migrate within the super-national organism of the EU, and well developed political, institutional, and technological support systems. However, adaptation is generally low for natural systems. Also, equity issues come about, since more marginal and less wealthy areas (and groups of people within an area – less wealthy, with less advantageous housing quality and location, level of education, mobility etc.).) are less able to adapt. Enhancing adaptive capacity i.e. increasing system's coping capacity and coping range is needed (cf. *Kundzewicz*, 2007).
Adaptation policy stakeholders are manifold, from central via regional to local authorities, individuals and communities affected or threatened, planning bodies, NGOs, researchers and the media. Central governments may create enhancing environment. Mainstreaming should be sought, based on integration of adaptation strategies, becoming part of national or regional development policies.
The water resources are distributed unevenly in space and time and people try to adapt to this unevenness and to smooth the spatial-temporal variability. Regulating flow in time to suit human needs can be achieved by storage reservoirs (capturing water when abundant and using it when it is scarce), while regulating flow in space can be achieved via water transfer.
There are several adaptation strategies in the area of coping with floods: protect, accommodate, or retreat (relocate). Strategies for flood protection and management may modify either flood waters, or susceptibility to flood damage and impact of flooding.
There exist limits to adaptation, therein physical limits (e.g. when rivers dry up completely, becoming ephemeral); economic limits (affordability; cost–benefit and cost–efficiency thresholds); socio-political limits (e.g., constructing water storage reservoirs may not be acceptable due to the detrimental effects to the environment and the need for resettlement); or institutional limits (e.g. inadequate capacity), cf. *Arnell & Delaney* (2007). Barriers to adaptation to floods via relocation can be external, e. g. lack of land for relocation, or internal, such as unwillingness of people to relocate.

4. Adaptation to climate change in water management

Adaptation to changing conditions has always been the core of water management. In the past, water management focused on meeting increasing demand. Climate changes cause changes in both water supply and demand and challenge the existing water management practices by adding uncertainties and posing novel risks often outside the range of experience.

Both mitigation of (causes of) climate change and adaptation to (effects of) climate change are needed to avert or reduce adverse impacts. Adaptation strategies can reduce vulnerability to changes in climate at the local and regional level. Mitigation acts on a global level over larger time scales due to the inertia of the climate system, slowing the rate of climate change and thus delaying the date and magnitude of impacts. Most of the benefits of mitigation will not be realized until decades later, thus adaptation is needed to address near-future impacts. However, without mitigation, the increasing magnitude of climate change would significantly diminish the effectiveness of adaptation.

Mitigation of climate change and adaptation to climate change and its impacts are sometimes in conflict. For instance, afforestation serves mitigation (carbon sequestration) but may play an adverse role in adaptation (transpiration of large amounts of increasingly precious water). Enhancing water storage in reservoirs brings co-benefits, being advantageous for both mitigation (hydropower without fossil fuel burning) and adaptation (weakening hydrological extremes – floods and droughts). Yet, construction of large reservoirs is not acceptable now in many countries, e.g. due to environmental and social concerns.

There exist a roster of adaptation options addressing water-related problems exacerbated by climate change, and in particular the increasing variability of water resources, i. e. increase frequency of occurrence of the state of having too little water and having too much water. (*Kundzewicz & Jania*, 2007).

Adaptation options for having too little water (water stress or drought) address water supply side by: conjunctive use of surface water and groundwater; increased water storage capacity; or address the water demand by: improving efficiency of water use (e.g., „more crop per drop") in irrigation; recycling water; water demand management through metering; promoting water saving technologies; leak reduction; market-based instruments, e.g. water pricing; re-allocation of water to high-value uses; awareness raising.

Adaptation for the having too much water addresses options aimed at reduction of the load: enhanced implementation of structural/technical protection measures, such as dikes, relief channels, enhanced water storage; watershed management ("to keep water where it falls" and reduce surface runoff and erosion), or increase of resistance: flood forecasting and warning; regulation through planning legislation and zoning; flood insurance; relocation of population living in flood-risk areas; flood proofing on location; flood plain protection measures.

The EU Floods Directive (*Commission of European Communities*, 2006) deals with a roster of adaptive measures, such as preliminary flood risk assessment ("taking into account long-term development including climate change"), and development of flood risk maps and flood management plans. In some countries, such as the Netherlands, Germany, and the UK, flood design values have been increased, based on early climate change impact scenarios.

Early adaptation is effective for avoiding damage, provided that projections of future climate change are sufficiently accurate. Delayed adaptation may lead to greater subsequent costs. However, due to climate change uncertainty, water managers do not have confidence in single projections of the future. The large range for different climate model-based scenarios suggests that adaptive planning should be based on ensembles (cf. ENSEMBLES Project web page). It is difficult to evaluate the credibility of individual scenarios.

Current water management practices are very likely to be inadequate to reduce negative impacts of climate change on water supply reliability, flood risk, health, energy and aquatic ecosystems. Adaptations consistent with sustainable development protect against both climate variability now and future climate change. This refers in particular to „no-regret" strategies – doing things that make sense anyway. It is always good to save energy and water. Improved incorporation of current climate variability into water-related management would render societies better prepared to future climate change.

References

Arnell, N.W. & Delaney, E.K., Adapting to climate change: public water supply in England and Wales. *Climatic Change* , 2007 (in press).

Commission of European Communities, Proposal for a Directive of the European Parliament and of the Council on the Assessment and Management of Floods {SEC(2006) 66}, 2006. http://www.ensembles-eu.org/

Kundzewicz, Z.W. Climate change impacts on water management and adaptation needs in Europe. In: *Climate Change Impacts on the Water Cycle, Resources and Quality – Research-Policy Interface*, Publication of Commission of European Communities, 2007 (*in press*).

Kundzewicz, Z.W. & Jania, J. (2007) Extreme hydro-meteorological events and their impacts. From global towards regional scale. *Geographia Polonica*, 2007 (in press).

Kundzewicz, Z.W. & Mata, L.J. (co-ordinating lead authors) Freshwater resources and their management. Chapter 3 in: Parry, M. L., Canziani, O.F. (eds) *Climate Change 2007. Impacts, Adaptation, and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2007 (in press).

The Application of the Conceptual Model Metq2006 for the River Iecava Basin as Case Study in Latvia

Ansis Ziverts[1], Anda Bakute[2] and Elga Apsite[3]

[1]Faculty of Rural Engeneering, Latvian University of Agricultural, Akademijas street 19, Jelgava LV-3001, e-mail: aziverts@apollo.lv
[2] Obervational Network Department, Latvian Environment, geology and meteorology agency, Maskavas street 165, Riga LV-1019, E-mail:anda.bakute@lvgma.gov.lv
[3]Faculty of Geographical and Earth Sciences, University of Latvia, Raina bulv. 19, Riga LV-1586, Latvia E-mail: elga.apsite@lu.lv

1. Abstract

The objective of the Latvia's hydrological network is to obtain information of the hydrological regime in all river basins. During last fifteen years some of hydrological observational stations are closed, including hydrological station Iecava – Dupši in this case study. The conceptual hydrological model METQ2006 is applied for the simulation of the daily runoff and evaporation for the River Iecava. Good coincidence between the measured and simulated daily discharges has been obtained. The efficiency criterion R^2 is 0.6 and the correlation coefficient r is 0.7 for the River Iecava at the hydrological station Dupši.

2. Introduction

The objective of the Latvia's hydrological network is to obtain information of the hydrological regime in each part of river basins. However, not always all parameters of hydrological regime or river basins have been observed. One of the explanations is that hydrological monitoring is rather expensive and there are financial problems during last fifteen years. Therefore, mathematical model as one of more accepted tools in hydrology could be use (Bergström 1991; Bergström 1992; Brandt and Arheimer 1998; Podstchine et al. 1999; Ziverts and Jauja 1999). In this paper is presented modelling results for the Iecava River basin at the hydrological station Dupši which is closed since 1995. The total basin of the river Iecava is 1166 km2. The model METQ2006 is applied for the upstream drainage area 519 km2. The average amount of precipitation ranges from 650 to 750 mm per year.

3. Materials and methods

In present study the model METQ2006 is basically applied for the simulation of the daily runoff and evaporation for the River Iecava at the Dupši gauging station. Input data for the model are daily mean values of air temperature, precipitation and vapour pressure deficit. The model can be classified as conceptual model and has 22 parameters. However, most of the parameters are physically based and the rest of parameters could be estimated by the calibration. The hydrological model METQ is successfully applied to a relatively large river and lake basin in Latvia as the Daugava River and the Burtnieks Lake (Ziverts and Jauja 1999; Bilaletdin et al. 2004).

To consider the runoff heterogeneity in runoff processes the studied catchment area of the River Iecava are divided in hydrological response units (HRU) characterised by a relative homogeneity with respect to the most important parameters, which include slope, vegetation and soil characteristics. Catchment area is divided in 6 HRUs: agricultural lowlands, hilly agricultural lands, forests, swamps, sands and lakes.

The water balance and runoff of each HRU has been simulated in three storages: snow (water content in snow cover), soil moisture (water in the root zone) and groundwater. The total runoff from each of HRU consists of three runoff components: Q_1 - surface runoff, Q_2 - subsurface runoff (runoff from the groundwater upper zone) and Q_3 - base flow (runoff from the groundwater lower zone). The snow accumulation and melting routine in the model is similar to the one used in the HBV model (Bergström 1992). The runoff routing of river channel has been simulated by modified method of the unit hydrograph (a sum of the runoff components $Q=Q_1+Q_2+Q_3$ has been calculated for one day intervals in the gauging station.

4. Results and discations

The observed meteorological data at station Bauska, Rīga and Skrīveri for the simulation of the daily runoff in the mathematical modelling of River Iecava have been used. Calibration period of the model is used from 1956 to 1994. Good coincidence between the measured and simulated daily discharges has been obtained. To analyses the results a statistical criterion R^2 (Nash and Sutcliffe 1970) and a correlation coefficient r are used. The efficiency criterion R^2 is 0.6 and the correlation coefficient r is 0.7 for the River Iecava at the hydrological station Dupši.

The main source of difference between the simulated and observed runoff values is the quality of precipitation input data, as well as the location of the available meteorological stations to characterise the spatial and temporal distribution of precipitation in the drainage basin upstream of the River Iecava. Also is very important to point out that investigated catchment is located on the sands and forested areas.

References

Bergstroms, S. 1992. The HBV Model – its structure and applications. SMHI reports Hydrology, No 4.

Bergstroms, S. 1991. Principles and confedence in hydrological modelling. Nordic reports Hydrology 22, 123-136.

Brandt, M. and B. Arheimer. 1998. "Nitrogen Transport to the Sea from Southern Sweden – Catchment Modelling, Retention and Source Apportionment." In Proceedings of the XX Nordic Hydrological Conference (Helsinki, Finland, Aug.10-13, 1998) Kajander J., 13-20.

Podsetchine, V.; T. Huttula; and H. Savijärvi. 1999. "A Three Dimentional-Circulation Model of Lake Tanganyika." Hydrobiologia, No.407, 25-35.

Krams, M., Ziverts A. 1993. Quantitative solutions in hydrogeology and groundwater modeling. CRC Press, 461 pp.

Ziverts,A., Jauja, I. 1999. Mathematical Model of Hydrological process METQ98 and its Application. Nordic Hydrology 30 (2), 109-128

Ziverts, A., Apsite, E. 2001. Watershead modelling of the lake Burtnieks in the present conditions. Nordic Hydrology 24, 309-322.

Water Levels and Flow in the River Systems of Lake Vänern and Lake Mälaren.

S-S. Hellström[1], S. Bergström[1] and J. Andréasson[1]

[1]Research and Development, Swedish Meteorological and Hydrological Institute (sara-sofia.hellstrom@smhi.se)

1. Introduction

Due to hurricanes, increasing sea levels, melting of glaciers and flooding with its consequences, the climate issue is, in Sweden, a topic of great interest.

The study presented here is a hydrological background material concerning flood risks in the river systems of Lake Vänern and Lake Mälaren (*Bergström et al., 2006*) that has been elaborated by SMHI on behalf of the Swedish Commission on Climate and Vulnerability.

The report presents the hydrological conditions and more in depth studies for Lake Vänern, River Göta älv, Lake Mälaren and Lake Hjälmaren both as concerns problems related to today's climate and impacts of climate change. In particular changing flood risks over time have been studied due to river regulation as well as impacts of global warming on these risks.

Figure 1. The two large lakes, Lake Vänern and Lake Mälaren, included in the study.

2. Climate scenarios

Data from the Rossby Centre Regional Atmosphere-Ocean (RCAO) model (*Dösher et al., 2002*) driven by two global models, HadAM3H (*Gordon et al., 2000*) from Hadley Centre and ECHAM4/OPYC3 (*Roeckner et al., 1999*) from the Max-Planck Institute have been used. Assumptions of future green house gas emissions were based on the SRES A2 and B2 scenarios (*Nakićenović, et al., 2000*). In total four scenarios have been used, RCAO-H/A2, RCAO-H/B2, RCAO-E/A2, RCAO-E/B2. The scenarios correspond to the time period 2071-2100 and the reference period (control) to 1961-1990.

The hydrological consequences were computed using the hydrological HBV model (*Lindström et al., 1997*). To transfer the climate model output to the hydrological model the so-called delta change method was used (*c.f. Andréasson et al., 2004*). In principal the method take the change between the control run and the scenario of the climate models and transfer it onto an observed climate database which was used for off-line impact simulations.

3. Lake Vänern

Lake Vänern, which is Sweden's largest lake and Europe's third largest lake, is situated in southwest of Sweden with a catchment area of 46 880 km^2 (including the lake) (Figure 1).

The regulation of Lake Vänern started in 1937. With the regulation the high water levels decreased and the fluctuations in the discharge increased due to the water power production (Figure 2).

Lake Vänern, through its size, is more sensitive to prolonged rainfalls than to short-term extreme precipitation or to the spring snowmelt.

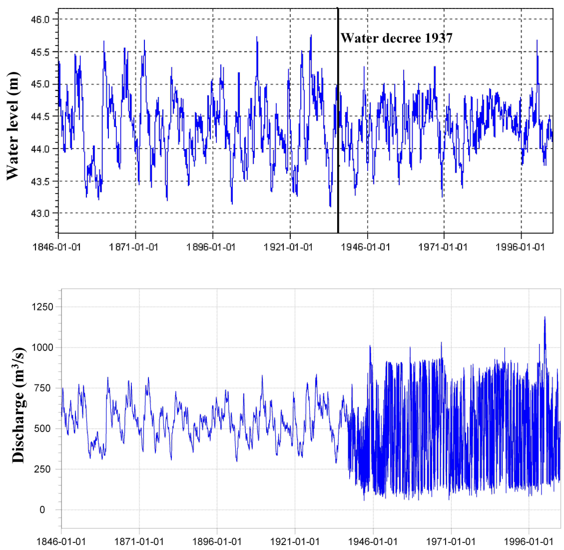


Figure 2. At the top: observed water levels (meters) for Lake Vänern during 1846-2005. At the bottom: Discharge (m^3/s) at the outlet of Lake Vänern.

4. Lake Mälaren

Lake Mälaren is Sweden's third largest lake. Including the lakes the catchment area is 22 650 km^2.

The system started to be regulated in 1943 with new regulation conditions in 1968 (*Ehlert, 1970*). The effect from the regulation on both the water levels and the discharge is obvious (Figure 3).

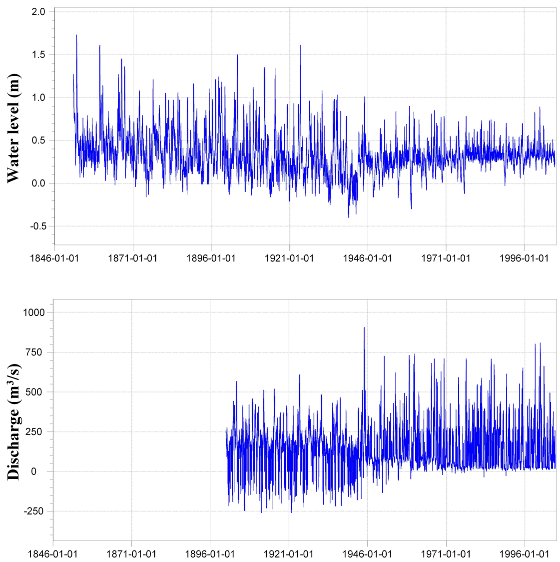


Figure 3. At the top: observed water levels (meter) (datum *RH00*) for Lake Mälaren during 1852 - 2005. At the bottom: Discharge (m^3/s) at the outlet of Lake Mälaren.

5. Results

According to the used scenarios the inflow to Lake Vänern (Figure 4) increased during the winter season with more instable winters. And the summer discharge decreased compared to the today's discharge. The change in the yearly volume varies between +1% and +22%.

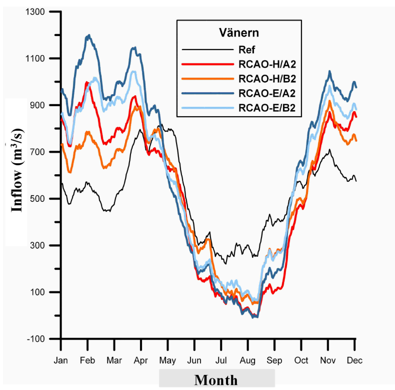


Figure 4. The average change in inflow to Lake Vänern according to four climate scenarios.

As for Lake Mälaren a changing climate gives more unstable winters with increasing runoffs. The summer runoffs decreased (Figure 5). The change in the yearly volume varies between -5% and +16%.

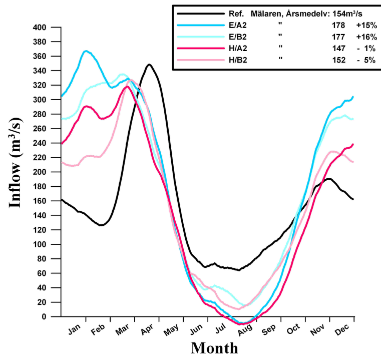


Figure 5. The average change in inflow to Lake Mälaren according to four climate scenarios.

6. Concluding remarks

The results show that there are great problems related to high water levels and high flows around Lake Vänern, Lake Mälaren, Lake Hjälmaren and along River Göta älv already under present climate conditions. Concerning the future climate, as it is pictured by existing climate scenarios, the problems seem to be aggravated around Lake Vänern and along River Göta älv. The problems related to the most extreme levels around Lake Mälaren and Lake Hjälmaren do not seem to change a lot, but high floods of somewhat lower return periods may become more frequent. It is shown that the problems related to Lake Vänern and River Göta älv can be alleviated by use of a new strategy for release of water, still within the framework of the existing decree by the water court.

References

Andréasson, J., et al., Hydrological Change – Climate Change Impact Simulations for Sweden, *Ambio*, 34, 4-5, pp. 228-234, 2004.

Bergström S., et al., Water levels and flow in the river systems of Lake Vänern and Lake Mälaren – Background material for the Swedish Commission on Climate and Vulnerability (in Swedish), *SMHI Reports Hydrology*, 20, 53pp, 2006.

Döscher, R., et al., The development of the regional coupled ocean-atmosphere model RCAO, *Boreal Environ. Res.*, 7, pp. 183-192, 2002.

Ehlert, K., Mälarens hydrologi och inverkan på denna av alternativa vattenavledningar från Mälaren, *SMHI Serie hydrologi*, 8, 1970.

Gordon, C., et al., The simulation of SST, sea ice extents and ocean heat transport in a version of the Hadley Centre coupled model without flux adjustments, *Clim.Dyn*, 16, pp.147-168, 2000.

Lindström G, et al., Development and test of the distributed HBV-96 model, J. Hydrology, 201, pp. 272-288, 1997.

Nakićenović, N., et al., IPCC Special Report on Emission Scenarios. *Cambridge Univ. Press,* 599 pp, 2000.

Roeckner E, et al., Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle, J. Climate, 12, 3004-3032, 1999.

Performance of the Operational HIROMB Model in Relation to the Oceanographic Extreme Events and Seasonal Fluxes in the Gulfs of Finland and Riga

Jüri Elken, Tarmo Kõuts, Urmas Lips, Urmas Raudsepp, Priidik Lagemaa and Taavi Liblik

Marine Systems Institute at Tallinn University of Technology, Akadeemia 21, 12618 Tallinn, elken@phys.sea.ee

1. Introduction

Results from the operational weather forecast models are used by a large scientific community to study the atmospheric processes and fluxes up to the decadal scales. Operational oceanographic forecast models, belonging to the HIROMB (High Resolution Operational Model for the Baltic Sea) consortium, have been running for the Baltic Sea since 1990s with primary purpose of giving short-term (48h) predictions of sea conditions in order to handle oil spills, storm surges, support navigation etc. The core of the model system is a 3D baroclinic circulation model that calculates also currents, temperature, salinity and turbulence in the water column. In recent years the interest to use the operational ocean models for wider purposes has grown significantly. Meeting those needs, GMES is planning to make the operational model products available to the wide range of scientific and industrial users by including them into the Marine Core Services.

Estonia has joined the HIROMB cooperation in 2005, after the hurricane-scale storm Gudrun caused extensive floods in the coastal towns of Pärnu and Haapsalu in 9 January. We present the analysis of HIROMB results in relation to the oceanographic extreme events and seasonal fluxes in Estonian sea areas.

2. Using the HIROMB model

The latest HIROMB version 3.0 is in a daily operational use at SMHI since 15.11.2005. As earlier, the model domain covers the whole Baltic Sea area with grid steps 1' by latitude and 5/3' by longitude. The model has 16 vertical layers, with 4 m thickness in the upper 12 m and increasing values towards the greater depths. The new version (*Jönsson,* 2004) has the κ-ω turbulence scheme (*Umlauf et al.,* 2003).

The distributed model output contains 48h forecasts (1h interval, recalculated each day) of sea level, ice characteristics (altogether 8 fields), and 3D fields - current components, temperature, salinity and eddy diffusivity. Wind components and cloudiness are also included. The model data are daily retrieved by the Marine Systems Institute and used for the operational forecasts, HIROMB model validation/development and research.

3. On-line coastal stations

Coastal observation network, run by the Marine Systems Institute, consists from 6 on-line (data delivery time 15 min) stations – Tallinn, Sillamäe, Paldiski (Gulf of Finland), Sõru, Lehtma (Hiiumaa/Dagö island, Northern Baltic) and Pärnu (Gulf of Riga). Observed parameters are sea level and water temperature.

4. Repeated hydrographic transects

A 4-year programme of weekly repeated high-reolution (distance between the stations 2.6 km) oceanographic transects between Tallinn and Helsinki (Gulf of Finland) started in summer 2006. The aim is to study the impact of subsurface mesoscale processes on the nutrient and plankton conditions in the upper layers and to explain the variability observed by the Al@aline system onboard the ferry. In 2006 CTD and fluorescence profiles were recorded at 27 stations during each of the 7 transects in July and August.

5. Extreme sea levels

Following the extreme storm surge in Pärnu, 9 January 2005 (highest recorded sea level +275 cm, critical "water on the streets" level +160 cm), the issue of reliable sea level forecasts got much attention. Analysis of forecast data showed a slowly varying "zero drift" relative to observations (range 30-60 cm) that is nearly coherent in all the Estonia stations. Regarding the sources of variable bias, *Grode* (2004) has evaluated that the specific flow resistance in the Danish Straits is about 2 times too high in 3-mile version and 6 times too high in 1-mile version of HIROMB. This results in the errors in filling and withdrawal of the Baltic Sea water volume. However, more research is needed on this issue and further analysis will be given in the presentation.

In the practical forecasts the model output is corrected by the 7-day lagged difference from the observations (*Elken et al.,* 2006). Stormy autumn-winter of 2006/2007 resulted in a significant number of events of sea level rise close to or slightly above the critical levels, both in Pärnu (Fig. 1) and in Tallinn. The forecasts given were adequate. Numerical ocean modelling became an issue of nation-wide importance.

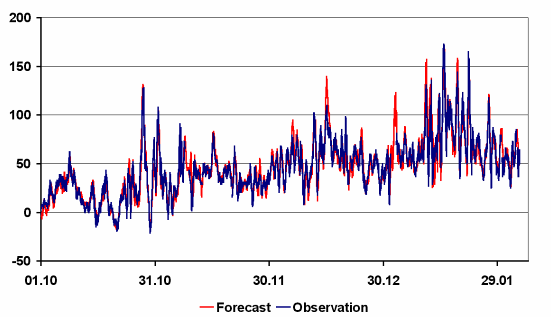


Figure 1. Observed and 24h forecasted sea levels (cm) in Pärnu during the stormy period from 01.10.2006 to 03.02.2007.

6. Upwelling structure in summer 2006

A long period of dominating easterly winds in August 2006 caused an upwelling of unusual intensity and duration near the Estonian coast of the Gulf of Finland. By the repeated hydrographic transects, very low temperature values (down to 5 °C) were recorded in the whole Tallinn Bay and the cold surface water covered more than 1/3 of the cross-section Tallinn-Helsinki. The upwelling was recorded by the continuous time series at coastal stations as well. Although the 1-mile resolution of HIROMB is too coarse to resolve the upwelling filaments (Zhurbas et al., 2006), the main upwelling features consistent with the satellite observations were well reproduced by HIROMB (Fig. 2). Baroclinic sub-surface structure of the upwelling event and associated fluxes will be analyzed jointly by the data from the model and the hydrographic transects.

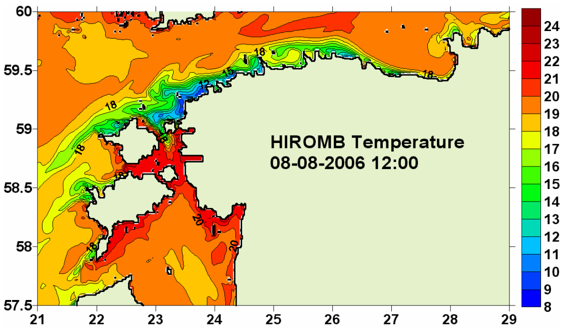


Figure 2. Sea surface temperature in Estonian coastal waters during the easterly winds in August 2006.

7. Seasonal model response in 2006

An example of seasonal response of the HIROMB model is shown in the Gulf of Finland (Fig. 3) in terms of mean water level and salinity.

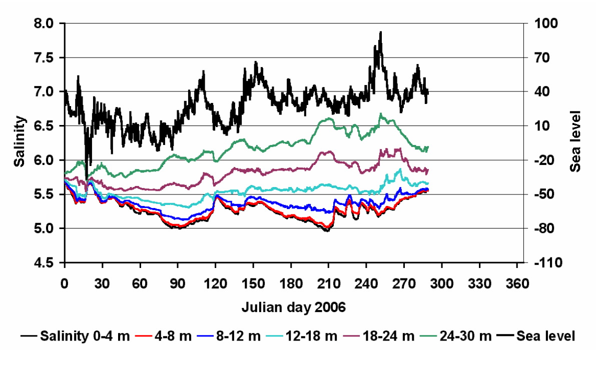


Figure 3. Mean salinity of the HIROMB layers and mean sea level in the western-central Gulf of Finland Sea from 21 E to 29 E during 2006.

The normal course of saline layering, derived from the hydrographic observations (*Haapala and Alenius, 1994*) – stronger stratification in summer and weaker in winter – is well evident in the HIROMB results. Also several deviations from the mean cycle and their causes can be identified. Namely, in Julian days 18-21, easterly winds with a mean speed of 10-15 m/s caused a significant lowering of the sea level. A few days before and after this event, winds of variable direction were strong enough to conduct effective mixing of the upper 30-m water column. Ice cover melted around day 120 that caused convection of surface heating at temperatures below the temperature of maximum density. Further in time, the upwelling near the Estonian coast in days 210-240 was accompanied by the decrease in stratification. The details of salt and heat flux estimates (*eg.* differences along the northern and southern coasts) will be given in the presentation. Comparative analysis will be made also for the Gulf of Riga.

8. Discussion

The 3D models have been successful in storm surge predictions and they are increasingly taking over this role from the 2D shallow water models. Regarding the stratification, the Baltic Sea models are „tuned" to perform well in the southern Baltic Sea and in the Baltic Proper. Still, the thermohaline stratification usually becomes weaker than observed. This mismatch of advective-diffusive balance has opposite sign in the Gulf of Finland (and to some extent in the Gulf of Riga), where numerical models usually give stronger thermohaline contrasts than observed, either vertically, or horizontally over the Gulf. Operational models like HIROMB may significantly contribute to the better understanding and quantification of processes that form the Baltic Sea water cycle.

References

Elken, J., Kõuts, T., Raudsepp, U., Laanemets, J. and P. Lagemaa, BOOS/HIROMB-Based Marine Forecasts in Estonia: Problems, Experiences and Challenges, In: Proceedings of the US/EU Baltic International Symposium "Integrated Ocean Observation Systems for Managing Global & Regional Ecosystems Using Marine Research, Monitoring & Technologies", Klaipeda, May 23-25, 2006, 22p (CD), 2006.

Grode, P., Validation of Sea Levels and Flow through the Danish Straits in HIROMB and GETM in 2002, 7th HIROMB-Scientific Workshop, December 7-9, 2004 in Helsinki, http://www.environment.fi/download.asp?contentid=28917&lan=en, 2004.

Haapala, J., and P. Alenius, Temperature and salinity statistics for the Northern Baltic Sea 1961-1990, Finnish Mar. Res., 262, 51-121, 1994.

Jönsson, A., Status of operational HIROMB, 7th HIROMB-Scientific Workshop, December 7-9, 2004 in Helsinki, http://www.environment.fi/download.asp?contentid=28920&lan=en, 2004.

Umlauf, L., Burchard, H. and K. Hutter, Extending the κ-ω turbulence model towards oceanic applications, Ocean Modelling, 5, 195-218, 2003.

Zhurbas V., I. S. Oh and T. Park, Formation and decay of a longshore baroclinic jet associated with transient coastal upwelling and downwelling: A numerical study with applications to the Baltic Sea, J. Geophys. Res., 111, C04014, doi:10.1029/2005JC003079, 2006.

GIS Modelling of Water Transfer in System of River Catchment – Lagoon – Sea (Pregel River - Vistula Lagoon - Gdansk Gulf)

Natalia Goncharova, D. Domnin, A. Korzh and E. Gurova

Atlantic Branch of P.P.Shirshov Institute of Oceanology RAS. 236000 Kaliningrad, pr. Mira, 1. e-mail: natte@inbox.ru

1. The goal

The goal of this work is a geoinformation analysis of different relief shape influence at surface flow witch moves from catchments of river systems to shelf area of the sea, integrating hydrophysical data of Gdansk Gulf and Baltic Canal, comparison of model run-off ways for water area and field experiments.

2. Research area

Kaliningrad region, northeast part of Poland, Vistula Lagoon and Gdansk Gulf correspond to research area.

Research area bounded by cartographic data available for land, lagoon and sea sides. Longitudinal extent is from 19° to 21° East, north and south are fit in with boundaries of topographic map sheets used (fig. 1).

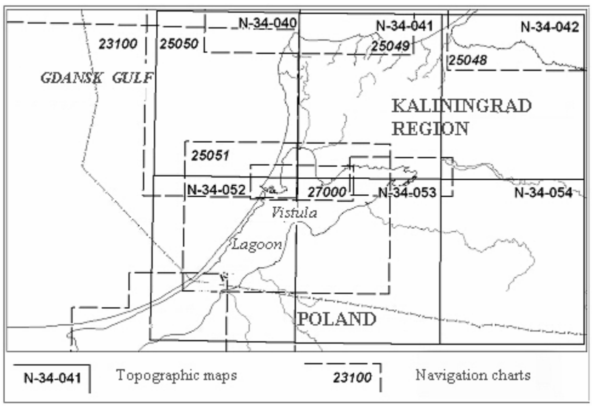


Figure 1. Research area and cartographic assurance.

3. Data base

Digital elevation model (DEM) includes data from cartographic information sources of various applications and scales. Terrain features information was taken from the topographic map sheets with a scale of 1:100000, bathymetry was taken from navigation charts with a scale of 1:50000, and 1:100000 for Gdansk Gulf.

Hydrophysical analysis used materials collected by author on October 2006 on yacht "Lastochka" wich belongs to Atlantic Branch of P.P.Shirshov Institute of Oceanology RAS (Russian Federal Programme "World Oceans", scientific chief V.T. Paka).

4. Methods

Regular grid with 300 m cell size (241x438 cells) has been calculated for runoff ways modeling. It allows visualize relief with essential details and don't fuss up it by hair-splitting landforms. River levels have been included into DEM for correct calculations of run-off ways. DEM have been calculated by isolines. There were hand made isobaths for water area (contour interval 10 m), because automatic interpolation of depth points didn't evidence forms of bottom relief (*Goncharova*, 2005). Validation of bottom relief model was made with using profiles, collected in cruises of R/V "Professor Shtokman".

The river catchments also have hand-made boundaries. Calculation of water-parting by geoinformation methods (using DEM) doesn't suit authors by quality of lines, but then direction of runoff ways preferably calculate with using DEM seeing thousands math options. Catchment areas were calculated automatically and compared with referential data. Quality of area measurements is ±2-8%.

Currents sections were calculated with using Acoustic Doppler Currents Profilograf (ADCP) data. Methods - *Korzh* (2006). As well as published data have been used.

5. Results and discussion

Kaliningrad region and northeast part of Poland are zone of glacial accumulation with extensive lowlands and hilly relief. Russian-Polish Border lies on moraine hills – Vishtyneckaya (max 242 m) and Varmiyskaya (max 191 m) hummocks. Base river systems of Vistula Lagoon catchment flow from there: Pregel, Pissa, Lava - Lyna in Poland, Angrapa – Wengorapa in Poland, Prohladnaya, Golubaya (russian), Nogat and Paleka (polish).

Sheshupskaya plain is on the northeast part of Kaliningrad region – average altitude 40-50 m. Affluents of Instruch river flow from there. Catcthment area of Sheshupe (Neman affluent) is 5770 km^2.

Sambiyskaya hummock is on the west part of Kaliningrad region. It's the divide for river systems of Vistula Lagoon catchment (Nelma and Primorskaya) and catchment of Gdansk Basin.

There are lowlands of Pregel, Deyma rivers (Pregolskaya lowland) and south part of Neman river delta.

Pregel catchment is the main source of water for Vistula Lagoon – most part of large river systems in research area are affluents of Pregel. The singularity of water transfer is Deyma river (catchment area is 319 km^2). Deyma runs on the maximum lowland area and diverts about 30% of Pregel flow into Curonian Lagoon.

The area of Vistula Lagoon catchment is 23500 km^2, most part of it is Pregel catchment (14600 km^2) with affluents: Lava-Lyna (7200 km^2), Angrapa–Wengorapa (2200 km^2), Instruch (1350 km^2), Pissa (1350 km^2), Golubaya (540 km^2) et all.

There are two hummocks on the figure 2 – Sambiyskaya and Varmiyskaya. There are two divides on the Sambiyskaya hummock extends in submeridian and subparallel directions. The result of it is surface waters flowing inside mainland and directly into the Baltic Sea.

The runoff from Varmiyskaya hummock flows to Pregel system and Vistula Lagoon. Farther, the ways of water transfer – through Vistula Lagoon to Gdansk Gulf and through Deyma valley to Curonian Lagoon.

Vistula Lagoon (area is 838 км^2) is natural zone of transit and accumulation from all catchment divided from sea by narrow (0.5-1.5 km) Vistula Spit and connected with Gdansk Gulf by navigable Baltic Canal (width - 450 m, depth - 10 m). Average depth of Vistula Lagoon is 2.8 m, max – 5.3 m.

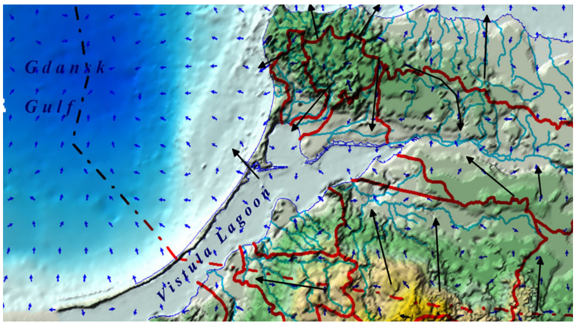


Figure 2. Borders of the river catchments (red lines) and model runoff ways (arrows) on DEM.

There are indefinite water transfer ways in the shallow Vistula Lagoon, only in the area of Baltic Canal – permanent navigation zone.

Alterations in river runoff conduce to bottom relief changing. Thus comparison of modern and historical charts demonstrates decrease of depth in the southwest part of Vistula Lagoon (0.5 m) and depth increase in its north part (1 m). There is intense depth increase near Baltic Strait in the Gdansk Gulf – 10 meters during XX century (*Domnin et all,* 2005).

Runoff from all coast sluices in Gdansk Gulf and accumulates in Gdansk Deep. According to the concept of *Emelyanov* (2002) drift and gradient currents are the dominant model of circulation in the Gdansk Basin. The counter-clockwise currents flow southeastward in the area east of the Hel Spit, and then running eastward-northeastward-northward along the coast. The speed of currents are commonly 30-50 sm/sec at depth of 20 m, 12-25 sm/sec at depth of 40 m, 8-12 sm/sec at depth of 100 m and 8-15 sm/sec at depth of 115 m.

Currents measurements in October 2006 were effected in system of the Pregel River (lower current) – Baltic Canal (axis of the Vistula Lagoon) – shallow seawaters (Gdansk Gulf).

Typical current velocities are represented on the figure 3.

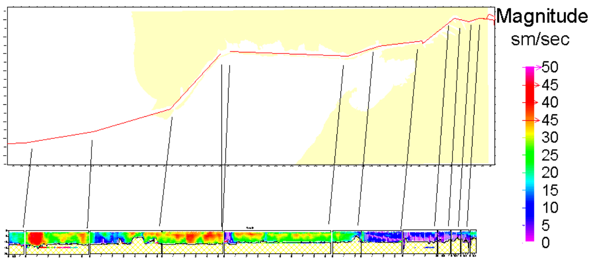


Figure 3. Currents velocity in the water transfer system Pregel – Baltic Canal – Gdansk Gulf.

Maximum current velocities was registered on the depth of 1-7 m and gradually decreases with depth. In this layer current velocity in the river is 1-15 sm/sec, in the Baltic Canal - gradually increases up to 35 sm/sec, in the Gdansk Gulf further increases and reaches locally 50 sm/sec. Average measurements acknowledge model directions of the gradient currents for Gdansk Gulf (fig. 2).

But in some synoptic situations especially with settled strong west wind current direction can inverse. It conduces to storm surge of salt water and blockage of Kaliningrad intakes up the river.

Thus water transfer research in system of river catchment – lagoon – sea is the matter of the first importance for Kaliningrad Region.

References

Korzh A.O., About ADCP data processing, *Proceedings of RGO (Kaliningrad department)*, Vol 5., pp. G1-G8, 2006

Goncharova N. GIS-analysis of morphometric characteristics of bottom relief for sediment dynamics estimation. *New and traditional concepts in geomorphology,* Moscow: MSU, pp. 398–400, 2005

Domnin D., Gurova E., Chubarenko B., Baudler H., Comparative analysis of long-term alterations in depths and coastline of the Vistula Lagoon by using historical and modern charts, *European lagoon and watersheds: function and biodiversity,* Klaipeda, p.35, 2005

Emelyanov E.M. (ed.) Geology of the Gdansk Basin. Baltic Sea, Monograph, Kaliningrad: Yantarny skaz, 494 p., 2002

COASTMAN – Coastal Zone Management

Jan Fidler, Ronald Wennersten*, Nils Brandt and Åsa Larsson

Industrial Ecology, KTH , Teknikringen 34, 114 28 Stockholm, * Corresponding author rw@kth.se

1. Summary

The coastal zones in the Baltic Sea Region (BSR) play an outstanding role for trade, transport, agriculture, fisheries, industrial production, as well as tourism. There is however several serious threats to a sustainable growth of welfare in the Baltic Sea zones. Two of them are conflict interests and environmental pollution. The environmental threats are often complex and versatile. Several of the existing problems have historical roots but the rapid growth of economies will create new problems which might turn up to be even worse than we today can imagine. One important example is oil transports from different terminals around the Baltic Sea. There is often a lack of system view in the handling of this problem. The solutions have to be found in a process where all spatial aspects are considered, where all stakeholders take part, and where cultural differences as well as levels of economic and social development is considered. The COASTMAN project has taken a very practical approach starting from well defined case studies which include conflict interests in coastal zone management (CZM). The case studies form the basis for exchange of experience how methods for conflict resolution have to adapt to cultural and economic differences in the different countries. COASTMAN, an INTERREG IIIB project, has been a starting process for harmonisation of methods and evaluation criteria to avoid serious conflicts related to a sustainable development of the BSR.

2. Central objectives

From a perspective of sustainable development, integrated coastal zone management needs interdisciplinary and spatially integrative approaches, where all important stakeholders who are responsible for planning and realization of exploitation of coastal zones are involved. Central objectives in this project have been:

- To demonstrate the conditions under which spatial conflict resolution in coastal zone management can be handled in a bottom-up perspective.
- To identify how legal, organizational, economic, methodological and cultural frameworks for CZM in participating countries influence strategies for conflict resolution on local and regional levels.
- To promote sustainable development of coastal areas through an information exchange platform, information events and specialist workshops.
- Development of joint educational program for coastal zone management in the BSR with focus on conflict resolution in spatial planning.
- Create awareness among the stakeholders in all BSR countries that problems to be solved contains a mixture of facts and values and that solutions very much have to be found in a participatory processes where all stakeholders are involved.

3. Location of activities

The central part of the project is case studies which have been carried out in several partner countries.

Swedish Case Study–Loudden – a controversial harbour for oil products in Stockholm

Stockholm has for long time been an important city for trade in northern Europe and the Baltic Sea Region (BSR). The scenario for the future is that this role will not be less important but the prediction is rather that the harbours in Stockholm will play an even more important role in the future. Loudden is one of several harbours in Stockholm County and the biggest oil terminal of the region. It is situated in the eastern part of the central Stockholm. After several years of infected debates between several stakeholders as politicians, oil companies, municipalities and NGOs, the city of Stockholm finally took a decision in 1999 not to prolong the contracts with the oil companies after 2011. Important motives for the decision to close Loudden were to get rid of the transportation of petroleum products by trucks travelling through the city and the transportation of petroleum products in the archipelago. Another important motive is also the city's strategy to build and expand the city inwards, which means to use as much of existing land as possible and in the same time use existing infrastructure for building residential areas and offices.

There are several stakeholders involved in the case. For example harbour company own by the city, oil companies renting the oil harbour from the city, neighbours to the industrial area, planners at city planning office, tourists, NGO:s , political parties, etc. The stakeholders wants to replace Loudden with several harbours located south and north of Stockholm to avoid long oil deliveries by trucks through the city. It's important to recognise that the interactions between stakeholders have consequences for the decisions that are made.

In the planning process of the new harbour structure the most important factors is the transport possibilities by sea, road and railway, environmental impacts, risks and the regional development.

The German Case Study - The Conflict in the Kadetrinne: The need for Integrative Approaches to Sustainable Coastal Zone Management in the Baltic Sea

This case describes the conflicts seen in the Kadetrinne area and outlines the possible solutions as well as lessons learned. Located in the Baltic Sea, between the German Darß peninsula and the Danish Falster Island, the 60 kilometre long Kadetrinne is one of the most often cruised and dangerous navigation routes in the world. The conflict in Kadetrinne oscillates between two main groups of stakeholders: (1) the non-governmental environmental protection organizations and local inhabitants of coastal zone, representing the interest of increasing security of the navigation route and (2) the shipping industry with the ship transport companies focused on the oil transport in tankers. The national as well as European maritime authorities and the International Maritime Organization are responsible for the legal aspects and international treaties on the ship standards and the ship traffic, to which the ship transport companies have to adhere.

Although the International Maritime Organization (IMO) recommends the use of pilots (CBSS, 2004), there have been no regulations for obligatory piloting in Kadetrinne so far. Further decisions at both national as well as at

European level have to be made, taking into consideration the recommendations of the non-governmental organizations. The conflict in Kadetrinne is a long lasting one, since it involves cooperation of the interested parties at the national and international level. To solve the problem – which ultimately revolves around the issue of inadequate security of ship traffic in this navigation route - international regulations and international cooperation are essential.

Latvian Case Study -Ventspils City

Ventspils oil port located on the coast line 200 km West of Riga. The uniqueness of the Baltic Sea coast in Latvia and surroundings of Ventspils is determined by its nature values. The length of the Baltic Sea coast in the administrative territory of Ventspils is around 12 km. Nearly fourth of the city administrative territory is occupied by Ventspils Free Port. When planning city development, interests of population and entrepreneurs should be taken into account, at the same time ensuring preservation of nature values and preventing and decreasing environmental pollution. Development of economic activities in Free Port territory together with preserving nature values is possible only following the principles of sustainable development – ensuring satisfaction of the current needs and not putting under threat satisfaction of needs of the further generations. It is the only way to successfully plan the development of the Baltic Sea coast and preserve nature values therein – particularly coastal dune area. Ventspils City Council as a partner of the COASTMAN project has been sharing experience of best practice for coastal management, as well as development of planning for Baltic Sea coast towns.

Lithuania Case Study - Klaipeda Sea Deepwater Port Development Issue

Klaipeda is the only port in Lithuania. It is the second city in the country according to the economic potential. City distinguishes itself by the fast economic growth. The city distinguishes itself by the fast economic growth. In order to improve its economy and to expand East-West sea trade Lithuania has to develop the port Klaipeda, to maintaining its competitive ability with other Baltic ports. The water area of the port is a natural channel connecting Curonian lagoon and Baltic Sea. The west bank of the channel is the coast of Curonian spit and is designated as a national park. These site conditions place physical constrains on large-scale expansion inside the port. The negative environmental impact of economical activities could destroy the shore and sea natural ecosystems and lead to minimization of local flora and fauna biodiversity. The aim of the study has been to find out recommendations for Lithuanian Costal Zone harmonisation through Strategic Environmental and Environmental Impact Assessments using Integrated Coastal Zone Management and cross-border experience exchange methods. The main targets were: to analyze port development in northern direction environmental and social consequences, to identify foremost stakeholders groups, to determine essential issues of the establishment of Klaipeda Deepwater Port development for different type of stakeholders, and to define prerequisites for conflict prevention.

Estonian Case Study - Coastal zone management in Haapsalu Bay area,

The case study has focused on developing a coastal zone management strategy and measures for protection of the Haapsalu Bay area in western Estonia. According to the EU Water Framework Directive (WFD) all ground, surface and coastal water bodies should be of at least good ecological quality by 2015. Fulfilment of this requirement needs more complex solutions to maintain and improve the ecological status of the bay. To satisfy different users (e.g. coastal population, recreation, industry, fishery sector, nature conservation) with water in accordance with the quality standards and norms for their respective purposes, the goals of coastal development and economic growth should be balanced with environmental protection.

The Russian Case Study - Decision making tools for implementation of Integrated Coastal Zone Management (ICZM) in Primorsk Area

The territory of the city of Primorsk has been selected as a case study, because it is characterised by high dynamics of development caused by construction of a new oil transportation complex. As a result of the construction of the 1st oil terminal, Primorsk has changed from a small village to one of the developing centres of the North-Western Russia. Further extension of the oil terminal is increasing the anthropogenic pressure on the coastal zone, and conflicts between different stakeholders. Furthermore, the "Beryozovye Ostrova" ("Birch Islands") State Reserve is located close to the constructed oil terminals. The reserve's total area is 12,000 ha, including 7,000 ha of marine waterbodies that can be influenced by the oil terminals. According to the Law of Russian Federation "On Ecological Expert Examination", public examination procedures have to be considered as an integral part of the Environmental Impact Assessment in the process of assessment of construction and investment projects. However, neither the law nor other related normative documents properly define the procedure of public participation as well as norms for objective estimation of the level of public awareness and involving in decision-making processes.

4. Outcomes from the COASTMAN project

The main results from the project are:

- Described legal, organizational, economical, methodological and cultural frameworks for CZM in participating countries.
- A set of recommended methods and guidelines for conflict resolution in coastal zone management, methods which have been tested on practical cases in the BSR
- Recommendations for conflict resolution in practical cases based on a participatory process where all stakeholders take part.
- Shared vision among participants on differences in the frameworks and how these differences influence strategies for conflict resolution in CZM.
- Published report with description of practical cases, evaluation of selected methods and recommendations how to use methods to resolve conflicts in coastal zone management.
- Improved practical skills among involved stakeholders in methods for conflicts resolution.
- A web based course with on-line material focused on conflict resolution in coastal zone management. Stakeholders involved in the project case studies are trained in practical methods for conflict resolution during training sessions.
- Developed information exchange platform on the web, published handbook on conflict resolution, shared experience and best practice in CZM with related INTERREG projects.

Klaipeda Sea Deepwater Port Development Issue

Olga Belous, Saulius Gulbinskas and Rosita Mileriene

Herkaus Manto 84, LT-92294, Klaipeda University, Klaipėda, Lithuania
obelous@gmf.ku.lt

1. Introduction

Klaipeda is only port in Lithuania. It is the second city in the country according to the economic potential. City distinguishes itself by the fast economic growth.
Klaipeda is a multipurpose, universal, deep – water port, providing high – quality services complying with the requirements of the European Union. 19 big stevedoring companies, ship - repair and ship – building yards operate within the port and all marine business and cargo handling services are being rendered. The annual port cargo handling capacity is up to 40 million tons. It is Lithuanian transit center connecting the main transportation corridors between the East and West via sea routes (Klaipeda State Seaport, 2006).
In order to improve its economy and to expand East-West sea trade Lithuania has to develop the port Klaipeda, maintaining it's competitive ability with other Baltic ports (The Law of Klaipeda State Sea Port, 1996).
The water area of the port is a natural channel connecting Curonian lagoon and Baltic Sea. The west bank of the channel is the coast of Curonian spit and is designated as a national park. These site conditions place physical constrains on large-scale expansion inside a port. The negative environmental impact of economical activities could destroy the shore and sea natural ecosystems and lead to minimization of local flora and fauna biodiversity (Jokšas et al., 2003, Lazauskienė et al., 2000).
The aim of the study is to find out recommendation for Lithuanian Costal Zone harmonisation through Strategic Environmental and Environmental Impact Assessments using Integrated Coastal Zone Management and cross-border experience exchange methods. The main targets are: to analyze port development in northern direction environmental and social consequences, to identify foremost stakeholders groups, to determine essential issues of the establishment of Klaipeda Deepwater Port development for different type of stakeholders, and to define prerequisites for conflict prevention.

2. Conflict description

Even if the existing port is fully renovated, the traffic demand would exceed the existing port capacity by around 2015 to 2017. To cope with the anticipated capacity shortage and to meet the shipping needs based on Klaipeda port being able to receive Baltmax-type vessels, Klaipeda port should be expanded beyond the existing port territory (JICA 2004).
Klaipeda port is a very important in the economy of the country and a major influence on the life of the city, and is also in an area of considerable environmental importance and sensitivity:
- the Curonian Spit in the west, which has internationally important landscapes, culture and ecology, and is designated as National park and World Heritage Site;
- the channel between the Spit and the Port, through which commercially exploited and rare fish, and birds migrate each year;
- the village of Melnrage and the Baltic coast in the north, which are used for recreation and tourism by local people and visitors;
- Klaipeda city in the east, where commercial and residential areas are located close to the port with little or no buffer in places;
- land immediately at south of the port is a groundwater protection zone as it contains boreholes from which water is extracted to supply the city;
-the Curonian Lagoon in the south is a fish spawning ground, a resting and over wintering site for birds, a tourist attraction and supports commercial fishery.
The port is therefore surrounded on all sides by areas and features that are of local, national and international importance, which are sensitive in different ways and to varying degrees to damage and disturbance. Proposals to expand the port therefore need to be developed and implemented with a great deal of sensitivity to environmental considerations to prevent damage and disturbance to important assets (Žaromskis, 2006).
Among some alternatives, the decision of port development North direction is chosen. This alternative offers to pour an island in the sea, opposite the Melnrage village and make a deep-sea port. A study of this kind of port construction possibility has been arranged (JICA, 2004).
To accommodate the above terminals an artificial island (1500 m long and 700 m wide) will be developed 350 m offshore from the coast line. The reclaimed outer port area will have road/railway access linked to the existing railway and road networks inshore (JICA, 2004).
Construction of deep-sea port is not considered with Klaipeda city general plan. There is social conflict with local people, land and realty owners. Construction of the deep-sea port would change coastal forming processes and would have a significant impact to other coastal zone resources users (Coastal zone protection program, 2003).

3. Conclusions

For successful deep-sea port development an efforts in preparatory works, port development project, combining city's needs and consulting with environmental organizations as well as with local community should be applied.
The following recommendations could help to prevent Coastal Zone development conflicts:
- to analize different stakeholders economic and social needs and find compromise between them;
- to applicate a mechanism of compensations for conflicts prevention between different stakeholders;
- to fulfil Strategic Environmental and Environmental Impact Assessments;
- to use tools of Coastal Zone conflicts resolution like organization of training course for various level of decision makers in order to improve the quality of decisions;
- to arrange of committee of independent advisers consisting from public representatives as good as from NGO and scientists for advanced study about Coastal Zone conflicts.

References

Coastal zone protection program, Environmental Ministry of Republic of Lithuania, Vilnius, No. 44, 09-01-2003

Klaipeda State Seaport, http://www.portofklaipeda.lt, 2006

Jokšas K , Galkus A., Stakėnienė R., The only Lithuanian sea port and its environment, Vilnius ,314 p., 2003

Lazauskienė L., Vaitonis G., Draugelis A., Klaipėda port: economy and ecology Baltic Eco, Vilnius, 150 p., 2000

Japan International Cooperation Agency (JICA) , The study on the port development project in the Republic of Lithuania, Final report, Klaipeda, 2004

The law of Klaipeda State Sea Port, Vilnius, No I-1340, http://www.portofklaipeda.lt, 1996

Žeromskis, R., Lithuanian Coast and Dunes. Klaipeda, 48 p., 2006

Coastal Zone Management in Haapsalu Bay Area, Estonia

Arvo Iital[1], Krista Vilta[2], Enn Loigu[1] and Kati Roosalu[1]

[1] Tallinn University of Technology, Ehitajate tee 5, Tallinn, arvo.iital@ttu.ee,
[2] Haapsalu Town Government, Posti 34, Haapsalu, krista.vilta@haapsalulv.ee

1. Abstract

The paper introduces Interreg IIIb project results in developing a coastal zone management strategy and measures for protection of the the Haapsalu Bay area in western Estonia. According to the EU Water Framework Directive (WFD) all ground, surface and coastal water bodies should be of at least good ecological quality by 2015. Fulfilment of this requirement needs more complex solutions to maintain and improve the ecological status of the bay. To satisfy different users (e.g. coastal population, recreation, industry, fishery sector, nature conservation) with water in accordance with the quality standards and norms for their respective purposes, the goals of coastal development and economic growth should be balanced with environmental protection.

2. Introduction

Haapsalu Bay is part of the Baltic Sea and extends deeply into the land in the western part of Estonia (Fig. 1). The surface area of the bay is 47 km^2 and the total catchment area is 412 km^2. The inner part of the bay is very shallow with a maximum depth of approx. one meter and characterised by intensive eutrophication, growth of reed and other macrophytes, decreasing open surface water area and sedimentation. The number of inhabitants in the Haapsalu bay catchment area is approx. 17,000. The biggest settlement is the local administrative center Haapsalu, with a population of approx. 12,000 inhabitants. The town is a well-known recreational area and seaside resort in the peninsula. The curative mud used in local sanatoria is widely spread in the seabed sediments. Environmental objectives for Haapsalu Bay have not yet been set up. However, different water users (e.g. recreation, industry, fishery sector, nature conservation) require a water quality in accordance with the quality standards and norms for their respective purposes. Reduced possibilities to satisfy all water users of the bay with their specific needs regarding the water quality and quantity can cause stress and conflicts.

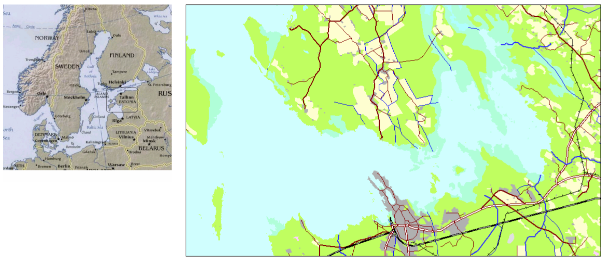


Figure 1. Map showing the location of the case study area

3. Aims of the project

The tasks of the work included:

- Developing proposals for a costal zone management strategy and measures of protection for the bay and its ecological potential taking into account that currently the applicable water quality standards for designated uses are being failed to be maintained.
- Demonstrating ways of spatial conflict resolution and initiating a forum between different stakeholders in order to resolve potential conflicts in the future.
- Identifying critical coastal areas and land uses in the catchment, which, individually or cumulatively, may contribute significantly to a degradation of coastal waters.

4. Main stakeholders, their interests and conflicts

1) County administration and coastal municipalities.
Local authorities are responsible for planning on county and local level. They are also responsible for the maintenance of a high quality coastal environment, the development of the area and for the implementation of relevant management measures. This includes delivery of high quality drinking water to all users, improved waste water treatment efficiency and a decreased point source pollution load to the bay. The investments to treat natural water to guarantee the quality necessary for potable water and to improve waste water treatment required additional investments. Consequently, these investments raised the price for the water and caused a remarkable decrease in per capita water consumption by the population. Even though waste water treatment efficiency is much higher now it is still not sufficient due to highly concentrated sewage water in the inlet of the waste water treatment plant, which makes it difficult to achieve necessary quality levels in the outlet.

2) Environmental authorities and Silma Nature Reserve.
Silma Nature Reserve includes the inner part of Haapsalu Bay and the coastal areas. The nature reserve is an important nesting area for water birds and a spawning area for freshwater fish. Intensive eutrophication has led to an increased reed area. Efforts to curb this development have created an increased pressure for using reed as a construction material or for incineration. The cleaning of the bay from reed also is expected to improve nesting conditions for birds and spawning conditions for fish but may result in a negative impact on the open bay if the capacity of the bay to serve as an effective filter, sink, and transformer of inorganic nutrients and eroded material is reduced. These sometimes controversial interests of reed users, fishermen, local population and recreation need careful environmental impact assessment.

3) Fishermen.
Fishermen use the bay area for fishing and as a transportation route. The use of ships requires periodic dredging of the shipping channel in the bay due to the shallowness of the bay and intensive sedimentation. Sedimentation is caused by eutrophication and solid material transported to the bay via rivers. The dredging will cause conflicts between ecological/recreational interests and fishing/yachting interests of the local people and visitors of health resorts. Fishermen are interested in maintaining a proper income from the fish catch that depends on the conditions in the bay. The water quality can deteriorate due to municipal discharges of sewage waters and diffuse load of nutrients via rivers. Hobby fishing in the Silma Nature Reserve is regulated by the Regulation of the Minister of Environment No. 75 of 15.12.2005. Fishing is not allowed from April 1 to September 19 and is restricted by a licensing system in other seasons. Since Haapsalu Bay is an important fish spawning area, it would be reasonable to use the water quality standards of Regulation 78/659/EEC for its fishing waters. At present, the water quality of the bay does not comply with this regulation.

4) Farmers.
According to studies (Brandt et al., 2003, Iital et al, manuscript) the riverine load of nitrogen on Haapsalu Bay even increased from the mid-1990s. This increase was caused mainly by intensified agricultural production after the depression in the 1990s and by the increased share of arable land actually in use. The use of inorganic nitrogen fertilisers for agricultural crops in Lääne county increased more than sixfold from 1996 to 2004, and the area specific fertilisation rate with inorganic fertilisers almost doubled from 78 kg/ha in 1996 to 122 kg/ha in 2004 (Statistikaamet, 1997; Statistikaamet, 2005). A similar increase took place as regards the use of organic fertilisers, from 24 tons/ha in 1996 to 35 tons/ha in 2004 (*Ibid.*). The fertilised area increased fivefold within the same time period. Assuming that those changes in Lääne county match those in the Haapsalu Bay catchment area, the intensification of agricultural production is evident. Assuming that the increased nutrient load does not cause immediate problems in the bay due to its high buffering capacity, more efforts should be made to implement the best agricultural practices accompanied by other legal, organisational and agro-technical measures. These actions will minimise the possible increase of agricultural load and the risk of failure in achieving the targets set up by the WFD.

5) Coastal population.
Inhabitants of Haapsalu town are more or less affected by increased tourism to the area, and by planning and developing processes. Their living conditions depend also on the quality of Haapsalu Bay, treatment efficiency of the WWTP and the water pricing policy. The rural population is interested in preserving the beautiful agricultural landscapes and environmentally friendly agricultural production. The income of the rural population is very much determined by the success of agricultural production. The maintenance of the quality of mud and its availability can be in conflict with other targets in the area, e.g. with maintaining sustainability of agriculture and industry in the area and enhancing tourism. The annual excavation of mud (400 tons) is not high compared to the estimated amount of active mineral deposit (162,300 tons). The areas of active mud deposits are surrounded by a protection belt of 1,000 m where economic activities including construction works as well as transport by motor boats, setting up of ice routes and ice collection are prohibited by the order of the Minister of Environment. The total amount of mud in the bay is nearly 4 million tons. These deposits are not fully protected, which may cause deterioration of mud quality in the bay.

6) Developers.
Regardless of the high land price in coastal areas there is a growing interest in building up these areas. Therefore, growing pressures on the bay are evident. The lack of detailed plans causes uncontrolled changes in land-use in the project area, especially in coastal areas suitable for summer resorts. The development and construction works cause possible conflicts between local municipalities, population and developers. The importance of an improved planning process is evident, especially due to possible flooding in the coastal zone that has increased interest of developers to carry out environmental impact assessment of plans and projects.

5. Conclusions

Coastal planning and control measures for development are essential to protect the water quality of the bay. In the case of Haapsalu the goals of coastal development and economic growth should be balanced with environmental protection. When dealing with the coastal areas goals for coastal resource use and protection have to be established. This involves an inventory of coastal resources as the first step, as well as an analysis of existing problems and future needs. It was demonstrated that organisational aspects of implementing EU water policy (political, research, administration, etc.) and problems of communication and information exchange between various levels of governance present major difficulties in the implementation of this policy. Involving multiple stakeholder groups in the development and implementation of EU and national water policies is of critical importance.

6. Acknowledgements

The study was performed within the BSR Interreg IIIB project “Coastal Zone Management for the Baltic Sea Region-Coastman”.

References

Brandt, N., Gröndahl, F. and Loigu, E. (2003). Nutrient mass balance of the Haapsalu Bay, Baltic Sea, Estonia. 30th Pacem in Maribus. A year after Johannesburg. Ocean Governance and Sustainable Development: Ocean and Coasts – a Glimpse into the Future. Kiev, Ukraine, October 27-30, 224-234.

Iital A., Gröndahl, F., Brandt, N., Loigu, E. and Reihan, A. Impact of changed nutrient fluxes to the water quality of Haapsalu Bay, the Baltic Sea. (submitted to Hydrobiologia)

Statistikaamet (1997). Agriculture 1996. Yearbook, Statistical Office of Estonia, 130 p.

Statistikaamet (2005). Agriculture 2004. Yearbook, Statistical Office of Estonia, 80 p.

The Conflict in the Kadetrinne: The Need for Integrative Approaches to Sustainable Coastal Zone Management in the Baltic Sea

Prof. Walter Leal, Agnieszka Holda, Dörte Krahn

TuTech Innovation, Harburger Schlossstrassse 6-10, 21079 Hamburg, coastman@tutech.de

1. Abstract

This paper describes the conflicts seen in the Kadetrinne area and outlines the possible solutions as well as lessons learned. It was developed within the European Interreg III B BSR project "Coastman".

2. Introduction

For many decades, an important topic for German coastal zone management has been the need to increase the security of ship passage in accident-prone Kadetrinne. This issue has gained a new momentum after the accident of *Prestige* in November 2002, which released about 63000 tons of fuel oil, polluting the coasts of Spain and France. Many questions arouse about the traffic in the Kadetrinne, including the appropriate age and design of tank ships, as well as about the preparedness of Germany to deal with a damaged tanker. After all, *Prestige* was also swimming on the Baltic waters, passing through Kadetrinne from time to time. If an oil tanker faced damage in this passage, the German coastline from Lübeck, through Rostock and Rügen till Usedom could be endangered (Greenpeace, 2002a).

The conflict in Kadetrinne oscillates between two main groups of stakeholders: (1) the non-governmental environmental protection organizations and local inhabitants of coastal zone, representing the interest of increasing security of the navigation route and (2) the shipping industry with the ship transport companies focused on the oil transport in tankers. The national as well as European maritime authorities and the International Maritime Organization are responsible for the legal aspects and international treaties on the ship standards and the ship traffic, to which the ship transport companies have to adhere.

Multiple discussions and initiatives were undertaken by NGOs such as WWF or Greenpeace, at regional, national, international and European wide level proposing recommendations on how to improve the security in Kadetrinne, thus lowering the risk of pollution of the German Baltic Sea coastal zone. Although those actions contributed to some of the necessary changes in the marine legislation and international maritime treaties, the conflict is not yet completely solved. Further decisions, based on the stakeholders' recommendations, at both national as well as at European level, still have to be made

3. Background of the problem

Located in the Baltic Sea, between the German Darß peninsula and the Danish Falster Island, the 60 kilometer long Kadetrinne is one of the most often cruised and dangerous navigation routes in the world (Greenpeace, 2003a).

The passage is only 1 km. wide. Therefore, for two ships swimming in opposite directions, there is a space of 500 m for each. In addition, Kadetrinne is only 17 m deep, having on the left and right side shallow waters of 10-11 m. depth, while ships of 160000 T capacity have the draught of 15.5 m and the outflow length of 20 km (Seifert, K., 2004).

Around 63000 ships cross the passage each year (roughly 173 per day), from that 8200 tank ships and 14600 ferries (Greenpeace, 2002a). Almost one fourth of the tankers was identified in 2003 as 'swimming time bombs' - being over 20 years old and having only single hull (Greenpeace, 2003a).

Twenty two accidents happened in the past ten years in Kadetrinne (Greenpeace, 2003a), with the biggest oil accident in the spring of 2001, when 3000 tones of oil were disgorged from the 'Baltic Carrier' (NSL, 2001) polluting Danish coasts and killing around 20000 birds (WWF, 2004). Also, the results of a four weeks ship-traffic observation performed by Greenpeace in the Kadetrinne indicate 1 ship aground and 200 ships not going according to the rules (NSL, 2001).

4. Description of the conflict and relevant conflict resolution methods

The conflict in the Kadetrinne area has two relevant groups of stakeholders. The first group represents the interest of increasing security of the navigation route in order to diminish the risk of pollution of the sea and the coastal zone areas. A possible tanker damage and oil spillage could cause long lasting environmental damage and could have severe economical impacts, especially for the inhabitants of the coastal zones living from fishing and tourism. This group of stakeholders comprises of the non-governmental environmental protection organizations and institutions such as Greenpeace, WWF, HELCOM, CBSS (Council of the Baltic Sea States), EUCC (The Coastal Union Germany), Aktionskonferenz Nordsee e.V, ROBIN WOOD, and local inhabitants of coastal zones. The second interest group is the shipping industry with the ship transport companies focused on the oil transport. Without proper legislation, imposing the obligation of piloting in Kadetrinne and banning the single hull and old tankers, those ships are swimming through the passage bearing high risk of an accident and thus posing threats to the environment. Those are the national as well as European maritime authorities and the International Maritime Organization that are responsible for the legal aspects and international treaties on the ship standards, the ship safety as well as on the ship traffic, to which the ship transport companies have to adhere.

In the discussed conflict, those were the NGOs representing the stake of environment and the voice of local inhabitants of coastal zones, who were actively demanding changes in the maritime legislations and further improvements with regard to safety of the passage to be introduced. During four weeks monitoring initiatives undertaken by Greenpeace in 2001, and 2002 (Greenpeace, 2002a) to observe the ship traffic and ship behavior in Kadetrinne, the maritime experts learnt about the occurring ship navigation problems and their frequencies. They also kept a record of all ships passing through Kadetrinne together with their further specifications, such as the type of the ship, the year of its production, flag under which it swims as well as its carrying capacity (Greenpeace, 2002b). In addition, basing on the collected data, Greenpeace presented a broadened version of the EU 'Black list' containing 66 ships (Greenpeace, 2003a). The Greenpeace list contains 3437 old and/or single hull oil and chemical tankers swimming also on the Baltic Sea waters and passing through the Kadetrinne, which according to the organization should no longer be allowed the entrance on Baltic waters. In order to make the issue know to further public various NGOs published articles about the problems in Kadetrinne as well as shared their recommendations on how to improve the safety of the navigation route. Greenpeace attracted the attention of media protesting against old oil tankers and hanging banners expressing the threat to environment posed by the ships.

5. Possible solutions or lessons learned

To date, the many political initiatives have led only to a partial success in increasing the safety of marine and coast environment. One of them is namely the progressive ban of single hull tankers swimming on the European waters.

By the decision of the European Parliament and of the Council of 22 July 2003 (EC, 2003), revising regulation 13G of Annex I of MARPOL, the final phasing-out date for Category 1 tankers (pre-MARPOL tankers) is brought forward to 2005, from 2007. The final phasing-out date for category 2 and 3 tankers (MARPOL tankers and smaller tankers) is brought forward to 2010, from 2015 (IMO, 2003).

However, to improve the security in the Kadetrinne the environmental NGOs:Greenpeace, WWF, Aktionskonferenz Nordsee, Robin Wood, among others, recommend further several immediate actions to be taken (Greenpeace, 2003a) (WWF, 2004) (ROBIN WOOD, 2003). Some of these are:

- Obligatory piloting by means of smaller, tow vessels;
- Compulsory registration of all ships that intend to pass through Kadetrinne;
- Improvement of radar observation;
- 'Safe harbours' – harbours for damaged ships;
- Common international coast guarding;
- Early introduction of the Automatic Identification System (originally planned for 2008) both on vessels and on land-based points (NSL, 2001);
- Immediate ban of tankers, which are older than 20 years and which are not double hulled.

Mandatory piloting in the Kadetrinne would improve the situation considerably, but the concerned countries have not been able to agree on it so far. Similarly, other recommendations are still in progress and have not been implemented yet. The key learning points that can be drawn from the study of the Kadetrinne conflict are the importance of:

- being well prepared for the discussions with other stakeholders. This includes having expertise on the maritime issues together with being in possession of reliable and adequate data, such as the information on ship traffic and ship behavior in Kadetrinne gathered by Greenpeace over their monthly monitoring initiatives.
- taking the stand on all the meetings with other involved parties. The presence on all national, international and European summits, where maritime issues are discussed, and presenting the stakeholder's group interest and recommendations, is essential.
- making the conflict known to a broader range of public in order to win their interest and involve them in the issue.

Where legislation plays an important role, the process of conflict resolution is very slow, especially when it concerns not only national but broader international aspects. It is evident that the safety in Kadetrinne is not only a local issue but that it concerns the coastal zones of Baltic countries and global maritime safety. Moreover, many of the already recommended improvements have to be implemented at a local and regional level. However issues such as the banning of the transport of old single hulled tankers has an impact on the overall worldwide ship transport, and in addition its execution, it is a long lasting process.

6. Conclusions

Although the International Maritime Organization (IMO) recommends the use of pilots (CBSS, 2004), there have been no regulations for obligatory piloting in Kadetrinne so far. Further decisions at both national as well as at European level have to be made, taking into consideration the recommendations of the non-governmental organizations.The conflict in Kadetrinne is a long lasting one, since it involves cooperation of the interested parties at the national and international level. To solve the problem –which ultimately revolves around the issue of inadequate security of ship traffic in this navigation route - international regulations and international cooperation are essential.

References

CBSS, 2004: Germany and the Baltic Sea Region after EU enlargement. Speech by H.E. Busso von Alvensleben, 11 November 2004

EC, 2003: Regulation (EC) No 1726/2003 of the European Parliament and of the Council of 22 July 2003 amending Regulation (EC) No 417/2002 on the accelerated phasing-in of double-hull or equivalent design requirements for single-hull oil tankers.

Greenpeace, 2002a: Kampagne zur Schiffssicherheit gestartet.

Greenpeace, 2002b: Kadetrinne: Täglich ein Schrotttankert.

Greenpeace, 2003a: Kadetrinne: Ölkatastrophe jederzeit möglich.

Greenpeace, 2003b: Schiffsverkehr gefährdet die Ostsee.

Greenpeace, 2004a: IMO ermöglicht mehr Ostseeschutz.

Greenpeace, 2004b: Mehr Meer. Ein Vorschlag für Meerschutzgebiete für Nord- und Ostsee. August 2004.

IMO, 2003: Tanker safety – preventing accidental pollution. International Maritime Organization. Safe, Secure and Efficient Shipping on Clean Oceans.

NSL, 2001: Sustainable Transport Solutions in the Baltic Sea Area II – focus on maritime transport. Second international NGO conference in Stockholm. 5-6 October 2001. Page 6. Naturskyddsföreningen i Stockholms län.

ROBIN WOOD, 2003: Umweltministerkonferenz zum Meeresschutz Schifffahrt Topthema. Bremen, 18 June 2003.

Seifert, K., 2004: Probleme mit Offshore-Windkraftanlagen aus Sicht der Schifffahrt.

WWF, 2004: Mehr Schutz für die Ostsee. Hintergrundinformation. Bremen, November 2004.

Atmospheric Input of Nitrogen to the Baltic Sea Basin - Present Situation, Trends, Variability and Impact of Climate Change

Joakim Langner [1], Camilla Andersson [1, 2] and Magnuz Engardt [1]

1 Swedish Meteorological and Hydrological Institute, Folkborgsv. 1, Norrköping, Sweden, joakim.langner@smhi.se
2 Department of Applied Environmental Research, Stockholm University, SE-10691 Stockholm, Sweden

The atmospheric contribution to the input of nitrogen compounds to marine ecosystems in the Baltic Sea is significant. According to current estimates approximately one quarter of the total nitrogen input to the Baltic Sea comes from airborne nitrogen deposited directly into the sea (HELCOM, 2006). In addition some of the nitrogen deposited into the Baltic Sea catchment area reaches the sea via runoff from land. The load is highly variable regionally and temporally, which can be explained by changing emissions and meteorological conditions (Hongisto et al., 2002). Emissions of NOx and ammonia to the atmosphere in Europe have decreased by 25 and 20% respectively between 1980 and 2000. Deposition of total nitrogen has decreased by 15% over the same time period but the decrease has slowed since the beginning of the 1990:ies (EMEP, 2004). Current (year 2000-2005) deposition is basically the same as during the 1990:ies. Long term trends in deposition of nitrogen should be related to trends in anthropogenic emissions, but meteorological variability and nonlinearities in atmospheric chemistry and deposition can offset expected changes. Another important factor could be the increase in ship emissions of NOx. According to recent estimates (EEB, 2004), NOx emissions from international ship traffic on the European seas increased by more than 28% between 1990 and 2000. Emissions from shipping are expected to increase by two thirds by year 2020, even after implementation of agreed emission control. If this development holds, ship emissions will surpass land based emissions in Europe by 2020.

Recent advances in meteorological modelling and analysis like the ERA40 global meteorological reanalysis (Uppala et al., 2005) as well as the availability of high resolution regional climate modelling and scenarios has improved our possibilities to analyse past trends and variability in the cycling of nitrogen compounds in the atmosphere as well as interactions with climate change (Langner et al., 2005; Andersson et al., 2007). In this paper we will give an overview of available published estimates of atmospheric deposition of nitrogen to the Baltic to set a baseline of current deposition and variability. Next we will look into how possible climate change as well as emission reductions could affect the future development of nitrogen deposition to the Baltic Sea basin.

References

Andersson, C., J. Langner and R. Bergström, Interannual variation and trends in air pollution over Europe due to climate variability during 1958-2001 simulated with a regional CTM coupled to the ERA-40 reanalysis. *Tellus,* 59B, 77-98, 2007.

EEB – European Environmental Bureau. Air pollution from ships. http://www.eeb.org/activities/air/ship-briefing-nov-04-(1), 2004.

EMEP, EMEP assessment, Part I, European perspective. http://www.emep.int, 2004.

HELCOM, Airborne nitrogen loads to the Baltic Sea, Helsinki Commission, Baltic Marine Environment Protection Commission, 2006.

Hongisto, M., M. Sofiev and S. Joffre, Hilatar, a limited area simulation model of acid contaminants. Part II, Long-term simulation results. *Atmos.Environ.,* 37, pp. 1535-1547, 2002.

Langner, J., Bergström, R. and V. L. Foltescu, Impact of climate change on surface ozone and deposition of sulphur and nitrogen in Europe . *Atmos. Environ.* 39, pp. 1129-1141, 2005.

