7th Study Conference on BALTEX

10 - 14 June 2013
Borgholm, Island of Öland, Sweden

Conference Proceedings

Edited by Marcus Reckermann and Silke Köppen

BALTEX is a Regional Hydroclimate Project within GEWEX, the Global Energy and Water Cycle Exchanges Project and WCRP, the World Climate Research Programme.

Organisers and Sponsors

Swedish Meteorological and
Hydrological Institute
Norrköping, Sweden

University of Gothenburg,
Sweden

Swedish Institute
for the Environment,
Gothenburg, Sweden

Helmholtz-Zentrum Geesthacht,
Germany

Linnæus University
Kalmar, Sweden

Finnish Meteorological Institute
Helsinki, Finland

Marine Systems Institute
at Tallinn University of Technology,
Estonia

Gesellschaft zur Förderung des
Helmholtz-Zentrums
Geesthacht e.V., Germany

Scientific Conference Committee

- Andris Andrušaitis, Latvia
- Mikko Alestalo, Finland
- Berit Arheimer, Sweden
- Franz Berger, Germany
- Ryhor Chekan, Belarus
- Jüri Elken, Estonia
- Sven-Erik Gryning, Denmark
- Sirje Keevallik, Estonia (Co-Chair)
- Zbigniew W. Kundzewicz, Poland
- Maria Lamaanen, Finland
- Michael Lautenschlager, Germany
- Andreas Lehmann, Germany
- Kai Myrberg, Finland
- Anders Omstedt, Sweden (Co-Chair)
- Janusz Pempkowiak, Poland
- Bernd Schneider, Germany
- Benjamin Smith, Sweden
- Martin Stendel, Denmark
- Tapani Stipa, Finland
- Hans von Storch, Germany (Co-Chair)
- Valery Vuglinsky, Russia

Organising Committee

- Joakim Langner, Sweden (Chair)
- Anders Omstedt, Sweden
- Marie-Jose Gaillard, Sweden
- Marcus Reckermann, Germany
- Silke Köppen, Germany
- Hans-Jörg Isemer, Germany

More than twenty years ago …

… the idea of BALTEX was born and soon brought into life. The intention was to install a European research programme within the newly designed Global Energy and Water Cycle Experiment (GEWEX), with the Baltic Sea drainage basin as a challenging region to investigate the water and energy cycles in a major continental-scale catchment.

Since then, a lot has happened. Projects were designed and executed, data were collected and analysed, papers were written, networks and friendships were formed. With time, merited people left the programme for new challenges, and new people came, bringing in new ideas and networks. After about 10 years, Phase II was launched, extending the scope to climate variability and change, provision of tools for water management and coping with extreme events, biogeochemical changes, and more applied and societal topics like education and outreach. Now, after 20 years of successful research and scientific networking, BALTEX will be terminated at this conference. We will look back at the early days, and we are pleased to have some of the founding fathers at the conference.

At the same time, the conference will be the start of a new programme to succeed BALTEX. The new programme will have a new name and a new logo (which will be unveiled at this conference), but it will stand firmly in the BALTEX tradition of fostering the free collaboration between research groups from different countries and scientific disciplines in response to common research questions.

The first Study Conference on BALTEX took place in Visby, Gotland, in August 1995. With this 7th and final Study Conference on BALTEX, we are returning to the country with the longest Baltic Sea coastline and an exceptionally strong Baltic Sea research infrastructure. From the very beginning, Sweden has been an important country for the international research network BALTEX. Thus, keeping up the tradition to hold the conferences on Baltic Sea islands, Öland was chosen as the venue for this final BALTEX Study conference. In this respect, we are especially happy and proud that our conference is honoured by the presence of H.M. King Carl XVI Gustaf, King of Sweden.

The conference topics reflect the BALTEX Phase II objectives and goals:

Topic A: Improved understanding of energy and water cycles under changing conditions

Topic B: Analysis of climate variability and change, and provision of regional climate projections over the Baltic Sea basin for the 21st century

Topic C: Provision of improved tools for water management, with an emphasis on extreme hydrological events and long-term changes

Topic D: Biogeochemical cycles in the Baltic Sea basin and transport processes within the regional Earth system under anthropogenic influence

We received 110 contributions for oral and poster presentations, and the allocation to one of the above topics was often difficult. Again, this demonstrates the interdisciplinary nature of the BALTEX programme, and regional Earth system research in general. In a special session, some finalised BONUS+ projects will present their results.

We are happy to welcome high-ranking representatives of the global programmes GEWEX and Future Earth, who will present the programme´s prospects for the coming years. They may potentially provide a global embedment for the new, regionally focussed programme. Also, two sister GEWEX Regional Hydroclimate Projects will be presented.

A dedicated session will focus on the scope of the new programme, with ample time for an open discussion.

This proceedings volume contains all extended abstracts accepted for presentation at the conference, sorted alphabetically within each topic or session (except for the Opening Session, which is sorted chronologically). As usual at BALTEX conferences, no distinction is made between oral and poster presentations in this volume.

We would like to thank all the sponsors and everybody who has helped in the preparation and execution of the conference.

Marcus Reckermann

and the Conference Organisers

June 2013

Contents

Topic B: Analysis of climate variability and change, and provision of regional climate projections over the Baltic Sea basin for the 21st century

TOPIC C: Provision of improved tools for water management, with an emphasis on extreme hydrological events and long-term changes

TOPIC D: Biogeochemical cycles in the Baltic Sea basin and transport processes within the regional Earth system under anthropogenic influence

Special Session: Finalised BONUS+ projects

Special Session: The future programme and international cooperation

Special Session: GEWEX Regional Hydroclimate Projects (RHPs)

Author Index

Abstracts

Opening Session

BALTEX: 20 years of international and interdisciplinary research in the Baltic Sea region

Anders Omstedt

Department of Earth Sciences, University of Gothenburg, Sweden; anders.omstedt@gvc.gu.se

1. Introduction

The BALTEX programme, now completing its second phase, has served as a successful scientific network in the Baltic Sea region for 20 years. These years have seen great changes in terms of social and political developments, but throughout this time, BALTEX has remained a focal point for regional climate and environmental research. We have seen how this effort has generated excellent research and trustworthy networking around the Baltic Sea. This presentation will discuss some of the developing lines. Looking back over these 20 years, one notes several major achievements, and the presentation will give a sense of some of these.

2. Data are the basis of knowledge

At an early stage of BALTEX, we started to collect data on a great many variables and from the whole drainage basin. Precipitation and river runoff data were of high priority as were data on land and sea temperature, ice and snow, and salinity. The national services had ideas of selling data, but at an early stage BALTEX decided not to buy data. Available data were compiled into databases and used to analyse the water and heat balances (see Figure 1). New technological improvements, for example, in precipitation measurements at sea, automatic stations, turbulence measurement, and data quality checks were important advances. Major radar and satellite developments resulted in new products all serving as new scientific tools to help improve our understanding of the Baltic Sea and its drainage basin water and heat balances. A great amount of data therefore became available to the research community and often for free. This was a major achievement and should inspire further efforts in data collection, quality control, and data charging. Today storage is not a problem.

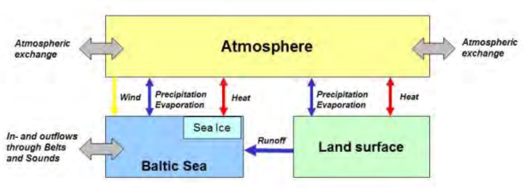


Figure 1. The BALTEX Box during Phase I, 1993–2002.

3. Models are the basis of system understanding

The development of Baltic Sea regional models has a long tradition and addresses many different problems. We have learned that models need to be problem oriented and that several models at different complexity levels are needed. Operational models have been in use for several decades, teaching scientists to combine theoretical and observational considerations. The development of coupled regional land–sea–atmosphere models has been a major activity, as has improving all components of the Earth system model. At the same time, computer development has resulted in rapid improvement in performance and storage capacity. Without such strong technological advances, climate science could only be conducted at a few large data centres. Instead, all scientists can today be involved in sharing models and data. This is another major achievement: the sharing and testing of complex model systems by independent groups guarantees that reproducibility of scientific results is possible. This progress should inspire us to make model codes, forcing data, and output data free and easily available to other groups. Data and models should no longer be protected.

4. Connecting data and models

The past decade has also seen great improvement in the creation of reanalysis datasets by assimilating data into models for the optimal description of nature. This has been dominated by work in the meteorological community, and several reanalysis products on decadal scales are now available. Interestingly, reanalysis data products started to be developed in the meteorological community during work on initial atmospheric modelling data in the late 1970s. Later, a number of products were generated. In the early phase of BALTEX, SMHI created a 1° × 1° horizontal resolution meteorological dataset available through the BALTEX Hydrological Data Centre. This dataset has been crucial for the BALTEX hydrological and oceanographic communities. New global reanalysis datasets are now available at greater time scales (i.e., several decades to one century) and higher horizontal resolutions. Some of these reanalysis products play important roles, serving as lateral boundary conditions or characterizing the Earth system in climate and environmental studies. The development of reanalysis data products is a major scientific achievement; however, further effort is needed as their horizontal resolution is often too coarse to resolve, for example, marine conditions over the Baltic Sea.

5. Connecting climate and environmental changes

BALTEX started focusing on physical processes in order to address the water and energy cycles of the Baltic region. These cycles lie at the heart of the climate system: it is impossible to understand the expected processes of change in the climate system without understanding the energy and water cycles and their interconnections. Phase II of BALTEX also addressed environmental problems (see Figure 2). Here the carbon (CO_2) cycle is at the heart of biogeochemical modelling, and new measurement efforts were made using ferries to measure the partial pressure of CO_2 and nutrient components. The importance of focusing on the CO_2–O_2 system in the Baltic Sea made it possible to connect studies of multiple system stressors, such as climate change, eutrophication, and acidification. Biogeochemical modelling on land and in the Baltic Sea has made major achievements, demonstrating the strength of the BALTEX approach by coupling land, atmosphere and sea. These models will play an important role in future research to improve our understanding of the Earth system.

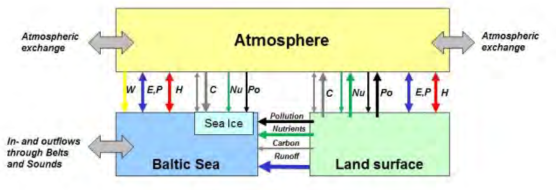


Figure 2. The BALTEX Box during Phase II, 2003–2012.

6. Increased complexity and improved communication

Articles in peer-reviewed international journals are the basis of scientific communication. BALTEX articles and other reports are now easily available through the BALTEX library available at the BALTEX website. At the same time, there is an increasing need for clear communication between scientists and society, in view of the many severe climate and environmental problems. Science–policy dialogue has particularly developed in climate communities where large international assessments are now standard. BALTEX has followed this trend and developed the BALTEX Assessment of Climate Change (BACC) project, now in its second assessment period. This work is conducted in close cooperation with HELCOM but is purely science driven. BACC is a major achievement in which many scientists are involved on a voluntary basis. The International BALTEX Secretariat has played a major role in supporting this assessment work, which is required for new assessment initiatives in the BALTEX science community.

7. Future possible changes and management options

When BALTEX started, almost no scenarios for the future were available. Now many scenarios are available to the science community – many of them free of charge. The implications are that today’s models can realistically reproduce many aspects of past and present climate and environmental conditions. Possible future changes are modelled while taking account of uncertainties regarding both knowledge gaps and management options. BALTEX-generated knowledge is obviously of major importance to society when it comes to managing our natural resources, so further work is needed. The BALTEX programme, which started with basic science questions, has now yielded several achievements that are of great practical importance to society.

8. Future challenges

BALTEX has proven to be a productive science-driven programme free of significant influence from other interest groups and with an outcome of considerable societal importance. The close links between universities and national institutions have improved the programme’s work. Future progress and challenges are all connected to our ability to create positive and creative science environments that ask basic and important questions. If a group of scientists can formulate the most interesting questions and obtain support and respect from national institutions around the Baltic Sea, progress is possible. With our new tools in terms of instruments, ships, satellites, reanalysis data products, and freely available models, much more can be learned. However, we have barely even started to understand how humans act: To improve environmental conditions, we must learn more about how to change our destructive behaviour and become more mindful environmental stewards.

Acknowledgments

It has been a pleasure working with BALTEX and getting to know so many interesting and kind people. The BALTEX Secretariat has provided stability for many years and BALTEX scientists have been my inspiration. Thanks to all for the many years of pleasure and inspiration.

Bringing together the East and the West: Joining ideas, people, datasets

Sirje Keevallik

Marine Systems Institute at Tallinn University of Technology (sirje.keevallik@msi.ttu.ee)

1. GEWEX and continental-scale projects

At the end of the 1980s, the World Climate Research Programme (WCRP) decided to launch the GEWEX – Global Energy and Water Cycle Experiment. Its mission was foreseen as follows: To observe, understand and model the hydrological cycle and energy fluxes in the Earth's atmosphere and at the surface. The plans for its Phase 1 were ready by 1990. Soon, the first regional project was launched: the GEWEX Continental-scale International Project (GCIP) that focused on the Mississippi River Basin. Preparations were going on to start a similar project on the Mackenzie River basin in Canada – MAGS (Mackenzie GEWEX Study) – and on the Amazon basin in South-America – LBA (Large-Scale Biosphere-Atmosphere Experiment in Amazonia). The Baltic Sea offered a wonderful possibility to establish a continental-scale project that comprises a sea and its catchment area. But there were 14 states around the sea that were different politically and economically.

2. Before 1990

The Baltic Sea was surrounded by the countries that had a well-developed scientific potential. Although contacts between the East and the West were restricted, both sides built ocean-atmosphere models, analysed satellite data and carried out process studies. The main difference between the eastern and western countries was data collection and storage.

In the former Soviet Union data were managed centrally by the State Committee for Hydrometeorology and Environmental Control (GOSKOMGIDROMET). This means that the quality of the data was under strict control, the equipment was unified and detailed prescriptions existed for the measurement routine. Unfortunately, the raw data were classified and available only with certain permission. Hydrometeorological data were stored at Obninsk at the Research Institute of Hydrometeorological Information of the USSR – World Data Centre (VNIIGMI-MCD), where the preliminary processing and statistical analysis was carried out. The local branches had at their disposal only tables that were printed at Obninsk and sent to the local services some months later.

Under such conditions, nobody dared to dream about an international experiment that would unite the East and the West.

3. Turbulent early 1990s

Political events in the eastern countries led to new possibilities but also to new difficulties.

Ehrhard Raschke was quick enough to start negotiations on the new project. He had the examples of other GEWEX continental-scale projects in view but he also stressed that data available to all participants is the key to the success, and Hydrology should be incorporated to the system on the same basis as meteorology and oceanography, i.e. on the grid.

At the 2nd Meeting of the BALTEX Science Steering Group in 1995 it was decided that data collection and preparation should be concentrated on the following periods:

- 1992/93
- 1986/87
- August to October 1995

For the eastern countries, formation of digitized data sets was a challenge. In the former Soviet Republics, earlier data could be ordered from Obninsk, but since 1992 the data were only at local institutions, partly on magnetic tapes, partly on paper. Also Poland was not ready to present the necessary data in the required form.

4. The West supports the East

To enhance data digitizing, contracts were signed between GKSS and the hydrometeorological services of Russia, Estonia, Latvia, Lithuania, Belarus and Poland. This was to support collection and processing non-real-time data, including radiation, snow cover, soil moisture and sea level, but especially precipitation and river runoff.

To solve current problems, BALTEX workshops were started under enthusiastic guidance of Hans-Jörg Isemer. The workshops took place in the eastern countries, but actually were focused on the unification of the data sets. Therefore, later also the western partners were involved.

5. What did we gain?

In the East, the inventory of measurement routine and equipment was accelerated, data processing intensified and the foundation to digital data base laid. In the West, the countries had to revise their own data and clarify the differences between national archives. Personal contacts tightened and the exchange of ideas intensified due to numerous visiting scientists from the East to the West and *vice versa.*

The BALTEX Study Conferences formed a wonderful meeting point for those who were interested in the regional problems. Young scientists from the East were supported to participate. The scientists of all countries got access to the data stored at the BALTEX data centres. The whole catchment area was covered with non-real-time data during certain periods that was absolutely necessary to run and validate the oceanographic, atmospheric and hydrologic models.

6. The Year 2013

The data era terminated in 2002 together with the end of the BALTEX Phase 1. By 2013, the conditions and activities in the West and the East are similar: Weather services cooperate to give better weather forecast and research groups cooperate to apply for money and promote science. The socio-economic problems are common and need solutions everywhere – in the East as well in the West.

Challenges for the Baltic Sea region from the HELCOM perspective

HELCOM Secretariat, Helsinki, Finland (www.helcom.fi)

The Helsinki Commission (or HELCOM for short) is an intergovernmental organization comprising the Baltic Sea coastal states and the European Union (EU) that has been working since the early 1970s to improve the status of the Baltic Sea marine environment. The priority issues of concern for HELCOM are eutrophication, pollution by hazardous substances, decline in biodiversity and safety of maritime activities, including shipping.

In 2007, the HELCOM Baltic Sea Action Plan (BSAP) was adopted with the aim to radically reduce pollution to the Baltic Sea and reverse its degradation by 2021. The holistic plan embodies an ecosystem-based approach to the management of human activities and contains concrete actions to solve the major problems affecting the Baltic Sea. Because the action plan embraces the concept of adaptive management, the environmental objectives and proposed cost-effective measures will be periodically reviewed and revised using a harmonized approach and the most updated information available.

The main challenges for reaching the BSAP goals are ensuring that effective measures are in place to reduce pollution to the Baltic Sea and to sustainably manage human activities causing pressures on the environment. Allocation of sufficient resources for protection measures and involvement of all relevant stakeholders is of course imperative. Also, the establishment of a good knowledge base to support decision-making, through follow-up of the status of the marine environment and the effectiveness of measures, is a priority. For this, input from the scientific community is essential.

HELCOM has a history of communicating complex scientific information to the policy-makers. In 2007, HELCOM published a thematic assessment on climate change, which was based on the BACC I report and served as input to the 2007 HELCOM Ministerial Meeting where the BSAP was adopted. In the 2007 BSAP, the ministers stated that they were "… fully aware that climate change will have a significant impact on the Baltic Sea ecosystem requiring even more stringent actions in the future". In the 2010 HELCOM Moscow Ministerial Meeting Declaration they agreed on the need for supplementary actions and admitted that climate change may have profound consequences both for the environmental status of the Baltic Sea as well as for the scope of the measures adopted by the Contracting Parties.

With another HELCOM ministerial level meeting approaching in October 2013, HELCOM is working on an updated assessment on climate change in the Baltic Sea region and its implications on the marine environment, in cooperation with BALTEX. At the ministerial meeting, the effectiveness of the Baltic Sea Action Plan, and especially its nutrient load reduction scheme, will be under scrutiny and may result in enhancements of the plan and even new measures.

In February 2013, HELCOM, together with BALTEX, arranged a workshop for experts and managers on Baltic Sea region climate change and its implications. The main objectives of the workshop were to share and discuss the latest updates and findings of scientific research on climate change in the Baltic Sea region and its implications on the Baltic Sea ecosystem, consider their implications on HELCOM policies, especially related to eutrophication and biodiversity, and to produce proposals to HELCOM decision makers on how climate change should be addressed in HELCOM policies.

The conclusions of the workshop contain inter alia a brief overview of the state of knowledge on the climate change in the Baltic Sea region and proposals for HELCOM decision makers such as: Climate change impacts should be included into the Baltic Sea Action Plan load reduction scheme review and other human pressures should be decreased to mitigate climate impacts on biodiversity. In addition, the workshop made proposals for further research subjects.

Climate Change in the Baltic Sea region - The BACC assessments

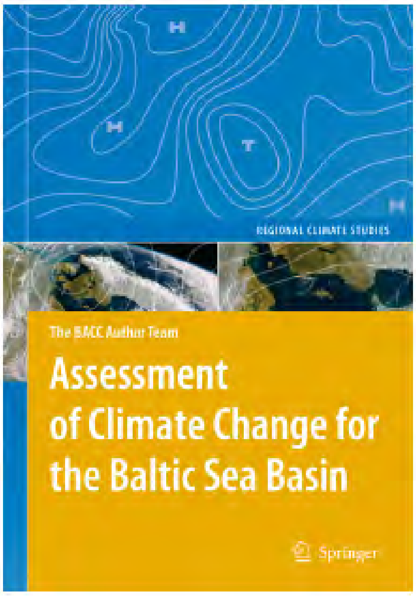
Hans von Storch

Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Germany (hvonstorch@web.de)

1. The BALTEX Assessment of Climate Change for the Baltic Sea basin - BACC

The BACC effort was launched in 2004 to summarize the published scientifically legitimized knowledge about climate change and its impacts in the Baltic Sea catchment area. For the first report, more than 80 scientists from 12 countries documented and assessed the published accessible knowledge in 2008 in a book (*"the BACC book"*, BACC Author Team 2008; Reckermann et al. 2008, Figure 1). The BACC assessment was used by HELCOM as a basis for future deliberations on regional climate change (HELCOM 2007).

In 2009, the second assessment report (BACC II) was initiated; the report is expected to be concluded in 2013, and the printed book will become available in 2014.



The BACC book from 2008. The book can be downloaded from http://www.academia.edu/2266407/BACC_Assessment_of_Climate_Change_in_the_Baltic_Sea_Basin

2. Principles of the BACC procedure

- The assessment is a synthesis of material drawn comprehensively from the available scientifically legitimate literature (e.g. peer reviewed literature, conference proceedings, reports of scientific institutes).
- Influence or funding from groups with a political, economic or ideological agenda is not allowed; however, questions from such groups are welcome.
- If a consensus view cannot be found in the above defined literature, this is clearly stated and the differing views are documented. The assessment thus encompasses the knowledge about what scientists agree on but also identifies cases of disagreement or knowledge gaps.
- The assessment is evaluated by independent scientific reviewers.

3. BACC I results from 2008 in short

- Presently a warming is going on in the Baltic Sea region, and is expected to continue throughout the 21st century.
- BACC considers it plausible that this warming is at least partly related to anthropogenic factors.
- So far, and in the next few decades, the signal is limited to temperature and directly related variables, such as ice conditions.
- Later, changes in the water cycle are expected to become obvious.
- This regional warming will have a variety of effects on terrestrial and marine ecosystems – some predictable such as the changes in the phenology others so far hardly predictable.

4. Preliminary list of key consensus findings in BACC II

- The new assessment finds results of BACC I are valid.
- Significant detail and additional material has been found and assessed. Some contested issues have been reconciled (e.g. sea surface temperature trends).
- Ability to run multi-model ensembles seems a major addition; first detection studies are available, but attribution still weak.
- Regional climate models partly still suffer from severe biases; the effect of certain drivers (aerosols, land use change) on regional climate statistics cannot be described by these models.
- Homogeneity is still a problem and sometimes not taken seriously enough.
- The issue of multiple drivers on ecosystems and socio-economy is recognized, but more efforts to deal with are needed.
- In many cases, the relative importance of different drivers next to climate change needs to be evaluated.

References

BACC Author Team, 2008: *Assessment of Climate Change in the Baltic Sea Basin.*, Springer Verlag Berlin - Heidelberg; ISBN 978-3-540-72785, 473 pp

HELCOM 2007. Climate change in the Baltic Sea area. HELCOM Thematic Assessment in 2007. Baltic Sea Environment Proceedings 111, 54 pp. http://www.helcom.fi/stc/files/Publications/Proceedings/bsep111.pdf

Reckermann, M., H.-J. Isemer and H. von Storch, 2008. Climate change assessment for the Baltic Sea basin. EOS Trans. Amer. Geophys. U., 161-162

A new science and outreach programme for the Baltic Sea region

H. E. M. Meier[1, 2]

[1] Swedish Meteorological and Hydrological Institute, Sweden (markus.meier@smhi.se)
[2] Stockholm University, Department of Meteorology, 10691 Stockholm, Sweden

1. Background and motivation

The BALTEX programme (www.baltex-research.eu/) was successfully running during the past 20 years, focusing on interdisciplinary research in the Baltic Sea region (Fig. 1). During BALTEX Phase I (1993 to 2002) the research aimed

- “to explore and model the various mechanisms determining the space and time variability of energy and water budgets of the BALTEX region and this region’s interactions with surrounding regions”,
- “to relate these mechanisms to the large-scale circulation systems in the atmosphere and oceans over the globe”,
- and “to develop transportable methodologies in order to contribute to basic needs of climate, climate impact, and environmental research”.

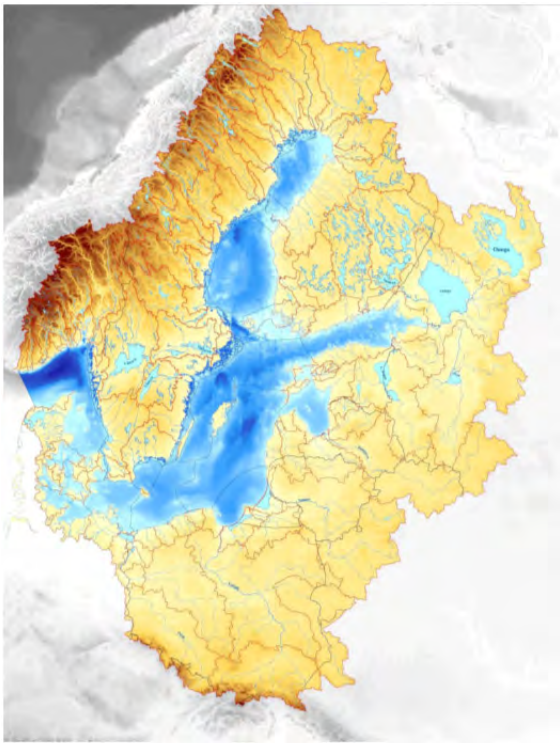


Figure 1. The Baltic Sea basin. Map by courtesy of SMHI, Sweden.

During Phase II (2003 to 2013) the objectives were revised. According to the BALTEX Science and Implementation Plans (2004, 2006) the research was aimed

- “to improve the understanding of energy and water cycles under changing conditions”,
- “to analyze climate variability and change, and provide of regional climate projections over the Baltic Sea basin for the 21st century”,
- “to improve tools for water management, with an emphasis on extreme hydrological events and long-term changes”,
- to investigate “biogeochemical cycles in the Baltic Sea basin and transport processes within the regional Earth system under anthropogenic influence”,
- “to strengthen the interaction with decision-makers, with emphasis on global change impact assessments”,
- and to promote “education and outreach at the international level”

Achievements of 20 years of BALTEX research are novel observational databases, coupled atmosphere-ocean-biogeochemical models, novel reanalysis products and milestone setting outreach and communication activities like the homepage, study conferences and summer schools organized and coordinated by the International BALTEX Secretariat (see Omstedt, 2013: BALTEX – 20 years of international and interdisciplinary research for the Baltic Sea region; this abstract volume). There have been several working groups, and the BALTEX Assessment of Climate Change for the Baltic Sea Basin (BACC) project (www.baltex-research.eu/BACC2/) deserves particular attention because it has provided and will provide, in context with the second assessment, important information to stakeholders of the marine environment, like HELCOM in particular, and to the wider scientific community in general.

With the 7th Study Conference on BALTEX on Öland, 10-14 June 2013, BALTEX Phase II will come to an end. However, intensive discussions within the BALTEX community since June 2010 have shown a strong interest for a follow-up programme fostering interdisciplinary and international collaboration. Hence it was decided by the BALTEX Science Steering Group to form a working group on “PostBALTEX”, to develop a science plan for a new programme. In January 2013 some members of the working group gathered and were given the mandate to form an Interim Science Steering Group (ISSG) for one year and to launch the new programme at the 7th Study Conference on BALTEX. As BALTEX is regarded by the scientific community as a successful programme, it was decided to build the science plan of the new programme on BALTEX achievements and on the objectives of BALTEX Phase I and II as summarized above.

2. A new science plan

The vision of the new programme is to “achieve an improved Earth System understanding of the Baltic Sea region” (Fig. 2). According to the science plan, the new scientific network will be flexible with a continuously on-going definition of core research questions which are identified to be key scientific issues, so-called Grand Challenges. New Grand Challenges will be developed within dedicated working groups. They will be research foci for periods of about 3-4 years. Furthermore, the new programme will communicate with stakeholders and research funding agencies to promote funding relevant for the Grand Challenges. Today, the following Grand Challenges are identified:

- Salinity dynamics in the Baltic Sea

- Land-sea biogeochemical feedbacks in the Baltic Sea region
- Natural hazards and extreme events as the key factor in understanding and predicting natural disasters in the Baltic Sea region
- Understanding sea level dynamics using new technologies (remote sensing)
- Anthropogenic changes and how the Earth system of the Baltic Sea region is affected
- Understanding of regional/local variability of water and energy exchanges

Further details of the new science plan will be presented and discussed at this conference.