Uppala, S. M., P. W. Kållberg, A. J. Simmons, U. Andrae, V. da Costa Bechtold and co-authors, The ERA40 re-analysis. *Quart.J. Roy. Met.Soc.,* 131B, pp. 2961-3012, 2005.

European Network of excellence for Ocean Ecosystems Analysis

Developing an Integrated View on the Baltic Sea Ecosystem: The EUR-OCEANS Baltic System Study

Fritz Köster[1], David Turner[2], Anders Omstedt[3], Christian Möllmann[4], Henrik Gislason[1], Riitta Autio[5], Anders Olsson[2] and Rabea Diekmann[4]

1 Technical University of Denmark, Danish Institute for Fisheries Research, Charlottenlund Castle, DK 2920 Charlottenlund
2 Göteborg University, Department of Chemistry, SE-412 96 Göteborg
3 Göteborg University, Earth Sciences Centre, P.O. Box 460, S-40530 Göteborg
4 University of Hamburg, Institute for Hydrobiology and Fisheries Science, Olbersweg 24, D-22767 Hamburg
5 Finnish Institute of Marine Research, Department of Biological Oceanography, Erik Palménin aukio 1. FI-00561 Helsinki
e-mail of lead authors: fwk@difres.dk; davidt@chem.gu.se

1. Project objectives

The overall strategic objective of the European Network of Excellence for ocean ecosystems analysis (EUR-OCEANS) is to achieve lasting integration of European research on global change and marine ecosystems and the relevant scientific disciplines. The overall scientific objective of EUR-OCEANS is to develop models for assessing and forecasting the impacts of climate and anthropogenic forcing on food-web dynamics, i.e. structure, functioning, diversity and stability of marine ecosystems.

2. Project structure

Activities comprise: (1) integration activities such as networking (WP1), data (WP2), and model integration (WP3); (2) jointly executed research, organised around four broad tasks on: pelagic ecosystems end-to-end (WP4), biogeochemistry (WP5), ecosystem approach to marine resources (WP6) and within-system integration (WP7); and (3) activities to spread excellence, i.e. training (WP8), outreach to socio-economic users (WP9), and the public (WP10). All activities are organised both at a global scale and regionally, in seven marine Systems, one of these being the Baltic.

3. Project research

The jointly executed research addresses the identification, quantification and parameterisation of major processes governing the structure, functional biodiversity and stability of ecosystems and the biogeochemical fluxes of substances that are relevant to the interactions between climate and pelagic ecosystems, the responses of these processes to climate and anthropogenic forcing, their effects on marine resources, and their feedbacks to the Earth System. It encourages, co-ordinates and integrates efforts to establish the scientific basis needed for the move to an ecosystem approach to marine resource management. It furthermore encourages sharing generic approaches across systems to improve within-system integration.

4. Why a Baltic System Study?

The Baltic Sea is located in a transition area between continental and marine climates and the oceanographic conditions and their variability are strongly linked to this. The physical conditions in the Baltic Sea respond to climate change through (i) direct air-sea interaction, (ii) the magnitude of freshwater runoff, and (iii) interactions with the Atlantic ocean through narrow straits. Surface temperatures are determined by the dominance of either westerly winds with mild “Atlantic air” or easterly winds with cold “continental air” resulting in low temperatures and extensive ice cover. The dominance of “westerly weather” since the late 1980s is associated with an increase in average water temperatures and river runoff with the consequence of decreasing salinities. Increased freshwater input prevents inflows of saline and oxygenated water from the North Sea, renewing the bottom water of the deep Baltic basins below the permanent halocline.

Whereas a general increase in chlorophyll a indicates an effect of increased eutrophication, a change in dominance from diatoms to dinoflagellates has been attributed to mild winters. A further consequence of increasing temperatures/decreasing salinities is a change in the mesozooplankton community, favoring euryhaline species, e.g. *Acartia* spp., whereas marine species, e.g. *Pseudocalanus acuspes*, declined in abundance.

Changes in the meso-zooplankton negatively affected herring and sprat growth and condition, but also recruitment of the top-predator cod. Additionally, climate mediated hydrographic changes affected directly the reproductive success of cod and eventually caused together with high fishing pressure a change in the fish community from a dominance of piscivores to planktivores. The consequences of this increase in planktivory on the population dynamics of zooplankton prey species and the interplay between these top-down and bottom-up processes is however not well understood.

Climate change may further amplify changes in the physical environment of the Baltic Sea with up to now unpredictable consequences for the ecosystem. Simulations revealed e.g. that increases in westerly winds may amplify the dominant cyclonic circulation pattern, with further consequences for trophic interactions. Physical modelling studies revealed further a clear sensitivity of the Baltic salinity level to increased freshwater supply, with unpredictable ecological and economical consequences. These distinct climate related trends in ecosystem structure and related fisheries and strong hydrographic and biogeochemical gradients provide unique opportunities for developing and testing ecosystem models.

5. Baltic System activities

Activities so far have centered around 1) scientific contributions to international conferences and workshops, 2) education of students in summer schools, training of Ph.D. and Post-docs, 3) formulation of international multidisciplinary research projects and their implementation and 4) development of a Baltic Sea research programme.

While scientific contributions to international fora and their publication is certainly the core of scientific dissemination activity, the longer lasting impact is achieved by education. The Baltic system study has co-organised one summer school "Controls in marine ecosystems", participated in a second "Climate change impacts on marine ecosystems" and plans to set-up of a third for 2008 "From biochemistry to upper trophic levels, from climate to ecosystem models". The latter is of direct relevance to BALTEX and cooperation is suggested. In total 15 Ph.D. students and a number of Post-docs are related to the Baltic System Study covering themes related to ecosystem modelling, carbon fluxes, and population dynamics of meso-zooplankton and fish. Furthermore meta-analyses are conducted addressing integrated assessment approaches, mass-balance modeling and carrying capacity of the Baltic ecosystem.

While the Baltic Sea study has substantially contributed to the planning, initiation and implementation of five FP6 EU projects and an Early Training Network as well a number of EUR-OCEANS specific activities like a project on rescuing of zooplankton data, the main emphasis of activities is actually more long-term, i.e. to develop an integrative Baltic Sea research programme covering all relevant marine science disciplines. This goal was specifically addressed during the 1st Baltic System workshop hold in 2006 and is planned to be continued during the forthcoming 2nd Baltic System workshop. The research themes and approach outlined below are of direct relevance for BALTEX and a close cooperation is a prerequisite for success. It is furthermore expected that this activity will impact on the planning of FP7 research calls under theme 2 and 6 of the programme "Cooperation" and especially calls issued under the BONUS + and article 169 initiative.

6. Developing a Baltic Sea research programme

The aim of the research programme is to identify, quantify and model major processes governing the response of the Baltic Sea system to climate and anthropogenic forcing with the ultimate goal to enhance our predictive capabilities on the energy cycle and mass transport as well as food web dynamics and utilisation of marine living resources. Accomplishment of this goal critically depends on our understanding of interlinked physical/chemical/biological processes and system feedback mechanisms on all trophic compartments and this requires integration of the various marine science disciplines.

A first step will be to describe the effect of changes in primary forcing conditions on various system components and the propagation of the effect to neighboring trophic compartments and through the food web. Secondly, the aim is to disentangle natural and anthropogenically induced variability and apply available knowledge to model scenarios of change, i.e. the effects of: i) climate, ii) nutrient and contaminant loading, iii) fisheries, and iv) other anthropogenic activities. Finally, to be able to meet management and policy demands, management measures need to be identified that monitor when set environmental targets are reached, and not limit the outcome to an evaluation of the consequences of a management action.

As a first step in this direction, the 1st Baltic system workshop identified scientific challenges related to the improved understanding of (i) the physical system and climate change, (ii) biogeochemistry: sediments and material cycles, nutrients and primary production, (iii) remineralization and nutrient regeneration, the microbial loop and microprotists, (iv) meso-zooplankton population dynamics, and (v) fish production. Special emphasis was given to the identification of crucial gaps in understanding of key ecosystem processes, and the impact of climate and anthropogenic forcing.

As s second step a reconstruction of the ecosystem in the last century is envisaged. Most biological data presently available for the Baltic Sea date back at the longest to the 1960s, in general to the early 1970s only. Consequently, the data represent potentially only a subset of states or regimes the ecosystem can display. Additionally, the covered period is characterized by heavy anthropogenic influence, both through pollution and fishery. For successful ecosystem management, a baseline regime representing an anthropogenically (as much as possible) undisturbed situation would be desirable. Consequently, reconstruction of the ecosystem back in time is necessary. Due to data limitations, this goal can only be achieved through a combination of data rescue and compilation activities, time-series data analyses and various modelling approaches. To accomplish this goal, we suggest formulating a project as a cooperation of BALTEX, EUR-OCEANS, GLOBEC, IMBER and other interested parties to be structured into 2 phases: a pilot phase heading for an ecosystem reconstruction back to the 1960s, and a hindcast-phase heading back to 1900.

A further step targets application of available knowledge and models to study different scenarios of change, e.g. effects of (i) climate change such as meteorological influence on trophic levels, (ii) changing loads, i.e. nutrients and (iii) change fishing pressure. The models should be used not only for scenario predictions, but also for designing field experiments. The interaction between modeling exercises and empirical studies should be enhanced by planning a Baltic Experimental year. This should include process studies to identify the gaps in knowledge and models, e.g. coast-offshore exchange fluxes and pathways of water masses, nutrients and organisms in their different life stages.

7. Cooperation with BALTEX

Intensified cooperation between BALTEX and EUR-OCEANS is suggested on 1) future workshops to develop the Baltic Sea research programme, 2) project planning and initiation to concretely define common research activities, e.g. under BONUS including planning of a Baltic Experimental year and 3) common education efforts, e.g. in relation to planned summer schools.

Another good opportunity to integrate the Baltic Sea science are conferences. EUR-OCEANS is thus happy to co-sponsor the 5th Study Conference on BALTEX. The scientific topics of the meeting largely overlap with the EUR-OCEANS scientific goals, and especially the impact of climate variability on the Baltic ecosystem and the development of regional coupled models are key focus areas for the future cooperation.

References

http://www.eur-oceans.eu/marine_systems/bs/

Köster, F.W., Möllmann, C. and Olsson, A. (editors). 1st EUR-OCEANS Baltic System workshop on developing an integrated view on the Baltic Sea ecosystem: Challenges for modeling, pp. 1-36, 2006.

Climate Change Impacts on the Ecosystems of the North Sea and Relevance to the Baltic: Evidence for Past Variability and Future Prognosis.

Philip C. Reid

Sir Alister Hardy Foundation for Ocean Science, The Laboratory, Citadel Hill, Plymouth, PL1 2PB, UK, pcre@sahfos.ac.uk

Partnership for Observation of the Global Oceans (POGO), Sir Alister Hardy Foundation for Ocean Science and the University of Plymouth

Plankton are sensitive indicators of environmental change that are generally little impacted by anthropogenic factors other than eutrophication in near shore marine waters and in the Baltic. A large volume of information at monthly sampling intervals is available on planktonic variability in the North Sea since 1931 from the Continuous Plankton Recorder survey. Changes since this date, with some data from other sources back to the beginning of the 20th century, will form the backbone of the evidence for the presentation. Comparisons will be drawn with time series information available from the Baltic and reference made to variability and possible links to climate change in other components of marine ecosystems, including fisheries and intertidal fauna. Strong and statistically significant relationships have been demonstrated between plankton measurements from the CPR survey and sea surface temperature including for example the seasonal timing of occurrence of dinoflagellates against temperature and a more complicated relationship that shows that phytoplankton abundance increases in colder regions as temperatures rise and in contrast reduces in warmer regions.

In the last two decades there have been a number of inflow events into the North Sea of warmer water plankton, these occurrences seem to be increasing and bringing in increasingly rare species from further south. To the west of the British Isles warmer water plankton has moved north by 1000 km in 40 years and boreal species have retreated to the north. Fish species have shown similar patterns. In the Northeast Atlantic (including the North Sea) chlorophyll levels have increased by 60% annually and 80% in winter months. The implications of these events for the ecosystem and possible downstream effects on the Baltic will be discussed and placed within the context of current knowledge on climate change. The presentation will end with an assessment of the likely impact of a predicted 3° C global temperature increase by 2100 (based on the mean value of the climate change models used by the International Panel on Climate Change in their recently published summary report), and associated ocean acidification, on the ecosystems of the North and Baltic Seas.

Long-Range Transport of Polycyclic Aromatic Hydrocarbons Over Europe and their Deposition into the Baltic Sea

Armin Aulinger, Volker Matthias and Markus Quante

GKSS Research Center, Max-Planck-Strasse 1, 21502 Geesthacht, Germany, armin.aulinger@gkss.de

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are semivolatile, lipophilic persistent organic pollutants (POPs), which originate primarily from incomplete combustion of organic material. Surveys have revealed that a variety of PAHs possess a high carcinogenic potential to animals and humans (ATSDR, 1995) and are bio-accumulated in the food chain. They can be transported over long distances in the atmosphere resulting in a widespread distribution across the earth, including regions where they have never been used. Due to their toxic and ecotoxic characteristics they pose a threat to humans and the environment, and therefore the international community has called for actions to reduce and eliminate the release of POPs, such as the Protocol to the UN-ECE Convention on Long-range Transboundary Air Pollution (CLRTAP) on POPs.

To study the atmospheric transport and deposition of PAHs over Europe our research group uses the Community Multiscale Air Quality (CMAQ) Modeling System developed under the leadership of the US Environmental Protection Agency (Byun and Ching, 1999; Byun and Schere, 2006) as basic model and extended it to treat semivolatile POPs, in particular PAHs. Benzo(a)pyrene (B(a)P) is one of the best investigated PAHs both because of its severe toxicity and its relatively good availability to measurements. In our modeling study it was for this reason used as a marker for carcinogenic PAHs. The release of PAHs into the environment is highly dependent on human activities whereas their distribution over e.g. Europe is driven by their physical-chemical characteristics and meteorological conditions. Thus, to investigate the pathways of PAHs and to assess the threat they may pose to particular ecosystems it is indispensable to apply proper emission data and meteorological fields together with a sophisticated chemical transport model.

2. Model Description

CMAQ is a 3D Eulerian regional model which is in our case configured for the European continent. The entire model domain covers Europe from the Mediterranean Sea to the North Polar Sea and from Iceland to Western Russia with a grid cell size of 54x54 km². The CMAQ system consists of three primary components which are devoted to meteorology, emissions, and chemical transport, respectively. The chemistry transport module is mainly designed for classical air pollutants like SO_2, NO_x, O_3, and particulate matter (PM).

At GKSS the CMAQ systems was extended to cope with the transport of B(a)P in the gas phase and adsorbed to particles (Aulinger et al., 2006). Thereby, special emphasis was laid on considering the mass transfer of B(a)P between the gaseous and the particulate phase. The partition of the compound between the gas and the particle phase as well as its distribution between the Aitken, accumulation and the coarse particle mode is dependent on temperature and particle surface, mass of organic aerosols and aerosol water content in each mode. The physical-chemical properties of B(a)P which determine the partition are hence its liquid vapor pressure, octanol-air partitioning coefficient and Henry's Law constant. Owed to the fact that B(a)P occurs at temperatures prevailing in middle Europe mainly bound to aerosols, the degradation of particle bound PAHs is orders of magnitude slower than those of gaseous PAHs (Esteve et al. 2005) and knowledge about heterogenous reactions of B(a)P is scarce it is treated inert as a first approach.

3. Emissions

Emission data for B(a)P is very sparse and the data is connected with large uncertainties. Van der Gon et al. (2005) published a technical report on emissions of B(a)P and other POPs for Europe that contain yearly bulk emissions projected on a 50 x 50 km² grid in polar stereographic projection for 2000. These data were interpolated to the CMAQ grid with the inverse distance weighting method considering conservation of mass (Figure 1).

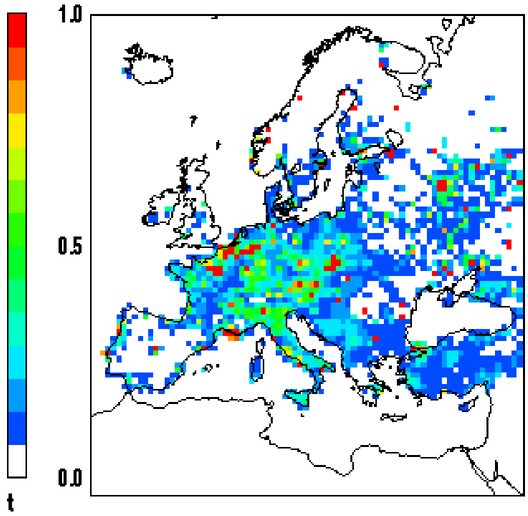


Figure 1. B(a)P emissions in 2000.

The emissions reported by Denier van der Gon are attributed to different emission sectors. Because more than 80 % of the B(a)P emissions emanate from the sector "residential combustion", a strong dependence of the emissions on season is expected. Unfortunately, the emission data base does not give any information on the temporal assignment of the data. To consider the temperature dependence of B(a)P emissions, therefore, emissions from sector "residential combustion" were linearly correlated to the ambient air temperature where the yearly total emissions in each grid cell were kept constant. This resulted in winter emissions to be about a factor of 2.5 higher than the annual average while emissions in summer were only about one tenth of the annual average. Concerning weekly and diurnal cycles that were additionally superimposed on the seasonal variations, emissions from residential combustion follow the same temporal evolution as the CO emissions in the same grid cell while emissions from traffic follow that of NO.

Industrial emissions, as the second important sector follow only weekly but no diurnal cycles.

4. Model Results

To evaluate the model performance monthly mean ground level B(a)P concentrations measured in 2000 at six measurement stations belonging to the Environmental Monitoring and Evaluation Program (EMEP) were compared to modeling results. At most of the sites a good correlation between measured and simulated concentrations of the year 2000 could be observed, where the highest correlation occurred at sites in the vicinity of source regions. The correlation coefficient at Kosetice, Czech Republic was 0.97 and at Preila, Lithuania 0.80. B(a)P as a mostly particle bound substance is primarily deposited near its sources. The good correlation indicates, thus, that the time variation of the emissions applied is sound. Also, at sites further away from the main sources, some correlation between measured and simulated concentrations could be established. As an example, the correlation at Roervik, Sweden was 0.69 which confirms the atmospheric transport processes used by the model. On the other hand, the absolute deviations between measured and simulated means were relatively high. The measured concentrations were on average five times overestimated by the model. The highest discrepancy could be observed at Pallas, Finland where the measured mean concentration in 2000 was 0.006 ng/m^3 whereas the simulated mean concentration was 0.079 ng/m^3. As it is unlikely that this deviation is only caused by omitting the degradation reactions the emissions must probably be revisited.

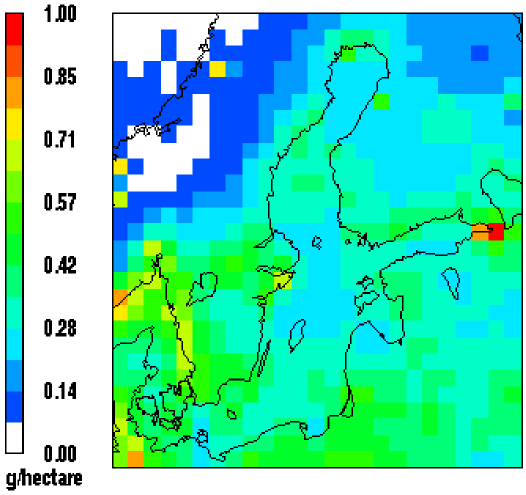


Figure 2. Total B(a)P depositions in 2000 into the Baltic Sea.

Generally, it is evident that the highest B(a)P concentrations and deposition fluxes occur in regions where also high emission rates can be observed. This is the case in densely populated areas like the Rhine-Ruhr area in Germany, and especially in regions where coal and oil are burned without efficient purification of the exhaust gases like the greater Moscow area. At the same time, the deposition rates are also determined by precipitation rates because wet deposition is the dominant sink for atmospheric B(a)P and other PAHs. The total B(a)P emissions in the Rhine-Ruhr area were in 2000 about ten tones. This resulted in a deposition rate of 0.92 g/ha for the year 2000 averaged over this area. Over the Baltic Sea without any emissions – ship emissions are not considered so far – the average deposition rate for 2000 was 0.32 g/ha (Figure 2) which sums up to 13.4 tones direct atmospheric input of B(a)P into the Baltic Sea. The reason is that B(a)P is transported mainly from middle and eastern European regions in northern direction towards the Baltic Sea where it is scavenged by rain water. The dominating influence of rain events on the deposition pattern can be seen from the fact that the highest deposition fluxes occurred in October and November, the months with the highest precipitation rates, and not in December and January, when emissions were at its maximum.

5. Conclusion

By means of numerical modeling the transport and deposition of B(a)P – as a model PAH – over Europe in 2000 was studied. Even if the absolute concentration values appeared to be overestimated the model proved its ability to simulate transport and deposition patterns of B(a)P. These patterns indicated that atmospheric transport from middle and eastern European land sources play a significant role for the input of B(a)P into remote regions like the Baltic Sea. Our further research will be concerned with explicitly studying different emission and weather scenarios to elucidate the conditions for long range transport of B(a)P and other PAHs over Europe. A special emphasis will be laid on emissions from ships.

References

Agency for Toxic Substances and Disease Registry (ATSDR), Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs). Public Health Service, US Department of Health and Human Services, Atlanta, GA, USA, 1995

Aulinger, A., V. Matthias, M. Quante, Introducing a partitioning mechanism for PAHs into the Community Multiscale Air Quality modelling system and its application to simulating the transport of benzo(a)pyrene over Europe, J. Appl. Meteorol., accepted 2007

Byun, D., J.K.S. Ching, Science Algorithms of the EPA Models-3 Community Multiscale Air Quality Modelling System. --EPA report, EPA/600/R-99/030, Office of Research and Development, Washington DC 20406, 1999

Byun, D., K.L. Schere, Review of the Governing Equations, Computational Algorithms, and Other Components of the Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. --Appl. Mech. Rev. **59**, 51-77, 2006

Denier van der Gon, H.A.C., M. van het Bolscher, A.J.H. Visschedijk, P.Y.J. Zandveld, Study of the effectiveness of UNECE Persistent Organic Pollutants Protocol and cost of possible additional measures. Phase I: Estimation of emission reduction resulting from the implementation of the POP Protocol. --TNO-report. B&O-A R 2005/194. Laan van Westenenk 501, P.O. Box 342, 7300 AH Appeldoorn, The Netherlands, 2005

Esteve, W., H. Budzinski, and E. Villenave, Relative rate constants for the heterogeneous reactions of NO2 and OH radicals with polycyclic aromatic hydrocarbons adsorbed on carbonaceous particles. Part 2: PAHs adsorbed on diesel particulate exhaust SRM 1650a. *Atmos. Environ.*, 40, 201–211, 2005

Impact of Anthropogenic Airborne Nutrients to the Bog Ecosystem in the Eastern Baltic Sea Basin

Marko Kaasik[1], Tõnu Ploompuu[2], Elle Meier[3], Ülis Sõukand[4], Helle Kaasik[5], Tiiu Alliksaar[6], Jüri Ivask[6] and Riinu Ots[7]

[1]Institute of Environmental Physics, University of Tartu, Tartu, Estonia, marko.kaasik@ut.ee; [2]Chair of Biology, University of Tallinn, Tallinn, Estonia; [3]Institute of Botany and Ecology, University of Tartu, Tartu, Estonia; [4]Tartu Environmental Research AS, Tartu, Estonia; [5]Institute of Physics, University of Tartu, Tartu, Estonia; [6]Institute of Geology, Tallinn University of Technology, Tallinn, Estonia; [7]Hugo Treffner Gymnasium, Tartu, Estonia

1. Introduction

Raised bog is a widespread landscape type in the Eastern Baltic region, intensely affecting the water and carbon cycles. Accumulation of precipitation water in the peat layers stabilizes the inflow to the Baltic Sea and affects the quality of its water. Bog is one of ecosystems on the Earth, permanently removing the carbon from the atmosphere and depositing it in the peat. Each km^2 of peat cover growing 1 – 2 mm per year removes a few tens of tonnes of carbon from the atmosphere annually.

Because the ecosystem of a raised bog is disconnected from the subsoil water, only nutrients dissolved in the rainwater are available for it. Thus, only species tolerant to extreme lack of nutrients can grow there. The ecosystem as a whole is very sensitive to any additional influx of airborne nutrients. *Sphagnum* species, building up the most of peat mass, make the bog water acidic (pH 3.5 – 4). Due to adaptation to the acidic environment, any alkaline impact can affect the ecosystem dramatically.

2. The human impact

Due to growing industrial, transportation an agricultural activities the concentration of atmospheric aerosol has increased everywhere over Europe during 20th century. The transparency of the atmosphere, mainly depending on the aerosol concentration, decreased during 1930 – 1980 and increased afterwards again due to efficient measures taken to reduce the emissions (*Wild et al*., 2005).

The anthropogenic emissions carry nitrates, sulphates, metals and other chemical species that are nutrients for plants. The biggest concentrated source of airborne nutrients in the immediate neighbourhood of Baltic Sea during 1960 – 1990 was the oil-shale-based industrial complex in the north-eastern part of Estonia, partially extending to the near-border areas of Russia. At the top of polluting activities during eighties the thermoelectric power plants and factories emitted about 400000 tonnes of fly ash and cement dust per year. Most of particles were deposited within 50 km around the sources, thus reaching directly the Gulf of Finland, but traces of oil shale ash were found even in Norway (*Semb et al*., 1995). Nowadays the airborne emissions from the Estonian oil shale industry are reduced down to about 10000 tonnes of fly ash and 50000 tonnes of SO_2 per year.

Both oil shale fly ash and cement dust contain about 50% of SiO_2, the rest of mass is soluble in water and contains alkaline oxides (CaO, MgO etc.), carbonates, sulphates. Thus, the deposited emissions act both as nutrients and reasons of alkaline impact. Unfortunately, raised and transitional bogs together constitute about 30% of the total terrestrial area in the immediate impact zone of Narva (the Estonian and The Baltic) power plants, emitting most of the fly ash.

3. Observational and theoretical methods

Most of the fieldwork was carried out during 1999 – 2006. Four main methods were applied:

1. chemical analyses of snow samples collected from the accumulated snow layer – to quantify the influxes;
2. measurements of pH of bog water – to quantify the alkalising effect of fly ash and cement dust;
3. half-quantitative estimations of frequencies of vascular plant and moss species at 32 monitoring squares, 100 m^2 each – to quantify directly the impact of nutrients influx to the ecosystem;
4. increment drilling of trees (*Pinus sylvestris,* over 600 trees in total) growing in the bogs – to understand growth conditions and possible effects of pollutants influxes in the past.

The measurements were focused on the area extending up to 30 km from the pollution sources in the oil shale mining and consuming area, but reference measurements were carried out in other parts of Estonia, increment drilling also at similar bog landscapes in southern Finland and Lithuania.

To estimate the geographical distribution of fly ash influxes nowadays and retrospectively during entire history of oil shale combustion, the air pollution dispersion and deposition model AEROPOL (Kaasik & Kimmel, 2004) was used.

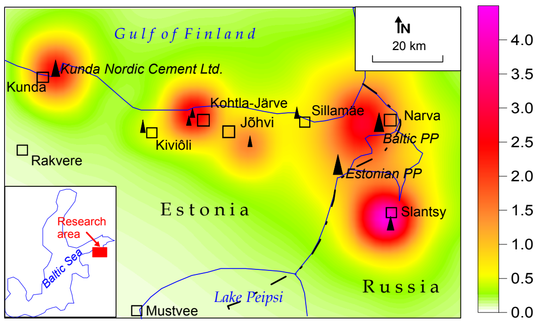


Figure 1. Cumulative deposition load of alkaline particles during 1960 – 2000, kg/m^2. Black triangles mark the emission sources.

4. Influxes

As any airborne effect to the ecosystem appears in the time scale of decades, the influxes were modelled retrospectively for time interval 1960 – 2000, i.e. the era of intense consumption of oil shale. The cumulative fluxes are given in Figure 1. The model estimations for certain years were validated using the snow-based deposition measurements of Ca and other main constituents of fly ash (*Kaasik et al*., 1999).

5. Bog water, plant cover and carbon balance

The pH of bog water was found strongly increasing with the long-term cumulative alkaline deposition (Figure 2). Total number of plant species at sample squares increases with moderate influx and decreases again with extremely high influx due to disappearing of pioneer species with longer succession after *Sphagnum* extinction. The percentage of typical species (*Kannuke & Kask*, 1982, *Kask*, 1982) for the bog decreases dramatically with increasing influx.

As the *Sphagnum* species start to extinct at pH about 5 – 5.5 and disappear almost completely at pH about 6, the peat accumulation ability is seriously damaged in bog covering more than 100 km^2 and probably completely halted at most affected sites. Even decomposition of already accumulated peat can take place there.

The repeated study six years later (in 2006) shows decrease of the number of vascular plants and increase of moss species, including partial revival of *Sphagnum* (more eutrophic species) at heavily affected Kõrgesoo.

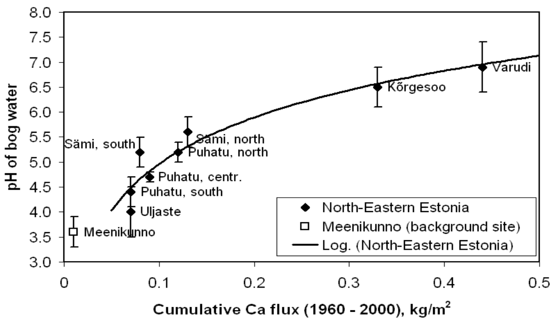


Figure 2. Dependence of bog water pH (in 2000 – 2001) on the calculated cumulative deposition flux of calcium (22% of the mass of fly ash).

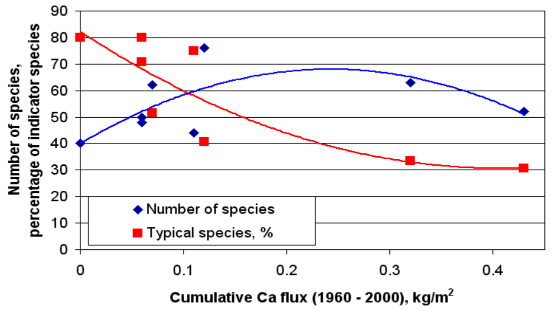


Figure 3. Total number of species and percentage of typical species at 100 m^2 squares of different bogs (ridge-hollow bog, in 2000 – 2001) vs. calculated cumulative deposition flux of calcium.

6. Retrospective of growth conditions

The increment drilling shows sharp growth acceleration of pines at the bogs of North-Eastern Estonia during 1960 – 1980 and deceleration after 1990. Such a sequence is in good agreement with high emissions occurring when Narva power plants were erected and their dramatic decrease in nineties when oil shale combustion was reduced. But some tendency of growth acceleration (although weaker) after 1940 is present also in time series of sites farther than 50 km from power plants, even in Lithuania and Finland (Figure 4). Slow-down due to growth is eliminated, averaging the increment of trees being 70±5 years old in reference year (horizontal axis). Effects of climate change are not excluded, but deposition of anthropogenic nutrients from the air seems a more straightforward explanation.

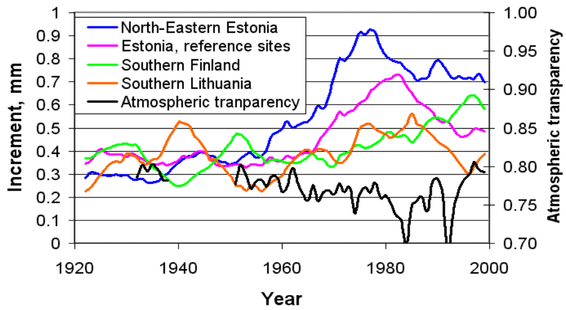


Figure 4. Radial increments of *Pinus sylvestris* at bogs of different regions, compared to the atmospheric transparency coefficient in Tõravere, Estonia (*Wild et al.*, 2005).

7. Conclusions

The ability of bogs to accumulate carbon from the air is damaged under the influence of alkaline deposition, containing nutrients. Thus, the oil-shale-based industrial complex has long-term impact to the atmospheric carbon balance.

The growth conditions for *Pinus sylvestris* have greatly improved at the bogs under immediate impact of nutrient influx from the oil-shale-based energy and cement production, but this tendency is remarkable in the whole Eastern Baltic region.

The bog ecosystem transformed due to alkaline and nutrient influx has some ability to recover, but according to the observed speed, this process can take several decades and its final condition is unclear yet.

8. Acknowledgements

The fieldwork was funded by Maj and Tor Nessling Foundation (Finland), grant 99194, Estonian Science Foundation, grant 5002, and non-profit organisation NGO GAIAA (Estonia). Authors thank all the students of University of Tartu and University of Tallinn, who assisted the fieldwork.

References

Kaasik, M., Kimmel, V., Validation of the improved AEROPOL model against the Copenhagen data set. *International Journal of Environment and Pollution*, 20, 1-6, pp. 114-120, 2004.

Kaasik, M., Liblik, V., Kaasik H., Long-term deposition patterns of airborne wastes in the north-east of Estonia, *Oil Shale*, 16, 4, pp. 315-329, 1999.

Kannukene, L. & Kask, M. A Preliminary List of Bryophytes of Estonian Peatlands, in: *Peatland ecosystems*, 34-38, Valgus, Tallinn, 1982.

Kask, M., A list of vascular plants of Estonian peatland ecosystems, in: *Peatland ecosystems*: 39-49, Valgus Tallinn, 1982.

Semb, A., Hanssen, J. E., Francois, F., Maenhaut, W., Pacyna, J. M. Long-range transport and deposition of mineral matter as a source for base cations, *Water, Air and Soil Pollution*, 85, 1933-1940, 1995.

Wild, M., Gilgen, H., Roesch, A., Ohmura, A., Long, Ch.N., Dutton, E.G., Forgan, B., Kallis, A., Russak, V., Tsvetkov, A. From dimming to brightening: decadal changes in solar radiation at Earth's surface, *Science*, 308, 5723, 847-850, 2005.

The Drift and Dispersion of an Oil Spill in the Baltic Sea Ice Season: Observation of the Runner 4 Case

Keguang Wang[1], Matti Leppäranta[1], Maria Gästgifvars[2] and Jouni Vainio[2]

[1]Division of Geophysics, University of Helsinki, Finland, keguang.wang@helsinki.fi
[2]Finnish Environment Institute, Finland
[3]Finnish Ice Service, Finnish Institute of Marine Research

1. Introduction

On the night of 5 March 2006, the Runner 4, a Dominica-flagged cargo ship, collided with Ship Svjatoi Apostol Andrey and sank in Estonian territorial waters in the Gulf of Finland, Baltic Sea. The ship was carrying a cargo of aluminum and had 102 tons of heavy fuel oil, 35 tons of light fuel oil and 600 liters of lubricant oil in its tanks when it sank.
The purpose of this paper is to report the drift and spreading of the oil spills from the Runner 4 during 6-19 March 2006, and the corresponding weather and ice conditions. The drift and spreading of the oil spills during this period was mainly due to the drift of the ice, and water current beneath the ice.

2. The Runner 4 Oil Spill

The Runner 4 sank at 26°19.84'E and 59°52.92'N (Figure 1), on the night of 5 March 2006. No action was made to combat the spilled oil during the first week. On March 12 the Estonian Border Service established two oil slicks off the northern coast of Parispea peninsula. Figure 1 shows the surveillance of the oil spill made at the noon of 15 March 2006 (HELCOM, 2006). Totally five patches of oil leaked from Runner 4 were identified. The patches #1 and #2 were rather close to the site of the wrecked ship. It was seen as rainbow colored in open water at #1, whereas it was brown oil mixed with ice at #2. All the other oil spills were observed to be as #2. The oil-covered areas of #1– #4 were all close to 0.01 km2, and at #5 it was about 0.09 km2.

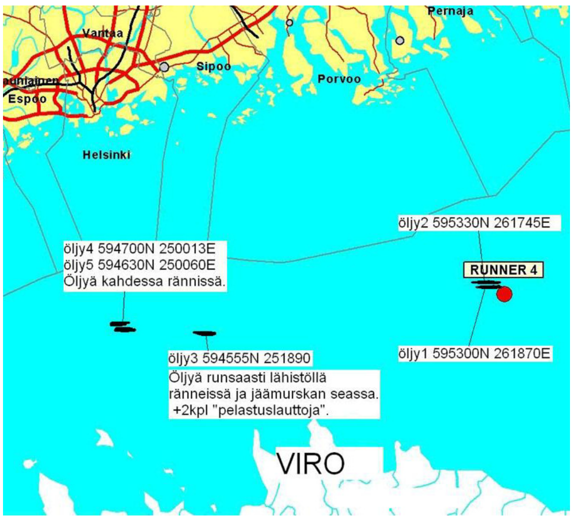


Figure 1. Oil spill observations on 15 March 2006 in the Gulf of Finland. The two patches on the left were in ‘ship channels’ and the middle one tells of ‘much oil around in ship channels and in brash ice’. The width of the gulf is about 100 km.

It can be seen from Figure 1 that the oil spills #1-3 were about 40-50 km from the site of the wrecked Runner 4. This means that the oil spills were drifting in a speed of about 4-5 km/day. In-situ observations show that the spills involved both light and heavy fuel oil, which stained a large area of ice field (Figure 2).

Figure 2. The special oil spill vessel Halli worked to collect oil from the icy sea in the Gulf of Finland on 16 March 2006 (photo by HANNES HEIKURA / HS)

On 19 March 2006, the oily field of ice was pushed south towards the Estonian shore by the wind, and it was not possible to work near the shore for the large oil-combating vessels. As a result, the three Finnish oil-combating vessels returned home (Helsingin Sanomat, 20 March 2006, http://www.hs.fi/english/print/1135219213761). The Finnish ships managed to collect nearly 15 m3 of oil from the sea during the combating operations.

3. Weather and Ice Conditions

Figure 3 shows the wind speed, wind direction and air temperature at Helsinki in March 2006. In general, the wind speed was moderate, mostly in the range of 3-7 m/s. East wind direction was dominant during 5-17 March; and during 18-20 March the wind direction turned to be west. The air temperature during this period was generally below 0˚C, with a mean of about -8˚C.

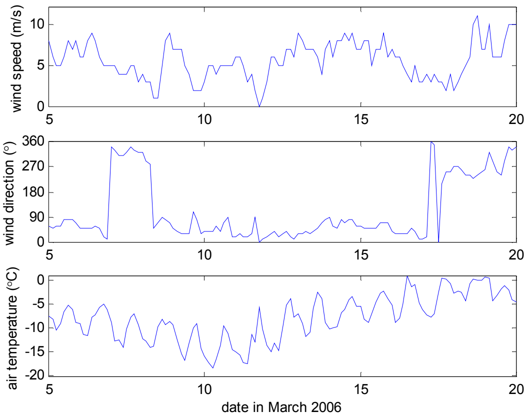
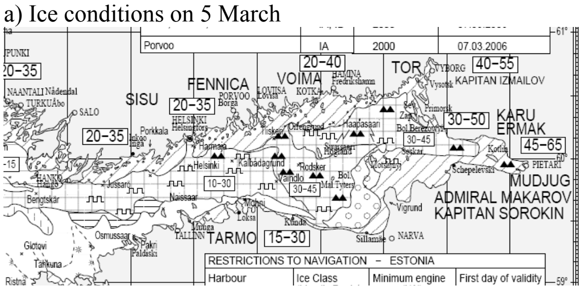


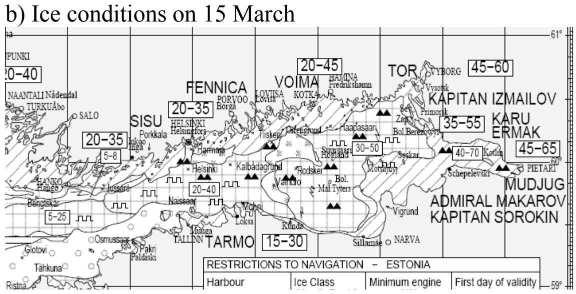
Figure 3. Measured wind speed (m/s), wind direction (deg) and air temperature (ºC) in Helsinki, 5-20 March 2006.

Figure 4 shows the ice conditions during 5–20 March 2006 (FIMR, 2006). In general, the ice thickness increased thicker from west to east. The drift ice was slowly moving towards the west during 5-15 March, consistent with the wind. During 15-20 March, the ice cover moved southeastward. This is particularly significant in the west part of the gulf, ice cover originally on the Finnish side on 15 March moved to the Estonian coast on 20 March. This is consistent with the in-situ combating observations reporting that the oily ice was pushing to the Estonian coast (Helsingin Sanomat, 2006, http://www.hs.fi/english/print/1135219213761).

a) Ice conditions on 5 March



b) Ice conditions on 15 March



c) Ice conditions on 20 March

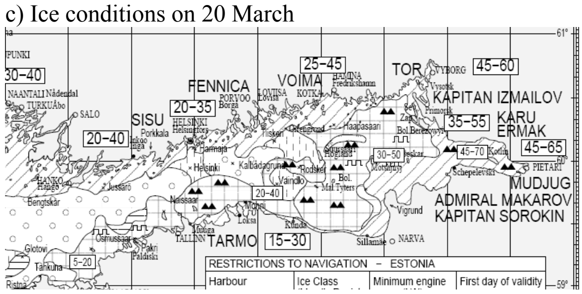


Figure 4. Ice conditions during 5-20 March 2006.

Acknowledgements

The authors gratefully thank the crews of the Finnish Frontier Guard, Captain Ilkka Lahtinen, Pilot Jukka Peitsala, and Operators Juho Ala-Lahti and Jouko Peltoniemi, for the careful observations of the oil spills. This study was supported by the Kone Foundation of Finland and the Maj and Tor Nessling Foundation of Finland.

References

FIMR, Ice Chart, 5-20 March 2006. Finnish Institute of Marine Research, Helsinki, 2006.

HELCOM, Pollution Observation Log. Helsinki Commission, Helsinki, 2006.

High Resolution Atmosphere-Sea Hydro-Ecological Modelling in the Coastal Zone

R. Tamsalu[1], V. Zalesny[2], R. Rõõm[3] and R. Aps[1].

[1]Estonian Marine Institute; University of Tartu; [2]Institute of Numerical Mathematics RAS; [3]Institute of Environmental Physics, University of Tartu.

The coastal zone comprises only 0,5 % of the volume of the world ocean The coastal ocean accounts for about 30% of the oceans primary production, for about 75 – 90% of the global sink of suspended river load and its associated pollutants, as well as for about 80% of the global organic matter burial. About 60% of the world population are living in a stretch less than 60 km from the shoreline; most of the world's largest cities are located at the sea. This area produces food and livelihood for a high percentage of the world's population; thus, these areas are exposed to sever pollution and environmental degradation.
Coupled atmosphere-marine 3D modelling complex FRESCO is used to simulate the hydro-ecological dynamics of the coastal sea and to study the transport of pollution under the different weather conditions. In this study FRESCO modelling complex is used as an operating model representing the best available understanding of atmosphere-sea interactions and the sea hydro-ecological dynamics from which simulated data are sampled by observation model (monitoring simulation). Sampled data are used to evaluate the possibilities to improve the Baltic monitoring design and the forecast of the pollution transport. Environmental sensitivity is evaluated using the methods of inverse modelling based on adjoint equations.
A multidisciplinary numerical model system FRESCO with horizontal grid for atmosphere of some kilometers and for sea are less than hundred meters simulates

- atmospheric dynamics,
- wind waves,
- marine hydrodynamics,
- marine ecosystem,
- oil slicks,
- suspended material transport.

It has been used for practical applications in coastal zones of the Baltic Sea.
Though computational resources have quickly increased, it is still advantageous to pursue cost effective methods for atmosphere-sea modeling to reduce computational expense. This is very important for very high resolution calculations in the modeling of coastal dynamics. We examine the computational advantage feasibility of using

- nested domains calculation
- online-offline modeling,
- splitting-up method,
- size-dependent parameterization of the biochemical reactions.

The aim of this presentation was to study the influence of the wind waves and turbulent mixing via boundary layer dynamics on the coastal hydro-ecological dynamics. Pronounced influence of the wind waves and turbulent mixing on the plankton community, nutrients and suspended material distribution is shown.

The Baltic Sea Carbon Cycle: A Challenge for Research within BALTEX

Bernd Schneider

Baltic Sea Research Institute, Seestrasse 15, D-18119 Warnemünde, Germany
bernd.schneider@io-warnemuende.de

1. Introduction

Marine biogeogemistry is heavily influenced by the physical background setting. Temperature and salinity distribution as well as stratification and mixing which result from atmospheric forcing and the hydrological cycle, have a strong impact on the characterstics and temporal development of the biogeochemistry in the Baltic Sea. Hence it is a logical consequence to integrate biogeochemistry into physical models after these have succeeded to describe the relevant hydrographic features of the Baltic Sea.
Traditionally, biogeochemical modelling is confined to the cycling of nutrients which limit the biomass production. It is suggested to include the formation/decomposition of organic carbon and in particular its interaction with the marine CO_2 system into biogeochemical models. This will allow the simulation of shifts in the Baltic Sea CO_2 and its biogeochemical implications due climate change and anthropogenic emissions.

2. The carbon cycle

The main processes that control the Baltic Sea carbon cycle are presented in Fig. 1. Rivers transport large amounts of total CO_2 (C_T=CO_2+H_2CO_3+HCO_3^-+CO_3^{2-}) and organic carbon (C_{org}) into the surface water. The riverine input of C_T is a consequence of carbonate dissolution in the watershed area which is reflected in the alkalinity (A_T), and subsequent uptake of atmospheric CO_2. Additionally, water exchange with the North Sea affects the budgets of C_T, A_T and C_{org} which constitute the major components of the carbon cycle. Controlled by the availability of nutrients, the surface water C_T is partly converted to C_{org} by plankton growth. After sinking into deeper water layers, most of plankton particles are decomposed by bacteria releasing C_T and nutrients which may return to the surface water by mixing. Only a small fraction of the C_{org} is buried and conserved in the sediments.
The interplay between these processes control the C_T and A_T and thus the state of the CO_2 system. This includes the CO_2 partial pressure (pCO_2) of the surface water which varies seasonally in accordance with the biological production/decomposition of C_{org}. The difference between the surface water and the atmospheric pCO_2 is the driving force for the CO_2 gas exchange and determines whether the Baltic Sea is a sink or source for atmospheric CO_2. Another property of the CO_2 system is the concentration of carbonate ions which is a critical quantity for the survival of organisms that form calcium carbonate shells. Finally, the CO_2 system controls the seawater pH which affects the adsorption of many trace metals by particles and thus the transport into the sediment.

3. State of the art

Experimental studies of the Baltic Sea carbon cycle were mainly focused on specific processes. Moreover, the investigations were widely confined to the Baltic Proper and only very few investigations were performed in the Gulf of Bothnia (e.g. *Algesten et al.*, 2004).

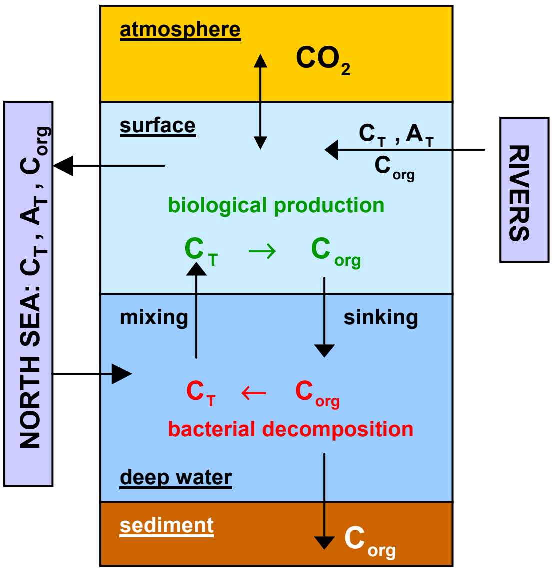


Figure 1. Simplified scheme of the Baltic Sea carbon cycle.

A comprehensive data set is available for the surface water pCO_2 distribution in the Baltic Proper. The measurements were performed with an automated measurement system deployed in 2003 on a cargo ship that commutes regularly at two day intervals between Lübeck and Helsinki. The data for 2005 (Fig. 2) demonstrate the large spatial and seasonal variability. Two characteristic minima were observed and indicate the spring plankton bloom and the biological production generated by nitrogen fixation during midsummer. Based on a CO_2 mass balance, the data were used to calculate the corresponding net biomass production (*Schneider et al.*, 2006).

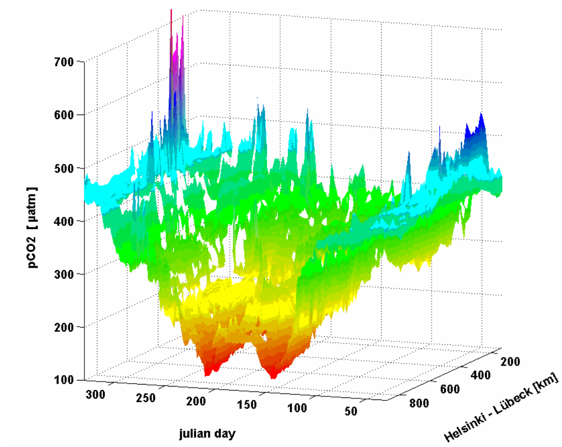


Figure 2. Seasonal distribution of the surface water pCO_2 between Lübeck and Helsinki in 2005.

Data for pCO_2 are also available through measurements of A_T and pH which in some countries are part of the Baltic

Sea monitoring programme. A first evaluation of the data from the past 10 years indicated that the Baltic Proper may be both a sink and a source for atmospheric CO_2 (*Wesslander and Omstedt*, unpublished data).
The alkalinity distribution in the Baltic Sea results from extreme differences in the A_T of riverwater and reflects the advective mixing pattern. Extrapolation of the A_T/salinity diagram to S = 0 for the Gulf of Riga and the Gulf of Bothia (Fig. 3) shows that rivers from limestone-rich central Europe are characterized by high A_T whereas the Scandinavian rivers are low in A_T. Since A_T controls the background C_T, measurements of A_T have a long tradition in chemical oceanography. A compilation of present and historic data (*Mintrop*, 2003) give first hints that changes in the riverine A_T input may have occurred during the last century.

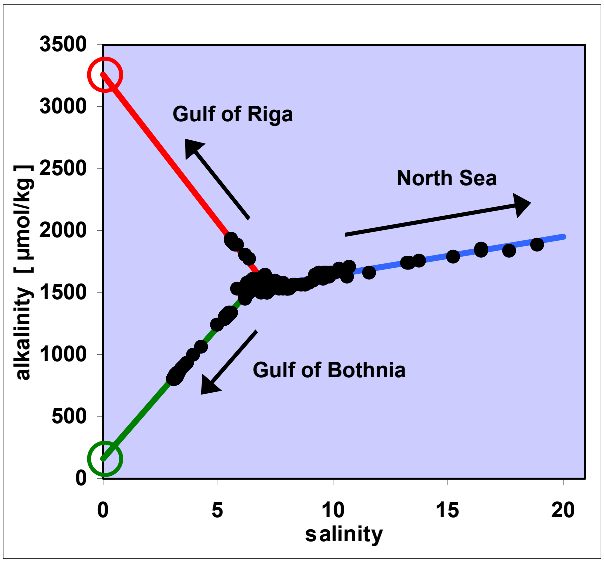


Figure 3. Alkalinity/salinity relationship for selected regions of the Baltic Sea (Data are partly from M. Perttilä, FIMR).

Studies of the CO_2 system in the below-halocline deep water have been performed in the Gotland Basin. Using C_T as an indicator for the mineralization of organic carbon, the mineralization rates and the underlying stoichiometry (C/O/N/P ratios) were determined for periods of stagnation (*Schneider et al.,* 2002).
An attempt to establish a carbon budget for the Baltic Proper which includes all input/output terms (Fig. 1) was presented by *Thomas et al.* (2003). However, considerable uncertainties are associated with this estimate due to the lack of data and questionable assumptions.
Large deficits exist with regard to modelling the carbon cycle. Many different biogeochemical (ecosystem) models have been developed for the Baltic Sea, however, only *Leinweber* (2002) included carbon and the CO_2 system into a 1D biogeochemical model. Using the surface water pCO_2 for the model validation, the results indicated shortcomings of many standard biochemical parameterizations.

4. Research needs

After several years of experimental studies there is now an urgent need for modelling the Baltic Sea carbon cycle and in particular the CO_2 system. The scientific value of such an effort has different aspects:
a.) Modelling the CO_2 system provides additional validation variables for both the biogeochemical and the physical model components. The pCO_2 responds extremely sensitive to biological production/decomposition of organic carbon and is an ideal variable for the validation of biogeochemical process parameterizations. To validate certain aspects of the physical model, the alkalinity may be used. The A_T input by river water varies greatly in the different areas of the Baltic Sea and its regional distribution may be used test the advective mixing in the model.
b.) Climate change and anthropogenic emissions may generate profound changes in the marine carbon/CO_2 cycle which have significant implications for the Baltic Sea ecosystem. An example is "ocean acidification" which is caused by increasing atmospheric CO_2 concentrations and acidic precipitation. The consequence is a decrease of the carbonate ion concentrations which on a long-term may lead to the extinction of organisms that form calcium carbonate shells. Another aspect of the acidification is the lowering of the pH and the decrease of the buffer capacity which are both potential threats to marine organisms. Moreover, changes in the riverine A_T input have to be taken into account when modelling potential shifts in the Baltic Sea CO_2 system. In watershed areas rich in limestone, A_T is increasing with increasing atmospheric CO_2, whereas in other areas acidic precipitation leads to a decrease of A_T in river water. It is also conceivable that the riverine input of organic matter will increase due to changes in the hydrological cycle and temperature. The subsequent mineralization of this material adds CO_2 to the system and modifies the CO_2 system accordingly. Modelling the complex interplay of these processes will provide a tool to estimate the future development of the Baltic Sea CO_2 system and its biogeochemical implications.
c.) Any modelling of pollutants in the sea has to include the carbon/CO_2 cycle. Particulate organic carbon is the main carrier for the export of harmful substances into the sediment and the pH which is a property of the CO_2 system, controls the adsorption of many pollutants by particles.

References

Algesten, G., J. Wikner, S. Sobek, L.J. Tranvik and M. Jansson, Seasonal variation of CO_2 saturation in the Gulf of Bothnia: Indications of marine net heterotrophy, *Global Biogeochem. Cycles*, 18, GB4021, 2004. year

Leinweber, A., Saisonaler Kohlenstoffkreislauf im Oberflächenwasser der zentralen Ostsee, *Dissertation at the University Rostock*, 2002.

Mintrop, L., *Project Report*, 2003, online available under: www.amc.gu.se/research/andersonresearch/CANIBAL

Schneider, B., G. Nausch, H. Kubsch and I. Petersohn, Accumulation of total CO_2 during stagnation in the Baltic Sea deep water and ist relationship to nutrient and oxygen concentrations, *Mar. Chem.*, 77, 277 – 291, 2002.

Schneider, B., S. Kaitala and P. Maunala, Identification and quantification of plankton bloom events in the Baltic Sea by continuous pCO_2 and chlorophyll a measurements on a cargo ship, *J. Mar. Sys.*, 59, 238 – 248, 2006.

Thomas, H., J. Pempkowiak, F. Wulff and K. Nagel, Carbon and nutrient budgets of the Baltic Sea, in *Carbon and nutrient fluxes in continental margins: A global synthesis*, edited by K.K. Liu, L. Atkinson, R. Quinones and L. Talaue-McManus, Springer, 2003.

Simulations of Atmospheric CO_2 Concentration over Europe

Ute Karstens

Max-Planck-Institute for Biogeochemistry, Jena, Germany, ute.karstens@zmaw.de

1. Introduction

The concentration of CO_2 in the atmosphere is influenced by natural as well as anthropogenic emissions. In view of the Kyoto Protocol a detailed understanding and quantification of the present continental scale carbon balance for Europe is needed. This is the major aim of the European Integrated Project CarboEurope-IP (www.carboeurope.org). The project combines measurements of atmospheric CO_2 concentrations and surface fluxes with modelling efforts on different spatial and temporal scales. In this framework regional scale modelling provides a useful tool to investigate the processes underlying the spatio-temporal distribution of atmospheric CO_2 and to establish a link between atmospheric CO_2 concentrations and surface fluxes of carbon on the continental scale.

2. Model System

The regional atmospheric transport model REMO (*Chevillard et al.*, 2002) was used to simulate the temporal and spatial distribution of CO_2 and other trace gases. In the current set-up the horizontal grid resolution is 55 km x 55 km and the model domain covers a large part of the northern hemisphere (north of 30ºN). Sources and sinks of CO_2 were prescribed as input to the atmospheric model. Results from different biosphere models (e.g. Biome-BGC (*Churkina et al.*, 2003); SiB2 (*Denning et al.*, 1996)), anthropogenic emissions from different inventories (EDGAR, *Olivier et al.*, 2005; IER, Institute of Energy Economics and Rational Use of Energy, University of Stuttgart, Germany) and climatological air-sea fluxes (*Takahashi et al.*, 1999) were used to investigate the sensitivity of the simulated atmospheric CO_2 to the surface fluxes. ECMWF analyses were used as initial and lateral boundary data for the meteorological part of REMO. For the tracer simulations lateral boundary conditions were obtained from global simulations with the off-line tracer transport model TM3 (*Heimann and Körner*, 2003).

3. Simulated CO_2 Concentration over Europe

Model simulations provide a detailed picture of the spatial distribution as well as spatial and temporal variability of the atmospheric CO_2 concentration over Europe including the Baltic Sea area. They also allow a separate investigation of the contributions of the different components to the carbon balance. During the growing season, the atmospheric CO_2 concentration over the continent shows high values over western and central Europe and a decrease towards the northeast with low values in Scandinavia and western Russia (Figure 1). This large-scale pattern is dominated by the biosphere-atmosphere interaction but also the strong regional influence of anthropogenic emissions is evident.

The temporal variations of atmospheric CO_2 in the lower part of the troposphere are, during the growing season, largely dominated by strong diurnal variations that are a result of the covariance between the diurnal cycle of the atmosphere-biosphere CO_2 exchange and the daily evolution of the boundary layer mixing regime. At night, CO_2 respired by soil and vegetation accumulates in the shallow nocturnal boundary layer whereas, during the day, the signal of photosynthetic uptake is diluted over a deeper, often convective, air column. Synoptic weather events contribute to the day-to-day variability of the diurnal cycle during the growing season by influencing the photosynthetic activity and hence the CO_2 flux as well as the strength of the vertical mixing in the atmosphere. In winter, the temporal variability of CO_2 is strongly reduced because at that time the biosphere is acting as carbon source.

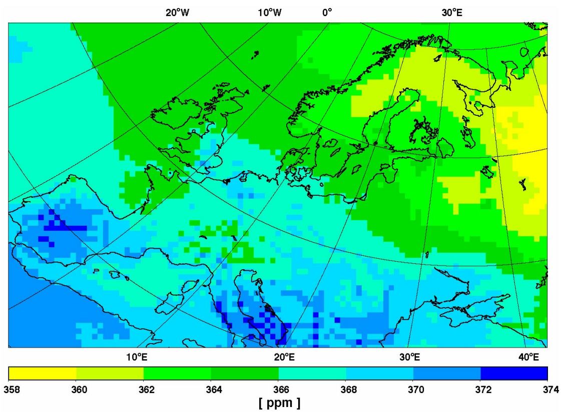


Figure 1. Monthly mean CO_2 concentration over Europe in July 2002 in the boundary layer at 300m above ground, as simulated with REMO using surface fluxes from the SiB2 biosphere model, EDGAR emission inventory and global ocean data.

4. Comparison with Observations

Time series of simulated CO_2 concentrations are compared with measurements at several sites in the area of the Baltic Sea basin and in Europe. Figure 2 (upper panel) shows as example a comparison of the CO_2 concentration in a typical summer month (July 2002) with observations made by the German Umweltbundesamt at the station Zingst (Germany), which is located close to the southern Baltic Sea coast. The observed CO_2 data exhibit intervals of low baseline concentrations and episodes characterized by a large amplitude of the diurnal cycle. Such destinct variability regimes are reproduced by REMO simulations although the amplitude during the first episode is clearly underestimated. In the observations as well as in REMO the variability is low when the wind comes from the sea whereas high variability prevails in situations with low wind speed and/or wind coming from the land. The lower panel of Figure 2 shows the REMO simulated CO_2 offsets (compared to background values) originating from biogenic sources and sinks, fossil fuel emissions and ocean fluxes. The CO_2 variability at this station seems to be dominated in summer by the biospheric component but also the signal of emissions from fossil fuel combustion transported to this station contributes significantly to the total CO_2 concentration. In general, comparisons with continuous observations at several ground stations as well as with some vertical profiles confirm that the model is able to realistically reproduce the characteristics of the observed synoptic and diurnal variations of CO_2.

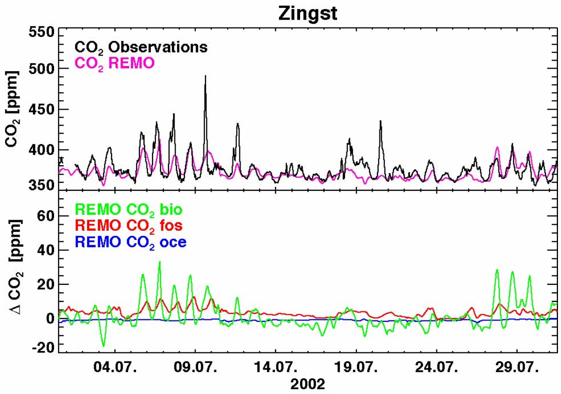


Figure 2. Comparison of continuous hourly CO_2 observations at the station Zingst (Germany) with respective REMO model estimates for July 2002. The upper panel shows the observations in comparison with the model results including all CO_2 flux components, the lower panel shows separately simulated components of the total CO_2 signal (ocean, terrestrial biosphere, and fossil fuel emissions).

References

Chevillard, A., U. Karstens, P. Ciais, S. Lafont, and M. Heimann, Simulation of atmospheric CO_2 over Europe and western Siberia using the regional scale model REMO, *Tellus*, 54B, 872-894, 2002.

Churkina, G., J. Tenhunen, P. Thornton, E. M. Falge, J. A. Elbers, M. Erhard, T. Grünwald, A. S. Kowalski, Ü. Rannik, and D. Sprinz, Analyzing the ecosystem carbon dynamics of four european coniferous forests using a biogeochemistry model, *Ecosystems*, 6, 168-184, 2003.

Denning, A. S., Randall, D. A., Collatz, G. J. and P. J. Sellers, Simulations of terrestrial carbon metabolism and atmospheric CO_2 in a general circulation model., Part 1: Surface carbon fluxes, *Tellus* , 48B, 521-542, 1996.

Heimann, M. and S. Körner, The global atmospheric tracer model TM3. Technical Report No. 5, Max-Planck-Institut für Biogeochemie, Jena, pp. 131, 2003.

Olivier, J.G.J., J.A. Van Aardenne, F. Dentener, L. Ganzeveld, and J.A.H.W. Peters Recent trends in global greenhouse gas emissions: regional trends and spatial distribution of key sources. In: "Non-CO_2 Greenhouse Gases (NCGG-4)". A. van Amstel (coord.), page 325-330. Millpress, Rotterdam, ISBN 9059660439, 2005. Information available online at www.rivm.nl

Takahashi, T., R. H. Wanninkhof, R. A. Feely, R. F. Weiss, D. W. Chipman, N. Bates, J. Olafsson, C. Sabine, and S. C. Sutherland, Net sea-air CO_2 flux over the global oceans: An improved estimate based on the sea-air pCO_2 difference. Proceedings of the 2nd CO_2 in Oceans Symposium, Tsukuba, Japan, January 18-23, 1999.

Upscaling of CO_2 Fluxes

Sven-Erik Gryning[1], Henrik Soegaard[2] and Ekaterina Batchvarova[3]

[1]Risø National Laboratory (DTU), Roskilde, Denmark; (sven-erik.gryning@risoe.dk)
[2]Institute of Geography, University of Copenhagen, Copenhagen, Denmark
[3]National Institute of Meteorology and Hydrology, Sofia, Bulgaria

1. Introduction

The distribution of CO_2 flux to sea and land surfaces is a critical factor in the estimate of the uptake of carbon when derived by mesoscale atmospheric models. In meteorological models, the individual horizontal grid cells often enclose regions of pronounced inhomogeneities: over land in the vegetation and over the sea in the differential pressure of CO_2 between the air and the sea caused by i. e. biological activity in the sea. Neither the land nor the sea surface can be considered homogeneous with respect to sensible and latent heat flux as well as fluxes of CO_2.
The estimation of the spatially integrated fluxes is therefore a central issue in a large number of problems concerning the exchange of CO_2 over land and sea and its parameterization in models.
The idea is to formulate the mass budget for CO_2 from the surface to the top of the atmospheric boundary layer, taking into account the entrainment of air from above the boundary layer caused by the growth of the boundary layer, as well as the effect of subsidence and the uptake of CO_2 by the vegetation. The mass balance reads (Levy et al., 1999):

$$h_1\rho_{b1}C_{b1} = h_2\rho_{b2}C_{b2} + \left(h_2\rho_{b2} - h_1\rho_{b1}\right)C_u + \left(C_u - C_b\right)\rho_u w_s\left(t_2 - t_1\right) + F\left(t_2 - t_1\right)$$

where ρ is molar density of air, C is molar concentration of CO_2, h is the height of the boundary layer, w_s is the vertical wind velocity at the top of the boundary layer (negative of the subsidence velocity), t is time and F is deposition to the ground or uptake by the vegetation or sea surface. Subscript b denotes a quantity within the boundary layer, u a quantity in the free air above the boundary layer and *1* and *2* the beginning and end of the period, respectively. Solving for the uptake of CO_2 reads:

$$F = \frac{h_1\rho_{b1}(C_u - C_{b1}) - h_2\rho_{b2}(C_u - C_{b2}) + \rho_u w_s\,(C_u - C_b)(t_2 - t_1)}{t_2 - t_1} \qquad (1)$$

where F is the flux of CO_2 over the foot-print (upwind area) of the boundary-layer, typically 10 to 100 times its height.

2. Measurements

Micrometeorological measurements including fluxes and concentrations of CO_2 were carried out over a grassland site near Risø (RIMI) and over a beech forest in the centre of Sealand (near the town of Sorø). During an intensive measuring campaign in June 2006 additional measurements were performed.
The growth of the boundary layer as function of time was determined from measurements by radiosondes, that were released at intervals of 3 hours at 06, 09, 12, 15 and 18 local time (=GMT+2). The radiosonde were of make Modem. The sonde measures temperature by use of a thermistor, humidity by a capacitor. A 3D GPS module build into the sonde provides the position, including the height, from which the horizontal wind speed components are derived. Measurements are performed every 1 second.

A Sky Arrow 650 ERA aircraft was used to measure vertical profiles over the RIMI site on 12 and 13 June 2006. The profiles extended from about 100 meters above ground up to 3000 meters. The aircraft carries sensors for measuring a wide variety of atmospheric variables. A nose mounted intake connected to a LiCor 7500 open path infrared gas analyzer allowed fast measurements (50 Hz) of CO_2 and H_2O gas concentrations. Unfortunately the GPS (Global Positioning System) on the aircraft was not operating during the flights which made it impossible to determine fluxes.

Figure 1. The airplane seen from the RIMI site during the experiment.

3. Boundary-layer height

The height of the boundary layer was determined by simultaneously considering several parameters in the radiosonde profile such as jumps in the temperature, wind-direction, wind-speed and humidity. It is also considered that the turbulence inside the boundary layer is more vigorous as compared to the air above, this effect is seen mainly in the fluctuation of the wind direction but also sometimes in the wind speed.
Interpolation of the height of the boundary layer was performed by use of a formula for the height of the boundary layer (for details see Gryning and Batchvarova (1990) and Batchvarova and Gryning (1991))

$$\left\{\frac{h^2}{(1+2A)h - 2B\kappa L} + \frac{Cu_*^2}{\gamma(g/T)[(1+A)h - B\kappa L]}\right\}\left(\frac{dh}{dt} - w_s\right) = \frac{(\overline{\theta' w'})_s}{\gamma}$$

Input to the calculation is the flux of heat $(\overline{\theta' w'})_s$ and momentum u_*, which are measured at the RIMI site, as well as the gradient of the potential temperature γ above the boundary layer. The gradient can be determined from the radiosoundings. The effect of the mean vertical motion, w_s of the air at the top of the boundary layer owing to large-scale subsidence can be estimated when the horizontal divergence is known, for a practical method see Gryning and Batchvarova (1999). The measured and interpolated heights of the boundary layer are illustrated in Fig. 2. Figure 3 shows measured concentrations of CO_2 at the RIMI site.

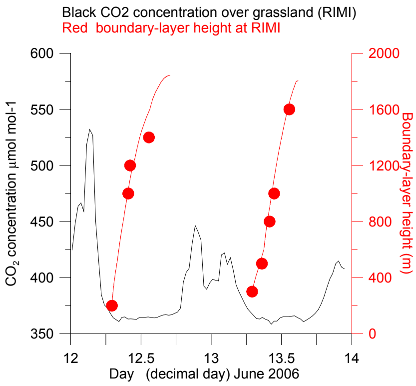


Figure 2. Measured CO_2 concentrations at RIMI, and the height of the boundary layer on 12 and 13 June 2006.

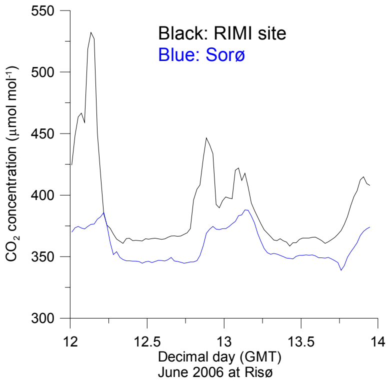


Figure 3. The measured CO_2 concentrations at RIMI/grassland and Sorø/(deciduous forest).

The height of the atmospheric boundary layer can also been seen in the vertical profiles of the CO_2 concentrations that were measured by the airplane.

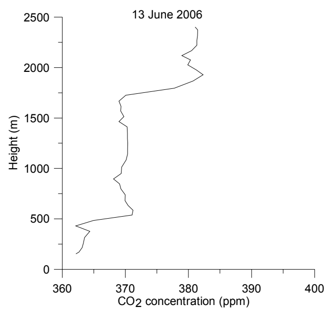


Figure 4. Profile of CO_2 concentration measured by the aircraft near the RIMI site on 13 June ~8:40.

In Fig. 4 it can be seen that the CO_2 concentration within the boundary layer is near constant with height from the surface up to 500 m where a jump of 5 ppm in the CO_2 concentration marks the top of the growing boundary layer. This is in agreement with the estimate of the boundary layer height from the radiosonde measurements, Fig. 2. It can be seen that the next jump takes place at about 1700 m which marks the top of the residual layer (top of boundary layer from the foregoing day). Above the residual layer the CO_2 concentration is about 380 ppm.

4. Aggregated CO_2 fluxes

Using the above parameters the aggregated fluxes were determined by Eq. (1). The results are shown in Figure5.

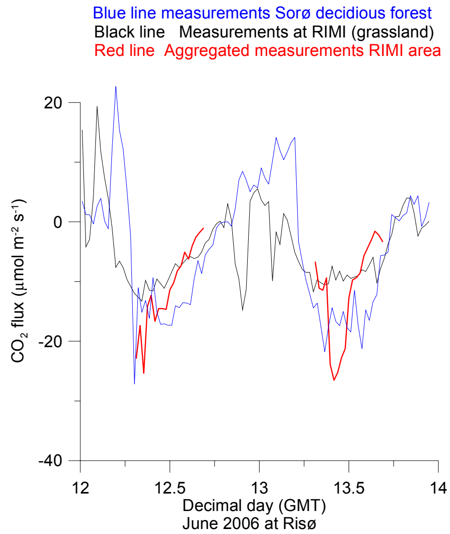


Figure 5. Measured CO_2 fluxes near the surface at RIMI (grassland), Sorø (deciduous forest), and the regional CO_2 fluxes from the boundary layer method.

It can be seen that the aggregated flux of CO_2 in broad terms follow the behavior of the flux of CO_2 at RIMI (grassland) and Sorø (deciduous forest). It is promising that to see that the aggregated flux is comparable not only in size but also in the general diurnal cycle of CO_2 fluxes at RIMI and Sorø.

The required information for use of the boundary layer method can be obtained from information on the concentration of CO_2 at the surface, and profiles of CO_2 concentration in order to estimate the jump at the top of the boundary layer. The information on the growth of the boundary layer can be obtained from wind speed and temperature profiles obtained by radiosoundings when they are performed frequently enough to provide a reasonable detailed structure of the development of the boundary layer. Alternatively data from remote sensing techniques can be used. Measurements of the CO_2 concentration is standard at many places. The jump of the CO_2 concentration at the top of the atmospheric boundary layer can be measured by airplanes.

Acknowledgement

The project is funded by the Danish Research Agency (Sagsnr 21-04-0499) and CARBOEUROPE_IP.

References

Batchvarova, E. and Gryning, S.E (1991). Applied Model for the Growth of the Daytime Mixed Layer. *Boundary-Layer Meteorol.*, 56, 261-274.

Gryning, S.E. and Batchvarova, E. (1999). Regional Heat Flux over the NOPEX Area Estimated from the Evolution of the Mixed Layer. *Agric. For. Meteorol.*, 98-99, 159-168.

Levy, PE, Grelle A, Lindroth A, Mölder M, Jarvis PG, Kruijt B and Moncrieff JB. (1999). Regional-scale CO_2 fluxes over central Sweden by a boundary layer budget method. *Agric. For. Meteorol.*, 98-99, 169-180.

A Comparison between Webb Corrected Humidity and CO_2 Spectra in the Marine Atmospheric Boundary Layer

Erik Sahlée, Ann-Sofi Smedman and Anna Rutgersson

Uppsala University, Department of Earth Sciences, Meteorology, Villavägen 16, 752 36 Uppsala, Sweden, Erik.Sahlee@met.uu.se

1. Introduction

This study compares the spectral characteristics of humidity and CO_2 in the marine atmospheric boundary layer. Such a comparison is made possible by the use of an alternative Webb correction which is applied directly on the 20 Hz data.

2. Density Measurements

Density measurements of CO_2 conducted with an open path instrument such as the LI-7500 are contaminated by simultaneous fluctuations of temperature and water vapour. Analogously, the water vapour density measurements are contaminated by temperature fluctuations (although these measurements less affected). Turbulent fluxes calculated from such measurements have to be corrected to get the true fluxes, commonly called the Webb correction *Webb et al.* (1980).

Likewise, the corresponding spectra and cospectra suffer from the same contamination. However, the traditional Webb correction is applied on the mean fluxes, i.e. it does not correct the spectra.

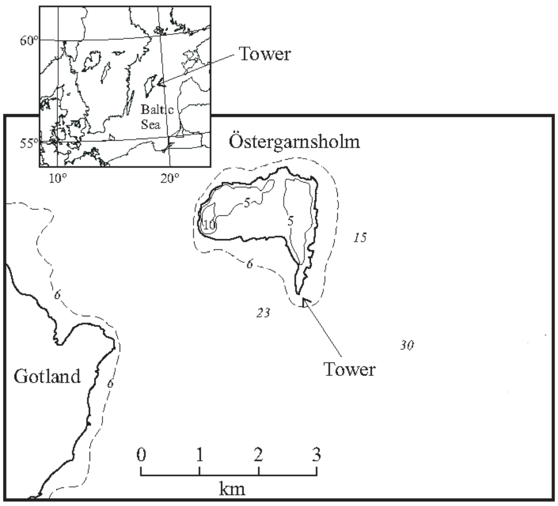


Figure 1. Map of Östergarnsholm and surroundings (modified from Johansson, 2003).

3. The Direct Conversion Method

By converting the high frequency density measurements point-by-point to a signal of mixing ratio relative to dry air one circumvents the need of the Webb correction. In practice, this is done by calculating a time series of the dry air density using high frequency measurements of temperature and humidity. The density measurements are then divided by the dry air density thus removing the contamination of temperature (and humidity) fluctuations in the density signals. This approach is hereafter referred to as the Direct Conversion (DC) method.

The DC method has previously been applied on closed path sensors. Some research groups also apply it on their data from open path sensors (i.e. FLUXNET-Canada project, *Bergeron et al*. 2007) although no evaluation of the method for open-path sensors has been presented.

4. Site and Measurements

Measurements were made at the Östergarnsholm site, a small flat island about 4 km east of the larger island of Gotland in the Baltic Sea (57°27'N, 18°59'E). The map in Figure 1 shows the site with its surroundings. A 30 m tower is situated at the southern most tip of the island from where the measurements are made. With winds from about 50°-220° there is long (>150 km) open water fetch.