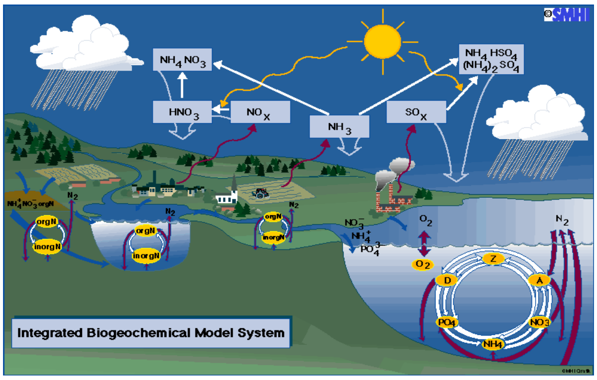


Figure 2. Processes important for Earth system science. Map by courtesy of SMHI, Sweden.

3. Present and new working groups

Important for the new programme, as for the BALTEX programme, are working groups. Today, existing working groups within BALTEX are

- BALTEX Working Group on Radar (Chair: Jarmo Koistinen, FMI and Daniel Michelson, SMHI)
- BALTEX Working Group on the Utility of Regional Climate Models (Chair: Markus Meier, SMHI)
- BALTEX Working Group on Data Management (Chair: Michael Lautenschlager, WDCC)
- BALTEX Assessment of Climate Change in the Baltic Sea Basin (Chair: Hans von Storch, HZG)

New working groups to be installed together with the launch of the new programme are

- Working Group on Outreach and Communication (Chair: Carin Nilsson). The task of this group will be to initiate and design potential outreach activities, the content and design of the new website and activities in social media
- Working Group on Education (Chair: Anders Omstedt). The task of this group will be to organise educational activities of the new programme, like Summer Schools etc.

4. Ongoing activities

Currently planned conferences that will be part of the new programme are:

- Climate Change - The environmental and socio-economic response in the Southern Baltic Region – II: 12-15 May 2014 in Szczecin, Poland
- 3rd Lund Regional-scale Climate Modelling Workshop: 21st Century Challenges in Regional Climate Modelling: 16-19 June 2014 in Lund, Sweden

Furthermore, the BACC II book will be published in early 2014. Follow-up activities will include the writing of a summary booklet for non-scientists in English and the Baltic Sea riparian languages. Other reports that wrap up the BALTEX Phase II are planned, like the BALTEX Assessment on the water and energy cycle (Berger et al.) and the BALTEX Assessment on regional climate system models (Meier et al.).

5. Implementation of the new programme

The ISSG will lead the new programme during the first year, i.e. from June 2013 until June 2014. During this year new terms of references and the structure of the new working groups and the new steering group will be elaborated. The author (Markus Meier) was elected as chair of the ISSG and Anna Rutgersson (Sweden) as vice-chair. Further members of the ISSG are Carin Nilsson (Sweden), Ben Smith (Sweden), Jari Haapala (Finland), Piia Post (Estonia), Karol Kulinski (Poland), Andreas Lehmann (Germany), Eduardo Zorita (Germany), Franz Berger (Germany), Marcus Reckermann (Germany), Anders Omstedt (Sweden), Sirje Keevalik (Estonia), and Hans von Storch (Germany). It is planned to invite more members, in an attempt to balance the criteria of country, gender and institutional affiliation. However, the main criterion for an ISSG membership will be the active contribution to the new programme, like participation in ISSG meetings, conferences, workshops, summer schools, and working groups.

In addition to the ISSG, a Senior Advisory Board (SAB) will be appointed to advise and support the ISSG and their activities. It was suggested that members of the SAB could be outstanding senior scientists, and representatives of important Baltic Sea region scientific and political stakeholders, like HELCOM, BONUS, ICES, and others.

6. Name and logo

The name of the new science and outreach programme and the logo will be published during the opening session of this final BALTEX Study Conference on Öland.

Acknowledgements

I am very thankful to be “grown up” as a scientist within the BALTEX programme and to be inspired by many scientists within this network. I would like to thank the members of the ISSG and of the “PostBALTEX” working group as well as the International BALTEX Secretariat for their support and help to establish the new programme. Especially, I would like to thank the Head of the International BALTEX Secretariat, Dr. Marcus Reckermann.

References

Science Plan for BALTEX Phase II 2003 – 2012. February 2004, International BALTEX Secretariat Publication Series, ISSN 1681-6471, No. 28, 43 pages

BALTEX Phase II 2003 – 2012 Science Framework and Implementation Strategy. April 2006, International BALTEX Secretariat Publication Series, ISSN 1681-6471, No. 32, 95 pages

Topic A

Improved understanding of energy and water cycles under changing conditions

Contributions of BALTEX towards the understanding of the Earth's water and energy cycle

Lennart Bengtsson

University of Reading, University of Uppsala, ISSI Bern

It was recognized from the early planning of the GEWEX program that it must include detailed studies of a number of representative river catchment areas from a selection of climate regions. In that context, the BALTEX program was suggested and accepted by the GEWEX science board. So far BALTEX has probably been one of the most successful programs. In my lecture I will give an overview of the global atmospheric water cycle with emphasis on high latitudes, what we have learned and what the future challenges are. A particular issue that I will comment on is the response of the high latitude water cycle to higher global temperatures.

Different tracks of Mediterranean cyclones towards Europe and their associated precipitation fields in Poland

Jan Degirmendžić

Faculty of Geographical Sciences, Department of Physical Geography, University of Łódź, Łódź, Poland (jandegir@geo.uni.lodz.pl)

1. Aims

The main goal of this paper is to distinguish separate tracks of Mediterranean or Black Sea's cyclones travelling towards Europe and to identify precipitation anomalies in Poland associated with different classes of trajectories. The analysis also focuses on seasonal changes in the position of the trajectories and precipitation fields. The annual and semi-annual cycles were analysed.

Distinguished classes of trajectories were compared with other cyclones tracks outlined in the literature (eg. Apostol, 2008), including Van Bebber's storm tracks (van Bebber, 1891).

Outlined above, the purpose of research is justified due to the fact that studies examining the long-term series of Mediterranean cyclones moving towards Europe and their impact on precipitation are very rare (eg. Bielec-Bąkowska, 2010), while case studies of selected low pressure systems, for instance Vb cyclones, associated with the extreme hydro-meteorological events are by far the more frequent (Kundzewicz et al. 2005; Bissolli et al., 2011; Ulbrich, 2003; Rezaćova et al. 2005).

2. Data and methods

Two main data sources were used. Information about cyclones position was obtained from Mark Serreze's database (Serreze, 2009). It is the result of an automatic procedure for detection and tracking of moving low-pressure systems for the Northern Hemisphere. From this database cyclones which meet two criteria were extracted:

1) at any stage of the development low pressure system is situated within the Mediterranean or the Black Sea basin.
2) at a later stage of development cyclone is located not further than 350 km from the Polish border. 351 such systems were selected.

Daily sums of precipitation for 60 meteorological stations in Poland were extracted from Institute of Meteorology and Water Management database. The analysis spans the period from the 1st of January 1958 to the 31st of December 2008. 351 trajectories are grouped into classes. Semi-subjective procedure of classification was used. In classification process one took into account the course of the trajectories' section between the Mediterranean / Black Sea and Poland. 12 classes were separated – passing east of Poland (2), west (2), south of Poland (2), the next two passes centrally through Poland and finally four classes of trajectories originate near the Black Sea. Example of E class of trajectories is presented in Figure 1.

The analysis of seasonality utilizes time series of monthly number of trajectories in the period 1958-2008. Harmonic analysis is applied in order to verify the existence of annual and semi-annual variations. Levels of statistical significance are set on the basis of Monte Carlo simulation.

Figure 1. The E class of trajectories – passing east of Poland from Mediterranean basin towards Europe (class similar to Vb track). Cyclogenesis sites – empty circles, cyclolysis sites – black circles. Period 1958-2008.

3. Trajectory classes and their frequencies

351 trajectories of Mediterranean lows which in later stages of development travelled through central or Eastern Europe were distinguished in the period 1958-2008. It corresponds to an average of about 7 cyclones per year. Comparing the track frequency within classes, it should be noted that most often low pressure systems move along the C' path towards Europe - such trajectories occur in 20.5% of all cases (Tab. 1). Class E ranks in a third place.

Table 1. Classes of cyclones trajectories travelling from Mediterranean basin towards Europe. The percentage of classes is given in comparison to all selected trajectories (351). Period 1958-2008.

Class	%	Class	%	Class	%
All	100,0	W+W'	7,7	C+C'	34,2
E	14,5	S	8,0	BSS	2,8
E'	8,3	S'	17,9	BSC	1,1
E+E'	22,8	S+S'	25,9	BSN	3,1
W	4,0	C	13,7	BSE	2,3
W'	3,7	C'	20,5	BS	9,4

As regards to groups of classes (E+E', S+S', W+W', C+C' and BS – starting from the Black Sea basin), it is worth noticing that in the third place ranks group E+E', which corresponds to Van Bebber's Vb trajectory. On average, annually about 1.5 cyclones pass along E or E' trajectory. According to this result, the Vb track is definitely not the most frequent route for Mediterranean cyclones travelling towards Europe (Table 1). Systems moving west of Poland (W+W') are the least frequent – they constitute only about 8% of cases.

4. Seasonal changes of trajectories frequency

Monthly frequencies of all trajectories are similar from August till December (Figure 2). In January, there is a marked decline. In February and March, the number of trajectories reaches a similar level to autumn. April is a clear maximum - about 15% of all selected low pressure systems develop in April. Cyclones are 4 times more frequent in April than in January. In May and June the decline is visible. In July, there is a second minimum of the year. It is slightly higher than that of January. This fact is of a great importance because it implicates that during the period when Mediterranean cyclones are carrying a lot of moisture, they are a relatively rare phenomena.

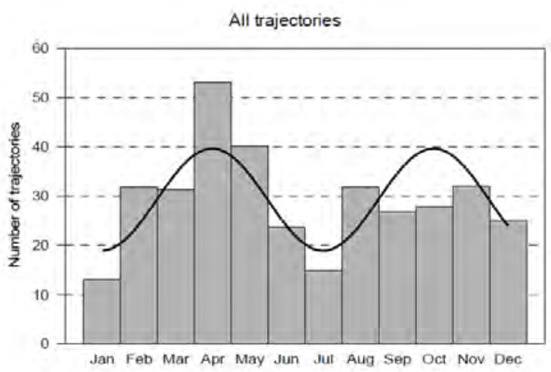


Figure 2. Number of trajectories of Mediterranean lows moving towards Europe in the period 1958-2008. Semi-annual harmonic is added.

There was no annual cycle detected in any time records, while semi-annual changes were observed in the series of: all trajectories, E class, W' class and E+E' group.

5. Precipitation anomalies in Poland

Maps of precipitation anomalies have been constructed for Poland for the periods with active Mediterranean cyclones moving in subsequent phases of the development over Europe. Rainfall spatial distributions were prepared separately for lows assigned to the 12 selected trajectory classes. Annual as well as monthly averages were computed on the basis of data from 51-year period. Spatial distributions of rainfall related to each trajectory class were characterized in details. Trajectory class resulting in the highest precipitation in Poland was distinguished. The trajectory segments associated with the highest precipitation in Poland were also separated.

Acknowledgments

This work was performed under National Science Centre Grant N N306 313739.

References

Apostol L. (2008) The Mediterranean cyclones – the role in ensuring water resources and their potential of climatic risk in the east of Romania, Pres. Env. Sus. Dev., No. 4, pp. 143-163

Bielec-Bąkowska Z. (2010) A classification of deep cyclones over Poland (1971-2000), Phys. Chem. Earth., Vol. 35, pp. 491-497

Bissolli P., Friedrich K., Rapp J., Ziese M. (2011) Flooding in eastern central Europe in May 2010 – reasons, evolution and climatological assessment, Weather, Vol. 66, No. 6, pp. 147-153

Kundzewicz Z., Ulbrich U., Brucher T., Graczyk D., Kruger A., Leckebusch G., Menzel L., Pińskwar I., Radziejewski M., Szwed M. (2005) Summer floods in central Europe – climate change track?, Nat. Hazards, Vol. 36, pp. 165-189

Rezaćova D., Kaspar M., Muller M., Sokol Z., Kakos V., Hanslian D., Pesice P. (2005) A comparison of the flood precipitation episode in August 2002 with historic extreme precipitation events on the Czech territory, Atmos. Res., Vol. 77, pp. 354-366

Serreze M. C. (2009) Northern Hemisphere Cyclone Locations and Characteristics from NCEP/NCAR Reanalysis Data. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Ulbrich U., Brucher T., Fink A., Leckebusch G., Kruger A., Pinto J. (2003) The central European floods of August 2002: Part 2 – synoptic causes and considerations with respect to climatic change, Weather, Vol. 58, No. 11, pp. 434-442

van Bebber W. J. (1891) Die Zugstraßen der barometrischen Minima nach den Bahnenkarten der Deutschen Seewarte für den Zeitraum von 1875-1890, Meteorol. Z., Vol. 8, pp. 361-366

Ground-based GPS networks for remote sensing of the atmospheric water vapour content: A review

Gunnar Elgered

Department of Earth and Space Sciences, Chalmers University of Technology, Onsala Space Observatory, Sweden (gunnar.elgered@chalmers.se)

1. Introduction

The variability in the atmospheric water vapour content is an important parameter both for operational weather forecasting and climate research. In this presentation I will first describe the interplay between the atmosphere and the accuracy of the estimated positions and vectors that can be obtained in space geodesy. Thereafter, I will focus on how the efforts to model the atmospheric influence on space geodetic measurements led to the application of measuring the water vapour content of the atmosphere. Two major applications have been seen so far: close to real time analyses for use of data in weather forecasting and (2) the long term application of climate monitoring.

2. The Atmosphere Problem in Space Geodesy

Space geodesy was born when manmade satellites were launched in the 1960ies. At that time also geodetic techniques based on radio astronomical measurements were developed. After about ten years it was realized that—for the application of Very-Long-Baseline Interferometry (VLBI)—variations in the time of arrival, due to water vapour, for the signals propagating through the Earth's atmosphere would soon become one of the limiting error sources.

Microwave radiometers were designed and used as an independent source of information on the water vapour content at VLBI sites, and were used to correct the VLBI observations (Elgered et al. 1991). At the same time the quality of the VLBI data was improved by introducing wider observing bandwidths and faster slewing antennas, resulting in better observing geometries. These facts made it possible to estimate the water vapour content above each site from the VLBI data themselves.

In the 1980ies also the high accuracy positioning applications of the Global Positioning System had reached the quality when it was possible to estimate the atmospheric influence, read the variations in the water vapour content, from the GPS data themselves (Tralli and Lichten 1990), and the term GPS meteorology was born (Bevis et al. 1992).

3. The Application to Weather Forecasting

Several European supported research projects were carried out during a ten-year period, starting around 1996 (e.g. WAVEFRONT, NEWBALTIC, MAGIC, TOUGH, and the COST Action 716) in order to assess the quality of time series of water vapour estimated from GPS data. At the same time national and international surveying and research organizations started to invest in continuously operating ground-based GPS networks and thereby taking the responsibility for a significant, and in some countries the entire, part of the investment costs.

Today we have an impressive GPS network in Europe (see Figure 1), used by the EUMETNET project E-GVAP. Several regional data processing centres routinely provide data in close to real time to a central data archive at the UK MetOffice from which data can be downloaded for operational weather forecasting.

The application of weather forecasting requires results in close to real time. This means that the most accurate results on an absolute scale will not be available but more important are the relative changes together with a good knowledge of the timing and the location of large changes in the water vapour content. These are important for regional and local precipitation events.

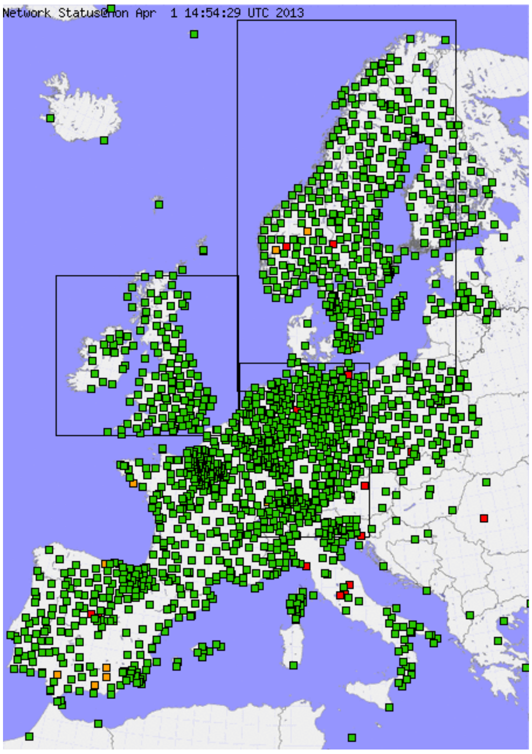


Figure 1. The present network of GNSS receivers in the E-GVAP project (from http://egvap.dmi.dk/).

4. The Climate Research Application

In difference to the application of weather forecasting the use of GPS data in climate research does not require data processing and results in close to real time. Instead the high accuracy on an absolute scale is of outmost importance. This is especially true for the task of climate monitoring, where trends in the water vapour content of the order of a few percent, or less, can be expected over a ten-year period. In order to achieve the best accuracy the most accurate orbit parameters must be used. On a global scale the International GNSS Service (IGS) coordinates many applications for accurate positioning and remote sensing. The global network of IGS stations shown in Figure 2 is routinely used to estimate orbit parameters of the GPS satellites.

Of relevance to the BALTEX project, existing GPS sites in Sweden and Finland were used to study long-term trends in the water vapour content from 1993 to 2000 (Gradinarsky et al. 2002). These results have thereafter been updated in several studies (Nilsson and Elgered 2008; Elgered et al. 2010). Figure 3 depicts the trends in the water vapour content together with the corresponding trends in the temperature at the ground. An interesting, but not yet understood, pattern is seen. The linear trends are positively correlated for sites in Sweden, whereas the correlation is close to zero for the Finnish sites.

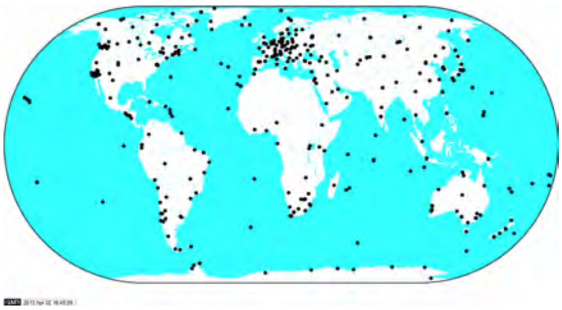


Figure 2. The present IGS network of GNSS receivers. A map of the present network can be downloaded from http://igscb.jpl.nasa.gov/network/netindex.html.

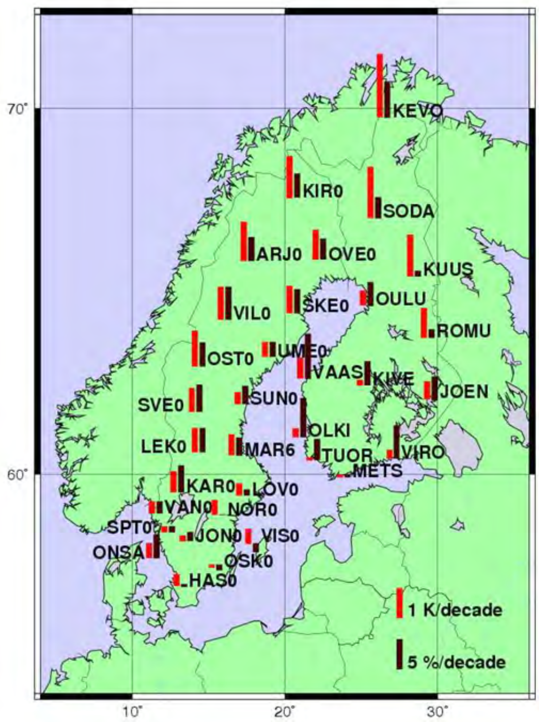


Figure 3. Estimated linear trends in the water vapour content and in the temperature at the ground for GPS sites in Sweden and Finland. The scales of the bars are defined in the lower right corner (from Elgered et al. 2010).

Another example of GPS data in climate research is the evaluation of climate models. Figure 4 depicts results for the diurnal cycle of the water vapour content. In total, 99 European GPS sites are used to evaluate the regional Rossby Centre Atmospheric climate model (RCA). The peak time from the GPS data are compared to the peak times from the RCA for the summer months of June, July, and August. We note an agreement in the geographical variation of the diurnal peak. Averaged over all the sites, a peak at 17 local solar time is obtained from the GPS data while it appears later, at 18 local solar time, in the RCA simulation.

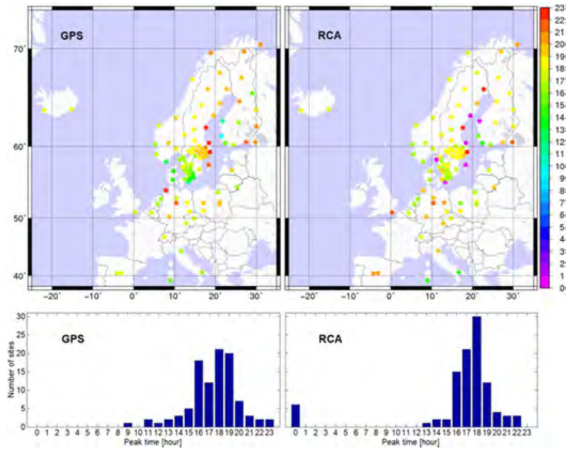


Figure 4. Peak time of the diurnal cycle of the water vapour content, for the summer months, obtained from the GPS data and the RCA simulation for each GPS site (upper) and histograms of the peak time (lower). The hour is in local solar time (from Ning et al. 2013).

5. Conclusions

The continuously operating ground-based GPS (today GNSS) networks have proven to be able to offer new information for the near-real time application of weather forecasting and for different types of studies in climate research. In the latter case the time series of the water vapour content can be used both for climate monitoring and for the evaluation of climate models.

References

Bevis, M., Businger, S., T.A., Herring, Rocken, C., Anthes, R., and Ware, R. (1992) GPS meteorology: remote sensing of atmospheric water vapor using the global positioning system, J. Geophys. Res., 97(D14), 15, pp. 787–801, doi:10.1029/92JD01517.

Elgered, G., Davis, J.L., Herring, T.A., and Shapiro, I.I. (1991) Geodesy by radio interferometry: water vapor radiometry for estimation of the wet delay, J. Geophys. Res., 96, pp. 6541–6555.

Elgered, G., Ning, T., Johansson, J., Willén, U., Kjellström, E., Jarlemark, P., Emardson, R., and Nilsson T. (2010) Validation of climate models using ground-based GNSS observations, Proc. General Assembly of the Nordic Geodetic Commission, 26–30 Sep., Hønefoss, Norway.

Gradinarsky, L.P., Johansson, J., Bouma, H.R., Scherneck, H.-G., and Elgered, G. (2002) Climate monitoring using GPS. Phys. Chem. Earth, 27, 335–340.

Nilsson, T. and Elgered, G. (2008) Long-term trends in the atmospheric water vapor content estimated from ground-based GPS data, J. Geophys. Res., 113, doi: 10.1029/2008JD010110.

Ning, T., Elgered, G., Willén, U., and Johansson, J.M. (2013) Evaluation of the atmospheric water vapor content in a regional climate model using ground-based GPS measurements, J. Geophys. Res., 118, doi:10.1029/2012JD018053

Tralli, D.M., and Lichten, S.M. (1990) Stochastic estimation of tropospheric path delays in Global Positioning System geodetic measurements, Bull. Geod., 64, pp. 127–159, 1990.

GNSS for global Earth observation: An update from the European coordination action Gfg²

G. Elgered[1], J. Wickert[2], C. Arras[2], M. Caparrini[3], A. Puig-Centelles[3], A. Egido[3], S. Fuller[4], M. Gauss[5], R. Haas[1], R. Jongman[6], J. Johansson[1], P. Monks[7], and S. Zolotikova[7]

[1] Department of Earth and Space Sciences, Chalmers University of Technology, Onsala Space Observatory, Sweden (gunnar.elgered@chalmers.se)
[2] GFZ German Research Centre for Geosciences, Potsdam, Germany
[3] Starlab, Barcelona, Spain
[4] The University of Nottingham, U.K.
[5] Norwegian Meteorological Institute, Oslo, Norway
[6] Alterra, Wageningen UR, The Netherlands
[7] University Leicester, U.K.

1. Introduction

The Gfgsquared (GfG²) project is an international research related project with focus on the use of Global Navigation Satellite Systems (GNSS) for Earth observation in a more general sense. Within the project novel GNSS applications with outstanding social importance are identified. These applications can be classified into the nine Social Benefit Areas (SBAs), which include current crucial problems of mankind. There are nine SBAs: agriculture, biodiversity, climate, disasters, ecosystems, energy, health, water, and weather. They are identified and described by the Group of Earth Observations (GEO, see: www.earthobservation.org). Examples of current and possible future applications for GNSS in the different SBAs are provided.

2. Agriculture

GNSS techniques are widely used for agriculture. Related to positioning are machinery guidance, mapping, and livestock monitoring. Reflected GNSS signals can be used for soil moisture estimation, land classification, crop development monitoring, and biomass monitoring. One example is shown in Figure 1.

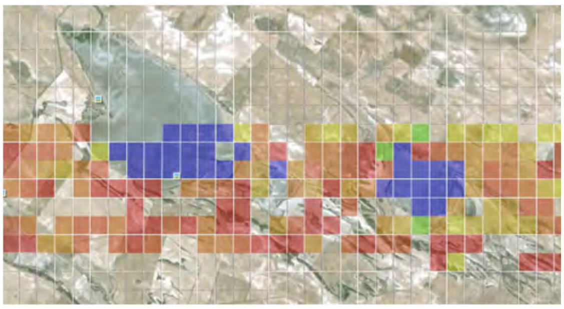


Figure 1. A soil moisture map, generated by using GNSS reflectometry measurements (red: dry; blue: wet) (© A. Egido, Starlab).

3. Biodiversity and Ecosystems

GNSS are used for animal tracking and positioning (see Figure 2). By studying the motion pattern of an animal, information about its health may be obtained. Another application is satellite image analysis for habitat mapping (spatial aspects, mapping, surveying, and digital elevation models).

Figure 2. Seals are tracked by using GNSS in several research projects, see e.g. http://sealtrack.ucc.ie/ (© M. Lejhall, Gothenburg University).

4. Climate

The GNSS occultation technique offers globally distributed estimates of temperature profiles covering the interesting region of the upper troposphere and the lower stratosphere. One example of the monitoring of climatological variations is shown in Figure 3.

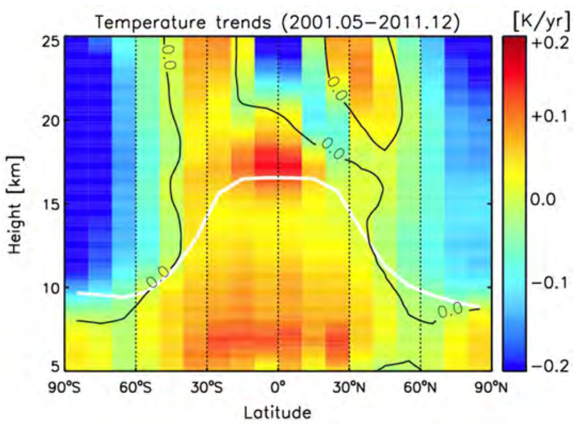


Figure 3. An example of temperature trends in the atmosphere inferred from the GNSS occultation technique (© T. Schmidt, GFZ).

5. Disasters

Fields of GNSS applications for all phases of the risk management cycle associated with hazards (mitigation and preparedness, early warning, response, and recovery) are: critical infrastructure (such as dams and bridges), earthquakes, volcanoes (an example is shown in Figure 4), landslides/avalanches and floods. Ground-based GNSS networks may provide useful information relevant to more than one type of disaster listed above. Examples for such networks are: COCONET for earthquakes and hurricanes in the Caribbean, Sumatran GPS Array (SuGAr) for tectonics, earthquakes, and tsunamis, and GEONET for monitoring of crustal deformation in Japan.

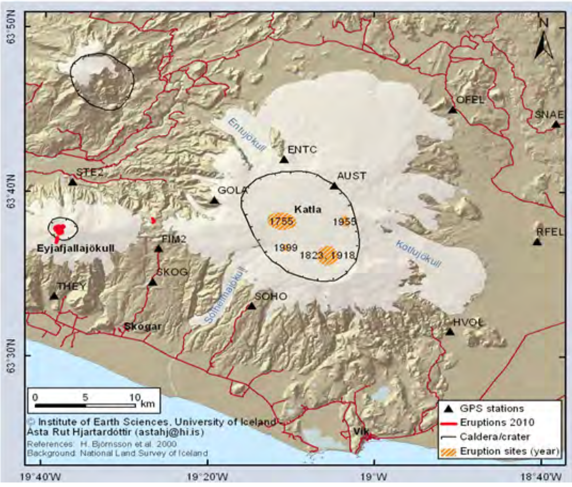


Figure 4. An example of a GNSS monitoring network on the Katla volcano on Iceland (© X.Y.Z).

6. Energy

Several GNSS applications could beneficially contribute to this SBA: Tracking of goods related to energy, time synchronization in smart grids, subsidence in mining, wind scatterometry, lake level monitoring (see Figure 5), and induced currents due to geomagnetic activity in the ionosphere.

Figure 5. GNSS-R instrument over Laja Lake, Los Angeles, Chile, for monitoring lake level.

7. Health

Health organizations are using GNSS positioning services to manage people and equipment, monitor disease propagation, and direct search and rescue operations.

8. Water

One example is the research on global sea level rise (see Figure 6). Global accurate observations of the sea level are not possible without GNSS. The orbit determination of radar altimetry satellites uses the international terrestrial reference frame (ITRF), which is also used to connect reference surfaces and for tide gauge calibration.

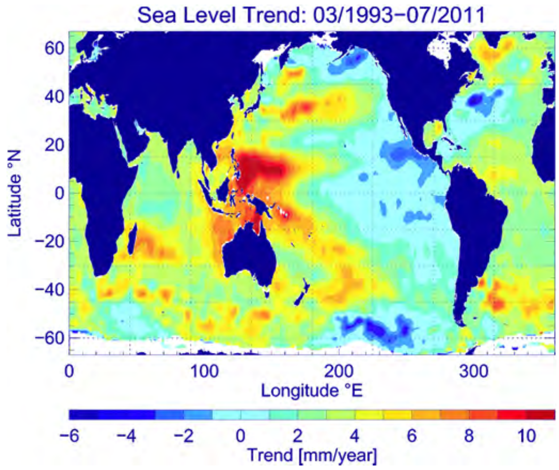


Figure 6. An example of estimates of the sea level trend (© S. Esselborn, GFZ).

9. Weather

This SBA is mainly about improving weather information, forecasting and warnings. GNSS contributes by providing meteorological data, which are already operationally used. The two major applications are based on occultation and ground-based geometries. For example, EUMETSAT operates the METOP satellites carrying the GNSS Receiver for Atmospheric Sounding (GRAS) for sounding of temperature and humidity profiles by observing the occultation of GNSS satellite signals. An example of ground-based networks of GNSS receivers is the E-GVAP project (http://egvap.dmi.dk/) operated by EUMETNET.

Parameters, which can be estimated (directly or indirectly) from GNSS data are: temperature, pressure, humidity, precipitation, soil moisture, snow cover and snow depth (see Figure 7), ice cover, and wind/turbulence.

Figure 7. The GNSS station NWOT in Boulder, CO, USA used to measure snow depth by means of reflections of GNSS signals (© K. Larson, Univ. of Colorado).

References (available from www.gfg2.eu)

Gauss, M., GNSS for Global Environmental Earth Observation (GEEO) and GEOSS, Public Report of the GfG2 project, European Union, FP7-ENV-2010 GA No. 265098, 22 p., 2011.

Wickert J., A. Egido, G. Elgered, S. Fuller, M. Gauss, R. Jongman, C. Martin-Puig, P. Monks, Novel GNSS applications for GEEO and GEOSS, Public Report of the GfG2 project, European Union, FP7-ENV-2010 GA No. 265098, 43 p., 2012.

Long term measurements of the energy balance in the urban area in Łódź, central Poland

Krzysztof Fortuniak, Włodzimierz Pawlak, and Mariusz Siedlecki

Department of Meteorology and Climatology, FGS, University of Łódź, Poland (kfortun@uni.lodz.pl)

1. Introduction

The modern mesoscale meteorological models deal with resolution less than a few kilometers. In a consequence the urbanized areas should be included in the models as a specific surface cover. The parameterizations especially developed for the urban areas are needed to fulfill these expectations. For these reasons a good measurement data are necessary to verify possible parameterizations. The measurements of the energy balance components in Łódź, included turbulent fluxes estimated with eddy covariance method, belongs to the longest on the urbanized areas. The aim of this work is to present a climatological characterization the energy balance components based on the more than 10 years time series.

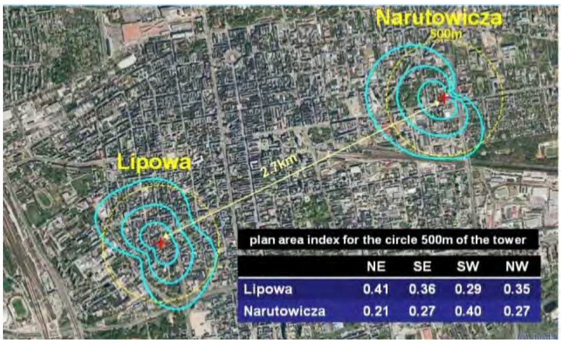


Figure 1. Location of the measurements sites in Łódź.

2. Sites characteristics, instrumentation and methodology

Regarding the population (750 000) Łódź is the third city in Poland. It is localized on the relatively flat area, on big European lowlands, with no large water reservoirs in the nearest neighborhood. The city arrangement is also very clear with a well defined roof level. Because of these Łódź is a favorable place for studies on urban climate. The measurements of full energy balance components, with eddy covariance technique for estimation of sensible and latent turbulent heat flux started in Łódź in November 2000 under cooperation between Łódź University and Indiana University (Sue Grimmond and Braian Offerle). The site was located in the west core of the old town at the University building at Lipowa 81 str. (Fig. 1). The measurements height was 37 m which was about 25 m above mean roof level (Fig. 2), so it gave hope that measurements were made in the constant flux layer just above the blending height. The wind speed components were measured with the aid of sonic anemometer (ATI) and the fluctuation of the water vapor concentration with KH20 krypton hygrometer. The measurements frequency was set as 10Hz. The turbulent fluxes was estimated for the one hour period with simple box averaging. All typical procedures was used for data corrections and analysis. Radiation balance components were measured with CNR1 net radiometer and other slow respond data was measured simultaneously to get meteorological a background. This experiment ended in 2003. The next system was set is the same place in the year 2006. The new system was very similar, but wind components were measured in RMYoung 81000 and Li7500 was used for measurements of H2O and CO2 components. This system is still working. In the year 2005 the other tower was set at Narutowicza 88 str. The site is located about 2.7 km east from the first site. The measurement height is 42 m a.g.l. withch is again about 25 m above the roof level. The system is equipped with RMYoung 81000 and KH20 for fast respond signals and CN1 for radiation balance. The data processing is the same as at the firs site.

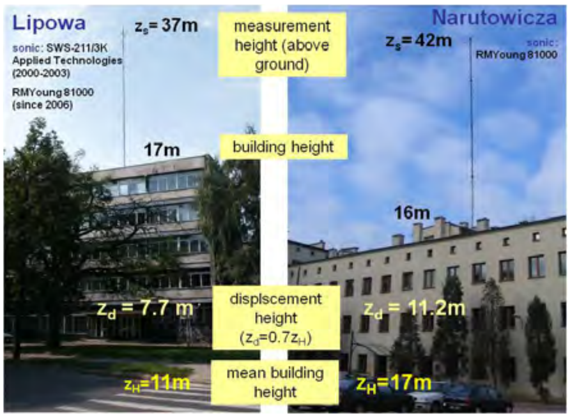


Figure 2. The measurements towers in Łódź.

3. Results

The results of measurements of sensible and latent heat as well as carbon dioxide fluxes registered at Lipowa street in the period 2006 – 2012 are presented at Figure 3. Annual variability of energy and mass fluxes observed in the center of Łódź, are similar to the reported in other mid-latitude cities. The QH and QE fluxes have a consistent rhythm with variability of temperature and radiation balance. The highest observed values of sensible heat flux values reach more than 400 W m^{-2} in summertime, while during cold season these values are lower, of the order of 100 W m^{-2}. Latent heat flux reaches significantly lower values with maximum ~200 W m^{-2} in warm season. Such low values are due to limited ability of urban surface to evaporation, because of low amount of green areas and rainfall water drainage to the city sewage system. Carbon dioxide flux annual variability can be characterized as opposite to annual rhythm of air temperature. Maximal values of this flux (~40-60 μmolm^{-2}s^{-1}) occur during wintertime due to intensive release of anthropogenic carbon dioxide related to fossil fuel combustion (car traffic, house heating, etc.). In summertime FCO_2 values are significantly lower (~10 μmolm^{-2}s^{-1}), firstly because of anthropogenic carbon dioxide release reduction, and secondly, due to carbon dioxide uptake by plants. Results of FCO2 measurements show that Łódź center is a source of carbon dioxide all year long.

Acknowledgements

The work was supported by Polish National Centre of the Science under project 2011/01/D/ST10/07419.

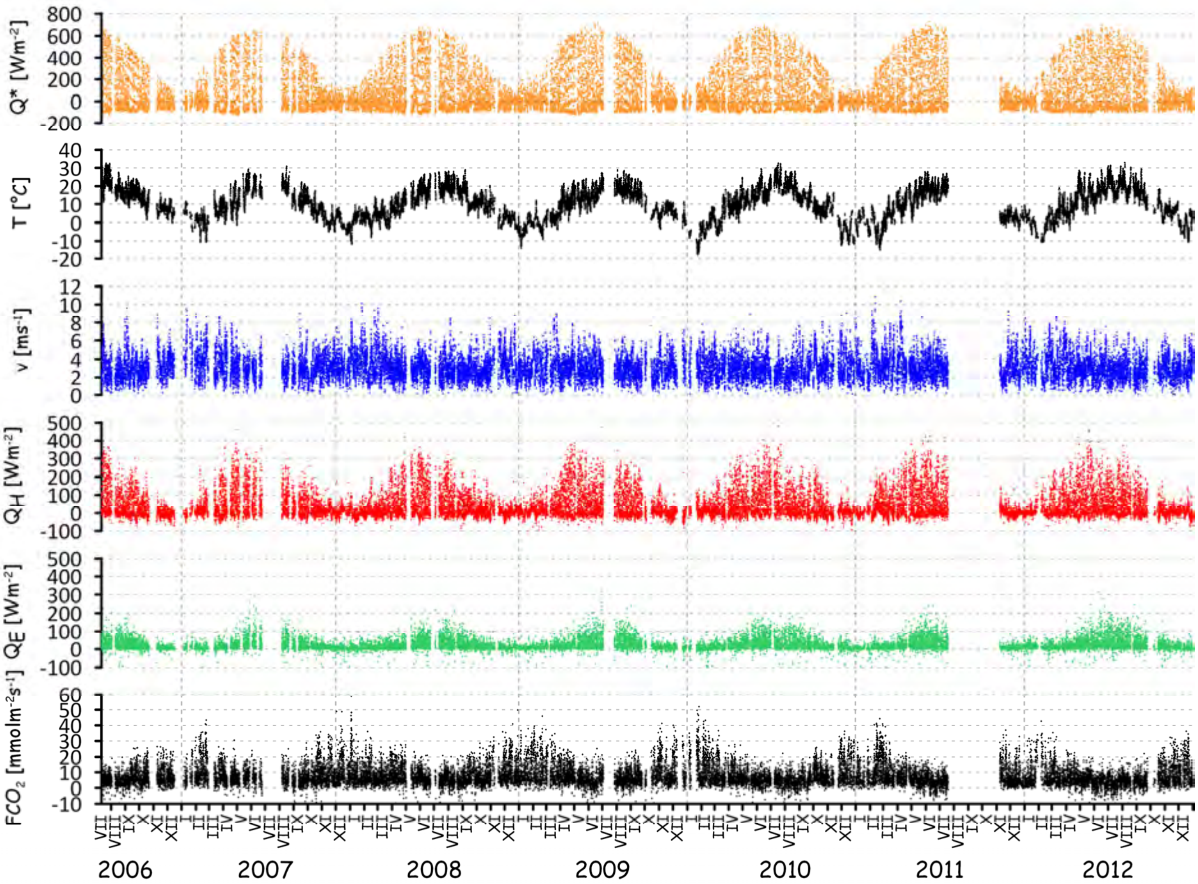


Figure 3. Example of the long term measurements of the energy balance components and CO2 flux at Lipowa 81 site in Łódź.

Surface energy balance and exchange of greenhouse gases in Eastern Poland wetland – A new EC site in Biebrza National Park

Krzysztof Fortuniak, Włodzimierz Pawlak, Mariusz Siedlecki, and Mariusz Zieliński

Department of Meteorology and Climatology, FGS, University of Łódź, Łódź, Poland (kfortun@uni.lodz.pl)

1. Introduction

An accurate estimation of net ecosystem exchange of main greenhouse gasses (H2O,CO2, CH4) for Eastern European wetlands is extremely important in for understanding of their role in the global climate system. The problem is vitally important in light of increase of global warming. Modern measurement techniques, like eddy covariance method (EC), allow for direct estimation of the net surface-atmosphere exchange. A lack of commercially available fast respond sensors as well as low possibilities in data storing and processing limited extensive applicability of the EC method in environmental studies for a long time. The rapid grow of the EC network observed in last two decades, originally focused on measurements energy balance components, next on additional estimation of the CO2 flux, and finally on the CH4 flux in the last years. Regular EC flux measurements in Poland are limited to a few sites only. A surface energy balance measurements at urban area are conducted in Łódź, central Poland, since November 2000. A complex measurement station (including EC flux measurements of H2O and CO2) was established in 2003 in the peatland in Rzecin (Western Poland) and a few years later in 2008 a tower for measurements over the pine forest was built in Tuczno. An agricultural station (EC measurements of H2O and CO2) operates in Annosław since 2011.

The aim of this work is to present preliminary results from a new station set in November 2012 at wetland of Biebrza National Park in north-eastern Poland.

2. Site location, instrumentation and data processing

Biebrza National Park is a biggest national park in Poland established to protect unique environment of wetland in north-eastern Poland. It covers the biggest marshes in Eastern Poland. Total area of the Park is about 592 km^2 of which marshes cover almost 255 km^2. Rest is covered by fields and meadows (182 km^2) and forests (155 km^2). For some years the natural area around Biebrza river suffer for partially draining due to irrigation systems. Recently there are some afford to re-cultivate original water system. For that reason biological and chemical processes at the area can differ from other wetlands. The problem is typical for a large part of western Poland where irrigation made a few decades ago altered natural ecosystem.

The measurement point is located at the periphery of the famous marshland called “Czerwone Bagno” near to the village Kopytkowo (53^{o}35'20"N, 22^{o}53'31"E). The system is built up on very characteristic land cover in the Park – the wetland covered by sedge and narrow small reed. The fetch is very homogenous in all direction except south sector where a 3 separate buildings are located in distance about 500m.

The eddy covariance system is equipped in a sonic anemometer (81000, RMYoung, USA) and two gas analyzers: Li7500 for fast measurements of H2O and CO2 and Li7700 for CH4 (Li-cor, USA). The measurement frequency of EC system is set as 10Hz. The system is completed by slow response measurements include: two temperature and humidity probes (HMP60, Vaisala, Finland), atmospheric pressure sensor, cup anemometer and wind wane, rain gauge, net radiometer (CNR1, Kipp&Zonen, Netherlands – independent measurements of downward and upward shorwave and longwave radiation), two PAR sensor faced up and down, ground heat flux plates, and volumetric water content sensor. The system is governed by CR5000 datalogger (Campbell Scientific, USA). Data are stored in 15min files at the PC computer connected to the logger.

Figure 1. Measurement site in Biebrza National Park, north-east of Poland.

The middle of path of the eddy covariance system is on the height 3.5m above the ground. The wind sensors are about 20-30cm lower. Net radiometer and PAR sensors are mounted at the height 3m above the ground on the horizontal arm in a distance of 3m from fast respond sensors. All electronics is in the box 1.5m below the horizontal arm (Fig. 1).

Data processing is standard for eddy covariance system. Preprocessing include checking of the consistency limits and spike detection. The covariance from the time shift +/- 2s was maximized to determine time shift between series used in further calculations. The fluxes are calculated in natural wind coordinate system with double rotation (Kaimal and Finnigan, 1994). The sonic temperature is corrected for humidity and the WPL (Webb et al. 1980) correction for mass imbalance is applied to the data. As both high frequency truncate due to sensors limitation and low frequency losses due to short averaging period can decrease results the correction for spectral losses is included. We use this correction together with other corrections by analytical solution of equations set by the method proposed by Horst (2003).

The stationarity condition is checked by using three tests: the test proposed by Foken and Wichura (1996) with a critical value of RN_{FW} = 0.3; the non-stationarity ratio, NR, given by Mahrt (1998) with a critical value of NR = 2; and the relative covariance stationarity criterion introduced by Dutaur et al. (1999) with a critical value of the relative covariance stationarity coefficient, RCS = 0.5.

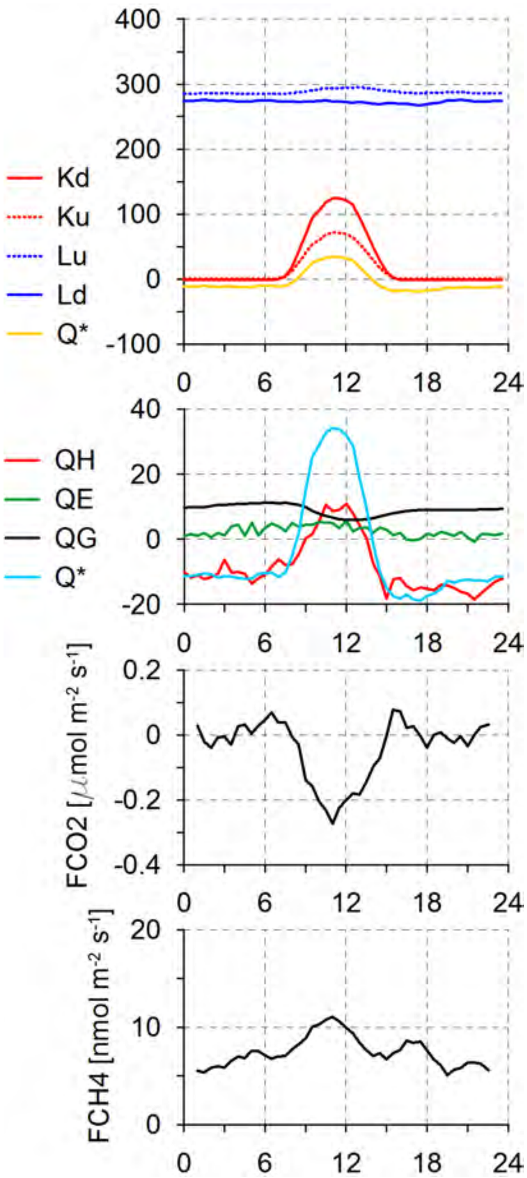


Figure 2. Average daily variation of the energy balance components, fluxes of CO2 and CH4 in the period December 2012 – January 2013.

3. Results

As the system was installed in November 2012 only the preliminary results are already available. Moreover, a high frequency of the rains/snows significantly reduce a number of available data. Figure 2 presents the average diurnal course of energy balance components (in W·m^{-2}) and the net fluxes of the CO2 and CH4 for the two months winter period December 2012 – January 2013. The mainly cloudy weather resulted in almost equal longwave radiation fluxes on the level of 280 – 300 W·m^{-2}, unvarying all over the day. Average downward shortwave radiation reached 120 W·m^{-2} in the noon. Large part of this energy was reflected because of considerable snow cover. As the result the total monthly radiation energy balance was negative, on the level of -0.36 MJ·m^{-2}. A sensible heat flux is positive (upward) in the noon hour only, whereas latent heat flux is positive over all 24h, but its values are on the very low level, comparable to the measurements accuracy. Even if vegetation is strongly reduced during winter period, the net ecosystem exchange (NEE) of CO2 is clearly negative in the noon hours (area is a sink of CO2). The mean uptake of CO2 is on the level of 0.26 g·m^{-2} per month. In the contrast, the ecosystem is a continuous source of CH4 on the level of 9 mg·m^{-2} per month with maximal values of NEE in noon hours.

Acknowledgements

We would like to thank Biebrza National Park for the cooperation and allowance for research on the Park area. The work was supported by Polish National Centre of the Science under project UMO-2011/01/B/ST10/07550 and Polish Ministry of Science and Higher Education (State Comity of Science Research) under project N N306 519638.

References

Mahrt L (1998) Flux sampling errors for aircraft and towers. Journal of Atmospheric and Oceanic Technology 15: 416–429

Foken T, Wichura B (1996) Tools for quality assessment of surface-based flux measurements. Agricultural and Forest Meteorology 78: 83–105

Dutaur L, Cieslik S, Carrara A, Lopez A (1999) The detection of nonstationarity in the determination of deposition fluxes. Proceedings of EUROTRAC Symposium '98, vol. 2. WIT Press: Southampton, 171–176

Horst, T.W., 2003, Corrections to sensible and latent heat flux measurements, http://weather.nmsu.edu/pecans/

Kaimal, J.C., Finnigan, J.J., 1994, Atmospheric boundary flows. Their structure and measurement, Oxford Univ. Press, 289 pp.

Sea ice thickness variability in the Baltic Sea

Jari Haapala, Mikko Lensu, Byoung Woon An, Jonni Lehtiranta and Iina Ronkainen

Finnish Meteorological Institute (jari.haapala@fmi.fi)

The recent years show a large inter-annual variability of ice conditions in the Baltic Sea. The winters 2008 and 2009 were very mild, and sea ice was formed only in the Bay of Bothnia and in the coastal areas of the Bothnia Sea and Gulf of Finland. The maximum ice extent was only 49000 km^2 and 110000 km^2 in 2008 and 2009, respectively. In contrast, the winters of 2010 and 2011 are classified as severe ice winters, with an ice extent of 244 000 km^2 and 309000 km^2, respectively.

For climate studies, sea ice thickness, or more desirably, large scale sea ice thickness distribution, should be the main indicator of sea ice changes since it essentially represents the mass of the ice pack. Unfortunately, sea ice thickness monitoring activity in the Baltic Sea is limited to the land-fast ice regions, where ice can be thinner than in the drift ice regions.

In order to obtain observations of large scale ice thickness distributions, FMI has conducted extensive measurement campaigns during the last years. Ice thickness data have been collected by helicopter- and ship-borne electromagnetic methods and bottom mounted sonar.

Locally, ice thickness is known to exceed 20 meters in ridges, but the contribution of the ridged ice to the total sea ice volume has not been quantified before. New observations show that even on the basin scale, mean ice thickness could be twice as large as purely thermodynamically produced ice mass would be.

In this paper, we combine measurements and numerical model simulations for a comprehensive analysis of inter-annual variability of ice thickness. The HELMI and LIM-3 multi-category sea ice models are used in the analysis. Both resolve ice thickness distribution, i.e. ice concentrations of variable thickness categories, redistribution of ice categories due to deformations, thermodynamics of sea-ice, and horizontal components of ice velocity and internal stress of the ice pack. Differences are that the HELMI makes a separation between the ice types, while the LIM-3 applies a general ice thickness distribution theory and is coupled to the NEMO ocean model. The simulation period covers the years 2004 – 2012 for HELMI, and 1960-1997 for LIM-3. Both models capture very well inter-annual variability of ice extent and thickness as well as spatial variability of ice thickness. Both models produce considerable thicker ice than traditional two-level ice models, but still slightly underestimate ice thickness.

Freshwater outflow of the Baltic Sea and transport in the Norwegian Current: A statistical correlation analysis based on a numerical experiment

Robinson Hordoir[1], Christian Dieterich[1], Chandan Basu[2], Heiner Dietze[3] and Markus Meier[1]

[1] Swedish Meteorological and Hydrological Institute, Norrköping, Sweden (robinson.hordoir@smhi.se)
[2] National Supercomputing Centre, Linköping University, Sweden
[3] IFM-Geomar, Kiel, Germany

1. Abstract

Based on the results of a numerical ocean model, we investigate statistical correlations between wind forcing, surface salinity and freshwater transport for the Baltic Sea outflow and Norwegian Coastal Current freshwater transport. These correlations can be explained in terms of physics and reveal how the two freshwater transports are linked with wind forcing, although this information proves to be non-sufficient when it comes to the dynamics of the Norwegian Coastal Current. Based on statistical correlations, the Baltic Sea freshwater transport signal is reconstructed and shows a good correlation but a poor variability when compared with the measured signal, at least when data filtered on a two-daily time scale is used.

A better variability is reached when data filtered on a weekly or monthly time scale is used. In the latest case, a high degree of precision is reached for the reconstructed signal. Using the same kind of methods for the case of the Norwegian Coastal Current, the negative peaks of the freshwater transport signal can be reconstructed based on wind data only, but the positive peaks are under-represented although some of them exist mostly because the meridional wind forcing along the Norwegian coast, forcing that is taken into account. Adding Norwegian coastal salinity data helps improving the reconstruction of the positive peaks, but a major improvement is reached when adding non-linear terms in the statistical reconstruction. All coefficients used to re-construct both freshwater transport signals are provided for use in European Shelf or Climate modeling configurations.

2. BaltiX : A NEMO based configuration for Baltic & North Sea Modelling

BaltiX is a Baltic & North Sea configuration based on the NEMO Madec et al. (2010) ocean engine. Its development was started in 2011 at SMHI (Swedish Meteorological & Hydrological Institute, Norrkping, Sweden). It follows closely the development of the NEMO ocean engine, and BaltiX is updated each time an update is done in it.

The computational domain of BaltiX covers the entire Baltic Sea, the English Channel and the North Sea, with open boundary conditions between Cornwall and Brittany (meridional), and between Hebride Islands and Norway (zonal). The reference bathymetry comes from the HIROMB Funkquist and Kleine (2007) model, except for the Danish Straights where the IOW bathymetry is used and is either averaged over each grid cell, or taken as the maximum value. The domain is therefore the same as that of the HIROMB configuration, has a resolution of approximately 2 nautical miles (≈ 3700m), and a basic vertical resolution of 3m close to the surface, decreasing to 22m at the bottom of the deepest part of the domain, that is the Norwegian trench. The vertical grid has a total of 56 levels and uses VVL coordinates (Adcroft and Campin, 2004) with an explicit free surface. Partial steps are used in order to reach a good consistency between the input bathymetry and that indeed used by the numerical model configuration. From a barotropic point of view, open boundary conditions are defined using the Oregon State University Tidal Inversion Model Egbert et al. (1994); Egbert and Erofeeva (2002) with 11 tidal harmonics defined both SSH and velocities. From a baroclinic point of view, Levitus Levitus and Boyer (1994) is used for temperature and salinity with a sponge layer, and simple radiation conditions are used for baroclinic velocities. The surface boundary condition uses a bulk formulation based on Large and Yeager (2004), and in addition the LIM3 ice model Vancoppenolle et al. (2008) is used with a fixed ice salinity equal to 10−3 PSU. A climatological runoff is used based on different databases for the Baltic and the North Seas, and the salinity of runoff is also set to 10−3 PSU which is enough to avoid any negative salinity issue close to river mouths even when the runoff is rejected on a single grid cell, as it is the case in this configuration. In addition to the TVD scheme mentioned later in the present article, the version of the NEMO Ocean Engine that is used (version 3.3.1) allows rejecting runoff as a lateral boundary condition, which produces an estuarine like baroclinic circulation close to river mouths, bringing enough salt to ensure a stable positive salinity even in the very low saline areas of the domain, such as the Gulf of Finland or the Bothnian Bay. A quadratic friction is applied at the bottom, and the drag coefficient is computed for each bottom grid cell based on a classical law-of-the-wall, with a constant bottom roughness of 3cm.