At a height of 9 m above the tower base, humidity and CO_2 are measured with an open-path infrared gas analyzer, LI-7500 (LI-COR Biosciences) at 20 Hz. Measurements of vertical wind speed and turbulent fluctuations of temperature is made using a SOLENT 1012R2 (Gill Instruments) sonic anemometer. The Sonic is mounted adjacent to the LI-7500. This instrumental configuration enables the possibility to perform eddy correlation measurements of the turbulent fluxes of CO_2 and humidity.

For the method comparison analysis, data fulfilling the following criteria are included:

1. Winds from 40-350°, to avoid the flow distortion initiated by the tower.
2. Relative humidity < 95%, to exclude situations with condensation on the LI-7500 window.

The remaining dataset consists of 2702 30-min-averages, collected from early May 2006 to late August 2006. Since the nature of the surface has no implications on this particular study data from the both land and sea fetch sectors are considered in the analysis.

For the spectral analysis data from the same period is used although situations with winds from the land sector are excluded.

5. Results,

(i) Method comparison

The Webb correction and the DC method are compared in Figure 2 where the turbulent vertical mass flux of CO_2, F, has been calculated and corrected with the two methods. This figures shows that the methods are equivalent. Similar results are obtained for the fluxes of water vapour (not shown). The mean ratio between F_{Webb} and F_{DC} is 0.995, i.e. considering the entire dataset there is no difference between the two methods.

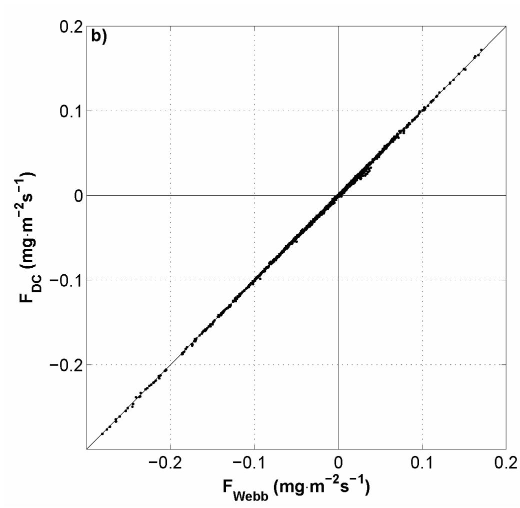


Figure 2. Comparison between the vertical turbulent fluxes of CO_2 using the two methods (F_{Webb} and F_{DC})

(ii) Spectra comparison

Spectra and cospectra are calculated from half hour 20 Hz data and consist of 21 points, each representing a mean spectral estimate for a certain frequency band. This approach is similar to that of *Kaimal et al.* (1972). Energy spectra and are shown in a log-log representation, cospectra are shown in a lin-log representation.

Figure 3 shows a comparison between CO_2 and humidity spectra during unstable stratification. The spectra are mean values of 115 half hour spectra and have been normalized according to *Kaimal et al.* (1972). Symbols according to legend.

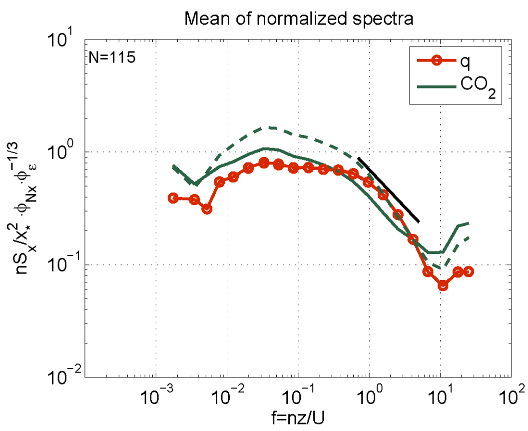


Figure 3. Mean of normalized CO_2 (green) and humidity (red with circles) spectra. Dashed lines shows the spectra calculated from the original (uncorrected) measurements. Solid black line denotes a -2/3 slope.

There is a large difference between the CO_2 spectra calculated from the original measurements and the spectra calculated from the time series corrected with the DC method. This illustrates the importance of using the DC method whenever spectra of CO_2 are studied. However, this effect is not seen for the humidity spectra.

The CO_2 spectra display a somewhat larger low frequency component compared to the humidity spectra. This difference is not as pronounced in the comparison between the normalized cospectra, shown in Figure 4.

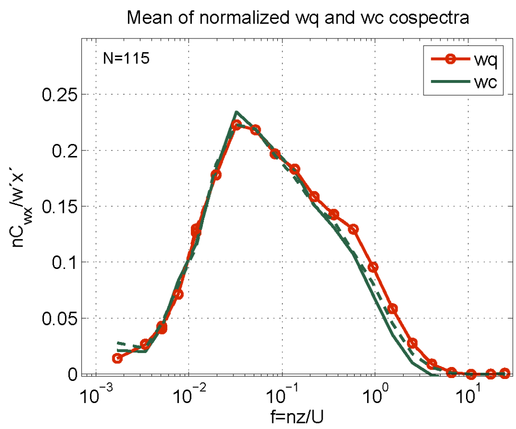


Figure 4. Mean cospectra of wq and wc during unstable stratification. Symbols as in Figure 3.

The wc cospectra have a larger low frequency peak compared to the wq cospectra although the difference is insignificant.

A comparison for spectra and cospectra during stable stratification has been made (not shown). As expected the peak is shifted to higher frequencies for both the humidity and CO_2 spectra, which display a strong similarity.

6. Summary and Discussion

The DC method was shown to be equivalent to the Webb correction. If the vertical fluxes of CO_2 are to be studied the choice of method is arbitrary. However, the DC method provides the possibility to calculate corrected versions of any turbulent moment based on the density measurements. When calculating spectra the DC method has to be applied on the time series.

The CO_2 and humidity spectra during unstable stratification are quite similar although the CO_2 spectra show a more pronounce low frequency peak. The normalized wc and wq cospectra are almost identical. This means that the turbulent transport of CO_2 and humidity are governed by the same eddy structures as intuitively expected.

References

Bergeron, O., H. A. Margolis, T. A. Black, C. Coursolle, A. L. Dunn, A. G. Barr and S. C. Wofsy, Comparison of carbon dioxide fluxes over three boreal black spruce forests in Canada, *Global Change Biology*, 13., pp. 89-107, 2007

Johansson, C., Influence of external factors on the turbulence structure in the boundary-layer, *PhD-thesis,* Uppsala University, 115p, 2003

Kaimal, J. C., J. C. Wyngaard, Y. Izumi, O. Coté, Spectral Characteristics of surface layer turbulence, *Quart. J. Roy. Meteorol. Soc.*, 98, pp. 563-589, 1972

Webb, E. K., G. I. Pearman and R. Leuning, Correction of flux measurements for density effects due to heat and water vapour transfer, *Quart. J. R. Meteorol. Soc.*, 106, pp. 85-100, 1980

The Annual Cycle of Carbon-Dioxide and Parameters Influencing the Air-Sea Carbon Exchange in the Baltic Proper

Anna Rutgersson[1], Ann-Sofi Smedman[1], Erik Sahlée[1], Maria Norman[1] and Bernd Schneider[2]

[1]Department of Earth Sciences, Uppsala University, Sweden, e-mail: anna.rutgersson@met.uu.se
[2]Baltic Sea Research Institute, Warnemünde

1. Introduction

The details of global carbon cycle and specifically the exchange of carbon dioxide (CO_2) between the atmosphere and the surface are presently not fully known. There is an ongoing debate on the relative role of the terrestrial biosphere and the oceans in absorbing some of the emitted anthropogenic CO_2. The total effects of oceans are as major sinks of CO_2. However, for smaller basins like the Baltic Sea as well as productive coastal regions the knowledge is limited. The exchange of CO_2 between the ocean and the atmosphere is a function of the difference in partial pressure of carbon dioxide (pCO_2) at the surface and of the transfer velocity. Biological, chemical and physical processes in the ocean control the partial pressure at the water surface and the transfer velocity is most likely controlled by the molecular diffusion layer in the ocean. The thickness of this layer is controlled by turbulence in the water and in the atmosphere.

2. Measurements

With a unique measuring site in the Baltic Sea (the Östergarnsholm site, Smedman et al., 1999) extended data of direct measurements of the flux of CO_2, the difference in partial pressure between the atmosphere and the ocean, as well as some parameters that probably influences the transfer (turbulence, heat fluxes and waves) gives the opportunity to gain significant new understanding of the processes controlling the transfer of CO_2 (as well as other gases) at the air-sea interface. The station has been running since 1995, with measurement of the flux of CO_2 since 2001 and measurements of the partial pressure of carbon dioxide at the ocean surface since 2005. Partial pressure at the surface of the central parts of the Baltic Proper from the ship FINNPARTNER have also been used to analyze the difference between the central parts of the basin with the regions closer to the coast.

3. Results

The variability of the partial pressure of CO_2 is surprisingly large both in the ocean and in the atmosphere. Figure 1 show an annual cycle of the concentration in the atmosphere (Figure 1a) and of the partial pressure at the surface in the ocean (Figure 1b). The atmospheric concentration varies between 360 and 410 ppm, the partial pressure in the ocean varies from 100 to 900 μatm. There is relatively good agreement between buoy data close to Östergarnsholm (dots) and ship data from the central parts of the Baltic Sea (solid line). There are, however, large differences during some situations. These situations can in general be described by strong upwelling. It has in previous investigations been seen that upwelling has a strong impact on the exchange of CO_2 between the atmosphere and the ocean.

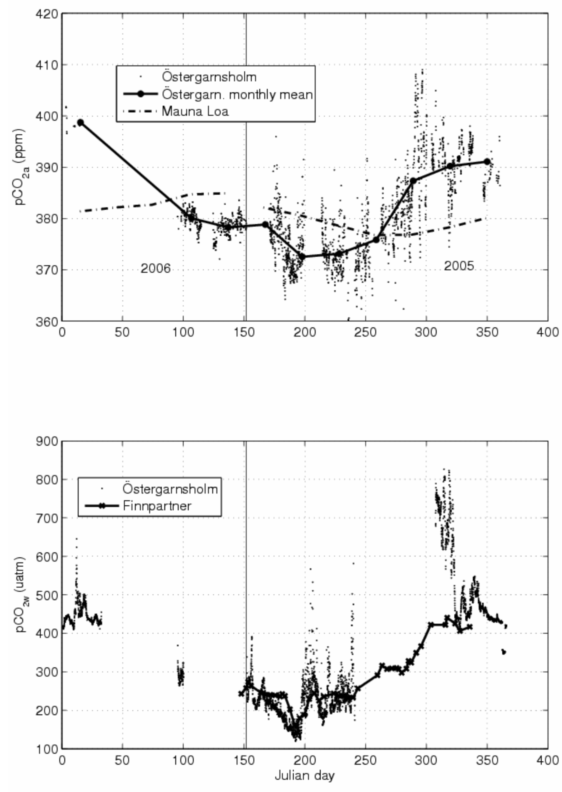


Figure 1. (a) Hourly concentration of CO_2 in the atmosphere from Östergarnsholm. Monthly averages from Östergarnsholm and the station of Mauna Loa on Hawaii. (b) Hourly values of partial pressure of carbon dioxide in the ocean from Östergarnsholm and from the central part of the Baltic Proper from the ship FINNPARTNER.

The air-sea flux of CO2, F_{CO2}, is usually parameterized using the bulk formula:

$$F_{CO_2} = K_0 k(pCO_{2w} - pCO_{2a}) \quad (1)$$

where K_0 is the salinity and temperature dependent solubility constant. k is the transfer velocity. The transfer velocity is usually described as a function of wind speed. In Figure 2 transfer velocity calculated using the expression from Wanninkhof (1992) is compared to the directly measured fluxes from July 2005. The different symbols show different wind directions. It is clear that the calculated and measured fluxes agree reasonably well only for wind direction 80 to 160 degrees (stars in Figure 2). This is when the buoy is in the direct footprint of the measured fluxes. Assuming the calculated fluxes are relatively correctly determined with the expression from Wanninkhof (1992) the very low agreement for the other wind directions indicate that the variability in the ocean is significant during the investigated month and that it is of great importance to use correctly determined partial pressure in the ocean. The flux of CO_2 is thus much more sensitive to footprint area than the fluxes of heat and humidity previously calculated for the same site (Rutgersson et al, 2001).

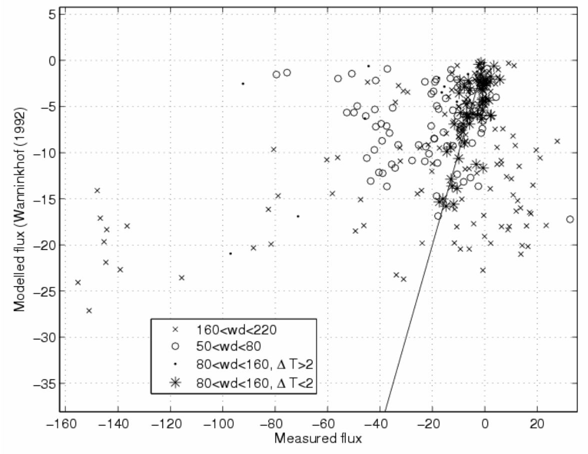


Figure 2. Modelled flux compared to measured flux for different wind directions. Solid line shows the 1:1 relation.

In Figure 3 the transfer velocity is shown as a function of wind speed using three commonly used expressions, Wanninkhof (1992): solid line, Wannikhof et al. (1999) dashed line and from Weiss et al (2006) dashed-dotted line. Measured fluxes from two seasons (summer filled circles and winter open circles) are also shown.

It is not from the investigated data possible to clearly decide if one formulation of the transfer velocity is better than another.

Investigating the importance of uncertainties in the parameters used for the calculation of the fluxes (in Equation 1) showed that uncertainties in the wind speed estimate (the wind speed is included in the calculation of the transfer velocity) have a small impact on the calculated flux compared to using different formulation of the transfer velocity. Realistic uncertainties of the partial pressure of CO_2 in atmosphere have a small impact compared to realistic uncertainties of the partial pressure of CO_2 in atmosphere (not shown here).

4. Conclusions

A land-based system like this can thus be used, with the advantage of giving parameters with a high temporal resolution, which has an advantage when calculating the fluxes. Coastal features can accurately be captured, even if this implies that the calculated flux is not representative for the flux outside the coastal region. The disadvantage is that the proximity to the coast gives variations in the surface values of pCO_2 and it is of great importance to take the flux footprint area into account when analysing the data.

For accurately calculated fluxes it is of great importance to have representative partial pressure of CO_2 for the ocean surface as well as a correct formulation of the transfer velocity. Accuracy of other parameters included in the calculations like the wind-speed estimate, sea surface temperature and the partial pressure of CO_2 in the atmosphere is of secondary importance.

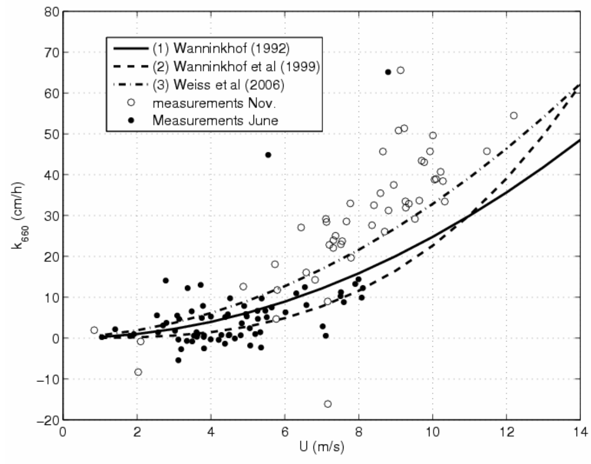


Figure 3. Transfer velocity for different wind speeds as calculated by three different expressions (1: Wanninkhof (1992), 2: Wanninkhof et al (1999), Weiss et al (2006). Filled circles show measurements from June and open circles measurements from November.

References

Rutgersson, A., A. Smedman and A. Omstedt, Measured and simulated latent and sensible heat fluxes at two marine sites in the Baltic Sea. *Bound.-Layer Meteor.,* 99, 53-84, 2001

Smedman, A., U. Högström, H. Bergström, A. Rutgersson, K. K. Kahma and H. Pettersson, A case-study of air-sea interaction during swell conditions, *J. Geophys. Res*., 104(C11), 25833-25851, 1999

Wanninkhof, R. 1992. Relationship between wind speed and gas exchange over the ocean. *J. Geophys. Res* 97:7373-7382, 1992

Wanninkhof, R., and W. R. McGillis. A cubic relationship between air-sea CO_2 exchange and wind speed. *Geophysical Research Letters* 26:1889-1892, 1999

Weiss, A., J. Kuss, G. Peters and B. Schneider, Evaluating transfer velocity-wind speed relationship using a long-term series of direct eddy correlation CO2 flux measurements, *Journal of Marine Systems*, In Press, 2006

Model for the Air-Sea Gas Exchange Through Film-Covered Water

Christoph Zülicke

Leibniz Institute for Baltic Sea Research, 18119 Rostock-Warnemünde, Seestraße 15, Germany
christoph.zuelicke@io-warnemuende.de

Sir Benjamin Franklin stilled the water with a drop of oil. This classical experiment demonstrates the impact of surface films on the dynamics of capillary-gravity waves. These waves play a key role for the air-sea exchange of momentum and passive tracers at moderate wind speeds. While much information is available for the fluxes of momentum, heat and moisture, the correct form of the transfer velocity for slightly soluble gases with small diffusion coefficients such as carbon dioxide is still not finally agreed upon. However, proper parameterizations are required in biogeochemical models and for the interpretation of observations.
A theoretical framework is presented which unifies several theoretical and experimental findings. Central quantity is the dissipation rate. For the turbulent bulk layer the Monin-Obukhov similarity theory is used while Levich's approach is applied to the molecular skin layer. As a result, a consistent description for momentum, heat, moisture and gases is developed extending Brutsaert's recommendations.
The proposed theory includes dependencies of the transfer velocity, surface roughness, dissipation and renewal rates on wind speed, buoyancy flux, diffusion coefficient and film elasticity. It accounts for the effects of wind-stirring, stable and unstable stratification and film coverage. Further, it allows for a discussion of different transfer velocity parameterizations in terms of observed wind speed, surface slope, renewal rate and dissipation rate.

1. Introduction

The transfer problem through the constant flux layer near an interface is defined with the stationary balances for the flow (u) and mass (c) as

$$u_*^2 = (\nu + \nu_t)\frac{\partial u}{\partial z}$$
$$F = (D + D_t)\frac{\partial c}{\partial z} \qquad (1)$$

Here, u_* is the friction velocity, ν the kinematic viscosity while c is the concentration of a passive tracer (for example heat, humidity or a chemical substance), F its flux and D its diffusion coefficient. The goal of this study is the description of transfer of slightly soluble and diffusing substances with a large Schmidt number ($Sc = \nu / D$). They locate their major transfer resistance in the diffusive sublayer of thickness δ and are associated with a transfer velocity of

$$K = \frac{F}{c} = \frac{D}{\delta} \qquad (2)$$

The quantities with the index "t" are the turbulent diffusivities. The central quantity for the turbulent processes is the dissipation rate (ε) which is estimated from the semiempirical balance of turbulent kinetic energy (Monin & Yaglom, 1971)

$$\varepsilon = \frac{u_*^4}{\nu_t} - \gamma_b F_b \qquad (3)$$

with the buoyancy flux F_b and the dimensionless constant $\gamma_b \approx 5$. In the turbulent bulk layer, the Monin-Obukhov similarity theory may be reproduced with Prandtls mixing length ansatz $\nu_t = k\, q\, (z + h)$. The formulation in terms of the so-called universal function ($\phi = u_* / q$) for $z >> h$

$$1 = \phi^4 - \gamma_b \zeta_{MO} \phi^3 \qquad (4)$$

includes the stability parameter $\zeta_{MO} = k\, F_b / u_*^3$. In the molecular skin layer ($z \rightarrow \delta_\nu$), the thickness of the viscose sublayer is associated with the size of the smallest turbulent eddy (the Kolmogorov length)

$$\delta_\nu = \left(\frac{\lambda^3}{k}\frac{\nu^3}{\varepsilon_\nu}\right)^{1/4} \qquad (5)$$

as argued by Levich (1948) and Brutsaert (1975). Using a constant turbulent Schmidt number ($Sc_t \approx 0.85$), the turbulent diffusivity appears to be similar to the turbulent viscosity

$$D_t = \frac{\nu_t}{Sc_t} \qquad (6)$$

The particular form the turbulent viscosity profile which will be specified further below

$$\nu_t = \nu\left(\frac{z}{\delta_\nu}\right)^n \qquad (7)$$

determines the thickness of the diffusive sublayer reading

$$\delta = \left(\frac{Sc_t}{Sc}\right)^{1/n} \delta_\nu \qquad (8)$$

Stratification effects have been discussed in Zülicke (2005) and will not be considered here ($F_b = 0$).

2. Smooth and rough flows

Some results for turbulent wall flow (Monin & Yaglom, 1971): The velocity profile in some distance from a smooth and rigid surface scales with the friction length $\delta_* = \nu / u_*$. The thickness of the viscose sublayer is found using $\nu_t \rightarrow k\, u_*\, z$ together with (3) and (5) reading

$$\delta_\nu = \lambda \delta_* : \text{smooth} \qquad (9)$$

with $\lambda = 11$. The continuity equation for divergence-free flow requires a viscosity profile (7) with $n = 3$ and results in a diffusive sublayer and transfer velocity of

$$\delta = \left(\frac{Sc_t}{Sc}\right)^{1/3} \delta_* : \text{smooth}$$
$$K = \frac{u_*}{\lambda Sc_t^{1/3} Sc^{2/3}} : \text{smooth} \qquad (10)$$

The flow near a rough and free surface is characterized by roughness elements of the height h. They scale the smallest eddies – using $\nu_t \rightarrow k\, u_*\, h$ with (3) and (5) an expression like

$$\delta_\nu = \lambda' \left(\delta_*^3 h\right)^{1/4} : \text{rough} \qquad (11)$$

with $\lambda' = 8$. A free surface allows for horizontal divergences and associated turbulent viscosity profiles (7) with $n = 2$. The diffusive sublayer and transfer velocity are

$$\delta = \left(\frac{Sc_t}{Sc}\right)^{1/2} \delta_\nu : \text{rough}$$
$$K = \frac{u_*}{\lambda' \mathrm{Re}^{1/4} Sc_t^{1/2} Sc^{1/2}} : \text{rough} \qquad (12)$$

with the roughness Reynolds number $Re = h / \delta_*$.
These results can also be represented as roughness lengths (z_0) due to $u = u_* / k \ln(z / z_0)$ as

$$z_0 \approx \begin{cases} \dfrac{\delta_*}{7} & : \text{smooth} \\ \dfrac{h}{25} & : \text{rough} \end{cases} \tag{13}$$

Concentration profiles can be parameterized with the mass roughness length (z_c) due to $c = F / u_* Sc_t / k \ln(z / z_c)$

$$\begin{aligned} z_c &= z_0 \exp\left(-\frac{k}{Sc_t}\left(\frac{c_b}{c_*} - \frac{u_b}{u_*} \right) \right) \\ &= z_0 \exp\left(-\frac{k}{Sc_t} BT \right) \end{aligned} \tag{14}$$

BT is the expression listed in Brutsaerts (1975) table which appears in our derivation as (15)

$$BT \approx \begin{cases} \lambda\left(Sc_t^{1/3} Sc^{2/3} - Sc_t\right) & : \text{smooth} \\ \lambda' \operatorname{Re}^{1/4}\left(Sc_t^{1/2} Sc^{1/2} - Sc_t\right) & : \text{rough} \end{cases}$$

Note, that the form is similar to Brutsaert with the advantage of a smooth transition from *c* to *u.*

3. Impact of ripples and films

In order to take into account the roughness effect of waves we relate the roughness elements to wave properties. If gravity waves are in equilibrium with the wind forcing

$$u_*^2 = gh \tag{16}$$

the familiar Charnock relation is reproduced ($h = u_*^2 / g$). Smaller capillary waves are arising from the boundary conditions at the sea surface. The normal pressure due to surface tension

$$p_0 - p + 2\eta \frac{\partial w}{\partial z} = \sigma \frac{\partial^2 \zeta}{\partial x^2} \tag{17}$$

is balanced by the static pressure and the *z-z*-component of the viscose stress tensor. This balance causes transversal capillary-gravity (Laplace) waves with the inviscid dispersion relation

$$\omega_0 = \left(g k_h + \sigma' k_h^3\right)^{1/2} \tag{18}$$

($\eta = \rho\, \nu$ and $\sigma = \rho\, \sigma'$). Longitudinal elastic (Marangoni) waves are bound by the tangential pressure component and the x-z-component of the viscoss stress

$$\eta\left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right) = e \frac{\partial^2 \xi}{\partial x^2} \tag{19}$$

where the elasticity coefficient $e = \partial\sigma/\partial \ln A$ appears. For the coupling of these waves with turbulence the Levich & Davies (1966) concept of "dynamic thrust" is used: A turbulent eddy in the water approaches the surface and transfers its energy to capillary waves and dissipative processes according to

$$u_*^2 = \frac{\sigma'}{h} + \frac{\lambda_{eff}\, \nu u_*}{\delta_v} \tag{20}$$

We propose the effective parameter

$$\begin{aligned} \lambda_{eff} &= \frac{\lambda e_0' + b e'}{e_0' + e'} \\ &\approx \begin{cases} \lambda & : \text{clean} \\ b & : \text{film} \end{cases} \end{aligned} \tag{21}$$

with b = 100 and the above-introduced smooth-surface λ which was not present in Davies theory. Another difference to Davies theory is the relation between viscose layer and roughness (11) and the use of elasticity instead of excess tension as suggested by Frew (1997). In order to complete (21) we suggest from dimensional considerations

$$e_0' = \nu u_* \tag{22}$$

4. Consequence for observations

If the film elasticity exceeds the critical value (22) the relative transfer velocity may drop from the clean rough (12) to the film-covered smooth regime

$$\delta_v = \lambda' \left(\delta_*^3 \frac{\sigma'}{u_*^2} \right)^{1/4} \to b\delta_* \tag{23}$$

The associated ratio of transfer velocity is

$$\frac{K(\text{film})}{K(\text{clean})} \approx \frac{\lambda'}{b} \left(\frac{\sigma'}{\nu u_*} \right)^{1/4} \left(\frac{Sc_t}{Sc} \right)^{1/6} \tag{24}$$

This could be examined in laboratory experiments with systematically varied film coverage and stirring rates. Associated changes in the surface slope may be observed with remote sensing methods. We adopt Phillips (1977) suggestion for a directionally integrated surface height (ζ) spectrum with $B = 2 \times 10^{-3}$

$$\chi = \frac{B}{k_h^3} \tag{25}$$

Integration from the peak wavenumber ($k_{peak} = 2\pi g / u_*^2$) to the viscose wavenumber ($k_v = 2\pi / \delta_v$) leads to the Charnock length (16) in the mean squared height

$$Z^2 = \left\langle \zeta^2 \right\rangle \sim \left(\frac{u_*^2}{g} \right)^2 \tag{26}$$

A logarithmic relation is derived for the mean squared slope

$$\begin{aligned} S^2 &= \left\langle \nabla \zeta^2 \right\rangle = B \ln\left(\frac{k_v}{k_{peak}} \right) \\ &= B \ln\left(\frac{u_*^3}{\lambda_{eff}\, g \nu} \right) = 3B \ln\left(\frac{u_*}{u_{*,0}} \right) \end{aligned} \tag{27}$$

According to this model, any ripple will disappear for a friction velocity below $u_{*,0} = (\lambda_{eff}\, g\, \nu)^{1/3}$ which depends on the film elasticity.

References

Brutsaert, W., 1975: The roughness length for water vapor, sensible heat, and other scalars. *J. Atmos. Sci.*, **32,** 2028 - 2031.

Davies, J. T., 1966: The effects of surface films in damping eddies at a free surface of a turbulent liquid. Proc. Roy. Soc. London A, 290, 515 - 526.

Frew, N. M., 1997: The role of organic films in air-sea gas exchange. *The Sea Surface and Global Change*, P. S. Liss and R. A. Duce, Eds., Cambridge Univ. Press, 121 - 172.

Levich, V. G., 1948: Theory of diffusional kinetics of heteorogeneous processes. III. Reactions at the liquid - gas interface. *Zh. fiz. Khimii*, **22,** 721 - 729.

Levich, V. G., 1962: *Physicochemical Hydrodynamics*. Prentice-Hall Inc., London, 700 pp.

Monin, A. S. and A. M. Yaglom, 1971: *Statistical Fluid Mechanics: Mechanics of Turbulence (Vol. 1)*. MIT Press.

Phillips, O. M., 1977: *The Dynamics of the Upper Ocean*. Cambridge University Press, 336 pp.

Zülicke, C., 2005: Air-sea fluxes including the effect of the molecular skin layer. *Deep-Sea Res.* II, **52**, 1220 - 1245.

Set Up of a Thermodynamic Model of Snow, Snow Ice and Sea Ice Evolution to be Coupled with a Biogeochemical Flux Model

Letizia Tedesco[1,2], Marcello Vichi[2], Jari Haapala[3] and Tapani Stipa[3]

[1]University of Bologna, Centro Interdipartimentale di Ricerca per le Scienze Ambientali, via S. Alberto 163, 48100 Ravenna, Italy, letizia.tedesco@studio.unibo.it
[2]INGV – CMCC, Euro-Mediterranean Center for Climate Change, via D. Creti 12, 40128 Bologna, Italy
[3]Finnish Institute of Marine Research, Physical Oceanography Department, Erik Palmenin Aukio 1, 00561 Helsinki, Finland

1. Introduction

A 1-dimensional thermodynamic model has been developed, which is capable of simulating seasonal changes of ice, snow and snow ice thickness. Particular attention has been paid to reproduce the snow ice formation when heavy snow loads cause sea water flooding at the ice-snow interface. Snow ice plays an important role not only because it changes the snow properties and the consequent rate of the ice growth, but also because it creates a suitable habitat for sea ice algae, bringing nutrients where the light is a minor limiting factor (Saloranta, 2000). Micro algae find a larger access to nutrients and more stable environmental conditions in the last centimeters of the ice sheet, but are often limited by thick snow covers that prevent sufficient light to penetrate (Arrigo, 2003). Sea ice ecosystem is still poorly understood, due to sparse observations and complexity of the interactions between environmental factors and ice biota. Ecosystem models can be then a valuable tool to better understand the processes that control the dynamics of the sea ice algal community.

2. Model description and first results

NCEP Reanalysis and ECMWF data have provided: air temperature at 2 m height, total cloud cover, precipitation rate, irradiance, wind speed at 10 m height, specific humidity at 2 m height and at the surface. The observed snow, snow ice and sea ice thicknesses have been provided by the Ice Service at the Finnish Institute of Marine Research.

Following Semtner 0-layer model (Semtner, 1976), the sea ice system consists of one layer of ice and one layer of snow on top. If the ice draft exceeds the ice thickness, snow ice formation is initiated, as in Fichefet and Morales Maqueda (1999). Snow density and compaction are changed accordingly and a new isostatic equilibrium is formulated. No seawater mass is added and snow is compressed to an amount of new snow ice equal to the initial depression below the water line (Schmidt et al, 2004). A schematic draw of the model is presented in Fig.1.

A 1-dimensional heat diffusion equation governs the vertical heat fluxes at the boundaries and between the different layers. The temperature at the bottom of the ice sheet is set constant at the freezing point of seawater. The different layers are supposed to be in thermal equilibrium and the temperatures at the interfaces are derived from the continuity of the heat fluxes. The surface temperature is obtained by linearly approximating the surface fluxes, expanding in a Taylor series and iterating according to the Newton-Raphson method for twenty times with a convergence criterion of maximum 0.5 K between consecutive time steps.

The computation of the total surface fluxes includes shortwave and longwave radiation, sensible and latent heat. When the ice is not covered by snow, a fraction of the penetrating solar radiation is stored in the ice and contributes to the melting. Different albedo values are used for the three layers during the growth and melting seasons. At the ice-water interface a constant value of 5 W/m^2, which is typical for the Baltic Sea (Lepparanta et al., 1997), takes account of the oceanic heat fluxes.

At the bottom, ice either growths or melts according to the net heat flux balance between the oceanic fluxes and conductive fluxes. At the surface, snow and snow ice melt whenever the surface temperature is at the melting point and the rate of melting is determined by the net heat flux balance between the surface fluxes and the conductive fluxes. Snow ice growths according to the balance previously described. Snow accumulates on top whenever the temperature of the air is under the freezing point of snow and an ice layer is already present.

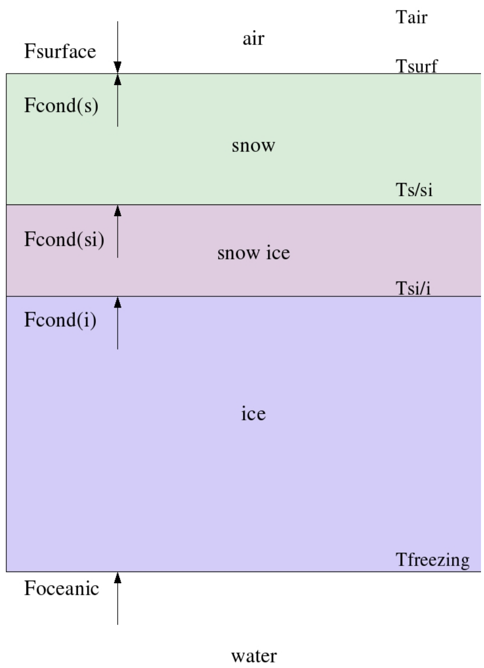


Figure 1. Schematic draw of the thermodynamic model (Fcond's are conductive heat fluxes and T's are temperatures).

The model has been running for many years in Kemi station (65° 39.8’ N, 24° 31.4’ E), located in the northern part of the Bay of Bothnia. An example of the simulated snow, snow ice and ice thicknesses evolution is plotted together with the observations for the years 1979-1980 in Fig. 2. Thickness of the layers and timing of the melting are generally in good agreement with the observed data.

Future effort will be made to better reproduce the timing of ice formation, sometimes some days prior to the observations.

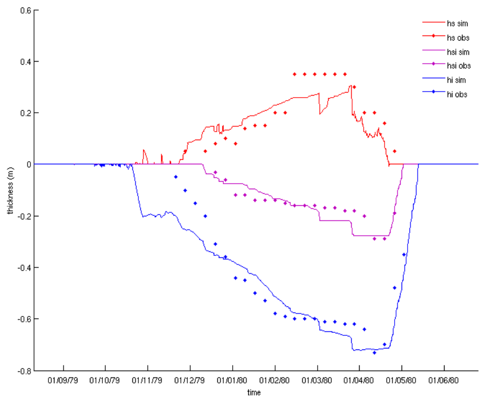


Figure 2. Model results (*hs, hsi, hi sim*) and observed data (*hs, hsi, hi obs*) during 1979-1980 at Kemi.

3. Conclusions and future developments

The model has been implemented in the Baltic Sea, but it is suitable for studies in all the areas where sea ice growth is mainly controlled by thermodynamic processes. The model can be further coupled with a 1-dimensional turbulence model to better resolve the oceanic fluxes and mixing/stratification processes. It can also be coupled with a dynamic model of ice growth for 3-dimensional simulations together with general ocean models. Finally, it is suitable for coupling with biogeochemical flux models to study the fraction of total primary production that resides in the snow and ice sheets and that can be up to 60% in some regions (Gosselin et al., 1997).

The model is currently running in other areas of the Baltic Sea, where observations are widely available, but it will be implemented in Arctic and Antarctic regions once its predictability will be better resolved.

Other geophysical properties, such as salinity, density and brines characteristics will be soon included, since they are closely related to the physiological response of sea ice algae.

Finally, the model will be coupled with the BFM (Biogeochemical Flux Model), a direct descendant of ERSEM (Baretta et al, 1995). The BFM represents the biogeochemical processes of pelagic ecosystem emphasizing the flows of the major biogeochemical elements from the (in)organic pelagic pools through the food web as a function of organisms' demand and trophic relationships (Vichi et al., 2007). It will be a valuable tool to gain a better understanding of the processes controlling sea ice algal distribution and its contribution to the total primary production in relation to phytoplankton dynamics.

Acknowledgments

This study is supported by the VECTOR project, funded by the Italian Ministry of the University and the Scientific Research. Collaboration with the Finnish Institute of Marine Research has started thanks to the "Marco Polo" scholarship awarded by the University of Bologna to the first author. NCEP Reanalysis and ECMWF data have been provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/. The observed snow, snow ice and ice thickness data have been provided by the Ice Service at the Finnish Institute of Marine Research.

References

Arrigo, K.R., Primary production in sea ice. In: Thomas, D.N. and Dieckmann G.S., *Sea ice: an introduction to its physics, biology, chemistry and geology*. Oxford, Blackwell Science, pp. 143-183, 2003.

Baretta, J.W., Ebenhöh, W. and Ruardij, P., The European Regioanl Seas Ecosystem Model, a complex marine ecosystem model, *J. Sea Res.,*Vol. 33, No. 3-4, pp. 233-246, 1995.

Fichefet, T. and Morales Maqueda, M.A., Modelling the influence of snow accumulation and snow-ice formation on the seasonal cycle of the Antarctic sea-ice cover, *Climate Dynamics*, Vol. 15, pp. 251-268, 1999.

Gosselin, M., Levasseur, M., Wheeler, P.A., Horner, R.A. and Booth B.C., New measurements of phytoplankton and ice algal production in the Arctic Ocean, *Deep Sea Res. II*, Vol. 44, No. 8, pp. 1623-1644, 1997.

Leppäranta, M., Shirasawa, K. and Saloranta, T.M., On the oceanic heat flux and ice thickness. In: *Proceeding of the 12th International Symposium on Okhotsk Sea and Sea Ice, 2-5 February 1997*, Okhotsk Sea and Cold Research Association, Hokkaido, pp. 154-159, 1997.

Saloranta, T.M., Modeling the evolution of snow, snow ice and ice in the Baltic Sea, *Tellus,* Vol. 52A, pp. 93-108, 2000.

Schmidt, G. A., Bitz, C., Mikolajewicz, U. and Tremblay, L.-Bruno, Ice-ocean boundary conditions for coupled models, *Ocean Modelling*, Vol. 7, pp. 59-74, 2004.

Semtner, A. J., A model for the thermodynamic growth of sea ice in numerical investigation of climate, *J. Phys. Oceanogr.*, Vol. 6, pp. 379-389, 1976.

Vichi, M., Pinardi, N., and Masina, S., A generalized model of pelagic biogeochemistry for the global ocean ecosystem. Part 1: Theory, *J. Mar. Sys*., Vol. 64, No. 1-4, pp. 89-109, 2007.

Alkalinity in the Baltic Sea During the 20th Century

S. Hjalmarsson[1], L. Anderson[1], L. Mintrop[1], K. Wesslander[1], A. Omsted[1] and M. Pertillä[2]

[1] Göteborg University, Göteborg, Sweden, E-mail to lead author: sofia@chem.gu.se
[2] Finnish Institute of Marine Research, Helsinki, Finland

Outline

The annual river runoff to the Baltic Sea corresponds to a height of ~1 m if evenly distributed over the entire Baltic Sea. Extensive investigations of the Baltic Sea have been performed for over one hundred years, resulting in long time series of hydrographic data. The historical data is used to assess environmental variability of the system, with focus on the strength and the chemical signature of the runoff. An indicator of changes in the chemical signature is total alkalinity, which could be impacted by changes in land use or increased acidification of the precipitation. The latter will increase total alkalinity in runoff originating from land with limestone bedrock and decrease total alkalinity in land poor in limestone. This study is performed partly by evaluating historical data directly and partly by a box model which gives information on the internal water exchange between different regions in the Baltic Sea.

Modelling the Carbon Cycle in the Baltic Sea Surface Water

Anders Omstedt and Karin Wesslander

Göteborg University. Department of Earth Sciences: Oceanography, Box 460, SE-405 30 Göteborg, Sweden.
Anders.Omstedt@gvc.gu.se

1. Introduction

The exchange of CO_2 between the ocean and the atmosphere is a function of the difference in partial pressure of carbon dioxide (pCO_2) at the air-water interface and of the exchange processes in the atmosphere and in the ocean. The partial pressure in the water surface is controlled by biological, chemical and physical processes in the ocean and the exchange processes in the atmosphere depends on the turbulence structure (wind speed, atmospheric stability etc).

The aim is to present a model for the carbon cycle in surface water that integrate the carbon cycle into a coupled model system that includes physical, chemical as well as biological aspects of the Baltic Sea.

2. The model

The modelling approach starts from a time dependent and one-dimensional perspective. The main biogeochemical processes that need to be considered are illustrated in Figure 1. In the figure three basic chemical reactions which need to be considered together with the physical dynamics are indicated. The physical part involves six equations including momentum in x and y-direction, temperature, salinity and two equations for turbulence and has been applied in a number of studies (e.g. Omstedt and Axell, 2003). The biological part includes five equations including oxygen, phosphorus, nitrogen and primary production represented by two types of plankton equations. The dissolved organic matter is calculated through Redfield ratio and controlled by the availability of light and nutrients. In the primary production the effects on the carbon cycle from spring bloom as well as blue-green algae are parameterized. The chemical part includes two equations for the acid and basic carbon from which total alkalinity and total inorganic carbon are calculated.

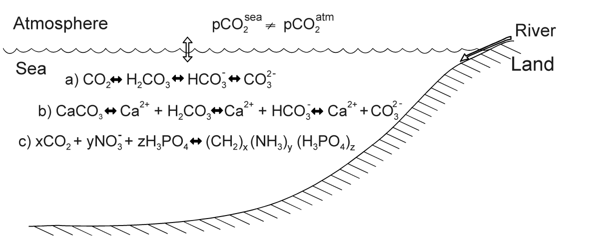


Figure 1. Basic reactions involved controlling the pressure of carbon dioxide (pCO_2) in the surface water. The reactions indicate: a) how carbon dioxide dissolves in sea water and reacts with other carbon ions. b) How limestone generates carbon ions and c) uptake/release of carbon dioxide during primary production/mineralization. With (x:y:z)=(106:16:1) the primary production is according to standard Redfield values.

3. Theory

The partial pressure of CO_2 in the water (pCO_{2aq}) can approximately be written as;

$$pCO_{2aq} \approx \frac{[CO_2]}{K_o} \qquad (1)$$

Where on the right side we have the concentration of carbon dioxide in water and an equilibrium constant that is temperature and salinity dependent.

If the ocean concentration of total inorganic carbon (C_T) and total alkalinity (A_T) are known we can derivate a simplified relation for the partial pressure (Broecker and Peng, 1982). The simplified relation reads:

$$pCO_{2aq} \approx \frac{K_2}{K_0 K_1}\left[\frac{(2C_T - A_T)^2}{A_T - C_T}\right] \qquad (2)$$

Where K_0, K_1, K_2 are equilibrium constants and dependent on salinity and temperature. An important aspect of this simplified equation is that the partial pressure of CO_2 in the water is strongly dependent on the difference between the total alkalinity and the total inorganic carbon. Estimating the maximum error we calculate:

$$\left|\Delta pCO_{2aq}\right| \le \left|\frac{\partial pCO_{2aq}}{\partial A_T}\Delta A_T\right| + \left|\frac{\partial pCO_{2aq}}{\partial C_T}\Delta C_T\right|$$

For A_T and C_T equal to 1500 µmol/kg and 1400 µmol/kg respectively and with an estimated absolute error of 5µmol/kg in each parameter the relative error in the calculated partial pressure according to Equation (2) is about 10%.

The full carbon system can not be solved analytically instead we model total inorganic carbon and total alkalinity and from that we calculate the partial pressure and pH by using iterative methods.

4. Results

In Figure 2, the calculated partial pressure of carbon dioxide using Equation (2) is illustrated during given conditions. The partial pressure increases with increasing temperatures or salinities and with a typical variation of 100 µatm. for temperature change of 10 ºC. or 10 salinity units.

The accuracy of Equation (2) compared to the full model calculation is illustrated in Figure (3). In general we can notice that the simplified model has an error of about 10-50 µatm or about the same size as was estimated from errors in A_T and C_T, Section 3. Even though the simplified equation can be calibrated for different values we however do not use it as both total alkalinity and total inorganic carbon varies considerable in the Baltic Sea. Instead we use the full model.

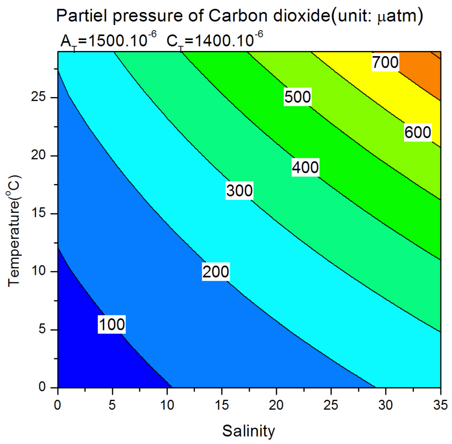


Figure 2. Calculated partial pressure of carbon dioxide for different salinities and temperatures but with constant total inorganic carbon and total alkalinity according to the simplified Equation (2).

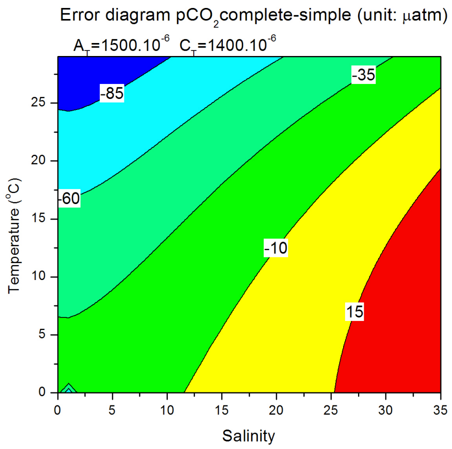


Figure 3. Error diagram showing the difference between our full carbon model and Equation (2).

Several sensitivity tests have been performed testing that the model behaves in a realistic way. The results are also compared with observed data and data calculated from observed data for the Baltic Sea. The model results will be further discussed during the seminar.

5. Discussion

One of the major goals in BALTEX II is to promote the integration of the carbon cycle into biogeochemical models and to include these into coupled regional atmosphere-ocean models (BALTEX, 2006). This task involves many interesting aspects of process understanding, particularly the relation to the primary production and to the river runoff, aspects that needs major research initiatives.

6. Acknowledgements

This work comprises part of the GEWEX/BALTEX and EUROCEANS programmes and has been funded by Göteborg University and the Swedish Research Council under the G 600-335/2001 contract. We would also like to thanks Leif Andersson, Kai Christensen, Agneta Fransson, Bo Gustafsson, Bernd Schneider, Anders Stigebrandt and Gösta Walin for valuable discussions.

References

BALTEX (2006): Baltex Phase II 2003-2012. Science Framework and Implementation Strategy. International BALTEX Secr., Publication, No. 34, pp.92, GKSS, Geestacht, Germany

Broecker, W.S., and T.-H.,Peng, 1982. *Tracers in the Sea*. Eldigio Press. Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York, USA.

Omstedt, A., Axell, L., 2003. Modeling the variations of salinity and temperature in the large gulfs of the Baltic Sea. *Continental Shelf Research* 23, 265–294.

Transferability Studies – Evaluating and Improving Simulated Precipitation during CEOP

Insa Meinke, John Roads and Masao Kanamitsu

Experimental Climate Prediction Center, Scripps Institution of Oceanography, University of San Diego, 9500 Gilman Drive, MC 0224, La Jolla, CA 92093-0224, USA; E-mails: imeinke@ucsd.edu, insa.meinke@gkss.de

1. Introduction

As the dominance of dynamical and physical processes vary in different regions of the globe, parameterization assumptions used for a particular regional model may provide good results for one region but poor results for other regions with contrasting climatic regimes. This sensitivity may become especially important for regional climate-change scenarios. To ensure that regional models are capable of assessing the regional consequences of global climate change, extensive evaluations are needed for many different climatological conditions. Accordingly, transferability studies such as the Inter-Continental Scale Experiment Transferability Study (ICTS; Rockel et al., 2005), whereby a regional model is transferred to several unique regional domains with unique climates, may eventually become an increasingly important evaluation methodology.

The aim of this particular transferability study is to evaluate the ability of the Regional Spectral Model (RSM) of the Experimental Climate Prediction Center (ECPC) to simulate precipitation over a large number of different regional domains. In particular, numerical simulations are conducted for regional climates in tropical, subtropical, mid-latitude, and polar regions, which all include small-scale convective systems and various large-scale circulation regimes such as monsoons, the ITCZ, and mid-latitude storms. These simulations are then systematically compared with GPCP and GPCC gridded observations as well as measurements undertaken at CEOP reference sites.

2. Experiment setup

The RSM was run over seven different computational domains located over the eight different CSEs (see Fig 1.).

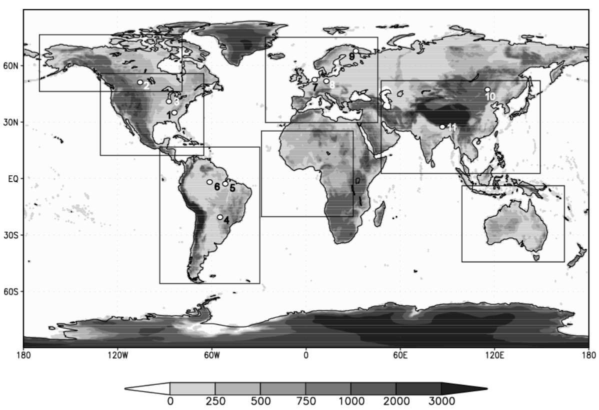


Figure 1. Model domains (rectangles) and CEOP reference sites used in this study: 1 Oak Ridge, 2 Ft. Peck, 3. Bondville, 4 Pantnanal, 5 Manaus, 6 Santarem 7 Cabauw, 8 Lindenberg, 9 Sodankylä, 10 Mongolia, 11 Himalayas.

The runs were carried out on a 0.5 x 0.5° latitude–longitude grid upon a Mercator projection. Initial and boundary conditions derived from NCEP Reanalyses II (Kanamitsu et al., 2002) were used to force the RSM. The initial simulation period was from July 1999 to December 2004. Although the period of interest in this study covers the period from October 2002 to March 2003, the simulations were initiated 3.25 years earlier than this date because the land surface model is required to be equilibrated. The global average surface water of the NCEP Global Spectral Model (GSM) was equilibrated after approximately 3 years (see Roads et al., 1999). Similarly long damping time-scales were used for the surface water in these runs.

3. Evaluation results

RSM simulated precipitation provides a reasonable estimate of seasonal variations in precipitation and spatial patterns of precipitation; however, a positive bias in the RSM simulation of precipitation amount was found over most regions. The bias is associated with ITCZ convection, monsoonal convection, and the forced lifting of air masses over elevated topography. The exception is the BALTEX domain, which does not show a significant domain averaged bias. Sensitivity tests with four different convection schemes showed that either the Kain Fritsch (KF) convection scheme or the Simplified Arakawa Schubert Scheme (SAS) provided the best precipitation simulations for most domains. In those regions where the SAS convection scheme provided the best results, the KF scheme had poor results. On the other hand, in those regions where the KF scheme had the best result, the precipitation simulation using the SAS scheme was only slightly worse. On the basis of these findings we decided to rerun our original long term ICTS runs (July 1999 to December 2004) with the SAS convection scheme. These new long-term runs are now being compared to the previous long-term runs, which used the Relaxed Arakawa Schubert (RAS) convection scheme. Major improvements have been identified over the LBA domain. Also, the annual cycles over the LBA and the AMMA domains were improved in the long-term runs. Further comparisons with other water and energy budget components will be presented at the conference.

References

I. Meinke, J. Roads, M. Kanamitsu: Evaluation of RSM-Simulated Precipitation During CEOP, JMSJ, Vol. 85, Special Issue, pp. 1-22, 2007.

Kanamitsu, M., W. Ebisuzaki, J. Woolen, J. Potter, and M. Fiorino, 2002: NCEP/DOE AMIP-II Reanalysis (R-2). Bull. Amer. Meteor. Soc., 83, 1631-1643.

B. Rockel, I. Meinke, J. Roads, W. J. Gutowski, Jr., R. W. Arritt, E. S. Takle, and . Jones: The Inter-CSE Transferability Study CEOP Newsletter, 2005 (available at: http://www.ceop.net)

Roads, J. O., S. Chen, M. Kanamitsu and H. Juang, 1999: Surface water characteristics in NCEP global spectral model reanalysis. J. Geophys. Res., 104, 19, 307-19,327.

COSMOS - Community Earth System Models

Daniela Jacob, Reinhard Budich, Martin Claussen and Marco Giorgetta

Max-Planck-Institute for Meteorology, Hamburg, Germany, daniela.jacob@zmaw.de

A major enterprise conducted at the international level, and specifically in Europe, in the US and in Japan, is the development of complex Earth System Models (ESM). Such models integrate our knowledge regarding the atmosphere, the ocean, the cryosphere and the biosphere; furthermore ESMs account for the coupling between physical and biogeochemical processes within and between these components. ESMs are needed to understand large climate variations of the past and to predict future climate changes. International programs, including the World Climate Research Program (WCRP) and the International Geosphere-Biosphere Program (IGBP), coordinate Earth System Modeling initiatives through their WFCM and GAIM projects, respectively.

The COSMOS Initiative, a project for Community Earth System Models, which exists now since 6 years, will be presented. COSMOS intends to enable the Earth System modeling community to answer questions they could not have answered before; this will support decision makers.

COSMOS is an interest group and an international network of excellent expertise; this will help to integrate the community. It is agreeing on a Memorandum of Understanding; this will have an aligning function for the members of the COSMOS network. First results from the project will be presented.

Keywords: Earth System Modeling, Climate change, Coupling

Diurnal Variability of Precipitable Water in the Baltic Region

Erko Jakobson[1], Hanno Ohvril[1] and Gunnar Elgered[2]

[1] Institute of Environmental Physics, University of Tartu, Tartu, Estonia erko.jakobson@ut.ee
[2] Department of Radio and Space Science, Chalmers University of Technology, Onsala Space Observatory, Sweden

1. Introduction

The humidity content of the atmosphere, expressed as the integrated columnar mass of water vapour in the zenith direction, usually called precipitable water, *W*, is an important input to environmental models. Water vapour also has a significant influence on the satellite monitoring of the underlying surface and on accurate geodetic GPS applications. However, the vertical distribution of water vapour, with its regional and temporal variations, is not well observed neither is it fully understood (Jacob, 2001).

The number of methods for observation of *W* has increased considerably in 1990s and now includes ground-based and satellite optical soundings, microwave radiometry and wet propagation delay estimation using GPS data. The modern techniques enable a high temporal resolution (some minutes) in the water vapour content. Bouma and Stoew (2001) found, that GPS, radiosonde and microwave radiometer data of precipitable water are in reasonable agreement with each other.

For most countries the classic balloon-borne radiosounding remains a dominant routine method for monitoring of precipitable water. This is the only method for retrospective studies of *W* before 1990. Due to high costs, the network of aerologic radio-sounding stations is sparse and sondes are launched usually only 1–2 times daily. The main launching time, 00 UTC, is for several stations the only daily one. Absence of reliable day-time *W* observations seriously restricts interpretation of routine solar radiation and satellite observations (e.g. calculation of the attenuation of the direct solar beam by aerosol particles, atmospheric correction of satellite images, etc) and raises the question about the diurnal pattern of *W*.

The support of interpretation of actinometric, AERONET (Aerosol Robotic Network) and satellite observations was the main motivation for this study.

2. Databases

GPS data from 32 sites were used (Fig. 1):

a) 21 Swedish stations (SWEPOS), 1996–2005,

b) 10 Finnish stations (FINNREF), 1997–2005,

c) 1 Latvian station, Riga, 1998–2005.

The data analysis and estimation of the GPS signal propagation delay due to the atmosphere and the derivation of the precipitable water is described by Johansson *et al.* (2002) and Gradinarsky *et al.* (2002). The southernmost station is Hässleholm (56.09 N, 13.72 E), the northernmost Kevo (69.76 N, 27.01 E), the westernmost Onsala (57.40 N, 11.93 E) and the easternmost Joensuu (62.39 N, 30.10 E).

From the longitudinal extent of stations, 18.2° (1 h 13 min) follows a ±37 min variation of the local solar noon relative to the region's central meridian, 21°E, where the local noon is at 13:24 UTC.

Averaged data with a temporal resolution of 2 hours are used. For illustration of fast variations in *W*, one case with a temporal resolution of 5 minutes is used.

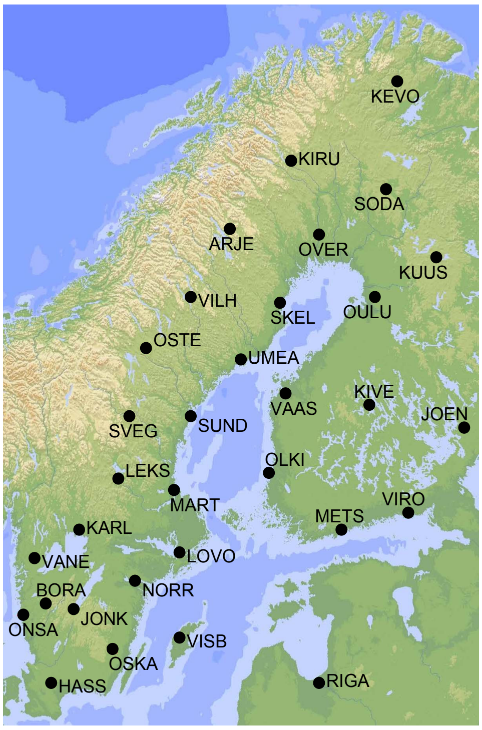


Figure 1. Map of used GPS sites.

3. Diurnal variability of precipitable water

Factors influencing the diurnal changes of *W* can be divided into two groups. The fast *W* variations are due to the changes of air masses. For example in Onsala, during 18th and 19th of June 2002, the *W* decreased during six hours from 40.4 to 13.3 mm with an average trend of –4.5 mm/hour (Fig. 2). Small, regular diurnal variations of *W* are driven by diurnal cycles of radiation and evaporation processes in the atmosphere and on the underlying surface, and by local air circulation.

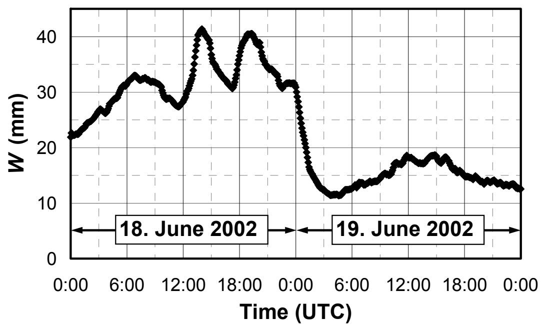


Figure 2. Rapid variations of the precipitable water at the Onsala site during 18th and 19th of June 2002.

In order to study the tendency of the regular diurnal variations in W, we averaged it over four seasons: spring (MAM), summer (JJA), autumn (SON) and winter (DJF). We found the W anomaly – hourly average value minus station seasonal average – for all stations. Anomalies for all four seasons are shown in Fig. 3.

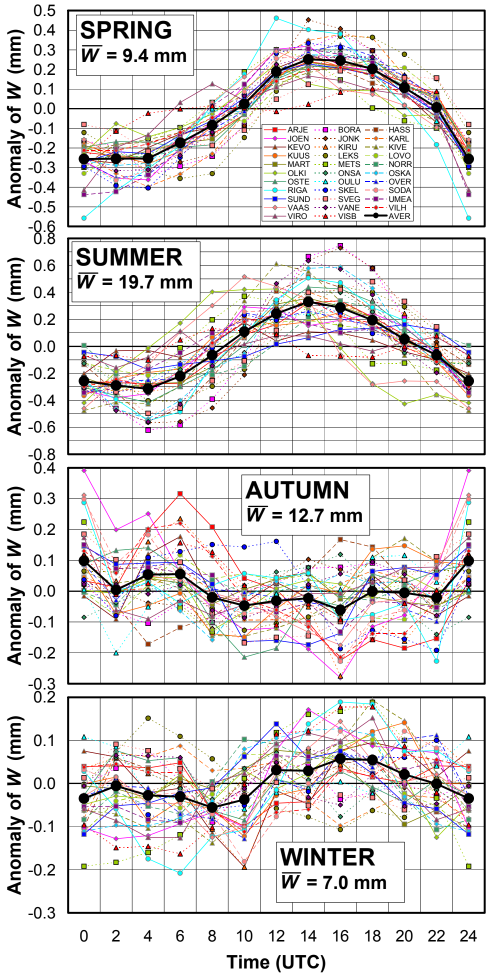


Figure 3. Seasonal mean diurnal anomalies (hourly average value minus station seasonal average) of precipitable water W for the 32 GPS-stations. Bold lines express average anomalies over all 32 stations, $\overline{W}$ is the seasonal diurnal average of W over all stations.

In the spring and in the summer the average diurnal evolution of the anomaly has a regular, almost sinusoidal pattern. The maximal daily value is reached at 14 UTC (about 15:20 Local Solar Time, LST) and exceeds daily mean only by 0.25 mm in the spring, and 0.33 mm in the summer. Minimal W values are from 00 to 04 UTC: in the spring 0.26 and in the summer 0.31 mm lower of the daily mean. The average peak-to-peak value (difference between the highest and lowest W) is in the spring 0.51 and in the summer 0.64 mm.

Diurnal anomalies of W are very weak in the autumn and in the winter with the average peak-to-peak values only 0.16 and 0.12 mm, respectively. Apparently, larger values of cloudiness in the autumn and in the winter smooth diurnal contrasts.

Further we calculated the diurnal standard deviations of W for all stations. For the summer and autumn the results are shown in Fig. 4 as functions of geographical latitude. A linear trend between the latitude and standard deviation of W was statistically significant only for these two seasons, in the autumn the coefficient of determination was $R^2 = 0.20$ and in the summer $R^2 = 0.15$. In the winter and in the spring the trends were insignificant ($R^2 < 0.01$).

As expected, the summer trend is negative – the diurnal W cycle variations at lower latitudes are larger than at the higher ones. This coincides with higher values of W at lower latitudes. However, in the autumn the trend was positive – the variations at lower latitudes were smaller than at higher ones. We do note that the variability is indeed very small and at this stage we cannot rule out that site dependent error sources affect the GPS-data causing this type of systematic patterns.

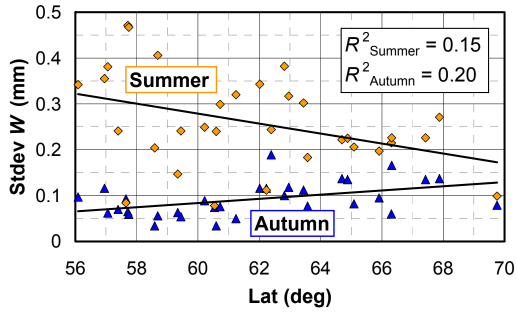


Figure 4. Diurnal standard deviation of precipitable water W as a function of geographical latitude.

4. Acknowledgements

We thank Lars Mueller at the Swedish Meteorological and Hydrological Institute (SMHI) for providing ground meteorological data. The Estonian Science Foundation has supported the investigation by the national grant No. 5857. The Swedish National Space Board has supported the research on GPS meteorology at Chalmers.

References

Bouma, H.R. and B. Stoew, GPS observations of daily variations in the atmospheric water vapor content, *Phys. Chem. Earth (A)*, Vol. 26, No. 6-8, pp. 389–392, 2001.

Gradinarsky, L.P., J.M. Johansson, H.R. Bouma, H.-G. Scherneck and G. Elgered, Climate monitoring using GPS, *Phys. Chem. Earth*, vol. 27, pp. 335–340, 2002.

Jacob, D., The role of water vapour in the atmosphere. A short overview from a climate modeller's view, *Phys. Chem. Earth (A)*, Vol. 26, No. 6-8, pp. 523–527, 2001.

Johansson, J.M., J.L. Davis, H.-G. Scherneck, G.A. Milne, M. Vermeer, J.X. Mitrovica, R.A. Bennett, B. Jonsson, G. Elgered, P. Elosegui, H. Koivula, M. Poutanen, B.O. Rönnäng, and I.I. Shapiro, Continuous GPS measurements of postglacial adjustment in Fennoscandia 1. Geodetic results, J. Geophys. Res., Vol.107, No. B8, 2002.

Examination of Wind Data from Automatic Weather Stations

Sirje Keevallik and Tarmo Soomere

Marine Systems Institute at Tallinn University of Technology, Akadeemia tee 21
Institute of Cybernetics at Tallinn University of Technology, Akadeemia tee 21, soomere@cs.ioc.ee

1. Introduction

The largest amendment to the wind measurements during the latter decades consists in the introduction of high-resolution automatic weather stations. While the older routine (in what follows called traditional) usually only provides the (observer-read) data once in three hours with a resolution of 1 m/s, the new devices are able to provide practically continuous data flow with an accuracy of 0.1 m/s. The use of these data for characterization of climatological wind properties as an extension of the traditional data set needs a care, because the new data are partially obtained with the use of a completely different integration procedure and it is not clear in advance whether their statistical properties coincide with those of the traditional data for the particular measurement site.

We make an attempt to quantify the compatibility of wind properties obtained from continuous high-resolution recordings and traditional wind data (obtained by means of averaging the wind speed over a 10-minute interval and the wind direction over a 2-minute interval once in every 3 hours) at selected observation sites in Estonia. The mean wind speed during a certain time interval obtained from the continuous measurements via simple averaging reflects its true value with a high accuracy whereas the traditional 10-minute mean can be interpreted as an approximation of the true value. Since the traditional data are not available any more, they have been simulated with the use of an integration procedure resembling the routine used from the mid-1960s until the end of the century (*Keevallik et al.* 2007) and called (quasi-)traditional in what follows.

2. Data

Data recorded during 2004–2005 at three sites representing largely different climate regions and wind regimes are used in the analysis. Vilsandi is situated on an island at the coast of the central part of the Baltic Proper. The site is open to the dominating wind directions and well represents the marine wind properties. The mean wind speed (>6 m/s) is the highest of the three sites. Jõhvi is situated in a relatively flat terrain in North-East Estonia, not far from the Gulf of Finland. Yet this site is practically not affected by this relatively large water body, because the mean wind speed here is only about 3.5 m/s. Võru is located in South-Estonia, the most continental region of the country. Winds in this area are affected by a number of small hills nearby. A combination of the continental climate and the high roughness of the surrounding landscape probably are the reasons for the low mean wind speed (about 2.4 m/s) at this site.

3. Wind speed

In many applications the basic wind properties can be assumed as random functions of time and the traditional recordings as their independent samples. These assumptions are usually adequate in cases when the time interval between subsequent observations is large. This was clearly the case in Estonia before the mid-1960s when the wind properties were measured three or four times a day, because substantial correlation between wind properties is lost within about 7–10 hours in Estonia (*Tomson and Hansen* 2001). To a certain extent these assumptions are acceptable for the traditional wind measurement scheme consisting of 8 observations a day.

The mean wind speed calculated from the quasi-traditional and continuous data perfectly coincides for Jõhvi and Võru, and insignificantly differs (by about 0.4 %) at Vilsandi. The differences in the standard deviation of the wind speed are noticeable: about 6 % at Võru, about 4.5 % at Jõhvi, and the smallest (about 3%) at Vilsandi. The standard deviation here has the meaning of the deviation of the 3-hour (10-minute) wind speed from the long-term average wind speed, thus mostly reflects the variability of the physical process.

The distribution of wind speeds is usually approximated with the use of the Weibull distribution. It has the probability density function $f(u) = ku^{k-1}b^{-k}\exp\left[-(u/b)^k\right]$. In the North European climate, the shape parameter $k \approx 2.0$ and the wind speed distribution is close to the Rayleigh distribution. Data from Estonia, Finland and the North Sea, among others, show that the wind speeds are mostly Rayleigh distributed in the *marine* wind climate. For example, the shape parameter $k \approx 2.0 \pm 10$ % at all coastal sites of the Gulf of Finland that are open towards dominating wind directions. At sites sheltered from marine winds by some local features it differs 17–23% from $k = 2$. The shape parameter of the Weibull distribution for the three sites is quite close to 2. The match $k = 2$ is nearly perfect for the continuously recorded wind data in which low winds (speed <0.5 m/s) are interpreted as calms. This finding suggests that the basic feature $k \approx 2.0$ of the North European wind climate may partially result from the limitations of the traditional measurement procedure, in particular, from its rounding routine.

4. Wind speed variations

A convenient measure of the spreading of the 10-minute estimates from the true value is the standard deviation σ_s of its *difference* from the 3-hourly mean. Although this measure also contains a certain portion of the natural wind variability, its primary meaning here is the typical error of the quasi-traditional measurements. It is $\sigma_s \approx 1$ for Vilsandi data and is clearly smaller for the other two sites. Consequently, it is not unexpected that the largest deviations between the 10-minute and 3-hour estimates occur at Vilsandi. The distributions of the differences in question are fairly close to the Gaussian distributions with the same standard deviation; however, the relevant Gaussian distributions (i) underestimate the portion of fairly close wind speeds, (ii) somewhat overestimate the probability of occurrence of deviations slightly exceeding the standard deviation and (iii) fail to describe properly the largest deviations. For example, the maximum difference (7.1 m/s) at Vilsandi more than 7 times exceeds the standard deviation. The probability of such large Gaussian distributed differences would be of the order of 10^{-11}. For the number of data entries (about 5840) the deviations are not expected to substantially exceed the fourfold standard deviation. For Vilsandi data this threshold is exceeded in 15 cases. At Jõhvi and Võru data the largest differences are about $\pm 5.5\sigma_s$ and $\pm 5\sigma_s$, respectively.

The quasi-traditional daily and monthly wind speeds represent $N = 8$ (for a day) or $N = 224\ldots248$ (for a month) estimates of the 3-hour mean wind speed based on 10-minute samples. The standard deviations σ_d of the empirical distributions (that are also approximately Gaussian) of their deviations from the true values are much smaller than the analogous values σ_s for the single measurements. This is an expected feature, because the standard deviation of such estimates generally decreases as $\sqrt{N}$, where N is the number of wind speed estimates used for calculation of the long-term mean. The standard deviations σ_d are slightly smaller than the theoretical predictions. The time scale after which the typical deviation of the quasi-traditional average is expected to lie within the resolution of the new devices (0.1 m/s) is $N > 12.5\sigma_s^2$ days. It is about two weeks at Vilsandi and less than one week at Jõhvi or Võru.

The error distributions are fairly close to Gaussian ones for the sites representing continental wind climate. However, an important non-Gaussian feature consisting in the existence of several large differences between these estimates of the daily mean wind speed is substantial at Vilsandi. This feature may reflect specific properties of marine winds. An expected difference between the two data sets is that averaging over 3 hours reduces the frequency of small wind speeds and calm situations. This is the result of using the whole 180 minutes period instead of a much shorter 10 minutes averaging period and has been documented in a number of previous studies. It implicitly shows that longer perfectly calm periods are infrequent both in marine and continental wind conditions in Estonia.

The continuous wind measurements seem to give a larger portion of higher wind speeds than the quasi-traditional scheme. This is an unexpected feature, because longer averaging times usually result in more narrow distributions of wind speeds.

5. Wind direction

Estimates of the wind direction may be formally interpreted as finding an average wind direction during the observation interval; yet their correct physical meaning consists in determination of the most frequent wind direction during this interval. In the majority of wind situations the wind direction does not vary substantially within a 2-minute interval. The average wind direction over longer time intervals is frequently meaningless and even the 3-hour mean wind direction should be interpreted with a great care. This ambiguity is reflected in rather large scatter of estimates of the wind direction according to the two schemes. The typical difference between the estimates is about 10°. Around 10 % cases show differences over 40° and at times simply opposite wind directions are recorded in the quasi-traditional and the continuous scheme. Such a large spreading is not unexpected, because the standard deviation of wind directions from the formal average typically lies between 20° and 40° (*Gadian et al*. 1998). An unexpected consequence is that the typical difference between the data sets is much smaller (about 10°). It suggests that the instantaneous wind direction during longer time intervals (a few hours) is frequently quite stable and/or concentrated in a narrow range of directions. For Estonian coastal areas the quite a strong correlation between wind properties within many hours was detected by *Tomson and Hansen* (2001). It apparently exists in more continental wind climate as well.

The averaging over 3-hour intervals not only reduces the frequency of calm situations but also at times distorts the wind rose. This reduction evidently reflects a much higher precision of the new devices that allows interpreting of many cases with a wind speed <0.5 m/s as winds from a certain direction. It is interesting to notice that interpreting all cases when the wind speed is <0.5 m/s as calm situations results in the correction of most of the deviations of the quasi-traditional wind roses from the ones obtained on the basis of continuous recordings

6. Conclusions

The performed analysis confirms the heuristically obvious guesses that (i) the traditional (that is, used since the 1960s) wind recording scheme well describes the long-term (scales exceeding a few weeks) variability of wind speed and that (ii) the differences between the traditional and continuous wind speed data are approximately Gaussian distributed. Yet quite large deviations of a few single recordings and daily averages of wind speed suggest that these differences may have certain site-specific features.

The potential influence of the increase of the accuracy of wind measurements on the wind statistics may have both site-specific and global dimension. A certain dependence of the parameters of the Weibull distribution on the threshold for calm situations is natural; however, it is probably not a simple coincidence that the shape parameter is close to 2 when the treatment of calm situations matches that in the traditional recording schemes with a resolution of 0.5 m/s. It suggests that one of the basic features of the North European wind climate – the approximately Rayleigh distributed wind speeds – may partially reflect the resolution of the wind measurements in the past. The distortions in the directional wind distributions also remain reasonable when the recording routine simulates the traditional one in which wind speeds <0.5 m/s are treated as calms. Consequently, a first approximation in compiling long-term data sets containing both the traditional recordings and the results from automatic weather stations consists in treating the situations when wind speed is less than 0.5 m/s as calms.

This study has been supported by the Estonian Science Foundation, Grant 5762.

References

Gadian, A., Dewsbury, J., Featherstone, F., Levermore, J., Morris, K. and Sanders, C. Directional persistence of low wind speed observations, Journal of Wind Engineering and Industrial Aerodynamics, 92, 1061–1074, 2004.

Keevallik, S., Soomere, T., Pärg, R., Žukova, V. Outlook for wind measurement at automatic weather stations, Proc. Estonian Acad. Sci. Eng., 13, 2007, in press.

Tomson, T. and Hansen, M. Seasonal wind stability on the West Estonian coast, Proc. Estonian Acad. Sci. Eng., 7, 3, 212–221, 2001.

Measurements of Solid Precipitation with an Optical Disdrometer

Guido Lempio[1] and Karl Bumke[2]

[1]Deutscher Wetterdienst, Ref. TI 23, Postfach 650150, 22361 Hamburg, Germany, email: Guido.Lempio@dwd.de
[2]Leibniz Institute for Marine Sciences, FB 1, Düsternbrooker Weg 20, 24105 Kiel, Germany, email: kbumke@ifm-geomar.de

1. Introduction

Snow plays an important role in the hydrological cycle and in the global energy budget. Several studies have been carried out to measure precipitation rate and size distribution of solid precipitation (e.g. *Lundberg and Halldin*, 2001). The main problem in measuring snow arises from wind induced flow distortion (*Yang et al*., 1999) yielding errors exceeding 100% in terms of precipitation rates at wind speeds of $10ms^{-1}$. The introduction of precipitation radars has strengthened the interest in using disdrometers because of calibration purposes. A recent study, focused on rain, showed the advantage of optical disdrometers to measure precipitation under high winds compared to the well known Joss Waldvogel disdrometer (*Bumke et al*., 2004).
In case of measuring solid precipitation some specific problems need to be addressed. In contrast to rain drops different snow crystals of the same size, mostly used in this context is the maximum dimension, have different fall velocities and different liquid water contents. Furthermore the disdrometer measures their shadow area, only, depending on the shape, size, and orientation of the snow crystals falling through the disdrometer's optical sensitive volume.

2. The Disdrometer – Technical Realization

The principle of measurements is light extinction by precipitation particles in a cylindrical illuminated volume of 120 mm length and 22 mm diameter, which is held perpendicular to the local flow direction by aid of a wind vane. The cylindrical form makes measurements independent from the incident angle of the particles. The light source is an infrared LED, emitting light at 880nm wavelength. The amount of light extinction is proportional to the particle's shadow area, the duration of the signal gives the time of flight through the sensitive volume. The detectable size range covers particles from 0.4 to 22 mm in diameter. It is divided into 129 size-bins with logarithmically increasing size.
Precipitation rates R in mm h^{-1} can be determined from the particle size distribution density n(bin) and their size depending liquid water content m(bin) and terminal fall velocity $v_\infty(bin)$.

$$R = 3600 \cdot \sum_{bin=0}^{128} n(bin) \cdot v_\infty(bin) \cdot m(bin) \qquad (1)$$

Therefore mass and terminal velocity have to be known as a function of the measured shadow area to get reliable precipitation rates.