A time splitting method is used, and a modified leapfrog method is implemented in order to ensure conservation Leclair and Madec (2009). A TVD scheme is used for tracer advection. A Laplacian diffusion scheme is used, and a Smagorinsky method Smagorinsky (1963) has been implemented in order to lower as much as possible the value of the diffusion coefficient into the two very different dynamical systems that are the North Sea and the Baltic Sea : one which is very dynamic and mixed, the other less dynamic and more stratified. A k − vertical turbulence model is used, and a parameterisation of the bottom boundary layer (Beckmann and Döscher , 1997; Campin and Goosse, 1999) is included both from an advective and a diffusive point of view. The advective part is included to help dense water flows cross over the Danish straights, which is mostly a high frequency wind driven circulation process driven both by barotropic and baroclinic currents Gustafsson and Andersson (2001). In addition, it is important for dense water inflows to be able to reach the centre of the Baltic proper, which is a lower frequency process Meier et al. (1999). This process requires several weeks or months during which it is important that bottom dense water flows follow the bathymetry, and that the z system coordinates do not induce artificial mixing.

The atmospheric forcing comes a downscalled run of ERA40 (used at the open boundaries) using RCA Samuelsson et al. (2011) for the period 1961-2007. The resolution of the atmospheric model is 50km but depends in terms of variability to the one degree horizontal resolution ERA40 re-analysis run that is applied at the open boundaries. The model has been first validated from a barotropic perspective, and shown to be able to represent the SSH (Sea Surface Height), tidally induced, and/or wind driven. This is especially true for critical measurement stations such as Landsort Deep (Baltic Sea) which variability is highly correlated with the total Baltic Sea volume, and the deep salt inflows. The model was also shown to provide realistic SSTs (Sea Surface Temperature) and ice covers, and the variability of the deep water salinity at Gotland Deep in the Baltic Sea is also realistic. Some tuning is still done in order to achieve a better representation of the halocline which appears still to be too stiff and too high.

References

Adcroft, A., and J.-M. Campin (2004), Re-scaled heightcoordinates for accurate representation of free-surface flows in ocean circulation model, Ocean Modelling, 7.

Beckmann, A., and R. Döscher (1997), A method for improved representation of dense water spreading over topography in geopotential-coordinate models., J.Phys. Oceanogr., pp. 581–591.

Campin, J.-M., and H. Goosse (1999), A parameterization of density-driven downsloping flow for a coarse resolution ocean model in z-coordinates, Tellus, pp. 412–430.

Egbert, G., A. Bennett, and M. Foreman (1994), Topex/poseidon tides estimated using a global inverse model, J. of Geophys. Res., 99, 24,821 – 24, 852, 1994.

Egbert, G. D., and S. Y. Erofeeva (2002), Efficient inverse modeling of barotropic ocean tides, Journal of Atmospheric and Oceanic Technology, 19 (2), 183–204, doi:10.1175/1520-0426.

Funkquist, L., and E. Kleine (2007), Hiromb - an introduction to hiromb, an operational baroclinic model for the baltic sea, Tech. rep., SMHI.

Gustafsson, B. G., and H. C. Andersson (2001), Modeling the exchange of the baltic sea from the meridional atmospheric pressure difference across the north sea, J. Geophys. Res., 106, 19,731–19,744.

Large, W. G., and S. Yeager (2004), Diurnal to decadal global forcing for ocean and sea-ice models : the data sets and flux climatologies, Tech. rep., NCAR Technical Note, NCAR/TN-460+STR, CGD Division of the National Center for Atmospheric Research.

Leclair, M., and G. Madec (2009), A conservative leapfrog time stepping method, Ocean Modelling, doi:10.1016/j.ocemod.2009.06.006.

Levitus, S., and T. P. Boyer (1994), World Ocean Atlas 1994, vol. 5, Salinity, NOAA Atlas NESDIS, U.S. Gov. Print Off., Washington, D.C.

Madec, G. (2010), Nemo ocean engine, version 3.3, Tech. rep., IPSL, http://www.nemo-ocean.eu/.

Samuelsson, P., C. Jones, U. Will´n, U. Ullerstig, S. Golvik, U. Hansson, C. Jansson, E. Kjellstr¨m, G. Nikulin, and K. Wyser (2011), The rossby centre regional climate model rca3: model description and performance, Tellus, 63A, 4–23.

Smagorinsky, J. (1963), General circulation experiments with primitive equations, 1. the basic experiment, Mon. Weather Rev., 91, 99–164.

Vancoppenolle, M., T. Fichefet, H. Goosse, S. Bouillon, G. Madec, and M. A. M. Maqueda (2008), Simulating the mass balance and salinity of arctic and antarctic sea ice, Ocean Modelling.

What do we know about the human impact on aerosol cloud-mediated climate processes in the Baltic Sea Region?

Olaf Krüger

Tartu Observatory, Tõravere and Institute of Physics, University of Tartu, Estonia (olaf.krueger@aai.ee)

Aerosol properties as well as cloud albedo are most uncertain forcing agents [IPCC, 2007]. However, while the planet's additional greenhouse effect is increasing, which is well supported by the analysis of temperature and concentration records, there are only few observations indicating climate change caused by aerosol abundance [Krüger, 2006]. This might be mainly due to the heterogeneity of the source strengths, a short residence time and a multitude of chemical and physical processes by which aerosols are characterized. The strongest uncertainty arises from the impact of the variable aerosol particle number and aerosol composition on optical properties of clouds and on cloud cover. Theoretical investigations underline: The influence of aerosol particles on radiative fluxes in cloudless atmospheres is neither negligible in the solar nor in the terrestrial spectral region. Within clouds aerosol particles may contribute remarkably to heating rates in the solar part of the spectrum, while cloud albedo is a function of aerosol particle number and their chemical characteristics [Grassl, 1978]. Consequently, the cloud radiation field modified by aerosol changes is an important and widely open issue, which needs to be addressed in estimates of the global and regional radiation budgets.

Contrary to the well-known positive radiative forcing caused by increased concentrations of long-lived greenhouse gases, anthropogenic aerosols can have different consequences for the radiation budget. They either can warm or cool the earth/atmosphere system. Thereby the sign of the direct aerosol forcing for cloudless atmospheres is determined both by back-scattering and absorption, which may vary considerably in the vertical. Also the reflectance of the under-lying surface plays an important role. If the surface is non-Lambertian the bidirectional reflectance distribution function (BRDF) has to be considered [Kriebel, 1977]. The apparent reflectance, i.e. the reflectance of a natural surface modified by the Rayleigh scattering and aerosol layer(s) above, varies with optical thickness and type of the aerosol. The wavelength dependent aerosol influence ranges from an increase for low reflectance to a decrease in case of a strong absorbing component. Higher absorption is characteristic for urban aerosols usually containing clearly more black carbon (BC) than continental aerosols. A lowering of reflectance, resulting in a warming effect at the surface can preferably occur for a strongly absorbing component in the aerosol above a highly reflecting surface like white sand, snow or ice [Krüger and Fischer, 1994].

Once deposited on the surface absorbing aerosols can also alter the surface reflectance. The analysis of BC in snow water shows mean values of 30ppb (parts per billion by mass; equivalent to ng/g or µg per liter meltwater) in fresh, non-fresh, firn and windblown snow even in the Arctic indicating the relevance for global warming [Noone and Clarke, 1988]. The values at rural sites e.g. in Lithuania often exceed 100ppb with peak values of 150ppb during the cold season [Amalis, 1999].
The Fourth Assessment Report (AR4) of the IPCC indicated that the mean global radiative forcing caused by the direct aerosol effect amounts to about –0.5W/m^2. The cloud albedo effect marked with the lowest level of scientific understanding is estimated to be negative, reaching in the global mean about –0.7 W/m^2 [IPCC, 2007]. Here, the major present deficiency in knowledge is, however, not just the accuracy of any global mean value. The more general question is if the global radiative forcing as defined in the AR4 is an adequate metric at all to describe potential effects of aerosol particle abundance.

Observations confirm that at different scales characteristic atmospheric perturbations become dominant dependent on solar irradiance and on location in the earth/atmosphere system. Generally the following changes are expected being relevant for the Baltic Region:

On the cloud scale the interaction of cloud and aerosol processes determine the initial concentration and size of droplets. The aerosol cloud interaction is perturbed in many regions by an increasing amount of anthropogenic aerosol particles. The major influence is due to changed cloud albedo, cloud lifetime and precipitation amount.

On the regional scale pronounced indirect aerosol effects are expected to occur in areas of strong anthropogenic release of particles, i.e. the so-called polluted regions. This may modulate the additional greenhouse effect considerably. The aerosol influence on clouds could dominate other perturbations dampening or amplifying the cloud-radiation feedback, which reduces the relative importance of any other forcing agent on this scale considerably. In case of the more heterogeneous aerosol perturbation the regional radiation regime in an initial environment will react by a more variable radiation budget in contrast to the much more homogeneous warming by long-lived greenhouse gases. This heterogeneity of the aerosol effects is also due to the pronounced dry and wet deposition processes in the atmospheric boundary layer. The general influence of aerosols may be recognized in data records for albedo, solar irradiance, temperature, precipitation and cloudiness.

For Europe a rather comprehensive knowledge about the emissions and concentrations of air pollutants, and in particular the availability of information about aerosols and their precursor gases exists. Measurements and model calculations in addition indicate a strong variability of this pollution plume due to changing emissions, chemical transformations, deposition and long-range transport of the manifold species all depending on season and weather type [see e.g. Eliassen and Saltbones, 1983, Krüger and Tuovinen, 1997, EMEP, 2004, Schaap et al., 2004, van Dingenen et al., 2004, Putaud et al., 2004].

During the late 1980s a strong contribution to the aerosol load over Europe originated from the enormous amounts of particulate matter and aerosol precursor gases emissions, such as sulphur dioxide, nitrogen oxides and ammonia. The exemplarily high sulphur dioxide emissions in the former German Democratic Republic (GDR), which amounted to even more than 5 Tg per year, were of major importance for the secondary aerosol particle formation. The strong contribution of elevated point sources around Halle, Leipzig and Cottbus resulted in pronounced spatial differences of sulphur dioxide (SO2) and particulate matter (PM) concentrations in air.

The collapse of the East Bloc in 1989 resulted in significant reductions of industrial activities and thus atmospheric pollution. A pronounced declining trend was observed in the area of the so-called 'Black Triangle', whose name originates from the enormous damages to human health and ecosystems also caused by soot. This area, covering the southern part of Saxony (Germany), Northern Bohemia (Czech Republic) and south-western Lower Silesia (Poland), is a prominent example for the extensive use of the lignite deposits in Europe.

Satellite data for this strong pollution episode in Europe indicate conspicuous changes in cloud albedo for changing emissions of sulphur dioxide and particulate matter. Furthermore, interesting similarities arise when analyzing the cloud albedo changes for different European Atmospheric Circulation Patterns (Großwetterlagen).

In my talk I will discuss the observational evidence for aerosol cloud-mediated processes over Europe and compare it with other findings, e.g. from long-term measurements of global irradiance and actual characteristics from observations of the European aerosol system. I will also sketch the climate processes which are required in regional atmospheric models for taking into account the feedback mechanisms of interest for interdisciplinary problems.

References

Armalis, S. (1999) Wet deposition of elemental carbon in Lituania. *The Science of the Total Environment* 239, 89-93.

Eliassen, A., C. and Saltbones, J. (1983) Modelling of long-range transport of sulphur over Europe: A two year model run and some model experiments. *Atmospheric Environment* 9, 425-429.

EMEP, Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (2004) Transboundary particulate matter in Europe, Status report 2004: Joint CCC & MSC-W & CIAM Report 2004.

EMEP Report 4/2004, Chemical Coordination Centre, Norwegian Institute for Air Research (NILU), Kjeller, Norway.

Grassl, H. (1978) Strahlung in getrübten Atmosphären und in Wolken. *Hamburger Geophysikalische Einzelschriften* 37, Universität Hamburg.

IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt,

M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Krüger, O. (2006) Indirect Aerosol Effects observed from Space, Rep. Earth Syst. Sci., 34, Max Planck Inst. for Meteorol., Hamburg, Germany.

Krüger, O. and Fischer, J. (1994) Correction of Aerosol Influence in Landsat 5 Thematic Mapper Data. *GeoJournal* 32, 61-70.

Krüger, O. and Tuovinen, J.-P. (1997) The effect of variable sub-grid deposition factors on the results of the lagrangian long-range transport model of EMEP. *Atmospheric Environment* 31, 4199-4209.

Putaud, J.P., Raes, F., Van Dingenen, R., Brüggemann, E., Facchini, M.C., Decesari, S., Fuzzi, S., Gehrig, R., Hüglin, C., Laj, P., Lorbeer, G., Meanhaut, W., Mihalopoulus, N., Müller, K., Querol, X., Rodriguez, S., Schneider, J., Spindler, G., ten Brink, H., Torseth, K., Wiedensohler, A. (2004) A European aerosol phenomenology - 2: chemical characteristics of particulate matter at kerbside, urban, rural and background sites in Europe. *Atmospheric Environment* 38, 2579-2595, doi:10.1016/j.atmosenv.2004.01.041.

Schaap, M., Van Der Gon, H.A.C.D., Dentener, F.J., Visschedijk, A.J.H., Van Loon, M., ten Brink, H.M., Putaud, J.-P., Guillaume, B., Liousse and Builtjes, P.J.H. (2004) Anthropogenic black carbon and fine aerosol distribution over Europe. *Journal of Geophysical Research* 109, D18207, doi:10.1029/2003JD004330.

Van Dingenen, R., C., Raes, F., Putaud, J.-P., Baltensperger, U., Charron, A., Facchini, M.C., Decesari, S., Fuzzi, S., Gehrig, R., Hansson, H.-C., Harrison, R.M., Hüglin, C., Jones, M., Laj, P., Lorbeer, G., Meanhaut, W., Palmgren, F., Querol, X., Rodriguez, S., Schneider, J., ten Brink, H., Tunved, P., Torseth, K., Wehner, B., Weingartner, E., Wiedensohler, A., Wahlin, P. (2004) A European aerosol phenomenology - 1: physical characteristics of particulate matter at kerbside, urban, rural and background sites in Europe. *Atmospheric Environment* 38, 2561-2577, doi:10.1016/j.atmosenv.2004.01.040.

Upwelling dynamics in the Baltic Sea studied by a combined SAR/infrared satellite data and circulation model analysis

Andreas Lehmann[1], Evgenia Gurova[2] and Andrei Ivanov[3]

[1] GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany (alehmann@geomar.de)
[2] Atlantic Branch of P.P Shirshov Insitute of Oceanology RAS, Kaliningrad, Russia
[3] P.P. Shirshov Institute of Oceanology RAS, Moscow, Russia

1. Introduction

Cold upwelled water can impose significant changes in the stability of the marine atmospheric boundary layer (MABL) as well as in the surface water density relative to surrounding waters. Lower wind stress caused by increased stability over colder and denser water leads to lower sea roughness creating areas of lower signal values in synthetic aperture radar (SAR) imagery. The appearance of upwelling on SAR and sea surface temperature (SST) images can have varied correlation because of other factors affecting SAR imaging. High surface concentrations of floating cyanobacteria during summer blooms also cause changes in sea surface roughness (SSR) and can affect imaging of upwelling by SAR (Gurova and Ivanov, 2011). Such areas of cyanobacteria accumulations can be detected by the use of optical remote sensing data like MODIS under cloud-free conditions. However, upwelling is often an intermittent process so that lowering in SST is not sustained. Furthermore, the strength and extent of upwelling signatures depends on the prehistory of upwelling events. When a chain of upwelling events is taking place previous upwelling plays a part in the initial stratification for a successive upwelling event, as a result a reduced wind impulse can impose the same upwelling strength in terms of SST drop (Myrberg et al. 2010). To further investigate upwelling events detected in SAR/MODIS satellite images, a high resolution coupled Sea Ice-Ocean Model of the Baltic Sea (BSIOM) has been applied. The model is able to simulate upwelling events realistically (Lehmann et al. 2012). Over upwelling areas the wind stress is significantly reduced if the mean wind speed is below a certain threshold. The upwelling signature can be obtained from satellite images, and, additionally, from the numerical model the associated upwelling dynamics can be derived.

2. Material and methods

In our analysis Envisat ASAR images and MODIS Aqua/Terra SST data and the high resolution coupled sea ice-ocean model (BSIOM), developed by GEOMAR (Kiel, Germany) have been used. In case of SAR, three key mechanisms are proposed to explain the lower radar returns observed in upwelling conditions: an increase in the atmospheric marine boundary layer stability, an increase in the viscosity of surface waters, and the presence of biogenic surfactants in the upwelling region (Clemente-Colón and Yan 1999). The transformation of the atmospheric boundary layer over the upwelling area and the reduction of the sea surface roughness (SSR) due to lower sea surface temperatures decrease the wind stress. Thus, in upwelling areas, where the stability increases, the wind stress will be reduced, and so the calculated wind stress fields can be directly compared with SAR image signatures. Furthermore, for this study additional conditions need to be met: the atmospheric forcing and the time of SAR acquisition must agree, and BSIOM must be able to produce upwelling with a similar temperature difference, and at the right location along the Baltic Sea coast.

Krauss and Brügge (1991) demonstrated that upwelling in the Baltic Sea should be regarded as a three-dimensional current system affecting not only the local coast but also the opposite coast and the interior of the basin. The principle response of a stratified elongated basin to constant wind in length direction of the basin can be described as follows:

(i) In the surface layers there results an Ekman transport in cross direction.

(ii) This Ekman transport produces (northern hemisphere) a sea level rise on the right hand coast (viewing in wind direction) and a fall on the left-hand-side. Furthermore, downwelling occurs on the right-hand-side and upwelling on the left-hand-side resulting in baroclinic effects of the same sign at both coasts.

(iii) Consequently coastal jets are produced along both coasts parallel to the wind direction and a slow return flow compensates this transport in the central area of the basin. The coastal jet is related to the corresponding rise or fall of the sea level close to the coast.

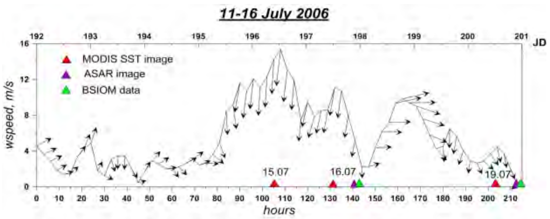


Figure 1. Wind speed and direction extracted at height 10 m at 56° 11.1' N, 20° 36.6' E on 11-19 July 2006, dates and time of ASAR and MODIS image acquisitions are shown by color triangles.

3. Results

In Figures 2c and 3, simulated SST, sea level heights (SSH), barotropic flow field and its relative vorticity on 16 July 2006 are shown. Due to northerly winds (Fig. 1) which triggered an Ekman transport offshore there was a drop of SSH close to the coast and a corresponding coastal jet, geostrophically balanced, developed (Krauss and Brügge 1991). The location of the upwelling filaments are controlled by the interaction of the coastal jet and the bottom topography (Zhurbas et al. 2004). If the water depth decreases in direction of the flow negative relative vorticity is induced and the flow turns offshore, if the water depth increases positive vorticity is induced and the flow turns back to the coast (Fig. 3 c, d). Thus, upwelling filaments in SST are related to the meandering coastal jet. From the model, transports along and offshore the coast were calculated. The transport of the coastal jet was as high as $5{\cdot}10^3$ m^3s^{-1} at the surface

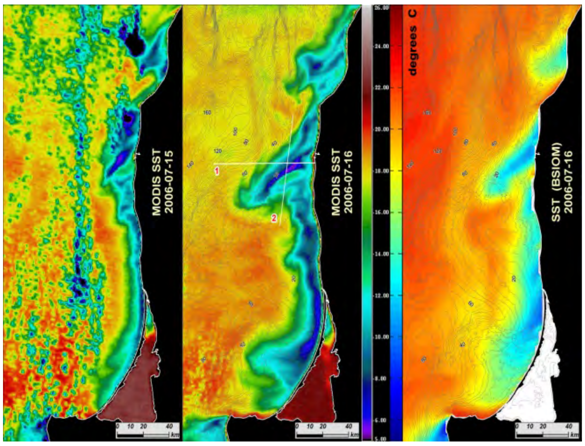


Figure 2. Sea surface temperature fields [°C] derived from MODIS data on 15 (a) and 16 July 2006 (b), and BSIOM model on 16 July 2006 (c). For b) and c) the bottom topography is overlaid.

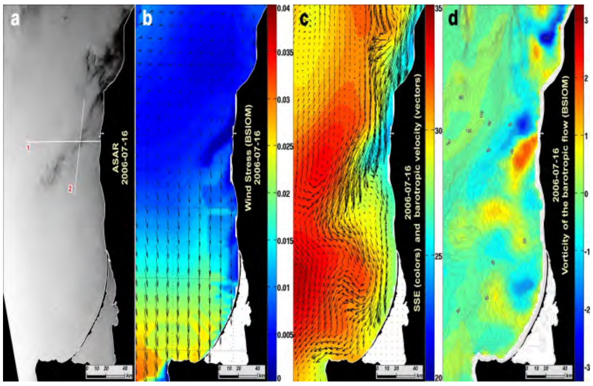


Figure 3. SAR image and modeling results for 16 July 2006: a) ASAR image, b) BSIOM wind stress [Nm^{-2}], c) BSIOM sea surface heights [cm] and barotropic flow, d) BSIOM vorticity of the barotropic flow [s^{-1}].

(average over the first 10 m), and $9{\cdot}10^4$ m³/s over the whole water column. The offshore transport at the surface through a meridional section at 20.5°E was on average $4{\cdot}10^3$ m³/s. Thus the surface transport is comparable with the largest river runoff, and the total transport of the jet is even larger than the mean total runoff to the Baltic Sea which is about $1.4{\cdot}10^4$ m^3s^{-1}.

The SAR image (Fig. 3a) shows distinct structures of low back-scatter correlated with the location of cold upwelled waters. However, the magnitude of the NCRS contrast is not uniform, getting rather weak to the south. The reduced contrast is due to increasing surface winds (Fig. 1) which exerts higher wind stress and increasing roughness on the ocean surface (Fig. 3b). The wind stress reveals similar structures as the SAR image (Fig. 3a, b). Areas of reduced back-scatter coincide with a reduction in wind stress.

4. Conclusions

The utilization of modeled hydrodynamics and wind stress data together with SAR/IR information can provide an extended analysis and deeper understanding of the upwelling process in the Baltic Sea. Infrared satellite images can be used to detect upwelling at the coast. Of course, cloud coverage is a problem, so that for most cases the full upwelling event, lasting normally from several days up to weeks, cannot be observed completely by infrared satellite images. However, SAR can provide information on sea surface roughness even in cloud-covered situations. Increased stability of the MABL over cold upwelled water leads to lower sea surface roughness creating areas of lower signal values in SAR imagery. However, SAR images are sensitive to changes in the background wind field. If a certain wind speed threshold which depends on the across-front temperature gradient is exceeded, the increase in sea surface roughness masks any structures of reduced back-scatter related to cold upwelling.

BSIOM is able to simulate upwelling events realistically. Over upwelling areas where the SST is lowered the wind stress (drag coefficient) is reduced if the wind speed is below a certain threshold (e.g. 5-7 m/s). Thus, SAR images and wind stress fields should show similar structures over upwelling areas. Transports related to upwelling were found to be in the order of $10^3 m^3s^{-1}$ offshore at the surface, and $10^4 m^3s^{-1}$ alongshore associated with the meandering coastal jet.

From the present analysis, the upwelling process and the development of typical upwelling filaments can be described as follows. The wind component parallel to the coast initiates an Ekman transport to/off the coast depending on the wind direction. For the upwelling case, the sea level will drop in direction to the coast resulting in a pressure gradient in the same direction. After geostrophic adjustment a coastal jet is excited. Furthermore, a cross-circulation is set up by the Ekman drift at the surface with an upward vertical velocity at the coast leading to a severe temperature drop if the circulation reaches the base of the thermal mixed layer, and an onshore flow below the thermocline. The barotropic coastal jet is controlled by vorticity dynamics related to depth variations in direction of the flow. Decreasing water depth leads to deflection of the jet from the coast, increasing water depth to return to the coast. The meandering of the coastal jet is associated with the position of upwelling filaments. Thus, along the Baltic Sea coast, typical upwelling patterns will occur at the same locations for similar wind events.

References

Clemente-Colón, P., Yan, X.H. 1999. Observations of east coast upwelling conditions in synthetic aperture radar imagery, IEEE Trans. Geosci. Rem. Sens., 37(5), 2239-2248.

Gurova, E.S., Ivanov, A.Yu. 2011. Appearance of sea surface signatures and current features in the South-East Baltic Sea on the MODIS and SAR images, Issledovanie Zemli iz Kosmosa, 4, 41-54 (in Russian).

Krauss, W., Brügge, B. (1991) Wind produced water exchange between the deep basins of the Baltic Sea. J Phys. Oceanogr., 21, 373-384.

Myrberg, K., Andrejev, O., Lehmann, A. (2010) Dynamics of successive upwelling events in the Baltic Sea – a numerical case study. Oceanologia, 52 (1), 77-99.

Lehmann, A., Myrberg, K., Höflich, K. 2012. A statistical approach to coastal upwelling in the Baltic Sea based on the analysis of satellite data for 1990-2009. Oceanologia, 54, (3), 369-393.

Zhurbas, V.M., Stipa, T., Mälkki, P., Paka, V.T., Kuz'mina, N.P. , Sklyarov, E.V. 2004. Mesoscale variability of the upwelling in the southeastern Baltic Sea: IR images and numerical modeling. Oceanology, Vol 44, 5, 619-628.

A statistical approach to coastal upwelling in the Baltic Sea based on the analysis of satellite data for 1990–2009

Myrberg, K.,[1,2] Lehmann, A.[3] and Höflich, K.[3]

[1]Finnish Environment Institute/Marine Research Centre, Mechelininkatu 34a, FIN-00251 Helsinki, Finland (kai.myrberg@ymparisto.fi)
[2] Department of Geophysics, Klaipeda University, Herkaus Manto 84, LT-92294 Klaipeda, Lithuania
[3]Helmholtz Centre for Ocean Research Kiel, Düsternbrooker Weg 20, D-24105 Kiel, Germany

1.Introduction

Upwelling is an important process in the World Ocean as well as in the Baltic Sea. The Baltic Sea is a semi-enclosed, relatively small basin, winds from virtually any direction blow parallel to some section of the coast and cause coastal upwelling, leading to vertical displacement of the water body and pronounced vertical mixing (e.g. Vahtera et al. 2005).

During the thermally stratified period, upwelling can lead to a distinct drop in sea surface temperature of more than 10°C during one or two days, abruptly changing the thermal balance and stability conditions at the sea surface (e.g. Lehmann & Myrberg 2008). Upwelling can also play a key role in replenishing the euphotic zone with nutritional components necessary for biological productivity when the surface layer is depleted of nutrients. Summer upwelling often transports nutrients with excess phosphorus in relation to the Redfield ratio (see e.g. Vahtera et al. 2005, Lips et al. 2009).

2. Material and methods

The analysis of upwelling regions and their occurrence is based on SST data with a horizontal resolution of about 1 km calculated from NOAA/AVHRR satellite data for the period 1990–2009. The accuracy of the satellite measurement (cloud detection has been carried out) in comparison with in situ data is about 0.5°C (Siegel et al. 1994). From the satellite data, weekly composites are available for the 20-year study period, provided by the Bundesamt für Seeschifffahrt und Hydrographie (BSH in Hamburg, Germany). For each year, upwelling was determined between May and September to cover the part of the year when SST differences due to upwelling are strong enough to be visible, i.e. during the thermally stratified period of the year. A satellite data set of 443 SST maps has been compiled for the 20-year period. Two methods were utilized here to detect and quantify upwelling events. For the visual detection method a horizontal grid with longitudinal resolution of 0.5° and latitudinal resolution of 0.25° resulting in a grid box about 28 km^2 was overlain on each SST map. For the automatic detection method, the full resolution of the satellite SST maps was utilized. A simple temperature threshold value was specified. For most parts of the year there exists a latitudinal SST gradient from south to north. Thus, upwelling was detected by calculating the temperature difference for each individual pixel from the zonal mean temperature, for every pixel line. To test the sensitivity of this method with respect to the temperature threshold, two different values (2ºC and 3.5ºC) were specified.

An additional source of SST data has also been provided from model simulations for the period 1990–2009. The numerical model used in this study is a general three-dimensional coupled sea ice-ocean model of the Baltic Sea (BSIOM, Lehmann & Hinrichsen 2000, 2002).