3. Model Study of the Shadow Areas

Hogan (1994) provides relationships for mass and terminal fall velocity of different ice crystal types depending on their maximum dimension D_{max}, which were derived from measurements of single particles.
Instead of the maximum dimension the disdrometer measures the shadow area, which is generated by the cross sectional area perpendicular to the optical axis of the instrument. It determines the diameter D_{bin} of a sphere having the same area. In order to use Hogan's parameterizations it is necessary to assume that ice crystals fall randomly orientated through the sensitive volume. Hence, a large amount of randomly orientated ice crystals of the same type and size should have a repeatable mean cross sectional area. This allows to develop a transformation function, which gives the maximum dimension for a measured cross sectional area of a certain ice crystal. However, the disdrometer cannot identify the type of an ice crystal. Hence, the following study can be regarded as a simple theoretical experiment to infer the sensitivity of the optical disdrometer on the assumed particle geometry and to get an idea how to solve the problem of measuring precipitation rates for snow.

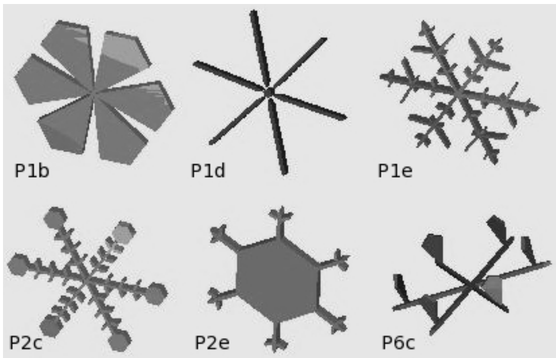


Figure 1. Simulated ice crystals

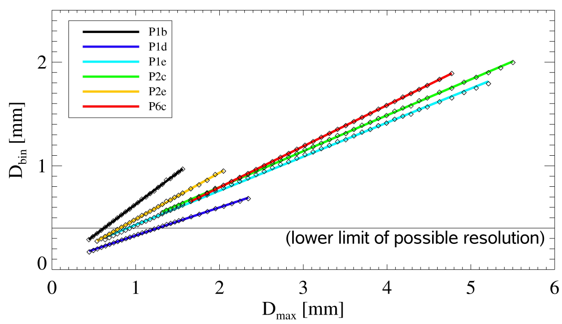


Figure 2. Transformation functions $D_{bin} \rightarrow D_{max}$ for the 6 different crystals of Fig. 1.

A geometrical model based on an ice crystal visualization program by *Macke et al.* (1998) was developed to estimate the relationship between maximum dimension and cross sectional area for 6 different types of ice crystals (Fig. 1). Linear regressions were performed (Fig. 2), their coefficients yield the transformation functions.
Applying Eq. (1) with a mono-disperse particle size distribution density to each measurable size of the 6 simulated ice crystals gives the precipitation rates depicted in Fig. 3; without (Fig. 3A) and with applying the

transformation functions (Fig. 3B). For comparison the precipitation rate of lump graupel (R4B from *Magono and Lee*, 1966) is shown, which needs no transformation function due to its nearly spherical shape.

As expected, precipitation rates are much smaller without implementing the transformation of the diameters, but surprisingly the precipitation rates as derived by using the transformation functions are close to the precipitation rates of lump graupel (Fig. 3B). Thus, given the preconditions of the given theoretical experiment, it follows that the products of liquid water content times the terminal velocity of different snow crystals are in the same order of magnitude and allow to use one common parameterization, in this case the parameterization of lump graupel.

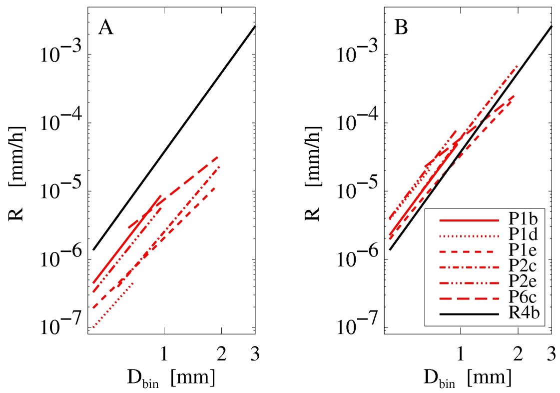


Figure 3. Simulated precipitation rates with n(bin)=1 for simulated crystal types and lump graupel. A: Without and B: With applying the transformation functions of Fig. 2 on the simulated crystal types (excluding lump graupel).

4. Data Analysis

As a first test of the hypothesis the parameterization of lump graupel was applied to disdrometer measurements from winter 1999/2000. The disdrometer was installed at the Meteorologisk Institut in Uppsala, Sweden. A Geonor gauge was mounted beside and during the measurements most of the time manual measurements were taken, too. Additionally temperatures from the measurement station and synoptical observations from the airport about 20km away were considered to identify the type of precipitation.

The daily accumulated precipitation sums of the disdrometer, the Geonor gauge, and the manual measurements are shown in Fig. 4. The integration time was from 6 a.m. of the present day to 6 a.m. of the next day. The temperature is shown at a resolution of 10min.

It is recognizable that on some days with high precipitation sums the disdrometer gave more precipitation than the other methods. Two factors may be accountable for this overestimation. Firstly the disdrometer measures also under strong wind conditions without underestimation by flow distortion, secondly the parameterization of lump graupel is only valid for particle diameters up to 9 mm (*Hogan*, 1994). During the observed period there had been several precipitation events with particle sizes exceeding 9mm in diameter. Thus, an adjustment of the parameterization for large particles is needed. On the other hand there are also some days with high precipitation rates, where the agreement is promising.

A linear regression of the disdrometer measurements on the manual measurements came out with a correlation coefficient of 0.794. The slope indicates that manual measurements overestimate daily precipitation sums up to about 1 mm d^{-1} while disdrometer measurements overestimate daily precipitation sums over 1 mm d^{-1}.

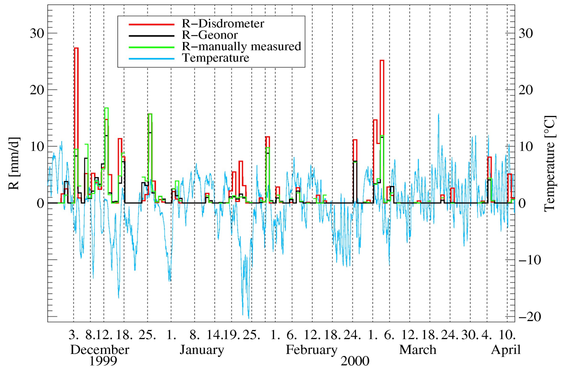


Figure 4. Daily precipitation from the disdrometer, Geonor gauge, and the manual measurements in comparison to temperatur measurements.

5. Conclusions

Although the first results of this study are promising, more detailed measurements are necessary for validation and improvement of the algorithm. This should especially include comparisons with other relevant instruments and measurements. It has been already started to detect the kind of precipitation automatically from the shape of the precipitation spectra (not shown here), but this also needs more measurements for validation and improvement of the method.

6. Acknowledgements

We would like to give special thanks to Ann-Sofi Smedman and Hans Bergström from the Meteorologisk Institut in Uppsala.

References

Bumke, K., M.Clemens, H.Grassl, S.Pang, G.Peters, J.E.E.Seltmann, and T.Wagner,, Accurate areal precipitation measurements over land and sea (APOLAS), *BALTEX newsletter*, 6, pp. 9-13, 2004

Hogan, A.W., Objective estimates of airborne snow properties, *J. of Atmospheric and Oceanic Technology*, 70, 11, pp. 432-444, 1994

Lundberg, A. and S.Halldin, Snow measurements techniques for land-surface-atmosphere exchange studies in boreal land shapes, *Theoretical and Applied Climatology*, 70, pp. 215-230, 2001

Macke, A., P.N.Francis, G.M.McFarquhar, and S.Kinne, The role of ice particle shapes and size distributions in the single scattering properties of cirrus clouds, *J. Atmospheric Sci.*, 55, No. 17, pp. 2874-2883, 1998

Magono, C. and C.W.Lee, Meteorological classification of natural snow crystals, *J. Fac. Sci. Hokkaido Univ.*, 7, pp. 321-362, 1966

Yang, DQ., E.Elomaa, A.Tuominen, A.Aaltonen, B.Goodison, T.Gunther, V.Golubev, B.Sveruk, H.Madsen, and J.Milkovic, Wind-induced precipitation undercatch of the Hellmann gauges, *Nordic Hydrology*, 30, No. 1, pp. 57-80, 1999

Extreme Marine Snowfall as seen by BALTRAD

Daniel B. Michelson[1], Uta Gjertsen[2], Jarmo Koistinen[3], and David M. Schultz[3,4]

[1]Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden. daniel.michelson@smhi.se
[2]Norwegian Meteorological Institute (met.no), Oslo, Norway
[3]Finnish Meteorological Institute (FMI), Helsinki, Finland
[4]Division of Atmospheric Sciences, Department of Physical Sciences, University of Helsinki, Helsinki, Finland

1. Background

Accurate quantitative precipitation estimates (QPE) are essential for improving our understanding of energy and water cycles in the long term, but also in improving our ability to provide reliable forecasts and warnings for facilitating transport and optimizing communications, benefiting various sectors of the economy, and ultimately to help save lives and property. Weather radar provides our only observation system capable of monitoring precipitation with high resolution in both time and space.

Within the framework of BALTEX, the BALTRAD network and BALTEX Radar Data Centre (BRDC) at SMHI have provided harmonized datasets since the start of the BRIDGE campaign in 1999. One of the products generated at the BRDC is 12-hour accumulated precipitation (RR) valid at the Earth's surface at 6 and 18 UTC.

During the evaluation of an operational implementation of the RR product at SMHI, extreme snowfall was observed over the Norwegian Sea during the period 3-5 March 2006, primarily from met.no's northernmost radar at Røst, but also from their radar further south at Rissa. This has led us to formulate this case study, with the objectives to determine whether the extreme snowfall amounts found in the RR product are achievable in reality, and to highlight the capabilities and limitations of weather radar-based QPE using the chosen methodology.

2. Data and methods

Today BALTRAD comprises the operational C-band weather radar networks in Norway, Sweden, Finland, Estonia, Denmark, and Poland, with renewed data feeds expected soon from e.g. Germany. Composite products containing radar reflectivity factor are generated every 15 minutes at two-km horizonal resolution. These composites are quality-controlled using cloud-type products from the Meteosat Second Generation (MSG) platform and NWC SAF classification algorithms (*Michelson* 2006). These composites provide the basis for subsequent QPE.

It is normal for weather radar data to systematically underestimate precipitation with increasing range from the radar. It is worth emphasizing that this underestimation is relevant only if the estimate is to be considered valid at the Earth's surface; otherwise the radar measurement is largely representative for the pulse volume aloft which it samples. Numerous methods have been developed throughout the years to describe and correct for this systematic underestimation which, especially in cold climates, can be extreme during winter. Generally speaking, there are two main families of correction algorithms which are relevant for application to large heterogeneous radar networks: methods employing precipitation gauge observations as external surface reference values, and methods employing the radar's own vertical profile of reflectivity (VPR) as a means of vertical extrapolation of radar data aloft to the surface. Both methods have their strengths and weaknesses, and both arrive at roughly equivalent results, although VPR-based methods have the advantage, in principle, of giving more representative results locally. The advantage of so-called gauge-adjustment is that it normalizes radar data to the levels given by gauges, which are still widely considered the surface reference.

At the BRDC, the RR product is based on gauge adjustment, where the original implementation is summarized in *Michelson and Koistinen* (2000), and its performance is given in *Koistinen and Michelson* (2002). The original implementation involves the analysis of a fully-spatial adjustment factor which is weighted against a first guess consisting of an adjustment factor as a function of surface distance from the radar. In practise, it has been found that the density of real-time SYNOP observations is so low that the spatial analysis has almost no impact on the final result. So, the real-time implementation mentioned above, and now in operation at the BRDC, uses only the first guess. The first-guesses automatically derived for the days of this case study are illustrated in Figure 1. An automatically-derived product, containing extreme snowfall over the Norwegian Sea, is illustrated in Figure 2.

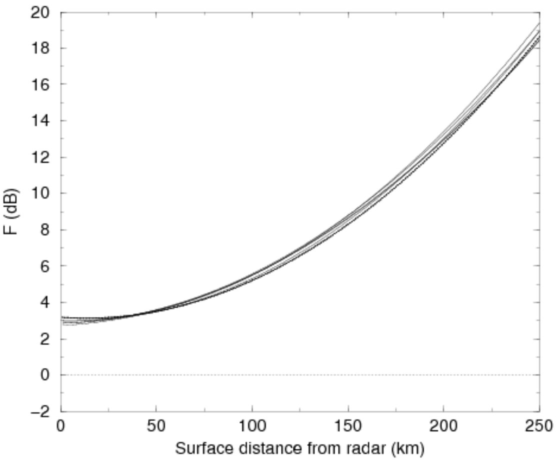


Figure 1. Automatically-derived adjustment factors for the period 3-5 March 2006, where F=10log(G/R) and G and R are 12-hour gauge- and radar-based precipitation accumulations respectively.

No operational NWP model was successful in resolving the extreme snowfall seen in the RR product. Operational analyses, e.g. from SMHI's Mesoscale Analysis (MESAN) system, were also unsuccessful. Satellite data indicate intense convective structures, but are not able to quantify snowfall. No other precipitation observations are available in the area, and no anecdotal evidence has come to our attention either.

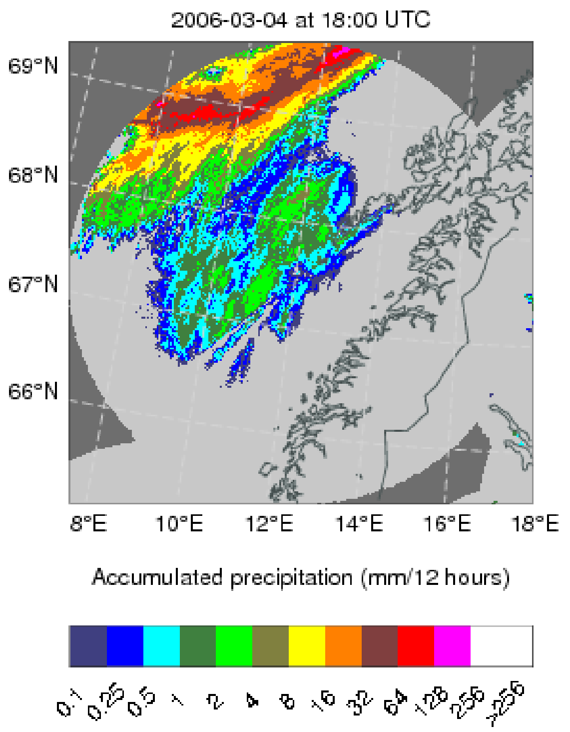


Figure 2. Automatically-derived 12-hour gauge-adjusted precipitation accumulation valid at 4 March 2006, 18:00 UTC. This is a sub-image of the RR product for the area covered by Norwegian radar Røst.

3. The weather of 3-5 March 2006

In northern Scandinavia and Finland, the period is characterized by low cloudiness over land, with little to no precipitation there. Temperatures were cold over land and warmer over the Norwegian Sea. A weak high-pressure ridge extended westwards over the area from Russia, and depressions were found in southern Scandinavia and between Norway and Svalbard. A second high-pressure ridge in the north Atlantic weakened from 3 to 5 March. An arctic type cold front pressed south and was held in place offshore, roughly parallel to the northern Norwegian coast.
These conditions produced sharp temperature gradients, and a large air-sea temperature difference, which are favorable for very low static stability. The resulting frontal convergence remained quasi-stationary for several days, producing intense convective snowbands observed by weather radar.

4. Preliminary discussion

The main question which requires answering is whether the extreme snowfall amounts found in the RR product are realistic. At face value, they appear to be too high, and this can be partially explained already. Yet, there are numerous factors that support such extreme snowfall. We hope to clarify as much as possible at the conference; until then, this discussion is incomplete.
First, it should be noted that the presence of atmospheric ducting is highly unlikely during the period. Such conditions lead to super-refraction of part of the radar beam, leading to the systematic underestimation being less than normal with increasing range. This means that the adjustment (Figure 1) would be too severe in such cases. However, during the period studied, low static stability above the sea and close to the radar, which is located on a small island, exclude the occurrence of ducting. On the contrary, atmospheric conditions along the radar beam were favourable for sub-refraction, suggesting enhanced underestimation of surface precipitation at long ranges.
Second, the temperatures are too cold for a melting layer to exist. Such conditions cause the infamous "bright band" in radar data, also resulting in higher reflectivities which would reduce the underestimation locally.
The main source of uncertainty appears to lie in the gauge-adjustment technique itself, and how it interacts with the characteristics of the input radar data. The technique is basically a range-bias correction, and the correction at distant ranges is extreme (Figure 1). The derived correction factor is based on gauge-radar comparisons for the complete BALTRAD coverage area which, in the case of the northerly area in this study, means comparisons from considerably warmer conditions. This means that the general nature of the correction is not always suitable for application locally. In this case, however, colder local conditions could imply shallow dry snowfall which commonly contains sharper vertical reflectivity (snowfall intensity) gradients. And this would mean that the correction should be even more extreme than the one used. Yet this is contradicted by the detectability of snowfall at maximum range which indicates that the convection is high. This issue requires addressing in more detail.
The gauge-radar relations are often noisy, and the large variability is due to several error sources. One of these errors is caused by partial shielding of the radar beam due to terrain, forest, buildings, and other obstructions. This results in a "system" bias forming, ie. a correction which is independent of range, and such a bias is pronounced (around 3 dB) in this case. Yet, even if this system bias were removed, the correction at distant ranges would still be extreme, and so would be the resulting snowfall in the RR product.
If the extreme snowfall in the BALTRAD RR product turns out to be realistic, then there will be, inevitably, implications for our ability to measure, forecast, and warn of such conditions in the future.

References

Koistinen J. and Michelson D.B., 2002: BALTEX Weather Radar-based Products and their Accuracies. *Boreal Env. Res*. 7 (3). p. 253-263

Michelson D.B. and Koistinen J., 2000: Gauge-radar network adjustment for the Baltic Sea Experiment. *Phys. Chem. Earth (B)* 25 (10-12). p. 915-920

Michelson D., 2006: The Swedish weather radar production chain. *Proc. ERAD* 2006. online at erad2006.org. 4 pp.

Relationships between Extreme Daily Rainfall in Estonia and Atmospheric Circulation

Piia Post

Institute of Environmental Physics University of Tartu, Ülikooli 18, 50090 Tartu, Estonia, e-mail: piia@ut.ee

1. Introduction

In recent years two remarkable extreme rain events had happened in Estonian towns: 2003 in Johvi and 2004 in Tallinn. Both rainfalls caused damages to houses, gardens and roads and were widely exposed by media. This increased attention raises the question as to whether extreme precipitation in Estonia is truly increasing or is it just the possibility of enhanced media attention biasing the pubic perception that extreme weather events are increasing. The same problem has been examined also by other investigators (e.g. *Ungar*, 1999; *Easterling et al.* 2000). The question of increasing extreme precipitation is also connected to climate change issue: the International Panel on Climate Change (*Houghton et al*, 2001) states that it is likely (66–90% chance) that extreme precipitation has increased in many Northern Hemisphere mid- to high latitude areas and that the positive trend will continue in a future climate with an enhanced greenhouse effect. There has been a set of studies to determine the change in the probability of heavy precipitation over the world using all available daily data. The results about extreme precipitation trends from measured station data in the Northern Europe and former Soviet Union are contradictory: *Heino et al.* (1999) do not find major change in daily precipitation extremes, while *Groisman et al.* (2005) find a widespread increase in the frequency of very heavy precipitation during the past 50 to 100 yr.

Groisman et al. (2005) conclude relaying on their own and others investigations that if there are statistically significant regional changes in the rainy season, relative changes in heavy precipitation are of the same sign and are stronger than those of the mean. Investigation of extreme precipitation in Estonia is at the very beginning (*Post and Merilain,* 2006), but Jaak Jaagus has thoroughly investigated trends of several Estonian climatic variables on monthly mean level. *Jaagus* (2006) states that the trends of monthly precipitation sums at Estonian stations during the second half of the 20th century are rather different and even of opposite signs. During the cold half-year an increase in precipitation has been observed. A positive trend is also present in June. During the rest of the months, no change or changes of opposite sign have been observed at different stations. That means no significant changes in the rainiest months: July, August and September.

This study aims at finding out the previous heavy precipitation events in Estonia from the 1960s up to 2005. The second aim of the present study is to identify to what degree variability of extreme precipitation in Estonia can be attributed to variations in the dominating atmospheric circulation. For this reason we analyse the synoptic situations that bring heavy precipitation to Estonia using several atmospheric circulation classifications selected by COST action 733 - Harmonisation and Applications of Weather Types Classifications for European Regions.

2. Data and method

24 hours accumulated precipitation sums (from 18 UTC of the previous day to 18 UTC) from 28 Estonian meteorological and 93 climatological stations (altogether 121 sites) during 1961–2005 have been used for this study. Only 40 of them have measured without skips, but 107 stations measured longer than 30% of the period.

Several threshold values or indexes have been chosen by investigators to define extreme precipitation (*Klein Tank and Konnen,* 2003: *Groisman et al* 2005). We have defined a heavy rainfall as an event when the rate of precipitation accumulation exceeds 50 mm per 24 hours. It is high threshold for mid-latitude climate, and specifies rare events that can cause serious damage. If we want to investigate statistically these events, then it is not feasible, because of too few events. For these purposes lower threshold values, for instance 20 mm per 24 hours, should be chosen. We have investigated also time series of annual highest 1-day precipitation amount values measured at stations and their 46-years means.

Atmospheric circulation is described by following circulation classifications: GWL – German Weather Service's (DWD) Grosswetterlagen (*Gerstengarbe et al*. 1999) for years 1961-2005 and two versions of synoptic weather types (*Jenkinson and Collison*, 1977) for the Baltic Sea region calculated using different initial datasets. PPT_NCEP for 1968–1997 with air pressure data from NCEP/NCAR Reanalysis (http://www.cdc.noaa.gov/) and PPT_grid for 1961–2001 with circulation indices calculated by Ian Harries from http://www.cru.uea.ac.uk /cru/projects/holsmeer/index_gales.html. PPT_grid is calculated for 8 grid-areas that extend over Estonia (Fig 1). PPT_ok is the circulation type (out of 8 PPT_grid) of the heavy rainfall recording station (s) grid-area. PPT_NCEP is calculated for grid-area centred at 60ºN and 23.75ºE (grid point 2 for PPT_grid).

3. Heavy rainfall statistics

In Estonia 509 heavy precipitation events were registrated during the period 1961–2005. Extreme rainfall occurred during 199 days: 66 days in July, 65 days in August, 42 days in June, 14 days in September, 9 days in May and 3 days in October. That means that all warm season months are represented except April and we can certainly call the events heavy rainfall (liquid precipitation). 50 mm precipitation threshold was exceeded in all climatological stations (where the whole 45 years period has been measured) and in all meteorological stations, except two: Pärnu and Kihnu. More than 100 mm per 24 h has been recorded in ten locations (see Fig 1). The absolute recorded maximum is from Metsküla 147.9 mm on July 4 1972. At meteorological stations the highest measured amount is from Võru – 130.9 mm on July 3 1988. Nearly half of the heavy rains have occurred in the central and SE parts of Estonia (Fig 1, grid area 7).

In Fig 2 annual highest 1-day precipitation amount values measured at 3 Estonian stations are presented. The stations are from different Estonian regions: Võru from SE, Narva from NE and Vilsandi is the most western point of Estonia. Jaagus (2006) showed the trends of monthly mean precipitation for the same stations and the tendencies of change for annual maximum values and mean values coincide.

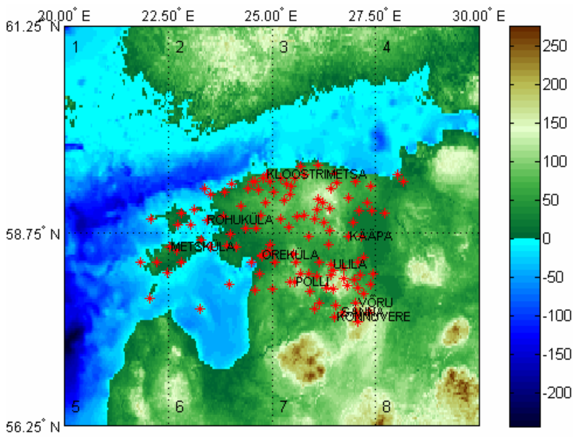


Figure 1. Location of all Estonian precipitation measuring stations (*), extreme rainfall recording stations (names) and circulation classification PPT_grid grid-areas (black numbers).

4. Preliminary results

- WZ (West cyclonic), BM (Central European ridge), TRW (Western European through), TRM (Central European through) are the Grosswetterlagen that often bring heavy rainfall to Estonia. They all belong to the most frequent Grosswetterlagen types.
- PPT weather types calculated using NCEP/NCAR Reanalysis pressure data or using pre-calculated circulation indices do not coincide. The reason is in different spatial averaging of pressure fields, for PPT_grid 2.5 degree grid in both directions is used. There are more directional types in PPT_grid than in PPT_NCEP.
- From all PPT weather types the most frequent heavy rain bringer is C (cyclonic). For PPT_NCEP it causes nearly half of heavy rains, for PPT_grid less than third.
- If we specified the location of the heavy rain in grid and chose the weather type of the right grid-area (PPT_ok), the share of cyclonic type have risen to one third of all heavy rainfall cases.
- From directional types the most frequent heavy rain bringers are western ones.
- Anticyclonic or anticyclonic hybrid types altogether bring heavy rainfall in less than 10% of cases.

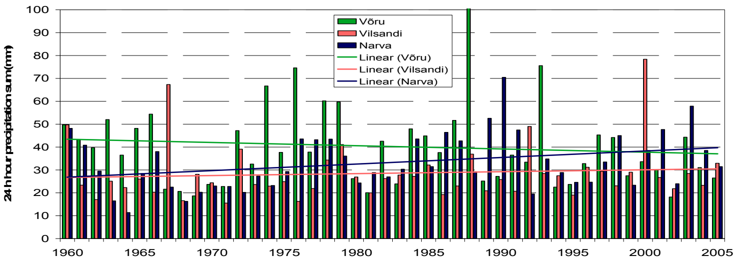


Figure 2. Time series of annual highest 1-day precipitation amount values measured at 3 Estonian stations: Võru, Vilsandi and Narva. For Võru the highest amount (130.9 mm) exceeds the figure's vertical scale.

References

Easterling, D.R., Evans, J.L., Groisman, P.Ya., Karl, T.R. Kunkel, K.E. and P. Ambenje, Observed variability and trends in extreme climate events, *Bull. Am. Met. Soc.,* 81, 417–425, 2000.

Heino, R., Brázdil, R., Forland, E., Tuomenvirta, H., Alexandersson, H., Beniston, M., Pfister, C., Rebetez, M., Rosenhagen, G., Rösner, S. and J. Wibig, Progress in the study of climatic extremes in Northern and Central Europe, *Climatic Change*, 42, 151–181, 1999.

Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. and Johnson, C.A. (eds), *Climate change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge University Press, 2001.

Gerstengarbe, F.-W., Werner, P.C., Rüge, U. Katalog der Großwetterlagen Europas (1881-1998) Nach Paul Hess und Helmuth Brezowsky. 5., verbesserte und ergänzte Auflage Potsdam, Offenbach a. M., 1999.

Groisman, P.Ya., Knight, R.W., Easterling, D.R., Karl, T.R., Hegerl, G.C., Razuvaev, V.N., Trends in intense precipitation in the climate record. *J. Climate*, 18, 1326–1350, 2005.

Jenkinson, A.F., Collison, F.P., An initial climatology of gales over the North Sea. *Synoptic Climatology Branch Memorandum*, Meteorological Office, Bracknell, 62, 1977.

Jaagus, J., Climatic changes in Estonia during the second half of the 20th century in relationship with changes in large-scale atmospheric circulation. *Theor. Appl. Clim.*, 83, 77–88, 2006.

Klein Tank, A.M.G., Können, G.P., Trends in indices of daily temperature and precipitation extremes in Europe, 1946–38, *J. Climate*, 16, 3665–3680, 2003.

Post, P., Merilain, M., Atmospheric circulation associated to extreme rainfall events in Estonia 1961-2005, EMS Annual Meeting Abstracts, 3, EMS2006-A-00258, (CD-ROM), 2006.

Ungar, S., Is Strange Weather in the Air? A Study of U.S. National Network News Coverage of Extreme Weather Events, *Climatic Change*, 41, 133–150, 1999.

Water Vapour Transport in Europe

Joanna Wibig

Department of Meteorology and Climatology, University of Lodz, Narutowicza 88, 90-139 Lodz, Poland, e-mail: zameteo@uni.lodz.pl

1. Introduction

In the continental Europe rainfall regime is strongly related to water vapor advection, because evaporation over land usually surpass precipitation. The aim of this paper is to describe the advection of water vapor and its divergence over Europe at different geopotential levels in the troposphere. Both these quantities are crucial for rainfall development. Regions where the moisture convergence occur can be identified with areas of strong convection.
Moisture advection Q at given level can be defined as:

$$Q = q \cdot v$$

where q is a specific humidity and v is a horizontal air velocity at this level. Convergence of water vapor occurs when the influx of water vapor surpass the outflux and results in vertical transport of water vapor. When the convergence integrated over the whole column of air is positive it means that there is an excess in precipitation over evaporation (*Pexioto and Oort*, 1992; *Vigaud et al*., 2007).

2. Data and methods

The data used in this study consist of 6-hourly values of specific humidity and horizontal wind components at levels 1000, 850, 700, 500 and 300 hPa from NCEP/NCAR re-analysis covering the period 1979-2003 (*Kalnay et al*, 1996). Moisture fluxes and divergence were computed at all levels over the area ranging from 30°N to 70°N in latitude and from 20°W to 50°E in longitude.
Climatological description comprises an analysis of fields of seasonal mean moisture fluxes and divergence at all levels with identification of key areas for convection.
The decomposition of the moisture fluxes into stationary and transient components was made based on the formula

$$Q = \langle q \rangle \cdot \langle v \rangle + \langle q' \cdot v' \rangle,$$

where parenthesis denote the averaging over a long time and primed values denote the deviations from long-term mean. The first and second term on the right side present the stationary and transient part of mean moisture fluxes respectively.
Vertical cross-section of zonal and meridional moisture fluxes and their stationary and transient components were also analysed.
Dynamical description comprises an analysis of short term variability in series of moisture fluxes. To do this the periodicities longer than seven days were filtered out and the remaining signal was analysed. On this basis the identification of storm tracks (wandering areas of strong convection) was made.

3. Preliminary results

Mean winter (Figure 1 and 3) and summer (Figure 2 and 4) surface moisture fluxes and their divergence at 850 hPa levels are shown. In both seasons the zonal flow dominates but in summer regions of domination of cyclonic and anticyclonic flow can also be identified.

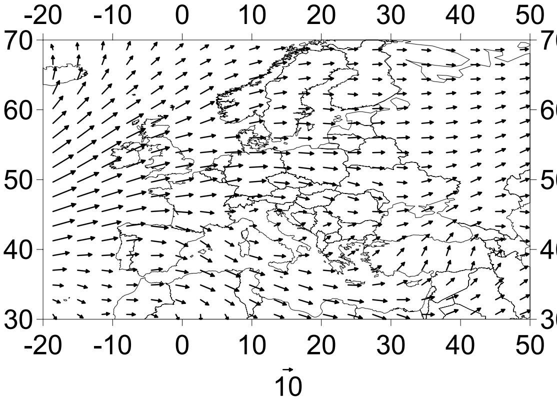


Figure 1. Mean winter (DJF) moisture fluxes at 850 hPa level in g kg^{-1} m s^{-1}.

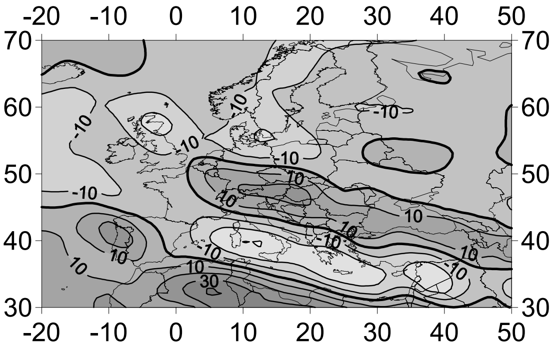


Figure 2. Mean winter (DJF) moisture divergence at 850 hPa level in 10^{-6} g kg^{-1} s^{-1}.

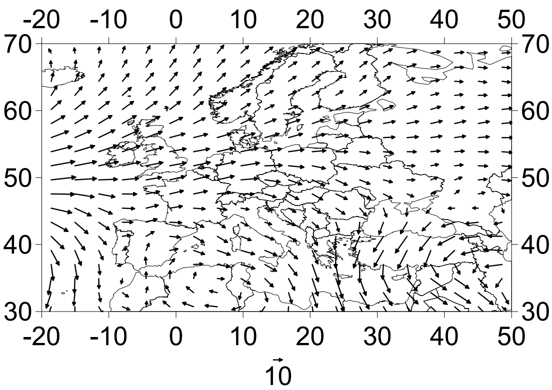


Figure 3. Mean summer (JJA) moisture fluxes at 850 hPa level in g kg^{-1} m s^{-1}.

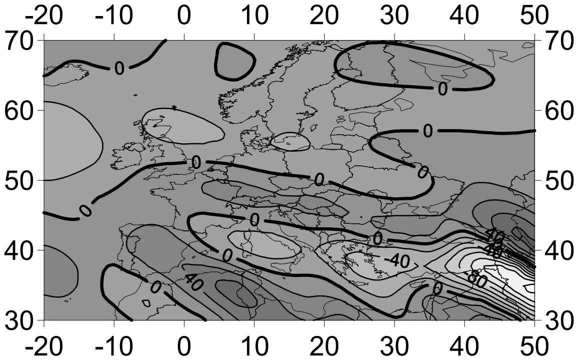


Figure 4. Mean summer (JJA) moisture divergence at 850 hPa level in 10^{-6} g kg^{-1} s^{-1}.

Areas of moisture fluxes divergence (positive values) can be identified as those with vertical moisture transport. Comparison with other level enable to decide if there are regions of convection or not.

4. Acknowledgement

The work is supported by EU under Project STATME – MTKD – CT – 2004 – 014222.

References

Kalnay E., Kanamitsu M., Kistler R., Collins W., Deaven D., Gandin L., Iredell M., Saha S., White G., Woollen J., Zhu Y., Chelliah M., Ebisuzaki W., Higgins W., Janowiak J., Mo K. C., Ropelewski C., Wang J., Leetmaa A., Reynolds R., Jenne R., Joseph D, The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc.*, 77, 437-470, 1996.

Pexioto J, Oort A, Water cycle. *Physics of Climate,* Amer. Inst. Phys., 270–307, 1991.

Vigaud N, Richard Y, Rouault M, Fauchereau N, Water vapour transport from the tropical Atlantic and summer rainfall in tropical southern Africa, *Clim. Dyn.*, 28: 113-123, 2007.

A Data Model for Hydrographic Data

P. Axe, J. Szaron, E. Falkenroth and L. Fyrberg

Swedish Meteorological and Hydrological Institute, Folkborgsvägen 11, Norrköping, Sweden.
philip.axe@smhi.se

1. Introduction

SMHI is Oceanographic Data Centre for a range of regional, national and international projects and programmes, including the Oceanographic Data Centre for BALTEX. Hydrochemistry data and supporting metadata extending back to 1902 are presently archived using a Mimer database system. Data are made available over the WWW using MySQL and PHP. Underway data and CTD profiles are stored using file structures. Work is currently underway in cooperation with NOAA to digitize hydrographic records made from Swedish lightships in the 1880s.

The principle database in the Data Centre is called SHARK (Svensk Havs ARKiv). This was primarily tailored to the needs of Sweden's national pelagic monitoring programme – in particular the handling of hydrochemistry data from oceanographic bottles. The system has proved robust, reliable and easy to use, but several design aspects make it difficult to extend for CTD and underway data. Additionally, increased international data exchange (through SeaDataNet and BALTEX), developments in data visualization (GIS/ Web Map Services), the EU Water Framework Directive (WFD), the INSPIRE Directive, and requests from data users have all motivated the development of a new data model.

2. Data Modelling

Data modelling is a method of describing an entire work process, prior to designing a computer system to support that work. The process of collecting hydrographic data requires that measurement campaigns are planned, using ships or other platforms; that data are collected using calibrated instruments operated by accredited personnel at the correct location; that data are processed and checked by skilled persons; that data are stored using physically meaningful units; that quality control stages are tracked and that finally data are reported internationally in the correct manner. The data model needs to be sufficiently flexible to handle data from underway systems (so-called Ferrybox observations). The model also needs to cope with data of varying quality supplied by external organisations.

Existing data models (e.g. ARC Marine UML, Wright 2005) were studied, but were not found to offer adequate support for the quality management of hydrographic data. In particular, they lacked integration with international data dictionaries, cruise planning or reporting. As a result, a new data model has been developed. The model allows data to be archived (and retrieved) in any system of units. Parameters can be related to the British Oceanographic Data Centre's Parameter Dictionary – but the model is sufficiently flexible that updates to the BODC system do not cause problems. The BODC data dictionary contains definitions for almost every type of oceanographic measurement. Of particular interest for the archiving of data from the 1800s is the inclusion of historical methods such as titration, and aerometry, which were used on lightships in the Baltic during the 1880s to determine salinity and density.

In the new data model, depths may be stored as wire depth, pressure, acoustic depth, "true" (salinity corrected) depth, depth intervals, height above a datum etc. Positions may be referred to by latitude/longitude, Helcom or International Hydrographic Bureau sea area, WFD water body or station name.

Different levels of user authorization control access to each data set, as certain data sets can be made available immediately, while some researchers demand a time-limited embargo before data are made generally available, to allow them to publish their findings. Only registered BALTEX data users may access data collected for BALTEX (though registration is freely available to scientists who support the work of BALTEX). The data model has to be sufficiently flexible to handle these various user requirements.

The model has been validated for both CTD profile and underway data, though is sufficiently general to be applied to a wider range of oceanographic data, such as sea level and buoy data, without significant changes.

When completely implemented in a relational database system with geodetic support, the system will facilitate integration with both local and remote GIS, as well as providing robust, reliable, long-term, quality assured data banking to both Swedish and international marine scientists.

References

Wright D, 2005, "ARC Marine UML diagrams and case studies", available online at http://dusk2.geo.orst.edu/djl/arcgis/diag.html, Last update: July 10, 2006

The Impact of Surface Albedo on Snow and Sea Ice Mass Balance in the Baltic Sea

Bin Cheng [1] Aku Riihelä[2] and Terhikki Manninen[2]

[1] Finnish Institute of Marine Research, Erik Palménin aukio 1, PL 2, 00561 Helsinki, Bin@fimr.fi
[2] Finnish Meteorological Institute, P.O. BOX 503, FI-00101 Helsinki,

1. Introduction

Sea ice cover has been reduced in the Baltic Sea in recent years. It has been reported that with more frequent cases of warm-air advection accompanied with snowfall, the contribution of meteoric ice to the sea ice mass is getting substantial (Granskong, et al, 2006). As the sea ice is involved in several key climate feedbacks (ice-albedo feedback, cloud-radiation feedback), it is of great importance to better understand the thermodynamic processes that have led to the changes of sea ice mass balance and the impact of these process to climate variability. The Finnish Institute of Marine Research (FIMR) has duties to make routine sea ice forecasts during the winter season. A high-resolution thermodynamic snow/ice (HIGHTSI) model has been developed in the FIMR (Launiainen and Cheng 1998). The model is targeted for process studies, i.e. to simulate evolution of snow/ice surface temperature, in-snow/ice temperature and snow/ice thickness. The model has been validated against several *in situ* data sets and, in general, yields good results of the surface heat balance, snow/ice mass balance and snow/ice temperature regimes (Cheng et al., 2003). Recent developments of HIGHTSI have focused on phenomena of snow/ice thermodynamics during the melt season, i.e. superimposed ice formation (ice refrozen from melt water), snow/ice sub-surface melting and re-freezing and the variability effect of snow (Cheng et al, 2006). HIGHTSI model has been setup for routine operation in the Finnish Ice Service in winter 2006/2007.

In this paper, we present modeling results of impact of surface albedo on sea ice energy and mass balance for the Baltic Sea. The motivation of this study is to exam how well the surface albedo parameterization schemes can response to the changes of snow/ice surface status and how well the snow/ice mass balance can be produced, in particular to the melting season. The instantaneous surface albedo products (SAL) generated by the Satellite Application Facility on Climate Monitoring (CM-SAF) have been used in order to validate modeled albedo.

2. External Data

Our modeling covers the winter 2006, from beginning of January to the end of April. The study area was the Bay of Bothnia, in particular the land-fast ice zone at Marjaniemi, Hailuoto Island. For regional study, the external forcing for HIGHTSI was the ECMWF daily 24 hrs forecasts, while for single-site modeling, data from Finnish Meteorological Institute (FMI) weather station was applied. Snow and ice thickness and vertical temperature profiles at different depth have been measured out of Marjaniemi. These data are applied to validate HIGHTSI results. Figure1 shows the time series of observed air temperature. Before day 80, air temperature was well below freezing point with only few occasions of above zero degree. From day 85 onward, the temperature increase gradually and after day 100, the air temperature fluctuated all the way above freezing point. Essentially, we can divide temperature changes into two phases, i.e. a) day 1 – 93.45 and b) day 93.45 - 150. During the period a), the precipitation likely contributes solidly to the snow accumulation, since the air temperature is rather cold (average of -8.6 °C), during period b), the average air temperature is +5.0 °C, melting of snow and ice was prevailing.

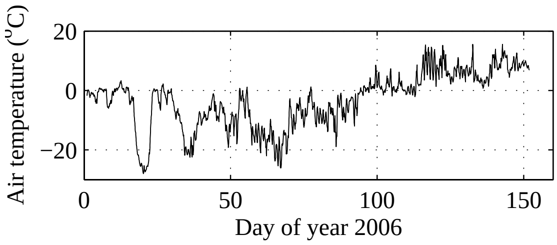


Figure 1. Air temperature observed at Marjaniemi weather station on Hailuoto island.

Figure 2. Web-camera images from Marjaniemi lighhouse on day 96 (6, April) at 15:30 and on day 99 (9, April) at 15:30. The road-right side is the sea area.

During the transition of air temperature from negative to positive, in situ data suggested a dramatic decreasing of snow thickness, we conclude that a positive ice-albedo feedback is likely the driving forcing for such a rapid melting event. Around day 97, air temperature was above zero degree, the sky was clear, snow surface was under a melting phase, which reduce the snow surface albedo. More solar radiation was available and further snowmelt was seen. This is a typical ice-albedo feedback mechanism. Figure 2 was the web-camera images from Marjaniemi light-house. We can clearly see the rapid changes of snow surface within few days.

The measured snow thickness at in-land Ojakyla and coastal land-fast ice site are shown in Figure 3. We can see almost the same trend of thickness changes, especially after day 94. This suggested a same melting mechanism, i.e. ice-albedo positive feedback acted.

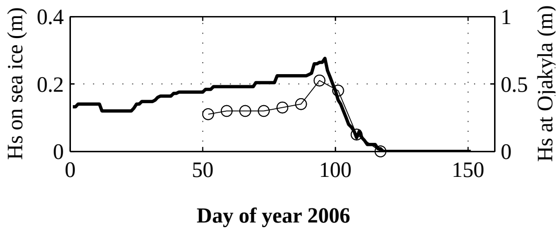


Figure 3. Measured daily and weekly snow thickness at Hailuoto Ojakyla (thick line) and land fast ice (dot-connected line) site, respectively. Note, the different magnitude of snow accumulation on land and on sea ice.

3. Results

In order to assess the impact of surface albedo on sea ice energy and mass balance, we have applied 9 parameterization schemes of surface albedo in HIGHTSI. These schemes have been used in various regional climate models or numerical weather forecast models. From very simple ones, i.e. clarified by surface type (e.g. Parkinson and Washington, 1979, Perovich, 1996), to some more complicated ones, i.e. surface temperature, snow depth and ice thickness dependent (e.g. Lynch et al, 1995, Flato and Brown, 1996 and Pirazzini, 2006) until most sophisticated scheme applied in National Center for Atmospheric Research Community Climate System Model (Briegleb et al., 2004). Some selected results of modeled surface albedo are given in Figure 4.

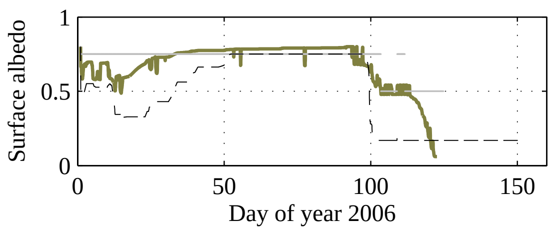


Figure 4. Surface albedo calculated by Parkinson and Washington (1979) (grey line), Pirazzini et al, (2006) (broken line) and Briegleb et al, (2004) (dark grey line).

In order to validate model results, satellite-based albedo was calculated based on the SAL product used in EUMETSAT's CM-SAF project. The algorithm to calculate the albedo over snowy areas is based on the study by Manalo-Smith et al. (1998). AVHRR optical and near-infrared channel radiances are used as the input, and then the narrowband albedo is calculated with a BRDF correction. Narrowband to broadband albedo conversion is based on the method of Xiong et al. (2002). Normally the SAL product also requires cloud mask data. However, this time the possibility of misclassification of clouds with snow over sea ice necessitated that the AVHRR imagery of the study area was limited to images from periods that had been confirmed as clear weather by ground observation. Therefore no cloud masking was used. During the middle-winter, the modeled surface albedo generally in good agreement with the SAF product.

Figure 5 gives the modeled snow time series by applying various surface albedo schemes. During cold period, the modeled snow mass balance are quite consistent using various albedo schemes, while during early melting season, various albedo schemes yield snow thickness differing gradually from each other. We need to pay more attention on improvement of albedo scheme during a melt season. The most accurate snow thickness was provided by model run using sophisticated albedo scheme. The cases of in-accurate snow thickness were provided by the model run with albedo schemes depending on surface temperature. The modeled surface temperature is normally liable to errors. These errors may probably produce a so-called artificial ice-albedo feedback (i.e. error of surface temperature enhance the error of albedo and further enhance the error of mass balance).

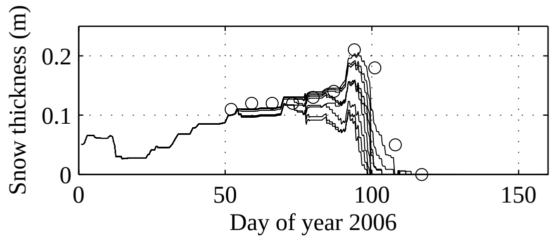


Figure 5. Modeled snow thickness with various albedo schemes incorporated into HIGHTSI. Dots are the measurement.

A time series of surface albedo composed by the SAF product and best simulated result from advanced scheme using *in situ* measurement was supplied to HIGHTSI, and such model run gives best simulated snow and ice mass balance.

References

Briegleb B.P, C. Bitz, E. Hunke, W. Lipscomb and J. Schramm, Scientific Description of the Sea ice Component in the CommunityClimate System Model, version (3),*http://www.ccsm.ucar.edu/models/ccsm3.0/csim*, 2004.

Cheng, B., T. Vihma, R. Pirazzini and M. Granskog, Modeling of superimposed ice formation during spring snow-melt period in the Baltic Sea, Ann.Glaciol.,44, in press. 2006.

Granskog, M, T. Vihma, R. Pirazzini, and B. Cheng, Superimposed ice formation and surface fluxes on sea ice during the spring melt-freeze period in the Baltic Sea, J. Glaciol., 52, 119-127, 2006.

Launiainen, J., and B. Cheng, Modelling of ice thermodynamics in natural water Bodies, Cold Reg. Sci. Technol., 27(3), 153-178, 1998.

Xiong, X, K. Stamnes and D. Lubin, Surface Albedo over the Arctic Ocean Derived from AVHRR and Its Validation with SHEBA Data, J. Appl .Meteor.,41, 413-425, 2002.

Pirazzini, R., T. Vihma, M. A. Granskog, and B. Cheng, Surface albedo measurements over sea ice in the Baltic Sea during the spring snowmelt period, Ann. Glaciol., 44, 7-14, 2006.

Validation of the Modelled Sea-Ice Thickness with the HEM-Data

Jari Haapala[1] and Christian Haas[2]

[1] Finnish Institute of Marine Research, Po. Box 2, FI-00561 Helsinki, Finland. jari.haapala@fimr.fi
[2] Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany, christian.haas@awi.de

1. Introduction

The main bottleneck of the development of the sea-ice models is the lack of proper validation data. Operational ice charts contain very good information on the ice extent and the thickness of coastal land-fast ice. The latter can be used for validation of thermodynamic models. Two important ice variables are, however, missing from the monitoring activities, namely the ice velocity and the thickness of drifting ice. In this paper, we utilize airborne electromagnetic measurement (Haas, 2005) for validating modelled ice thickness,

2. Model description

The HELMI model is a multicategory sea-ice model developed originally for the climate research (Haapala et al., 2005). The model physics and numeric are same both in operational and climate simulations. The only differences are in the horizontal resolution and atmospheric forcing used. The model resolves ice thickness distribution, i.e. ice concentrations of variable thickness categories, redistribution of ice categories due to deformations, thermodynamics of sea-ice, horizontal components of ice velocity and internal stress of the ice pack

Horizontal resolution of the model is 1 nm. In this hindcast simulation, NCEP/NCAR reanalysis data were used for forcing. Initial SST is obtained from the ice charts. The model integrations were made covering the the whole winter season. Figure 1 shows the modelled mean ice thickness on February 2003.

3. Results

Figure 2 shows helicopter EM-measurements averaged to the model grid and corresponding modelled mean ice thickness for the Bay of Bothnia. The large-scale pattern of the modelled ice thickness is rather similar than the EM-derived ice thickness field, but the model underestimate the mean ice thickness. The maximum modelled mean thickness is about 2 meters, but the mean EM ice thickness is 3-4 meters in several locations. A deeper analysis shows clearly that the correlation between the modelled mean ice thickness and mean EM-thickness is rather weak and it indicate directly that the production of the ridged ice is underestimated in the model simulations. Since the production of the ridged ice is a result of the spatial gradients of the ice velocity fields, possible reasons of the underestimation of the mean ice thickness are due to i) neglect of shear deformations, ii) rheological parameters of the model yield too stiff ice motion or iii) the wind stress used for the model simulation is too low.

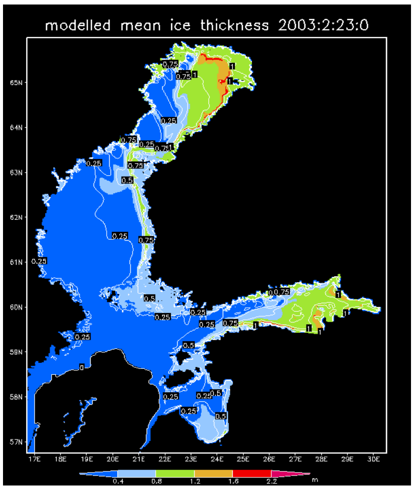


Figure 1. Modelled mean ice thickness on 23 Fec 2003

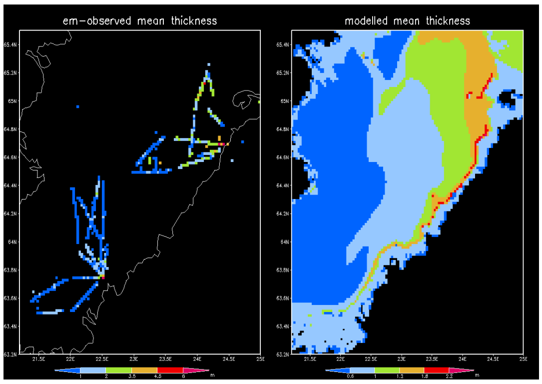


Figure 2. Modelled mean ice thickness on 23 Fec 2003

References

Haapala, J., Lönnroth. N. and A., Stössel, (2005). A numerical study of open water formation in sea ice, J.Geophys. Res., 110, doi:1029/2003JC002200

Haas, C.(2006).Airborne electromagnetic sea ice thickness sounding in shallow, brackish water environments of the Caspian and Baltic Seas, Proceedings of OMAE2006 25th International Conference on Offshore Mechanics and Arctic Engineering, June 4-9, 2006, Hamburg, Germany, 6pp.

Statistical Analysis of Surface Temperature and Salinity Variability of the Baltic Sea - A Comparison of Observations and Model Data

Anniina Kiiltomäki[1], Andreas Lehmann[2], Tapani Stipa[1] and Vivi Fleming-Lehtinen[1]

[1] Finnish Institute of Marine Research, Helsinki, Finland, anniina.kiiltomaki@fimr.fi
[2] Leibniz-Institute of Marine Sciences at the University of Kiel, Germany

1. Introduction

The surface temperature and salinity has been analyzed by statistical methods on the period from 2000-2004. Intensive flow-through measurements by Alg@line and a model results by BSIOM are used. The statistical methodology including principal component analysis has been applied to both observations and model data.

Besides the detailed analysis of variability in surface temperature and salinity of the Baltic Sea, the Alg@line data provides a data set for a systematic validation of ocean models. In addition, ocean models can be used for an extended surface or three-dimensional analysis of temperature and salinity fields. Furthermore, ocean modeling forcing functions can be used to analyze the causes of observed variations in temperature and salinity.

The main focus of this study is to present the statistical analysis (PCA) of surface temperature and salinity variability of the Baltic Sea for the period from 2000-2004. Interest is on inter-annual, seasonal as well as on meso and basin scale variations. Thus, the frontal movement and upwelling are also of interest. Frontal areas are known to be productive areas for algae blooms so that the results of this study can be related to the changing ecosystem and physical-biological interactions.

2. Alg@line Monitoring

Alg@line co-operation is a monitoring programme led by Finnish Institute of Marine Research. It extensively monitors the fluctuations in the state of the Baltic Sea ecosystem both in space and time. The main emphasis of Alg@line is the adequate monitoring of phytoplankton, especially harmful algae blooms. Additional to biological parameters, surface salinity and temperature are measured with high frequency across the Baltic Sea, (Rantajärvi, E. 2003).

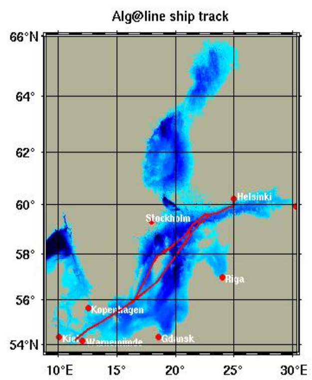


Figure 1. Alg@line ship track between Travemünde, Germany and Helsinki, Finland.

The temperature and salinity data used in this study was automatically collected on board during M/S Finnpartners continuous voyages between Travemünde, Germany and Helsinki, Finland (Fig. 1). The measurements were carried out with a flow-through system, which pumps water continuously from beneath the ship hull to the measurement system and out again while the ship is moving. The fixed sampling depth is about 5m. The measurements represent the surface water -depth depending on the season and the depths of the halo- and thermocline. Temperature and salinity are recorded frequently every 20 seconds. Spatial resolution of measurements is about 100-300m and the transect is repeated about every 3rd day, depending on the velocity and schedule of the ferry.

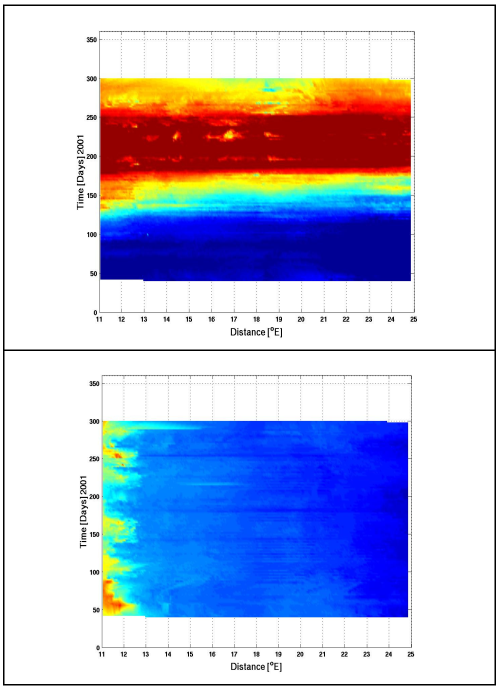


Figure 2. Alg@line sea surface temperature (upper panel) and salinity (lower panel) for 2001.

As an example, Alg@line sea surface temperature and salinity of the year 2001 are displayed as a Hovmöller diagram (Fig.2). High frequency monitoring data have been filtered by a running mean over three samples and amount of data have been further reduced to a longitudinal resolution of 0.01°.

3. Baltic Sea Model BSIOM

The numerical model we used is a coupled sea ice-ocean model of the Baltic Sea (BSIOM) including Kattegat and Skagerrak (Lehmann and Hinrichsen, 2000). The model has a horizontal resolution of 5 km and 60 levels in the vertical. The first model level (3 m thickness) represents surface water at 1.5 m depth. BSIOM is forced by realistic atmospheric conditions provided by the Swedish Meteorological and Hydrological Institute (SMHI's meteorological data base) Norrköping, Sweden and river runoff. Because the model is forced by realistic atmospheric conditions a direct comparison of observations with model results can be performed. Thus, the model can be directly validated through the quantitative comparison with observations. Furthermore, the model can be used as a tool to supply missing data within the observations and to provide additional spatial and temporal information of temperature and salinity variability. With the detailed analysis of atmospheric forcing data the physical interpretation of observed variability is possible.

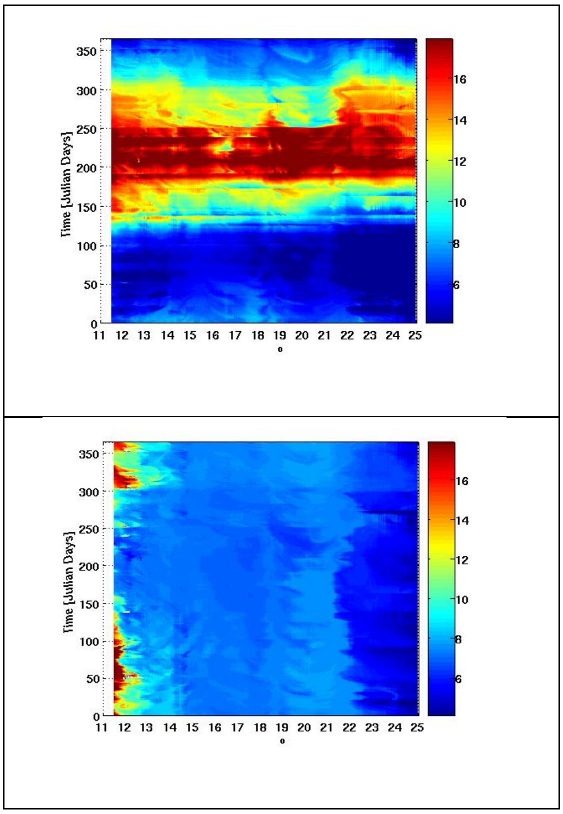


Figure 3. BSIOM sea surface temperature (upper panel) and salinity (lower panel) for 2001.

As an example, model sea surface temperature and salinity of the year 2001 are displayed as a Hovmöller diagram (Fig.3). The results are extracted from model surface layer on Alg@line track.

4. Similarity of Measurements and Model Results

For a qualitative comparison of measurements with model results the different temporal and spatial resolutions have to be taken into account. Alg@line data (complete track across the Baltic Sea) are recorded every 3rd day and model data have been extracted every 6 hours along the Alg@line ships track. However, there are a number of detailed similarities visible in both temperature and salinity figures. For salinity (compare Fig. 2 and Fig. 3) the same structures appear and the strongest signal is the moving Belt Sea front.

References

Lehmann, A. and Hinrichsen, H.-H., On the thermohaline variability of the Baltic Sea. *J. Marine Sys.* 25 (3-4), 333-357, 2000.

Rantajärvi, E (Editor), Alg@line IN 2003: 10 years of innovative plankton monitoring and research and operational information serviced in the Baltic Sea, Meri, No. 58, pp3-17, 2003.

Upwelling Parameters Derived from Satellite Sea Surface Temperature Data in the Gulf of Finland

Jaan Laanemets and Rivo Uiboupin

Marine Systems Institute at Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia
E-mail address: jaan@phys.sea.ee

1. Introduction

Coastal upwelling caused by the along-shore wind forcing typically brings cold and nutrient-rich deeper water to the surface layer. The baroclinic instability of a longshore upwelling jet results in the formation of filaments and eddies which cause the offshore transport of cold water thus widening the area of influence to far beyond the narrow coastal zone. In the Gulf of Finland, summer upwellings transport cold and phosphate rich water from the thermocline to the surface layer thus considerably changing the temperature distribution and promoting the growth of nitrogen-fixing cyanobacteria (e.g. *Vahtera et al*. 2005). The satellite sea surface temperature (SST) data, in addition to field measurements and numerical modeling, give an important information about the spatial extent and structure of wind-driven coastal upwellings. In the Baltic Sea satellite sea surface temperature (SST) images were analyzed by *Horstmann* (1983), *Bychkova and Victorov* (1986), *Gidhagen* (1987), *Siegel et al*. (1994) and *Kahru et al*. (1995) to determine upwelling parameters during the thermally stratified period. They estimated lifetime from 0.5 to 10 days, the alongshore extent in the order of hundreds of kilometers, the off-shore extent tens of kilometers and the temperature difference between the upwelling and the surrounding water from 2 to 10 °C. Owing to the prevailing south-westerly winds (e.g. *Mietus* 1998, *Soomere and Keevallik* 2003), the northern coastal sea of the Gulf of Finland is an active upwelling area in summer which was also shown by model simulations (*Myrberg and Andrejev* 2003).

In this study the 7-year (2000-2006) SST data measured by MODerate Resolution Imaging Spectroradiometer (MODIS) onboard of Terra and Aqua satellites were used to determine the area covered by the upwelled water, the location of upwelling filaments and the temperature difference between the upwelled and surrounding water. A total of 20 sufficiently cloud-free SST scenes comprising well-expressed coastal upwelling events during the warm period of year (June-September) in the Gulf of Finland were found.

2. Results and discussion

For the edge detection of the upwelled water the program ENVI 4.2 (Environment for Visualizing Images) of Research Systems, Inc. (2001) was used. Isotherms with 0.5 °C resolution were marked on the SST image. The edge was defined as the temperature contour line with the highest value adjoined to the coast. For the comparison the edge was also detected using the histogram analysis (*Cayula and Cornillon* 1992) which gave the similar outcome.

The examination of the SST data showed that the average area covered by the upwelled water was 4622 km^2, which is about 20% from the Gulf surface area. In case of the most intensive upwelling more than a third (12138 km^2, 38%) of the Gulf area was covered with the upwelled water. Also, the upwellings along the Finnish coast were more extensive when compared with upwellings along the Estonian coast: the average areas covered with the upwelled water were 5694 (27%) and 3912 km^2 (14%) correspondingly. The calculations of the area covered by the upwelled water were performed separately for the eastern and western part of the Gulf considering the shape of the Estonian coastline. The average area of the upwelled water in the western part of the Gulf was larger than in the eastern part, 3097 km^2 (22%) and 2414 km^2 (14%) correspondingly. The estimated temperature differences between upwelling water and surrounding water varied in a wide range, from 3.5 to 15.2 °C. In September the temperature differences were usually up to 7 °C, while in June-August when the thermal stratification is the strongest the temperature differences were much higher, between 8 and 15 °C. Considerably larger upwelling areas along the Finnish coastline could be explained by larger westerly than easterly along-gulf axis cumulative wind stresses (the product of the wind stress and duration) that generated the observed upwellings (data not shown). The approximate offshore displacement of the upwelling front is proportional to the cumulative wind stress and inversely proportional to the surface Ekman layer depth.

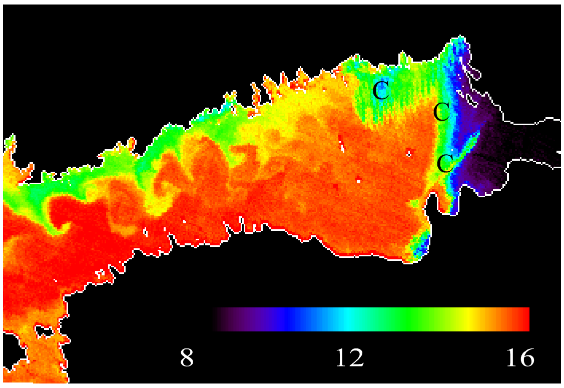


Figure 1. Satellite SST image on 24 September 2005. The near-shore upwelling is seen as filaments of colder water along the Finnish coast. C marks clouds.

The well-expressed filaments (Figure 1) were mainly related to the upwelling events along the Finnish coast while the filaments related to the upwellings along the Estonian coast were weaker and occurred more rarely. Upwelling filaments were most frequently observed off Hanko and Porkkala peninsulas. The length of filaments emerging from the upwelling front was up to 35 km. The area of filaments of an upwelling event was up to ~1000 km^2 which was about 20% from the area covered by the upwelled water in the western part of the Gulf. The generation of filaments is related to the instability of the longshore baroclinic jet associated with the upwelling. *Blumsack and Gierasch* (1972) and *de Szoeke* (1975) showed that in case of sloping bottom the baroclinic instability of the longshore upwelling jet depends strongly on the ratio of the bottom slope to an isopycnal slope, α. When isopycnal slope is smaller than the bottom slope (α >1) the baroclinic instability of the upwelling jet is not expected to occur. The cross-shore scale for the region of sloping isopycnals during upwelling is the baroclinic Rossby radius of deformation (*Allen* 1980). According to *Fennel and Seifert* (1995) in summer the baroclinic Rossby radius of deformation is about 3 km in the Gulf of Finland and the upper mixed layer depth is approximately 10 m, which gives a rough estimate for the isopycnal slope of 0.003. Although the bottom topography of the Gulf of Finland is complicated the estimates of the bottom slope off the Estonian coast of 0.006 and off the Finnish coast of 0.002 could be used. Thus, in the Finnish coastal sea $\alpha \approx 0.5$ while in the Estonian coastal sea $\alpha > 1$, i.e. the baroclinic instability of the upwelling jet along the Estonian coast could not be expected in general. These rough estimates can at least explain the observed differences between the occurrence and characteristics of the upwelling filaments off the Finnish and the Estonian coasts.

To conclude, the analysis of the satellite SST data showed that the upwelled water covered a considerable surface area of the Gulf and likely due to different atmospheric forcing and due to different topography at the northern and southern coasts of the Gulf, the characteristics of the upwellings differed: 1) upwellings off the northern coast were more extensive and the upwelled water covered larger areas of the coastal sea and 2) well-expressed upwelling filaments were predominantly observed off the northern coast.

References

Allen J. S., Models of wind driven currents on the continental shelf, *Annu. Rev. Fluid Mech.,* 12, pp. 389-433, 1980

Blumsack S. L. and P. J. Gierasch, Mars: The effects of topography on baroclinic instability, *J. Atmos. Sci*., 29, pp. 1081-1089, 1972

Bychkova I. and S. Viktorov, Use of satellite data for identification and classification of upwelling in the Baltic Sea. *Oceanology*, 27, pp. 158-162, 1986

Cayula, J-F. and P. Cornillon, Edge detection algorithm for SST images, *J. Atmos. Ocean. Technol*., 9, pp. 67-80, 1992

de Szoeke, R. A.,. Some effects of bottom topography on baroclinic instability, *J. Mar. Res*., 33, pp. 93-122, 1975

Fennel, W., T. Seifert, B. Kayser, Rossby radii and phase speed in the Baltic Sea, *Cont. Shelf Res*., 11 (1), pp. 23-36, 1991

Gidhagen L., Coastal upwelling in the Baltic – satellite and in situ measurements of sea surface temperatures indicating coastal upwelling, *Est. Coast. Shelf Sci*., 24, pp. 449-462, 1987

Horstmann U.,. Distribution patterns of temperature and water colour in the Baltic Sea as recorded in satellite images: Indicators for phytoplankton growth, Bericthe aus dem Institute für Meereskunde an der Universität Kiel 106, pp. 147, 1983

Kahru M., B. Håkansson and O. Rud, Distributions of the sea-surface temperature fronts in the Baltic Sea as derived from satellite imagery, *Cont. Self Res*., 15, pp. 663-679, 1995

Mietus M.. The climate of the Baltic Sea basin, Marine meteorology and related oceanographic activities Report 41, WMO/TD 933, Geneva, pp. 64, 1998

Myrberg, K. and O. Andrejev, Main upwelling regions in the Baltic Sea – a statistical analysis based on three-dimentional modelling, *Boreal Environ. Res*., 8, pp. 97–112, 2003

Siegel H., M. Gerth, R. Rudolff and G. Tschersich, Dynamic features in the western Baltic Sea investigated using NOAA-AVHRR data, *Dt. Hydrogr. Z*., 46, pp. 191-209, 1994

Soomere, T. and S. Keevallik, Directional and extreme wind properties in the Gulf of Finland, Proc. Est. Acad. Sci. Eng., 9, pp. 73–90, 2003.

Vahtera, E., J. Laanemets, J. Pavelson, M. Huttunen and K. Kononen,. Effect of upwelling on the pelagic environment and bloom-forming cyanobacteria in the western Gulf of Finland, Baltic Sea, *J. Mar. Syst*., 58, pp. 67-82, 2005

The Roles of Brine Release and Sea Ice Drift for Winter Mixing and Sea Ice Formation in the Northern Baltic Sea

Andreas Lehmann[1] and Riikka Hietala[2]

[1] Leibniz-Institute of Marine Sciences at the University of Kiel, Germany, alehmann@ifm-geomar.de
[2] Finnish Institute of Marine Research, Helsinki, Finland

1. Introduction

Sea ice is formed every year in the Baltic Sea. The sea ice extent varies considerably for different years with respect to the atmospheric conditions. There is good data coverage of the annual sea ice extent but there are less or almost no information on the mean sea ice thickness and sea ice mass/volume. For an assessment of different winters and the impact of climate variability and change the estimation of the total sea ice mass and volume is important. Besides atmospheric conditions, the sea ice thickness is controlled by the oceanic heat flux and sea ice mobility. Drifting sea ice forms ridges and open leads in which new ice can be formed. Thus, years with nearly the same sea ice extent can have considerable differences in mean sea ice thickness and volume/mass. In a numerical model sensitivity study of the winter 2005, the roles of brine release and sea ice drift for winter mixing and sea ice formation have been studied. The combined effect of vertical convection caused by brine release and turbulent mixing due to the moving ice causes a heat release of the ocean to the ice with cooling of the upper oceanic layers below the temperature of maximum water density, eventually close to the freezing temperature down to 40-60 m depth. Results of this study are compared with observed sea ice evolution and CTD casts taken under the ice.

2. Baltic Sea-Ice-Ocean Model (BSIOM)

The numerical model used in this study is a general three-dimensional coupled sea-ice-ocean model of the Baltic Sea (BSIOM; Lehmann an Hinrichsen, 2000). The horizontal resolution of the model is 5 km, and in the vertical 60 level are specified, which enable the upper 100 m to be resolved with levels of 3 m thickness. The model domain comprises the Baltic Sea including Kattegat and Skagerrak. The coupled sea-ice-ocean model is forced by realistic atmospheric conditions taken from the Swedish Meteorological and Hydrological Institute's (SMHI) meteorological database which covers the whole Baltic drainage basin on a regular grid of 1 x 1°. The temporal increment of the different records is 3 hours. The database includes the surface pressure, precipitation, cloudiness, air temperature and humidity at 2 m height and the geostrophic wind. Surface winds at 10 m height are calculated from geostrophic winds with respect to different degrees of roughness on the open sea and in coastal waters. The calculation of the ocean-atmosphere exchange is described in Rudolph and Lehmann (2006). Following Harder and Lemke (1994) BSIOM has been extended for sea ice ridging (Flato and Hibler, 1991). The two-dimensional sea ice modul of BSIOM consists of two ice classes representing level and ridged ice, and a snow layer assumed to be equally distributed on the surface of level and ridged ice.

3. Heat flux from the sea

Before ice formation can start the surface layer of sea water has to be supercooled. The proceeding cooling of the sea is combined with convection which is in the northern Baltic Sea determined by the excess of the maximum of density of sea water before freezing commences. This leads to a shallow thermocline. Consequently the thin mixed surface layer cools down more rapidly and relative warm water remains in the vicinity of the water surface and the ice, respectively. In addition to convection (thermohaline), advection and turbulent heat transport have to be considered. F_w is the turbulent heat exchange between ice and ocean. The temperature at the bottom of sea ice T_f (freezing temperature) remains unchanged as long as sea ice is present. If the stratification beneath the ice tends to be stable F_w remains small or not very variable.

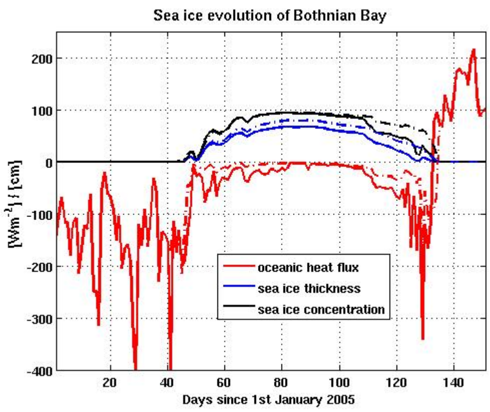


Figure 1. Simulated sea ice evolution and oceanic heat fluxes of the central Bothnian Bay, January to May 2005. Full lines represent the evolution affected by brine release, for broken lines, brine release was switched off.

In BSIOM the oceanic heat flux F_w is part of the surface energy budget, $T_{surface}$ is prognostically calculated from heat and radiation fluxes, advection and turbulent mixing. The oceanic heat flux (Fig. 1) is strongly variable ranging between 100 and 400 Wm^{-2} before sea ice is formed. After sea ice formation F_w decreases to values less than 10 Wm^{-2} depending on sea ice thickness and concentration. In April (day > 100) with decreasing sea ice concentration again the ocean is losing heat until the sea ice has completely melted and increasing air temperatures and radiation lead to warming of the ocean surface.

4. Brine release

During sea ice formation salt is rejected to the sea by brine release. Because of the relatively low salinity of the northern Baltic Sea it is generally assumed that effects due to brine release on sea ice formation and haline convection are of minor importance. Sea ice salinity is not a prognostic variable of BSIOM. In case of sea ice formation sea ice salinity will be 20% of the surface salinity.

80% of the salt of the surface layer is immediately rejected into the sea during ice formation, and the remaining 20% will be released during melting. During sea ice formation brine release leads to an additional vertical mixing due to static instability of the water column, thus leading to an increasing oceanic heat flux and consequently to reduced sea ice thicknesses (Fig. 1). For the station in the central Bothnian Bay the sea ice thickness is reduced by 15 % compared to the case when brine release is switched off.

5. Numerical model sensitivity study

To investigate in detail the effect of brine release and sea ice drift on vertical mixing and sea ice formation a numerical model sensitivity study has been performed. The analysis focuses on differences in sea ice evolution including sea ice thickness, extension and volume and vertical mixing including the oceanic heat flux and the deepening of the mixed layer. Thus, we varied the sea ice salinity, the friction coefficient between water and ice and the drag coefficient between atmosphere and sea ice. The choice of the demarcation thickness has also a significant influence on the sea ice compactness during ice formation and thus on sea ice mobility. As a significant sea ice cover was not registered until the middle of February, the numerical model sensitivity study was restricted to the period January to May 2005. Model results are compared with sea ice maps of the Finnish Sea ice service (FIMR), AMSR-E sea ice concentrations and available CTD-casts. Figure 2 shows the sea ice concentration measured by AMSR-E for 16th March 2005.

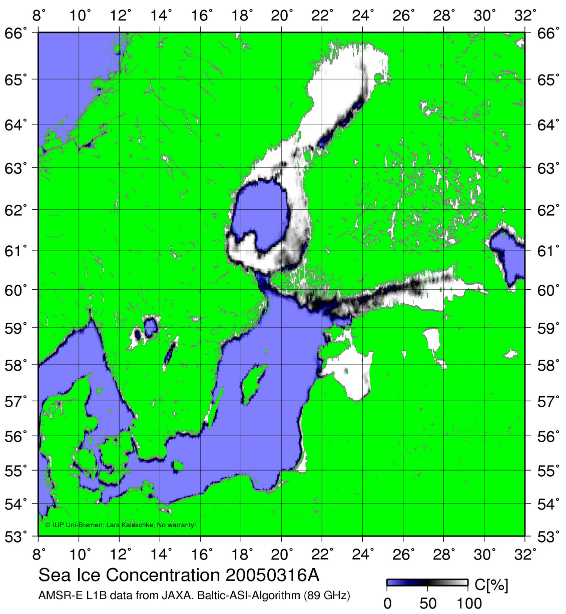


Figure 2. AMSR-E satellite sea ice concentration of 16th March 2005 (http://iuo.physik.uni-bremen.de:8084/baltic/baltic.html).

References

Flato, G.M. and Hibler, W.D. III, An initial numerical investigation of the extent of sea ice ridging. *Ann. Glaciol.*, 15, 31-36, 1991.

Harder, M. and Lemke, P., Modelling the Extent of Sea Ice Ridging in the Wedell Sea. The Polar Oceans and Their Role in Shaping the Global Environment, *Geophys. Monograph,* 85, 187-197, 1994.

Lehmann, A. and Hinrichsen, H.-H., On the thermohaline variability of the Baltic Sea. *J. Marine Sys.* 25 (3-4), 333-357, 2000.

Rudolph, C. and Lehmann, A., A model-measurements comparison of atmospheric forcing and surface fluxes of the Baltic Sea, *Oceanologia,* 48,3, 333-360, 2006.

Upwelling in the Baltic Sea
– A Review -

Kai Myrberg[1] and Andreas Lehmann[2]

[1]Finnish Institute of Marine Research, Helsinki, Finland, [2]Leibniz-Institute of Marine Sciences University of Kiel, Germany
kai.myrberg@fimr.fi

1. Introduction

The importance of upwelling in the World Ocean is generally known and thus there is widespread literature dealing with the phenomenon. It is commonly known that upwelling is also an important process in the Baltic Sea. However, for the authors' knowledge no general review article of this phenomenon exists. Due to this the objective of this presentation is to give a comprehensive review of the upwelling dynamics and its reflections to ecosystem level in the Baltic Sea using all relevant literature. Our present knowledge of upwelling in the Baltic Sea is somewhat fractional and the understanding of the basic physics needs a thorough analysis of published material. Collecting all existing literature together will help us to close the gaps of our present knowledge of upwelling and some recommendations for future work can be outlined accordingly.

At first we will review the historical development in upwelling studies in the Baltic. The first documented scientific observation of upwelling in the Baltic Sea has been carried out by Alexander von Humboldt. During August 1834 Humboldt was travelling with a Russian steam boat from Szczecin to Kaliningrad and back to Szczecin. After this introductory part the knowledge of upwellings according to observations from traditional methods to remote sensing is reviewed. After the descriptive view of upwellings the basic physics of it is introduced, also taking into account the scales of this feature and its description as a three-dimensional process. Next modelling efforts to study upwelling are discussed. The resolution needed for modelling and the role of atmospheric forcing are introduced additionally. At the end of the presentation the implication of upwellings to marine environment are reported. The presentation is concluded by giving recommendations for the future work.

2. Upwelling in the Baltic Sea (some examples)

The first documented scientific observation of upwelling in the Baltic Sea was carried out by Alexander von Humboldt (1834). During August 1834 von Humboldt was traveling with a Russian steam boat from Szczecin to Kaliningrad and back to Szczecin. While the boat was traveling at about 2-3 nm off the coast, Humboldt measured a strong drop in sea surface temperature of about 10°C near the 18° longitude off the Polish coast, while eastward of Hel Peninsula, the temperature again increased to values of about 20°C. Von Humboldt speculated that in deeper layers of the Baltic Sea cold water exists which reach the surface, in a similar manner like katabatic winds but in opposite vertical direction. In Figure 1 the sea surface temperature distribution of the southern Baltic Sea at the end of August 1997 is displayed. A similar upwelling situation was observed by Alexander von Homboldt in August 1834 when traveling form Szczecin (Swinousjcie) to Kaliningrad.

A first comprehensive explanation of the upwelling process could be given by the application of Ekman's theory (1905). He provided a basis for understanding the effect of wind stress on ocean circulation, and showed that due to the effect of Earth's rotation and frictional forces, the net transport of water due to the wind stress is directed 90° to the right of the wind in the Northern Hemisphere.

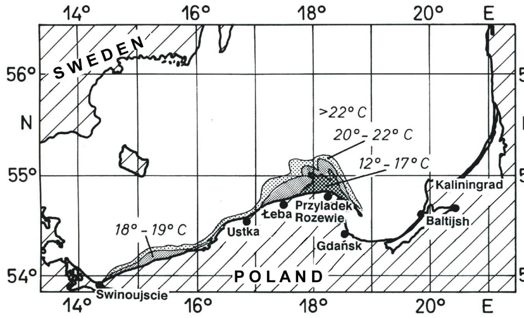


Figure 1. Sea surface temperature distribution of the southern Baltic Sea at the end of August 1997. The figure has been redrawn from SST satellite data. A similar upwelling situation observed A. v. Humboldt in August 1834.

A comprehensive analysis of satellite data have been performed by Bychkova and Viktorov (1986). From the analysis they identified and classified main upwelling regions in the Baltic Sea.

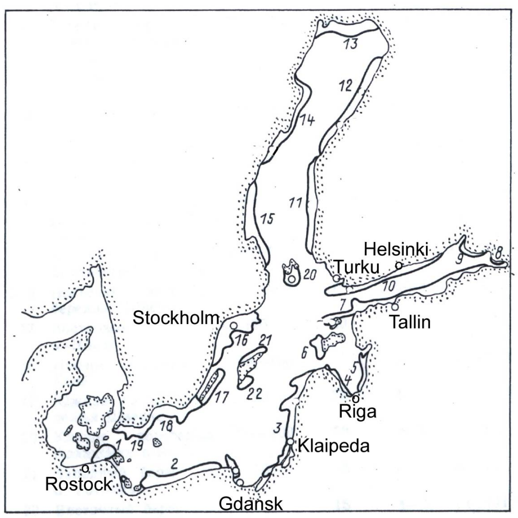


Figure 2. Main upwelling regions, redrawn from Bychkova and Viktorov 1986.

References

Bychkova, I.A. and Viktorov S.V., Use of satellite data for identification and classification of upwelling in the Baltic Sea. *Oceanology,* 27,2,158-162,1986.

On the Quasi-Steady Current along the Northern Slope of the Gulf of Finland

Juss Pavelson[1], Timo Huttula[2], Urmas Lips[1] and Kai Myrberg[3]

[1]Marine Systems Institute at Tallinn University of Technology, 12618 Tallinn, Estonia, juss@sea.ee
[2]Finnish Environment Institute, FI-40014 Jyväskylä, Finland
[3]Finnish Institute of Marine Research, FIN-00561 Helsinki, Finland

1. Introduction

Density mapping performed over the northern slope of the Gulf of Finland (GOF) has often indicated a relatively strong downward tilt of isopycnals below the seasonal thermocline (e.g. *Laanemets et al*. 1997, *Stipa* 2004). Proceeding from the geostrophic cross-shore momentum balance such inclination of isopycnals reflects the along-slope westward (out of the gulf) current. Though there are no published current velocity measurements providing the evidence of the current, several model simulations over the time scale of years distinctly show the westward current in the upper layers (*Andrejev et al.* 2004). Hereafter, following *Stipa* (2004), we use the notation 'Finnish Coastal Current' (FCC) to quote this westward baroclinic current flowing along the Finnish coastal slope.

The dynamics of the GOF water is strongly influenced by the wind activity. The westerly winds force upwelling at the Finnish coast and thus considerably reduce the tilt of isopycnals, and easterly winds force the downwelling which contributes to the isopycnals lowering. The both, up- and downwelling, cause also the sea level changes. The combination of these processes can vigorously modify the FCC. Therefore, the aim of the present study is to demonstrate the existence of the quasi-steady FCC (as estimated from direct measurements and derived from the density field) just during the low wind conditions. In particular, we focus to the reliability of the geostrophic current calculation.

2. Data and methods

The data were obtained during about 2-week measurement campaigns in summers (July) of 1994 and 1997. The study area is located between the longitudes 23 and 24°E i.e., in the north-western part of the GOF. The measurements consisted of mesoscale surveys with a towed undulating CTD (r/v Aranda, horizontal resolution 500 m on the legs 4 km apart) and CTD survey casts (r/v Reet in 1997, horizontal resolution 1×1 nm). In 1997, a bottom-mounted ADCP current profiler (RDI, 600 kHz) was deployed in the survey area of r/v Reet almost in the centre of the across-shore icopycnal slope.

The measured current velocity time-series were low-pass filtered to exclude the inertial motions (13.9 h) and seiches (26–27 h). To reduce the small-scale variations in the geostrophic calculations the vertical density profiles were smoothed with the 2-m running average. The representativeness of the calculated geostrophic currents was tested following *Yankovsky* (2006). For this the vertical shears of the ADCP measured currents and the vertical geostrophic shears from CTD were estimated at fixed depths. The relationship between the both shears enabled to evaluate the order of the validity of the thermal wind balance during our measurements.

The wind data during the field measurements were recorded by automatic weather stations onboard the ships. To cover the pre-study period, the wind data from Kalbådagrund Weather Station (FMI) were utilized.

3. Results and discussion

Meteorological conditions – The summers of 1994 and 1997 were warm in the Baltic Sea region, and therefore the vertical stratification below the upper mixed layer was strong. Both measurement periods as well as the 1-week time intervals preceding the measurements were characterized by relatively low winds. In 1994, the westerly winds with the mean speed of 4 m s^{-1} dominated. Only in some short intervals (of about 0.5–1 day) the along-shore wind velocity component reached up to 6 m s^{-1}. The easterly winds, which prevailed in 1997 were somewhat stronger. Two 3-days periods with the along-shore wind velocity component varying between 5 and 9 m s^{-1} were recorded. As the periods with the wind velocity bursts larger than 7 m s^{-1} never lasted longer than a half day, it is not likely that these two major wind events induced downwelling.

Observed currents – The raw time series of the current velocity (1-m vertical resolution) contained the inertial motions and seiches as a consequence of moderate winds during the first half of measurements. The amplitudes of both velocity components of the inertial motions were ~10 cm s^{-1} and the amplitudes of the along-shore velocity component of seiches reached up to 7 cm s^{-1}.

The residual current below the thermocline was always directed about along the isobaths and its core was located at the depth of 20–25 m. The maximum westward along-shore velocities of 10–15 cm s^{-1} in the core were found in the beginning of the study period. We interpret this current as a segment of the quasi-steady FCC, which is supported by the distinct cross-shore slope of isopycnals and by the less saline core. Hereafter the westward current continuously died off and reversed to an eastward very weak current during the last two days of observations. Such temporal scenario in our site could be explained by the eastward advection of colder and saltier water mass originating from the upwelling at the Estonian coast (about 10 days before the measurements). To conclude, it shows that the FCC could be affected not only by the strong wind events (our unpublished data), but also by the circulation in the central GOF.

Geostrophic currents – The along-shore components of the geostrophic currents were calculated from the density field measured by a towed undulating CTD. For 1994 the depth of 50 m was adopted as the level of no motion. The direct velocity measurements enabled to evaluate the level of no motion at 45 m depth for 1997. The data from altogether 5 mesoscale surveys (each of 4–9 legs) from the both years were used in the analysis.

During the whole measurement period in 1994, the density surfaces were strongly inclined towards the sloping bottom (Figure 1). The mean cross-shore slope was ~0.0025. In 1997 the slopes of isopycnals in the first half of observations were considerably less (~0.001–0.0015), and hereafter were almost missing. The horizontal scale of the inclination of isopycnals i.e. the width of the directed current (FCC), was nearly the same in both years – about 10 km. The difference of the density fields measured in different years was clearly reflected in the geostrophic current: in 1997 the current was much weaker than in 1994 when its velocity reached up to 15 cm s^{-1}. As seen in Figure 1 the FCC is to some extent lifted above the sloping isopycnals. This is obviously an artificial manifestation due to the problem of calculating of the current in the waters shallower than the chosen reference level. Correspondingly, the velocity values in the FCC core might be slightly smaller than expected from the existing isopycnal slopes.

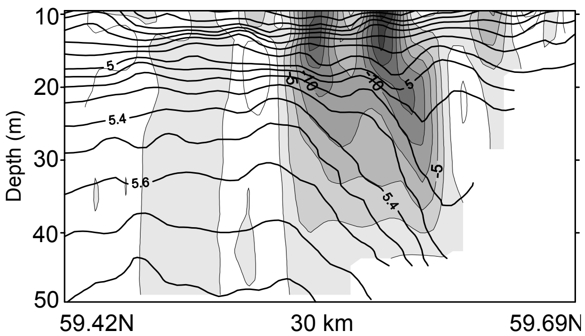


Figure 1. The typical contour plots of density (isopycnals as bold lines at 0.1 kg m^{-3} intervals) and along-shore component of geostrophic current velocity (isotachs at 2.5 cm s^{-1} intervals, eastward current in grey scale) in 1994.

The sequence of geostrophic current maps enabled to follow the spatio-temporal variations of the FCC. The meandering and even some splitting of the current were the characteristic features in 1994. The largest cross-shore excursion of the FCC, ~6 km, occurred within about four days.

Comparison of vertical shears – The vertical shears of the along-shore geostrophic velocity component were calculated using the density mappings over the grid with 1×1 nm resolution for 1997. According to this scale, the vertical shears of the measured along-shore current velocity components were estimated over the 2-m depth interval. All shear estimates (daily during a week and at every 5-m depth in the interval of 10–35 m) are presented in Figure 2.

Despite of a remarkable scatter of the measured vertical shear around the vertical geostrophic shear, the correlation between them is relatively high (correlation coefficient is 0.63). The scatter could be explained mainly by the large distance of 2.0 km between the locations of the ADCP and the suitable for the geostrophic calculations CTD casts. The linear regression line with the slope 0.57 crosses the point (–0.005 s^{-1}, –0.005 s^{-1}). It means that on the average the larger absolute geostrophic shear values are overestimated and the small ones are slightly underestimated.

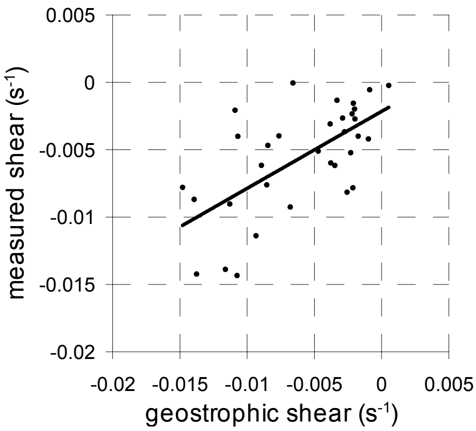


Figure 2. Scatter plot of the vertical shear determined from the measured along-shelf current velocity component and the geostrophic vertical shear calculated from the density field in 1997. The bold line represents the linear regression.

To summarize, the vertical geostrophic shear agreed sufficiently with the directly measured vertical shear i.e. the use of the dynamic method (relying on the thermal wind balance) for the calculation of geostrophic velocities was justified in our study. A slight imbalance between the geostrophic and observed shears could be likely addressed to the ageostrophic shear. The mechanisms contributing to the ageostrophic shear in the coastal areas of the GOF need additional investigations.

References

Andrejev, O., Myrberg, K., Alenius, P. and Lundberg, A., Mean circulation and water excanhange in the Gulf of Finland – a study based on three-dimensional modeling, Boreal Environment Research, 9, 1–16, 2004.

Laanemets, J., Kononen, K. and Pavelson, J., Nutrient intrusions at the entrance area to the Gulf of Finland, Boreal Environment Research, 2, 337–344, 1997.

Stipa, T., Baroclinic adjustment in the Finnish coastal current, Tellus, 56A, 79–87, 2004.

Yankovsky, A. E., On the validity of thermal wind balance in alongshelf currents off the New Jersey coast, Continental Shelf Research, 26, 1171–1183, 2006.

Surface Radiation Budget and Cloud Radiative Forcing on Sea Ice During the Spring Snowmelt Period in the Baltic Sea

Roberta Pirazzini[1,2] Timo Vihma[3], Mats Granskog[4] and Bin Cheng[2]

1 University of Helsinki, Division of Atmospheric Physics, Finland, pirazzini@fimr.fi
2 Finnish Institute of Marine Research, Helsinki, Finland
3 Finnish Meteorological Institute, Helsinki, Finland
4 University of Lapland, Rovaniemi, Finland

1. Introduction

This study investigates the evolution of surface radiation budget and cloud radiative forcing during the crucial and rapid process of spring snowmelt over sea ice in the Gulf of Bothnia (Baltic Sea). Observations on radiative fluxes, cloud cover, wind, air temperature and humidity were made during a four-week field experiment over first-year sea ice in spring 2004 (from 16 March to 11 April). Most previous studies on cloud radiative forcing over snow/ice-covered surfaces have been made in Polar regions (*Intrieri et al.,* 2002; *Wendler et al.,* 2004). The present data set collected in the Baltic Sea gave the unique opportunity to study the cloud radiative forcing over snow and ice under the contemporary effects of alternation between daylight and night time, strong seasonal trend in solar radiation and surface albedo, and strong influence of air mass advection from different climate zones (as e. g. Central Europe and northern Scandinavia).

2. Surface radiative fluxes

Being at the beginning of the spring, the measurement period was characterized by a strong progressive increase of the shortwave incoming radiation at the top of the atmosphere calculated on a horizontal surface ($S_{\downarrow TOA}$) with noon values ranging from 609 Wm^{-2} (on 17 March) to 829 Wm^{-2} (on 11 April). The increase of $S_{\downarrow TOA}$ was parallel to a marked decrease of surface albedo (Figure 1) caused by the melting of the snow. Consequently, the diurnal variation of the shortwave and total radiation budgets (Sn and Rn respectively) increased dramatically during the campaign (Figures 1 and 2).

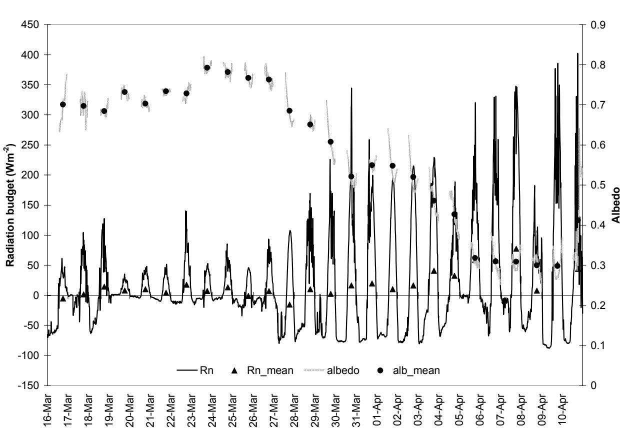


Figure 1. Surface radiation budget Rn (10-minute values and daily means) and surface albedo (10-minute values and daily means) during the measurement campaign.

The longwave radiation budget (Ln) was mostly negative during the measurement campaign. Ln was zero or slightly positive only in some occasions during overcast conditions, when the radiative warming of thick, low or middle level clouds compensated or dominated the surface cooling. The cloud cover variation was the main factor affecting the changes in downward longwave radiation ($L_{\downarrow}$). Nevertheless, there was not any evident correlation between cloud cover and 2-m air temperature, as it was also observed at Barrow, Alaska, in June and September, when surface temperature was close to 0°C (*Stone*, 1997). While a strong correlation between cloud cover and air temperature is present during colder conditions in snow-covered regions of the Arctic and Subarctic (*Overland and Guest*, 1991; *Stone*, 1997), during the melting period the temperature-cloud correlation is prevented by the strong coupling between the 2-m air temperature and the almost constant surface melting temperature, so that the air temperature has only a limited range of variability. In addition, in comparison with colder conditions, the temperature around 0°C allows a larger range of variability of the atmospheric water vapour content, which has a large infrared emissivity and thus a large impact on the air temperature, and can mask the effect of clouds.

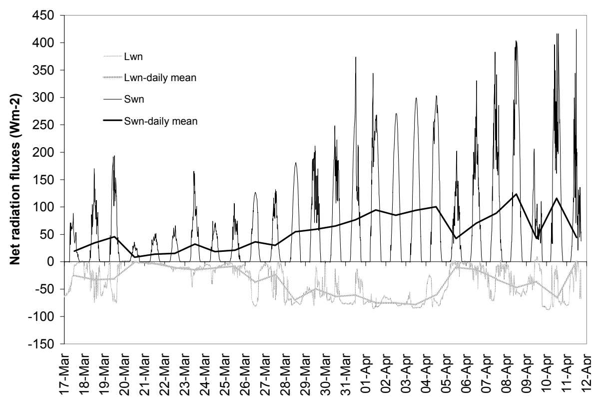


Figure 2. Surface longwave radiation budget Ln (10-minute values and daily means) and shortwave budget Sn (10-minute values and daily means) during the measurement campaign

At the beginning of the campaign when albedo was high the sky was mostly cloudy or overcast, Sn was low and Ln was negative but close to zero. Thus Rn was on average positive, with negative values only during days with mostly clear sky or optically thin clouds. On 5 April all snow had melted, ice albedo was around 0.3 and Rn increased following the increase in Sn. During the last overcast day (9 April) Rn clearly decreased in comparison with the previous partly clear day. Thus, the effect of clouds on Rn had changed during the campaign, from a warming effect at the beginning to a cooling effect at the end.

3. Cloud radiative forcing

Clouds act to decrease the shortwave flux reaching the surface and to increase the longwave flux. To investigate the net effect of clouds on the radiation budget, we calculated the daily mean cloud radiative forcing for overcast days during the whole measurement period. The cloud net radiative forcing (NCF) is the sum of the shortwave and longwave forcing (SCF and LCF, respectively), which where obtained from the following expressions:

$$SCF = \overline{S_{\downarrow TOA}} \cdot (K_{ov} - K_{cl}) - \overline{\alpha} \cdot \overline{S_{\downarrow TOA}} (K_{ov} - K_{cl}) \qquad (1)$$

$$LCF = (L_{\downarrow ov} - L_{\downarrow cl}) - (L_{\uparrow ov} - L_{\uparrow cl}) \qquad (2)$$

The above formulae define the cloud forcing as the difference between the cloud forcing in the downward and upward radiative fluxes. Each downward or upward forcing is then calculated as the difference between the radiative fluxes in overcast conditions (subscript ov) and the mean fluxes observed in clear conditions (subscript cl).

In (1), $\overline{\alpha}$ and $\overline{S_{\downarrow TOA}}$ are, respectively, the daily mean surface albedo and the daily mean shortwave flux at the top of the atmosphere incident on an horizontal surface, while K_{cl} and K_{ov} are the daily mean total atmospheric transmittance in clear and overcast days, respectively. The transmittances are obtained from the ratio between the observed $S_\downarrow$ and the calculated $\overline{S_{\downarrow TOA}}$. We used a constant value for K_{cl}, corresponding to the average observed in the three clear days (28 March, 2 and 3 April, mean ± std = 0.67 ± 0.01).

Table 1. Number of daylight hour (h), daily mean values of surface and air temperatures (T_s and T_{air} respectively, in °C), surface albedo ($\overline{\alpha}$), atmospheric transmittance in overcast conditions (K_{ov}), and net cloud radiative forcing (NCF) during overcast days.

	h	T_s	T_{air}	$\overline{\alpha}$	K_{ov}	NCF
20 Mar	11.8	-0.1	0.6	0.73	0.15	62
21 Mar	11.9	-0.1	0.7	0.70	0.21	59
22 Mar	12	-3.6	-3.6	0.73	0.26	55
24 Mar	12.2	-5.0	-4.1	0.79	0.38	57
25 Mar	12.3	-3.9	-2.9	0.78	0.40	62
5 Apr	13	-1.5	0.3	0.42	0.25	28
9 Apr	13.3	-0.7	2.0	0.30	0.20	7

4. Discussion and conclusions

In Table 1 the observed overcast days are listed, together with some parameters that affect the cloud radiative forcing: length of the day, daily mean surface and air temperature, albedo and atmospheric transmittance in overcast conditions. Although daily mean NCF is positive throughout the whole campaign, there is a remarkable decrease toward the end, which is mostly associated to the decrease in albedo. Sometimes differences in the factors controlling NCF compensate each other, as we can see on 20 and 25 March when NCF was identical although low Stratus were present on 20 March and middle level Altocumuls on 25 March, so that all parameters listed in Table 1 were different in the two days (especially T_{ov}). In Table 2 the mean shortwave and net cloud forcing during daylight hours is shown: the dramatic effect of the albedo decrease is clearly visible in the sharp increase in magnitude of SCF and it dominates the net cloud forcing, so that in the last two days NCF became negative during daylight hours.

The warming due to downward LCF was larger during night, because during daylight clouds masked the surface from solar heating, which must be subtracted from LCF. On 20 and 21 March, warm air advected from the east caused surface melting also during nigh time. The strong surface longwave emission during these warm nights compared to the much lower surface emission during clear-sky caused a larger upward longwave forcing during night compared to daytime. Hence, the net LCF was practically identical during day and night.

On 24 March cold air was advected from the north and the snow surface did not reach the melting temperature: the downward longwave cloud forcing was more than $30 Wm^{-2}$ smaller than on 20 and 21 March, and in particular during daytime the surface temperature was colder than in clear days, which were characterised by warm and dry air from northwest that was adiabatically heated while descending from Swedish mountains (*Granskog et al.,* 2006). The upward cloud longwave forcing was therefore negative both during night and day, but smaller during daylight. The net LCF was therefore again quite similar during day and night time.

The warmer climate of the Baltic region and the earlier spring melt compared to Polar regions has added new insight into the various aspects and parameters that affect the cloud radiative forcing over snow/ice covered surfaces.

Table 2. Mean daylight values of cloud radiative forcing in overcast days on the downward, reflected and net shortwave fluxes (SCF↓, SCF↑, and SCF, respectively, in Wm^{-2}), and on the downward, upward and net radiation budget (NCF↓, NCF↑, and NCF, respectively, in Wm^{-2}).

	SCF↓	SCF↑	SCF	NCF↓	NCF↑	NCF
20 Mar	-110	-80	-29	-23	-72	49
21 Mar	-99	-70	-29	-15	-62	46
22 Mar	-92	-67	-24	-36	-78	42
24 Mar	-69	-54	-14	-20	-69	48
25 Mar	-65	-50	-14	-2	-57	54
5 Apr	-123	-52	-70	-54	-45	-9
9 Apr	-145	-43	-101	-81	-38	-43

References

Granskog, M. A., T. Vihma, R. Pirazzini and B. Cheng, Superimposed ice formation and surface fluxes on sea ice during the spring melt-freeze period in the Baltic Sea, *J. Glaciol., 52,* 119-127, 2006.

Intrieri, J. M., C. W. Fairall, M. D. Shupe, P. O. G. Persson, E. L. Andreas, P. S. Guest, and R. E. Moritz, An annual cycle of Arctic surface cloud forcing at SHEBA, *J. Geophys. Res.*, *107*(C10), 8039, doi:10.1029/2000JC000439, 2002.

Overland J. E., and P. S. Guest, The Arctic snow and air temperature budget over sea ice during winter, *J. Geophys. Res.*, *96*(C3), 4651-4662, 1991.

Stone, R. S., Variations in western Arctic temperatures in reponse to cloud radiative and synoptic-scale influences. *J. Geophys. Res.*, *102*, 21769-21776, 1997.

Wendler, G., B. Moore, B Hartmann, M. Stuefer, and R. Flint, Effects of multiple reflection and albedo on the net radiation in the pack ice zone of Antarctica, *J. Geophys. Res.*, *109*, D06113, doi:10.1029/ 2003JD003927, 2004.

CryoVEx 2005 – Altimeter Remote Sensing of Sea Ice Thickness in the Bay of Bothnia

Eero Rinne[1], Jari Haapala[1], Christian Haas[2], Istvan Heiler[1] and Stefan Hendricks[2]

[1] Finnish Institute of Marine Research, Po. Box 2, FI-00561 Helsinki, Finland. *Eero.Rinne@fimr.fi*
[2] Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

1. Introduction

One of the most promising methods of determining sea ice thickness from satellites is based on altimetry. However, if sea ice thickness is obtained from sea ice freeboard measured by altimeter, large uncertainties exist due to the variability of snow load, horizontal variability of ice thickness, density of ice ridges and uncertainities of the exact location of the backscattering surface. Within the European Space Agency's CryoSat calibration and validation activities the sea-ice measurement campaign was carried out in the Bay of Bothnia in March 2005. Campaign took place on landfast and drift ice east from island of Hailuoto near city of Oulu. Data was also collected during the transit flights through the whole Bay of Bothnia. In the campaign, extensive airborne ASIRAS radar altimeter, ALS scanning laser altimeter, HEM electromagnetic ice thickness and in-situ measurements were made.

2. ASIRAS instrument

Airborne SAR/Interferometric altimeter system ASIRAS is designed to support CryoSat mission, which was dedicated to long term global ice surface measurements. CryoSat mission was lost during launch in 2005, but similar CryoSat-II -satellite is planned to be launched during year 2009. ASIRAS is designed to provide airborne measurements over ice with an instrument operating according to the same principle as CryoSat but scaled in parameters. ASIRAS has many operating modes to meet with corresponding CryoSat-II SIRAL operating modes. In Bay of Bothnia, Low Altitude Mode (LAM) was used for the first time. LAM allows combined use of ASIRAS and laser scanner systems which usually operate at altitudes less than 1500 m. ASIRAS data was processed at Alfred Wegner Institute for Polar and Marine Research. ASIRAS Level 1b data consists of power received from different ranges from the instrument aka. waveform, aircraft attitude and position data, instrument configuration data as well as some higher level products such as measured elevation of ice surface *Cullen* (2006).

3. Laser Scanner Altimeter

Elevation of ice surface was measured with Riegel Laser Scanner coincidently with ASIRAS. Laser scanner is a well known technique to produce a large number of high resolution elevation measurements. These data can be used in interpretation of ASIRAS data as well as validating ASIRAS sea ice information retrieval algorithms.

4. Measurement flights

Total of 19 ASIRAS and ALS profiles were acquired on March 14:th from validation area. Measurements were made at 300, 500, 700, 900 and 1100 m flying altitudes. In addition data was also collected during the transit flights Stockholm – Oulu and Oulu – Stockholm on 13:th and 14:th of March respectively. *Helm et al*. (2006)

5. In-Situ measurements

A 2200 m long calibration line was formed on ice. Two corner reflectors were placed on the line. Ice thickness, freeboard, surface elevation and snow thickness were measured.

6. ASIRAS measured surface elevations

Comparison between ASIRAS measured surface elevation and in-situ measured freeboard was made. Limitations due to roll dependency of re-tracker used by ASIRAS Level 1b processor had to be taken into consideration when converting ASIRAS measured elevation into ice freeboard. ASIRAS elevations were directly compared with in-situ freeboard and ALS measured elevations. After averaging sufficient number of ASIRAS measurements a good agreement between three datasets was found. Also a less roll dependent re-tracker was tested.

7. ASIRAS waveform ice type classification

ASIRAS waveforms measured during the Bay of Bothnia campaign have been connected with ice types (Open water , New ice and Deformed ice). Preliminary analysis of these waveform suggest a possibility of a relatively simple ice classification algorithm using waveform shape. Simple algorithms using width of received waveform have been built. These algorithms are to be validated with Laser scanner data and applied to data collected during long transit flights.

References

R. Cullen: ASIRAS Data Description, ESA/CryoSAT Ref.:CS-LI-ESA-GS-0371 2006

V. Helm, S.Hendricks, S. Goebell, W. Rack1, C. Haas, U. Nixdorf, T. Boebel: CryoVex 2004 and 2005 (BoB) data acquisition and final report, ESA Contract C18677/04/NL/GS, 2006

Sensitivity Tests with Parameterization of Flow Along Bottom Slope and Simulation of 1993 Major Baltic Salt Inflow with 3D Hydrostatic Model

Irene Suomi[1], Oleg Andrejev[2] and Kai Myrberg[2]

[1] University of Helsinki, Division of Geophysics, P.O. Box 64, FIN-00014 Helsinki, Finland, irene.suomi@helsinki.fi
[2] Finnish Institute of Marine Research, P.O. Box 2, 00561 Helsinki, Finland

1. Introduction

Parameterization of flow along the slope is in a key role when simulating Baltic inflows with a geopotential (z-) coordinate models because in a z-coordinate model the bottom slopes are represented in a step-like manner.
In this study we will use a three-dimensional hydrodynamic model in order to test different possibilities for parameterization of the flow along the slope. As a test case we will use the well-documented major Baltic inflow of January 1993 to validate model results with observations.

2. The model

The model used in this experiment is a hydrostatic 3D-model described by *Andrejev and Sokolov* (1989), *Andrejev et. al.* (2002) and *Myrberg and Andrejev* (2006). Model studies are made in two different model domains. Some sensitivity tests are first conducted in a domain that covers only Kattegat, the Danish Straits, Arkona Sea and part of the Bornholm Sea. Then, the simulation of the actual inflow is made in a domain that covers the whole Baltic Sea.

3. Sensitivity tests with restricted area model

In the experiments with the small area model, the results show that slope convection plays a significant role in modeling of salt water inflows (figure 1). However, the model results show too high salinity in the south-western Baltic when compared with observations. This is because the model underestimates the fresh water outflow as the eastern boundary locating in the Bornholm basin with a closed boundary there.

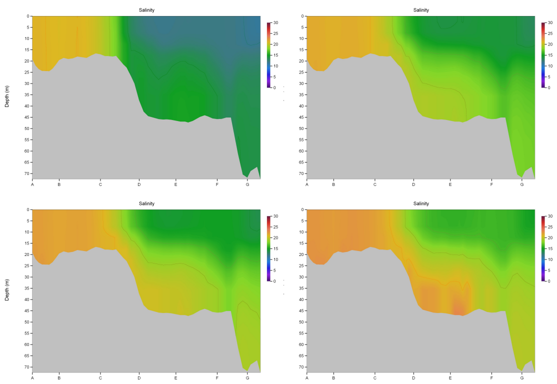


Figure 1. Modelled salinity cross-section from Darss sill through Arkona basin on January 10, 1993. Detailed explanation is found in the text.

In figure 1, upper left hand side figure shows the result with no parameterization of slope convection, in the upper right hand side convection is taken into account, the results in lower left hand side figure is obtained with mixing limit of 0,05 kg/m^3 and on the lower right the effects of flow field at the bottom is ignored in slope convection. Results show that slope convection is necessary to obtain realistic salt water inflows. However, the effect of flow field on the slope convection is significant. Whether this is realistic needs more experiments.

4. Experiments with whole Baltic Sea

It seems to be essential in modelling the salt inflows to have the model domain that covers the whole Baltic Sea. However, in this case the initial as well as boundary conditions in the open boundary become more important. On the other hand, as figure 2 shows, the importance of parameterization of slope convection is obvious.

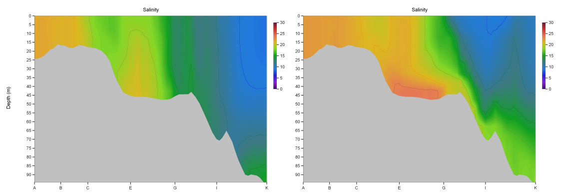


Figure 2. Modelled salinity cross-section from Darss sill through Arcona basin to Bornholm basin in 10.1.1993. In the figure on the left no slope convection is used and on the right hand side figure parameterization is used.

5. Conclusions

Preliminary results show that sub-area model can only be used for sensitivity test because, for instance, it underestimates the fresh water outflow and hence the resulting salinity is too high. With the model domain of the whole Baltic Sea results become more realistic but now the choice for initial conditions as well as the conditions at the open boundary in Kattegat become more important.

References

Andrejev, O., K. Myrberg, P. Mälkki and M. Perttilä, Three-dimensional modelling of the Baltic main inflow in 1993, *Environmental and chemical physics,* 24, 3, 121-126, 2002

Andrejev, O., A. Sokolov, Numerical modeling of the water dynamics and passive pollutant transport in the Neva inlet (in Russian), *Meteorologia I Hydrologia*, 12, 75-85, 1989

Myrberg, K. and O. Andrejev. Modelling of the circulation, water exchange and water age properties of the Gulf of Bothnia. *Oceanologia* 48 (S), 55-74, 2006

Some Features of Bottom Water Spreading into the Baltic Sea

Valeriy Tsarev[1] and Maria Sharatunova[2]

[1] Russian State Hydrometeorological University, 98, Malookhtinsky Ave., St.Petersburg, 195196, Russia, e-mail: tsarev@rshu.ru; [2] Joint Stock Company for Disigning, Investigations and Research n Field of Sea Transport “Lenmorniiproekt”, Mezhevoy kanal,3,korp.2,St.Petersburg, 198035, Russia1, e-mail: MSharatunova@lmniip.spb.ru

1. Introduction

Because of specific features of the Baltic sea bottom topography the spreading of incoming bottom saline water from the Kattegat to the Central Baltic doesn’t occur as a continuous process but as a chain of local processes of water exchanges between neighboring sub-basins. That’s why for understanding the process of renewal of deep water in the Baltic it is important to investigate main features of local processes of water exchange between neighboring sub-basins. Presented investigations includes results of numerical simulation of i) bottom saline water inflow into the Arcona Basin, ii) water exchange between the Arcona Basin and the Bornholm Basin through the Bornholm Channel.

2. The governing equations

The model used is close to POM model, see *Blumberg A. F. et al* (1987). It includes equations of motion, equation of mass conservation, equation of salt and heat conservation, equation of the state.

$$\frac{\partial u}{\partial t} - fv - k_z \frac{\partial^2 v}{\partial z^2} - k_l \nabla_l^2 u = -\frac{1}{\rho_0}\frac{\partial \xi}{\partial x} - \frac{g}{\rho_0}\int_0^z \frac{\partial \rho}{\partial x} dz'$$

$$\frac{\partial v}{\partial t} + fu - k_z \frac{\partial^2 v}{\partial z^2} - k_l \nabla_l^2 v = -\frac{1}{\rho_0}\frac{\partial \xi}{\partial y} - \frac{g}{\rho_0}\int_0^z \frac{\partial \rho}{\partial y} dz'$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0.$$

$$\frac{\partial S}{\partial t} + (\mathbf{u}\cdot\nabla)S = k_z \frac{\partial S}{\partial z} + k_l \nabla_l S$$

$$\frac{\partial T}{\partial t} + (\mathbf{u}\cdot\nabla)T = k_z \frac{\partial T}{\partial z} + k_l \nabla_l T$$

$$\rho = f(T,S)$$

where u, v, w are velocity components along coordinate axes x, y, z; f is Coriolis parameter; g is gravitational acceleration; k_z, k_l are coefficients of vertical and horizontal diffusion; S is water salinity; T is water temperature; ρ is water density; ξ is sea surface displacement.

3. Bottom water inflow into the Arcona Basin

The saline water inflow into the Arcona Basin is connected with wind forced sea lever elevation in the Kattegat. That’s why it is very changeable. The inflow continues for some days and then is changed by outflow. The variability of the inflow in the Arcona influences on saline water spreading over the Arcona. That process was simulated with presented model. Model area was chosen of rectangle form with constant depth 40 m. The saline water inflow-outflow through Oresund was simulated by boundary condition applied at liquid boundary (Fig. 1). At the left liquid boundary (Oresund) currents velocity (v) was set as $v=v_0 sin(2\pi/T)$. Period (T) was accepted equal to 20 days. Salinity at this boundary was 30 PSU. At the other liquid boundary (The Bornholm Channel) velocity was set as $v= -v_0 sin(2\pi/T)$, salinity was 25 PSU. Initial salinity was 25 PSU. From the model run the inflowing bottom water at $t=T/2$ covered almost all area (Fig.2). Later during outflow the bottom saline water moved back. But at the end of the outflow ($t=T$) the saline water moving appeared to be rather small. It can be explained by sufficient role of baroclinic factors in formation of bottom water spreading. To prove that explanation the calculations were repeated without last terms in equations of motion. These terms represents baroclinic factors. In that case at $t=T/2$ bottom water occupied almost all model area. But during outflow almost all area became free from bottom saline water (Fig.3).

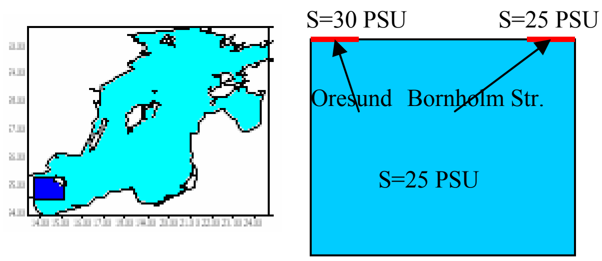


Figure 1. Model area, initial salinity and boundary conditions.

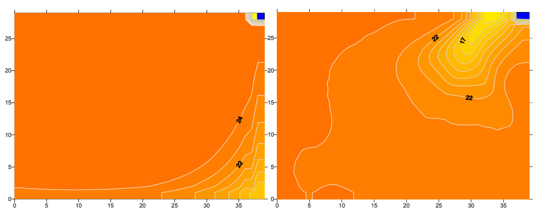


Figure 2. Bottom salinity distribution at $t=T/2$ (a), $t=T$ (b); (baroclinic factors included).

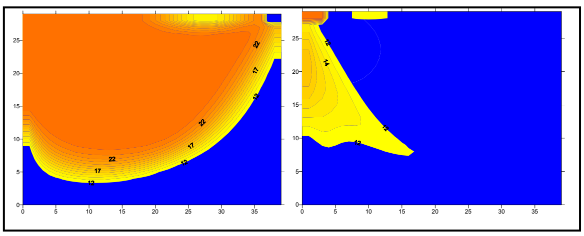


Figure 3. Bottom salinity distribution at $t=T/2$ (a), $t=T$ (b); (baroclinic factors excluded).

4. Water exchange between the Arcona and the Bornholm Basins

The bottom water outflow from the Arcona to the Bornholm Basin was simulated as water exchange between two rectangular areas connected through narrow channel (fig.4a). The bottom depth of the left area was 40m. For the right area it increased from 40m at the side boundary to 80 m at the area middle. Specific feature of initial salinity was bottom layer of more saline water in the left area (Fig.4). The bottom layer thickness was 30 m.

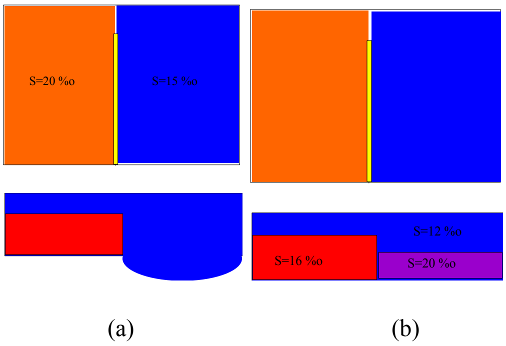


Figure 4. Model area and initial salinity distribution

Simulation shown that in the downstream area incoming saline water turned to right and continued along boundary in anticlockwise direction (fig.5).

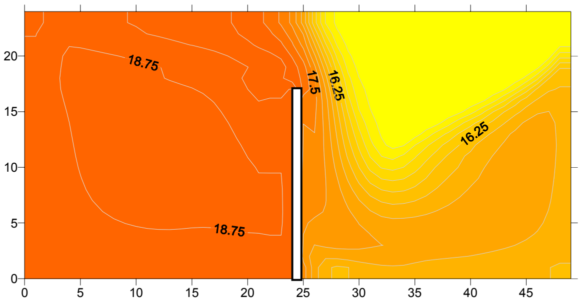


Figure 5. The bottom water salinity distribution at t=10 days

Bottom currents velocity was close to geostrophic and closely related to salinity distribution (Fig.6).

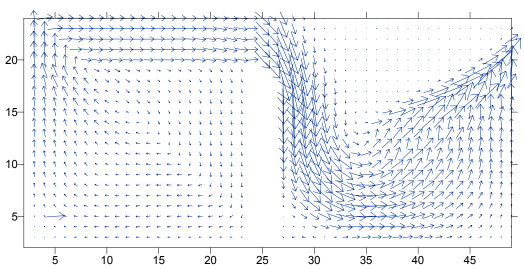


Figure 6. The bottom current velocity distribution at t=10 days

The width of spreading dense water tong was close to baroclinic radii of deformation (*Gill A.,* 1982). In the upstream area the decreasing of bottom layer thickness was distributed not uniformly. The most decreasing took place at the boundary. With time the width of near boundary areas increased (Fig.5).

5. Inflow into the area with bottom dense water layer

The same simulation was run for the case when downstream area was occupied by bottom layer. Its salinity exceeded bottom layer salinity of upstream area (Fig.4b). To make the path of incoming water more visible the initial temperature of upstream area bottom layer was set 10^{o}. The calculations shown that as at the privies case the incoming water spread along side boundary. But now it was found at the density interface instead of to be on a sea bottom (Fig.6).

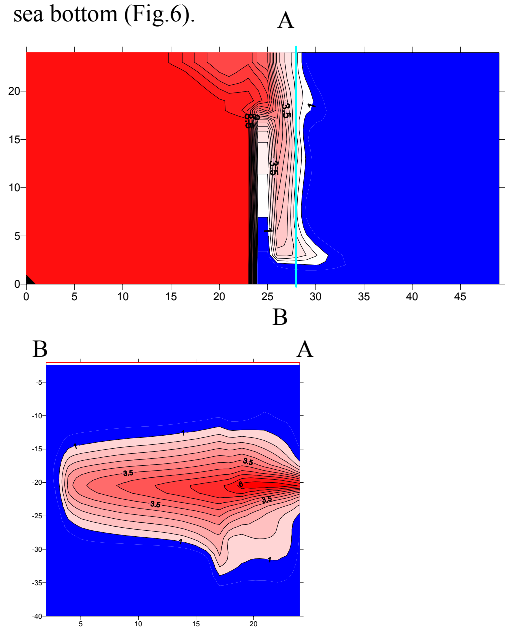


Figure 7. Water temperature distribution at t=7 days at the level z=20m (a) and at y-z section AB (b)

6. Conclusions

The numerical simulation made it possible to discover some important features of water exchange process between neighboring basins connected by narrow channel. So it shown that in downstream area the spreading bottom dense water follow side boundaries in form of tongue of saline water. In the upstream area the bottom layer thickness decreases not uniformly over all area. The most decreasing takes place near the side boundary. Discovered features are related with baroclinic processes of geosrtophic adjustment (*Gill A*, 1982).

References

Blumberg, A. F. and G. L. Mellor, *A description of a three-dimensional coastal ocean circulation model*, Three-Dimensional Coastal ocean Models, edited by N. Heaps, 208 pp., American Geophysical Union, 1987.

Gill A., *Atmosphere-Ocean Dynamics*, 415 p., Academic Press, 1982.

Estimation of Lateral Mixing in the Gulf of Finland Caused by Upwelling/Downwelling Squirts

Victor Zhurbas[1, 2] and Jaan Laanemets[2]

[1] Shirshov Institute of Oceanology, Nakhimovski Prospekt 36, 117997 Moscow, Russia, zhurbas@ocean.ru
[2] Marine Systems Institute at Tallinn University of Technology, Akadeemia tee 21, 12618 Tallinn, Estonia

1. Introduction

Westerly (easterly) wind generated upwelling (downwelling) along the Finnish coast and downwelling (upwelling) along the Estonian coast. The Gulf of Finland is a shallow and elongated basin (the length is about 400 km and the width varies from 48 to 135 km). Therefore, relaxation of the coupled upwelling and downwelling event may remarkably increase the lateral mixing in the upper layer. Data of in situ measurements and infrared imagery presented in (*Vahtera et al*. 2005) displayed the existence of intensive squirts in the Gulf of Finland formed immediately after an inflow event observed along the northern coast of the Gulf in the period of 21-29 July1999. Several squirts, or cold water jets crossing the upwelling front, visible in the infrared images, extended over almost the entire gulf's width. One may suggest such squirts contributing substantially to the lateral mixing in the Gulf. The objective of this study is to simulate the observed squirts in the framework of an ocean circulation model and to estimate the corresponding lateral mixing.

2. Model Setup

We apply the Princeton Ocean Model – POM (*Blumberg and Mellor* 1983). The POM is primitive equation, σ coordinate, free surface, hydrostatic model with 2.5 moment turbulence closure sub-model (*Mellor and Yamada* 1982) embedded. The model domain includes the whole Baltic Sea closed at the straits; the digital topography is taken from (*Seifert et al*. 2001). A model grid with varying grid spacing refined to 0.5 nm in the Gulf is applied; there are 20 σ layers in the vertical direction. The atmospheric forcing (wind stress and heat flux components) for a 20–day period starting on 20 July1999 was taken from a meteorological data set established and maintained by Lars Meuller at the Swedish Meteorological and Hydrological Institute (SMHI). The wind stress field calculated from the SMHI data set was eventually calibrated to fit the wind observations at Kalbådagrund weather station (Finnish Meteorological Institute). The initial thermohaline fields were constructed with the help of Data Assimilation System coupled with the Baltic Environmental Database established and maintained by Alexander Sokolov and Fredrik Wulff at the Stockholm University (see http://data.ecology.su.se/models). The model runs were started from the motionless state.

3. Results of Simulation

Figure 1 presents maps of simulated temperature and flow velocity in the surface layer (at 1 m below the sea surface) at three time moments within 20-day period from 00:00 on July 20 (which corresponds to t=0 day in Figure 1 and 2) to 24:00 on August 8, 1999 (*t=20 days*). The easterly wind produces a southward Ekman transport in the upper layer. As a result, at t=5.8 day when the westerly wind is passing its culmination, two eastward baroclinic longshore jets and the related upwelling and downwelling fronts are formed along the northern and southern shores of the Gulf, respectively. As soon as the wind culmination is passed, the longshore baroclinic jets begin to relax. The relaxation process is characterized by generation of cold water squirts propagating to the south and warm water squirts propagating to the north. Again, Figure 1, the middle and bottom panels, displays the possibility of transformation of the cold (warm) water squirts into cyclonic (anticyclonic) eddies. The selective formation of mostly cyclonic (anticyclonic) eddies from an upwelling (downwelling) longshore baroclinic jet was asserted earlier by *Zhurbas et al*. (2006). It can be seen in Figure 1 that the flow velocity in the squirts can be as high as 0.4-0.5 m s^{-1}. Such squirts running back and forth across the Gulf may substantially contribute to the lateral mixing.

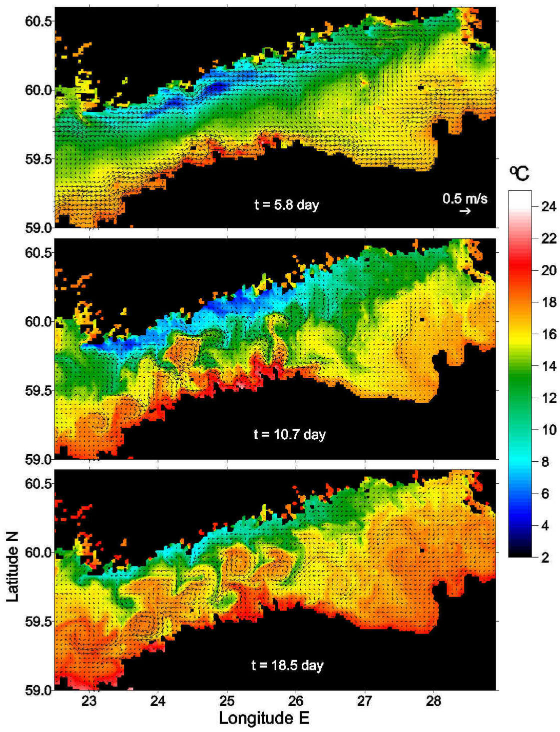


Figure 1. Simulated temperature (color scale) and velocity of currents (arrows) in the surface layer of the Gulf of Finland at t=5.8, 10.7 and 18.5 days. The velocity scale is shown in the lower right corner of upper panel

The numerical simulation data are used to estimate the apparent lateral diffusivity produced by the squirts. To arrive to the direct lateral diffusivity estimates, the fluctuations of temperature and transversal component of the flow velocity in the surface layer were extracted by means of high-pass filtering of the simulated data with the averaging length of the range of 40-90 km, and their cross-correlation was divided by the mean transverse temperature gradient. The time dependence of the lateral diffusivity, K, is shown in Figure 2. Having a vanishingly small value during the high wind period, K increases substantially after the wind dies off when the squirts are developing. The maximum values of K in the range of (1-

3)·10^3 m^2 s^{-1} are achieved at the moments when the squirts are the most pronounced (cf., Figure 2 and 1, the mid and bottom panels).

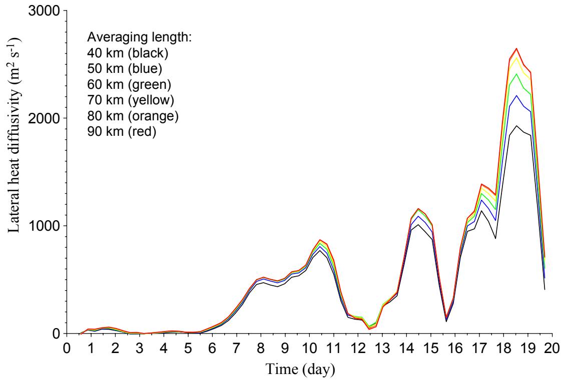


Figure 2. Time dependence of the apparent lateral diffusivity in the Gulf of Finland calculated from numerical simulation results. The calculation period is from 20 July to 9 August1999.

4. Conclusions

Numerical simulations show that the relaxation of longshore baroclinic jets caused by a coupled upwelling and downwelling event at the northern and southern shores of the Gulf of Finland, respectively, occurs in the form of cold and hot water squirts running back and forth across the Gulf and thereby contributing to the lateral mixing. The apparent lateral heat diffusivity due to the squirts is directly estimated to be of the order (1-3)·10^3 m^2 s^{-1}.

References

Blumberg, A. F., and G. L. Mellor, Diagnostic and prognostic numerical calculation studies of the South Atlantic Bight, *J. Geophys. Res*., 88, pp. 4579-4592, 1983.

Mellor, G. L., and T. Yamada, Development of a turbulence closure model for geophysical fluid problems, *Rev. Geophys.,* 20, pp. 851-875, 1982

Seifert, T., F. Tauber and B. Kayser, A high resolution spherical grid topography of the Baltic Sea – revised edition. Baltic Sea Science Congress 2001: Past, Present and Future – A Joint Venture. Abstract Volume. Stockholm Marine Research Centre, Stockholm University, p. 298, 2001. Web reference: http://www.iowarnemuende.de/en_iowtopo.html.

Vahtera E., J. Laanemets, J. Pavelson, M. Huttonen, K. Kononen,: Effect of upwelling on the pelagic environment and bloom-forming cyanobacteria in the western Gulf of Finland, Baltic Sea, *J. Mar. Sys*., 58, pp. 67-82, 2005.

Zhurbas, V., I. S. Oh, and T. Park, Formation and decay of a longshore baroclinic jet associated with transient coastal upwelling and downwelling: A numerical study with applications to the Baltic Sea, *J. Geophys. Res*., 111, C04014, doi:10.1029/2005JC003079, 2006.

Longstanding Fluctuations of the River Streamflow in Belarus Part of Baltic Sea Basin According to Atmospheric Circulation

Irina Danilovich and Ryhor Chekan

Republic Hydrometeorological Center of Belarus, 220014, prospect Nezavisimosti, 110, Minsk, Belarus
e-mail: irina-danilovich@yandex.ru

1. Introduction

Atmospheric circulation or whole atmospheric flows are used for characterizing of global climate in general and at the same time greatly influences the climatic conditions of the certain regions. Variations in the streamflow over the year strongly depend on climatic conditions. Deviations of climatic elements from average levels caused by, e.g., changes in the atmospheric circulation modify the conditions in which the streamflow is formed.

The aim of the research work was to define spatial and temporal patterns of streamflow formation according to atmospheric processes. Analysis of atmospheric circulation dynamic during 1900-2000 was conducted, connection between atmospheric processes and meteorological conditions within the territory of Belarus were established, and streamflow formation in different epochs of atmospheric circulation was carried out. Study of North Atlantic oscillation and its influence on streamflow in different epochs of atmospheric circulation was conducted. NAO Index Data provided by Hurrell, the Climate Analysis Section, NCAR. Data from 16 stream-gaging stations which are situated in Baltic Sea basin within the territory of Belarus and belong to the Department of Hydrometeorology of the Ministry of Natural Resources and Environmental Protection of the Republic of Belarus were used in the analysis.

2. Methodological approach of research

Climate changes indicate longstanding fluctuations in atmospheric circulation. The macro circulation approach of Vangengeim-Girs`s was used for the analysis of streamflow formation in Belarus. The approach is based on the definition of elementary synoptic processes and classification whole of processes into three types of atmospheric circulation – western (W), eastern (E) and meridional (C). The macroprocesses of western, eastern or meridional type of atmospheric circulation lasts during long time and forms a definite type of weather and than climate *Girs* (1971).

According to well-known results of previous research we accept follow scheme of atmospheric circulation dynamic:

W	→	E	→	C	→	EC	→	W
1900-1928		1929-1939		1940-1948		1949-1968		1969-2000

The data types of atmospheric circulation recurrence in the Northern hemisphere which were expressed in quantity of days with definite processes or its deviations were used for analysis.

3. Connection between types of atmospheric circulation and meteorological conditions in Belarus

There is a brief characteristic of meteorological conditions in Belarus according to dominate type of atmospheric circulation.

W – western type. The cyclones move from west to east and bring wet weather to Belarus. When western type of atmospheric circulation dominates positive deviations of air temperature have been observed in winter. The long thaws are observed in winter in Belarus. Also positive deviations of precipitation are very likely but precipitation is liquid. Cool and rainy weather is more likely in summer. Negative deviations from average of air temperature and positive deviations of precipitation have been registered in summer.

E – eastern type. The cyclones move from the Black Sea to the European part of Russia. The crest of Siberian anticyclone influences the weather. When eastern type of atmospheric circulation dominates cool and snowy weather in winter. The deviations of air temperature and positive deviations of precipitation have been recorded in winter in Belarus. The deficiency of precipitation and quit hot weather comes in summer under eastern circulation.

C – meridional type. The cyclones move from the Balkan Peninsula to the Baltic region and North of Russia. A huge area of air temperature negative deviations are formed under territory of Belarus in winter. Cold weather, significantly below average temperature, and the deficiency of precipitation are observed in winter. Quite high positive anomalies of air temperature are observed in summer.

Water supply in snow forms according to the eastern type of atmospheric circulation. The dynamic of means water supply in snow corresponds with recurrence of eastern processes which we can explain by positive deviations of precipitation caused by eastern circulation.

4. Streamflow formation in different epochs of atmospheric circulation

The research work found out that there are significant differences in streamflow formation within the Belarus part of Baltic Sea basin in different epochs of atmospheric circulation. At the same time there are differences in the formation of the streamflow within the territory of Belarus under the same atmospheric circulation. It is caused by orientation of the pressure system over the territory of Belarus and influences the meteorological conditions in the republic.

The impact of atmospheric circulation could be seen at monthly streamflow and intra-annual distribution. The western circulation determines a high winter streamflow (December-March), but low share of streamflow in spring (April, May). Meridional and eastern circulation determines low streamflow during the winter and high streamflow during spring flood *Danilovich* (2006).

The analysis show that formation of the streamflow in the Belarus part of Baltic Sea especially in cold part of the year significantly varies in different epochs of atmospheric circulation. During the epoch of western circulation the winter streamflow was a little below the average – about 10-20% and close to average. Spring streamflow observed above the average near 10-20% during this epoch. Eastern and meridional epochs characterized by low winter streamflow – 60-80% of the average but in the end of spring season raised and became above the average about 15-30%. In the last epoch of western circulation high winter streamflow formed – about 25-40% above the average but in spring it fell below the average about 10-30%.

5. Impact of North Atlantic oscillation on the streamflow

First studies of the connection of the North Atlantic Oscillation (NAO) and streamflow in the Belarus part of Baltic Sea revealed low (R=0.20-0.50, P<95%) but significant correlation between NAO indexes and monthly, seasonal and annual discharges on rivers within the territory of Belarus. The length of observational series was 105 years. The closest connection was stated between seasonal indexes of North Atlantic oscillation for December-January (NAOdjfm) and monthly and seasonal discharges during the cold season of the year. *Wrzesiński and etc* (2005). There is a direct connection during December-March and the inverse connection in April, May. The correlation coefficient in summer and autumn are low and not significant.

The macro circulation approach of Vangengeim-Girs`s was applied for the detailed analysis impact of North Atlantic oscillation on the river streamflow within the territory of Belarus.

The observation series were divided into groups according to duration of the epochs of atmospheric circulation. The correlation coefficients between monthly discharges and monthly indexes of North Atlantic oscillation for December-March were obtained (NAOdjfm) which varies significantly in different atmospheric epochs.

During 1900-1928 in the epoch of western circulation the correlation coefficients are low and not significant in the beginning of the year (January). In February connection has becomes closer, correlation coefficients are still not significant and total -0.2…-0.3. In March correlation coefficients increase and total 0.5…0.6. In the beginning of the year the connection between NAOdjfm indexes and discharges are direct that means corresponding high values of indexes to high values of discharges. But in April correlation becomes inverse, but values of correlation coefficients increase and total -0.5…-0.64 (-0.64 got for majority of rivers). For some rivers the correlation coefficients total -0.7. For the Zapadnaya Dvina correlation coefficients total -0.25…-0.3. In May significant correlation coefficients stays the same, but for major part of the Belarus part of Baltic Sea it was week. In the rest of the year correlation coefficients were low and not significant.

During 1928-1939 in the epoch of eastern circulation correlation of NAOdjfm indexes and discharges is quite high, but periods of close connection do not correspond with previous epoch. The closest inverse connection is observed in the Neman and Viliya river basins, reach -0.83. In the Zapadnaya Dvina basin correlation coefficient average 0.5…0.7 in other basins.

During 1940-1948 in the epoch of meridional circulation higher correlation coefficients are observed in the first quarter of the year. They total 0.5…0.7 in January and April and are not significant in February and March in the Zapadnaya Dvina basin. In the rest of the year the correlation coefficients become negative and total -0.5…-0.85 in June, October and December. For the Neman basin the correlation coefficients are positive in January-March and total 0.3…0.6. In April they become negative but their values are quite high over the whole territory of republic and total 0.7…0.9, but in May their values decrease and in the rest of the year they are not significant.

During 1949-1968 in the epoch of eastern and meridional circulation connection between North Atlantic oscillation and river streamflow was quite week, except of April and May with negative correlation coefficients about -0.5.

During 1969-2000 in the epoch of western circulation the correlation coefficients are positive: 0.4…0.7 during January-April, They increase from January to April. Than they become lower and not significant.

References

Wrzesiński, D., Nekrasova, L., Danilovich, I., Chekan G. Impact of the North Atlantic Oscillation (NAO) on the monthly, seasonal and annual flow of the rivers in Belarus. The theses of the international conference "Theoretical and applied problems of Geoecology". Minsk, 2005. pp. 35-38. (In Russian).

Girs A. Longstanding fluctuations of atmospheric circulation and long-term Hydrometeorological forecasts Leningrad,1971. p. 214. In Russian).

Danilovich I. Impact of atmospheric circulation on river streamflow in Belarus. The thesis of second young scientist conference UNS. Moscow, 2006, p.13. (In Russian).

Reconstructing the Past 500 Years of River Runoff to the Baltic Sea.

Christin Eriksson, Daniel Hansson, Anders Omstedt and Deliang Chen

Earth Sciences Centre, Göteborg University, Sweden, chpe@oce.gu.se

1. Background

The inflow of freshwater is important for maintaining the Baltic Sea as a brackish sea. Freshwater inflow to the Baltic Sea is restricted to river runoff from the catchment area and net precipitation over the sea. Variability of the atmospheric circulation gives rise to an annual river runoff of about 15 000 m^3s^{-1} to the Baltic Sea. During the year, there are large seasonal differences ranging from a maximal freshwater discharge during snowmelt in late spring and early summer to a minimum discharge of freshwater during the winter; when most of the precipitation comes in the form of snow. Ongoing freshwater budget modelling efforts are in need of reasonable estimates of annual river runoff as well as seasonal distributions of freshwater discharge. River runoff estimates on a monthly basis are available for the 20th century.

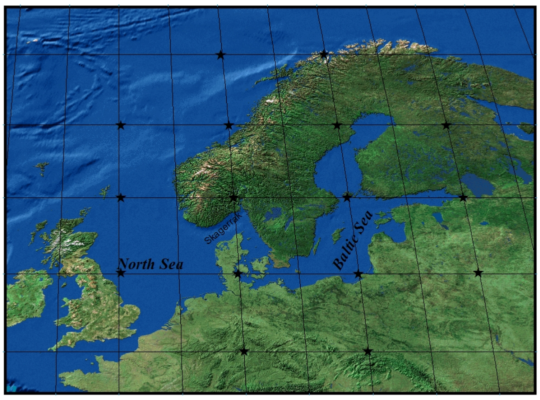


Figure 1. Baltic Sea region.

2. Method

A gridded data set were used and consists of a sea level pressure reconstruction with a resolution of 1° × 1° over the area from 30° to 70° N and 30°W to 40°E. This is an updated version of the 5° × 5° data set by *Luterbacher et al. (2002)* for the period 1500-1995, with monthly data back to AD 1659 and seasonally before. Circulation indices were calculated over the Baltic Sea region by using the points shown as stars in Figure 1. The circulation indices were calculated on a seasonal time scale extending back to 1500.
From the gridded data set, indices that describe the geostrophic velocity field and the rotational components of the atmosphere were calculated. A decomposition of the SLP field like this provide information about the entire field and are therefore better than single circulation indices such as the North Atlantic Oscillation.

3. Statistical modelling

A simple statistical model, based on multiple regression methods, was then employed to develop a statistical relationship between the river runoff series and changes in atmospheric circulation. The indices are used as climatic predictors and serve as base for the statistical model. The statistical model was formulated to inspect the atmospheric circulation indices and thereby find the parameters that significantly contribute to the series. This inspection was made possible by using the stepwise regression method. The stepwise regression routine chooses predictors whose importance will be considered in terms of an F-test. The statistical model was calibrated and validated during the period 1902-1995 with realistic results (Eriksson et al, 2007), see Figure 2.

4. Results

By using century long time series of river runoff in combination with seasonally resolved atmospheric circulation indices for the past half millennium a statistical relationship was established. This relationship is used to reconstruct the seasonal variation of the river runoff covering the past 500 years. The statistical relationships reveal important physical mechanisms regarding the seasonal signal of the river runoff. The reconstructed river runoff can be used as forcing when modelling the Baltic Sea salinity of the past 500 years.

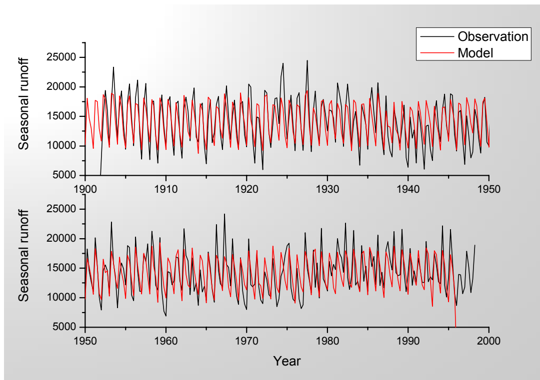


Figure 2. Model results for the period 1902-1995.

References

Eriksson, C., D. Hansson, A. Omstedt, D. Chen, Reconstructing the past 500 years of river runoff to the Baltic Sea, *In preparation*, 2007

Luterbacher, J., E. Xoplaki, D. Dietrich, R. Rickli, J. Jacobeit, C. Beck, D. Gyalistras, C. Schmutz and H. Wanner, Reconstruction of sea level pressure fields over the Eastern North Atlantic and Europe back to 1500. *Clim. Dyn.*, **18,** 545–561, doi:10.1007/s00382-001-0196-6. 2002

Comparison of Selected Storminess Indices Based on Point Pressure Measurements

Krzysztof Fortuniak[1] and Lars Bärring [2]

[1]University of Łódź, Department of Meteorology and Climatology, Łodź, Poland, e-mail: kfortun@uni.lodz.pl
[2] SMHI, Rossby Centre, Norrköping, Sweden, email: Lars.Barring@smhi.se *and* Lund University, Department of Physical Geography and Ecosystem Analysis, Geobiosphere Science Centre, Lund, Sweden, e-mail: Lars.Barring@nateko.lu.se

1. Introduction

A long-term variability in extra-tropical cyclones frequency and strength is one of key issue in studies on potential climate changes in Baltic region. Beside theoretical considerations and numerical simulations, valuable information on recent changes in cyclone activity can be extracted from observed data. The most common approaches to the problem cover individual cyclone counting (*Schinke* 1993, *Stein and Hense* 1994, *Lambert* 1996), analysis of the real wind data and geostrophic wind calculated from pressure data (*Alexandersson at al.* 1998), or studies on the pressure fluctuations on selected stations (*Schmith at al.* 1998, *Bärring and von Storch* 2004). Application of real wind measurements or weather maps is limited because of inhomogenity in data sets (*von Storch et al.* 1993, *WASA Group* 1998). The quality of pressure data since the beginning of 19th century is much better. However, before this date high quality data exist for a few stations only, which restricts a triangle method used to calculate geostrophic winds. Instead Eulerian statistics like the variance in frequency bands or other indices can be evaluated to extend knowledge on deep cyclone activity further back in time. However, there exists no standard method and different proxies are used. The main goal of the present work is to compare eight different storm indices derived from pressure readings in Lund (1780-2005) in order to analyse long-term changes in storminess in southern Scandinavia.

2. Data and methods

The analysis is based on the long series of pressure observations from Lund, southern Sweden (55°42'N, 13°12'E). Pressure readings from the period January 1780-May 1997 were compiled and homogenised by *Bärring at al.* (1999). Data consist of three observations per day, but time of the observation has varied during the whole period. The observation period was extended to the end of 2005 with data from Falsterbo meteorological station (55°23' N, 12°58'E) with the same methodology as used before.

In this work we use eight different storminess indices. The first four belong to the most intuitive and widely used proxies; by counting events when pressure exceeds a fixed threshold or calculating percentiles:

1) annual number of pressure observation below 980 hPa (N_{p980}),
2) intra-annual 1-percentile of the pressure data set (P_{1p}),
3) annual number of absolute pressure tendencies exceeding 25 hPa/24 h ($N_{\Delta p/\Delta t}$),
4) intra-annual 99-percentile of the absolute pressure differences in 8 h ($P_{99\Delta p/\Delta t}$).

Thresholds were select so as to allow comparison with previous studies (*Alexandersson et al.* 1998, *WASA Group* 1998, *Bärring and von Storch* 2004). These indices are easy to calculate but they suffer for several limitations. For example, N_{p980} does not take into account the background pressure field. Relatively shallow cyclones embedded in a larger scale low can be taken into account by this index, whereas it is possible to miss a deep vigorous cyclone in a general high pressure situation. $N_{\Delta p/\Delta t}$ can ignore gradually developing deep cyclone with tendencies between individual observations only slightly lower than the threshold.

Next two indices are based on the pressure variance in selected frequency bands. Instead of digital filtering of the data, classical spectral analysis is used to find the variance in specific spectral bands for creating two proxies:

5) annual pressure variance in the frequency band 0.3-0.6 day^{-1}, ($Sf_{0.3\text{-}0.6}$),
6) ratio of the annual pressure variance in the frequency band 0.3-0.6 day^{-1} to the pressure variance in the frequency band 0.1-0.3 day^{-1} (R_{Sf}).

Variance in the frequency band 0.3-0.6 [1/day] (period 1.7-3.3 day) shows fast synoptic transients. Second spectral index, R_{Sf}, gives information on relative changes in the spectrum shape. An increase of deep, fast moving cyclones together with reduction of total cyclonic activity imply a shift to higher frequencies in the power spectrum (changes in spectrum colour).

Applicability of classical spectral analysis is limited to the evenly sampled data, which is not a case in Lund pressure time series. To avoid this problem the original data were linearly interpolated to fixed measurement hours; 7, 13, and 21 GMT (8h time step). Errors introduced in this way are small in comparison to the typical amplitude of waves being analysed.

Last two indices are based on the idea of a wavelet transformation. In the first of them a convolution, W_{ab}, of pressure time series, $p(t)$, with a scaled and translated mother wavelet, $\psi(x)$, is calculated as a indicator of a cyclone occurrence in time point b:

$$W_{ab} = \sum p(t) \cdot a^{-1}\psi\left(\frac{t-b}{a}\right)$$

This mother wavelet is an inversed version of the classical 'Mexican Hat'. Parameter b denotes wavelet location and parameter a scale (dilation) of the wavelet. For the Mexican Hat wavelet parameter a is related to characteristic cyclone time scale by a factor $2\sqrt{3}$. Deep, fast moving cyclones appear as high peaks in W_{ab} for low values of a. A cyclone activity index is defined as:

7) annual sum of the structures characterised by W_{ab} values higher than a fixed threshold in a chosen range of parameter a (N_{MexHat})

Because of lack of an objective method for selecting a threshold it is set as 22. This gives annual number of cyclones at the same order of magnitude as N_{p980} and $N_{\Delta p/\Delta t}$. To keep the similarity to the spectral analysis the range of a scale parameter was set as: $1 \le a \le 4$. For thrice-daily pressure observations, this corresponds to the cyclones characterised by a time scale (range between two maxima in wavelet function) from 1.1 to 4.6 days.

The mother function for the last index is defined as $\varphi(x)=|x| - 1$ for $-1 \le x \le 1$ and 0 elsewhere. This function does not have zero mean, so the covariance, C_{ab}, with the pressure for the interval ($-a$, a) was calculated instead W_{ab}:

$$C_{ab} = \mathrm{cov}\left(p(t), \varphi\left(\frac{t-b}{a}\right)\right)$$

In similarity with the previous index, the cyclone activity index is defined as:

8) annual sum of the structures characterised by C_{ab} values higher than 2.3 for the range of scale parameter from 2 to 5 ($N_{|x|-1}$)

This corresponds to a cyclone time scale of 1.3 to 3.4 days.

3. Results and discussion

Temporal changes of all 8 indices presented in Figure 1 show two main features:

1) the overall long-term variability of the indices agree, but the high frequency variability differ,
2) there is no evidence for extraordinary intensification of the cyclonic activity in last decades.

Indeed, except for N_{p980}, and the highly correlated P_{1p}, there no positive trend is visible. And for these two indices this trend can be a result of low values at the beginning of the 19th century. For the 19th century, the highest values in were recorded around 1870 and 1850 whereas the last two decades was a relatively calm period. For the first years of the 20th century most indices suggest a recovery of the cyclonic activity. After these first decades, there is a decreasing tendency up to the 1960's in several indices, but amplification of cyclonic activity begins already in the 1940's is also well pronounced in some indices. Last five decades is at the centre of interest because of potential changes related to global warming. All indices increase since beginning of 1960s to about 1990, but in general they turn down toward low values around 2000. Some indices (P_{p980}, P_{1p}, $Sf_{0.3\text{-}0.6}$, R_{Sf}) show quite dramatic decrease in last years whereas others suggest only slight reduction of the activity. However, in all cases variability in last few decades is within the limits of the earlier variability. All indices are highly correlated ($p<0.01$) except R_{Sf} which is rather weakly linked to the others indices, except $Sf_{0.3\text{-}0.6}$ ($p>0.01$ for correlation with N_{p980}, P_{1p}, and N_{MexHat}). Results show that no single index is representative for the secular changes in cyclonic activity and an analysis based on one index only can be misleading. However, general information variations in storminess can be extracted from a set of several proxies - like the 8 indices presented here - with the aid of principal component analysis. The first PC (not shown) correlates well with previous studies (e.g. *Alexandersson at al.* 1998) and can be use as a good proxy for long term changes in storminess at relatively large area.

Acknowledgements

This work was funded by European Community under STATME project (Contract MTKD-CT-2004-014222). Thanks to Rossby Centre where K. Fortuniak had opportunity to study this issue during a training period.