3. Results

The present paper extends the statistical investigation of Baltic Sea upwelling to cover the entire area of the sea for the first time. For the period 1990–2009, weekly maps based on NOAA/AVHRR satellite data were used to analyse the locations and frequencies of upwelling along the Baltic Sea coast. These characteristics compare very well with earlier studies, also based on satellite observations (Gidhagen 1987, Bychkova et al. 1988). Additionally, daily SST fields derived from a coupled sea ice-ocean model run were analysed for the same period. The statistical analysis was carried out over the thermally stratified period from May to September but also for each individual month. Different methods and various thresholds were applied to different data sets (satellite observations and numerical model results). The overall agreement of the derived statistics was very high, which confirms the robustness of the results.

Upwelling events occurred most frequently along the Swedish east coast and the Finnish coast of the Gulf of Finland (Fig. 1). Upwelling frequencies were related to prevailing wind conditions during particular months and the orientation of the coastline with respect to the wind direction. For the period 1990–2009 a positive trend of upwelling frequencies along the Swedish east coast and the Finnish coast of the Gulf of Finland was calculated, which is in accordance with the positive trend in the wind conditions forcing upwelling, i.e. an increase in south-westerly winds over the Baltic Proper and more westerly directions over the Gulf of Finland. A negative trend occurs along the east coast of the Baltic Proper, the south coast of the Gulf of Finland and the Finnish coasts of the Gulf of Bothnia.

For our analysis we assumed a fixed mixed layer depth, which of course varies during the summer and from year to year. For a deep mixed layer the necessary wind impulse to force upwelling is larger than for a shallow mixed layer in order to produce a signal in SST (Haapala 1994). Additionally, during successive upwelling events, mixed layer depths will not be as deep as during the initial event (Myrberg et al. 2010). Thus a consideration of the mixed layer depth would lead to a better correspondence between upwelling frequencies and favourable wind conditions, but this is somewhat beyond the scope of the present paper. Mixed layer depths can be determined from the numerical modelling results, but our focus was on the statistical analysis of SST observations derived from infrared satellite data for which no information on mixed layer depths was available. Our results show that upwelling frequencies can be up to 40% in some coastal areas of the Baltic Sea; in certain cases upwelling can cover even one third of the surface area of the sea. Upwelling strongly affects the environmental conditions of the sea by increasing vertical mixing, replenishing nutrient-depleted mixed layers and cooling vast areas of the sea surface. This not only impacts biological processes, but can strongly affect the coastal weather, causing unexpected fogs in late summer and an abrupt cooling of coastal areas. The accurate numerical prediction of SST should thus be coupled even better than now as a part of routine numerical weather prediction modelling.

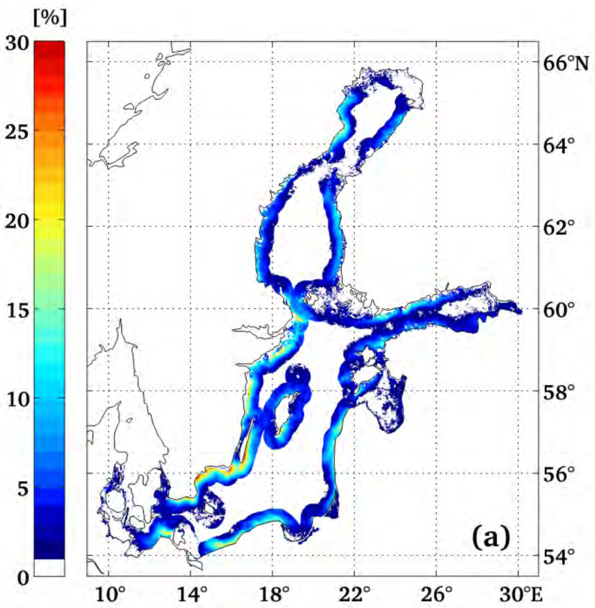


Figure 1. Upwelling frequencies [%] for the months May to September obtained using the automatic detection method, 2◦C temperature threshold, based on 3060 BSIOM SST maps for the period 1990–2009.

For tourist areas, increasing upwelling frequencies during summer will have a negative impact because of the lower sea surface temperatures. Moreover, the nutrient supply to the nutrient-depleted summer mixed layer can trigger phytoplankton blooms. Values of pH could drop by 0.1 pH-units in upwelled water, so with increasing upwelling frequencies in certain areas, there is greater stress on marine organisms resulting from these rapid changes in environmental conditions. Hence, even if the process of upwelling is fairly well understood, climatological changes may affect the frequencies and locations of coastal upwelling; further investigation of upwelling conditions are therefore of vital importance.

References

Bychkova I., Viktorov S., Shumakher. (1988). A relationship between the large scale atmospheric circulation and the origin of coastal upwelling in the Baltic, Meteorol. Gidrol., 10, 9–98, (in Russian).

Gidhagen L. (1987). Coastal upwelling in the Baltic Sea – satellite and in situ measurements of sea-surface temperatures indicating coastal upwelling, Estuar. Coast. Shelf Sci., 24 (4), 449–362, http://dx.doi.org/10.1016/0272-7714(87) 90127-2.

Lehmann A. and Hinrichsen H. -H. (2000). On the thermohaline variability of the Baltic Sea, J. Marine Syst., 25 (3–4), 333–357, http://dx.doi.org/10.1016/ S0924-7963(00)00026-9.

Lehmann A., Hinrichsen H. -H. (2002). Water, heat and salt exchange between the deep basins of the Baltic Sea, Boreal Environ. Res., 7 (4), 405–415.

Lehmann A., Myrberg K. (2008). Upwelling in the Baltic Sea – a review. J. Marine Syst., 74 (Suppl.), S3–S12, http://dx.doi.org/10.1016/j.jmarsys.2008.02.010.

Lips I., Lips U. and Liblik T. (2009). Consequences of coastal upwelling events on physical and chemical patterns in the central Gulf of Finland (Baltic Sea), Cont. Shelf Res. 29 15, 1836–1847, http://dx.doi.org/10.1016/j.csr.2009.06.010.

Siegel, H., Gerth, M., Rudolff , R. and Tschersich, G. (1994). Dynamic features in the western Baltic Sea investigated using NOAA-AVHRR data, Dt. Hydrogr Z., 46 (3), 191–209, http://dx.doi.org/10.1007/BF02226949.

Vahtera, E., Laanemets, J., Pavelson, J., Huttunen, M. and Kononen, K. (2005). Effect of upwelling on the pelagic environment and bloom-forming cyanobacteria in the western Gulf of Finland, Baltic Sea. J. Marine Syst., 58, 1–2, 67–82, http://dx.doi.org/10.1016/j.jmarsys.2005.07.001.

Snow cover impact on ground freeze-thaw in northern Sweden

Maria Nilsson

Department of Social and Economic Geography, Uppsala University, Sweden (maria.nilsson@kultgeog.uu.se)

1. Introduction

The aims of this study are to examine freeze-thaw and related environmental conditions in sub-Arctic Sweden, in order to understand how climate change may affect ground temperatures in the region. Of special interest is snow cover impact on ground temperatures. Results can be used to adapt infrastructure planning to how climate and transports in the region are changing and to improve understanding of how changes in air temperature and precipitation may alter conditions in the ground for ecological processes.

Northern Sweden has a sub-Arctic and boreal climate with a latitudinal temperature gradient in a North-South direction and an altitudinal and moisture gradient in West-East direction. The close proximity to the Arctic, the climate of the region is understood to experience a more rapid climate change in the future (Callaghan et al. 2010, Hassol et al., 2004; Serreze et al., 2000). Warming of the North Sea is further contributing to a larger upheaving of air and increase in precipitation (Kohler et al., 2006). Hence northern Sweden is a key area for studies of ground freeze-thaw as the region is climatologically sensitive to changes (Hassol et al. 2004). Ground frost appears in northern Sweden as short-term freeze-thaw cycles in the topsoil, and as seasonal frost and permafrost. The frost depth is controlled by a stable negative temperature; snow cover depth and duration; and soil and vegetation (Johansson et al., 2006; Juknevičiute & Laurinavičius, 2008). The influence of the snow cover on ground frost is under discussion; a warmer atmosphere is suggested to result in an increase in both freeze-thaw frequency and intensity as a response to snow insulation decrease (Isard & Schaetzl, 1998; Kohler et al., 2006), and a larger spatial variability in ground temperatures is expected as a results of larger regional differences in snow accumulation capacity (Mellander et al., 2007). In these studies it is understood that snow cover have a major influence on ground temperatures. However, results from across Canada, Germany, and sub-Arctic Sweden show instead that ground temperatures correlate in larger terms to air temperatures than to snow precipitation and a temporal increase in freeze-thaw frequency due to snow loss seem to vary with latitude (Henry, 2007; Kreyling & Henry, 2011; Johansson et al., 2011; Schmidt, 2011). There is a gap in knowledge of ground frost development in Sweden in general and boreal northern Sweden in special and thus this needs to be studied more.

2. Methods and Material

Two stations for logging of temperatures of air and ground were installed in northern Sweden in October 2012. Each station logged temperatures at 1 m above ground; at ground surface; and at -0.1 m, -0.2 m and -0.4 m. TINY TAGS© collected temperatures hourly in the period October 2012 - May 2013.

The two stations were installed in Kalix (N65°81'97", E23°30'96") close to the Gulf of Bothnia. The stations were installed on an open grass field, according to the Swedish Meteorological and Hydrological Institute recommendations (SMHI, 2013) The air temperatures were measured at 1 m above ground inside a PVC-tube to avoid turbulence respectively strong insolation. While one station was used for manipulation of snow cover, the other station was used as a reference station. Snow depth was measured after snowfall and the manipulated station was cleaned from snow.

Ground and air temperature data collected by Swedish Administration of Transport (STA) were used to examine spatial ground freeze-thaw in Northern Sweden. 31 STA-stations along roads were used. They were divided into four transects for presentation of both meridional and zonal patterns. These stations were logging temperatures every half hour. Adjacent to these, five STA-stations for logging of temperatures from ground surface to -2 m were used to analyze frost depth in the ground. In these stations temperatures were logged every second hour. The data were further analyzed in a multi-criteria decision analysis (MCDA) to examine snow cover impact on freeze-thaw. Spatial STA data of the season 2011-12 were also compared to the measured data during the season 2012-13.

Mean monthly air temperatures and mean monthly ground temperatures at different levels were calculated along with different aspects of ground freeze-thaw, i.e. frequency, duration and intensity. Through this the spatial variability of freeze-thaw in northern Sweden were analyzed. The results were then analyzed in relation to a digital elevation model, snow depth and land use in terms of traffic. The multi-criteria decision analysis (MCDA) of snow impact on road temperatures was further compared with empirical data.

3. Results and Discussion

The presentation will present primary results of how the removal of snow will affect freeze-thaw at different levels in the ground. The data are used to make inferences about what impact the snow cover depth will have on ground temperatures in sub-Arctic Sweden. Preliminary results show that freeze-thaw frequency decrease and duration increase with ground depth and latitude. Snow cover and air temperature may have different impacts on ground temperatures depending on which months that are studied. Similarly ground temperatures may respond differently to thin snow packs resulting in freeze-thaw differences.

MCDA has been developed for landslide hazard mapping (Lee & Talib 2005; Xu et al., 2012) and environmental decision-making (Huang et al., 2011) but not used in studies of freeze-thaw previously. This study could thus be seen as an attempt to explore MCDA methodology with possible comparisons to Geographical Weighted Regression (GWR) analyses performed for permafrost probability in sub-Arctic Abisko (Ridefeldt et al.2008).

The new findings of this study are a contribution to ground temperature mapping in Sweden, which has up until now been poorly investigated and understood.

Acknowledgements

This study is performed within the licentiate project "Road freeze-thaw in Northern Sweden" at the Research School in Geography at Uppsala University, funded by Kammarkollegiet and Vetenskapsrådet. Nordiskt Vägforum and Uppsala University are acknowledged for their financial support of the fieldwork. Further I would like to thank Jonas Hallenberg at STA for support of data. I also wish to express my appreciation to Jan Boelhouwers, Anders Brandt, Magnus Bohlin and Eva Sahlin for methodological discussions.

References

Callaghan, T. V., Bergholm, F., Christensen, T. R., Jonasson, C., Kokfelt, U., & Johansson, M. (2010). A new climate era in the sub-Arctic; accelerating climate changes and multiple impacts. *Geophysical Research Letters, 37*(14).

Hassol, S. J., Corell, R., & Berner, J. (2004). Impacts of a warming Arctic. Cambridge: Cambridge University Press.

Henry, H. A. L. (2007). Climate change and soil freezing dynamics: historical trends and projected changes. Climatic Change, 87(3-4), 421-434.

Huang, I. B., Keisler, J., & Linkov, I. (2011). Multicriteria decision analysis in environmental sciences: Ten years of applications and trends. *Science of the Total Environment, 409*(19), 3578-3594.

Isard, S. A., & Schaetzl, R. J. (1998). Effects of winter weather conditions on soil freezing in southern Michigan. Physical Geography, 19(1), 71-94.

Johansson, M., Akerman, J., Keuper, F., Christensen, T. R., Lantuit, H., & Callaghan, T. V. (2011). Past and present permafrost temperatures in the Abisko area: Redrilling of boreholes. Ambio, 40(6), 558-565.

Juknevičiute, L., & Laurinavičius, A. (2008). Analysis of the Change in the Depth of Frozen Ground in Different Soils under Lithuanian Conditions. Environmental Engineering, The 7th International Conference, May 22-23, 2008 Vilnius, Lithuania. 1160-1168.

Kohler, J., Brandt, O., Johansson, M., & Callaghan, T. (2006). A long-term Arctic snow depth record from Abisko, northern Sweden, 1913-2004. Polar Research, 25(2), 91-113.

Kreyling, J., & Henry, H. A. L. (2011). Vanishing winters in Germany: Soil frost dynamics and snow cover trends, and ecological implications. Climate Research, 46(3), 269-276.

Lee, S., & Abdul Talib, J. (2005). Probabilistic landslide susceptibility and factor effect analysis. *Environmental Geology (Berlin), 47*(7), 982-990.

Mellander, P.-E., Lofvenius, M. O., & Laudon, H. (2007). Climate change impact on snow and soil temperature in boreal Scots pine stands. Climatic Change, 85(1-2), 179-193.

Ridefelt, H., Etzelmuller, B., Boelhouwers, J., Jonasson, C., (2008) Statistic-empirical modeling of mountain permafrost distribution in the Abisko region, sub-Arctic northern Sweden. *Norsk Geografisk Tidsskrift, 62*(4), 278-289

Schmidt, A.-S. (2011). Time series analysis of ground frost conditions at Abisko, sub-Arctic Sweden, 1985-2010. MSc thesis, Department of Earth Sciences, Uppsala University.

Serreze, M. C., Walsh, J. E., Chapin Iii, F. S., Osterkamp, T., Dyurgerov, M., Romanovsky, V., . . . Barry, R. G. (2000). Observational evidence of recent change in the northern high-latitude environment. Climatic Change, 46(1-2), 159-207.

Xu, C., Xu, X., Lee, Y. H., Tan, X., Yu, G., & Dai(2012). The 2010 Yushu earthquake triggered landslide hazard mapping using GIS and weight of evidence modeling. *Environmental Earth Sciences, 66*(6), 1603-1616.

http://www.smhi.se/kunskapsbanken/meteorologi

Knowledge of the Baltic Sea physics gained during the BALTEX II and related programmes

Omstedt[1], A., Elken[2], J., Lehmann[3], A., Leppäranta[4], M., Myrberg[5], K. and Rutgersson[6], A.

[1] Department of Earth Sciences, University of Gothenburg, Sweden. (anders.omstedt@gvc.gu.se),
[2] Marine Systems Institute at TUT Tallinn, Estonia,
[3]IFM-GEOMAR Kiel, Germany,
[4]Helsinki University, Helsinki, Finland,
[5]Finnish Environment Institute, Helsinki, Finland,
[6] University of Uppsala, Uppsala, Sweden.

1. Introduction

The present review has two main aims: (1) to trace the development of Baltic Sea physics research, in particular into its oceanographic development including sea ice and interaction with atmosphere and land, and Baltic Sea modelling over the last 10 years; and (2) to indicate where we stand today: what is known and what seem to be the key questions for future Baltic Sea research. The review is based on results from the BALTEX Phase II period (2003–2012), but also includes results from other programs that have improved the understanding of how the Baltic Sea functions. Examples of such programme are the BONUS+ programs, BACC I and BACC II. The review starting point is based on two of the objectives during BALTEX Phase II, which are:

- Improved understanding of energy and water cycles under changing conditions
- Analysis of climate variability and change, and provision of regional climate projections over the Baltic Sea basin for the 21st century.

2. Some major findings

- New important data sets and tools available
- New understanding regarding large scale circulation and the Baltic Sea
- Improved water and heat balances
- Improved understanding on sea ice physics (including snow interaction)
- New knowledge about strait flow dynamics
- Improved understanding of sub-basin processes
- New studies on turbulence
- Improve understanding of processes related to air-sea and air-ice interaction
- Improved Baltic Sea models and coupling to land and atmosphere

3. Missing knowledge and future research needs

Despite successful Baltic Sea research several issues are still poorly understood or modelled. Such basic aspects as major inflows to the Baltic Sea need more research efforts. Also the modelling of the hydrological cycle in the atmosphere climate models has severe bias. Bias corrections in both the water and heat balances in these models indicate strong need for new research efforts. River runoff data is not yet easy available. This must be regarded as a major failure in the science development since river runoff data is the most important parameter for evaluating changes in salinity or transports of nutrient and carbon. Also we still lack efforts in making long-time datasets within hydrology and oceanography homogeneous. Here the meteorological science community is leading and give much inspiration.

In the presentation more information on successful development and future research needs will be given illustrating that BALTEX research still are needed and a new decade of research is strongly needed.

BALTEX: 20 years ago and before

Ehrhard Raschke

University of Hamburg and MPI Meteorology, Hamburg)

BALTEX, the Baltic Sea Experiment, was developed about 20 years ago as a consequence of at that time recent developments of regional-scale hydro-meteorological projects within the frame of the Global Energy and Water Cycle Experiment (GEWEX), which was founded in 1988. These had the purpose to investigate and model with highest possible resolution the exchanges of energy, momentum and water between the atmosphere and the surface and the transport of water in systems of rivers and creeks. Three such projects were installed over the discharge area of the rivers Mississippi and Missouri in the USA (GCIP), Mc-Kinsey River in Canada (MAGS) and the Amazon-Basin over South-America.

The area of interest for the studies within BALTEX covers the entire drainage basin of the Baltic Sea which is occupied by 10 nations. The fall of the "Iron Curtain" with all consequences for new political developments within the related countries provided an enormous challenge for such work of common interest. This momentum had been used successfully to establish the major frame of the BALTEX, which still exists in its principles.

First discussion for the need of such an experiment began already in 1990 in Germany with the goal to provide a platform for common work by atmospheric scientists, oceanographers and hydrologists. The German Research Association (DFG) enabled the establishment of a small (GERMAN) BALTEX nucleus in 1990 which drafted first versions of a research plan, which were later subject of discussions and improvements during several workshops. It was finally published in January 1994. The name BALTEX was first proposed by W. Krauß (IfM Kiel) in 1990.

Many hurdles had to be taken to convince national and international scientific and also financial (donators) organizations to establish BALTEX and support the envisaged research and to improve also operational measurements. The WCRP and the GEWEX management endorsed the foundation of BALTEX in 1992. In 1994, finally the BALTEX Secretariat could be established at the former GKSS Research Center in Geesthacht, Germany (now: Helmholtz-Zentrum Geesthacht, HZG). An international BALTEX Science Steering Group was finally founded in 1994. Its purpose was and still is to coordinate and stimulate research activities within BALTEX and to seek (and establish) connections to already existing research and political bodies of particular interest.

Year 2013: BALTEX is still alive and is working healthy with updated scientific goals, while all other regional scale experiments were terminated.

Figure 1. The Baltic Sea drainage basin and the contributing countries (including Skagerrak). Figure courtesy SMHI.

A coupled Atmosphere Ice Ocean Model for the Baltic Sea

Thomas Raub[1,2], Klaus Getzlaff[3], Daniela Jacob[1,2] and Andreas Lehmann[3]

[1] Max Planck Institute for Meteorology, Hamburg, Germany (thomas.raub@zmaw.de)
[2] Climate Service Center, Hamburg, Germany
[3] GEOMAR, Helmholtz Centre for Ocean Research Kiel, Germany

1. Introduction

To improve the understanding of the water and energy cycles of the Baltic Sea was one of the key issues of the BALTEX program. In order to simulate the relevant processes of this complex physical system with its feedback mechanisms, we developed a coupled regional atmosphere-ocean model system consisting of the regional atmosphere model REMO and the Baltic Sea ice ocean model BSIOM. This study presents the first results of the coupled model system.

2. The Model Description and Experimental Design

The model system is an updated version of the coupled model system BALTIMOS [Lehmann(2004)] that was developed within the first phase of BALTEX. The atmospheric part is the hydrostatic version of the regional model REMO [Jacob(2001)] with a horizontal resolution of 1/6° (~18km). The ocean is represented by the Baltic Sea ice ocean model BSIOM [Lehmann & Hinrichsen (2000), Lehmann & Hinrichsen (2002)] with a resolution of 2.5km.

The model is used to simulate the period from 1989 to 1993 using the ERA-Interim reanalysis product from the ECMWF as lateral boundary conditions.

3. Results

The focus of the analysis of the simulation lies on the energy and freshwater budgets of the Baltic Sea. The seasonal thermocline is investigated with respect to its role in the air-sea interactions.

Figure 1 shows the mean sea surface temperature over the Baltic Sea (excluding Kattegat) from the model simulation as well as from several observational and reanalysis data sets. Temperatures in the winter months are in the range of the observations. In spring and summer surface temperatures are too high. This can be explained by a too shallow thermocline.

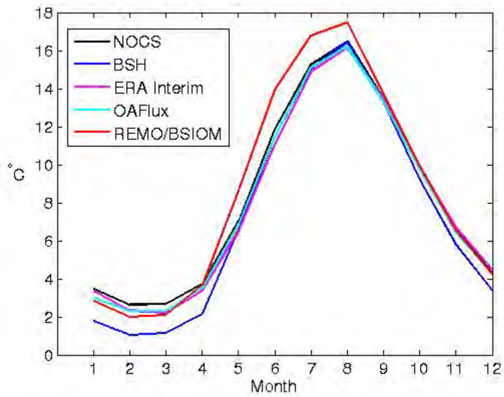


Figure 1: Monthly mean sea surface temperature over the Baltic Sea from the REMO/BSIOM simulation and several observational data sets for the period 1990-1993.

Figure 2 shows the mean net surface heat fluxes over the Baltic Sea. As for the sea surface temperature, the fluxes are well represented in the simulation for the winter months. In summer the fluxes are lower then in the observations and reanalyses as a consequence of the too high sea surface temperatures.

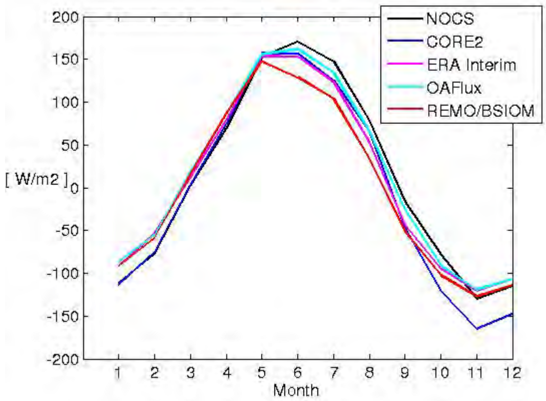


Figure 2: Monthly mean net surface heat fluxes over the Baltic Sea for the period 1989-1993.

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 (2001), A Comprehensive Model Intercomparison Study Investigating the Water Budget during the BALTEX-PIDCAP Period. Meteorology and Atmospheric Physics, Vol.77, Issue 1-4, pp. 19-43.

Lehmann, A., and Hinrichsen, H.-H. (2000), On the thermohaline variability of the Baltic Sea, J. Mar. Syst., 25, pp. 333–357.

Lehmann, A., and Hinrichsen, H.-H. (2002), Water, heat and salt exchange between the deep basins of the Baltic Sea, Boreal Environ. Res., 7, pp. 405–415.

Lehmann A, Lorenz P, Jacob D (2004), Modelling the exceptional Baltic Sea inflow events in 2002/2003, Geophys Res Lett 31: L21308

Atmospheric circulation during dry periods in Lithuania

Egidijus Rimkus, Justas Kažys, Donatas Valiukas, Gintautas Stankūnavičius

Department of Hydrology and Climatology, Vilnius University, Lithuania (egidijus.rimkus@gf.vu.lt)

1. Introduction

One of the most devastating extreme climatic events is drought. In boreal zone of excessive moistening devastating droughts are not a very common phenomenon, meanwhile it can hardly affect regional economy, social- and wild-life. Droughts have major impact on agriculture as well as on increasing number of forest fires in Lithuania.

Droughts in Lithuania are identified using Selianinov hydrothermal coefficient (HTC), when during 30 consecutive days HTC is lower or equal to 0.5. Droughts were recorded four times (1992, 1994, 1996, and 2002) in the entire territory of Lithuania during investigation period of 1961-2010. In this study to determine the circulation conditions which lead to formation of droughts shorter dry periods when HTC was less or equal to 0.5 for 15 consecutive days were analyzed. Over the 50 year period such dry periods at least in one third of the territory of Lithuania were recorded 14 times.

Four droughts events which covered the entire Lithuanian territory were analyzed in more detail. Earlier studies show that there is no typical chain of processes linking to summer drought occurrence neither in Northern Europe nor in northern North America (Girardin et al. 2006; Kingston et al. 2013). However some circulation indices are still useful diagnostic tool for the large scale atmospheric circulation impact on regional hydro-thermal anomalies (Zveryaev 2004).

2. Data and methods

Atmospheric circulation patterns which lead to dry periods and droughts formation in 1961-2010 were analyzed in this study. Daily air temperature and precipitation data of vegetation period (May-September) from 18 meteorological stations were used. Selianinov hydrothermal coefficient was used for droughts identification. HTC for each day was calculated according to the following formula:

$$HTC = \frac{\Sigma \mathrm{p}}{0{,}1\Sigma t}$$

where Σp – sum of the precipitation, o Σt – sum of the mean air temperature for the 30 consecutive days. Interpretation of HTC values: <0,5 – severe drought; <0,7 – medium drought; <0,9 – weak drought; >1 – sufficient moistening; >1,5 – excessive moistening. HTC can be calculated when the mean average air temperature becomes higher than 10 °C. In Lithuania this transition is most often recorded at the beginning of May. Therefore during investigation calculations of the HTC index were started from May 1. In this way, the first HTC values were calculated for the beginning of June.

All dry periods were divided into three parts. The first thirty-day period prior to the start of the dry period has been named as the dry period development stage; the whole investigated period (with exception of the last five days of dry period) has been named as the persisting dry period; the last five days of dry period and five days after the dry period has been named as the drought attenuation phase. It was also analyzed 30 days period which lead to minimum HTC value of the whole dry period.

Using k-means clustering method according to peculiarities of drought formation Lithuanian territory was divided into three parts: the Western, Northeastern and Southeastern. In all stations of these regions the droughts usually were determined at the same time. The study found the differences between atmospheric circulation conditions determining the formation of dry periods in the separate regions. Atmospheric circulation patterns during dry periods were analyzed using P. Hess and H. Brezowski macro-circulation form classification (Werner and Gerstengarbe 2010). The classification distinguished three circulation forms, six weather types and 29 weather condition subtypes. Circulation patterns frequency during dry periods compared with overall frequency in 1961–2010. Mean circulation patterns and their anomalies during four severe drought events were identified using NCEP/DOE Reanalysis 500 hPa geopotential height field and averaged using composition analysis. Blocking episodes during drought developing, persisting phases and one month before were identified using S. Tibaldi and F. Molteni blocking index (TMI) for the longitudinal belt from 20W to 60E (Tibaldi and Molteni 1990). TM index represents the reversal of climatological meridional gradient of H500 (easterly flow) at 60N ±Δ. Daily NAO and AO indices obtained from NOAA Climate Prediction Center. 10-days running mean filter was applied to the NAO and AO daily indices because of the high temporal variability of those indices in summer.

3. Atmospheric circulation forms during dry periods

Results showed that weather type recurrence frequency is shifted from general distribution during dry periods in 1961–2010 (Table 1). In general dry periods are determined by decrease of zonal and increase of meridional circulation forms. The largest changes are specific to western (weather type A) and south (north)-eastern (E and F) flows. Recurrence of most frequent (15%) weather condition WZ (West cyclonic), which brings moist air from the west, decreases by half during dry periods while recurrence of weather conditions NEZ (Northeast cyclonic) and HNFZ (Norwegian Sea – Fennoscandian high, cyclonic) more than two times higher than in overall circulation. Blocking anticyclone over Fennoscandia and low-gradient pressure field over Lithuania let warm continental air masses flow from north-east. Also frequency of weather condition BM (Central European ridge) which let southern warm air masses enter Lithuania is 40% higher under dry period conditions.

It is obvious that recurrence of different weather types during dry period phases vary a lot (Table 1). Changes from overall circulation patterns already have appear on first 15-days period, however, most drastic change in circulation could be seen on the next 15-days of the developing phase (30-days). The circulation frequency of the persisting phase slightly differs from the developing phase, while highest difference from overall circulation occurs on dry period maximum phase (30-days). Predominant continental air masses flow from south-east (type F), north-east (type E) and high pressure center (type B) explains 80% of atmospheric circulation. The attenuation phase (l0-days) characterized by restoration of overall circulation frequency with even more intense western (32% compare to 23% for overall circulation) flows (type A) which brings cooler and moister air.

Table 1. Frequency (%) of different weather types over Lithuania during different phases of dry periods versus overall circulation (May–September) patterns in 1961–2010

Dry period phases	Weather type	Weather types frequency (%) in Lithuania				
		Overall circulation	Part of Lithuanian territory affected by dry period			
			Whole	Western	Northeastern	Southeastern
The developing	A	23	10	12	12	10
	B	36	36	30	43	49
	C	4	3	3	2	2
	D	11	6	7	5	1
	E	19	36	37	31	31
	F	6	7	9	5	6
	U	1	2	2	2	1
The persisting	A	23	11	10	10	13
	B	36	40	35	43	44
	C	4	2	1	1	3
	D	11	8	9	10	7
	E	19	31	33	28	26
	F	6	7	10	7	6
	U	1	1	2	1	1
The attenuation	A	23	32	25	27	45
	B	36	23	27	36	10
	C	4	7	3	0	10
	D	11	12	18	17	24
	E	19	19	18	16	4
	F	6	6	8	3	4
	U	1	1	1	1	3

The regional differences are not so specific though some peculiarities could be determined. The influence of meridional flows (types E and F) to dry period developing and persisting phase is higher in west than in other regions. While more frequent situation for dry periods are high pressure center (type B) in southeast and northeast. The largest regional difference determined in the attenuation phase.

4. Atmospheric circulation patterns during severe droughts events

Composite analysis of 500 hPa height anomalies of the four most extreme and persistent regional drought episodes in Lithuania sector show the dipole pressure pattern with positive anomaly center located over Scandinavia and negative center (negative anomaly belt) – over Western Europe, Mediterranean and Balkans (Figure 1). Adding or excluding few less extreme drought episodes to the composition reveals almost the same pattern with stable positive center however substantial changes (in shape and magnitude) appear within the southern pole of this pattern. An analysis of intraseasonal variation of the blocking index over European domain during most intense droughts in Lithuania indicates the clear signal of blocking over Baltic region longitudinal belt 0–20 days before drought started. Most extreme drought of summer 1992 has the strongest blocking signal, which related to the more extended blocked circulation to the west while other droughts development related only to the regional, short lived blocking episodes. Also blocking tends to recur during drought persistency phase.

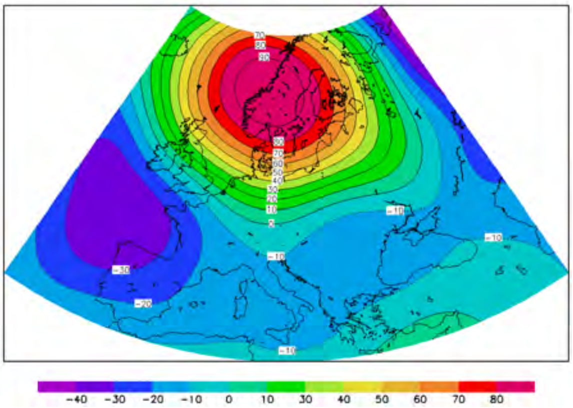


Figure 1. Composition of 500 hPa geoptential height anomalies (gpm) for the 4 most extreme droughts in Lithuania: in summer 1992, 1994, 1996 and 2002. Contour interval 10 gpm. Anomalies calculated according 1981 -2010 year reference period.

The smoothed daily AO and NAO indices tend to be positive prior to drought onset and that phenomenon is in good agreement with spatial pattern of positive NAO phase in summer: positive geopotential height anomaly over Central and Northern Europe and negative – over Balkans and eastern Mediterranean. Such spatial pattern correlates with the blocking pattern over Central Europe and initiates lack of precipitation in Baltic region due to split of continuous storm track over Atlantic to the southern and northern flanks. In case of positive phase of AO there are no significant changes in geopotential height anomaly between winter and summer patterns however geopotential height variance substantially increase over Northeastern Atlantic and Northwestern Europe in positive AO phase. At the end of the drought episodes both NAO and AO indices show permanent decreasing and move to the opposite phase at the last days of the drought.

References

Girardin M. P., Tardif J. C., Flannigan M. D., Bergeron Y. (2006) Synoptic-Scale Atmospheric Circulation and Boreal Canada Summer Drought Variability of the Past Three Centuries, Journal of Climate, 19, 1922–1947.

Kingston D. G., Fleig A. K., Tallaksen L. M., Hannah D. M. (2013) Ocean–Atmosphere Forcing of Summer Streamflow Drought in Great Britain. Journal of Hydrometeorology, 14, 331–344.

Zveryaev I. I. *(*2004) Seasonality in precipitation variability over Europe, Journal of Geophysical Research, *109*, D05103, doi:10.1029/2003JD003668.

Tibaldi, S., Molteni F. (1990) On the operational predictability of blocking, Tellus, 42A, 343–365.

Werner P.C., Gerstengarbe F.W. (2010) Katalog der Großwetterlagen Europas (1881-2009), PIK Report 119, Potsdam.

First long-term ARGO float experiment in the Baltic Sea

Petra Roiha, Aleksi Nummelin , Simo Siiriä and Tero Purokoski

Finnish Meteorological Institute, Helsinki, Finland (petra.roiha@fmi.fi)

1. Introduction

In the year 2012 Finnish Meteorological Institute tested the ARGO floats for the Baltic Sea. The reason was to get more observations for environmental monitoring and model development from the sea areas which are not often visited by research vessels.

2. Argo floats

ARGO program was initiated in 1999 and the first ARGO floats were deployed the next year. Today, there are over 3,000 free-drifting profiling ARGO floats in the world's oceans. They measure temperature and salinity of the upper layer of the ocean. All the data is transmitted by satellite and made available in a public database. Thus, continuous measurement data becomes available from sea areas where sampling otherwise would be sparse.

In the year 2010 FMI decided to purchase two APEX floats, to be tested in the Baltic Sea. Before that FMI had had ARGO floats in the Greenland Sea. The floats were balanced to work on low salinity conditions of the Bothnian Sea and the Bothnian Bay. The other float's firmware was also modified with Aalto University to tune its diving algorithm faster.

The floats have standard salinity, temperature and pressure sensors and a two-way Iridium satellite connection which enables the manoeuvring of the float.

In comparison with oceans the Baltic Sea is very shallow, the water is brackish and the vessel traffic is very heavy. The Sea also freezes during the winter. Keeping these issues in mind The Bothnian Sea was selected to be the first test site.

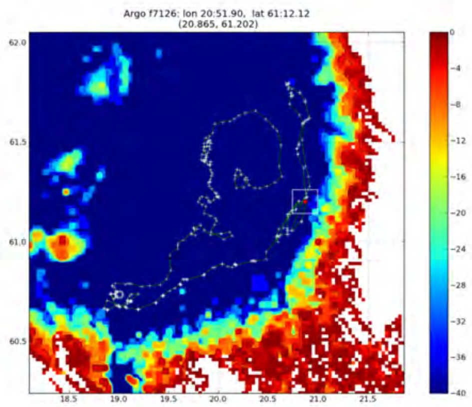


Figure 1. Argo float's route during its mission from 17th May to 5th December 2012. The red dot indicates the location where the float was recovered.

3. The first mission

The float measuring cycle was 24 hours with drifting depth of 50-70 metres on average. This was a change from the usual parameters used in the oceans, where the typical measuring cycle for ARGO float is 10 days and the typical drifting depth around 1-2 kilometres.

The float with unmodified firmware was deployed on 17th of May 2012 in the Bay of Bothnia with the help of Pori Coast Guard. The mission lasted over half a year ending on 5th of December, when it was recovered with Turku Air Patrol helicopter and a rescue swimmer. The float worked flawlessly during the mission, even in difficult conditions with average wave height around 4 metres. The float measured and delivered over 200 salinity and temperature profiles during its mission.

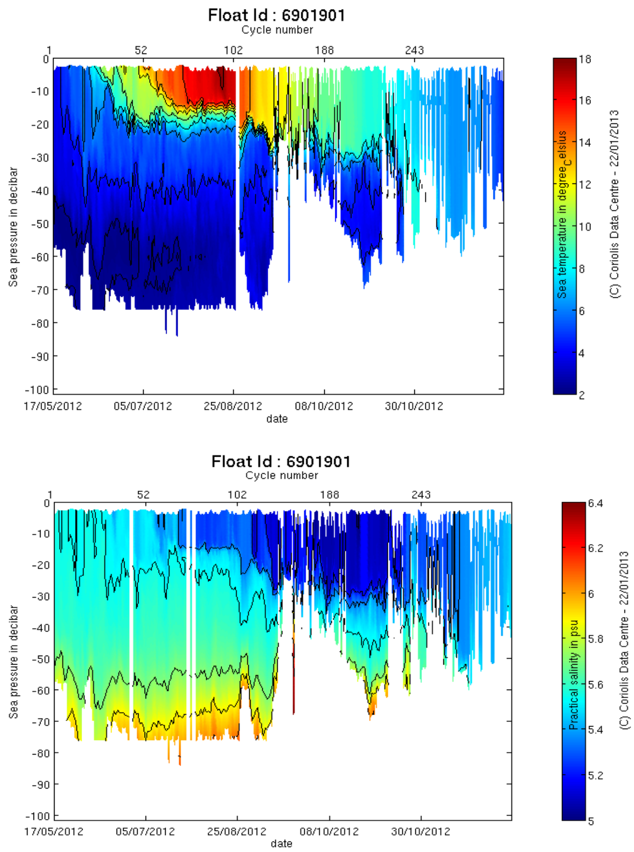


Figure 2. Temperature and salinity profiles measured during the mission

A new perspective on atmospheric requirements for major inflow events into the Baltic Sea

Semjon Schimanke, Christian Dieterich and H. E. Markus Meier

Department of oceanography, SMHI, Norrköping, Sweden (Semjon.schimanke@smhi.se)

1. Introduction

Major Baltic inflows (MBI) are the main source for the renewal of the Baltic Sea deep water and herewith the main source of oxygen-rich water which is crucial for marine life. Moreover, MBIs bring a crucial amount of salt into the Baltic Sea, which is generally characterized by a freshwater surplus making it one of the largest brackish water areas in the world.

It is well known that MBIs are forced to a substantial amount by atmospheric variability. For instance, Lass and Matthäus (1996) claim that major salt water inflows are very likely forced by a sequence of easterly winds in late autumn lasting for 20-30 days followed by strong to very strong westerly winds of similar duration. Moreover, MBIs are barotropic events depending on a sea level difference between the Kattegat and the southern Baltic Sea. Once more, the atmosphere forces this. Namely, pressure difference explains more than 70% (max. > 80%) of sea level variance for periods between 15 and 200 days in the Kattegat (Gustafsson and Andersson, 2001). Finally, Matthäus and Schinke (1994) showed typical SLP composites related with MBIs. However, other parameters besides direct atmospheric forcing are discussed as well, e.g. the long-term effect of river discharge (Schinke and Matthäus, 1998). In general, the precise interaction between atmospheric conditions and the ocean leading finally to an MBI is still not fully understood. Moreover, reasons for the stagnation period 1983-1993 are still under discussion. The scope of this work is to use updated time series which span roughly 20 years more of observations. Moreover, used atmospheric parameters have been on a rather coarse grid. Consequently, we will investigate how much results improve by using longer data series with a higher resolution. Thereby, we will consider SLP-fields as the only forcing parameter for MBIs.

2. Model, Data and Methods

The atmospheric data comes from the regional climate model RCA4 (Samuelsson et al., 2011). It is forced with ERA40/ERA-interim data at the boundary and is therefore mimicking real weather conditions for the period 1961-2012. To minimize the deviation from observations in the rather large model domain a spectral nudging approach was used. The analyzed data are 3 hourly SLP fields using almost data out of the entire model domain merely neglecting the very south (the used domain can be seen in Fig. 1).

EOF analysis is used as the statistical tool to identify large-scale impact patterns. MBI dates are taken from observations (e.g. Matthäus and Schinke, 1994).

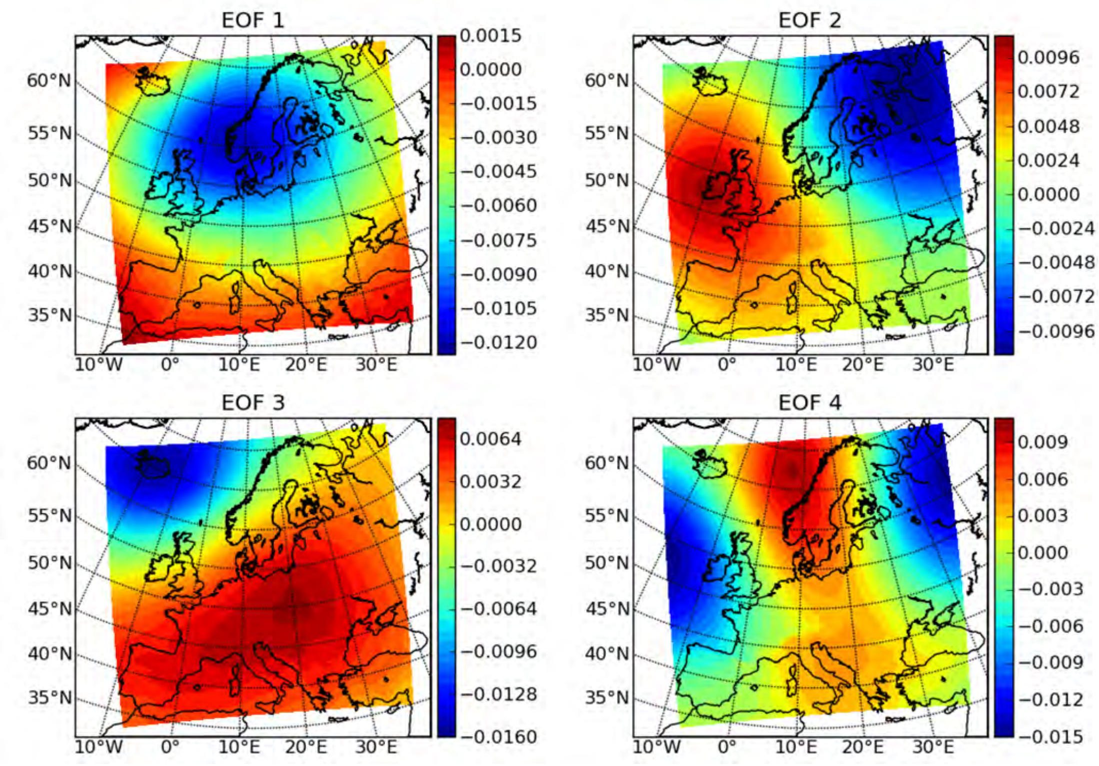


Figure 1. The first four EOF patterns of SLP for inflow events. The explained variance of the EOFs is 36.7%, 22.2%, 14.7%, and 7.1%.

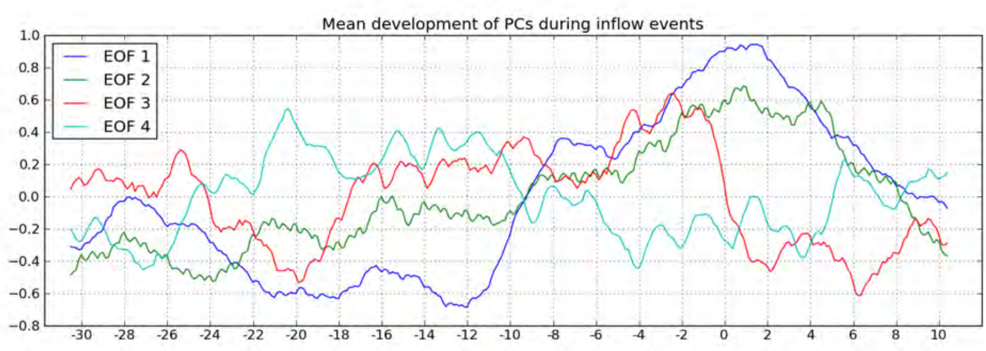


Figure 2. Mean development of the PC1-PC4 according to the pattern shown in figure 1. The x-axis indicates days relative to the onset of the MBI (at day 0). The y-axis indicates the standard deviation.

3. Results

SLP fields related to the 13 strongest MBIs within the period 1961-1993 are chosen to compute the EOF-patterns and PCs. A lead-time of 30 days is considered as well as 10 days following the onset of an MBI. The first EOF (explaining 37% of the variance) shows that highest variability related to MBI occurs over the southern Scandinavia including the North and Baltic Sea (Fig. 1). The mean development of PC1 shows clearly an on average negative EOF for days more than 10 days ahead of an MBI and switching to positive values ±10 days around the MBI. This resembles the change from high pressure over Scandinavia to low pressure or in other terms the turning from general easterly winds to westerly winds in the southern Baltic and the North Sea. Herewith, the first EOF and its mean development mirror pretty much the SLP composites shown by Matthäus and Schinke (1994, their figure 6). The second EOF (22% of explained variance) reveals in how far a switch from northerly winds to southerly winds is important for MBIs. PC2 follows PC1 in general but with lower amplitude. Thus, indicating southerly winds in the early preconditioning phase (days -30 to -10) with a switch to northerly winds. The third EOF (15% explained variance) highlights a special behavior in time. PC3 is fluctuating around zero in the early preconditioning phase. However, ±5 days around the onset of the MBI it is clearly positive before and negative thereafter with a very distinct jump on the onset day. PC4 (EOF4 has only 7% explained variance) is general positive on days before day -10 and positive on days -10 to +4. However, it amplitude is rather low.

4. Work in progress and outlook

The mean development of the PCs in the surrounding of MBIs should be used to identify MBIs in the entire period, consequently including MBIs not used for the EOF-analysis discussed above (Fig. 1+2). The idea is to use running correlations of the mean PC-evolution (Fig. 2) with the complete time series. The clever combination of several PCs spanning also different lead-times is considered to identify MBIs. First tests show already promising results.
Finally, if successfully implemented, the method could be used to estimate the number and perhaps even strength of MBIs based on atmospheric conditions only. Hence, estimates for MBIs could be made using atmospheric models only. However, by no means this can be a substitute for real modeling of the Baltic Sea as done for example by Dieterich et al. (2013).

References

Dieterich, C., S. Schimanke, S. Wang, G. Vali, Y. Liu, R. Hordoir, L. Axell, A. Höglund, H.E.M. Meier (2013), Evaluation of the SMHI coupled atmosphere-ice-ocean model RCA4_NEMO, SMHI-Report, RO 47, pp. 76

Gustafsson, B.G. and Andersson, H.C. (2001), Modelling the exchange of the Baltic Sea from the meridional atmospheric pressure difference across the North Sea, JGR (106), 19731-19744

Lass, H. U. and Matthäus, W. (1996), On temporal wind variations forcing salt water inflows into the Baltic Sea, Tellus A (48), 663-671, No. 5, doi: 10.1034/j.1600-0870.1996.t01-4-00005.x

Matthäus, W. and Schinke, H. (1994), Mean atmospheric circulation patterns associated with major Baltic inflows, Deutsche Hydrografische Zeitschrift, 46 (4), 321-339, doi: 10.1007/BF02226309

Samuelsson, P., and Colin G. Jones and Ulrika Willen and Anders Ullerstig and Stefan Gollvik and Ulf Hansson and Christer Jansson and Erik Kjellström and Grigory Nikulin and Klaus Weyser (2011), The Rossby Centre Regional Climate model RCA3: model description and performance, Tellus, 63A, 4-23, doi: 10.1111/j.1600-0870.2010.00478.x

Schinke, H. and W. Matthäus (1998), On the causes of major Baltic inflows - an analysis of long time series, Continental Shelf Research (18), 67 – 97, doi: 10.1016/S0278-4343(97)00071-X

Snow storage formation specifics for the Neman river basin

Alexander Volchak, Nikolay Sheshko, Dmitriy Kostiuk, Dmitriy Petrov

Brest State Technical University, Brest, Belarus (dmitriykostiuk@bstu.by)

Along with the flooding estimation, published in the Cabinet Council of Belarus Regulation «On Approve of the Republican program "Engineering hydroeconomic measures to protect population aggregares and agricultural areas from floods in most flood-unsafe regions of Polesie for 2011-2015 years", spring flood annually covers substantial territories, causing noticeable harm to national economic. Under increase of the environment landscapes technogenic transformation, problem of lands protection from natural physical and climatic effects also becomes more significant. Flood protection of territories is mainly done with use of technical (hydrotechnical) constructions controlling the water body, and planned organizational actions. Not least important is prediction of the natural and climatic acts, their evolution and economic consequences.

Main sources of peak water discharges, which provide the possibility of material loss and social injury, are snow storages at the beginning of the active snow melting period. Beside snow cover, substantial contribution to spring flooding is done by the weather conditions. Thus, having an estimation of the water amount in the form of snow on the river basin, one can predict runoff volume of the river. Midterm temperature and fallout forecast, in their turn, allow to estimate snow melting intensity and thus the maximum river discharge at flooding.

Inequality of snow cover over the basin makes it difficult to estimate the snow storage and the amount of water in it. Observed values of snow thickness and its density are corresponding to the placement of snow courses, but snow forming conditions are inhomogeneous over the territory. Beside of landscape differences (swamp, forest, field) snow accumulation is also substantially influenced by anthropogenic impact. These conditions make it non-purposeful to map or even interpolate measured depth values of the snow cover to the whole river basin.

Methods of geographical analysis and forecasting are widely used nowadays practically in all spheres of the economic activity, including appearance and evolution of dangerous hydrological phenomena, like water-logging and flooding, as shown by Volchek at al. (2010). Main information sources in this case are results of the remote scanning and sensing of the Earth surface and atmosphere. Development of microwave diagnostics in aerospace observations have become an important level of the whole remote Earth sensing. Remote images examination and understanding for the “Earth surface – atmosphere” system have carried out the new opportunity to study earth objects. Obvious advantages of microwave diagnostics, mentioned by Sharkov (2004), such as possibility to get information in any time, wide weather conditions range, and sunshine independence, have brought a lot of attention of the researchers.

Snow storage is estimated using space observations for a long time, particularly based on passive microwave radiation measurements with use of MODIS SSMR and MODIS SSM/I platforms, according to Kitaev et al. (2010). This approach allows to generally estimate the snow storage distribution over the basin. Data themselves are digital analogues of daily maps of snow storage for the whole globe with a regular grid of 25 km size. The grid size makes approach useful on large basins only (about 1000 km^2 or more). Along with Chang et al. (1982), snow storage restoration model is based on the following equation:

$$S = 4,8 \cdot \left(T18H - T37H \right)$$

where $T18H$, $T37H$ are brightness temperatures in 18 and 37 GHz channels on a horizontal polarization.
Equation was produced for SSRMR data, and further detailed for SSRM/I data in case of different frequencies:

$$S = 4,8 \cdot \left(\left(T19H - 5 \right) - T37H \right).$$

Based on these formulas we have calculated the estimate of snow storage accumulation for the Neman river basin territory. Most interesting from the spring flood forecast point of view are such factors as snow accumulation maximum and summarized accumulation through the cold period of a year. Summarized accumulation is a sum of snow cover increments. Accuracy of the remote sensing results was checked by the factor of snow cover accumulation and melting balance. These characteristics are shown in table 1 in the form of a water equivalent.

Maximum of the snow storage on a basin S_Σ can be used for midterm forecast of the river maximum discharges, as these parameters are not changing after the beginning of a melting period.

At preliminary stage of the research, it was find out based on the paired linear correlation factor, that statistical connection is not high for factors individually ($r \le 0,35$). But in case of multiple correlation connection this factor is increasing up to $R = 0,65$ at its critical value of $R_{\text{krit, 5\%}} = 0,40$. In this case we have following statistical model:

$$Q'_{\max} = 254 + 22 \cdot S_{\max} + \frac{30}{1 - \dfrac{S_{\max}}{S_\Sigma}}$$

Table 1 Maximum snow discharge and accumulation over the Neman river basin

years	Maximum discharge, Neman river, Grodno, $\bar{Q}_{max}$, m³/s	Maximum value of snow storage, S_{max}, mil. m³	Summarized accumulated snow storage, S_{Σ}, mil. m³	accumulation and melting balance, m³
1989	262	9,78	10,92	0,0
1990	320	2,44	5,39	-34
1991	445	8,11	14,07	0,0
1992	320	1,81	5,89	0,0
1993	456	4,08	8,04	0,0
1994	845	8,24	18,58	0,0
1995	451	7,44	16,62	0,0
1996	840	7,79	16,63	0,0
1997	308	5,33	9,38	0,0
1998	350	4,98	10,59	0,0
1999	692	4,03	8,75	0,0
2000	359	3,25	7,64	0,0
2001	288	0,77	2,31	0,0
2002	475	1,24	4,81	-96
2003	424	6,16	14,66	62
2004	192	1,43	3,03	0,0
2005	455	10,85	17,78	-56
2006	631	4,94	11,44	0,0
2007	517	2,14	6,63	0,0
2008	312	5,74	10,10	0,0
2009	338	3,40	11,70	0,0
Average value	442	4,95	10,24	-6
Dispersion	174	2,85	4,68	-

To check the model reliability, 2010 year data where removed from the database. Equation brought out maximum discharge of Neman river at Grodno city equal to $Q'_{max} = 447$ m³/s, while observed value was $Q_{max} = 436$ m³/s, and so predicted one is in 95 % quantile.

Statistical model allows to estimate conditions of the snow accumulation. The $\frac{S_{max}}{S_{\Sigma}}$ ratio determines which part of the snow have been melted while the period of maximum snow store forming, so the more close is this value to 1, the biggest part of the snow would form the spring flood. The $S_{\Sigma} \geq S_{max}$ condition may exist for snow maximum accumulation in theory, but real basins always have $S_{\Sigma} > S_{max}$. For more accurate maximum discharges forecast one should take into account conditions of snow melting after the maximum snow storages are formed. It is possible on the basis of climate factor analysis (air temperature, atmospheric condensation, etc.). Also with snow melting intensity factor and in case of continued tendency it seems to be possible to estimate the runoff volume for a concrete year spring flooding. Maximum discharge should be determined in this case by the analysis of the typical spring flood hydrographer for the concrete river.

Presented approaches allow to predict average value of the maximum river discharge depending on the accumulated snow storage, thus providing the possibility to carry out necessary actions in advance to lower negative effect of territories flooding. Statistical models instead of complicated physical and mathematical models allow in this case to avoid rough errors caused by multiple local factors and specifics.

References

Cabinet Counsil of Belarus Regulation No.1280, 06.09.2010 (revision of 13.01.2012) «On Approve of the Republican programme "Engineering hydroeconomic measures to protect population aggregares and argicultural areas from floods in most flood-unsave regions of Polesie for 2011-2015 years"

Sharkhov, E.A. (2004) Passive microwave sounding of Earth: past, present, and future plans [in Russian]. Contemporary problems of remote sensing from space. Moscow: Polygraph-service, pp. 70–80.

Volchek A., Kozak A., Kostiuk D., Petrov D. (2010) Electronic system of flood monitoring and visualization // Hydrology: from research to water management. XXVI Nordic hydrological conference. Riga, Latvia, August 9-11, 2010. – Riga: University of Latvia Press, 2010. – P. 66-68.

Kitaev L.M., Titkova T.B. (2010) Snow storage estimation based on satelite information data [in Russian]. Earth cryosphere., Vol. 14, No1., pp.76-80.

Chang, A., Foster J.L., Hall D. (1982) Snow water equivalence determination by microwave radiometry. Cold Regions Sci. and Technol.,, No. 5, pp. 259–267.