References

Alexandersson, H., Schmith, T., Tuomenvirta, H., 1998, Long-term variations of the storm climate over NW Europe, *Global Atmos. Ocean System*, 6, 97-120

Bärring, L. and H. von Storch, 2004: Scandinavian storminess since about 1800. *Geophys. Res. Lett.*, 31, 1-4

Bärring, L., Jönsson, P., Achberger, C., Ekström, M., Alexandersson, H., 1999, The Lund instrumental record of meteorological observations: reconstruction on monthly sea-level pressure 1780-1997 *Int. J. Climatol.*, 19, 1427-1443

Lambert, S. J., 1995, The effect of enhanced greenhouse warming on winter cyclone frequencies and strengths. *J. Climate,* 8, 1447-1452

Schmith, T., Kaas, E., Li, T.-S, 1998, Northeast Atlantic winter storminess 1875-1995 re-analysed, *Clim. Dyn.*, 14, 529-536

Schinke, H., 1993, On the occurrence of deep cyclones over Europe and the North Atlantic in the period 1930-1991, *Contrib. Atmos. Phys.*, 66, 223-237

Stein, O., Hense, A., 1994, A reconstructed time series of the number of extreme low pressure events since 1880, *Meteorol. Z.,* NF3, 43-46

von Storch, H., at al., 1993, Changing statistics of storms in North Atlantic?, *Report No. 16,* Max-Planck-Institut für Meteorologie, Hamburg, Germany

WASA Group, 1998, Changing waves and storms in the northeast Atlantic? *Bull. Amer. Met. Soc.*, 79, 741-760

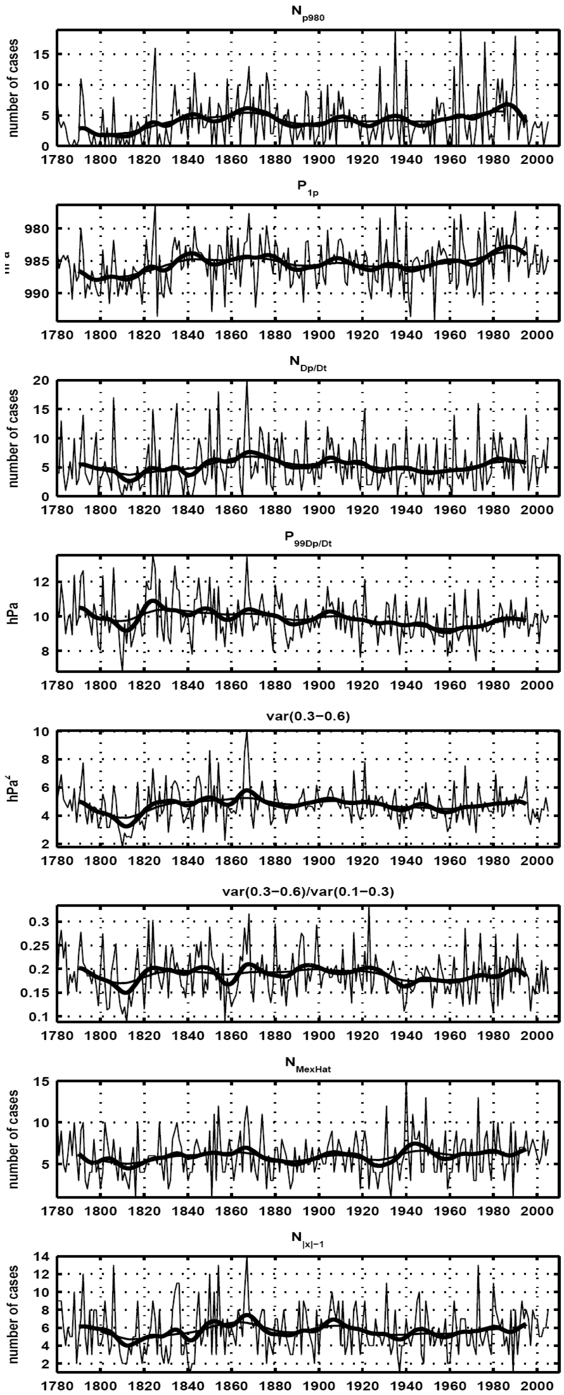


Figure 1. Time series of pressure-based storminess indices derived from pressure readings in Lund.

Regional Differences in Winter Sea-Level Variations in the Baltic Sea for the Past 200 Years

Birgit Hünicke[1], Eduardo Zorita[1], Jürg Luterbacher[2] and Andreas Pauling[3]

[1]Institute for Coastal Research, GKSS Research Centre, Max-Planck-Str.1, 21502 Geesthacht, Germany; [2]Institute of Geography and NCCR Climate, University of Bern, CH-3012 Bern, Switzerland; [3]Federal Office of Meteorology and Climatology Meteoswiss, Zurich, Switzerland. E-mail: huenicke@gkss.de

1. Introduction

Estimations of future global sea-level from simulations with coarse-resolution global climate models mostly depend on large-scale processes, such as the heat-flux into the ocean, on changes in the ocean circulation and on the rate of melting of land-ice masses. In regions with complex coastlines, as the Baltic Sea, sea-level changes may additionally depend on other regional factors which are not properly represented in global models. In wintertime, inter-annual Baltic sea-level variations at its northern and eastern boundaries are influenced by the westerly winds, related to the sea-level-pressure (SLP) pattern of the North Atlantic Oscillation (NAO). Stronger westerlies in positive NAO phases cause higher sea-level in some areas of the Baltic Sea. Some studies indicate that the connection between individual Baltic stations and SLP may be heterogeneous in time and in space, concluding that other processes different from the wind-stress forcing are important for sea-level variability. For instance *Hünicke and Zorita* (2006) have suggested that precipitation and temperature may also contribute to sea-level variations, thus modulating the correlations between sea-level and the NAO. The question arises whether these local processes may significantly influence also sea-level variability at low-frequencies, i.e. multi-decadal, so that their contribution should be considered for future sea-level projections at local scales.

2. Methods

We present a statistical analysis of the relationships between Baltic sea-level and large-scale atmospheric forcing in the past 200 years, using winter means (December to February) of long gauge sea-level records (PSMSL) and gridded climate reconstructions of SLP, air-temperature and precipitation covering the European land area (*Luterbacher et al.*, 2002, 2004; *Pauling et al.*, 2006). These reconstructions coincide with corresponding observational records in their calibration period 1901-1990 (for precipitation 1901-1983) and did not include any sea-level information as predictors. We aim at confirming the heterogeneous regional response of sea-level to large-scale forcing at multi-decadal timescales and at identifying possible factors for this behavior. We consider each gauge station individually to ascertain whether the effect of large-scale factors may also vary regionally.

Our approach is based on statistical regression methods to hindcast sea-level variations, calibrated in the 20th century and validated in the 19th century, examining the skill of the different predictors. However, the processes responsible for regional winter sea-level variations for high-latitude semi-enclosed seas are complex, as sea-ice, precipitation, run-off, may affect sea-level, in some regions more strongly than in others. In this study the predictors considered are restricted to those for which long observations or reconstructions are available and which are potentially well simulated by coarse resolution models, so that its conclusions may be applied to the output of GCM simulations. In practice, these are SLP (an indicator of geostrophic wind), area-averaged precipitation and air-temperature.

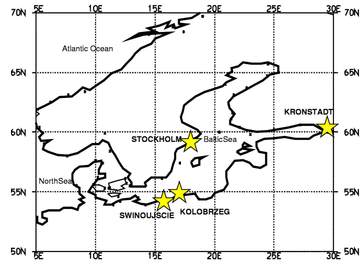


Figure 1. The location of the sea-level gauges

The trend in the sea-level records, caused by a combination of post-glacial land uplift and eustatic sea level change, is assumed to be linear and is eliminated by statistically estimating individually the linear trend and subtracting it. The analysis is then restricted to variations around the long-term linear trend. As we are interested in variability at decadal and longer timescales, all timeseries (sea-level and gridded climate reconstructions) were smoothed with an 11-year running mean filter.

3. Relationship between Baltic Sea level and large-scale gridded fields

In the 20th century, sea-level variations in the four stations used in this study evolve quite coherently, in the 19th century their agreement is less obvious, particularly between the Southern stations and the other two (Fig.2).

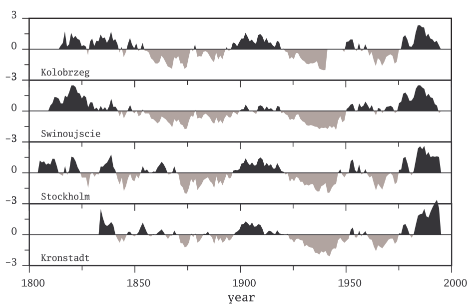


Figure 2. Relative winter mean (DJF) sea-level height in years 1800-2000: deviations from the 1900-1999 mean, linearly detrended, smoothed by a 11-year running-mean and standardized to unit standard deviation.

When decadally smoothed, the inter-station correlation exceeds 0.85 for all pairs in the 20th century, but in the 19th century the correlations between the southern stations and the rest falls about 0.5. A view of the possible external atmospheric forcings that may give rise to this behavior is presented in Fig.3.

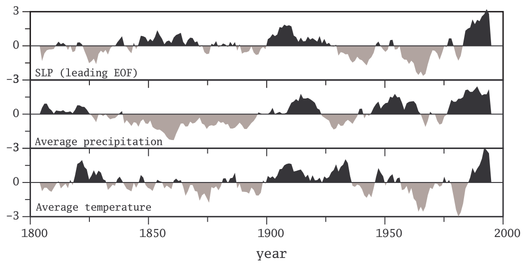


Figure 3. Timeseries of the leading winter SLP EOF in the North Atlantic-European sector, area average precipitation and area average temperature in the Baltic Sea region: deviations from the 1900-1999 mean, smoothed by a 11-year running mean and standardized to unit standard deviation (temperature has bee previously linearly detrended).

In the 20th century, all three time series behave coherently at decadal time scales, while in the 19th century they tend to diverge. Noteworthy are the large negative precipitation anomalies in the last decades of the 19th century, which is not matched by the SLP and temperature and suggests that these factors might force sea-level in a spatially heterogeneous way.
Thus, as a first predictor in a regression equation SLP is considered. The SLP field is previously decomposed in its Principal Components (PCs) to avoid co-linearity. In a second step we explore whether area-averaged precipitation could be a skillful predictor for the Southern sea-level stations (which show a low calibration and a very poor validation skill using SLP as predictor) Fig. 4 and Fig. 5 show the results. The skill of the regression was evaluated by the Reduction of Error statistics (RE, which adopts a value of unity for a perfect estimation and a value of zero foe a skill equal to climatology) and by the correlation coefficient (r) between observations and estimations, both evaluated in the validation period (indicated in the Figures).

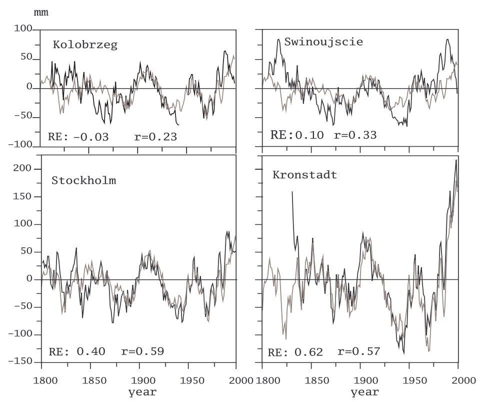


Figure 4. Decadally smoothed and linearly detrended observed sea-level and reconstructed sea-level (deviations from the 1900-1999 mean) using the SLP field as predictor.

In a third step winter air-temperature was used as a sole predictor, but the statistical model did not show any improvement relative to the SLP-only model.

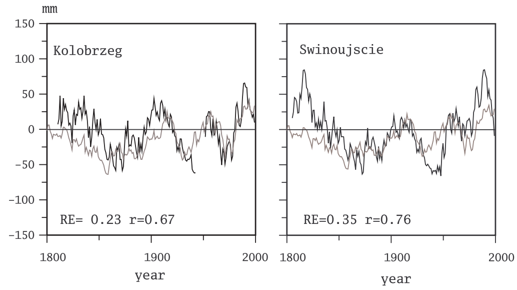


Figure 5. As in Figure 4, but for the southern Baltic stations only and using the area-average precipitation as predictor.

4. Summary and Conclusions

The study analyzes the spatial heterogeneity of sea-level records at decadal timescales and its possible physical origins. It is found that in regions with complex coastline structure, as in the Baltic Sea, sea-level records may show periods of homogenous behaviour, but also records of divergence. The explanation for this heterogeneity is found to be the heterogeneous influence of large-scale forcing factors, such as atmospheric circulation and precipitation.
Decadal sea-level variations in southwestern, central and eastern Baltic Sea tend to be less coherent in the 19 century than in the 20th. The evolution of the North Atlantic SLP, precipitation and air-temperature from gridded climate reconstructions has been considered to explain this behavior. The influence of these factors on sea-level varies for the different stations. In the central and eastern Baltic, sea-level variations are well described by SLP alone, whereas in the southern Baltic Sea area-averaged precipitation is a better predictor. The evolution of precipitation in the 19th century could explain the different behavior of the Southern Baltic stations. The effect of temperature variations may be contained in the SLP field or is less important for decadal sea-level variations. Depending on the evolution of these forcing factors in the past and future climate, regional sea-level variations might be affected by different physical mechanism and sea-level trends in different parts of one region may display some divergence. If SLP and precipitation trends diverge in future climates, e.g. due to humidity, sea-level trends in different parts of the Baltic Sea may also diverge. This may be relevant when trying to estimate past sea-level variations based on the average of a few long available records or when estimating future sea-level changes at regional scales.

References

Hünicke, B. and E. Zorita, Influence of temperature and precipitation on decadal Baltic Sea level variations in the 20th century, *Tellus*, 58A, 141-153, 2006

Luterbacher, J. et al., Reconstruction of Sea Level Pressure fields over the Eastern North Atlantic and Europe back to 1500, *Clim. Dyn.*, 18, 545-561, 2002.

Luterbacher, J. et al., European seasonal and annual temperature variability, trends and extremes since 1500, *Science*, 303, 1499-1503, 2004

Pauling, A. et al., Five hundred years of gridded high resolution precipitation reconstructions over Europe and the connection to large-scale circulation, *Clim. Dyn.*, 26, 387-405, 2006

Climate Fluctuations in the Belarus Part of the Baltic Sea Basin

Alena Kamarouskaya and Iryna Kulyashova

Republic Hydrometeorological Center of Belarus, 220014, prospect Nezavisimosti, 110, Minsk, Belarus
e-mail: clim@by.mecom.ru

1. Introduction

It is known that climate changes took place in the past. However, in the past, they were caused by natural reasons. But the changes which have begun at the end of the 1980s of and which proceed until now are caused not only by natural reasons, but also by human activity. Global temperature has increased approximately by 0,6°C. Observed temperature changes naturally reflect the regional conditions in the Belarus part of the Baltic Sea basin.

2. Changes in air temperature regime

During the observation period of more than 100 years, short-term periods of temperature rise (with respect to the average long-term temperature) changed with similar periods of falling temperatures, approximately until the end of the 1980s. Since 1989, the longest period of temperature rise of the century occurred, which is still in progress (*Golberg et al.* 2003).

Only once, in 1996, the average annual temperature was a little lower than normal, in other years it was much higher. For a series of very warm years – 1989, 1990, 1999, 2000, the temperature norm was exceeded by more than 1,5 °C. Such a deviation from the norm was observed only once in 1975 for the previous 100 years before 1989. The average temperature of the warming period is approximately 6,9 °C in the Belarus part of the Baltic Sea basin, whereas the average temperature for the century is 5,8 °C, and exceeds the temperature of all previous periods of warming.

3. Changes of annual air temperature profile

The positive anomaly of this period is most significant in winter and early spring months. It reaches a maximum in January (3,7 °C) and, slowly decreasing, proceeds until April (2 °C). Positive anomalies of spring months result in earlier snow cover melting, an earlier onset of vegetation and an increased activity of vegetation. On the average, the summer months for these years were also warm, but the size of the anomaly was less, about 0,5 °C. However, the absolute values of July anomalies in 2001 and 2002 are comparable with January.

Another feature of the warming period is the change of annual air temperature profiles in the Belarus part of the Baltic Sea basin. For some years, the period of the lowest temperatures has shifted to the beginning of winter, and in some years (1993, 1998) even to November, when average monthly temperatures decreased to -5 to -6 °C, i.e. they were comparable to former January and February temperatures. Using monthly average values, February was the coldest month of winter, although in some years the coldest month was December.

4. Changes in thunderstorm activity

As the result of significant warming in January and February, thunderstorm activities during these months became frequent in the Belarus part of the Baltic Sea basin. Before 1988 (52 years), thunderstorms in January and February were observed only 15 times at 11 stations, while after 1988 they were observed 35 times at 25 stations.

5. Changes in precipitation regime

The period of rising temperatures at the end of the 20th century had no effect on the annual amount of precipitation in the Belarus part of the Baltic Sea basin (*Loginov* 1996). Precipitation during the warm (April - October), as well as during the cold period of the year (November - March) was similar to the norm. However, the irregularity of precipitation events inside the year, and on the whole between the different years, has risen noticeably.

6. Changes in wind speed regime

The increased irregularity of precipitation and global warming caused droughts, which occurred twice in the Belarus part of the Baltic Sea basin. A reduction of wind speed was observed in Belarus since the 1970s. The average wind speed was 3,6 m/s until 1970, then it decreased by 0,5 m/s during the subsequent period.

7. Extreme climate phenomena

During this period an increase in extreme climate phenomena was observed in the Belarus part of the Baltic Sea basin. According to the forecast of the World Meteorological Organization, the frequency of extreme climate events will increase.

References

Golberg M., Volobueva G. Kamarouskaya E., Kulyashova I. Change of the basic climatic characteristics of Belarus in XX century. *Reports of the National Academy of Sciences of Belarus* Volume 47 № 1 2003, pp. 119-123 (In Russian).

Loginov V. *The natural environment of Belarus*. 1996, pp. 35 (In Russian).

Tendencies of Seasonal Variability of Snow Storage in Conditions of Regional Climate Changes over Northern Europe.

Lev Kitaev[1] and Raino Heino[2]

[1] Institute of geography RAS, 109017, Staromonetniy per. 29, Moscow, Russia, lkitaev@online.ru
[2] Finnish Meteorological Institute, P.O.Box 503, FIN-00101 Helsinki, Finland

1. Introduction

In previous diagnostic and modeling studies related to national and international projects, the essential role of the snow cover for climatic and hydrological systems over high latitudes of Northern hemisphere has been revealed. The growth of snowiness contrary to increase of winter temperatures as well as circulation changes of distinctions of snow changes between regions have been identified for the north of Eurasia (*Heino et al. 2006; Kitaev et al. 2002*). Interactions of variability of a snow cover, water balance, regional meteorological regime and ground conditions have also been determined (*Krenke et al. 2004; Kitaev et al. 2005_a; Kitaev et al. 2005_b*). Regional features of snow cover duration over Scandinavian Peninsula and northern part of Earth European plain have been studied by *Kitaev at al., 2006*. Three regions with special conditions of snow cover duration and climatic parameters changing are indicated in Fig. 1.

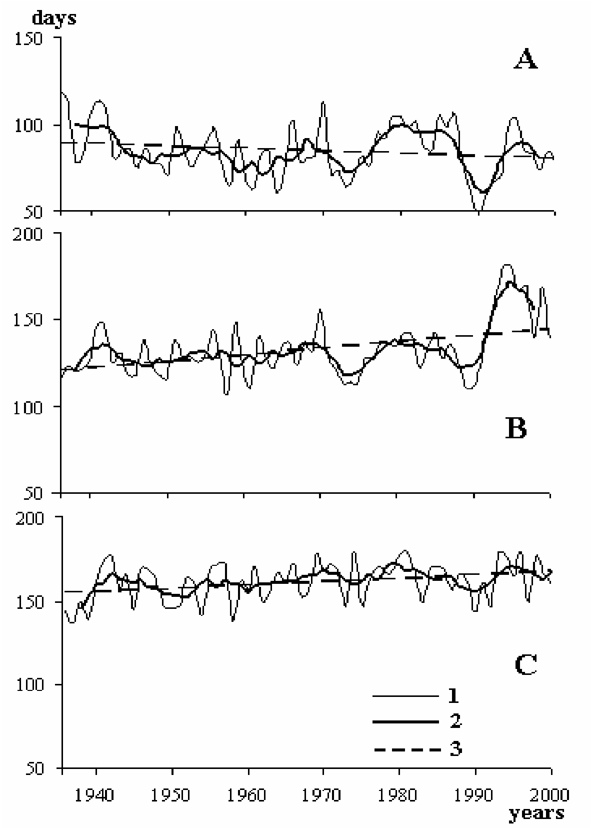


Figure 1. Time series of spatial mean duration of snow cover in parts of Scandinavian Peninsula and northern part of East European plain: (A) western, 5-15 °E; (B) central, 15-25 °E; (C) eastern, 25-45 °E, including 5-year moving mean series and linear trends.

Recent studies within BALTEX framework and according the tasks of the International Polar Year (projects EALÁT (Norway) and NOSCAM (Russia) have been initiated: Seasonal variations of snow storage in conditions of regional climate variability and the tendency of snow storage changes by means of statistical and mathematical modeling have been evaluated. Seasonal changes of snow cover and accumulation have also been investigated for the autumn-winter period. Changes were examined in monthly steps: for average for a month of air temperature and snow storage on last date - accordingly for November, December, January and February. And the gain of snow storage month by month were especially investigated.

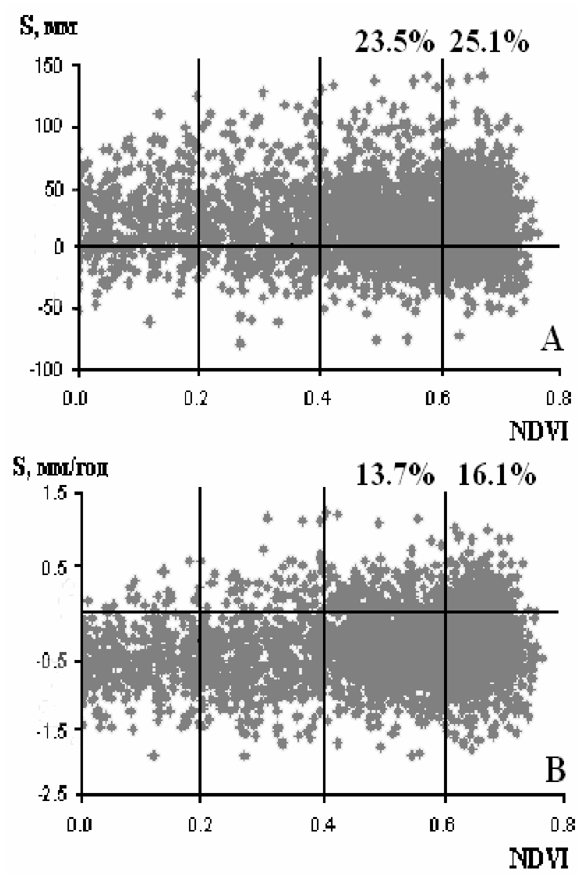


Figure. 2. Distribution of month snow gain (A) and its trends (B) in January within NDVI volumes - for grids 1x1 degree of all territory.

2. Seasonal tendencies of the snow storage

Positive trends of air temperature in winter period are defined by lowering of monthly temperature drops aside downturn. The negative trends of the snow gain in November and in December on this background are observed. And the January snow gain has a positive trend, having increased for the period of 1966-2000 by 19 mm.

Snow gain in January renders the most essential contribution to long-term increase of snow storage in February, the greatest for the winter period over Northern Eurasia. The analysis of step-by-step regress shows, the January snow gain to the greatest degree in comparison with autumn months provides snow storage variability in February - for 17 % of the general dispersion (regression 0.42), and in aggregate with a snow gain in December - for 28 % of the general dispersion (regression 0.53).

3. Spatial features and long-term tendencies of snow storage variability

The greatest snow gain is characteristic for 0.6-0.8 microns of index NDVI (zone of woods): positive trends of snow gain are marked basically over these territories also (fig. 2).
Modeling temperatures (ECHOG_SRES_A2Ga_MM (*Min S.-K. et al. 2005; Min S.-K. et al.2006*)) during 20th century exceed the standard deviation of the observed data. Crossing of trends of the observed and modeling data is marked for January snow gain during 2002-2005. It is possible to mark this period as limit of snow increase on background of temperature increasing.
The received results about snow storage variability are detailed for Scandinavian Peninsula and the north of East European plain. Regional distinctions of snow cover variability are received in connection with distinctions of landscape structure and features of atmospheric circulation. The forecast of snow cover variability for 50 years is carried out by the combined analysis of the observed and model data.

References

Heino R., Razuvaev V. and Kitaev L. Snow cover changes over Northern Eurasia during the last century (INTAS-SCCONE Project). *Ice and Climate News.* N7, pp.6-7. 2006.

Kitaev L., Kislov A., Krenke A., Razuvaev V., Martuganov R. and Konstantinov I. The snow cover characteristics of northern Eurasia and their relationship to climatic parameters. *Boreal Environment Research.* Vol. 7. N 4. pp. 437-446. 2002.

Kitaev L., Forland E.. Razuvaev V., Tveito O.-E. and Krueger O. Distribution of snow cover over Northern Eurasia. *Nordic Hydrology.* Vol. 36. N 4-5. pp. 311-319. 2005_a.

Kitaev L. M., Razuvaev V. N., Heino R. and Forland E. Duration of snow cover over Northern Europe. *Russian Meteorology and Hydrology*, Allerton Press. Inc., New York , NY, USA, 2006, N 3, pp. 95-100.

Krenke A., Popova V., Titkova T. and Kitaev L. Role of snow cover in the average water cycle in the Northern Eurasia. *The ACSYS Decade and Beyond.* WCRP-118(CD), WMO/TD/No 1232, September. 5 p. 2004.

Kitaev L.M., Krueger O., Sherstyukov B.G. and Hobe H. Indications of influence of vegetation to the snow cover distribution. *Russian Meteorology and Hydrology.* Allerton Press. Inc., New York , NY, USA.. N 7. pp. 61-69. 2005_b.

Min S.-K., Legutke S., Hense A. and Kwon W.-T. Internal variability in a 1000-year control simulation with the coupled climate model ECHO-G - I. Near-surface temperature, precipitation and mean sea level pressure. *Tellus.* N 57A. pp. 605-621. 2005.

Min S.-K., Legutke S., Hense A., Cubasch U., Kwon W.-T., Oh J.-H. and Schlese U. East Asian climate change in the 21st century as simulated by the coupled climate model ECHO-G under IPCC SRES scenarios. *Journal of the Meteorological Society of Japan.* N 84. pp. 1-26. 2006.

River Discharge Regime in Latvia in Respect to Climate Variability

Maris Klavins and Valery Rodinov

University of Latvia, Department of Environmental Sciences, Raiņa bulv. 19, LV 1586, Rīga, Latvia, e-mail: maris.klavins@lu.lv

1. Introduction

Long term observations of hydrologic systems provide time series of evapotranspiration, precipitation and river discharge. River discharge time series have been extensively studied worldwide. Relevant trends regarding global climate changes have been identified in Nordic countries. Commonly, river discharge patterns have been studied in terms of linear trend analysis, even though they can be much more complex. Analysis of river discharge patterns is important for the Baltic countries, which are located in a climatic region directly influenced both by atmospheric processes in the Northern Atlantic and by continental impacts from Eurasia.

The aim of the present study is to analyse the hydrological regime and long term changes of river discharge in Latvia.

2. Methods

The study area covered the whole territory of Latvia. The stream flow data before of analyses of variability have been tested by Fisher test for data homogeneity. For the calculation of the periodic changes (oscillation) of discharge, moving average (step 6 and 10 years) values of discharge data as well as integral curves were utilized. The multivariate Mann-Kendall test for monotone trends in time series of data grouped by sites was chosen for the determination of trends, as it is a relatively robust method concerning missing data, and it lacks strict requirements regarding data heteroscedasticity. The trend was considered as statistically significant at the 5 % level if the test statistic was greater than 2 or less than -2. The use of integral curves, which depict differences in discharge for each study year in comparison with mean values for all observation period, allows identify the pattern of discharge changes. In the calculation, ratio K was used:

$K = \frac{Q_i}{Q_0}$ where: Q_i - discharge in year i; Q_0 – mean discharge for the entire period of observation.

Using this approach, the integral curve is produced by summing these deviations $\sum(K-1)$. By integration of the deviations, the amplitude of the oscillations increases proportionally to the length of the period, with one-sign deviations in the row. The analyses of integral curves allow precisely identify significant change points of low-water and high-water discharge periods. High-water discharge periods are considered to be years for which K > 1, and low-water flow periods are indicated by a K < 1.

3. Results and discussion

Depending on the hydrological regime, the river basins in Latvia can be grouped into 4 hydrological regions. The hydrological regions differ in the seasonal river discharge variability in spring and autumn, by the relative proportion between spring and autumn floods, and also in other factors (precipitation, evapotranspiration, runoff, temperature).

Changes in river discharge were determined using linear trend analysis. The discharge trends in rivers of Latvia and the north-eastern part of the Baltic Sea are evident: the discharge has significantly increased for rivers Venta, Gauja, Bārta, Irbe and Tulija, but the changes are significant and increasing for all of the other studied rivers. It is also evident that river discharge is characterized by stronger increase if period of trend analyses is reduced to the last 50 years. It should be mentioned discharge trends and trends for precipitation, temperature are similar for the II, III, IV hydrological regions. Regarding the River Venta, located in the type I hydrological region, a positive trend of discharge is more expressed. The long-term trends of seasonal river discharge indicates that most of the increase happens during winter season. The river discharge (for example, Daugava, Venta, and Lielupe rivers) in winter (December – February) shows a significantly increasing trend while no trend has been detected in other seasons. A particularly significant increase in winter discharge can be observed during the recent two decades.

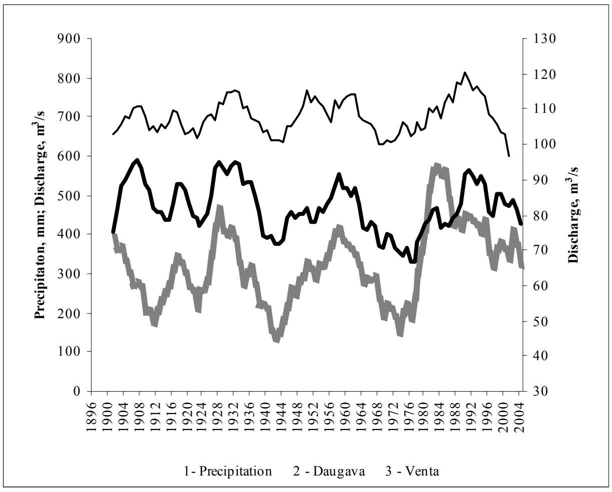


Figure 1. Long term changes of mean annual discharge of the rivers in Latvia and precipitations. 1- precipitations (Station Riga-University); 2- River Daugava; 3- River Venta. Date were smoothed with a 6-year moving average.

An observation period of more than 150 years at the Meteorological Station Riga-University shows that, during the last century, the mean annual temperature has increased by about 0.8 - 1.4 ^{o}C, and the total annual precipitation by about 7.5 mm every year. Using moving average values (in this case with step 6 years), good coherence is seen between changes in annual precipitation at the Meteorological Station Riga-University and discharges of the largest rivers in Latvia (Fig. 1).

The use of integral curves allows better identify oscillation patterns. Fig. 2 shows integral curves for water discharge in the five largest rivers in Latvia.

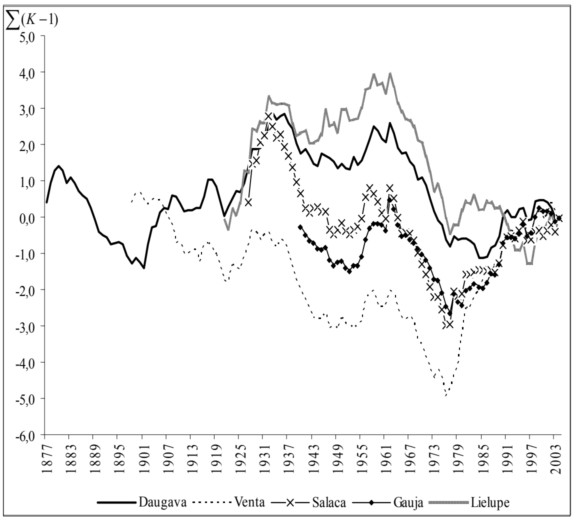


Figure 2. Normalized integral curves for coefficients of the annual runoff of rivers in Latv

Differences are seen between Lielupe and the other four rivers in Latvia, and in all rivers there is an apparent difference between observations before and after 1920. For example, in the River Lielupe, water discharge decreased from 1986 to 2000, in contrast to the other rivers that showed stable increasing tendency. As it can be seen from Fig. 2, in year 1996 the water discharge reached the lowest value during the last ten years in rivers in Latvia. The difference in flow patterns between the River Lielupe and other rivers in Latvia can be explained also considering that the sampling station in Lielupe, which is situated quite upstream (110 km) and thus can reflect slightly more than 50 % of the total river discharges. The Lielupe River basin is moderately affected by melioration and by construction of various hydrotechnical constructions (dams, ponds etc.). Also agricultural activities influence the water flow regime in this river.

Table 1. Significance test for temporal changes of water discharge for rivers in Latvia

River, sampling station	Period of observation	Normalised test statistic
Daugava- Daugavpils	1961-2004	2,41
Venta- Kuldīga	1961-2004	1,09
Lielupe-Mežotne	1961-2004	1,94
Gauja- Sigulda	1961-2004	2,50
Salaca- Lagaste	1961-2004	2,79
Aiviekste- Lubāna	1961-2003	2,25
Dubna-Siļi	1961-1999	3,00
Barta- Dūkupji	1961-1999	2,53
Irbe- Vičaki	1961-1999	2,67
Tulija-Oļi	1961-2004	2,85

* - The trend can be considered as statistically significant at the 5 % level if the test statistics is greater than 2 or less than -2.

For last 100-125 years low discharge periods for rivers of Latvia are longer than high discharge periods and their last from minimally 10 years up to maximally 21 - 27 years. In the same time high discharge periods last from 10 years (6-8 years), but during last 30 years for the biggest rivers (except Lielupe) their prolongation can reach even 20 to 27 years. Goudie (1992) and Pekarova et al. (2003) described sinusoidal changes of river discharge in Eastern Europe. An approximately 20-year periodicity has been suggested in earlier studies for rivers in the Baltic region and Eastern Europe (Glazacheva 1988), along with a period of about 20 to 50 years for monthly mean precipitation and water level which may be the result of interference of the precipitation and temperature regimes**.** In previous studies, a 26 year periodicity of River Daugava flow was considering as the main period, which includes 2-, 6- and 13- year smaller cycles (Glazacheva 1988). However, there is no well-defined explicitness of physical meaning of river discharge regime.

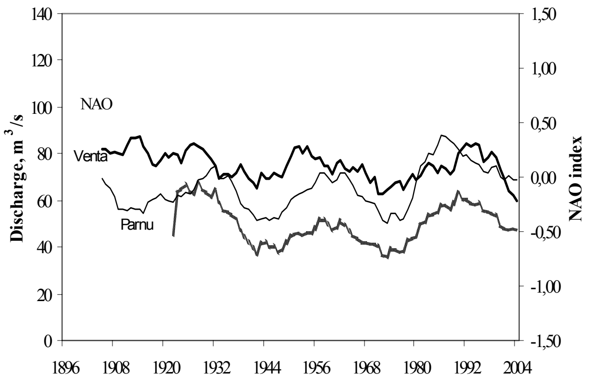


Figure 3. Long term changes of River Venta and River Pärnu discharges and index of North Atlantic oscillation index (data were smoothed with a 10-year moving average).

It is important to recognize that assessment about factors driving changes of river discharge is far beyond aims of this article as far as basically these questions are a part of global climate change problems. Long term changes of river discharge patterns can be directly related to changes in North Atlantic oscillation (Fig. 3). Unless there it can be only a guess about factors determining oscillatory pattern of river discharge, it can urge to reconsider conclusions made on short-term observations and also conclusions, when analyzing river discharge changes only as linear process.

4. Conclusions

River discharge regime in Latvia during last century has been subjected to major changes, highly possible due to climate change. In the same time well expressed regular changes of high water and low water periods are evident.

References

Goudie, A., (1992) *Environmental change*, Clarendon Press, Oxford.

Glazacheva, L. Long-term trends of the river run-off, air temperature in the Baltic region and atmospheric circulation in the Euro-Atlantic sector. In: The factors of regime formation, hydrometeorological conditions and hydrochemical processes in the seas of USSR. Leningrad, Hydrometeorological Agency, 227-241 (in Russian).

Pekarova P., Miklanek P., Pekar J. (2003) Spatial and temporal runoff oscillation analysis of the main rivers of the world during the 19th-20th centuries. *J.Hydrol.*, 274, 62-79

Past Storm Climate in Southern Sweden: A Comparison of Modelled Data with Observational Data, a NW/SE Storm Index and Aeolian Proxy Data

Carin Nilsson[1], Rixt de Jong[2] and Lars Bärring[3,1]

[1]Geobiosphere Science Centre, Dept. of Physical Geography and Ecosystems Analysis, Lund University, Sölvegatan 12, S-223 62 Lund, Sweden. [2]Geobiosphere Science Centre, Dept. of Quaternary Sciences, Lund University, Sölvegatan 12, S-223 62 Lund, Sweden. [3]SMHI, Rossby Centre, Norrköping, Sweden. Corresponding author: Carin.Nilsson@nateko.lu.se

1. Abstract

The past storm climate in southern Sweden is investigated by calculating the geostrophic wind from extracted sea level pressures from a downscaling experiment using the Rossby Centre regional atmospheric climate model, RCA3. The two time spans include year 1000 to 1200 and 1750 to 1930. The calculations based on modelled data were compared to observational-based calculations of the geostrophic wind from pressure readings at Göteborg – Visby – Falsterbo. Further, a NW/SE storm index and proxy data of aeolian transport were compared to the geostrophic wind based on modelled data, in order to interpret the early history of strong winds in southern Sweden.

2. Introduction

Recently northern Europe has experienced several devastating storms (Ulbrich et al., 2001, Schelhaas et al., 2003, Nilsson et al. 2004), which have led to severe damage in terms of deaths, phone and electric supply failure, uprooted and damaged forests and complications in transport communications. In December 1999, three large storms in ruined much of the forests in Denmark, France, Germany and neighbouring countries. In Sweden the hurricane force winds during the night between the 8th and the 9th of January, 2005, completely destroyed vast parts of the southern, forested areas, in Sweden's worst storm of the century (SMHI,2005). Again, on the 14th of January, 2007, a new severe storm devastated forests and infrastructure in southern Sweden,.

Despite these storms, earlier studies with focus on storminess during the 20th century have not found any indication of a long-term trend in northern Europe. Instead, the stormy turn of the 19th century in Scandinavia, Finland and the Baltic Sea was followed by a slowly decreasing trend, including decadal variations, until the early 1960´s (Alexandersson et al.1998). After that, a slight increase in storminess has been noted until a peak in the 1990´s (Alexandersson et al, 2000).

Extending further back in time, Bärring and von Storch (2004) study the storminess in Scandinavia from the early 19th century by using storm indices from trice-daily pressure series in Stockholm and Lund. Fischer-Bruns et al. (2005) extends the time perspective further by using a coupled global model (ECHAM4/HOPE-G) to study the past storm activity on the northern and southern hemisphere during winter months, from 1550 to 1990. Here we try to combine some of the ideas from these studies. We keep the regional focus, in this case southern Sweden and analyse past wind climate in southern Sweden, in two time slots from year 1000 to 1200 and 1750 to 1930. We calculate geostrophic winds from observed and simulated sea-level pressure. The later period will be compared with geostrophic winds, calculated from pressure readings for the southern Sweden, and a geostrophic wind component giving the NW-SE

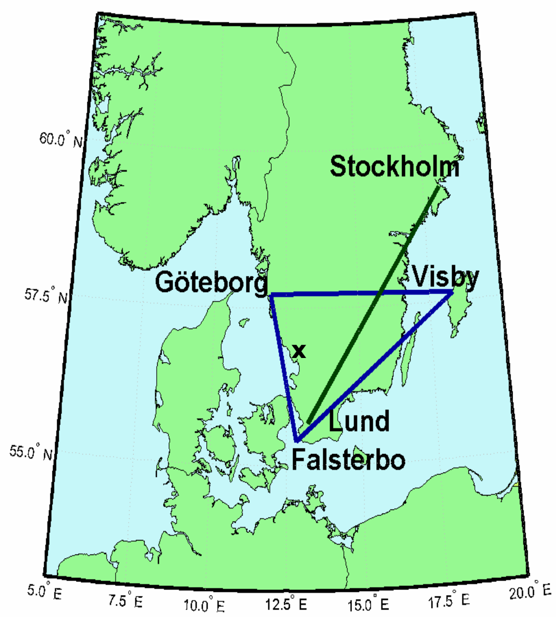


Figure 1: The stations forming the geostrophic triangle, Göteborg/Säve – Visby – Lund/Falsterbo, and the pressure stations Lund and Stockholm, in southern Sweden. The x marks the position of the peat bog, from which the aeolian proxy data is reconstructed.

winds. This relation will be used to interpret the storm climate from the year 1000 to 1200.

Our findings are compared to a proxy data set reflecting aeolian activity, reconstructed from an ombrotrophic peat bog in Halland, southwest Sweden (De Jong et al., 2006).

3. Data and Methods

Modelled sea-level pressure are extracted from a downscaling experiment using the Rossby Centre regional atmospheric climate model RCA3 (Kjellström et al, 2005). The downscaling experiment (Moberg et al., 2006) use boundary conditions from the global couple model ECHO-G (von Storch et al., 2004) every 12 hours, and the model output of sea surface pressure from RCA3 is every 3 hours, with a spatial resolution of 1.00 x 1.00 degree.
Geostrophic wind data, covering the time period from 1881 to 1930, with thrice-daily resolution, developed from observations at the pressure stations in Göteborg–Säve, Visby and Lund-Falsterbo (Alexandersson et al., 2000) (Figure 1) are used as reference data, together with pressure data from Lund (Bärring et al., 1999) and Stockholm (Moberg et al., 2002), combined to a storm index for NW and SE winds.

Proxy data-based reconstructions of aeolian activity in southwest Sweden are available for the last 6500 years (De Jong et al., 2006). Data are derived from an ombrotrophic peat bog situated 1 km off the modern coastline of south west Sweden (Figure 1). The reconstruction is based on aeolian sediment influx values, thus the number of wind-blown sand grains deposited on the bog surface per year. Since these large (> 125µm) sand grains require high wind speeds for transport, and transport is facilitated under niveo-aeolian conditions, the aeolian sand influx record is interpreted as a winter storm record.

Model values of sea surface pressure from the regional climate model RCA3, is used to calculate the geostrophic wind from grid boxes corresponding to the stations Göteborg, Visby and Falsterbo.

4. Results

We show a comparison of the geostrophic wind calculated from obervational data and modelled pressure data from 1881-1930, including a comparison with NW/SE storm index developed from the pressure difference between Stockholm and Lund, 1881-1930.

Further we show the results of the comparison between proxy data of aeolian activity and the geostrophic wind, from 1000 – 1200 and 1750 – 1930. The proxy data indicate relatively low storm activity from 1000 to 1150, whereas high values were reconstructed between 1150 and 1200 and around 1700 and 1850.

5. Discussion

Possible sources of uncertainty that might interfere with our interpretation of the results involve the area-point problem while comparing a grid-cell out put with an observational point data. This problem we have partly addressed by comparing the geostrophic wind, based on calculations of pressures readings from three stations and the three most suitable corresponding grid cells. However, the difficulty of the area-point problem is still there, since the model does not capture extremely low pressures, which in turn affects our calculations.

References

Alexandersson, H., Schmith, T., Iden, K., and Tuomenvirta, H., 1998, Long-term variations of the storm climate over NW Europe, GlobalAtmosphere-Ocean System 6, 97-120

Alexandersson, H., Tuomenvirta, H.,Schmith, and T., Iden,K., 2000, Trends of storms in NW Europe derived from an updated pressure data set, Climate Research 14, 71-73

Bärring, L., Jönsson, P., Achberger, C., Ekström, M., and H. Alexandersson, 1999, The Lund instrumental record of Meteorological Observations: Reconstruction of Monthly Sea level Pressure 1780- 1997, Int. J. Climatology, 19: 1427 – 14443

Bärring, L. and von Storch, H., 2004, Scandinavian storminess since about 1800. Geophysical Research Letters, 31, 1-4

De Jong, R., Björck, S., Björkman, L, and Clemmensen, L. B., 2006, Storminess variation during the last 6500 years as reconstructed from an ombrotrophic peat bog in Halland, southwest Sweden, Journal of Quaternary Science, 21(8) 905-919.

Fischer-Bruns, I., von Storch, H., Gonzalez-Rouco, J. F. and Zorita, E., 2005, Modelling the variability of midlatitude storm activity on decadal to century time scales, Climate Dynamics, DOI 10.1007/s00382-005-0036-1

Kjellström, E., Bärring, L., Gollvik, S., Hansson, U., Jones, C., Samuelsson, P., Rummukainen, M., Ullerstig, A.,Willén, U. and Wyser, K., 2005. A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). SMHI reports Meteorology andClimatology No 108, SMHI, SE-60176 Norrköping, Sweden, 54 pp.

Moberg, A., Bergström, H., RuizKrigsman, J. and O. Svanered, 2002, Daily Air temperature and Pressure Series for Stockholm (1756 – 1998), Climate Change, 53:171-212

Moberg, A., Gouirand, I., Schoning, K., Wohlfarth, B.,Kjellström, Rummukainen, M., de Jong, R., Linderholm, H. and Zorita, E. 2006. Climate in Sweden during the past millennium - Evidence from proxy data, instrumental data and model simulations. Technical Report TR-06-35. Swedish Nuclear Fuel and Waste Management Co (SKB). (ISSN 1404-0344), 87 pp.

Nilsson, C., I. Stjernquist, L. Bärring, P. Schlyter, A. M. Jönsson, and H. Samuelsson, 2004: Recorded storm damage in Swedish forests 1901-2000. Forest Ecolology andManagement., 199, 165-173.

Schelhaas, J.-M., Nabuurs, G.-J. & Schuck, A. 2003. Natural disturbances in the European forests in the 19th and 20th centuries. Global Change Biology 9: 1620-1633.

SMHI, 2005. Januaristormen 2005. Faktablad No. 25. Swedish Meteorological and Hydrological Institute. SE-601 76 Norrköping, Sweden. <http://www.smhi.se /sgn0102/n0205/faktablad_janstorm.pdf> 12 pp.

Ulbrich, U., Fink, A., Klawa, M., and Pinto, J.,2001, Three extreme storms over Europe in December 1999. Weather, 56 (March 2001), pp. 70-80.

Multi-centurial Temperature Reconstructions by Farmers' Diaries

Øyvind Nordli

Norwegian Meteorological Institute, Box 43 Blindern, N-0313 Oslo, oyvind.nordli@met.no

1. Reconstructed series, an overview

Partly funded by the NORPAST (PAST climate of the NORwegian region) project temperature reconstructions by farmers' diaries have been established. These are spring-summer temperature series going back to the 18th century for three Norwegian temperature regions: south-eastern Norway, western Norway, and Trøndelag. By use of ice break-up data mainly from Lake Randsfjorden in south-eastern Norway a reconstruction back to 1758 of February – April mean temperature has also been established.

2. Reconstruction of spring-summer temperature based on the date of grain harvest

All reconstructions of spring-summer temperature describe a changing climate from the Little Ice Age (LIA) to present. There are positive trends in all reconstructions showing the main picture of increasing temperature, but they also show substantial variations on different time scales. Cold and mild periods seem to have occurred at the same time in the three southern Norwegian temperature regions (south-eastern, western and Trøndelag), but the amplitudes might be different. As the reconstructions depict temperature during the grain growing season they also represent important knowledge on food supply in Norway ready for historical analyses. These are, however, beyond the scope for this abstract.

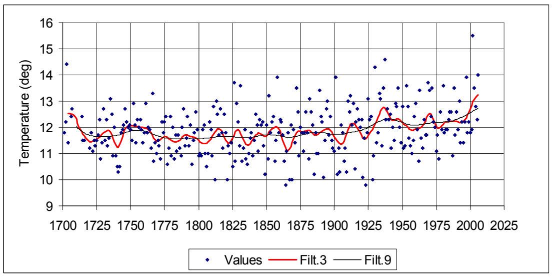


Figure 1. Reconstruction of spring-summer temperature (May-August) for Trøndelag: instrumental observations (1858-2006), proxy data (1701-1857).

During the LIA the following periods stand out for their severity: the early 1740s, the first decade of the 19th century, around 1840, and the 1860s (figure 1). In western Norway the period around 1840 (*Nordli et al.* 2003) seems to have been more severe than the 1860s, whereas in Trøndelag (*Nordli* 2004) it is vice versa. The reconstruction for Trøndelag shows high temperature in the start of the series in the early 18th century.

3. Reconstruction of late winter – early spring temperature using ice break-up data

A reconstruction of late winter early spring temperature (February- April) for south-eastern Norway (*Nordli et al.* 2007) also shows a significant trend towards milder climate (figure 2). The 20th century was 1.3°C warmer than the 19th century, whereas the 19th century was 0.4°C warmer than the 43 last years of the 18th century. The mild winters in the 1990s and early 21st century are unprecedented during the whole series. The lowest temperatures of the series are seen in the period of the Dalton Sunspot Minimum (DSM) in the early 19th century. However, a reconstruction made by *Tarand and Nordli* (2001) based on the time for entering of the first ship into the Tallinn harbour, showed relatively high winter temperature during the first half of the 18th century.

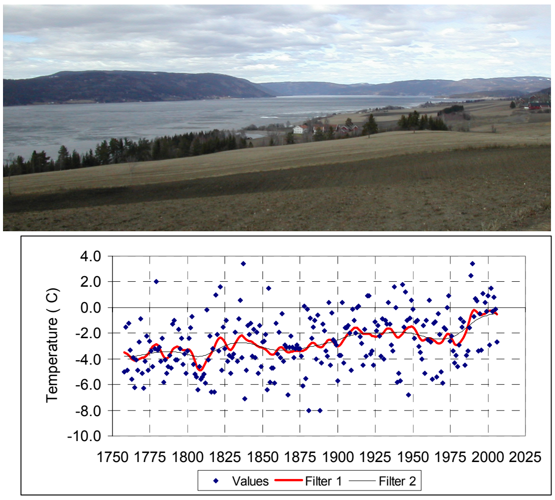


Figure 2. Reconstruction of mean February - April temperature by ice break-up dates of Lake Randsfjorden southeastern Norway: instrumental observations (1875-2006), proxy data (1758-1874).

4. Syntheses for the season from late winter to early spring

During the DSM decadal filter curves for both winter and summer temperature reconstructions show very low minima. Thus, the DSM was a period with severe winters as well as cold springs-summers in southern Fennoscandia.

5. The latest climate variations seen in an historical perspective

The high mean February – August temperature for the last decade of the 20th century and the six first years of the 21st century are unprecedented in a 250-300 years perspective.

References

Nordli, Ø., Spring and summer temperatures in Trøndelag 1701 – 2003. *met.no report*, no 05/2004. Meteorologisk institutt, Oslo, 1-21, 2004.

Nordli, Ø., Ø. Lie, A. Nesje, S.O. Dahl. 2003: Spring-Summer Temperature Reconstruction in western Norway 1734 – 2003: a data-synthesis approach. *Int. J. Climatol.*, Vol. 23, 1821-1841.

Nordli, Ø., E. Lundstad, A.E.J. Ogilvie, A Late Winter-Early Spring Temperature Reconstruction for Southeastern Norway from 1758 to 2006. *Annals of Glaciology*. (accepted), 2007

Tarand A., Nordli Ø., The Tallinn temperature series reconstructed back half a millennium by use of proxy data. *Climatic Change*, Vol. 48, 189 – 199, 2001.

Changes in Frequency and Mean SLP of Cyclones Formed over the Baltic Sea Region

Mait Sepp

Department of Geography, University of Tartu, 46 Vanemuise st., 51014 Tartu, Estonia. E-mail: mait.sepp@ut.ee,

1. Introduction

The Arctic and the Northern Europe are regions where the increase in surface air temperature has been remarkable during the 20th century. Many studies *(e.g. McCabe et al.* 2001, *Zhang et al.* 2004, *Bengtsson et al.* 2004) demonstrate that the Arctic warming is caused by changes in the atmospheric circulation, especially in cyclonic activity. The number and intensity of cyclones entering the Arctic from the midlatitudes has increased during the second half of the century.

Changes in atmospheric circulation over Northern Europe also occurred during the 20th century. Numerous studies have demonstrated that there has been an increase in cyclone activity and in frequency of westerlies over the Baltic Sea region. Those changes are generally related with developments in the NAO processes, i.e. changes in the Island minimum area (*Alexandersson et al.* 1998*, Omstedt et al.* 2004, *Pryor and Barthelmie* 2003, *Sepp et al.* 2005).

But as it came out from the article by *Sepp et al.* (2005), the Baltic Sea region is also a relatively active cyclogenesis area. The aim of the present research is to analyse long-term changes in frequency and mean sea-level pressure (SLP) cyclones formed over the Baltic Sea region.

2. Data and methods

The database of cyclones described by *Gulev et al.* (2001) was used in the present study. The database consists of cyclone tracking output of the 6-hourly NCEP/NCAR reanalysis (*Kalnay et al.,* 1996) SLP fields using the software worked out by *Grigoriev et al.* (2000). Cyclones are presented by the geographical coordinates of their centres and SLP at these points. Baltic cyclones which have formed within the Baltic region (in present case the territory restricted by lines with coordinates 70°N, 20°E - 60°N, 37°E - 50°N, 25°E - 50°N, 15°E - 55°N, 8°E - 60°N, 8°E - 70°N, 20°E) during the period of 1948-2002 are analysed.

Linear regression analysis is applied for detecting long-term changes. A linear trend is calculated for every time series and their significance level is found using the Student's t-test. Trends are considered statistically significant on $P<0.05$. Time series of annual and seasonal mean values are formed.

Seasons were defined by grouping three months – winter (DJF), spring (MAM), summer (JJA) and autumn (SON). Deep cyclones with minimum sea-level pressure below 1000 hPa and shallow cyclones were selected. To determine changes in relations between deep and shallow cyclones, percentage of deep cyclones in all cyclones was calculated.

3. Results

The total number of cyclones which formed over the Baltic Sea region during 1948-2002 was 2372. It amounts 1.8 per cent of total number of cyclones over the Northern Hemisphere available in the database of cyclones (*Gulev et al*., 2001).

The mean annual number of Baltic cyclones is 43.1; the minimum number of cyclones – 29 was observed in 1949 and 1953, and the maximum – 64 was recorded in 1973. Seasonal maximum of Baltic cyclones appears in summer.

The total number of cyclones formed in the Baltic Sea region has an increasing but insignificant trend (Fig. 1).

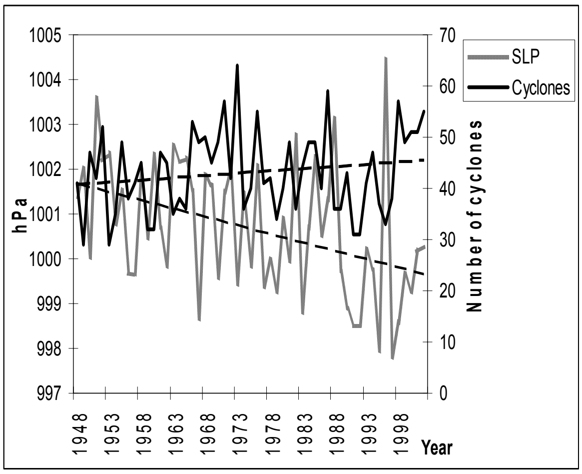


Figure 1. Time series and linear trends in annual numbers of cyclones and mean sea-level pressure (SLP) of the Baltic cyclones during the period of 1948-2002. The decreasing trend of SLP is statistically significant but not the trend of annual numbers of cyclones.

After dividing cyclones into two groups – deep (mean pressure below 1000 hPa) and shallow (pressure above 1000 hPa) there appeared significant changes and differences in time series of those cyclones. Time series of the deep cyclones indicate that their frequency has significantly increased during 1948-2002.

This change is very remarkable when taking into account that the annual mean number of deep cyclones was 17.9 (standard deviation 5.3) and their percentage in the total number of cyclones was 41.4, which has increased by 10.3%.

The frequency and percentage of the shallow Baltic cyclones have decreased, correspondingly, but it is not as fast as the increase in deep cyclones.

The mean sea-level pressure of all Baltic cyclones was 1000.7 hPa (standard deviation 1.5 hPa). It has significantly decreased (by 2.1 hPa) during the 55-year period (Fig. 1).

Mean pressure of the deep Baltic cyclones was 993 hPa. It has a statistically significant decreasing trend while the change by trend was 2.2 hPa.

Seasonal changes in frequency of cyclones and mean SLP are in line with general changes. But statistically significant changes occurred mostly in winter and spring.

References

Alexandersson, H., T. Schmith, K. Iden and H. Tuomenvirta, Long-term trend variations of the storm climate over NW Europe. *Global Atmos Ocean System* 6, 97-120, (1998) Bengtsson, L., Semenov, V. A., Johannessen O. M. The Early Twentieth-Century Warming in the Arctic – A Possible Mechanism. *J. Climate* 17, 4045-4057 (2004)

Gulev, S. K., Zolina, O., Grigoriev, S., Extratropical cyclone variability in the Northern Hemisphere winter from the NCEP/NCAR reanalysis data. *Climate Dynamics* 17, 795–809 (2001)

Grigoriev, S., Gulev, S. K., Zolina, O., Innovative software facilitates cyclone tracking and analysis. *EOS* 81, (2000)

Kalnay E., Kanamitsu M., Kistler R., Collins W., Deaven D., Gandin L., Iredell M., Saha S., White G., Woollen J., Zhu Y., Leetmaa A., Reynolds R., Chelliah M., Ebisuzaki W., Higgins W., Janowiak J., Mo K.C., Ropelewski C., Wang J., Roy Jenne & Dennis Joseph, The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Am. Meteorol. Soc.* 77: 437—472, (1996)

McCabe, G. J., Clarc, M., P. and Serreze, M. C., Trends in Northern Hemisphere Surface Cyclone Frequency and Intensity. *J. of Climate*, 14, 2763-2768, (2001)

Omstedt, A., Pettersen, C., Rodhe, J. and P., Winsor. Baltic Sea climate: 200 yr of data on air temperature, sea level variations, ice cover, and atmospheric circulation. *Climate Research*, 25, 205-216. (2004)

Pryor S.C. and Barthelmie R.J., Long term variability of flow over the Baltic. *Int. J. of Climatology* 23 271-289, (2003)

Sepp, M., Post, P. & Jaagus, J., Long-term changes in the frequency of cyclones and their trajectories in Central and Northern Europe. *Nordic Hydrology* 36, 297-309, (2005)

Zhang, X., Walsh, J.E., Zhang, J., Bhatt, U.S. and Ikeda, M., Climatology and interannual variability of Arctic cyclone activity: 1948–2002. *J. of Climate* 17, 2300–2317 (2004).

Formation of a Hydrological Regime of Rivers and Reservoirs during the past Decades in the Belarus Part of the Baltic Sea Basin

Lyudmila Trafimava, Ryhor Chekan, Irina Danilovich and Lyudmila Nekrasava

Republic Hydrometeorological Center of Belarus, 220014, prospect Nezavisimosti, 110, Minsk, Belarus
e-mail: gid2@by.mecom.ru

1. Introduction

The problem of global warming is one of the most important nowadays. People all over the world are worried about consequences of climate fluctuation. And a great number of scientists join their efforts to study this question. Therefore, climatic and hydrological investigations have become more active in Belarus in the last decades. It is caused by climate warming and by intensifying of its extremes in our country. However, previous research in this field has been limited due to the lack of data for analysis and generalization.

The research has focused on changes of the main hydrological indicators under the increasing air temperature of more than 1.1 ^{o}C during the last 18 years (*Golberg and Volobueva* 2003). We have gathered observation data from hydrological stations on the rivers and lakes. The generalization process of data included analysis, calculation of month and annual discharges, and intra-annual distribution of temperature and ice regime.

2. Observations data used for the assessment

For this assessment of the climate change influence on the hydrological regime of the rivers in the years of 1988-2005, observational data of hydrological observation stations were used, which were published in "The Surface Water Regime and Resources Annual Data" for the corresponding years, and also long-term data from the regime reference data bank "Hydrology – rivers and channels", which has been produced in the Republic Hydrometeorological Center.

All data are from rivers in the Baltic Sea basin: the Zapadnaya Dvina (Daugava) and its tributaries – the Obol, Polota, Nacha, Berezovka, and Drysa; and the Neman and its tributaries – the Viliya, Shchara, Svisloch, Kotra, and Naroch.

3. Change of water resources

Water resources in the Belarus part of the Baltic Sea basin develop in close correlation with physical geography factors. Water resources are determined by annual precipitation and by humidity of the previous period. In the long-term period, cyclic fluctuations are characteristic for precipitation, and, consequently, for water resources. For the period of 1945-2005, the duration of high and low annual runoff series varied and corresponded to precipitation cycles.

The analysis of cyclic changes in water resources during the years 1945-2005 revealed dry periods of 2 to 8 years (1945-1952, 1954-55, 1959-1961, 1963-1965, 1967-1969, 1972-1974, 1976-1977, 1983-1987, 1995-1997, 2001-2003), and wet periods of 2 to 5 years (1970-1971, 1978-1982, 1989-1991, 1993-1994, 1998-2000, 2004-2005).

During the warming of 1988-2005, river runoff in the Belarus part of the Baltic Sea basin changed in correlation with the precipitation regime. The greatest precipitation for the post-World War II period was recorded in Belarus in 1998, which generated high runoff that year; however, this runoff did not exceed high runoff in the year 1958 (37.8 km^3), because of the preceding 4 dry years. For 8 years out of the 18 years of the warming period, water resources were higher than the long-term average; during the other years they were within the long-term average, or lower. As a whole, there appears to be no clear tendency for change of the annual average runoff.

4. Changes intra-annual distribution of runoff

Intra-annual runoff distribution has changed in all rivers of the Belarus part of the Baltic Sea basin during the warming (*Nekrasova* 2004). The share of winter runoff in annual runoff distributions has considerably increased. The increase in winter runoff is seen in all years of the warming period, except for 1996. This is a result of increased precipitation, of frequent thawing weather, of winter high waters, of the shift of start dates of spring floods and of the shift of dates of the greatest discharges of water during this period. The greatest increase in rivers' runoff, ranged from 84 to 160% and was observed in February and March in basins of the Zapadnaya Dvina; up to 35% increase in runoff was registered in the Neman and the Viliya basins. The greatest average monthly discharges in all the observation period were observed in these months during the warming.

5. Change of spring flood characteristic

As during the warming period air temperatures rose above 0^{o}C early in the year, an early start of the spring flood was observed. During the warming (1989, 1990, 2000, 2002), the earliest date of the greatest discharge of spring flood were observed (36-50 days ahead of long-term average dates).

In 1989-1995, 1997, 1998, 2000-2002, the spring floods ended earlier than usually, and the earliest dates of their ending for the entire observation period were recorded in 1989, 1992 and 1995.

The maximum discharge volume of spring floods has changed. Compared to the long-term average, the mean of the greatest water discharge for the period of 1988-2002 has decreased in the basins of the rivers: the Zapadnaya Dvina by 21-26%; the Neman -- by 37-43%; the Viliya -- by 59%; the Lesnaya -- by 55%. It is necessary to note, that the decreasing tendency for the maximum discharges appeared since the 1970's, and became clearly evident during the warming.

A significant decrease in runoff volumes was observed in the basins of the Neman and in the in flows of the Western Bug (16-26% lower than the norms).

6. Changes in ice regime of rivers

A change in the ice regime of the rivers of the Belarus part of the Baltic Sea basin took place during the warming. In several years, the occurrence of ice and the freeze up of the rivers have shifted to earlier dates (a week or two ahead of long-term average terms) because of early dropping of air temperature below 0^oC (*Nekrasova, Chekan, Danilovich* 2003). However, because of warm winters, the ice cover formed during freeze up disintegrated and was unstable; in some years it formed in January. The duration of ice cover during 1988-2005, except for the years of 1994, 1996 and 1999, was much less than the long-term average duration. The greatest thickness of ice cover during the period was lower than the long-term average. Dates of the greatest thickness of ice shifted from the end of February and March to January and to the beginning of February, and in some years to December.

7. Changes in temperature regime of rivers

In the autumn and spring, the dates where water temperatures fall below and rise above 0.2°C, respectively, have changed in rivers of the Belarus part of the Baltic Sea basin. In connection with the changed rise of air temperature above 0^oC in the autumn and spring, an early rise of water temperature above 0.2^oC was also observed. The earliest dates of a temperature rise above 0^oC fall into the period of 1988-2005.

The average monthly water temperature has everywhere increased in the spring months (March through May) and in July, August and November,. there was no clear tendency for maximum water temperature. The highest water temperature was above long-term average within hot years (1994, 1999, 2001). During 1988-2005, the highest water temperature in the entire period of instrumental observations was recorded (1999, 2001); however, in this period one of the lowest water temperatures was recorded (1993), too.

8. Dates indicating seasonal variations in temperature in lakes and reservoirs

The dates at which water temperature in spring rose above certain thresholds (+0.2, +4 and +10°C) in the lakes of the Belarus part of the Baltic Sea basin have significantly changed during the period 1988–2005. Within the last 18 years, spring phenomena occurred before the average. Dates of water temperature above 0.2^oC which occurred between the first decade of March and the first decade of April have shifted by 11 days in comparison with the long-term average of the previous term. The average dates when water temperature rose above 4^oC and 10^oC in lakes have changed, too. During 1988-2005 they have shifted earlier by 5 and 7 days, respectively.

9. Surface layer water temperature of lakes and reservoirs

The most significant deviations from long-term average values were observed in the spring. The mean water temperature in the first decade of April in the observed lakes and reservoirs of the Belarus part of the Baltic Sea basin during the study period was 1.2°C higher than the long-term average. In the second and third decade of April, the deviation was even higher – 1.5 and 2.2°C. During the study period, the monthly average water temperature in lakes for April exceeded the long-term average by 1.6^oC.

In the following, monthly air temperature and water temperature anomalies are compared. Air temperature deviations from long-term averages are higher than deviations of water temperature. Air temperature in May for the period 1988–2005 was a little bit below the long-term average (0.2°C), while the water temperature in lakes was higher by 1.1°C.

Deviations of water temperature for summer averaged 0,4 - $1{,}3^oC$ for the period of 1988-2005. In October, anomalies of water temperature of $+0.3^oC$ were observed, while anomalies of air temperature were $+0.1^oC$. The water temperature in the first decade of November preserved a positive anomaly of 0.3°C while in the second and a third decade, negative anomalies of --0.2 …--0,1°C were registered.

10. Changes in ice regime of lakes and reservoirs

Freeze up dates of all lakes and reservoirs of the Belarus part of the Baltic Sea basin were registered, on the average, 6 days earlier.

During 1988–2005 ice cover break-up, end of ice cover period and clarification from ice on lakes were observed 14-15 days ahead of multi-annual mean dates.

Ice thickness regime has changed. The average value of the maximal ice thickness on lakes became lower than long-term average by 13 cm during the warming period. In 80% of cases during the last 15 years, the maximum ice thickness on lakes did not reach the long-term average (exceptions were registered on certain lakes in 1994, 1996 and 1999).

References

Golberg M., Volobueva G. Komarovskaya E., Kuleshova I. Change of the basic climatic characteristics of Belarus in XX century. *Reports of the National Academy of Sciences of Belarus* Volume 47 № 1 2003, pp. 119-123 (In Russian).

Nekrasova L. Chekan, G., Danilovich, I.. Hydrometeorological conditions and runoff in 2002. *State water cadastre* – under the editorship of Kolobaev A.. - Minsk, 12-16. 2003 (In Russian).

Nekrasova L. Influence of climate warming on hydrological regime of rivers in Belarus during 1988-2002. *Materials of XXIII Nordic hydrological conference,* NHP Report 48. Tallinn, p.697. 2004 (In English).

Variations in the West Dvina River Annual Runoff

Alexander Volchak[1], Sergey Parfomuk[2]

[1]National Academy of Sciences of Belarus, Moskovskaya st., 204, Brest, Republic of Belarus, volchak@tut.by
[2]Brest State Technical University, Moskovskaya st., 267, Brest, Republic of Belarus, parfom@mail.ru

1. Introduction

The research problem included a definition of stability of the time series of annual runoff of the rivers with a varying degree of anthropogenic influence. For these purposes, the time series of annual runoff of the West Dvina River at Vitebsk and Polotsk stations are used. The West Dvina River is one of the basic rivers of the Republic of Belarus. It is a typical river of Europe. It flows on the territory of three countries: Latvia, Belarus and Russia. It can also serve as a range for a rating of various changes. The length of researched time series covers the period till 1877 since 2000.

2. Materials

In tab. 1 the basic statistical parameters of the time series of annual runoff for the period till 1877 since 2000 are submitted.

Table 1. The basic statistical characteristics of annual runoff of the West Dvina River

Station	Mean of runoff, $\overline{Q}$, m^3/s	Factor of variation C_v	Factor of asymmetry Cs	Factor of autocorrelation r(1)
Vitebsk	226	0,27	0,57	0,27
Polotsk	306	0,25	0,62	0,24

Empirical curves of occurrence for both stations correspond to Pearson's distribution of III type at Cs=2Cv. As the function of distribution of annual runoff at such ratings of parameters insignificantly differs from those for normal distribution, application of parametrical criteria for check of statistic hypotheses can be counted allowable.
On fig. 1 hydrographs of annual water flow of the West Dvina River are submitted. On hydrographs cycles of fluctuations is precisely traced. It is possible to allocate three obviously expressed twenty years' trends on the flow's increase: till 1890 since 1910, till 1940–1960 and till 1970 since 1990.

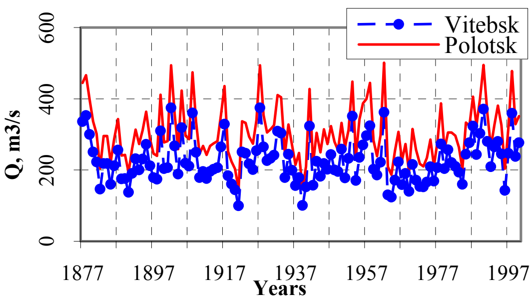


Figure 1. Hydrographs of annual runoff of the West Dvina River.

3. Analysis of the homogeneity of runoff values

Let us consider stability selective statistic parameters (mean, variance, factor of autocorrelation) for two versions of researched time series: actual and anthropogenic (the period of intensive melioration). In tab. 2 the basic statistical parameters of these intervals of researched time series are resulted.

Table 2. The basic statistical parameters of annual water flows of the time series of the West Dvina River

The period	Parameters for the station Vitebsk / Polotsk			
	Q, m^3/s	σ, m^3/s	Cv	r(1)
1877 – 1964	226 / 307	63,0 / 80,0	0,28 / 0,26	0,20 / 0,20
1965 – 2000	226 / 302	59,0 / 73,2	0,26 / 0,24	0,45 / 0,34

The matrix of statistical Student's criteria, Fisher's criteria and autocorrelation criteria and their critical values for two researched periods is resulted in tab. 3.

Table 3. Statistical criteria (numerator) and their critical values (denominator)

1877 – 1964	1965 – 2000		
Station	t-criterion for means	F-criterion for variances	Criterion for autocorrelation
Vitebsk	0,00/1,99	1,14/1,65	1,41/1,96
Polotsk	0,29/1,99	1,19/1,65	0,75/1,96

The analysis of the average values of annual runoff for two examined periods shows that it is necessary to recognize distinctions insignificant in means. The hypothesis about equality of variances also is correct. Distinctions in factors of autocorrelation it is not established.
Studying laws of long-term fluctuations of the river flow, doubtless interest represents the connected analysis of dynamics of runoff and the generalized characteristics of circulation of atmosphere. These characteristics are based on three forms of circulation: W (western), E (eastern) and C (meridional), *Ismailov G., Fedorov V.* (2001). In detail, this question for meteorological series is considered in Loginov's monography where their full analysis is resulted. Apparently from tab. 4, the range of change of characteristics of annual runoff is rather significant.
Check of a hypothesis about uniformity of examined parameters of annual runoff for the periods with different types of circulation is based on the Student's criteria and Fisher's criteria. The research has shown that the series of annual runoff of the West Dvina River are possible to recognize uniformity by three statistical criteria with some assumptions. At the same time, it is possible to believe that for the separate time periods of atmospheric circulation conditions of the stability are not carried out. Transition from one status to another occurs in natural conditions under influence of the external climatic factors essentially that change the ratio between precipitation and evaporation within the limits of the territory of the West Dvina basin.

Table 4. The basic statistical parameters of annual water flows

The period	Type of circulation	Parameters for the station Vitebsk / Polotsk			
		Q, m^3/s	σ, m^3/s	Cv	r(1)
1881 – 1890	C	192 / 262	38,8 / 48,9	0,20 / 0,19	-0,17 / -0,17
1891 – 1928	W	230 / 311	62,2 / 78,6	0,27 / 0,25	0,16 / 0,16
1929 – 1939	E	216 / 292	61,7 / 78,1	0,29 / 0,27	0,47 / 0,46
1940 – 1948	C	211 / 288	51,4 / 65,6	0,24 / 0,23	-0,77 / -0,81
1949 – 1964	E+C	234 / 321	72,5 / 92,7	0,31 / 0,29	-0,09 / -0,07
1965 – 1988	E	206 / 278	46,2 / 55,6	0,22 / 0,20	0,43 / 0,17
1989 – 2000	W	268 / 353	61,4 / 80,9	0,23 / 0,23	0,11 / 0,14

4. Construction of prediction models

When the trend obviously is not expressed, it is necessary to consider in common sample autocorrelation (AC) and partial autocorrelation (PAC) functions of the process. They help to define the character of annual runoff of the rivers. AC and PAC functions have a significant size at τ=1 for the West Dvina River, whereas all other values of their ordinates are statistically insignificant and are characterized by alternation of positive and negative values. That corresponds to such kind of model as auto-regress of the first order. Hence, examined process of annual runoff can be identified by model of the following kind:

$$Q(t) = Q_{ñð} + r(1) \cdot \left[Q(t-1) - Q_{ñð} \right] + \xi(t), \qquad (1)$$

where $Q(t)$ and $Q(t-1)$ are annual runoff values in the t and previous to it (t-1) years; $\xi(t)$ is "white noise" with zero mean and $\sigma_{\xi} = \sigma_{Q} \cdot \sqrt{1 - r(1)^2}$.

Results of the research of laws of long-term fluctuations of annual runoff of the West Dvina River have formed the basis for the description as simple Markov model, i.e.

$$Q(t) = r(1) \cdot Q(t-1) + \xi(t), \qquad (2)$$

where $Q(t)$ is runoff of the current year; $Q(t-1)$ is runoff of the previous year; $\xi(t)$ is random variable that independent of Q.

The first constituent in the right-hand part of (2) can be treated as the runoff caused by accumulation of a water-modular part of atmospheric precipitation of the previous year and their dump into the channel of the river. Thus, the casual component $\xi(t)$ in (2) should include that part of runoff of the current year that is generated due to precipitation of this year.

In result, it is possible to write down the following equations:

$$Q(t) = a \cdot Q(t-1) + b \cdot W_{oc}(t) + \xi(t_1), \qquad (3)$$

$$Q(t) = c \cdot W_{oc}(t-1) + d \cdot W_{oc}(t) + \xi(t_2), \qquad (4)$$

where $W_{oc}(t)$ and $W_{oc}(t-1)$ are annual precipitation of the current and previous years.

If time series of annual values of atmospheric precipitation and river runoff are available, it is possible to determine a, b, c, d factors from (3) and (4) with the help of multiple regression. With reference to the basin of the West Dvina River at the station Vitebsk for the annual runoff, the following equations are received:

$$Q(t) = 0{,}295 \cdot Q(t-1) + 0{,}466 \cdot W_{oc}(t) - 131{,}62 + \xi(t_1), \qquad (5)$$

$$Q(t) = 0{,}446 \cdot W_{oc}(t) + 0{,}17 \cdot W_{oc}(t-1) - 158{,}9 + \xi(t_2), \qquad (6)$$

Polotsk:

$$Q(t) = 0{,}271 \cdot Q(t-1) + 0{,}588 \cdot W_{oc}(t) - 144{,}715 + \xi(t_1), \qquad (7)$$

$$Q(t) = 0{,}549 \cdot W_{oc}(t) + 0{,}241 \cdot W_{oc}(t-1) - 188{,}182 + \xi(t_2). \qquad (8)$$

We tried to describe annual fluctuations of the runoff of the West Dvina River with the help of complex Markov model. The individual models for the station Vitebsk have been received by the regression-correlation analysis:

$$Q(t) = 0{,}25 \cdot Q(t-3) + 0{,}24 \cdot Q(t-5) + 0{,}31 \cdot Q(t-24) + 46 + \xi(t), \qquad (9)$$

For the station Polotsk:

$$Q(t) = -0{,}28 \cdot Q(t-7) + 0{,}36 \cdot Q(t-14) + 497{,}7 + \xi(t). \qquad (10)$$

5. Conclusions

The estimation of the time series of annual runoff values of the West Dvina River for the 124-years period allows us to make a conclusion on uniformity of the researched series of annual runoff. Instability of the process of long-term fluctuations of annual runoff of the West Dvina River may only be marked on separate pieces of the time series. Instability is caused by climatic and anthropogenic changes of a hydrological cycle.