Forecasting sea level variations in the northern Baltic Sea with a three-dimensional hydrodynamical model

Antti Westerlund, Petra Roiha, Laura Tuomi, Simo Siiriä, Hanna Boman

Finnish Meteorological Institute, Helsinki, Finland (antti.westerlund@fmi.fi)

1. Introduction

Sea level forecasting in the Baltic Sea is important for early warning systems for flooding and for safety and managing the flow of the shipping. In this work we analyse the ability of the three-dimensional hydrodynamical model HBM (HIROMB-BOOS Model) to forecast these events in the northern Baltic Sea areas in years 2007 and 2008. Two different sets of meteorological forcing were used to evaluate the accuracy of the model in forecasting the sea level variations in the northern Baltic Sea. Sea level forecasts were compared against measurements from 13 water level gauges in the Finnish coast.

The accuracy of the water level simulations depends, in addition to atmospheric forcing, on the water exchange between the North Sea and Baltic Sea and the accuracy of the boundary conditions and model bathymetry in the area of interest. Inaccuracies in these cause a level difference between the measured and modelled values. Due to land uplift and different geodetic levelling systems in different countries the level correction is not universal in space and time, but needs to be done separately for each model at each measurement location for each time period in question. Since the main interest was in forecasting abilities, the level correction was done with same principle as used in the safety weather services at Finnish Meteorological Institute (FMI), using a running mean difference between the model and measured during 7 days period prior the forecast date.

The levelling improves the results and diminishes efficiently difference between meteorological forcings in statistical sense (centred RMSE, correlation and standard deviation). The horizontal resolution, bathymetry and the shoreline configuration used in the model had significant impact on the accuracy of the sea level forecasts. Furthermore, the selection of a representative model point for the comparison, when the nearest point was a land point (due to the coastal location of the sea level gauges) was not trivial.

2. Methods

The model configuration used in this study was FMI's operational setup of the HBM code (Berg and Poulsen, 2012). HBM has been developed in co-operation between DMI (Danish Meteorological Institute), SMHI (Swedish Meteorological and Hydrological Institute), BSH (German Federal Maritime and Hydrographic Agency) and FMI during the GMES MyOcean project (see http://www.myocean.eu). HBM is based on the DMIcmod (Circulation MODel), which in turn is based on BSHcmod (Dick et al., 2001). The FMI implementation of HBM is used for operational forecasting, including currents and sea level.

The FMI setup of the model has the same grid as the official MyOcean Baltic product V2, covering the Baltic Sea and the North Sea. Horizontal resolution is 3 nautical miles, with finer nested grids around the North Sea/Baltic Sea transition zone and Wadden Sea at approximately 0.5 nm resolution. In the vertical there are a maximum 50 layers in the model domain, with the topmost layer being 8 metres. The following layers are then 2 metres deep up to the depth of 100 metres, then 50 metres up to the depth of 550 metres. DMI bathymetry is used. The model is forced with both ECMWF IFS and FMI HIRLAM atmospheric data. The open boundary at the North-West end of the grid is handled with a sponge layer. Climatological values are used for open boundary temperature and salinity data and an inverse barometer calculation based on the atmospheric forcing for water levels. The k-omega turbulence scheme is used, applied as explained by Berg (2012). Solar penetration within the thermodynamic is handled as suggested by Meier (2001). The model uses climatological river runoffs. Ice module used in this study included only ice thermodynamics.

Simulated time period was 2007-2008, with half-a-year spin-up period from 2006. Simulations were made separately with ECMWF IFS and FMI HIRLAM atmospheric forcing data. Simulations were made of 12-hour forecasts starting from each UTC midday and midnight.

References

Berg, P. and J. W. Poulsen (2012). Implementation details for HBM. DMI Technical Report No. 12-11, ISSN: 1399-1388, Copenhagen.

Berg, P. (2012). Mixing in HBM. DMI Scientific Report No. 12-03, ISBN: 978-87-7478-610-8, Copenhagen.

Dick, S. et al. (2001). The Operational Circulation Model of BSH (BSHcmod): Model Description and Validation. Berichte des Bundesamtes für Seeschifffahrt und Hydrographie.

Meier, H. E. M. (2001). On the parameterization of mixing in three-dimensional Baltic Sea models. J. Geophys. Res. 106, C12, 30997-31016.

Surface radiation budget of the Baltic Sea from satellite data

Tomasz Zapadka[1], Damian Stoltmann[1], Marcin Paszkuta[2], Maciej Sokólski[3]

[1] Institute of Physics, Pomeranian University in Słupsk, Poland (zapad@apsl.edu.pl)
[2] Institute of Oceanography, University of Gdańsk, Poland
[3] Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

1. Abstract

The surface radiation budget of the Baltic Sea is the subject of our research. This paper shows the possibility of applying information from satellite data to estimate the shortwave *SW* and longwave *LW* radiation fluxes (downward, upward) for the Baltic Sea region. The components of the radiation budget were determined using algorithms developed for the Baltic Sea. The input data came from MSG/SEVIRI, AVHRR and Prognostic Model UM. Possibility of using these algorithms we showed on an example of daily maps of individual fluxes. The results obtained from the algorithms have been compared with empirical data and empirical verification was carried out. The presented methods are used in the SatBałtyk project.

2. Introduction

The net radiation flux (difference between upward and downward shortwave 280 - 3800 nm and longwave 4 - 100 µm radiation) is one of the main Earth's energy budget components.

$$SW_d = \int_{0.3\mu m}^{3.8\mu m} E_d(\lambda, z=0)\,d\lambda \qquad SW_u = \int_{0.3\mu m}^{3.8\mu m} E_u(\lambda, z=0)\,d\lambda$$

$$LW_d = \int_{4\mu m}^{100\mu m} E_d(\lambda, z=0)\,d\lambda \qquad LW_u = \int_{4\mu m}^{100\mu m} E_u(\lambda, z=0)\,d\lambda$$

$$NET = (SW_d + LW_d) - (SW_u + LW_u)$$

In clear situations downward components of the radiation budget depend on the sea surface temperature, vertical profiles of the air temperature, water vapour and other greenhouse gases (Zapadka et al. 2007). However, the largest radiation modulators in the atmosphere still remain clouds (see Fig 1). Cloudy conditions dominate the Baltic Sea area for approximately 2/3 of the year (Krężel et al. 2010). The satellite (e.g. MSG/SEVIRI - Meteosat Second Generation - with Spinning Enhanced Visible and Infrared Radiometer Instrument on the board) observations give an overall view of the considered region in one moment. However, despite advanced satellite techniques, the parameters obtained from these observations still do not give a satisfactory accuracy. Therefore, finding a good relation between cloudiness and the above mentioned parameters appears critical. Upward radiation flux LW_u depends mainly on the skin temperature. This value is determined with high accuracy from radiometers (e.g. AVHRR) working on the boards of polar-orbiting satellites for cloudless area. AVHRR has higher space resolution than SEVIRI but lower time resolution and gives few images per day for Baltic Sea, while SEVIRI gives 96 images per day (every 15 minutes). For long period of overcast area and at the same time of rapid change cloudiness parameter obtaining any information about the sea surface is possible by frequent observations. Such frequent information about cloudiness are very useful to estimate shortwave downward and upward radiation fluxes SW_d and SW_u. The aim of this work is to show the method for determination the radiation budget components and its accuracy.

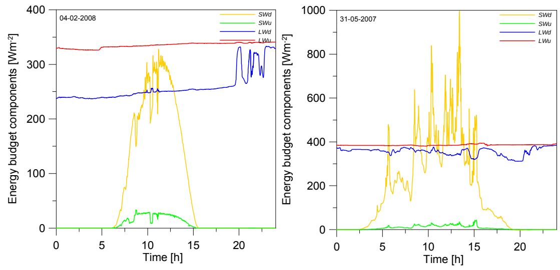


Figure 1. The daily changes of components of the net radiation budget at the sea surface for cloudy and cloudless situations.

3. Material and methods

Algorithms used in the analyses were developed for the Baltic Sea or adopted for Baltic.

- SW_d - based on formula Krężel et al. 2008
  $SW_d = SW_{d,0} T_{cloud}$

where $SW_{d,0}$ the irradiance for a cloudless atmosphere, T_{cloud} - cloud transmittance computed on the basis satellite algorithm

- SW_u - based on Payne 1979 modified by Rozwadowska 1992 for Baltic Sea
  $SW_d = SW_d A_s$

where A_s sea albedo dependent on the transmission of the atmosphere and solar zenith angle

- LW_d - based on Zapadka et al. 2001, 2007, 2008 with modified cloud function
  $LW_d = LW_{d,0} f(c_i)$

where $LW_{d,0}$ the longwave irradiance for a cloudless atmosphere, $f(c_i)$ - a satellite cloud function different for night and day

- $LW_u = \varepsilon \sigma T_s^4$

where ε emissivity of the sea surface, T_s sea surface temperature from MSG/SEVIRI.

The input data to the algorithms come from three sources: MSG/SEVIRI (VIS and IR channels), AVHRR (AOT), UM model (air temperature, water vapour pressure). Maps were imported into a 4 km resolution format (352x320 pixels).

The empirical material for comparative purposes was collected during cruises of s/y Oceania in the southern

Baltic and Baltic Proper in 2009 - 2012. The fluxes were measured using CG1, CGR3 pyrgeometers and CMP3 pyranometers (Kipp&Zonen).

4. Validation

The validation of the algorithms was carried out on the basis of the data measured at the sea. The comparison of empirical and modelled data required temporal and time assimilation. The position of the vessel and the pixels are synchronized with the help of the coordinates and the times. The measurements were averaged to 10 minute intervals for satellite exposition. Fig. 2 shows a comparison of measured and calculated data respectively for SW_d, SW_u, LW_d, LW_u fluxes. The plots represent cloudy and cloudless situations.

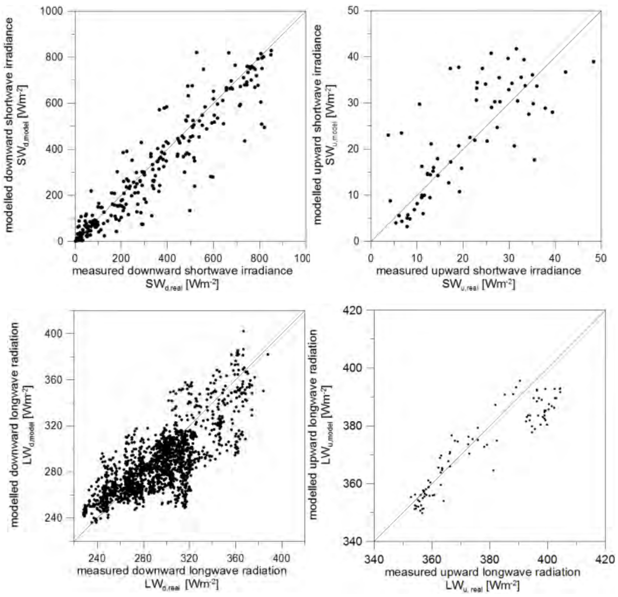


Figure 2. Comparison between calculated and measured values of the downward and upward shortwave and longwave radiation.

The errors of the estimations shows table 1. The values of the SW_d have been determined with the statistical error c. 90 Wm^{-2}, SW_u with 8 Wm^{-2}, LW_d with 23 Wm^{-2} and LW_u with 6 Wm^{-2} (Table 1). Detailed analysis shows that smaller error is for day than night in the case LW_d. This is due to using different satellite cloud functions for day and night. The maximum deviation for LW_d reaches 80 Wm^{-2} and it is situation when the cloud algorithm determines the sea as clouds but in fact it is all inverse. This error affects also on accuracy of the other fluxes. Therefore, the presented method requires a correct mask of clouds and appropriate functions of cloudiness.

Table 1. Verification of the formulas for calculating the components of the radiation budget (standard deviation and BIAS).

flux	Syst. error [Wm^{-2}]	Stat. error [Wm^{-2}]	Correlation coefficient
SW_d	-18	95	0.91
SW_u	2	8	0.77
LW_d	-0.2	23 (17; 28)	0.77
LW_u	0.2	6	0.97

5. Daily maps

The presented method allows to estimate radiation budget components for every day using satellite data. The Fig. 3 shows examples of the average daily maps for SW_d, SW_u, LW_d, LW_u. The maps are developed on the basis of instantaneous products for which an empirical verification was carried out (see **4**).

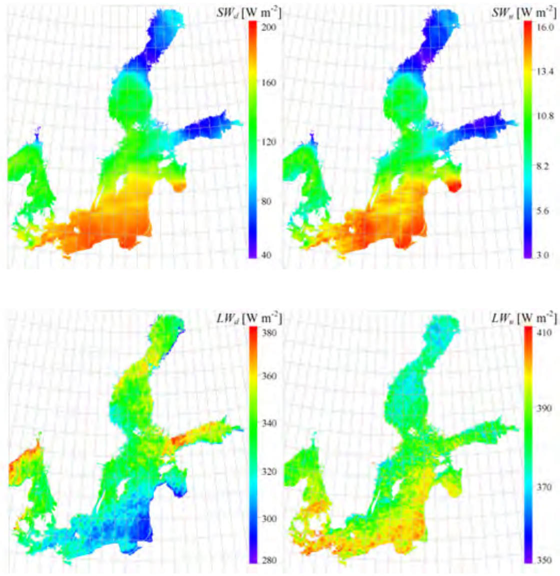


Figure 3. Maps of the daily average components of the surface radiation budget for 2012-09-10.

6. Summary

In this work, possibilities to estimate of the surface radiation budget components using satellite data for Baltic Sea were shown. An empirical verification showed the accuracy of the estimated fluxes. (Fig. 2, Table 1). The average minimum errors of the estimated value changes from c. 2 % to c. 15 % depending on flux. The main cause of errors is a problem with identification of clouds. Described method can run operationally to calculate the components of the radiation budget. The examples of such calculations has been shown on Fig. 3.

References

Krężel A., Kozłowski L., Paszkuta M. (2008) A simple model of light transmission through the atmosphere, Oceanologia, Vol. 50, No. 2, 125-146

Woźniak M., Krężel A. (2010) Sea surface temperature retrieval from MSG/SEVIRI data in the Baltic Sea area, Oceanologia, Vol. 52, No. 3, pp. 331-344

Payne R.E. (1979) Albedo of the sea surface, J. Atmos. Sci., 29, pp. 959-970

Rozwadowska A. (1992) The variability in solar energy influx to the southern Baltic, Ph. D. thesis, Gdańsk Univ., Gdynia, (in Polish)

Zapadka T., Woźniak S. B., Woźniak B. (2001) A simple formula for the net lon-wave radiation flux in the southern Baltic Sea, Oceanologia, 43, 3, pp. 265-277

Zapadka T., Woźniak B., Dera J. (2007), A more accurate formula for calculating the net longwave radiation fluz in the Baltic Sea, Oceanologia, 49, 4, 449-470

Zapadka T., Krężel A., Woźniak B. (2008) Longwave radiation budget at the Baltic Sea surface from satellite and atmospheric model data, Oceanologia, Vol. 50, No. 2, pp. 147-166

Singularities of turbulent sensible heat flux in urban areas – The Łódź case study

Mariusz Zieliński

Department of Meteorology and Climatology, University of Łódź, Poland (mariusz.r.zielinski@gmail.com)

1. Introduction

Cities could be considered as the areas where the impact of climate change is the most distinctly pronounced. Therefore the knowledge on the energy balance and its components is of a significant importance to climate modelers. The scintillometry gives the opportunity to deliver the turbulent fluxes estimates that could be representative for relatively large areas (i.e. up to a few square kilometers). The experiments conducted in a few cities (i.a. Kanda et al., 2002, Roth et al., 2006, Lagouarde et al., 2006) revealed that scitillometer measurements could be reliable source of heat flux estimates. The heterogeneity of the surface in urban areas could contribute to the variation of maximal sensible heat flux (Q_H) values depending on the wind direction. This study gives a consideration to some singularities of Q_H in relation to the wind direction.

2. Data and methods

Łódź (51°47'N, 19°28'E) is the third biggest city in Poland (population of approximately 730,000). The measurements including the radiation balance and turbulent fluxes are conducted in the city centre, that is occupied with 15-20 m height building rather evenly distributed.

The Scintec BLS900 scintillometer (hereinafter BLS) operated from August 2009 to November 2012. The time series was discontinuous as a result of technical problems. The BLS transmitter was mounted at height of about 31 m above ground level at the mast standing on the roof of the 17 m height building at Lipowa 81 Str while the receiver was mounted 3142 m to the north-east from the transmitter on the roof of the 36 m height building at Matejki 12 Str (Fig. 1). Since the height of the BLS path was not uniform the effective measurement height had to be computed and in considered case it was about 22 m depending on the stability.

The data set from June 2012 to November 2012 is not considered in this study, as the extensive construction works including i.e. buildings demolition had started in 2012 close to the centre of measurement path. Still some more consideration has to be given to the possible influence of such construction works on measured refractive index structure parameter values.

The scintillometer operated with 125 Hz frequency and data were stored in 1-minute intervals. The ultimate fluxes were averaged in 1-hour blocks. Data quality control was performed and during that procedure blocks with data stored with BLS errors (i.e. misalignment), blocks with decreased amount of data, intervals with precipitation occurrence were excluded from analyzes.

In addition to the BLS two eddy covariance system operated simultaneously during the measurement campaign. For more details concerning the location of EC sites and data processing see Fortuniak et al. (2012).

The turbulent sensible heat flux was computed from the temperature structure parameter obtained from the BLS measurements with the application of Monin-Obukhov Similarity Theory (MOST).

The FSAM (Schmid 1994, 1997) footprint model was applied for BLS source area estimation. The sum of a superposition of multiple model runs was used to reflect the path-averaging.

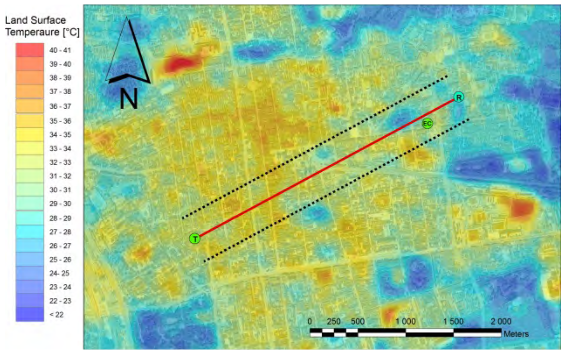


Figure 1. Measurements sites in Łódź shown on Land Surface Temperature map retrieved from LANDSAT 5TM on 6th June, 2011. T – BLS transmitter and eddy covariance, R – BLS receiver, EC – eddy covariance. Red solid line – BLS measurement path, black dashed lines indicates the area for which the mean building height along BLS path was estimated.

3. Results

Turbulent sensible heat flux in considered city strongly depends on the inflow direction. In considered period the highest Q_H values were observed for airflow from west, northwest and north (Fig. 2) i.e. the most densely built up area of Łódź (Fig. 1). The absolute maximum (339 Wm^{-2}) Q_H occurred on 13th June 2010, when the strong cold advection appeared from the west. On the other hand the lowest Q_H was found under conditions of southern and southwestern inflow.

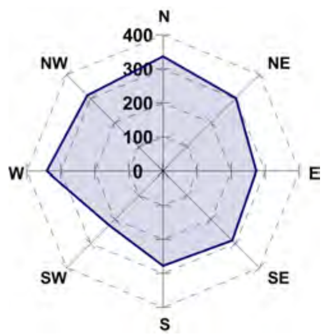


Figure 2. Maximal sensible heat flux observed in Łódź in the period from September 2009 to May 2012 according to the wind direction.

In Figure 3, the examples of diurnal course of Q_H observed during the days when the highest Q_H values were noted for airflow from east and north-west is shown. Moreover the source areas that contributed to observed maximal Q_H values is included in that figure. Since the BLS path orientation was approximately SSW – NNE, the source areas for airflow from south-east and north-west were significantly smaller (wind direction parallel to BLS path) in comparison to the airflow from north-west or south-east (wind direction perpendicular to BLS path).

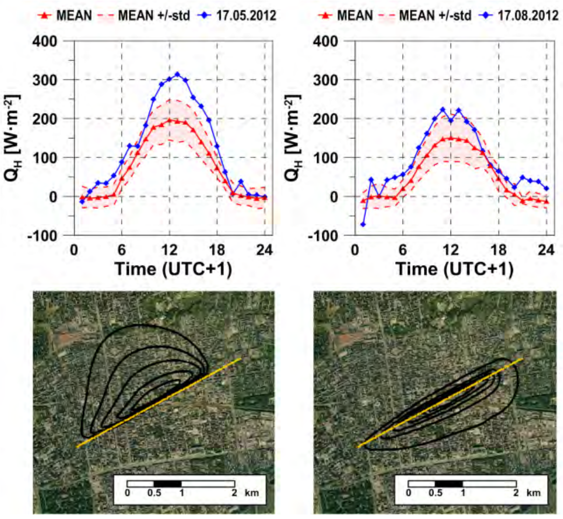


Figure 3. Diurnal course of the sensible heat flux Q_H observed in the days with maximal Q_H according to definite wind direction and ensemble (MEAN) diurnal Q_H for May (on the left) and August (on the right), source area of scintillometer at p=25, 50, 75, 90 and 99% at noon.

The probability density functions computed for Q_H according to wind direction stress the relationship between the observed Q_H and the airflow (Fig. 4). When the airflow from southern sector prevailed the heat flux was developed over the less densely built-up areas, thus relatively low Q_H values were observed. Night-time fluxes from that sector were rather negative than positive. On the contrary the Q_H that developed over the city centre was frequently positive what was the result of greater heat capacity of that part of Łódź.

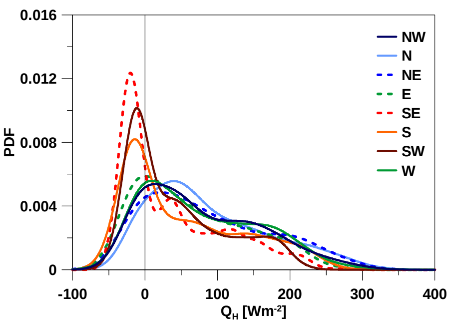


Figure 4. Probability density function for sensible heat flux measured under airflow from different directions.

4. Summary

This study has investigated the influence of the airflow direction on observed Q_H in the centre of Łódź. As expected the highest values of Q_H were found while the inflow from the city centre prevailed.

The scintillometer measurements could deliver the sensible heat flux values that could be representative for up to a few square kilometer. However, in case of measurements conducted over heterogeneous surface Q_H values could strongly depend on the wind direction.

Acknowledgments

Present work was funded by Polish National Science Centre under grant DEC-2011/01/N/ST10/07529 in years 2011-2014.

References

Fortuniak K., Pawlak W., Siedlecki M. (2012) Integral Turbulence Statistics Over a Central European City Centre. – Boundary-Layer Meteorol., Published online August 15th, 2012; DOI: 10.1007/s10546-012-9762-1.

Kanda, M., Moriwaki, R., Roth, M., Oke, T. (2002) Area-averaged sensible heat flux and a new method to determine zero-plane displacement length over an urban surface using scintillometry. *Boundary-Layer Meteorol.* 105. 177-193.

Lagouarde, J.P., Irvine, M., Bonnefond, J.M., Grimmond, C.S.B., Long, N., Oke, T.R., Salmond, J.A., Offerle, B. (2006) Monitoring the sensible heat flux over urban areas using large aperture scintillometry: case study of Marseille city during the ESCOMPTE experiment. *Boundary-Layer Meteorol.* 118. 449-476.

Roth, M., Salmond, J.A., Satyanarayana, A.N.V. (2006). Methodological considerations regarding the measurements of turbulent fluxes in the urban roughness sublayer: the role of scintillometry. *Boundary-Layer Meteorol*,121. 351-357.

Schmid, H.P., (1994) Source areas for scalar and scalar fluxes. *Boundary-Layer Meteorol.* 67. 293–318.

Schmid, H.P. (1997) Experimental design for flux measurements: Matching scales of observations and fluxes. *Agric. For. Meteorol.* 87. 179–200.

Topic B

Analysis of climate variability and change, and provision of regional climate projections over the Baltic Sea basin for the 21st century

Consistency of recently observed trends over the Baltic Sea basin with climate change projections

Armineh Barkhordarian and Hans von Storch

Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Geesthacht, Germany (armineh.barkhordarian@hzg.de)

Future climate change in general is an issue of broad interest, satisfying a general intellectual curiosity but also having much to do with practical managerial decisions about how to plan, design and shape our future on global to local scales.

In this study, we examine to what extent the observed climate trends over the Baltic Sea basin are already an indication of the conditions described by the climate change scenario (A1B) at the end of this century. With this purpose, we investigate whether the ensemble of projections, derived from 12 regional climate models, encompass the observed trends - if this is the case, we conclude that the observed change can be interpreted as a harbinger of future change.

This approach, which has earlier been applied over the Mediterranean region (Barkhordarian et al. 2012a, 2012b and 2013) is being applied to near-surface temperature, precipitation, surface relative and specific humidity, cloud cover and solar irradiance changes over the Baltic Sea basin.

References

Barkhordarian A, Bhend J and von Storch H (2012a) Consistency of observed near surface temperature trends with climate change projections over the Mediterranean region. *Climate Dynamics*, 38, 1695--1702.

Barkhordarian A, von Storch H and Zorita E (2012b) Anthropogenic forcing is a plausible explanation for the observed surface specific humidity trends over the Mediterranean area. *Geophys. Res. Lett.*, 39. L19706, doi:10.1029/2012GL053026.

Barkhordarian A, von Storch H and Bhend J (2013) The expectation of future precipitation change over the Mediterranean region is different from what we observe. *Climate Dynamics*, 40, 225 --244.

Dynamics of the Baltic Sea environment under the influence of climate change (A case study of the most important Lithuanian coastal summer resorts)

Aldona Baubiniene and Regina Morkūnaite

Institute of Geology and Geography of Nature Research Center, Vilnius, Lithuania
baubiniene@geo.lt; morkunaite@geo.lt

The western boundary of Lithuania is represented by a short (99 km) Baltic Sea coast famous for its sandy beaches and summer resorts. Similar beaches can be found in Latvia, Poland, and Russia (Kaliningrad Region), i.e. countries which have a gateway to the Baltic Sea.

Over the last century, the Baltic Sea environment has been changing under the impact of the rising Baltic Sea water level (up 14.9 cm at Klaipeda in the 20th century) (Rimkus et al. 2011), annual air temperature (since 1940 the seashore is characterized by variable temperature) and increasing average wind velocities (deep cyclones became more often from the thirties of the 20th century) Bukantis et al. 2001).

Intensive recent processes have taken place in the Lithuanian coastal area: the budget of continental coastal surface sediments (in 1993-2003) was negative. The annual loss of sediments from the continental coasts is 47930 m³ of sand on the average (Zilinskas and Jarmalavicius, 2003). The beach-forming processes are entailed by wave action, degradation of the beach foredune ridge, and jamming up with sand of the mouths of the Baltic Sea tributaries, which fall into the Baltic Sea in the most popular recreational beaches. All these processes deteriorate the ecological state of the Baltic Sea.

The Lithuanian coastal zone was transformed strongly by the hurricane “Anatoly” (December 3–4, 1999), which raged along the south-eastern coast of the Baltic Sea. During the hurricane, the wind velocity reached 40 m/s and the sea level rose by 165 cm (Zilinskas and Jarmalavicius, 2003). Another strong hurricane “Ervin” devastated the Lithuanian coast in January 8–9, 2005. The hurricane washed away the beaches, damaged the dunes and transformed the beds of small tributaries. The restoration of the transformed landscape is impossible without huge investments.

The aim of the present article is to evaluate climate change in the last thirty years and the associated transformations of the Lithuanian coastal environment. The study is based on the data for 1961–1990 (Navasinskiene, 2003) and the next decade (Galvonaite, 2007), obtained from the Klaipėda and Nida meteorological stations, a comparison of orthophotographs of the studied area in different years and material collected during the expedition of 2011. A photographic inventory of the territory was performed.

References

Rimkus E., Stanevicius E., Ramanauskiene V., 2011. Coastal Climate Change. Protecting and adapting maritime regions. Vol. 20, N 3.

Navasinskiene J. 2003.Climate of Maritime.Vilnius.

Galvonaite A. 2007. Climate of Lithuania, Vilnius.

Zilinskas G., JarmalaviciusD. 2003. Trends of Lithuanian sea coast dynamics. The Geographical Yearbook, Vol. 36, Vilnius.

Bukantis A., Gulbinas Z., Kazakevicius S., Kilkus K., Mikelinskiene A., Morkunaite R., Rimkus E., Samuila M., Stankunavicius G., Valiuskevicius G., Zaromskis R. 2001. The influence of climatic variations on physical geographical processes in Lithuania. Vilnius.