References

Ismailov G., Fedorov V., The analysis of long-term fluctuations of annual runoff of the Volga River, *Water Resources*, Vol. 28, No. 5, pp. 517–525, 2001

Recent Warming of the Arctic Ocean and Possible Consequences for Climate

Jan Piechura

Institute of Oceanology, PAS, Powstańców Warszawy 55, 81-712 Sopot, Poland
e-mail: piechura@iopan.gda.pl

1. Abstract

Observed during last years changes in climate on the Earth are the most pronounce in the northern high latitudes. Dramatic decrease of the sea-ice extent and volume in the Arctic Ocean is the most visible effect. The role of the thermohaline circulation (THC) in general and the heat and salt transport through the Nordic Seas into the Arctic Ocean in particular, is discussed as well as the influence of climate change on THC.

Since 2003 considerable increase of water temperature and heat content of the Atlantic Water (AW) curried by the West Spitsbergen Current (WSC) into the Arctic Ocean is observed.

Since 2004 signal of higher AW temperature and salinity has propagated to the north towards the Fram Strait. Also heat content of the AW layer in WSC region raised rapidly. In summer 2005 the record-breaking high salinity and temperature of AW in the WSC core, west of Spitsbergen were observed. Additionally, the unusually large antycyclonic eddies at the western branch of AW inflow, over underwater ridges were noticed. Those structures carried through the Fram Strait large amount of heat into the Arctic Ocean. The possible influence of this on Arctic Ocean hydrography and sea-ice cover is discussed.

Winter 2005/2006 was in Svalbard unusually warm, possible because of more intensive release of heat from the AW into atmosphere and inflow of warm AW into fjords.

Research plans for the IPY, DAMOCLES project in particular, are presented as well.

Climate Change Impacts on the Total Annual Rivers' Runoff Distribution in Latvia

Elga Apsīte, Līva Širiņa and Anda Bakute

Faculty of Geographical and Earth Sciences, University of Latvia, Raina bulv. 19, Riga LV-1586, Latvia, e-mail: elga.apsite@lu.lv

1. Abstract

The paper presents the results of study on the climate change impacts on hydrological regime of 20 different river basins in Latvia. Analysis of hydrological and meteorological data series has been done for the periods 1951-2005. Climate change has influenced temporal and spatial distribution of rivers' runoff in Latvia at the turn of century. The present results confirm the basic hypothesis that main tendency in runoff changes are following: decreased in spring flood and as opposite - increased in winter thaw-period.

2. Introduction

In Latvia rivers' runoff is very important renewable energy recourse. The uneven relief, humid climate, and geological development have developed a comparatively dense network of rivers (mean value is 0.59 km/km^2). Total number of rivers is about 12 500. The mean annual runoff is ~35 km^3, of which only 16 km^3 is formed within the territory of Latvia. Mean annual precipitation varies from 550 to 850 mm. The seasonal distribution of the precipitation favours a wet growing season: about 30% falls in the cold part of the year, and 70% in the warm period (April-October). About 70-75% of precipitation falls in the form of rain, about 15% as now, and the remaining fraction as slush.

Climate change impacts on rivers' hydrological regime have been extensively studied world-wide in nowadays. Also in Latvia the studies of long-term rivers' runoff and time of ice-break have presented mainly for the large and medium size rivers *Kļaviņš et al.* (2002), *Frisk et al.* (2002), *Kļaviņš et al.* (2004), and rivers' runoff prediction under different climate scenarios *Ziverts and Apsite* (2005), *Rogozova* (2006). Theses studies pointed out the river runoff changes in seasonality. *Briede* (2006) has found out that the highest mean air temperature increase has occurred in March 3-5 ^{o}C and an increase of precipitation – in January, February, March and June in study period 1950–2003.

The aim of the study was to analyse the climate change impacts on the total annual rivers' runoff distribution in Latvia to cover different river basins.

3. Data and methods

Data series of 20 hydrological stations have used for the analysis of long-term trends and total annual river runoff distribution by months, seasons and tree study periods. The study periods are following: from 1951 to 1990 (basic of 40 years), 1991–2005 (climate change impacts) and 1951–2005 (all study period). The analysis of air temperature and precipitation data series was taken in account for the interpretation of rivers' runoff results. Statistical methods, including Mann-Kendall test with 5% significance level, were used for the data series analysis. In order to interpret the obtained results, the territory of Latvia was divided into three parts – Western, Central and Eastern. Data source: the Latvian Environment, Geology and Metrology agency.

4. Results and discussions

The rivers in Latvia have mixed water feeding: rain, snowmelt water and groundwater. The rivers have typical following hydrograph: two main discharge peaks during the spring snowmelt and in the late autumn during intensive rainfall, and low river discharge in winter and summer. In warm winter the low river discharges can not observed in Western part of Latvia. For this region a comparatively shorter ice cover period can be observed, thus ice break and spring floods begin sooner. There is greater impact on the river discharge regime from meteorological processes occurring over the North Atlantic and Baltic Sea that for others rivers in Latvia, especially to compare with Eastern part.

The study period 1951–1990 presents the basic total annual distribution of rivers' runoff: the discharge of rivers during spring reaches 35-55% of the total annual river runoff, compared to 15-30% during winter. The highest percentage in spring runoff has found for the rivers of Central and Easter parts. The rivers of Western part preset the highest percentage in winter runoff. The bulk of total annual runoff comes to be in April 15-30% and less water discharge – in February 4-8%.

The study period 1991–2005 presents the total annual river runoff distribution under climate change impacts during last 15 years. The results show that rivers' runoff remarkably increase in winter (average 7-12%) and decrease in spring (average 4-10%) to compare with study period 1951–1990. Theses seasonal changes in total annual river runoff could substantially observed in Western and Central parts of Latvia due to occurring warmer winters at the turn of century. The analysis of monthly results shows interesting data for the small rivers of Coastal Lowland in Western part. For example the river Bārta in Figure 1: the highest percentage of river runoff was occurred in January (17%) and February (16%) with gradual decrease in April (about 10%).

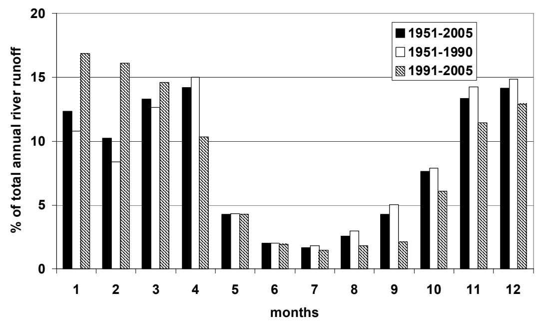


Figure 1. Percentage of total river annual runoff distribution by months for the river Bārta.

In the Central part main changes in river runoff could found in January and, especially in February (increase) and April (decrease). In the Eastern part the climate is more continental to compare with others parts of Latvia. Therefore, the changes in river runoff reflected more gradually – increasing in January, February and March and decreasing in April and May (Figure 2).

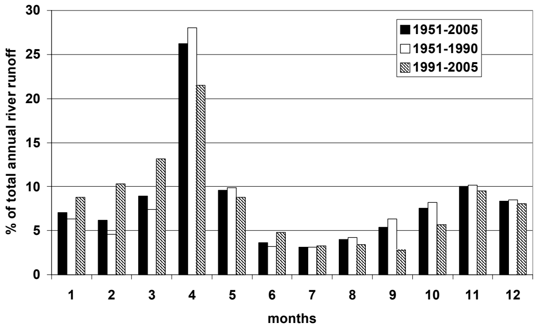


Figure 2. Percentage of total annual river runoff distribution by months for the river Amata.

The similar conclusions come from the obtained results between study periods 1951–2005 and 1951–1990.
The trends of changes of river discharge also depend on the season.

5. Conclusion

The present results confirm the basic hypothesis that main tendency in runoff changes are following: decreased in spring flood and as opposite - increased in winter thaw-period for the study period 1951-2005. The analysis of results shows regional differences in total annual river runoff distribution among Western, Central and Easter parts of Latvia.

References

Briede A. Tendencies of climate changes in Latvia. 64th conference of University of Latvia, thesis in Geography, geology and environmental sciences, Riga, pp. 19-20, 2006 (in Latvian)

Frisk T., Kļaviņš M., Rodinov V., Kokorīte I., Briede A., Long term changes of hydrologic regime and aquatic chemistry in inland waters of Latvia. *The Finnish Environment,* No.586, Tampere, 82 pp. 2002

Kļaviņs M., Briede A., Rodinovs V., Lizuma L., Frisk T., Ice Regime of rivers in Latvia in relation to climatic variability and North Atlantic oscillation. *Proc. of Latv. Acad. Sci.*, Vol. B, No. 58/5, pp. 175-182, 2004

Kļaviņš M., Rodinovs V., Kokorīte I., Chemistry of surface waters in Latvia. Univeristy of Latvia, Rīga, 286 pp., 2002

Rogozova S., Climate change impacts on hydrological regime in Latvian basins, *European Conference on Impacts of Climate Changes on Renewable Energy Sources*, pp. 137-140, 2006

Ziverts A. and Apsite E., Simulation of daily runoff and water level for the Lake Burtnieks. 19th European Conference on Modelling and Simulation ECMS 2005, Simulation in Wider Europe, 1-04 June, Rīga, pp. 633-637, 2005

Quantification of Climate Change Impacts in Urban Areas Caused by Extreme Rainfall

Karsten Arnbjerg-Nielsen[1], Christian Onof [2] and William May[3]

[1] COWI A/S, Parallelvej 2, DK-2800 Lyngby, Denmark (kar@cowi.dk),
[2] Imperial College, London, SW7 2AZ, Great Britain
[3] Danish Meteorological Institute, D-2100 Copenhagen E, Denmark

1. Introduction

Large changes in precipitation patterns have been observed within the last few decades. The changes can be observed throughout Europe, leading the EU to propose a Floods directive in order to cope with the increased risk of flooding (EU, 2006). Madsen *et al* (2006) estimates that the changes in Denmark with respect to design rainfall intensities are 5 - 20 % when comparing the period 1979 - 1996 with 1979 - 2005. This development is expected to continue. The paper suggests a methodology by which to evaluate how much the extreme rainfall will change within the expected lifetime of urban infrastructure, i.e. typically 100 years. The paper focuses on scaling from regional climate change models down to a resolution needed for analysis of sewer system performance. The objective is to quantify how much design rainfall for urban sewer systems will increase as a function of duration and return period.

2. Methodology

In Arnbjerg-Nielsen (2006) a literature review on scaling methods is reported that will link regional climate change model outputs with high resolution rainfall models. Two methods have been identified as most promising:

- Parametric modelling of extreme values by means of the Partial Duration Series (or Generalized Extreme Value) approach (Madsen *et al*, 2002). The relationship between the point precipitation series and the climate change model is established by scaling parameters in the models for each duration in question according to the predicted change in the parameters in the regional model.
- Parametric modeling of precipitation series in a coarse temporal resolution combined with methods for scaling of precipitation in higher temporal resolutions. The relation between precipitation series and climate model is established by relating statistics at different spatial scales. The underlying rainfall model is a Bartlett-Lewis model (Onof et al, 2000) and the scaling method applied is discussed in Onof et al (2002)

These methods will by applied to Danish data in order to identify climate change impacts in urban cities in Denmark. The regional climate change model is the HIRHAM4 model (Christensen *et al*, 1998), based on the global model HadAm3H AGCM (IPCC Scenario A2). The results will be compared to a third method, known as "parallel climates". The Parallel climate approach consists of identifying climates where the present weather conditions resemble predicted future weather conditions of the location in question (i.e. Denmark). The third method is needed also because the first two methods are applied to the same regional climate model output.

3. Partial Duration Series approach

The model consists of four parameters (Madsen et al, 2006):

- *z0:* Threshold parameter. This parameter defines the lower bounds for extreme rainfall
- λ: Annual number of exceedances
- μ: mean of exceedances
- κ: shape parameter (skewness of distribution)

All parameters show an increase towards more extreme rainfall in the future, see Figure 1. The overall change is visualized in Figure 2.

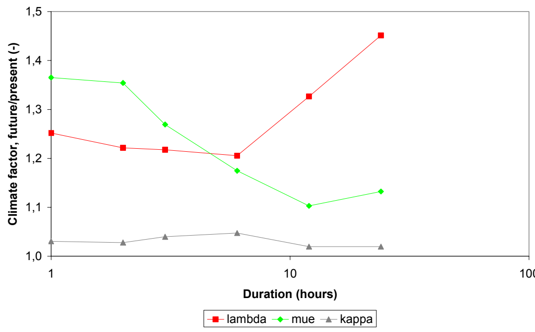


Figure 1. The predicted change for each parameter in the PDS-model.

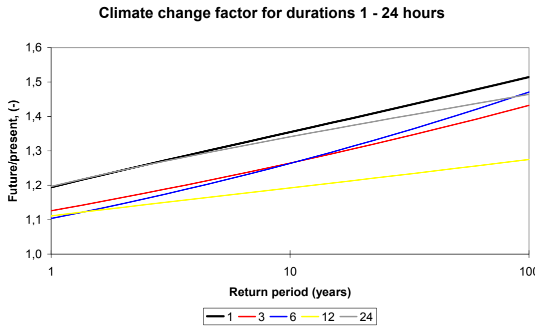


Figure 2. The predicted increase in extreme rainfall design value as a function of duration and return period based on the Partial Duration Series model.

4. Modelling of precipitation series based on the Bartlett-Lewis model

The Bartlett-Lewis model uses 8 parameters to describe the precipitation series on an hourly basis. An additional two parameters are used to scale the precipitation series to minute rainfall. These parameters are fitted on a monthly basis. A full description of a precipitation series thus requires 12*10 = 120 parameters.

Given that the model works properly, the output of this approach is a number of simulated precipitation series with characteristics according to the future climate. An example is shown in Figure 3 below. Climate factors using this approach is shown for one location in Figure 4.

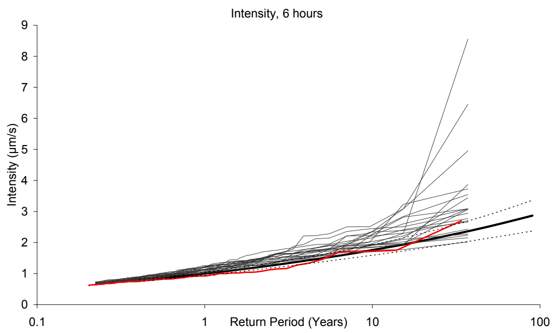


Figure 3. Simulated series compared with the regional model (fat black line) and historical precipitation series (red line).

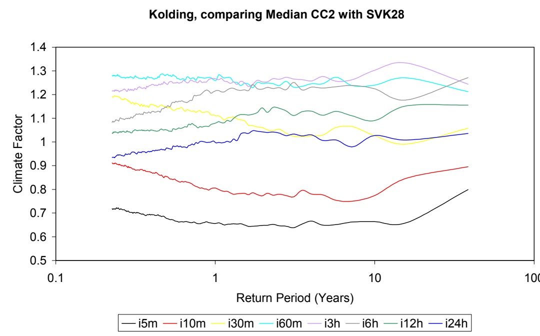


Figure 4. Climate factor calculated based on the precipitation series and compared with the present regional model.

5. Parallel Climates approach

The results differ quite substantially between the two model outputs described in the preceding sections. Therefore a third approach is needed in order to identify which method provides the most realistic approach. A map with parallel climates has been produced, based on precipitation characteristics, see Figure 5. A "climate" factor will be calculated and compared to the other two approaches.

6. Future work

There are two aspects of the work that needs refinement:

- The precipitation series climate model is compared with the present regional model. It is believed that is will be a more correct calculation to calculate a climate factor based on a comparison of model outputs from both present and future climate.
- The parallel climate approach needs to be finalized. Currently data are being collected and processed from an area covered by Hamburg, Munich, Paris, and Amsterdam.

Both aspects are expected to be finalized before the conference.

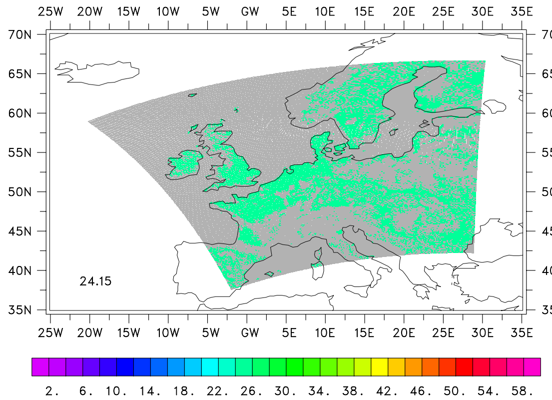


Figure 5. Map showing pixels with identical climates of future Danish extreme rainfall and present extreme rainfall

7. Conclusions

Three different approaches have been identified and tested with the objective of quantifying climate change impacts on extreme rainfall. The changes in design rainfall intensities are expected to be -20 - +50 % depending on return period and duration of the design rainfall. The study suggests that the largest increases in design intensities are to be found for durations 1 - 6 hours; this is the duration that typically generates the biggest floods in Denmark.

References

Arnbjerg-Nielsen, K., Climate Change Impacts on Extreme Rainfall and Subsequent Effects on Hydraulic Performance of Sewer Systems. *Working Report Series 9/2006*. Danish EPA, Copenhagen. 2006.

Christensen, O.B., Christensen, J.H., Machenhauer, B., and Botzet, M., Very-high-resolution regional climate simulations over Scandinavia. Present climate. *J. Climate*, 11, pp 3204 -3229.

EU, Proposal for a Directive of the European Parliament and of the Council on the Assessment and Management of Floods. Commission of the European Communities, Brussels, 18.01.2006. 2006/0005(COD)

Madsen, H., Mikkelsen, P.S., Rosbjerg, D., Harremoës, P. Regional estimation of rainfall-intensity-duration-frequency curves using generalized least squares regression of partial duration series statistics. *Water Resources Research*, 38, 11, 21-1-21-11. 2002

Madsen, H., Arnbjerg-Nielsen, K., and Mikkelsen, P.S., Evidence of increased storm intensities in denmark from the augmented rain database (1997-2005). *In: Molnar et al: 7th International Workshop on Precipitation in Urban Areas. December 2006, St Moritz, Switzerland*. pp 129-133. 2006.

Onof, C., Chandler, R.E., Kakou, A., Northrop, P.J., Wheater, H.S., Isham, V.S.: Rainfall modelling using Poisson-cluster processes, *Stochastic Environmental Research and Risk Assessment*, 14, 384-411. 2000.

Onof, C., Townend, J., Kee, R., Kellagher, R.B.B.: Rainfall Disaggregation Tool, *Report SR608, HR Wallingford*. 2002.

Simulated Crop Yield – An Indicator of Climate Variability

Triin Saue and Jüri Kadaja

Estonian Research Institute of Agriculture, Teaduse 13, Saku 75501, Estonia, triin.saue@eria.ee

1. Introduction

To assess climate variability, several meteorological elements, their mean and cumulative values as well as limits of variation are often used. Climate variability is a result of many different factors, therefore search for integral indices has been held in different fields. E.g., in agricultural meteorology different indices reflecting the balance between radiation or warmth and water resources are widely used for a long time. Climatologists use the NAO index, which is traditionally defined as the difference of normalized sea-level pressure between 2 stations situated close to the "centers of action" over Iceland and the Azores. It is the dominant mode of atmospheric behavior in the North Atlantic sector throughout the year, although it is most pronounced during winter (Dickson et al., 2000).

In Estonia, relationships between NAO indices and weather factors are weak in summer (Jaagus, 2006). Integral values representing weather conditions of the summer half-year are biological production of plants and yield of agricultural crops. The last is a quite numerously measured value. Unfortunately, long homogeneous time series of crop yields are hard to attain, due to inequalities in cultivars, agricultural techniques, economical or other factors. A more convenient and valid way is to use simulated time series of crop yields, computed by dynamic plant production process models. These models are compiled using knowledge about different physiological processes in the plant and integrate different daily or more frequent weather data.

In this work a potato production model POMOD (Kadaja, Tooming, 2004), based on the principle of maximum plant productivity and method of reference yields, is used to simulate potato yield in Estonia over the last 105 year period. The variations of computed yield series are compared with variations in different cumulated meteorological elements and NAO indices.

2. Model and Data

The method of reference yields, based on the principle of maximum plant productivity, is described as a conceptual basis for composing models of agricultural crops (Tooming, 1984). Proceeding from this principle, the maximum production and yields are observed under different limiting factors divided into agroecological groups: in general into biological, meteorological, soil and agrotechnical groups. These groups are included in the model separately, starting from optimal conditions for plant community. The corresponding categories of reference yields are the potential yield, the meteorologically possible yield, the actually possible yield and the commercial yield.

This concept is applied in the dynamic model POMOD for modeling potato production process and yield (Kadaja, Tooming, 2004). In present state POMOD uses variety-specific and meteorological data (radiation, air temperature, precipitation, soil moisture) and allows computing potential yield (PY) and meteorologically possible yield (MPY).

To simulate time-series of meteorologically possible yield for years 1901-2005, the meteorological data series for Tartu, Estonia, were applied. Daily mean air temperature, precipitation, radiation or sunshine duration for the period from April to September were used. Soil moisture values were calculated by the model using initial soil moisture values measured or evaluated by soil drying observations in spring. Biological parameters of late variety ‘Anti’, bred for Estonian conditions, were determined on the basis of field experiments (Kadaja, 2004, 2006).

Comparison of simulated yields and direct meteorological series of precipitation, temperature and solar radiation was implemented using cumulated values over different periods.

Another comparison was performed using different NAO indices. Three different sets of NAO data were used: GR is calculated on the basis of the pressure data in Gibraltar and Stykkisholmur/Reykjavik (Iceland) (Jones et al., 1997); PDR is found on the basis of Ponta Delgada (Azores) and Stykkisholmur/Reykjavik (Hurrell, van Loon, 1997); PDA on the basis of Ponta Delgada and Akureyri (Iceland) (Roger, 1984). All datasets have updated versions available in the Internet.

3. Long-term time series of yield

Potato yield series was established for the period 1901-2005 (Fig. 1). A weak decreasing trend exists in this series, but it is not significant. No periodical changes can be detected, but some quite stable periods appear. The meteorological conditions have been quite stable in the second decade of the last century and in the sixties and seventies. The most unstable period begins after 1980. However, the standard deviations of the MPY of the first and second half of the period are practically equal.

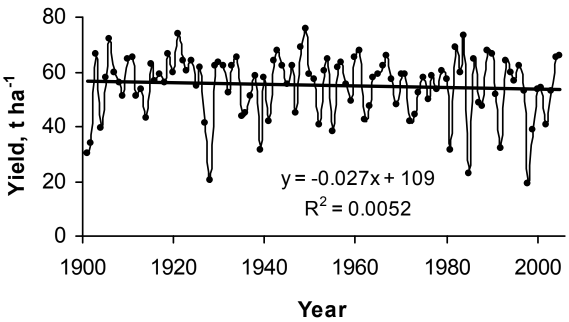


Figure 1. Simulated potato yield for Tartu in 1901-2005.

The distribution of the yields is not symmetric. Low yields, corresponding to extreme meteorological conditions, form deep deviations. The decline of cumulative distribution is quite steep after the mean value of MPY (Fig. 2). The high values of MPY correspond to the years well balanced by the different meteorological resources throughout the summer period. As rule, these are the years very similar to the climatic normal by all factors.

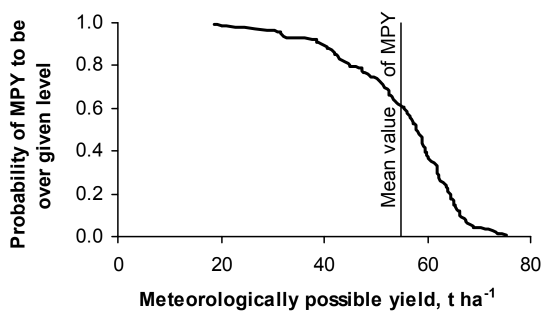


Figure 2. Cumulative distribution of MPY

4. Relationships between MPY and other indicators

No significant linear correlations exist between MPY and cumulative meteorological factors of the summer period. Better relationships with precipitation as well as with temperature and solar radiation form if a curve with maximum, describable with a polynomial of second order, is applied. Best correlation (r = 0.62) occurred with precipitation summarized from May till August (Fig. 3). Quite good results were obtained for all summer periods which included spring months May and April, also for the period from April to September. Strong polynomial relationships of MPY with temperature and solar radiation occur for period from June to August (r = 0.519 in both cases). Including spring months into the calculation decreased these correlations, especially for temperature.

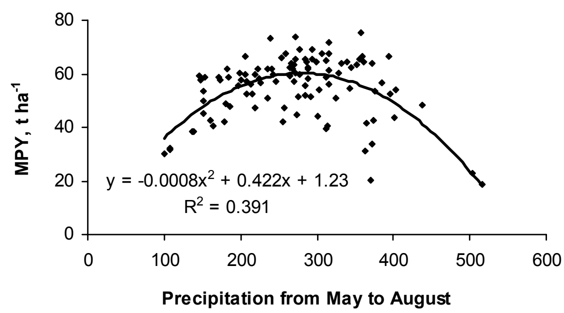


Figure 3. MPY compared to precipitation from May till August.

Despite of significant polynomial relationships between MPY and cumulated meteorological elements, the variance is high. This means that in our conditions MPY gives qualitatively new information about climate variability, integrating the influence of different weather factors. In the conditions, where one limiting factor is very dominant, the need for such indicator is minor, e.g. near the Polar Circle where MPY is very well correlated with temperature (Sepp et al., 1989) or in the arid regions where water deficit is dominant.
Comparison of MPY and NAO indices gave reliable correlations only for few months. Negative correlation of MPY and NAO indices PDA and PDR for the previous November was established on the significance level 0.05. Positive correlation is reliable with January's GR and PDA indices. Here the influence can be expected through the temperatures in January, Baltic Sea ice cover and snow cover to the spring heat conditions (Tooming, Kadaja, 2006). Although, the correlations are not reliable for February and March separately, these are reliable in case of all the three indices averaged over the period January–March. From April to August the correlations are very weak having negative values in April and July. Reliable positive correlations (for PDA on the 0.01 significance level) exist again between MPY and the NAO indices in September.

5. Acknowledgements

This investigation is funded by the Estonian Science Foundation Grant No. 6092.

References

Dickson, R.R., Osborn, T.J., Hurrell, J.W., Meincke, J., Blindheim, J., Adlandsvik, B., Vinje, T., Alekseev, G., Maslowski, W., The Arctic Ocean Response to the North Atlantic Oscillation. *Journal of Climate:* Vol. 13, No. 15, pp. 2671–2696, 2000

Hurrell, J.W., van Loon, H. Decadal Variations associated with the North Atlantic Oscillation. *Climatic Change:* Vol. 36, pp.301–326, 1997.

Jaagus, J. Climatic changes in Estonia during the second half of the 20th century in relationship with changes in large-scale atmospheric circulation. *Theor. Appl. Climatol.* 83, 77–88, 2006.

Jones, P.D., Jónsson, T., Wheeler, D. Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. *Int. J. Climatol.* **17**, pp. 1433-1450, 1997.

Kadaja, J. Dependence of growth functions and leaf area parameters on fertilization of potato crop. *IX ESA Congress. Book of proceedings. Part I.* (Eds. M. Fotyma and B. Kaminska). *Bibliotheca Fragmenta Agronomica 11*. Pulawy–Warszawa, pp.131-132 2006.

Kadaja, J. Influence of fertilisation on potato growth functions. *Agronomy Research* 2(1), pp. 49-55, 2004.

Kadaja, J. Tooming, H. Potato production model based on principle of maximum plant productivity. *Agric. For. Meteorol.* 127, (1–2), pp. 17–33, 2004.

Rogers, J.C. The association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. *Mon. Wea. Rev.*, 112, pp. 1999–2015, 1984

Sepp, J., Tooming, H., Shvetsova, V.M. Comparative assessment of potato productivity in the Komi A.S.S.R. and in Baltic republics by the method of dynamic modelling. *Fiziologija Rastenii (Plant Physiology)* 36 (1), pp. 68–75, 1989 (in Russian).

Tooming H., Ecological Principles of Maximum crops productivity. Gidrometeoizdat, Leningrad, 264 p., 1984 (in Russian).

Tooming, H., Kadaja, J. Relationships of snow cover in Estonian climate – relations from winter to spring. *Handbook of Estonian snow cover*. H. Tooming, J. Kadaja (Compilers), A. Kallis (Ed.). Estonian Meteorological and Hydrological Institute – Estonian Research Institute of Agriculture, Tallinn – Saku, pp. 112–133, 2006.

Sea Surface Temperature Development and Cyanobacteria in the Baltic Sea

Herbert Siegel[1], Monika Gerth[1] and Gisela Tschersich[2]

1 Baltic Sea Research Institute Warnemünde (IOW), Seestrasse 15, D-18119 Rostock, herbert.siegel@io-warnemuende.de
2 German Federal Maritime and Hydrographic Agency, Hamburg (BSH), Postfach 30 12 20, D-20305 Hamburg

1. Introduction

Sea surface temperature (SST) is an important variable in the ocean / atmosphere system because it is directly related to the exchanges of heat, momentum and gases. Satellite derived SST delivers synoptical temperature distribution of the entire Baltic Sea in a high temporal resolution over a long period. Therefore, the application covers a wide range of topics including climatological aspects. Furthermore, the water temperature is one of the most important factors affecting the development of phytoplankton.
The Sea Surface Temperature (SST) maps were used to investigate seasonal and inter-annual variation, the development of yearly means of the period 1990-2006 of the entire Baltic Sea to identify potential trends. The trends were compared to the development at the northern hemisphere.
Inter-annual variations of SST affect strongly the development of cyanobacteria.

2. Data set

The SST-maps of the investigation period 1990-2006 were derived from the infrared channels of the Advanced Very High Resolution Radiometer (AVHRR) of the weather satellites of the National Oceanic and Atmospheric Administration (NOAA) received by the German Federal Maritime and Hydrographic Agency Hamburg (BSH), compare SIEGEL ET AL., 1999. Monthly mean SST maps were calculated on the basis of all cloud-free pixels of the available scenes (overpasses) during each month (Fig. 1). SeaWiFS data were provided by the SeaWiFS Project of NASA (Siegel et al. 2001).

3. Seasonal and inter-annual variations in SST

The seasonal development of SST is characterized by minimum in February/March and a maximum in July/August (Fig. 1, lower image line). The coldest winter was in 1996 in the south-western Baltic, 2003 and 2006 in the Baltic Proper. The coldest summer in the Baltic Proper was in 1998 followed by 1993, whereas 1992 was extremely cold in the Gulf of Bothnia. The highest temperatures were observed in August 1997, in Bothnian Sea in 2002 and in Bothnian Bay in 2003. Further exceptional warm months were June 1992 and 2002, July 2006 in the Baltic Proper and western parts and 2003 in the entire Baltic Sea, September 2002 and 1999 as well as October 2006 and 2000. The number of warm summers increased particularly in the northern Baltic Sea.
Based on yearly means SST maps for the entire Baltic Sea (right column, Fig.1) colder years were recognised in the early 90's and in 1996. The temperatures in these years varied between 8 and 9°C in the Baltic Proper. The number of warmer years increased at the beginning of this century. The warmest years in the Baltic Proper were 2006, 2005, 2002, and 1999 with temperatures between 9 and 10°C. Particularly, in the Bothnian Sea the temperature arises in the second half of the investigation period.

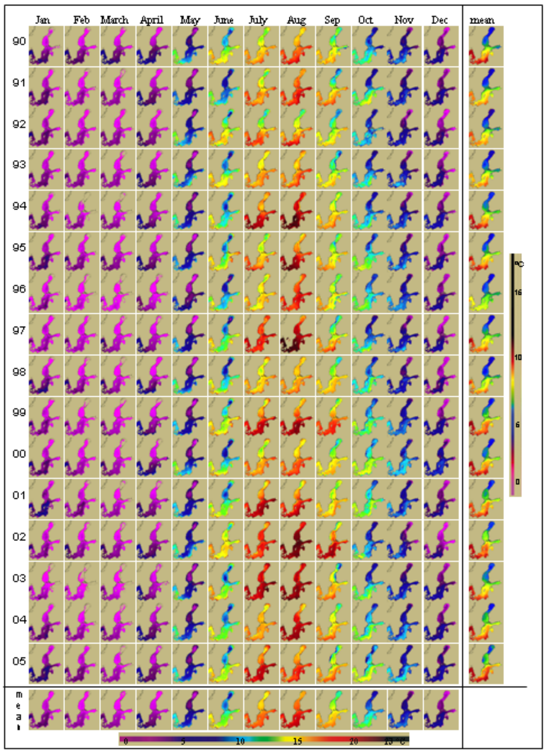


Figure 1. SST-Maps of the period 1990-2006, monthly means, average of the months and of the years.

4. SST trends in the Baltic Sea

The mean SST of the entire Baltic Sea was calculated from these yearly mean values to examine potential trends of 17 years observation period. Time series of anomalies and trends for the Baltic Sea and for the northern hemisphere are presented in Fig. 2. The mean value of the entire period is 7.37°C. The minimum of the yearly means (6.55°C) was observed in 1996. The warmest year was 2006 with more than 8°C. Since 1999 all years showed positive anomalies. The yearly mean SST of the entire Baltic Sea show a stronger positive trend than the northern hemisphere. To investigate seasonal and regional differences a trend analysis was performed for each month. The results are displayed in Fig. 3. The slopes of the linear trends were calculated for each pixel. Slight negative trends in March are particularities of the investigation period due to the March 1990 being the warmest of the last 100 years. The other month from January to May show no significant trends. Strong positive trends occurred in the summer month particularly in July but also in August, and September - November. The maximum was found for July in the Bothnian Sea with a slope partly >0.3 K/year which means an increase in the investigation period (1990-2004) of more than 4 K.

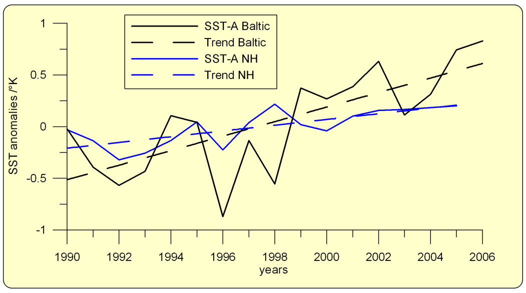


Figure 2. SST-anomaly and trends of entire Baltic Sea compared to the northern hemisphere for the period 1990-2006.

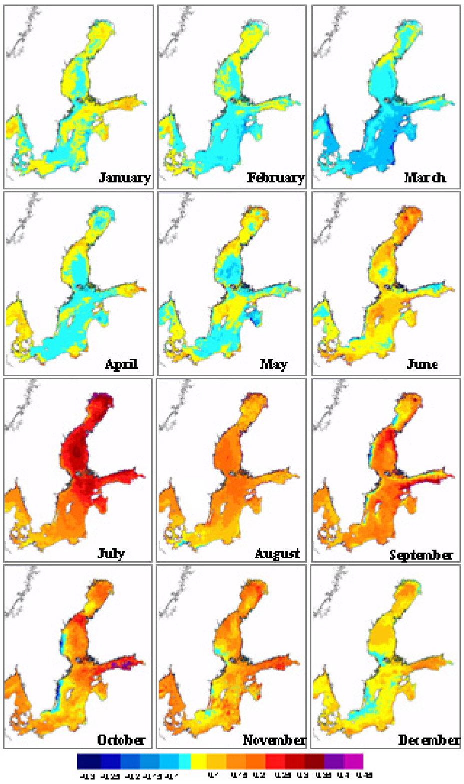


Figure 3. Maps of the slopes of SST-trends for the period 1990-2004.

5. Cyanobacteria development in summer

Cyanobacteria develop in warm summers during stable thermal stratification, high solar radiation, and depletion of inorganic nitrogen in the top water layer of the Baltic Sea. They are able to use dissolved molecular nitrogen for the photosynthesis. During low wind-mixing, they form aggregates and float up to the surface due to their buoyancy-increasing intercellular gas vacuoles. In the top layer they form subsurface clouds or surface accumulations. The patchy distribution of subsurface clouds and surface scum and their high spatial and temporal variability favoured ocean colour satellite data to investigate the development of blooms. The initial temperature for the cyanobacteria growth was in 1980s and early 1990 about 15-17 °C (Kahru, 1997) and for the period 1998-2004 approximately 13-15°C (Siegel et al. 1999). The starting day varied in the last years between 8 June (2001) and beginning of July. The starting areas were the northern Gotland Sea and Gulf of Finland. Strong inter-annual variations occurred in the 1980s with high accumulations in 1980 and without any in 1985 and 1986. This inter-annual differences were also documented by Kahru (1997) showing a slight increase in cyanobacteria in early 1990s. End of the 1990s years and beginning of this century the accumulations rose with the increasing summer temperatures in the Baltic Sea (Siegel et al. 2006). Strong surface accumulations were observed south of Gotland Island in the warm August 1997. In the period 1998-2004 the bloom was strong in the warm summers 1999, 2001, and 2003 in the Baltic proper and in particular in 2002 in the Gulf of Finland. The bloom mostly started in the northern and western Gotland Sea. Only in 1999 and 2001 the bloom extended into the western Baltic Sea. In colder summers 1998 and 2000, the intensity of the bloom was much lower. In contrast to the early 1980's filaments were also observed in the Bothnian Sea, particularly in 2001. The monthly mean chlorophyll maps in Fig. 4 show examples for low and high intense blooms in 1998 and 1999. In 2005, the maximum was already reached on 13 July in the central part and the western Baltic was excluded. In 2006, the northern Baltic Sea was only shortly influenced, but the western Baltic was affected from beginning of July until end of August. For the first time, the bloom was transported with the outflow of the Baltic Sea into the Kattegat.

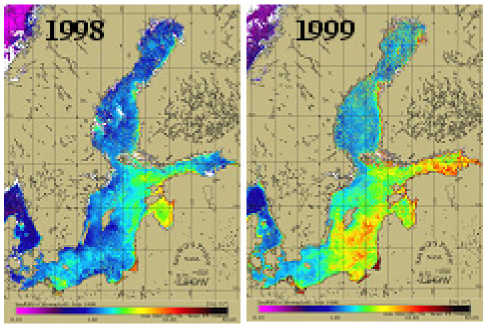


Figure 4. Mean chlorophyll distribution of July 1998 and 1999 (low and high productive years)

References

Kahru, M., 1997. Using satellites to monitor large-scale environmental change: A case study of cyanobacteria blooms in the Baltic Sea. In: Monitoring Algal Blooms, M. Kahru and C.W. Brown (Eds.), Springer, pp. 43-57.

Siegel, H., Gerth, M., Tschersich, G., 2006. Sea Surface Temperature development of the Baltic Sea in the period 1990-2004. Oceanologia, 48 (S) 119-131.

Siegel, H., Ohde, T., Gerth, M., 2001. SeaWiFS validation and application in the Baltic Sea. In: Proc. 4th Workshop on Ocean Remote Sensing, 30 May-1 June 2001, Berlin, pp. 97-105.

Siegel, H., Gerth, M., Neumann, T., Doerffer, R., 1999. Case studies on phytoplankton blooms in coastal and open waters of the Baltic Sea using Coastal Zone Colour Scanner data. Int. J. Remote Sensing, Vol. 20, No. 7, 1249-1264.

Storm Surges in the South Coast of the Gulf of Riga

Tatjana Koltsova and Jelena Belakova

Latvian Environment, Geology and Meteorology Agency,165, Maskavas str., LV-1019 Riga, LATVIA; e-mails: tatjana.kolcova@meteo.lv; jelena.belakova@meteo.lv

The Lielupe River is the second of largest rivers in Latvia. Annual water runoff of Lielupe River to the Gulf of Riga is 3,37 km^3.

After Jelgava city the river starts forming a typical estuary with riverbanks, small islands and peninsulas, swamps etc. From here and down to the river mouth the gradient of the river is five to ten centimetres per kilometre, and occasions of the high water level in the Gulf of Riga have a damming effect of the flow of the river. The riverbed is much lower than average Baltic Sea level over a length of 100 km upstream from the mouth. As a result river flows to the opposite direction during the backwaters from the sea in autumn and winter.

The highest backwater affect for an observation period of 80 years was in 1969. That water rising event was wind driven. The second highest water level, caused by the wind, has been observed in January 2005 with the probability of 3%. From 2 years, in January 2007 the water level with the probability of 5% was recorded.

The air temperature, wind direction and speed and water level data series was analysed with respect to climate change.

Storm Surges in the Odra Mouth Area in the 1997-2006 Decade

Halina Kowalewska-Kalkowska and Bernard Wisniewski

Institute of Marine Sciences, University of Szczecin, Waska 13, 71-415 Szczecin, Poland, e-mail: halkalk@univ.szczecin.pl

1. Introduction

The storm surges in the Odra mouth area (the southern Baltic Sea), caused by passages of deep low-pressure systems over the Baltic Sea, result in flooding events on coastal areas, polders and areas near rivers. They cause destruction of sea coast and beaches and are dangerous for the navigation safety. The fluctuations of water level result from the combined effects of persistent wind over a shallow body of water and changes in atmospheric pressure on the sea surface, that generate a sea surface deformation, the so-called baric wave, with its positive phase inside the low and its negative phases outside it (*Wisniewski and Kowalewska-Kalkowska* 2005, in press). In the study the storm surges in the 1997-2006 decade were analysed. At first, water level fluctuations in the Odra mouth area were analysed in relation to characteristics of a corresponding atmospheric low (trajectory, velocity of passage, pressure in the centre) and local wind conditions (direction and velocity). On that basis, an impact of the wind and baric wave on the duration and extent of the storm surge in the Pomeranian Bay, Szczecin Lagoon and the lower Odra branches was estimated. Subsequently, the effect of instantaneous water level in the lower Odra branches was taken into consideration. Then typical scenarios of water level fluctuations in the Odra mouth area were separated.

2. Results

The study revealed the following typical scenarios of the storm surges in the Odra mouth area:

1. Wind- and baric wave-caused storm surges with a typical wind-driven back flow in the Odra branches (Fig.1). In such cases, the water level was observed to increase, at first at the Pomeranian Bay coasts, then in the Szczecin Lagoon, and finally in the Lower Odra channels. The maximum level resulted from an overlap of the positive phase of the baric wave and winds from the northern sector. Subsequently, the water level was observed to drop as a result of the shift of the low outside the Baltic and an air pressure increase. The effect of the negative phase of the baric wave on the sea surface was very distinct. In the Szczecin Lagoon and along the downstream Odra reach, the water level fluctuations were weaker and followed, with a time lag, the changes in the sea level.

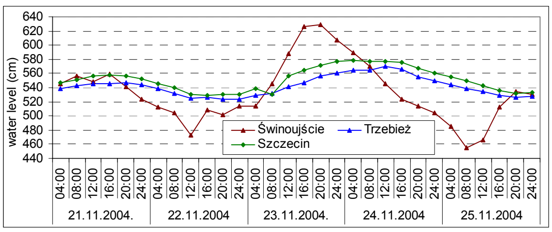


Figure 1. Water levels in the Odra mouth area during the 21-25 November 2004 storm surge.

2. Storm surges with a typical wind-driven back flow in the Odra branches and high water levels in the Lower Odra channels and the Szczecin Lagoon (Fig.2). In such cases, the rise of the water levels caused by the passage of a deep low-pressure system over the Baltic Sea was stronger, occasionally resulting in flooding events. Such situations were common in spring, as a result of ice thawing and accumulation of water derived from a previous storm surge.

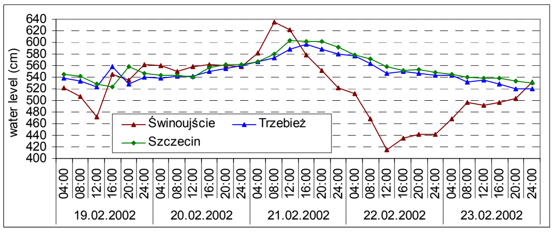


Figure 2. Water levels in the Odra mouth area during the 19-23 February 2002 storm surge.

3. Short-lived storm surges, registered only at the Pomeranian Bay coasts (Fig.3). The surges were generated by a fast shift of a deep low over the Baltic Sea and by appropriate winds. The effect of the low's shift was often negligible in the Szczecin Lagoon and the downstream Odra reach because of a too low hydraulic capacity in the straits connecting the Lagoon with the Pomeranian Bay.

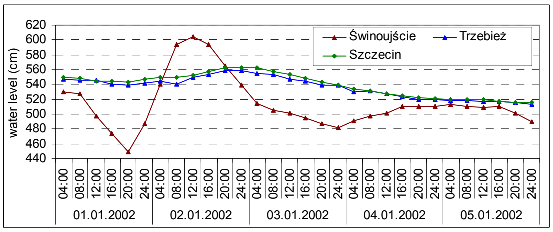


Figure 3. Water levels in the Odra mouth area during the 1-5 January 2002 storm surge.

4. Storm surges caused mostly by strong wind (Fig.4). In such surges, both the increasing and the decreasing phase of the water level change were slow and mild. The pressure effect was imperceptible. The raised water levels were observed in the Pomeranian Bay and the Szczecin Lagoon as well as along the downstream reach of the Odra.

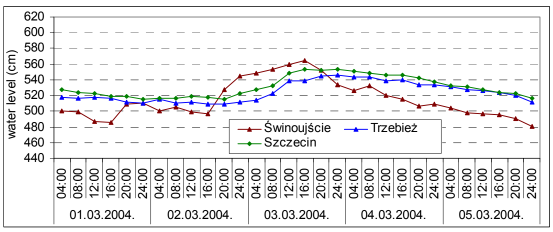


Figure 4. Water levels in the Odra mouth area during the 1-5 March 2004 storm surge.

5. Storm falls. Deep storm falls (below 440 cm NN) were recorded during passages of deep low-pressure systems as a result of a negative phase of the baric wave and southerly winds. They were particularly deep whenever a high-pressure system over the Baltic Sea developed and a low was passing over the North Sea. Such cases were additionally accompanied by the outflow of the Baltic water into the North Sea.

References

Wisniewski, B., Kowalewska-Kalkowska, H., The influence of low-pressure systems on water levels in the Odra estuary, In: Gurgul, H. (ed.), *Physicochemical problems of natural waters ecology*, University of Szczecin, Szczecin, Vol.3, pp. 211-226, 2005.

Wisniewski, B., Kowalewska-Kalkowska, H., Water level fluctuations in the Odra mouth area in relation to passages of deep low-pressure systems, *Oceanological and Hydrobiological Studies* (in press).

Meteorological Features of Spring Flood Formation in Nemunas River

Egidijus Rimkus, Gintautas Stankunavicius, Gintaras Valiuskevicius and Arunas Bukantis

Department of Hydrology and Climatology, Vilnius University, M. K. Ciurlionio 21, 03101 Vilnius, Lithuania
e-mail address: egidijus.rimkus@gf.vu.lt

1. Introduction

Spring flood accounts for about 40 % of the annual run-off volume in Lithuania. So hydrologists and forecasters direct their attention to studies concerning snow water equivalent and snow melting conditions. This paper is concerned with atmospheric circulation as the central factor influencing the snow melting conditions and consequently the spring run-off characteristic of the Nemunas river. The analysis includes a very informative variable - snow water equivalent (SWE) accumulated before snow melting run-off starts and its relation with maximal water discharge and the flood volume. Nemunas – the largest Lithuanian river draining about 5.3 % of Baltic Sea basin area. River length is 937 km, total catchment area ~ 98 000 km^2. Up to 1960, the mean water level amplitude during flood period was about 10 m in the middle stream and 2-3 m in the lower reaches. After 1960, the Hydropower station with dam was built on Nemunas-river near the town of Kaunas and floods were suppressed in this region. At present the floods are dangerous only in lower reaches and delta region. Usually every spring about 200 km² of territory in the northern part of Nemunas river delta is flooded.

2. Data and methods

The Smalininkai gauge station was chosen as the closest point to the lower reaches (112 km from lower reaches, and 81 200 km² catchment area up to this cross section) in this study. The analyzing period covers 1960-1999, and the flood run-off characteristics were calculated for this period. The following parameters were chosen to describe the main flood characteristics: maximal water discharge (Q_{max}, m^3s^{-1}) during flood period; flood volume without base flow (FV_B, km^3). Stored water in snow cover – snow water equivalent (SWE) was chosen as the main parameter describing snow cover before snow melt runoff onset. SWE data is collected from 20 measurement points almost equally spaced and located in central part of the catchment. They represent the last five day period before snow melting run-off starts. It is sure that other indices like precipitation rate during snow melting period and particular watershed conditions make very substantial contribution to the character of the spring run-off volume and the hydrograph shape as well. Nevertheless, atmospheric circulation is the foremost on the snow melting factors and the subsequent spring run-off characteristic was the main purpose of present research.

The sea level pressure and 500hPa geopotential height daily data from NCEP/NCAR Reanalysis: absolute values and anomalies (*Kalnay et al.* 1996) were used. Daily anomalies are based on 1968-1996 period's climatology. All this data was used in a weather pattern classification scheme for different snow melt runoff hydrograph types.

The classification scheme includes classification of 500 hPa height anomaly (HA500) fields and sea level pressure (SLP) fields over the European region. Later the timeseries of consecutive averaged fields were formed and dominant patterns (covered more than one third of period) were extracted. The HA500 field classification procedure includes determination of positive and negative anomaly fields, field magnitude and field position in relation to Lithuanian territory. SLP fields were divided into cyclonic, anticyclonic and divergent (non gradient) flow patterns.

Each year the spring flood was divided into the three different time segments. The first represents the period between the beginning of snow melt and flood start. The second period lies within the maximal flood wave period. And the third period represents the remaining flood period: from highest point to the end of hydrograph slope. This procedure was necessary to assign weather patterns to different spring run-off stages.

3. Results

The connection between SWE in pre-flooding period and maximum water discharge (Q_{max}) was analyzed in this study. The results show the dipolar character of the relation: increasing SWE maximal values correspond to rapidly increasing Q_{max} (A years) and slowly increasing Q_{max} (B years) (Fig. 1). Consequently the relation was separated into two groups of scattered points and every group is represented by a linear regression curve with a corresponding equation. Further, these groups were analyzed separately in order to determine dominant weather patterns that influence different types of flood and its (the flood's) characteristics.

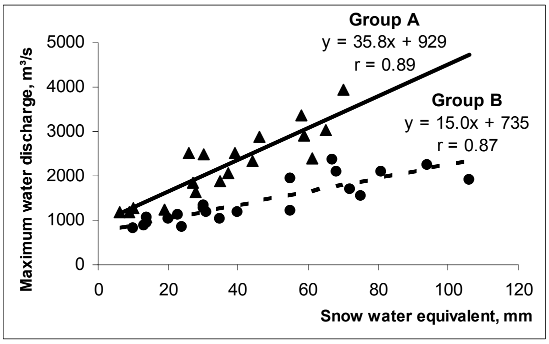


Figure 1. The relations between the snow water equivalent (SWE) calculated before spring run-off onset and the maximum water discharge (Q_{max}, m^3s^{-1}) in the Nemunas river in 1960-1999.

Mean SLP anomaly over Baltic region are predominantly negative in A years, particularly in the first and second flood time segments, and such SLP anomaly has an opposite sign in B years. The exception is the third segment when averaged SLP anomalies change their sign to opposite (Fig. 2). Also the analysis showed that two thirds of spring run-off seasons are distinguished by negative (positive) SLP anomaly in A (B) years in the first flood time segment. And in the second spring runoff time segment this relation is rather weak.

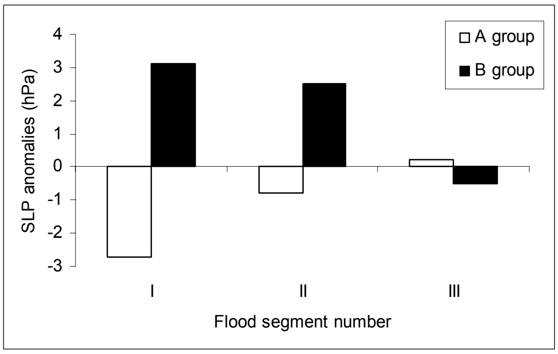


Figure 2. Averaged sea level pressure anomalies (hPa) during different spring flood time segments and in different flood seasons (A and B) over southern Baltic region.

Negative HA500 anomalies prevail over Western Europe and North East Atlantic and positive HA500 anomalies prevail over Eastern Europe in the spring runoff seasons belonging to group A. Such atmospheric pattern (first) accounts for 27.6 % of total snow melting period length and produces enhanced southerly flow over Baltic region (Fig. 3a).

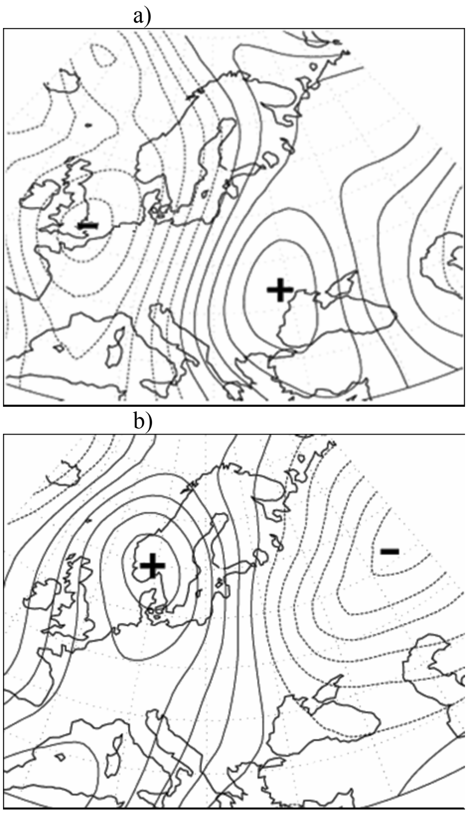


Figure 3. The typical H 500 hPa anomaly schemes for European region during a) intense snow melting period in group A; b) main run-off period in group B.

The second pattern looks like meridionally stretched dipole system: high above Northern Europe and low over Mediterranean and Balkans and explains 22.6 % of variation of pressure fields during the spring runoff season. That pattern is blocking the pattern over whole Europe and induces easterly and southeasterly low level winds over Baltic and Central Europe. The third pattern (17.1 %) shows significant negative geopotential height anomaly over Central Europe and the North Sea and also induces southerly winds (weaker) like in pattern one. The fourth pattern substantially differs from the previous patterns because it represents intensive zonal flow over most of Europe (15.4 %) and highly correlated with NAO index. Other large scale weather patterns together account for less than 20 % of data variation and show no significant temperature advection over Lithuania.

Quite different picture is seen in B group during spring runoff periods. The positive values of HA 500 field are located over Western Europe during intense snow melting period (35.5 %). Positive anomalies over Baltic and the first circulation type make - 45.4 % of periods (Fig. 3b). The anticyclonic SLP fields are dominant (77.2 %) with prevailing western part of surface anticyclone - 58.2 %.

4. Conclusions

Meteorological conditions of snow water melting are very important flood formation factors in Nemunas catchment. Their influence is quite different during intense snow melting period and the main flood period, when maximal water discharge values are observed.

Mean sea level pressure is lower (higher) than normal in A group (B group) intensive snow melting periods. Southerly flow with accompanied warm advection is the typical large scale atmosphere circulation feature during snow melting period in years with A group floods over Baltic region. Anticyclonic circulation is the dominant in SLP field during main spring runoff seasons belonging to the group B. In those seasons blocking ridges damp cyclonic circulation over Europe and favor for the dry air invasions from the east: snow melting process delays and despite high precedent SWE values, the maximum spring runoff discharge is lower than normal.

The classification of atmospheric processes for flood period seems to be accurate only in the first (one or two) flood time segments. In the rest flood periods one could find only inertial flood behavior due to earlier atmospheric forcing.

References

Kalnay E. M. and Coauthors, The NCEP/NCAR 40-Year Reanalysis Project, Bulletin of American Meteorological Society, No. 76, pp. 437-471, 1996.

Transformation of the Water Run-off of the Baltic Sea Basin Rivers in the Territory of Belarus

Volchak Alexander[1], Luksha Vladimir[2] and Volchek Anastasiya[2]

[1]National Academy of Sciences of Belarus, Moscovskaya st., 204, Brest, Republic of Belarus, Volchak@tut.by
[2]Brest State Technical University, Moscovskaya st., 267, Brest, Republic of Belarus, vvl@bstu.by
[2]Brest State Technical University, Moscovskaya st., 267, Brest, Republic of Belarus, Volchek_An@rambler.ru

1. Introduction

Water resources play a main role not only in the formation and the development of natural ecological systems, but also render significant influence on the economy of any country. A big dynamical parameter in the context of water resources is runoff, which is strongly influenced by climate factors.However, recent anthropogenic influences can affect a natural water regime essentially. Besides essential influence renders observable global warming of the climate, which the nearest decade will to the full be shown in aggregate regional changes of river ecological systems. The importance of the problem grows also because almost all large rivers of Belarus are trans-boundary and changes caused in one country of the river basin may concern other countries in this basin. Having necessary volume of the information on a run-off for the long period and modern geoinformation technologies, today it is possible to give a quantitative estimation of run-off change of the rivers and to reveal the reasons resulted in these changes. Thus it is important to examine all kinds of a river run-off of water to find out in a complex the origin of these changes.

2. Initial materials and methods of researches

The basic rivers of the Baltic Sea basin located in the territory of Belarus are the Western Dvina and Neman. As initial materials, time series of annual, maximal spring high water, the minimal summer-autum and minimal winter run-off of water of 64 rivers ranges of the rivers of the Baltic sea basin located on the territory of Belarus for the period of tool observation of the Department of Hydrometeorology of the Ministry for Protection of the Environment and Natural Resources of Belarus were used.
For a correct estimation of run-off quantity, it is necessary to allocate anthropogenic and natural components being based on the expression:

$$M_{est.} = M_{izm.} \pm \Delta M_{aper.} \pm \Delta M_{k\,lim.} \pm \Delta M_{antr.}\,, \qquad (1)$$

where $M_{est.}$ - amount of a run-off, which would be observed in conditions of stationary process; $M_{izm.}$ - the measured amount of a run-off for the examined period of time; $\Delta M_{aper.}$ - the natural fluctuations of a run-off caused by periodic fluctuations of a climate; $\Delta M_{k\,lim.}$ - the changes of a run-off caused by global warming; $\Delta M_{antr.}$ - the complex estimation of the influence on a run-off of economic activities in the territory of water inflow of the river.

Complexity of practical use of the formula (1) is connected to errors of definition and uncertainty of its components.

The size of $\Delta M_{aper.}$ usually represents itself as the amendment to average amount of a run-off for the period proceeding from its long-term norm. It is possible to determine $\Delta M_{aper.}$ using values of average quadratic errors of an estimation of norm and a variation of a run-off in view of features of its regime fluctuations.

The size of $\Delta M_{k\,lim.}$ can be revealed according to supervision if the above-stated amendment is authentically determined, and the element $\Delta M_{antr.}$ is absent, or with the help of regional models such as «precipitations, temperature – run-off», at known changes of the climate.
Natural fluctuations of a climate and caused by these fluctuations of a run-off ($\Delta M_{aper.}$) on the territory are distinctly asynchronous, and the run-off changes caused by change of a climate ($\Delta M_{k\,lim.}$) have more universal unidirectional character for the big territory that allows to divide their contribution.
Element $\Delta M_{antr.}$ shows cumulative influence on the run-off of economic activities on surfaces of territory of water inflow. Its definition is connected to the big errors in a kind of absence of mass measurements. As the simplified estimation of changes of a run-off the relation $\Delta M_{antr.} / M_{izm.}$ serves. If it less than 1-3 %, this size without loss of accuracy is insignificant. Otherwise the developed analysis of reliability of components and an exception of the element $\Delta M_{antr.}$ is required by restoration of a run-off under the given factor.

A priori necessity of the calculation of the formula (1) was proven by the analysis of uniformity of initial rows of hydrometric observes by various methods. When it has been established, that infringement takes place within the limits of critical statistical parameters, in procedure of calculations in addition was included standard statistical methods, namely:
- for revealing tendencies of changes chronological schedules of fluctuations and summary integrated curves were used;
- dynamics of change of time series was estimated with the help of linear and quadratic trends.

For an estimation of distinctions in statistical parameters the criteria of Student and Fisher were used.
After the all-round analysis hypotheses about influence on a run-off of warming of a climate and large-scale land improvements were checked.

3. Discussion of results

The analysis of hydrographs of various kinds of a run-off has allowed to estimate uniformity of time series and to reveal the rivers, where anthropogenous influences were the most essential and are visually appreciable (change of the area of a territory of water inflow, redistribution of a run-off, etc.). Further with the use of statistical criteria the estimation of influence of hydraulic engineering land improvements and warming of a climate was carried out. Fragments of hydrographs of all kinds of run-off of the basic rivers are resulted in figure.

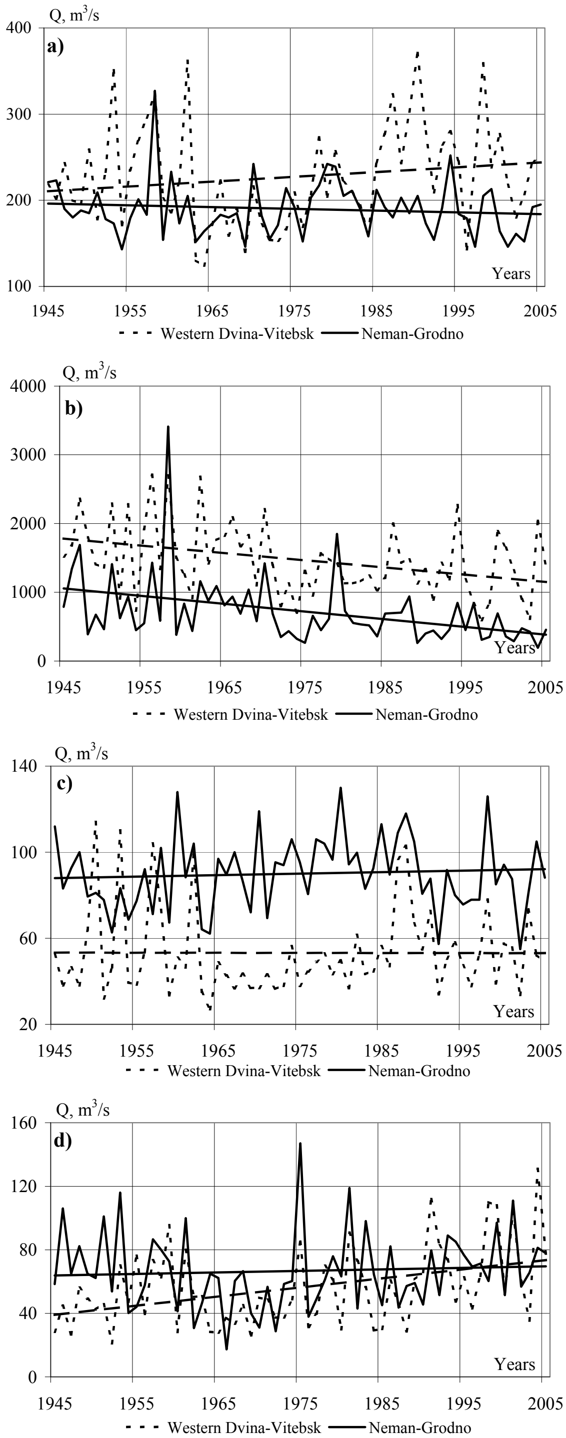


Figure 1. Gidrographs and trends of the Baltic Sea basin rivers run-off: a - annual; b - maximal a spring high water; c - minimal summer-autumnal; d - minimal winter

The analysis of spatial structure of change of an annual run-off has shown, that they have taken place in the territory of water inflow of r. Western Bug, to the most subject to meliorative influences. As a whole, changes of annual run-off are insignificant do not exceed 5 % and is within the limits of a statistical mistake. Practically in all the territory, the reduction of the maximal run-off of a spring high water is taken place, and in some cases reaches 50 %. Changes of a summer-autum minimal run-off obviously are not expressed, some increase, which does not exceed 10 %, is observed.

The increase in a winter run-off has made on the average 13 % that is caused by the long thawing weather, and during this period, an intensive thawing of snow and updating of stocks of subsoil waters take place, that considerably reduces the maximal run-off of a spring high water. Confirming the results in Table 1, the comparative analysis of statistical characteristics of time series of the basic rivers of Baltic basin is presented.

Table 1. Statistical parameters of various kinds of a run-off of the rivers of Baltic Sea

River-Ranges	Period	$\overline{Q}$, м^3/s	C_v	C_s	r(1)
Annual					
r. Western Dvina – c. Vitebsk	1960 – 1980	195	0,28	1,49	0,03
	1981 – 2005	248	0,22	0,40	0,30
	1960 – 2005	224	0,27	0,61	0,34
r. Neman – c. Grodno	1960 – 1980	191	0,16	0,38	0,11
	1981 – 2005	186	0,14	0,33	0,13
	1960 – 2005	188	0,15	0,40	0,14
Maximal of a high water					
r. Western Dvina – c. Vitebsk	1960 – 1980	1460	0,34	0,69	0,03
	1981 – 2005	1290	0,33	0,60	0,06
	1960 – 2005	1370	0,34	0,67	0,08
r. Neman – c. Grodno	1960 – 1980	772	0,50	1,15	0,05
	1981 – 2005	502	0,39	0,66	0,02
	1960 – 2005	626	0,52	1,56	0,20
Minimal summer-autumnal					
r. Western Dvina – c. Vitebsk	1960 – 1980	45,6	0,31	2,85	-0,08
	1981 – 2005	56,1	0,32	1,17	0,14
	1960 – 2005	51,3	0,33	1,59	0,17
r. Neman – c. Grodno	1960 – 1980	94,7	0,20	0,05	-0,13
	1981 – 2005	90,2	0,19	0,04	0,13
	1960 – 2005	92,3	0,19	0,08	0,02
Minimal winter					
r. Western Dvina – c. Vitebsk	1960 – 1980	45,1	0,38	1,08	-0,06
	1981 – 2005	68,3	0,41	0,55	0,18
	1960 – 2005	57,7	0,45	0,95	0,24
r. Neman – c. Grodno	1960 – 1980	57,1	0,49	1,75	-0,18
	1981 – 2005	71,2	0,29	0,57	-0,47
	1960 – 2005	64,8	0,39	0,94	-0,19

Statistically, authentic distinctions on 5% significance value in run-off of water on r. Western Dvina - Vitebsk are established for all kinds of run-off, and for r. Neman - Grodno only for minimal winter run-off.

4. Conclusions

Thus, principal causes of transformation of a river run-off are global change of climate. Run-off changes have various characters, thus the certain interannual transformation of a water regime of the rivers is observed. The occurring decrease in the maximal run-off of a spring high water is compensated by essential increase in the minimal run-off, both winter, and summer-autumn. That is, global climatic changes have led to interannual change of a run-off while the annual run-off practically has not changed.

A Distributed Automated System of Flood Registration and Prediction

Alexander Volchek [1], Yu. Kuzavko [1], D. Kostiuk [2] and An. Volchek [2]

[1]The Polesie Agrarian Ecological Institute of the National Academy of Sciences of Belarus, Brest, Belarus, kuzavko@newmail.ru

[2]The Brest State Technical University, Brest, Belarus

1. Abstract

Flood protection of territories is important from the point of view of a complex use of environmental resources and is a serious social-economic problem. This problem can be solved only partially, as floods cannot be totally eliminated. One of such solutions presented here, is being developed by the United Information Center (UIC) of flood observation and prediction, which processes data streamed from the distributed network of Autonomous Hydrological Devices (AHD), placed in different points of river basin. The information, based on ultrasound measuring of river flow speed and depth, is primarily processed by AHD and transmitted to UIC, which performs secondary calculations, based on digitized reliefs and bottom-land profiles, derived from statistical data and computer models.

2. Introduction

Protection against flooding is especially applicable for territories, which may become a subject of a catastrophical influence of high waters nowadays. Carrying out anti-flood actions results in a reduction of actual damages caused by flooding, however it demands significant expenses and exploitation charges. As it is impossible to completely exclude flooding, the priority is to adapt economic activities as much as possible to probable extreme conditions and thus minimize the damage. Here, we present the complex of distributed hardware and software appliances, being in state of development for the Muhavets river basin in Belorussian Polesye.

The system is based on the UIC unit, which is aimed for wireless supervision and forecasting of the flooding, and processes data stream from a network of AHDs. AHD is the unit for measuring the speed of a watercourse and its depth. AHDs are available in various points of the river basin. The query of data is transferred from AHDs to UIC by means of a GSM-network. The calculating server, collecting the information coming through a cell communications channel, would count with several days delay the degree of flooding of river basin, on the basis of computer models of water flows and ground waters using digitized 3D-maps of terrain and cut-outs of near-by area. The software is realized with use of self-teaching algorithms and long-period data of hydrological measurements. This prediction would be maximal close to the real situation and will show the time and place of flooding, thus making it possible to carry out timely anti-flooding measures. The results of prediction calculations are mapped to a wide sized display to be operatively used.

Main planned results of developing the United Information Center of flood prediction are the following:

1. Creation of a database of pre-history of floods, and modelling of flooding of nearby territories on the basis statistical data, measurements and 3D-map of the river basin;
2. Software for modelling the flooding of near-shore territory on the basis of the digitized 3D-map of the river basin, and optimization of the mathematical prediction models.
3. Laboratory and nature testing of the water filling prediction system is currently oriented on the area of the Muhavets river of the Belorussian Polesye, but can be obviously tuned to any other territory.

The easily expandable and configurable computer network with necessary equipment would make possible a prediction of floods in arbitrary river basins with maximum reliability, with support of a proper database. Let us note that the proposed devices are applicable for any water conductors, but the system turns to be more effective, supported by proper digitized 3D-map of the terrain and available flood statistics into the UIC.

3. Autonomous hydrological device

The first problem is the development of the effective AHD, placed in concrete points of the river to measure current speed and water depth by means of a wireless interface transmitted to the UIC. The second problem is gathering and using the information in UIC. After examining possible ways of wireless network technologies, the infrastructure of the GSM network was chosen, due to its already deployed infrastructure and good coverage of requested territories and relatively small power consumption of transmitters. Measurement and transmission of data can be activated on a scheduled basis by stand alone commands from UIC. Time between measurement queries is supposed to be in limits of 12 - 0.5 hours, and transmission duration will not exceed several seconds, thus saving battery energy *(Volchek et al. 2002).*

Let us look in more detail on the AHD structure. AHD includes two parts: a measuring unit, placed underwater on the river bottom and connected with transmitting unit. The last one is placed on the river bank in a vandal-proof box hanging high and including a microcontroller, GSM modem, LI-ION battery and photoelectric cell for its recharging *(Volchek et al. 2006).*

Water speed is measured by two ultrasonic piezoceramical transducers (UPT). To achieve the maximal sensitivity, their arrangement line is 45° with the current direction, and no more than 15 cm apart (see Fig. 1).

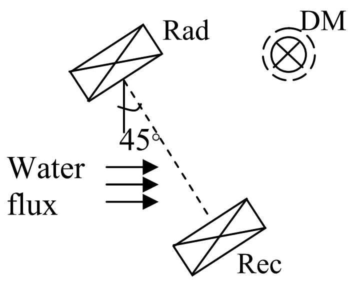


Figure 1. Acoustic channels of AHD: Rad and Rec for measure of speed of flow, DM for measure of depth of the river

The speed of water flow is calculated from the Doppler shift of frequency of the accepted signal concerning the frequency of the radiated signal. As known from the information theory, frequency phase measurements are the

most exact (Novitskiy 1968). As the Doppler instrument registers the average speed of a stream between source (Rad) and receiver (Rec) with the assumption of preservation of its constancy, the distance between them gets out small.
The AHD System contains also the measuring instrument of depth (DM) representing UPT, being simultaneously as Rad perpendicular to surfaces of water and a bottom the narrow-directed acoustic pulses, and Rec. Water depth is defined by the time delay between the radiated signal and the reflected one from the bottom of a reservoir. Thus, the frequency phase method of measurements is realized as in a Doppler measuring instrument. The basic errors in depth measuring arise owing to non-mirror reflections of the ultrasonic signal from sand-slime bottom, wave fluctuations of the surface of the reservoir, reflections from fish and amphibians occasionally crossing an acoustic beam. Their elimination is achieved by multiple measurements, not the account obviously false, introduction of the appropriate values of amendments.

4. United Information Center

The developed UIC is a complex modern system with input from a GSM modem. The information is displayed as digitized relief maps of a three-dimensional model of the inspected area (Fig. 2a), to represent the current flooding situation (*Volchek et al. 2006*).

a)

b)

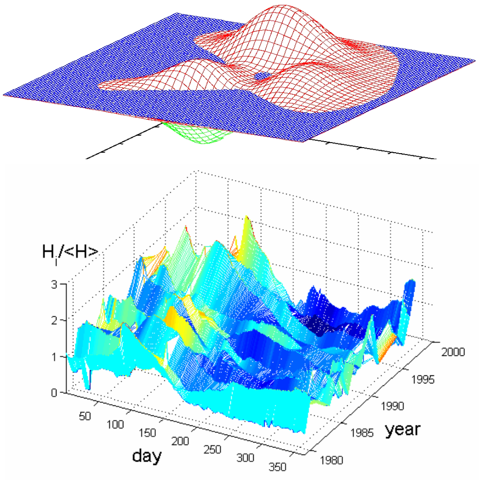


Figure 2. Three-dimensional representation of flooding: a - flooded terrain fragment modeled on the basis of real-time measured data; b – spatial representation of flood statistics in (water level; day; year) coordinates

For now, applied prediction methods include the calculation of water movement between AHDs and statistics-based flood prediction.
In the first method, an adaptive model is used to make near-by prediction of water level dynamics on the concrete observation post on the basis of a real-time date of AHDs, placed upper on the river current. The computer model is based on a query of delay elements, through which water level changes are propagated from one AHD to another in discrete time moments. The amount of delay elements is changed on the basis of a difference between the propagated value and the one measured by the AHD at the end of a query. The quantity of adaptation corrections may be also a subject of measured water speed.
The second method is based upon multi-year statistical data and performs more long-term prediction. It uses a sliding window method. A given frame of current data is compared one from previous years, and a year with minimal mean error is chosen for a prognosis. While the mean error is calculated, a window slide is performed in given bounds to reach more close coincidence. Real data from past years can be used, as is shown on Fig. 3, as well as their mathematical approximation.
The forecast may be further improved using more advanced mathematical models of water movement for observed territories.

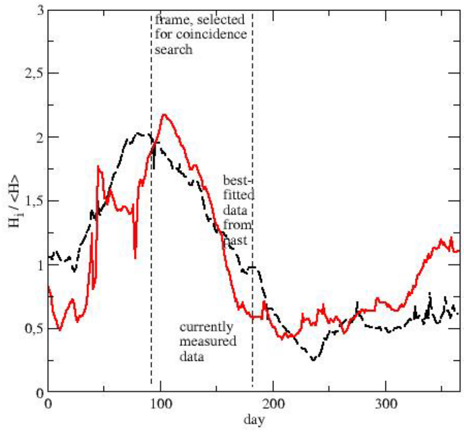


Figure 3. A statistical forecast

5. Conclusion

The network of autonomous observation posts for flooding supervision and forecasting is a substantial part of engineering actions for protection against flooding and flood protection improvement.
It is known that for ecological forecasts, in particular meteorological, the computer systems specially focused on such purposes are rather expensive and have enormous memory and speed. Despite that, a computer network with increased memory and required periphery will allow to solve the problem of maximum authentic forecasting of flooding, proceeding from the measured database, on two - three days forward. The given system with insignificant operating time is suitable to use in any water areas.

References

Novitskiy P.V. The basis of information theory of measuring devices, L.: Energiya, 248 p., 1968

Volchek A.A., Kostjuk D.A., Kuzavko Y.A. The remote radio-electronic measuring methods and appliances of flood wave registration and computer prediction, Proceedings of the 11th international Symposium on Acoustic Remote Sensing and Associated Techniques of the Atmosphere and Oceans. Rome, 2002

Volchek A.A., Kostiuk D.A., Kuzavko Yu. Informational and technological appliances for floods supervision and prediction [in Russian], 7th International congress of "Water: ecology and technology" AQUATEC-2006. Moscow, pp. 362-363, 2006

Volchek A.A., Kuzavko Yu.A., Kostiuk D.A., Volchek An.A., Mathematical modeling and forecasting of a river flow [in Russian], The remote probing of a natural environment: proc. of III th International scientific practical conference. Minsk, pp. 95-98, 2006

The Dynamics and Protection of the Sea Coasts and Dunes in Lithuania as a Result of Extreme Climate Events (according to ASTRA Project Activities)

Regina Morkunaite[1], Arunas Bukantis[2], Gintas Zilinaskas[1]

[1]Quarternary Research Department, Institute of Geology and Geography, Vilnius, Lithuania
[2]Vilnius University, Department of Hydrology and Climatology, Vilnius, Lithuania

There is an international consensus about the human influence on global conditions; the majority of scenarios is anticipating a general trend towards global warming and associated impacts. In the INTERREG III B Programme ASTRA, climate change impacts have been investigated, taking into account the average life span of infrastructure and economic activities. Storm surges, winter storms and sea level rise have to be taken into account in coastal construction activities and infrastructure development. In this project, the dialogue with stakeholders and public participation play an important role in defining adaptation strategies to climate change.

The Institute of Geology and Geography has carried out investigations on the effects of the hurricanes “Anatoli” (1999), and Ervin (2005). In an attempt to ensure a sustainable development of the coastal zone and to solve successfully the problems of coastal degradation, the programme “Management of the Lithuanian coast of the Baltic Sea” has been worked out under the guidance of the Ministry of the Environment of the Republic of Lithuania. The programme contains recommendations for stabilization measures for coastal sectors, taking into consideration their actual state (eroded, stable, accumulated), their character of coastal use (preserved territories, recreational or technogenic zones), and predicted development trends. Data on erosion and accumulation processes in dunes, on the influence of tourism, and on the wind regime and the related impact on eolian sand transformations in the Curonian Spit are used in the ASTRA project. The ASTRA project has provided some practical discussion inputs for stakeholder workshops.

Results obtained for 1999-2005 revealed the dynamics of deflation basins in Curonian Spit eolian segments, which depend on a few factors. Today, strong recurring winds of the same direction are the main driving force for the deflation processes. Deflation and accumulation processes are responsible for a steady alternation between the positive and negative forms of the relief. It can be shown that a slow migration of the upper edge of the slope eastwards (0.4-1.0 m/y) is the main trend of the western slope dynamics. In this case the aspects of climate change are important for the movement of sensitive eolian sands.

It appears obvious that the protection of dunes from degradation in the Curonian Spit National Park is important because the dune ecosystems are very attractive but changing at the same time.

The improved tools used for coastal and dune management, with the emphasis on extreme events and long-term changes including assessments of process dynamics, are very important to adjust to today´s and future climate.

Education in Sustainable Conflict Resolution - Experiences and Objectives of the Coastal Zone Management Project

Nils Brandt, Jan Fidler* and Åsa Larsson

Industrial Ecology, Royal Institute of Technology, Teknikringen 34, 114 28 Stockholm, Sweden
e-mail: fidler@kth.se, http://www.ima.kth.se, * corresponding author

1. Abstract

This paper describes a course in sustainable conflict resolution developed within the European Interreg III B BSR project "Coastman".

2. Introduction

The Coastman project (Costal Zone Management in the Baltic Sea region) studies real and/or possible conflicts in several harbour areas of the Baltic Sea, aiming to gather knowledge and develop methods and solutions for conflict mitigation and for sustainable planning processes in coastal areas.

3. Background

As a part of the Coastman project a course on "Conflict Resolutions" was developed and launched during the autumn 2006. The aim of the course was to share knowledge regarding sustainable development (SD) and experiences from planning processes and stakeholder analyses. The course participants came from countries participating in the Coastman project and consisted of people with different background; scientist, politicians and officials. They were trained to improve practical skills in and understanding of methods for conflict resolutions.

Due to international character of the course a webpage was develop serving as an information and communication platform – providing study materials, links and a discussion forum.

4. Course structure

The course included lectures, two seminars and individual assessment. During the first seminar participants were divided into smaller groups discussing what SD means in general and which criteria may be used to evaluate SD in a harbour planning processes. The working groups used a virtual case study to analyse possible conflicts, which may erase when locating a future harbour in a virtual coastal area. The task was to suggest how decision making process should be carried out and what kind of methods could be used.

The second seminar was centred on a role play. The role play was aimed to simulate a decision making process, and the course participants played the roles of different stakeholders practicing negotiation and workshop techniques. Two bigger groups played the same play, discussing several topics and trying to reach agreement about each of them. In the end of the seminar both groups gather together and presented their results.

5. Conclusions

The course is now under evaluation with intention to start it as an ordinary course. Participants were asked to rank different indicators for SD before and after the course in order to measure the course's educative performance. There were also a questionnaire delivered between participants to gather information about the role play and the course as hole.

References

Webpage: The course in Conflict Resolution. http://www.webforum.com/pilotcourse

The Swedish Case Study Loudden - A Controversial Harbour for Oil Products in Stockholm (COASTMAN)

Jan Fidler, Nils Brandt, Ronald Wennersten* and Åsa Larsson

Industrial Ecology, KTH , Teknikringen 34, 114 28 Stockholm,
* Corresponding author rw@kth.se

1. Background of the problem

Stockholm has for long time been an important city for trade in northern Europe and the Baltic Sea Region (BSR). The scenario for the future is that this role will not be less important but the prediction is rather that the harbours in Stockholm will play an even more important role in the future.

Loudden is one of several harbours in Stockholm County and the biggest oil terminal of the region. It is situated in the eastern centre of Stockholm. After several years of infected debates between several stakeholders as politicians, oil companies, municipalities and NGOs, the city of Stockholm finally took a decision in 1999 not to prolong the contracts with the oil companies after 2011.

Important motives for the decision to close Loudden were to get rid of the transportation of petroleum products by trucks travelling through the city and the transportation of petroleum products in the archipelago. Another important motive is also the city's strategy to build and expand the city inwards, which means to use as much of existing land as possible and in the same time use existing infrastructure for building residential areas and offices.

In this case study we will discuss Loudden problem from some important perspective:

2. Relevant stakeholders

There are several stakeholders involved in this case. For example harbour company own by the city, oil companies renting the oil harbour from the city, neighbours to the industrial area, planners at city planning office, tourists, NGO:s , political parties, etc. How do these stakeholders interact and what are the consequences of the decision for these stakeholders.

The stakeholders wants to replace Loudden with several harbours located south and north of Stockholm to avoid long oil deliveries by trucks through the city. In the planning process of the new harbour structure the most important factors to consider are the transport possibilities by sea, road and railway, environmental impacts, risks and the regional development.

3. Description of the conflict

Many stakeholders are affected by the decision. The decision was based on political consensus but still no alternative place for the harbour has been pointed out. One of the problem is that a solution for the region will effect not only the city of Stockholm, but also several other municipalities in the region. Today there is no regional political organ that works together for finding a new harbour solution. This means that this is a multiregional conflict, with very unclear decision situation. Who owns the decision and the consequences?

Several stakeholders have under the process produced and delivered different form of reports and scenarios, reflecting different stakeholders' opinion about the alternative in the future.

4. Relevant conflict resolution methods

Main problem with this kind of decision is that it tends to create intractable downstream conflicts. For this reason we have tried to look and test conflict resolution methods which can be used to reveal information and values among the stakeholders as early as possible in planning process, e.g. Logical Framework Analysis, hearings and seminars, enquiries and interviews, risk assessment and indicators for sustainable development.

The Logical Framework approach has been presented in this case study as one thinkable analysis tool for conflict resolution. This approach gives the possibility to structure the project planning, after the decision about the result of the conflict (Loudden yes/no) has been made.

An enquiry was used to investigate the stakeholders' opinions about the harbour planning process for oil import in Stockholm region. One result showed that mainly stakeholders from Stockholm are taking part in the harbour planning process and the stakeholders think that the harbour planning process affects a bigger region and more stakeholders outside Stockholm should be active in the process.

One of the main issues in our case has been the possibilities for large accidents e.g. oil spills or explosions. For many of the activities there are existing risk assessments developed by the companies, but the general experience is that the results are difficult to communicate and that other stakeholders are very suspicious that results are manipulated in order to favour the planned activities. In the case we have developed more robust methods for estimating risks and studied worst case scenario as a method.

5. Lessons to learn

Of course it is hard to find alternatives for such a grown structure as Loudden. By using conflict resolution methods as mentioned in the paper it's possible to reveal information and values among the stakeholders. The outcome of the conflict is highly dependent on the willingness and commitment of the stakeholders to find a reasonable and practical solution. This will be discussed as lessons to learn in the final part of our presentation.

Participation of Ventspils City Council in the Project „Coastal Zone Management in the Baltic Sea Region / COASTMAN"

Ilga Zīlniece, Tatjana Valdmane and Ineta Kraule

Ventspils City Council, Juras street 36, Ventspils, Latvia, LV 3601, ilga.zilniece@ventspils.gov.lv

1. Abstract

The uniqueness of the Baltic Sea coast in Latvia and surroundings of Ventspils is determined by its nature values. The length of the Baltic Sea coast in the administrative territory of Ventspils is around 12 km. Nearly fourth of the city administrative territory is occupied by Ventspils Free Port. When planning city development, interests of population and entrepreneurs should be taken into account, at the same time ensuring preservation of nature values and preventing and decreasing environmental pollution. Development of economic activities in Free Port territory together with preserving nature values is possible only following the principles of sustainable development – ensuring satisfaction of the current needs and not putting under threat satisfaction of needs of the further generations. It is the only way to successfully plan the development of the Baltic Sea coast and preserve nature values therein – particularly coastal dune area. Ventspils City Council as a partner of the COASTMAN project is going to share best practice experience for coastal management, as well as in development planning for Baltic Sea coast towns.

2. Background of the problem

Ventspils historically is located on the coast of the Baltic Sea and on both banks of the River Venta. This case study developed within the scope of the Coastman project relates not only to the narrow part of the seashore referred to in the legislation of Latvia as the Baltic Sea protective belt, but assuming that the term "coast" here refers to the river shores as well, it takes into account the city as a whole. The case study describes methods and planning instruments to be used on the municipal level to fully prevent conflicts and to solve any potential problems before a conflict can arise. Therefore, the essence of the Ventspils case study comprises how to develop a town preserving valuable natural resources while at maximum level satisfying interests of all parties involved (different groups of population and institutions, including developers and environmentalists), as well as ensuring economic growth and meeting of social needs. The methods of conflict resolution were chosen with the aim to encourage elaboration of the integrated strategy for the coastal area in its narrower sense and the sustainable development of the whole town, thereby facilitating the best possible decision making for coastal area management.

3. Approaches used

The main legislative acts setting requirements for the Baltic Sea coastal area management are laws „On Environmental Protection", "On environmental Impact Assessment", "On Protective Belts", Construction law and related Regulations of the Cabinet of Ministers, as well as legislative acts that set the requirements for territory planning. Essential are legislative requirements for the Baltic Sea coast protective belt management and environmental impact assessment for planned activities, including strategic environmental impact assessment for territory planning that is landmark approach to solving environmental issues.

On the level of local legislation relevant are municipal binding regulations. In case of Ventspils Environment Protection Licensing Regulations, Seashore Management Regulations and Building Regulations that are currently under development should be mentioned. Coastal management is promoted by various voluntary movements as well. Ventspils City local government already in 1997 took a decision on involving in the Blue Flag movement, and starting with 1999 every year the Blue Flag of the Global Environment Education Fund waves on the Ventspils beach, showing not only development of bathing places and cleanliness of bathing waters, but also systematic and purposeful approach to solving environmental issues in the local government.

4. Conslusions

Coastal zone management must be organised by implementing a large number of tools and methods on a national and local level, especially spatial planning, as well as by involving all interest groups- municipal and local institutions, developers, enterprises, NGOs, independent consulting companies and scientists.

The most useful instrument for planning this city located on the coast of the Baltic Sea is integrated strategy for the coastal area in its strategic environmental assessment, which is carried out during the preparation of the planning document, before this document is being submitted for approval. The strategic impact assessment is to be carried out regarding the planned development, implementation of which can substantially influence the health of the population and/or the environment, including developments in the areas of agriculture, forestry, fishery, energy, industry, transport, waste management, water resource management, telecommunication, tourism, mining, as well as plans related to regional development, land lease, spatial planning and the European Union funds.

Due to the fact that the port plays a dominant role in the development of Ventspils, efforts by environmentalists and planners are devoted to the following aim: the development of economic activities in a free port area while at the same time preserving valuable natural resources is possible only by following the principles of sustainable development – development that meets the needs of the present generation without compromising the needs of the future (Brundlandt report).

References

CCB report "Checking coastal conservation. International requirements to safeguard nature on the Baltic sea coast", Uppsala, Sweden, 2004.

Gronholm B., Joas M., Nordstrom M. Success Factors for Local Agenda 21 in the Baltic Sea Region, Abo Akademi University, 2001.

Strategy for Sustainable Development of Latvia approved by the Cabinet of Ministers of the Republic of Latvia 13.09.2002.

Ventspils Environmental Policy Plan. Popular version, Ventspils, 2005.

Long-Term Trends in the Seas Surrounding Sweden. Part One - Nutrients

Pia M. Andersson and Lars S. Andersson

Swedish Meteorological and Hydrological Institute, Oceanographic department, Nya Varvet 31, S - 426 71, Gothenburg, Sweden, Pia.Andersson@smhi.se

Abstract

The main aim of this work is to present data as typical concentration values for different nutrients in the various sea areas surrounding Sweden, and how these have varied over time. Long term trends and estimates of typical concentrations before the onset of eutrophication are of great importance hence a 30 year trend has been calculated for various nutrient parameters.

SMHI is the Swedish National Oceanographic Data Centre (NODC) to where several countries have supplied hydrographical data originating from various platforms (vessels, buoys etc.). Stations that have been in regular use for most parts of the last 30 years are included in the analysis.

Due to differentiating water characteristics, 14 sea areas are selected to represent the waters surrounding Sweden.

In this report all available data from 1976 up till 2005 is used and presented in diagrams and tables. The figures of the parameters are presented as time series. Each parameter is divided into winter, summer, surface and bottom values. In the tables, in formation on a yearly basis is given to indicate changes that vary over time.

Both a classical linear regression method and a non-parametric method (the Mann-Kendall) are used in the trend analysis to account for normal and non-normal distribution of the data. The trend magnitude and significance are also calculated. An overview of the results of significant trends of all the areas in the surface and the bottom for the winter and the summer are presented as arrows in a summary figure. There are no discussions of what have caused the trends or possible effects that may come from the continuation of the trends.

Simulations of the Particulate Organic Carbon in the Southern Baltic Sea

Lidia Dzierzbicka-Głowacka, Karol Kuliński and Janusz Pempkowiak

Institute of Oceanology, Polish Academy of Sciences, Powstanców Warszawy 55, 81-712 Sopot, Poland
dzierzb@iopan.gda.pl

1. Abstract

A POC model was coupled with a one-dimensional physical and biological upper layer model to simulate the particulate organic carbon fluxes in the southern Baltic Sea. The calculations were done for one year (1999) for a station in the Gdańsk Deep (southern Baltic Sea).

2. 1D-CEM

A one-dimensional Coupled Ecosystem Model (1D-CEM) consists of three submodels: a meteorological submodel for the physics of the upper layer and a biological submodel which is also driven by output from the physical submodel (*Dzierzbicka-Głowacka* 2005, 2006). The biological submodel with a copepod model and a simple prey-predator module consists of seven mass conservation equations. There are six equations of the diffusion type for phytoplankton, microzooplankton, mesozooplankton, fish, two nutrient components (total inorganic nitrogen and phosphate) and benthic detritus. In this model the mesozooplankton (herbivorous copepods) is represented by two species – *Pseudocalanus minutus elongatus* and *Acartia* spp., which are represented by 6 cohorts in different development stages. The fish - predator is represented by 3 cohorts of early juvenile herring *Clupea harengus*.

3. POC model

The seasonal dynamics of particulate organic carbon was obtained using the 1D-CEM with an equation for pelagic detritus. The temporal changes in the pelagic detritus concentration are affected by dead phytoplankton and zooplankton, fecal pellets, sedimentation, grazing by zooplankton and pelagic regeneration. The particulate organic carbon concentration is determined as the sum of phytoplankton and pelagic detritus concentrations.

4. Results

The development of particulate organic carbon POC was exactly correlated with the development of phytoplankton and pelagic detritus. Generally, the greatest amounts of POC occurred in the upper 30 m layer, in the periods of large biomass of algae. Concentration of POC was characterized by the occurrence of two peaks in a year; at the turn of April and May and October.

5. Model validation

Currently the described model is under validation. To this end systematic measurements of POC concentrations in vertical profiles at stations situated at the Gdańsk Deep, and sporadic measurements at the Gotland Deep have been carried out. Measured and predicted concentrations agree reasonably well in the surface (0-30 m) layer, while the agreement in the subsurface water layer is worse.

References

Dzierzbicka-Głowacka Lidia., Modelling the seasonal dynamics of marine plankton in southern Baltic Sea. Part 1. A Coupled Ecosystem Model, *Oceanologia*, 47(4), 591-619, 2005

Dzierzbicka-Głowacka Lidia., Modelling the seasonal dynamics of marine plankton in southern Baltic Sea. Part 2. Numerical simulations, *Oceanologia*, 48(1), 41-71, 2006

Transformation of the Surface Water Quality in the Baltic Sea Rivers on Belarus Territory

Mikhail Kalinin and Alexander Volchak

1 / 2 Slavinskogo Str., Minsk, 220086 Belarus, cricuwr@infonet.by ,kamu@tut.by
204 Moskovskaya Str., Brest, 224017 Belarus

1. Introduction

Under the influence of the natural and anthropogenic impacts the hydro chemical regime of the Belarus rivers was greatly changed – and in many cases it had negative effect. This process will increase due to the development of the industries, cities and agriculture. Most of the Belarus rivers are transboundary and deterioration of the surface water quality may produce a negative impact not only to the environment but to the biodiversity conservation and may cause problems to the relations of the states located in the same river basin.

In the current paper the case of assessment of the transformation of the surface water quality in the main parameters is considered.

2. Original data and research methods

In the researches the data of the State Water Cadastre of the Republic of Belarus was used for the 1994-2005 period. The changes in the water quality were studies on the following parameters: the content in the water of the dissolved oxygen, nickel, mineral oil, iron, cuprum, zinc, phosphate, nitrite nitrogen, ammonia nitrogen, compositive surfactant materials, impurity index, biochemical oxygen demand (BOD_5).

The maximum permissible concentration of the chemical mattes (MPCCM) is considered as the main standard for the river water quality, which is set up for the for the water objects of various function. The water assessment is done with the help of integral index – index of water pollution which has 7 levels of surface water pollution.

For the assessment of the transformation of the hydro chemical regime of the rivers the linear trend mainly was applied, where the meaning was determined by the trend index correlation. The assessment of changes of the time series was determined by the gradient of changes (α) that is the quantity which is equal to the regression coefficients (a) multiplied by 10 years (α =a · 10 years). The significance of the correlation coefficient is set up on 5-% level ($r_{кр}$=0,58).

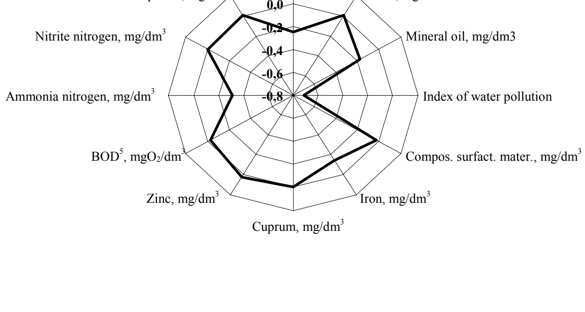
3. Result discussion

At present the water in the most of the rivers in the country is ranked to the category as relatively clean or reasonably polluted. The surface water of the rivers of the Baltic Sea watersheds is polluted mainly with oxidized organic matters, nitrogen matters, phosphate matters, heavy metals and mineral oil, which appears as a rule in excess raises the maximum permissible concentration of the chemical mattes (MPCCM). The pollutants come into the water objects with industrial and municipal sewage discharges, from the storm sewers, parking places, roads and high ways, waste disposals, live stock-raising waste water discharge. The irrigation work being done without environmental analysis in combination with climate warming has lead to the change in the direction of the biochemical processes which took place before when the marches were formed. In well aerated upper layer of the drained peatbog the process of the demolition of the organic complex starts and the peat becomes mineralized. As a result, water which runs off the irrigated marches, has a slightly mineralized character. The river water is filled with ions of iron, manganese, which were stored in the peat due to the age-old processes in march formation. The entry of the nitrogen to the surface water is connected with the mineralization process of the organic matters due to which the ammoniacal, nitrate and nitrite matters are formed which are not stored in the river water due to its high migration ability in natural conditions. The violation of the natural biochemical cycle in nitrogen is indicated in particular in the increase in the water the contents of ammonia nitrogen and nitrite nitrogen. The increase in the concentrations of these components create the conditions which lead to the eutrophication of the watercourses.

The transformation of the hydrodynamic condition has lead to the modification in the hydro chemical processes (the gas composition of the water has been changed, migration of the chemical elements). The irrigation process is accompanied by the growth in mineralization level (SO^{2-}_4, Ca^{2+}, Mg^{2+}, occasionally HCO^3). Sulphates are characteristic components of the ground water of the irrigated lands. The accumulation in the water of Ca^{2+}, Mg^{2+} ions is determined by the processes of drained peat destruction. When the marches are irrigated, the high decrease in the ground water levels leads to the substantial growth in iron concentrations.

Frequently acting source of water pollution with biogenous matter is atmospheric precipitation, which are highly polluted. Transport, energy objects and industries as well as transboundary pollution are the main sources of the atmospheric emissions. The peculiarities of the geographic situation of Belarus as well as the dominance of western winds determine the transboundary pollution to be the main source of surface water pollution.

Under the anthropogenic impact non-biological and biotic components of the water system were substantially transformed. The first significant transformations in hydrological and hydro chemical regimes of the aquatic ecosystems were dated at the end of the 1960 and beginning of 1970. In the water of rivers and lakes practically everywhere was indicated the growth of concentrations in the number of components, authentically excessing the background (natural) concentration in chlorides by 2-9 times, sulphates – 1.5-2 times, alcali metals – 1.3-3.



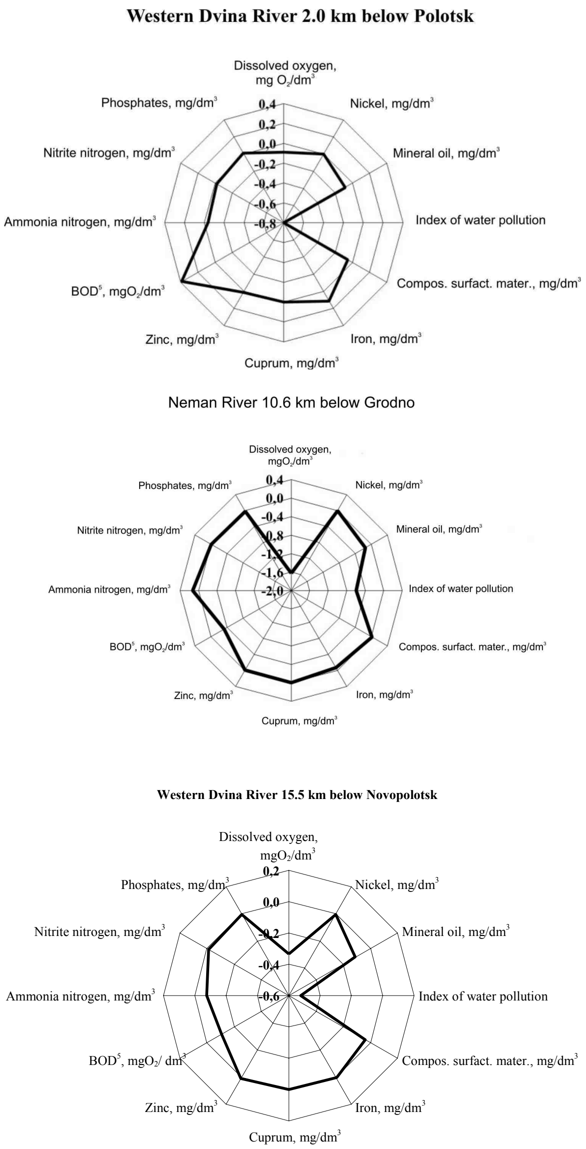


Figure 1. Transformation gradient in the annual concentrations of the priority matters in the water of Belarus rivers.

The transformation gradient in the annual concentrations of the priority matters in the water of several rivers of the Belarus Baltic Sea territory is shown in Fig. 1 and Table 1. The transformation in the annual concentrations of the ammonia nitrogen has equidirectional character, but it has a tendency to the contamination degression in the northern part of Belarus, and in the west – the tendency is of an increase character. Contamination of the rivers by the nitrite nitrogen has s tendency to degression. The same picture is retraced with mineral oil and degression of this index is obvious in nearly all Belarus rivers. Practically in all river observation stations the contamination index is decreasing. There is a small increase in such matters as phenols, zinc, nickel, cuprum. In most water objects there is a degression in the content of the dissolved oxygen, but the most speedy process can be seen in Niemen River near Grodno. It is indicated that the biochemical oxygen demand is decreasing as well as compositive surfactant materials.

Parameter	River – River Station					
	Western Dvina River, 2.0 km below Vitebsk	Western Dvina River 1.5 km below Polotsk	Western Dvina River, 5.5 km below Novopolots	Western Dvina River .5 km below Vercknedvins	Niemen River 10.6 km below Grodno	Muckavets inside Brest
Dissolved oxygen, mgO_2/dm^3	-0,25 / -0,30	-0,09 / -0,06	-0,34 / -0,29	0,49 / 0,29	-1,63 / -0,68	0,79 / 0,41
Nickel, mg/dm^3	-0,002 / -0,19	0,004 / 0,71	0,002 / 0,44	0,004 / 0,55	0,000 / 0,03	-0,001 / -0,36
Mineral oil, mg/dm^3	-0,18 / -0,79	-0,09 / -0,54	-0,11 / -0,64	-0,06 / -0,60	-0,16 / -0,78	-0,17 / -0,66
Index of pollution of water	-0,717 / -0,72	-0,797 / -0,64	-0,524 / -0,63	-0,983 / -0,76	-0,598 / -0,77	-0,493 / -0,59
Compositive surfactant materials, mg/dm3	-0,029 / -0,69	-0,050 / -0,71	-0,038 / -0,71	-0,044 / -0,76	0,015 / 0,28	0,040 / 0,71
Iron, mg/dm3	-0,152 / -0,41	0,113 / 0,36	0,005 / 0,02	-0,057 / -0,14	-0,068 / -0,22	0,312 / 0,46
Cuprum, mg/dm3	-0,005 / -0,71	-0,001 / -0,30	-0,002 / -0,47	-0,001 / -0,21	-0,003 / -0,43	-0,002 / -0,39
Zinc, mg/dm3	0,014 / 0,53	0,007 / 0,71	0,009 / 0,81	-0,003 / -0,10	-0,007 / -0,46	-0,006 / -0,37
BOD_5, mgO2/dm3	-0,03 / -0,03	0,38 / 0,38	-0,10 / -0,14	-1,33 / -0,77	-0,33 / -0,31	-0,48 / -0,45
Ammonia nitrogen, mg/dm3	-0,314 / -0,45	-0,039 / -0,07	-0,075 / -0,11	-0,130 / -0,17	0,124 / 0,22	0,385 / 0,55
Nitrite nitrogen, mg/dm3	-0,007 / -0,27	-0,023 / -0,40	-0,011 / -0,40	-0,038 / -0,58	-0,007 / -0,27	-0,041 / -0,24
Phosphates, mg/dm3	-0,002 / -0,04	0,006 / 0,18	0,002 / 0,06	0,003 / 0,12	-0,020 / -0,03	0,049 / 0,74

Table 1. Transformation gradient of the annual concentrations of the priority matters in the Belarus rivers.

Note. In the numerator the gradients are indicated as α mg/dm³/10 years/, in the denominator – correlation coefficients. In dark colour the statically important parameters are marked.
In general the decreasing tendency in the contamination of the Belarus rivers is indicated nevertheless the surface water quality is still a subject to improvement in some of the cases.

4. Conclusions

Contamination process of the water objects is suspended and there are positive tendencies to improve the environmental state of some of the river basins. Nevertheless the decline in sewage discharge there is no essential improvement in the surface water quality. The main direction of the improvement still is the lowering of the anthropogenic impact and restoration of the environmental well-being of the water objects, namely improvement of the functioning of the water treatment facilities, construction of the local treatment plans in agriculture and other measures.

Changes of Flows of Major Dissolved Substances from Territory of Latvia

Ilga Kokorite, Maris Klavins and Valery Rodinov

University of Latvia, Department of Environmental Sciences, Raiņa bulv. 19, LV 1586, Rīga, Latvia, e-mail: ilga.kokorite@lu.lv

1. Introduction

Analysis of long-term changes of aquatic chemistry and river discharge is of importance to study processes in surface waters. Trend analysis of aquatic chemistry is yet more important as far as decision-making process in area of environmental protection often is aimed at reduction of loading, at first of persistent pollutants and nutrients to waters, and so trend analysis can help to evaluate efficiency of monitoring systems and to support necessary management activities.

The aquatic chemistry of surface waters of Latvia has been included into net of monitoring programs since 1947, but extensive studies have been done since 1972 and so substantial amount of information has been accumulated. In the case of Latvia, it can be possible to link three variables: a)changes of river discharge (dominantly natural process), b)changes of human loading (direct human impact); c)the reaction of water composition (response factor) to identify environmental consequences of these much differing impacts.

The objective of the present study is to study long-term changes of aquatic chemistry in surface waters of Latvia in relation to natural fluctuation (changes of river discharge) and recent dramatic reduction of industrial and agricultural production.

2. Methods

Data used in the study were obtained from the Latvian Hydrometeorological Agency, Latvian Environmental Agency and Department of Environmental Sciences of the University of Latvia.

The multivariate Mann-Kendall (*Libiseller and Grimvall, 2002*) test for monotone trends in time series of data grouped by sites, plots and seasons was chosen for determination of trends, as it is a relatively robust method concerning missing data and it lacks strict requirements regarding data heteroscedasticity. This test can be applied for data sets that have non-normal distribution, missing values or "outliers", serial character (e.g., seasonal changes). Partial Mann-Kendall test was used to detect trends of water quality parameters as it allows including covariates representing natural fluctuations (e.g., water discharge, precipitation) that may affect the studied response variable. The conditional Mann-Kendall test (program MULTIMK/CONDMK) was applied separately to each variable at each site, at a significance level of $p<0.5$. The trend was considered as statistically significant at the 5 % level, if the test statistic was greater than 1.65 or less than –1.65.

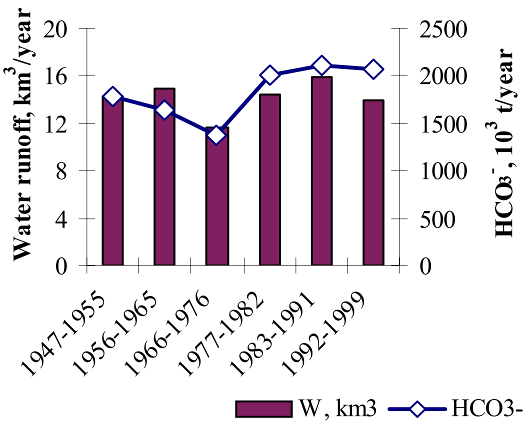
3. Results and Discussion

Surface waters of Latvia are comparatively hard, rich in organic matter, but elevated nutrient concentrations can be observed in the waters of rivers in the River Lielupe basin, due to intensive agricultural production. The intensive agricultural land-use there also leads to increased soil erosion, which in turn affects water chemistry considering the geochemical composition of soils.

Long-term changes of surface water quality in Latvia have been analysed in several studies, but different groups of substances as well as different time periods have been analysed (*Tsirkunov et al., 1992; Stålnacke et al., 2003*).

The present water flow regime may be regarded as comparatively increased if compared with centennial mean values for rivers of Latvia. Evidently, the water flow pattern is among the most important factors influencing aquatic chemistry and recent increase of river discharge determines increase of runoff of dissolved substances.

For most of the studied substances, trend analysis indicated a monotonous increase or decrease of their concentrations, and their changes may be correctly described as linear trends. Trend analysis of water quality parameters identified increasing trends for magnesium (Table 1), hydrogencarbonate, sulphate and calcium concentrations in most of the rivers, indicating a more active role of carbonate mineral weathering processes. However, it is difficult to relate these weathering trends to human activities.



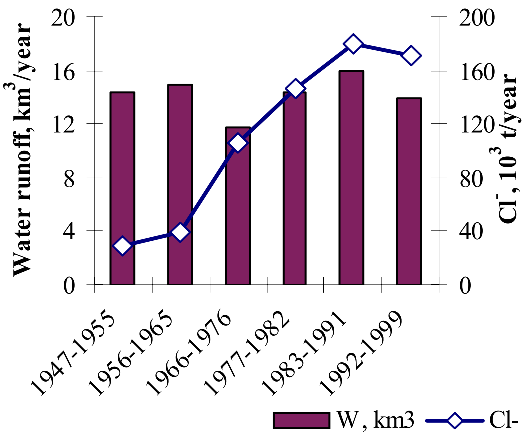


Figure 1. Long-term changes of river discharge and hydrogencarbonate and chloride ion loading in the River Daugava.

Table 1. Long-term trend (1977-2001) of water quality changes for rivers of Latvia after Mann-Kendall test criteria.

River	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+
Daugava	1,897	**2,883**	0,016	1,848	**3,555**	-1,821
Aiviekste	**2,324**	-0,452	**-2,172**	0,491	**2,341**	**-3,000**
Gauja	**2,256**	**-2,151**	**-4,168**	0,143	1,566	**-3,571**
Lielupe	**2,657**	0,163	**-2,254**	0,409	1,662	**-2,297**
Venta	**2,527**	-1,672	-1,878	-0,091	**3,211**	**-2,440**
Salaca	1,189	**2,135**	**-2,072**	1,323	**2,485**	**-2,400**

Declining trends of ammonia ion concentrations are characteristic for the whole period of observations and thus cannot be associated with recent reductions of anthropogenic impacts. The above indicates that basic water chemical composition and its long-term changes largely reflect the intensity of natural processes, such as weathering of soils and minerals, and exchange with mineralized subsurficial waters. At the same time trend analysis for changes of nutrient concentrations indicate that the changes in human loading influence the actual concentrations of dissolved substances in waters (Fig.2). Unless there are differences between results obtained using regular and the so, called conditional Mann – Kendall test (trend values are normalized in respect to changes of river discharge) still they are minimal, but the reduction of nutrient concentrations after reduction of their loading is evident (Fig.2).

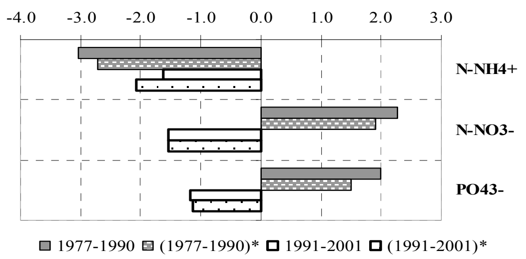


Figure 2. Mann – Kendall test results (normal; conditional test marked *) for changes of nitrate ion nitrogen and phosphate concentrations in the River Daugava.

Indicative in this respect can be analysis of long-term changes of dissolved substances and their loading. As far as in Latvia the surface water monitoring system started regular observations in 1947 and analysis of chloride and hydrogencarbonate ions has been made using comparable methods with contemporary used, changes of their loading can be applied to compare changes of predominantly naturally originating substances and substances significantly affected by human activities. Analysis of long term changes are also important to provide comparison of these water ingredients for which data are available, with anthropogenic compounds, such as nutrients, where the length of observation rows are much shorter. Actual loading of hydrogencarbonate ions for five decades for all major rivers of Latvia has been substantially fluctuating (Fig.1.), and the dimension of changes of loading can reach nearly 30 % of the mean value. The explanation of this variability lies in long-term changes of water discharge, as far as changes in loading of hydrogencarbonate ions perfectly follow changing pattern of water runoff. Different is the character of long-term changes of chloride ions, where well expressed increase of chloride loading takes place, evidently due to human impacts.

Table 2. Mann – Kendall test results for changes of nutrient concentrations in rivers of Latvia for time periods 1977-1989 and 1990-2001 (in bold – statistically significant values at 95% level).

River	Periods	$N\text{-}NH_4^+$	$N\text{-}NO_2^-$	$N\text{-}NO_3^-$	PO_4^{3-}
Gauja	1977-1989	**-3,085**	**-1,836**	-0,178	-0,914
	1990-2001	-0,959	-1,406	**-2,873**	1,116
Venta	1977-1989	**-2,820**	**-3,072**	1,299	**1,914**
	1990-2001	**-2,057**	-0,407	**-2,854**	0,128
Lielupe	1977-1989	**-3,273**	-1,071	-0,226	1,157
	1990-2001	-1,216	-1,505	**-2,249**	-1,438
Salaca	1977-1989	**-3,215**	-0,224	-0,956	-0,803
	1990-2001	-1,642	-1,410	-0,982	1,199

Considering the dramatic decrease in agricultural production, the drastic reduction of fertilizer use in the country, and the installation of many new municipal waste water facilities, different trends are observed for changes of nutrient concentrations. Long-term changes of nutrient concentrations (Table 2) still commonly can be described as linear trends for the study period. However, substantial differences exist for the studied rivers and substances. The concentrations of ammonia are decreasing, and this trend is significant for the largest rivers of Latvia. After 1990, there have been observed decreasing trends of nitrate concentrations for most of the studied rivers (Table 2). The failure of the reduction of nitrate concentrations in the River Salaca waters may be due to slow mineralization of organic nitrogen bound in agricultural and forest soils (*Stålnacke et al., 2003*). Another factor may be exaggeration of fertilizer-use data during the Soviet rule. Also, presently there is still a lack of understanding of nutrient cycling in humus rich soils. Phosphates represent a different situation, and statistically significant increasing trend is evident only for the River Venta till 1989. After 1990, changes of phosphate concentrations do not show consistent trend-lines. However, the dependence on changes in loading to inland waters is evident: increase till 1991-1993 followed by a gradual decrease after 1992.

4. Conclusions

The study of long-term changes of water quality parameters for the study period indicates changes in the intensity of natural geochemical processes and response to changes in human loading. Long-term variability of river discharge should be considered among the major driving processes influencing water chemical composition and loading with river waters. The long-term variability of water chemical composition and the sensitivity of the studied parameters to changes in the environment should be considered in the development of monitoring programs and decision-making process.

References

Libiseller C. and Grimvall A., Performance of partial Mann-Kendall tests for trend detection in the presence of covariates. *Environmetrics,* 13, 71-84, 2002

Stålnacke P., Grimvall A., Libiseller C., Laznik M. and Kokorite I., Trends in nutrient concentrations in Latvian rivers and the response to the dramatic change in agriculture. *J. Hydrol.,* 283, 184-205, 2003

Tsirkunov V.V., Nikanorov A.N., Laznik M.M. & Dongwei Z., Analysis of long-term and seasonal river water quality changes in Latvia. *Wat. Res.,* 26, 9, 1203-1216, 1992

Natural Water Quality Testing in Kaliningrad Area

Evgeny V. Krasnov

Immanuel Kant Russian State University, Kaliningrad 236041, Russia, ecogeography@rambler.ru

More or less systematic data on the natural water quality in Kaliningrad area are presented. Problem of water quality will be discussed in terms of its suitability for human consumption, but also in relation to aquatic organisms responses.

Totally 7 500 sources of pollution are available in the Kaliningrad area, 178 large industrial enterprises including, and only 62 % of them are provided with treatment plants. Annual harmful emission from land-based sources account for 100 000 t (20 000 t of solid substances including).

Annually up to 12 t of suspended substances, 11 t of acetic acid and 35 t of tannids are discharged into the mouth of Pregel river (the majority of the peoples has been settled just here). Rivers and lakes are polluted with petroleum hydrocarbons, phenols, fats and heavy metals. Organic compounds and pesticides from the cattle-breeding farms and fields. Annual waste water discharge is estimated at 250 mln. m^3 (including 40 mln. m^3 of untreated water).

The most typical contaminants for the underground waters are nitrites, nitrates and pesticides. Sometimes high concentration of iron, chlorides and sulphates are found in the coastal waters. The results proved the poultry factories and pig-breeding farms to be the most dangerous sources of pollution for upper underground drinking waters. The calculation showed that total nitrogen applied with the organic and mineral fertilizers is discharged into the river catchments areas via underground and surface flows 5 % and 15 % respectively.

The oxygen concentration in the deep waters of the Vistula and Curonian lagoons from April to October every year have remained at their normal level of saturation (9.1 – 13.7 mg/l). However, in the estuaries oxygen deficit can be observed. Hydrogen concentration range are from 8.2 to 9.1 pH, but in the mouth of the Pregel River decrease to about 7.1 pH. Hydrogen sulphide in the last area up to 0.8 mg/l without oxygen being presented. In the estuaries have been found maximum organic phosphorous concentration, from 0.152 to 0.28 mg/l. The nitrogen concentration have recently been at a normal level but increasing ammonia nitrogen occurred in the Vistula lagoon (on the average up to 0.471 mg/l).

Mainly in the estuaries the phenol concentration exceed the maximum permissible level (0.03-0.07 mg/l), primarily in summer and autumn. In some shallow areas phenol-containing sediments have been found (to about $7.38 \cdot 10^{-3}$ mg/l) in dry mass.

Classification of the Water Quality for Nutrients in Agricultural Runoff.

Ainis Lagzdiņš, Viesturs Jansons and Kaspars Abramenko

Latvia University of Agriculture, Faculty of Rural Engineering, Department of Environmental Engineering and Water Management, 19 Academy Str., Jelgava, Latvia, LV – 3001. E-mail: ainis.lagzdins@llu.lv

1. Abstract

The paper deals with assessment of the surface water quality and includes recommendations for the water quality classification system based on nutrient concentrations. For EU Member States the overall aim of the Water Framework Directive is to achieve "good ecological status" and "good surface water chemical status" in all water bodies by 2015. Human activities including use of the fertilizer and manure in agriculture have caused widespread increase of nitrates in shallow ground water and concentrations of nitrogen and phosphorus in streams (*G. J. Fuhrer, R. J. Gilliom et al., 1999; P.De. Clercq et al., 2002; Baltic Marine Environment Protection Commission, 2005*). Therefore agricultural run – off is main subject of the research.

2. Introduction

Water quality classification system is not well established in legislation of Latvia. During project Transposition and Implementation of the EU Water Framework Directive in Latvia consultant company Carl Bro has made recommendations for surface water quality classification, where small streams and drainage field outlets are not included.

Nutrient concentration data were collected in two agricultural monitoring sites with measurement structures and sampling equipment – Berze and Mellupite (Figure 1). The Berze catchment represents intensive farming area, but Mellupite catchment could be evaluated as typical considering nutrient application. Share of agricultural land in the Berze catchment is 98%, in Mellupite – 69% of total area. The runoff measurements and water sampling were carried out in small streams and drainage field outlets.

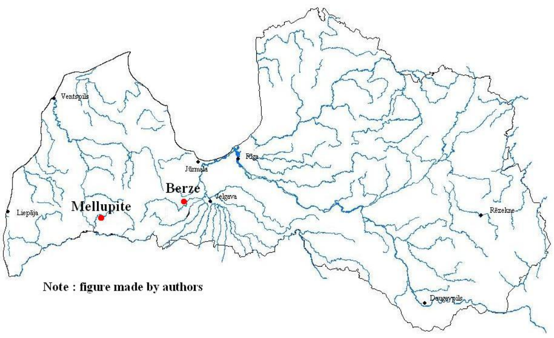


Figure 1. Agricultural run - off monitoring sites.

3. Materials and methods

It may be concluded that both Berze and Mellupite monitoring sites represents typical area of agriculture in Latvia, therefore water quality data may be included in one data set. In above mentioned monitoring sites data was collected during the years 1994-2006. In the field level 224 and in catchment level 259 water samples were collected and analyzed.

All available total nitrogen and total phosphorous concentration data were analyzed using normal distribution curves. According to Stergess formula class intervals (c) depending on number of observations (n) can be calculated, n<100 $c = (X_{max}-X_{min})*(1+3,32\ lg(n))^{-1}$ where X_{max} un X_{min} is minimal and maximal values (*I. Arhipova, S. Bāliņa, 1999*).

Percentile selections of data plotted as frequency distribution are used to establish water quality class boundaries: 10% high status, <10% - 25% good, 25% - 75% moderate, 75% - 90% poor, >90% bad status (Figure 2) (*S. Buck, G. Denton et al., 2000; A.C. Cardoso, J. Duchemin et al., 2001; M. Wallin, W. and R. Torgny, 2003*). Approach described above will produce criteria of greater scientific validity.

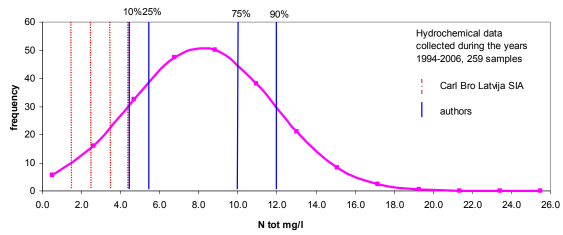


Figure 2. Evaluation of the drainage runoff.

4. Results

Consultant company Carl Bro has made recommendations for surface water quality classification based on professional judgments It is obvious that Carl Bro recommendations can not be used for evaluation of the run – off water quality from agricultural land. This conclusion is supported by results of agricultural monitoring data measured during year 1994 - 2006. The most important findings of the research are that water quality requirements for drainage water as well as for water in small streams in agricultural area should be less stringent (Figure 3). Otherwise, it will not be possible to fulfill objectives of Water Framework Directive.

Quality class	N_{tot} (mg/l)			P_{tot} (mg/l)		
	Agricultural area		CarlBro	Agricultural area		CarlBro
	Drainage water	Small streams	Small river	Drainage water	Small streams	Small river
High	<4.5	<1.5	<1.5	<0.015	<0.025	<0.045
Good	4.5-5.5	1.5-2.5	1.5-2.5	0.015-0.020	0.025-0.050	0.045-0.090
Moderate	5.5-10.0	2.5-7.5	2.5-3.5	0.020-0.075	0.050-0.150	0.090-0.135
Poor	10.0-12.0	7.5-10.5	3.5-4.5	0.075-0.135	0.150-0.250	0.135-0.180
Bad	>12.0	>10.5	>4.5	>0.135	>0.250	>0.180

Figure 3. Range of N and P values for water quality classification

References

G. J. Fuhrer, R. J. Gilliom et. al. U.S. Geological Survey, The Quality of Our Nation's Waters—Nutrients and Pesticides: *U.S. Geological Survey Circular 1225*, 82 p. 1999.

P.De. Clercq, A.C. Gertsis, G. Hofman, S.C. Jarvis, J.J. Neeteson & F. Sinabell, Nutrient Management Legislation in European Countries, Wageningen, The Netherlands, 347 pp. 2002.

Baltic Marine Environment Protection Commission, Nutrient Pollution to the Baltic Sea in 2000, *Baltic Sea Environment Proceedings No.100*, 2005.

I. Arhipova, S. Bāliņa, Statistika ar Microsoft Excel 97 ikvienam. 1. daļa / *Mācību līdzeklis*. Rīga: Datorzinību Centrs, 1999.

S. Buck, G. Denton et. al., Nutrient Criteria Technical Guidance Manual: Rivers and Streams, EPA, 2000.

A.C. Cardoso, J. Duchemin, P. Magoarou, G. Premazzi Criteria for the identification of freshwaters subject to eutrophication. European Commission, Joint Research Centre, EUR 19810 EN, Luxembourg, 2001.

M. Wallin, W. and R. Torgny, Guidance on establishing reference conditions and ecological status class boundaries for inland surface waters, CIS Working group 2.3. (Reference conditions for inland surface waters), 2003.

Justification of the First Long-Term Prediction on the Main Environmental Factors and Fish Stocks in the Baltic Estimated after 20 Years

Evald Ojaveer and Margers Kalejs

E. Ojaveer: Estonian Marine Institute of the University of Tartu, Mäealuse 10a, 12618 Tallinn, Estonia. evald.ojaveer@ut.ee
M. Kalejs: Georga Apina 22-8, Valmiera 4201, Latvia.

1. Abstract

The forecast was composed based on the materials collected up to 1985. It was presented on the conference on Baltic fish resources in early 1988 and published in 1989 (Rapports et Procès-verbaux des Réunions du Conseil international pour l'Exploration de la Mer, 190: 153-158). Based on the regularity of periodical alterations in the regime-forming factors of the sea induced by changes in climate and solar activity, the main environmental conditions -- salinity (freshwater discharge) and thermal situation (area of ice cover) as well as the expected qualitative fluctuations in the chief exploited fish stocks were predicted for the periods up to 1992 and from 1993 to 2008. In the year 1993 the change of the periods was foreseen – indeed this happened as the first considerable saltwater inflow after a long stagnation period occurred. For the fish stocks considered (cod, sprat, Southern Baltic herring, gulf herring in the Northern Baltic) the forecast justified. In the poster the forecast and its justification based on the data of the International Council for the Exploration of the Sea and other institutions are indicated.

Continuous CO_2, O_2 and N_2 Measurements on a Cargo Ship: An Efficient Tool to Study the Baltic Sea Carbon Cycle

Bernd Schneider

Baltic Sea Research Institute, Seestrasse 15, D-18119 Warnemünde, Germany
bernd.schneider@io-warnemuende.de

A fully automated system for the determination of the surface water CO_2 partial pressure was deployed in 2003 on the cargo ship FINNPARTNER in cooperation with the Finnish algaline project. The ship commutes regularly at two day intervals between Lübeck and Helsinki and takes alternately the route east and west of the Island of Gotland (Fig. 1). In 2006 the system was complemented by a module for measuring O_2 and for 2008 it is planned to include also N_2 into the measurements.

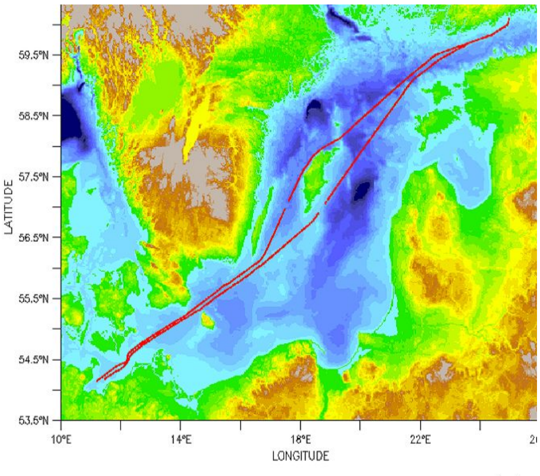


Figure 1. Route of cargo ship FINNPARTNER

The seasonal cycle of the pCO_2 (Fig. 2) was characterized by two minima which were most pronounced in the northeast and at the entrance to the Gulf of Finland. This pattern is a consequence of CO_2 consumption by biological production during the spring plankton bloom and the midsummer bloom fuelled by nitrogen fixation. High pCO_2 were observed in autumn and winter when deep water enriched in CO_2 was mixed into the surface. Extreme high pCO_2 were caused by upwelling events which occurred occasionally close to the southeastern coast of the Island of Gotland. Since this seasonal distribution pattern is a consequence of biological production and decomposition of organic matter, the pO_2 showed an opposing seasonal distribution.

The data were used to identify plankton bloom events and to calculate the net biomass production in the different regions of the Baltic Sea. On the basis of CO_2 surface water mass balances, production rates were obtained for both the spring bloom and the nitrogen fixation period. A distinct southwest to northeast gradient was found with production rates increasing by a factor of 3 – 4 towards the northeast.

Nitrogen fixation rates were estimated from the midsummer biomass production using the C/N ratio of particulate organic matter. The rates showed a considerable interannual variability and caused production rates that can exceed the spring bloom production. Future measurements of N_2 will provide data that are directly related to the nitrogen fixation and thus yield more accurate estimates of the nitrogen fixation which is constitutes a major term in the Baltic Sea nitrogen budget.

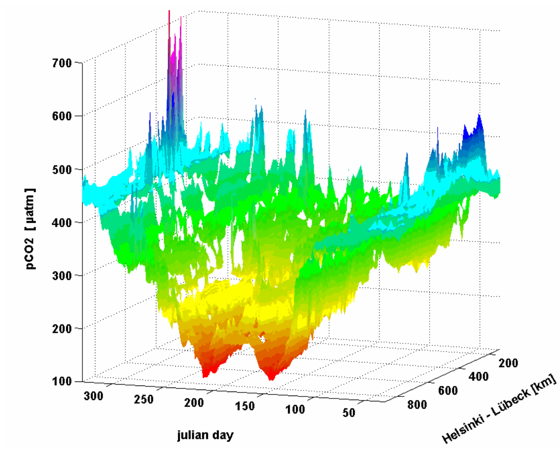


Figure 2. Seasonal distribution of the surface water pCO_2 between Lübeck and Helsinki in 2005.

The measurement system was also used to determine CO_2 in the atmosphere over the Baltic Sea. The mean concentrations and the sesonal amplitudes differed only by a few ppm from those observed at remote northern hemisphere background stations. Based on the difference between the atmospheric and the surface water pCO_2, the CO_2 gas exchange was calculated. High CO_2 uptake rates during spring and summer were almost balanced by the CO_2 release during autumn and winter. The average annual net CO_2 flux for 2004 – 2006 indicated that the Baltic Sea is a weak sink for atmospheric CO_2. But large differences were found for the individual years. This is due to both the interannual variability of the surface water pCO_2 and of the wind speed distribution.

However, a considerable error in the CO_2 flux calculations must be taken into account since the uncertainties associated with the parameterization of the gas exchange transfer velocity are large. Current parameterizations describe the gas exchange transfer velocity as a function of wind speed. A variety of different and contrasting functions have been proposed which yield differences in the transfer velocity by a factor of 2 – 3 in particular at high wind speeds. In order to reduce these uncertainties it is intended to establish surface water mass balances for both CO_2 and O_2 by which mean transfer velocities may be estimated.

Effect of Hydrological Regime and Nutrient Loadings on Lake Zuvintas Eutrophication

Edvinas Stonevicius

Vilnius University, Department of hydrology and Climatology, M. K. Ciurlionio 21/27, 03101 Vilnius, Lithuania, e-mail: stonevicius@geo.lt

1. Introduction

Lake Zuvintas is one of the most eutrophication lakes in Lithuania. The reservation regime was established in Lake Žuvintas since 1937. Despite this, the basin of the lake was reorganized for the requirements of agriculture and fishing industry. The reorganization of the basin and the natural processes resulted even more intensive europhication. At this moment, overgrowth of the lake by submerged vegetation is the main problem caused by eutrophication. The objective of this study was to estimate the impact of hydrological regime and loadings of nutrients to lake's water chemistry and ecosystem structure.

2. Data and methods

Lake ecosystem model PCLake was used for estimation of effect of hydrological regime and nutrient loadings on Lake Zuvintas eutrophication.

PCLake is the ecological model designed to estimate shallow (non-stratified) lake eutrophication. Model calculates the main water quality parameters: nutrient concentration, chlorophyll-a, transparency and the biomass of submerged macrophytes and phytoplankton. It also calculates the distribution and fluxes of the nutrients in water and top sediment layer.

Model inputs are hydrology of the lake, nutrient loadings, dimensions of the lake (mean depth and size) and climate parameters.

Regular discharge measurements in the Lake Zuvintas basin were made only for a short period (1969-01 - 1971-08) and only at one site. For this study daily inflow discharges, modeled with SIMGRO model for a period from 1994-01-01 to 2005-05-01, were used *Povilaitis (2005)*. Lake water level was also calculated with the SIMGRO model for the same period *Povilaitis (2005)*.

Lake Zuvintas is macrophyte-dominant. The predominant family of submerged vegetation is pondweeds. The most common species is shining pondweed (Potamogeton lucens). The macrophytes module was parameterized according to the characteristics of this species *Janse, Puijenbroek (1997)*.

There were not enough data to parameterize food web modules, so the default parameters were left. These default parameters were estimated during multi-lake study of 20 shallow lakes and represents the "typical shallow" lake *Janse, Liere (1995)*.

The main boundary conditions for PCLake are the nutrients loadings to the lake. The sampling data does not show the recognizable annual pattern of nutrients concentration in the inflow water, therefore the long term mean was used.

3. Model results

National lake water quality monitoring and expeditionary data was used for model verification (Figure 1, 2).

The model suggests that the maximal nitrogen and phosphorus concentrations are in the beginning of the spring, the minimal concentrations are in late summer.

The measured data defines the transition between maximum and minimum. Therefore, the collected data did not explain the whole range of possible concentrations

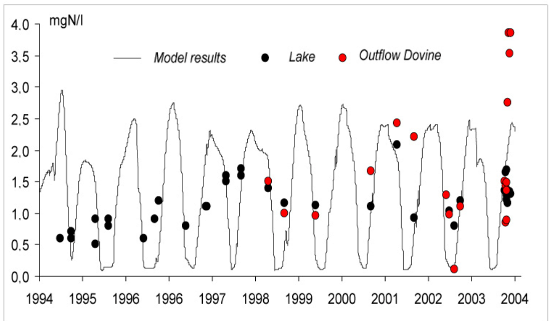


Figure 1. Calculated with PCLake and measured total nitrogen concentrations in the Lake Zuvintas and its outflow Dovine.

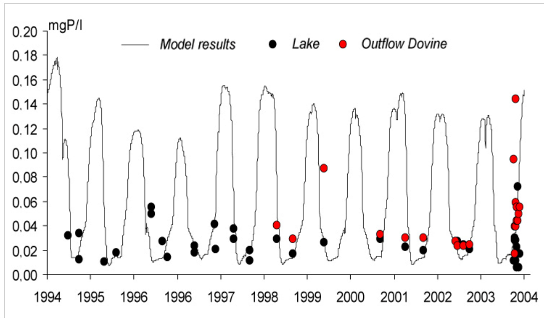


Figure 2. Calculated with PCLake and measured total phosphorous concentrations in the Lake Zuvintas and its outflow Dovine.

The results of modelling could be more accurate if there were more data about concentrations of nutrients in the inflow water. The loadings of nitrogen and phosphorus may be overestimated in inflow water during spring floods, if the concentrations are constant. As a result the modelled concentration of nutrients in the lake could be higher then real.

The maximum concentrations of nutrients in the lake are highly correlated with the spring flood discharge. When the discharge is greater, the phosphorus concentration in the lake is higher, but the nitrogen concentration is lower. The opposite relationship between inflow discharge and nutrients explains the different proportion of nitrogen and phosphorus concentrations in inflow water and in the lake. The phosphorous concentration in inflow water is higher then in the lake. The nitrogen concentration in inflow water is lower then in the lake, so the lake water is "diluted" in the case of nitrogen.

4. Hydrological regime

It is possible to improve water quality by optimizing water regime. We held the hypothesis that it is possible to rise water level (and increase lake depth) by 0.5 and 1.0 m.

When water level is increased the seasonal variation of nitrogen in the lake water is lower. The main reason is the smaller amount of submerged vegetation in the lake. Reduction of submerged vegetation is determinated by the increase of water turbidity in the beginning of shoots growing period. The water turbidity is the outcome of large amounts of phytoplankton. The phosphorus concentration variation differs less then nitrogen, because the phosphorus is the growing limiting element and the minimal concentrations are almost the same for all scenarios.

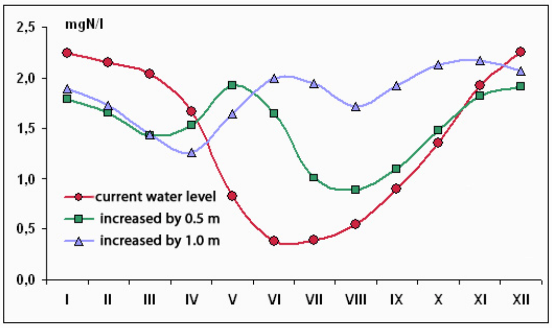


Figure 3. Total nitrogen concentration in the Lake Zuvintas at different water levels

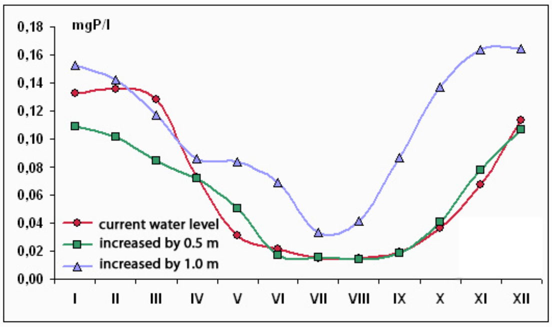


Figure 4. Total phosphorous concentration in the Lake Zuvintas at different water levels

There are a lot of diatoms during sprig, when the average water depth is increased by 0.5 m. Diatoms uses the dissolved forms of nitrogen and phosphorus and decrease the maximal concentration of these nutrients. The concentrations of nitrogen and phosphorus increases again when diatoms dye (early summer). When the average lake depth is increased by 1.0 m, there is lots of phytoplankton during late summer and autumn. When phytoplankton dies, big amounts of organic nitrogen and phosphorus are released into lake water.

5. Nutrient loadings

Theoretically, it is possible to reduce nutrients concentrations till the natural (without anthropogenic influence) level. We made a hypothesis that the anthropogenic pollution is reduced by 25%, 50% and 100%
Less pollution by nutrients means the drop of nutrients concentration in lake water and top sediment layer. The largest differences are during winter and early spring, when the inflow discharge is the largest. The influence of pollution reduction is more significant when the water level is lower, because the volume of the lake is also smaller.
The amount of submerged vegetation does not change significantly with the reduction of pollution. The main reason is more intensive exchange of nutrients between water column and top sediment layer. The shortage of nutrients in the water is compensated by their resources in the sediments.

6. Conclusions

It seems that the best measure to increase water quality of Lake Zuvintas is to reduce the pollution by nutrients from the lake basin and leave the current (or close to it) water level regime. When water level of the lake is raised, the amount of submerged vegetation decreases, but the amount of phytoplankton increases. The phytoplankton and submerged vegetation are less sensitive to nutrients loadings changes when water level is high. When the pollution is reduced the amount of submerged vegetation does not change significantly, but at least it did not increases. On the other hand, it results lower maximal concentrations of nutrients in the lake water and the decrease of nutrients storage in the sediments.

References

Povilaitis A. Hydrological modeling of the Dovine River basin to evaluate various water management alternatives PIN-Matra project ref. No. 2003/040 (final report), 2005

Janse J. H., Puijenbroek van P. J. T. M.. PCDitch, een model voor eutrofierinf en vegetatie – ontwikkeling in sloten. RIVM rapport Nr. 703715004, 1997

Janse J. H., Liere van L. PCLake: a modelling tool for the evaluation of lake restoration scenarios. Water Science and Technology; 31 (8): 371-375, 1995

Pilot Study of the Spring Air-Sea CO_2 Exchange in a Baltic Sea Coastal Region

Karin Wesslander [1], Leif G Anderson [2], Per Hall [2], Sofia Hjalmarsson [2], Dominique Lefevre [3], Anders Omstedt [1], Anna Rutgersson [4], Erik Sahleé [4] and Anders Tengberg [2]

[1] Göteborg University, Department of Earth Sciences, Box 460, SE-405 30 Göteborg, Sweden, karinw@gvc.gu.se
[2] Göteborg University, Department of Chemistry, SE-412 96 Göteborg, Sweden
[3] Université de la Mediterranée, Marseille, France
[4] Uppsala University, Department of Earth Sciences, Villav 16, SE-752 36 Uppsala, Sweden

1. Introduction

Regional and global flux estimates of the gas exchange between air and sea have assumed new importance because of the current interest of the oceans as a sink or source for carbon dioxide (CO_2). The understanding of the processes controlling air-sea exchange is presently incomplete. The exchange of CO_2 between the ocean and the atmosphere is controlled by the air-sea difference in partial pressure of carbon dioxide (pCO_2) and of the efficiency of the transfer processes. The partial pressure in the ocean is controlled by biological, chemical and physical processes, which all need to be described correctly for accurate estimates of the exchange.

The aim of this study was to perform a field experiment with measurements from several disciplines to increase our knowledge of the measuring process and the carbon system in the Baltic Sea surface water.

2. Material and methods

During 5-10 April 2006 we did a multidisciplinary field experiment in the centre of the Baltic Sea east of Gotland near Östergarnsholm. In the about 20 m deep sea area we made ship based measurements of salinity, temperature, total alkalinity (TA), total dissolved inorganic carbon (DIC), pH, oxygen and nutrients. We deployed moored instruments for continues measurements of pCO_2 with a SAMI sensor at 5 m, current speed and direction using a RDCP, oxygen, temperature, salinity and production and consumption of DIC using a water incubator. Measurements of wind speed and direction, air temperature, humidity and turbulent fluxes of temperature, humidity as well as CO_2 fluxes were made from a meteorological tower located on Östergarnsholm.

The measurements of pCO_2 with the SAMI sensor was compared with calculated pCO_2 from the ship based measurements of TA and DIC. pCO_2 was calculated according to *Lewis and Wallace* (1998).

The measured flux of CO_2 was compared to the calculated according to Eq. 1.

$$F_{CO_2} = K_0 k (pCO_{2w} - pCO_{2a}) \qquad (1)$$

where K_0 is the solubility constant and k is the transfer velocity. For comparison we parameterised k according to *Wanninkhof* (1992) Eq 2, *Wanninkhof and McGillis* (1999) Eq. 3 and *Weiss et al.* (2006) Eq.4.

$$k = 0.31u^2 (Sc/660)^{-1/2} \qquad (2)$$

$$k = 0.0283u^3 (Sc/660)^{-1/2} \qquad (3)$$

$$k = (0.365u^2 + 0.46u)(Sc/660)^{-1/2} \qquad (4)$$

where u is the wind speed and Sc is the Schmidt number.

3. Results

Calculations of pCO_2 from the ship based measurements scattered around the SAMI curve within a range of up to ± 30 μatm (Fig. 1). This difference is realistic based on the accuracy in the determination of TA and DIC combined with the use of these parameters to compute pCO_2 and the accuracy of the SAMI sensor. During our experiment, pCO_2 varied between 260–330 μatm. pCO_2 in the sea was significantly lower than the atmospheric value of around 390 μatm.

The flux of CO_2 was directed downwards, in to the sea because of the pCO_2 gradient (Fig. 2). The three parameterisations of k gave fluxes of different magnitude and the highest flux was given by *Weiss et al.* (2006). Measured flux was scattered around the calculated with varying agreement.

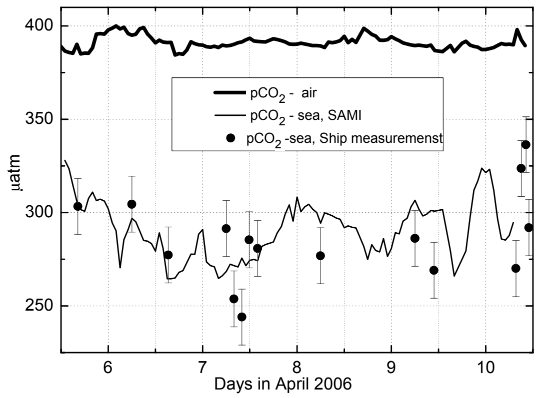


Figure 1. Comparison of pCO_2 measured from ship (with error bars) and measured with the SAMI sensor at 5 m depth together with atmospheric pCO_2.

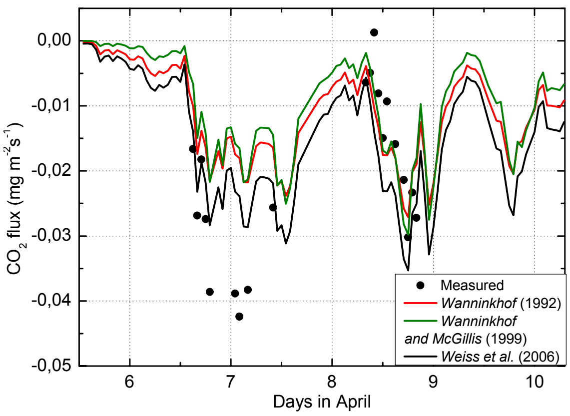


Figure 2. Measured (dots) and parameterised CO_2 flux.

4. Discussion

The mean air-sea difference in pCO_2 was about 100 µatm, which indicated an ongoing primary production. Variations in pCO_2 were surprisingly large and demonstrated e.g. the patchiness in primary production. During our 5 days experiment 1.23 mg CO_2 m^{-2} (0.028 mmol CO_2 m^{-2}) entered into the sea. In the three flux parameterization used, the wind enters the equations differently and more measurements are needed before a proper parameterization can be developed. As the wind is highly variable in the Baltic Sea winds may change the fluxes considerably. The dynamics of the carbon cycle in the water illustrates a strong influence due to biological production. There is a clear need for further multi-disciplinary field experiments.

5. Acknowledgement

This work comprises part of the GEWEX/BALTEX programme and has been funded by Göteborg University and its Marine Research Centre (GMF), the Swedish Research Council under the G 600-335/2001 contract and Swedish Research Council for Environment, Agriculture Sciences and Spatial Planning (FORMAS) under contract 21.0/2004-0374. Björn Carlsson and Dr Hans Bergström (Uppsala University) are acknowledged for the practical help with the meteorological measurements and data processing. We also like to give our appreciation to Sara Jutterström and Daniela Hanslik for laboratory work and the crew at R/V Skagerak.

References

Lewis, E., and Wallace, D.W.R., Program Developed for CO_2 Systems Calculations, ORNL/CDIAC-105, Carbon Dioxide Information Analysis Centre, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee, 1998

Wanninkhof, R., Relationship between wind speed and gas exchange over the ocean, *J. Geophys. res.,* 97, C5, 7373-7382, 1992

Wanninkhof, R. and W. R. McGillis, A cubic relationship between air-sea CO_2 exchange and wind speed, *Geophys. Res. Lett.* 26, 13, 1889-1892, 1999

Weiss, A., J. Kuss, G. Peters and B. Schneider, Evaluating transfer velocity-wind speed relationship using long-term series of direct eddy correlation CO_2 flux measurements, *Accepted for publication in Journal of Marine Systems*. ***In Press***, 2006

International BALTEX Secretariat Publication Series

ISSN 1681-6471

No. 1: Minutes of First Meeting of the BALTEX Science Steering Group held at GKSS Research Centre in Geesthacht, Germany, 16-17 May, 1994. August 1994.

No. 2: Baltic Sea Experiment BALTEX – Initial Implementation Plan, 84 pages. March 1995.

No. 3: First Study Conference on BALTEX, Visby, Sweden, August 28 – September 1, 1995. Conference Proceedings. Editor: A. Omstedt, SMHI Norrköping, Sweden, 190 pages. August 1995.

No. 4: Minutes of Second Meeting of the BALTEX Science Steering Group held at Finnish Institute of Marine Research in Helsinki, Finland, 25-27 January, 1995. October 1995.

No. 5: Minutes of Third Meeting of the BALTEX Science Steering Group held at Strand Hotel in Visby, Sweden, September 2, 1995. March 1996.

No. 6: BALTEX Radar Research – A Plan for Future Action, 46 pages. October 1996.

No. 7: Minutes of Fourth Meeting of the BALTEX Science Steering Group held at Institute of Oceanology PAS in Sopot, Poland, 3-5 June, 1996. February 1997.

No. 8: *Hydrological, Oceanic and Atmospheric Experience from BALTEX.* Extended Abstracts of the XXII EGS Assembly, Vienna, Austria, 21-25 April, 1997. Editors: M. Alestalo and H.-J. Isemer, 172 pages. August 1997.

No. 9: The Main BALTEX Experiment 1999-2001 – *BRIDGE*. Strategic Plan, 78 pages. October 1997.

No. 10: Minutes of Fifth Meeting of the BALTEX Science Steering Group held at Latvian Hydro-meteorological Agency in Riga, Latvia, 14-16 April, 1997. January 1998.

No. 11: Second Study Conference on BALTEX, Juliusruh, Island of Rügen, Germany, 25-29 May 1998. Conference Proceedings. Editors: E. Raschke and H.-J. Isemer, 251 pages. May 1998.

No. 12: Minutes of 7th Meeting of the BALTEX Science Steering Group held at Hotel Aquamaris in Juliusruh, Island of Rügen, Germany, 26 May 1998. November 1998.

No. 13: Minutes of 6th Meeting of the BALTEX Science Steering Group held at Danish Meteorological Institute in Copenhagen, Denmark, 2-4 March 1998. January 1999.

No. 14: BALTEX – BASIS Data Report 1998. Editor: Jouko Launiainen, 96 pages. March 1999.

No. 15: Minutes of 8th Meeting of the Science Steering Group held at Stockholm University in Stockholm, Sweden, 8-10 December 1998. May 1999

No. 16: Minutes of 9th Meeting of the BALTEX Science Steering Group held at Finnish Meteorological Institute in Helsinki, Finland, 19-20 May 1999. July 1999.

No. 17: Parameterization of surface fluxes, atmospheric planetary boundary layer and ocean mixed layer turbulence for BRIDGE – What can we learn from field experiments? Editor: Nils Gustafsson. April 2000.

No. 18: Minutes of 10th Meeting of the BALTEX Science Steering Group held in Warsaw, Poland, 7-9 February 2000. April 2000.

No. 19: BALTEX-BASIS: Final Report, Editors: Jouko Launiainen and Timo Vihma. May 2001.

No. 20: Third Study Conference on BALTEX, Mariehamn, Island of Åland, Finland, 2-6 July 2001, Conference Proceedings. Editor: Jens Meywerk, 264 pages. July 2001.

No. 21: Minutes of 11th Meeting of the BALTEX Science Steering Group held at Max-Planck-Institute for Meteorology in Hamburg, Germany, 13-14 November 2000. July 2001.

No. 22: Minutes of 12th Meeting of the BALTEX Science Steering Group held at Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands, 12-14 November 2001. April 2002.

No. 23: Minutes of 13th Meeting of the BALTEX Science Steering Group held at Estonian Business School (EBS), Centre for Baltic Studies, Tallinn, Estonia, 17-19 June 2002. September 2002.

No. 24: The eight BALTIMOS Field Experiments 1998-2001. Field Reports and Examples of Measurements. Editors: Burghard Brümmer, Gerd Müller, David Schröder, Amélie Kirchgäßner, Jouko Launiainen, Timo Vihma. 138 pages. April 2003,.

No. 25: Minutes of 14th Meeting of the BALTEX Science Steering Group held at Lund University, Department of Physical Geography and Ecosystems Analysis, Lund, Sweden, 18 - 20 November 2002. May 2003.

No. 26: CLIWA-NET: BALTEX BRIDGE Cloud Liquid Water Network. Final Report. Editors: Susanne Crewell, Clemens Simmer, Arnout Feijt, Erik van Meijgaard, 53 pages. July 2003.

No. 27: Minutes of 15th Meeting of the BALTEX Science Steering Group held at Risø National Laboratory, Wind Energy Department, Roskilde, Denmark, 8 - 10 September 2003. January 2004.

No. 28: Science Plan for BALTEX Phase II 2003 – 2012. February 2004, 43 pages.

No. 29: Fourth Study Conference on BALTEX, Gudhjem, Bornholm, Denmark, 24 - 28 May 2004. Conference Proceedings. Editor: Hans-Jörg Isemer, 189 pages. May 2004.

No. 30: Minutes of 16th Meeting of the BALTEX Science Steering Group held at Gudhjem Bibliotek, Gudhjem, Bornholm, Denmark, 23 May 2004. October 2004.

No. 31: BALTEX Phase I 1993-2002 – State of the Art Report. Editors: Daniela Jacob and Anders Omstedt, 181 pages, October 2005.

No. 32: Minutes of 17th Meeting of the BALTEX Science Steering Group held at Poznan, Poland, 24 – 26 November 2004. November 2005.

No. 33: Minutes of 18th Meeting of the BALTEX Science Steering Group held at Meteorological Observatory Lindenberg – Richard Aßmann Observatory, Germany, 18 – 20 October 2005. February 2006.

No. 34: BALTEX Phase II 2003 – 2012 Science Framework and Implementation Strategy, 95 pages. April 2006.

No. 35: BALTEX Assessment of Climate Change for the Baltic Sea Basin. Summary. Editors: The BACC lead author group, 26 pages. June 2006.

No. 36: Minutes of 19th Meeting of the BALTEX Science Steering Group held at Ågrenska Villan of Göteborg University Sweden, 23 – 24 May 2006. October 2006.

No. 37: Minutes of 20th Meeting of the BALTEX Science Steering Group held at St. Petersburg, Russia, 6 – 7 December 2006. March 2007.

No. 38: Fifth Study Conference on BALTEX, Kuressaare, Saaremaa, Estonia, 4 - 8 June 2007. Conference Proceedings. Editor: Hans-Jörg Isemer, 209 pages. May 2007.

Copies are available upon request from the International BALTEX Secretariat.