Figure 1. Investigated area and changing view of beach in Sventoji

Estimations of social and economic consequences of modern climate change in St. Petersburg and the Leningrad region

I.M. Baykova, N.F. Ivanova and V.L. Marich

St. Petersburg University of Management and Economics, Russia (irinabaykova@yandex.ru)

Ten years ago, the global environmental problem connected with modern climate warming was considered as a scientific problem, exciting only “the academic minds”. Now global climate warming is acknowledged not only by the majority of researchers, but also by the world community and the political elite of many countries. The last decade is marked by dangerous weather events, also caused by climate change. The majority of scientists connect the rise in air temperature with industrial emissions of carbonic gas, methane and other gases in the atmosphere, causing a hotbed effect. The past two-three decades of natural climatic cycles are influenced by fluctuations connected with an anthropogenic influence more considerably.

According to estimations of the Intergovernmental Panel on Climate Change (IPCC), natural variations of global air temperature did not exceed ± 0,2 ˚C within the last 600 years, while the increase in global air temperature has made more than 0,8 ˚C for the last 100 years.

Northwest Russia is in a zone where climate change is both observed and predicted to a considerable extent and where onsequences of global warming can be tested. In St. Petersburg, meteorological *in-situ* measurements began more 250 years ago and are among the longest time series in Europe.

The last 30 years in St. Petersburg were the warmest and the dampest, with positive trends in the dynamics of water temperature of the Neva River mouth and the Gulf of Finland. Flooding has increased, and maximum of flooding was shifted from the autumn to the winter. Appreciable changes in circulating processes in the region of the Baltic Sea and, in particular, in trajectories of the cyclones causing strong flooding are revealed.

In 2011, the construction of complex protective flood barriers in St. Petersburg was finished. This modern hydraulic engineering construction extends to 25,5 km and consists of 11 stone and earth dams with two locks for ship passage and six water passage constructions.

Now considerable experience exists in St. Petersburg and the Leningrad region on the gathering, analysis and processing of ecological information, which is presented in the scientific and special literature, as well in open access for all interested users in the Internet.

In the near future, observable changes of the modern climate will continue, and probably even accelerate, putting new ecological challenges to the city. Epidemiological conditions and the health of the millions of inhabitants, as well as natural, technological, historical and cultural features of the coast of the Neva River mouth and the Gulf of Finland can be considerably influenced by global warming.

Thus, with all the evidence, it can be said that the awareness of possible consequences of modern climate change on the security of the economy, the population and the vital interests of the people has ripened.

It is not only a test for the security and natural adaptation of territories and objects to weather and climate conditions, but also for social and economic losses. The climatic instability through weather and climate conditions challenges society in all aspects and leads to social and economic damage and a more vulnerable industrial sphere.

The vulnerability of the Baltic Sea region should be carefully investigated including meteorological and macroeconomic characteristics and indicators. Special attention should be given to economical areas which depend on the weather, such as agriculture, transport, power, tourism, housing and communal services.

The variability of wind speed and wind direction of mean and extreme winds over the Baltic Sea

Svenja Bierstedt, Hans von Storch, Eduardo Zorita and Birgit Hünicke

Institute of Coastal Sciences, Helmholtz Zentrum Geesthacht, Geesthacht, Germany (svenja.bierstedt@hzg.de)

We investigate whether the statistics of wind direction of extreme wind events follow statistics of mean wind and thus whether changes in mean wind statistics can be used to approximate extreme wind changes. This study shows that this hypothesis is not valid over the Baltic Sea region.

The focus of the study lies on the differences and changes of wind directions between mean and extreme winds but also on contrasts between seasons.

1. Introduction

There are numerous studies regarding wind speed in Europe. Analysis for shorter time periods like 1960-1990 in Alexanderson et al. (2000) mention positive trends. However other studies with longer time series show that the amplitudes in this wind period is within the long-term variability (Bärring and Fortuniakc 2009, Bärring and von Storch 2004).

Studies concerning wind direction variability are quite rare. First estimations of wind direction frequencies were presented for Estonia (Jaagus and Kull 2011). These authors found an increasing trend for south-westerly winds for the period from 1966-2008.

This study investigates and compares the variability of wind speed and wind direction of mean and of extreme wind in the Baltic Sea region.

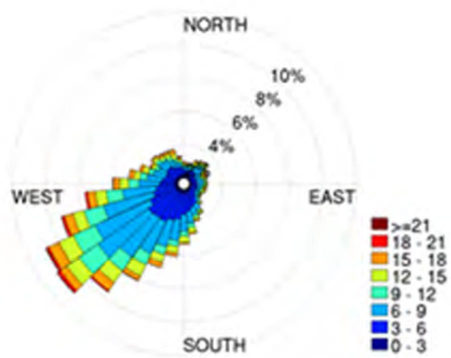


Figure 1. Winter (DJF) wind speed (color) and wind direction (bins) of mean wind for all grid points of CoastDat.

2. Data

For our main investigation, the reanalysis data set CoastDat (1948-present) is used. This data set is the result of a regional climate simulation (model CLM) conducted with spectral nudging and driven by the boundary forcing of NCEP to gain a higher temporal and spatial resolution. Hourly data on a 12,8 x 12,8 (km) grid is available for central Europe.

3. Method

This study analyzes differences between the seasons. The four seasons are defined as winter (DJF), spring (MAM), summer (JJA) and autumn (SON). The mean is defined as the 50th percentile of wind speed. Extreme wind is defined as the 98th percentile of wind speed. The study area is limited to 10°-25°E longitude and 51°-61°N latitude. The most northern parts are excluded as this study focuses on the southern Baltic Sea. To analyze the variability of wind speed and wind direction we accomplished trend analysis as well as principal component analysis (EOF).

4. Results

As expected the highest mean wind speed can be found in winter, followed by spring and autumn. Summer shows the lowest mean wind speed in the whole region. For all seasons there is no significant trend, neither for mean nor for extreme wind speeds. The variability of wind speed is also very similar for all seasons.

South-West (SW) could be determined as main wind direction for mean and extreme winds and for all seasons. The most conspicuous difference is the frequency distribution of mean and extreme wind directions. Mean winds show a very broad distribution for all directions with a maximum for SW. Extreme winds are much more limited to SW directions. This is valid for all seasons except spring where a second maximum can be found in NE direction.

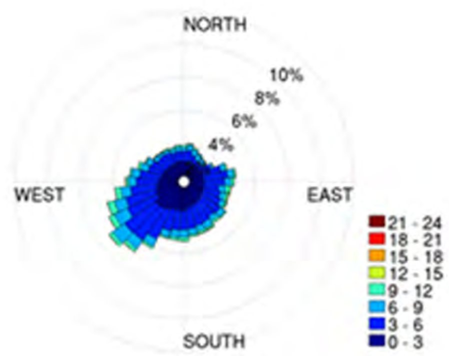


Figure 2. Wind speed (color) and wind direction (bins) for three strongest wind events per winter (DJF) for all grid points of CoastDat.

The complex correlation coefficient between mean and extreme wind speed is small; the magnitude of complex numbers is for all seasons lower than 0.22. This points to a very weak co-variation of mean and extreme wind. Obviously there is an important difference between mean and extreme wind directions in the Baltic Sea region. The underlying patterns of variability (EOF) show only low correlations between seasons. Hence there are no persistent patterns across seasons. The trend analysis showed no robust trend in changes of wind directions for mean and extreme wind over the whole period.

5. Conclusion

The hypothesis that the statistics of mean wind can serve as a proxy for statistics of extreme wind is not valid over the Baltic Sea region. Conclusions about the variability of extreme wind directions cannot be derived from the variability of mean wind directions.

References

Alexandersson, H., Tuomenvirta, H., Schmith, T., and Iden, K. (2000). Trends of storms in NW Europe derived from an updated pressure data set. Climate Research, 14: 71-73.

Bärring, L. and Fortuniakc, K. (2009). Multi-indices analysis of southern scandinavian storminess 1780-2005 and links to interdecadal variations in the NW Europe North Sea region. Int. J. Climatol., 29: 373-384.

Bärring, L. and von Storch, H. (2004). Scandinavian storminess since about 1800. Geo-phys. Res. Lett., 31:L2020.

Jaagus, J. and Kull, A. (2011). Changes in surface wind directions in Estonia during 1966-2008 and their relationships with large-scale atmospheric circulation. Estonian Journal of Earth Sciences, 60:220 -231.

Climate variability in the Baltic Sea Basin over the last 12,000 calendar years: Lessons from the past for the future

Irena Borzenkova[1], Eduardo Zorita [2], Olga Borisova [3], Laimdota Kalnina[4], Dalia Kisieliene[5], Tiiu Koff [6], Denis Kuznetsov[7], Geoffrey Lemdahl[8], Tatyana Sapelko [7], Migle Stancikaite [5], Dimitry Subetto[9]

[1] State Hydrological Institute, St. Petersburg, Russia;
[2] Helmholtz Zentrum Geesthacht, Germany;
[3] Institute of Geography, Moscow, Russia;
[4] University of Latvia, Latvia;
[5] Vilnius University, Lithuania;
[6] Tallinn University, Tallinn Estonia;
[7] Limnology Institute, St. Petersburg, Russia;
[8] Linnaeus University, Kalmar, Sweden;
[9] Pedagogical University, St. Petersburg, Russia

Introduction

Quantitative past climate data obtained using new methods and technology have improved the testing and tuning of numerical climate models. In addition, this data helps understanding causes and mechanisms of climate variations. In practice, almost all future climate scenarios are based on the gradual, though relatively fast, increase in global temperature due to greenhouse gases concentration growth in the atmosphere, primarily, carbon dioxide and methane. However, analyses of the paleoclimatic records show that relatively long-term past warm periods were followed by a shift to much colder weather, and vice versa, cooling periods changed to rapid (of the order of a few decades) warming periods. These abrupt climate changes are assumed to be related to nonlinear processes in the climate system. At some threshold values the climate system can transit “jump wise” from one stable condition to another one, almost “instantaneously” within first few decades. The mechanism of these abrupt climate events is likely to depend on a massive influx of fresh continental glacial meltwater into the oceanic waters and intensified hydrological cycle under global warming. In high latitudes, abrupt climate changes are most noticeable, especially in the areas adjoining the continental ice sheet. The Baltic Sea Basin is believed to be a key region in studying the causes of the past abrupt climate change. This knowledge is important not only to understand the mechanisms involved in the generation of climate variations and climate chance at centennial time scales, but also to estimate the magnitude of possible deviations of future climate from a monotonic long-term global change caused by increasing concentrations of atmospheric greenhouse gases. At regional scales, these deviations can be substantial and should be factored-in when designing regional policies for climate change adaptation.

Data and methods

New quantitative information has been obtained from pollen and chironomids data during the last years due to more detailed analysis and ^{14}C dating of sediments. These new insights are based on calibration of the modern pollen, diatoms and beetles fauna data to climate parameters (annual and seasonal air figure 1 shows key sites dated by ^{14}C which was used in this study.

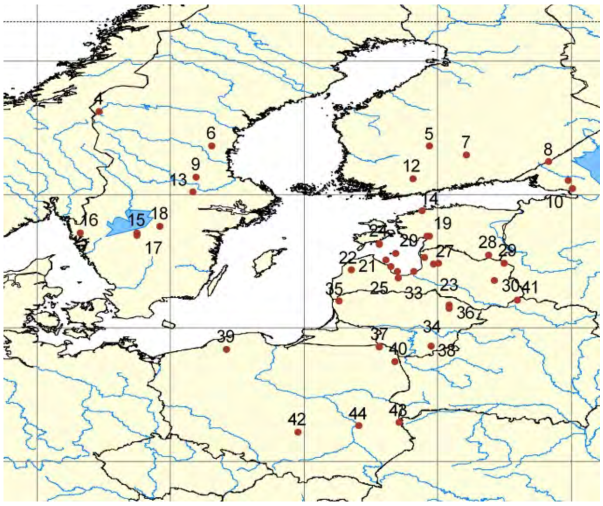


Figure 1. Some key sites dated by ^{14}C in the Baltic Sea Basin

Results and discussion

Climate change in the Baltic Sea Basin has been the result of both on external and internal factors during the Holocene: Changes in incoming solar radiation due to astronomical factors , variations in the concentration of stratospheric aerosol caused by volcanic activity, changes in the content of greenhouse gases in the atmosphere due to natural factors, changes in surface albedo of the sea-lake itself and changes in vegetation on the surrounding land, changes in the intensity and type of circulation due to changes in the basin salinity, which exerted direct influence on the surface and deep currents and ice conditions in different parts of the basin.

The Baltic Sea Basin and the Atlantic Ocean have been exchanging water masses for their entire history of. This exchange has been modulated by both glacio-isostatic land uplift and eustatic sea level changes. Approximately 250 years after the final drainage of the Baltic Ice Lake (BIL), sea water flowed into the Baltic basin through the Närke Billingen strait due to a rapid sea-level rise resulting from the melting of the Scandinavian ice sheet (Yu, 2003). This caused the Baltic Basin to turn into a brackish basin between 11,300 and 11,100 cal yr BP (Yoldia Sea stage). Subsequent climate warming caused the rapid melting of the continental ice sheets and pronounced isostatic uplift led to the isolation of the Baltic Basin from the Atlantic Ocean, turning into a large fresh water lake (Ancylus lake). The culmination of the transgression phase of this lake is dated to ca.10,700 cal yr BP. The subsequent regression phase of the lake is believed to have occurred due to cooling in the Early Holocene. The stage of Ancylus Basin lasted until approximately until ca. 10,000 cal yr BP. The modern Baltic Basin is part of the last Littorina stage when sea level and salinity varied significantly.

The final deglaciation stage in the Baltic Sea Basin is supposedly related to an abrupt warming at the end of the Bølling and Allerød interstadial about 14,600 cal BP when the events became irreversible. At that time arborous vegetation first appeared in ice-free regions of the Baltic Basin. The warming was interrupted with a series of Dryas coolings. The strongest one of 1000 years long ended about 11,600-11,500 cal BP at the Holocene boundary. At that time about 10,200 years ago, a cold oscillation – the Preboreal Oscillation – occurred which then shifted to an extended warming of 2000 years long and the arborous vegetation expanded rapidly throughout the Baltic Basin. The subsequent two cooling periods about 9,300 and 8,200 cal BP are indicated in Greenland ice cores, North Atlantic marine sediments, and clay-varve chronologies.

The second "8.2 ka event" of about 160 to 200 years long has been known long ago. This cold episode correlates with mountain glaciation in the Alps and Scandinavia and reduction in warm-loving arborous species in pollen spectra from different parts of the Baltic Basin. These cold episodes are theorized to be related to a massive meltwater surge outflow to the North Atlantic from Lakes Superior and Agassiz that were formed after the destruction of the Laurentian Ice Sheet. "The 8.2 ka" event was the last cooling episode of the Early Holocene resulting in a stable and relatively warm climate period with summer temperatures of 1-2^{0}C higher than the present ones.

The period between 7,500 and 5,500 ago was the warmest one for the entire Baltic Basin area, though the times of maximum temperatures were not synchronous in different parts of the region. In Sweden territory, pollen and chironomids chronologies show that the times of maximum temperatures changed in different regions between 7,900 and 5,700 cal BP with the amplitude varying from 0.8 to 1.0^{0}C and higher.

The negative Northern Hemisphere temperature trend and increased climate instability are typical of the last Holocene interval. The Baltic region cooling about 5,000 to 4,500 years ago coincided with decreased summer solar radiation incoming to the earth's surface. Different proxy data allow us to reconstruct a two-stage air temperature decrease over the last 4,500 years.. The first stage occurred between 5,000 and 4,500 cal yr BP and the second one between 4,300 and 3,300 (2,800) cal yr BP. During each period the temperature drop was not less than 1^{0}C. A complicated climate change nature in the Baltic Sea Basin in the Lateglacial and the Holocene was reflected in changing lake levels, vegetation, and in the formation of a complex hydrographic network. These environmental changes affected the stages of ancient humans' dispersion in this territory.

Conclusion

In summary, the Holocene climate history in the Baltic Sea region, as inferred from the analysis of different proxy data for the past 12,000 cal years has revealed the following three stages of natural climate oscillations in the Baltic Sea Basin: 1. Some 200-year long short-term cold episodes related to deglaciation occurred between 11,000 and 8,000 cal yr BP against the backdrop of a stable positive temperature trend driven by a higher summer solar insolation due to astronomical factors. 2. A period of warm and relatively stable climate between 8,000 and 4,500 cal yr BP with air temperatures of 1.5-2.5°C above modern levels. 3. The Late Holocene (the last 5,000-4,500 years), characterized by the temperature decrease trend and increased climate instability.

References

Antonsson K, Brooks SJ, Seppä, H., Telford RJ, Birks HJB (2006) Quantitative palaeotemperature records inferred from fossil pollen and chironomid assemblages from Lake Gilltjärnen, northern central Sweden. J. Quatern. Science 21: 831–841.

Heikkilä M., Seppä H. (2010) Holocene climate dynamics in Latvia, eastern Baltic region: a pollen based summer temperature reconstruction and regional comparison. Boreas 39: 705– 719

Hünicke B., Zorita E, Haeseler S. (2010) Baltic Holocene climate and regional sea-level change:A statistical analysis of observations, reconstructions and simulations within present and past as analogues for future changes. GKSS Forschungszentrum Geestnacht GmbH, Geesthacht, 64 p.

Kalnina, L., Cerina, A., Ozola I., Grudzinska I., Pujate A., Kuske E., (2012). Fen and raised bog development in the areas of the former Littorina Sea lagoons at the Coastal Lowland of Latvia. 14thIPC "Peatlands in Balance". Proceedings of the 14th International Peat Congress.

Stančikaitė M., Kisielienė D., Moe D., Vaikutienė G. (2009). Lateglacial and early Holocene environmental changes in northeastern Lithuania. Quaternary International 207:80-92.

Veski S, Seppä, H., Ojala A.E.K. (2004) Cold event at 8200 yr B.P. recorded annually laminated lake sediments in Eastern Europe. Geology, 32:681–684.

Wastegård S., Possnert G., Khomutova V. I. (2002). Climate and environment on the Karelian Isthmus, northwestern Russia, 13 000-9000 cal. yrs BP. Boreas, 31:1–19.

Wohlfarth B., Lacourse T., Bennike O., Subetto D., Filimonova L., Tarasov P., Sapelko T., Demidov I. (2007) Review Article: Climatic and environmental changes in NW Russia between 15,000 and 8000 cal yr BP Quatern. Sci. Rev. 26:1871-1883

ECDS, an infrastructure for Swedish researchers in climate and environment and a source to find interesting data sets

Barry Broman[1], Thomas Klein[2] , Britt Frankenberg[1] , Jan Svensson[1] and Cecilia Bennet[1]

[1] Swedish Meteorological and Hydrological Institute (SMHI),Norrkoping, Sweden (barry.broman@smhi.se)
[2] Swedish Meteorological and Hydrological Institute (SMHI), Gothenburg, Sweden

1. ECDS website (www.ecds.se)

ECDS is a website constituting a portal for Swedish researchers in climate and environment to make their data available through the web. Here you can find information on data from different IPY datasets, model output from climate models, different reanalysis datasets, oceanographic and meteorological datasets as well different web tools concerning hydrology and climate.

2. Background

Environment Climate Data Sweden, ECDS, is an existing Swedish service, facilitating the searching, publication and long-term accessibility of data for research in the fields of environment and climate. During the pilot phase 2009-2013, ECDS focused primarily on metadata and discovery of data. This included the development of a data portal, using internationally agreed standards (ISO, INSPIRE), support services and advocacy for data sharing.

Figure 1. The ECDS logo.

3. The ECDS vision

ECDS aims to provide a state-of-the art environment and climate data infrastructure in support of world class Swedish research. In close collaboration with the research community, ECDS will provide for full, open and trouble-free long-term access to well-documented environment and climate data, stored in robust, accessible and interoperable repositories.

4. Technical infrastructure

Technically, ECDS consists of a website, a data portal and the external data storage facility Swestore. The website (ECDS 2012) provides information and support material to both experienced and new users and represents the main entry point to the ECDS data portal. The data portal (Klein et al. 2013) uses the open-source software GeoNetwork (GeoNetwork 2012) and a PostgreSQL database for the management of standardized dataset descriptions. GeoNetwork also provides the user interface for search and publication of data. The ECDS data documentation standard (metadata profile) builds on the internationally widespread standard ISO19115:2003. The ECDS metadata profile has recently been extended to include mandatory metadata elements for geospatial data according to the European INSPIRE directive (INSPIRE 2012). The ECDS data resource descriptions are clustered into thematic categories with the help of Global Change Master Directory (GCMD) Earth Science Keywords (Olsen et al. 2007). The use of well-documented and widespread standards allows for the efficient exchange of metadata with other portals and thus supports the establishment of federated collective global resources for scientific data such as GEOSS. Already, ECDS is a registered component of GEOSS with documented technical interfaces for metadata exchange.

References

Klein, T., Langner, J., Frankenberg, B., Svensson, J., Broman, B., Bennet, C. and T. Langborg, 2013: ECDS – A Swedish research infrastructure for the open sharing of environment and climate data. Data Science Journal Vol. 12 (2013) p. 1-9

Variations in projections of atmospheric climate change for the Baltic Sea region

Ole Bøssing Christensen[1] and Erik Kjellström[2]

[1] Danish Climate Centre, Danish Meteorological Institute, Copenhagen, Denmark (obc@dmi.dk)
[2] Rossby Centre, SMHI, Norrköping, Sweden

1. Introduction

During the EU FP6 ENSEMBLES project (van der Linden and Mitchell, 2009), a synchronized regional climate modeling effort resulted in an archive of output from around 25 model simulations. This archive is publicly accessible and contains many meteorological fields in a daily time resolution for grids of around 25km grid distance.

During work with the second Baltic Sea Assessment of Climate Change (BACC2), data from 13 of these simulations were analysed. These 13 simulations were the ones reaching the end of this century, and using one particular model grid; this way, model results could be compared point by point without any interpolation.

2. Scope

From the data archive, daily surface air temperature, precipitation, wind speed and snow were extracted for these 15 models for the periods 1961-1990 and 2070-2099. Quantities like average temperature, precipitation and wind are calculated for each model and each grid point; also extremes are calculated similarly. The span of model projections of the quantity in question is now calculated through maps of the pointwise minimum, median and maximum among the models for each grid point.

As a consequence of the pointwise selection, these plots do not show the span between large-scale averages among the models but rather the much larger point-by-point range.

3. Results

As examples we show absolute changes in average surface air temperature for winter (DJF) and summer (JJA) in Fig. 1, and in Fig. 2 the percent-wise change in precipitation extremes, *in casu* the 10-year return value of daily total precipitation. In the presentation, additional fields will be presented.

Regarding Fig. 1, a north-south gradient of highest warming in the north in winter is general, but there is a spread in the magnitude of the change. Summer warming in the Baltic Basin is smaller than winter warming, and it is comparatively homogeneous across the area. The above-average warming over the Baltic Sea may be an artifact due to the lack of a coupled ocean model in the models investigated here. The highest-percentile summer warming is large in the southeast. This is related to the large-scale pattern of warming in Europe with strongest summertime warming in southern Europe. Also, in the very north-east there is a large warming, probably connected to ice-albedo feedback. Similar results also exist for other GCM/RCM-combinations (e.g. Christensen and Christensen, 2007; Kjellström et al., 2011). The results shown in Fig. 1 are consistent with the results for an earlier time period (2021-2050) based on a larger ensemble of RCM-GCMs as presented by Déqué et al. (2011).

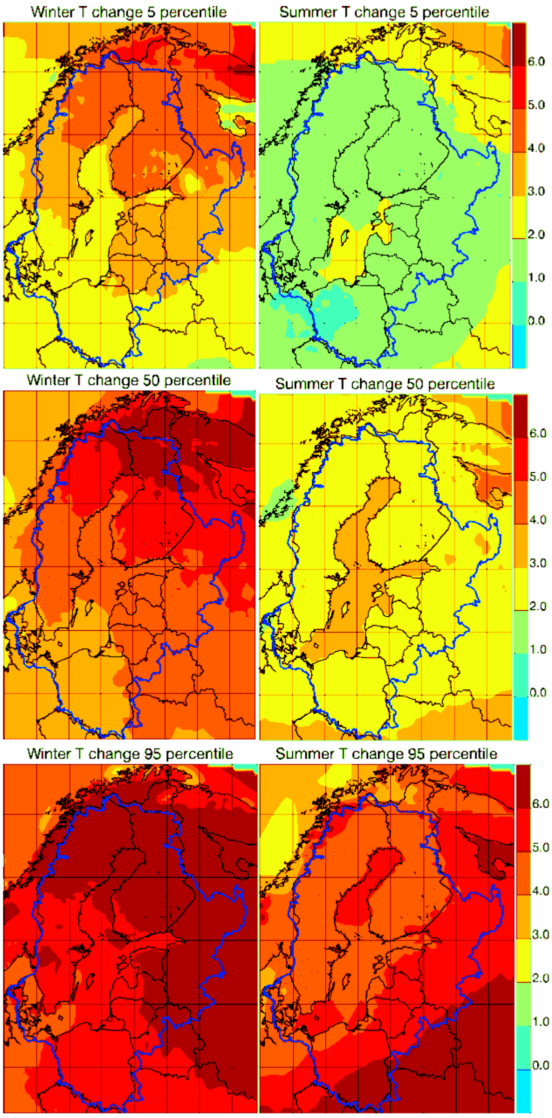


Figure 1. Simulated surface air temperature change (°C) between 1961-1990 and 2071-2099 according to SRES A1B as simulated by 13 RCM models from the ENSEMBLES project. Left column: Winter (DJF), right column: Summer (JJA). Upper row: Pointwise smallest result. Middle row: Pointwise median result. Lower row: Pointwise largest result. The Baltic Sea catchment is indicated by the coloured line.

The median signal in Fig. 2 is consistently positive across the domain. The increase in the Baltic Basin is of the same order for both summer and winter, but the inter-model spread is somewhat larger in summer, corresponding to the larger influence of local processes in this season. The relative change in winter of the extreme precipitation looks very much like the relative change of average precipitation (not shown here), indicating an unchanged shape of the intensity distribution function. The picture is very different for summer, where the change in extremes is considerably larger than the change in the average.

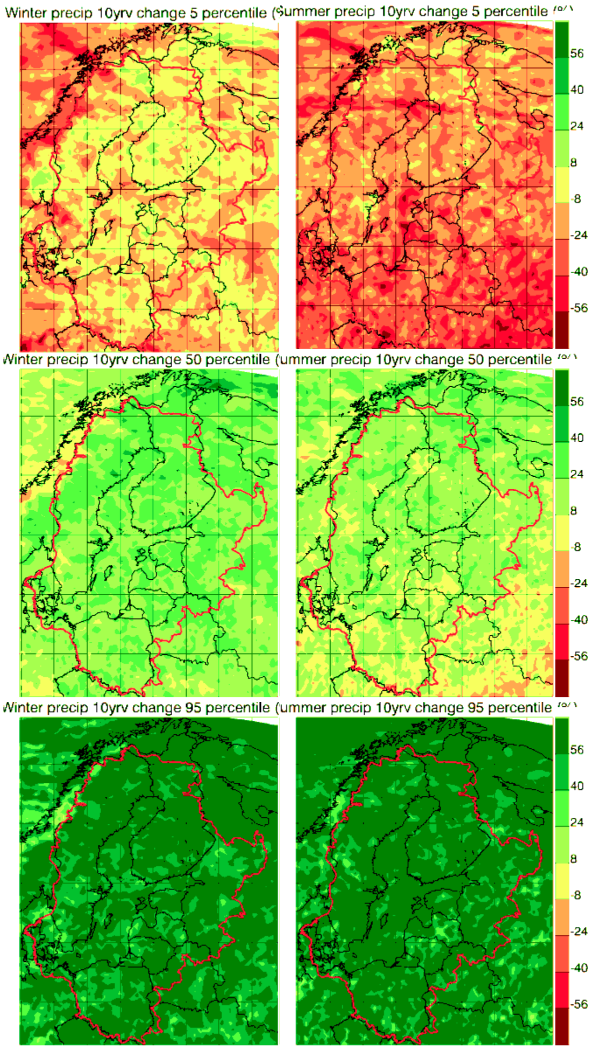


Figure 2. Like Fig. 1, but for relative change (%) in 10-year return values of daily precipitation

References

Christensen J.H. and Christensen O.B., (2007). A summary of the PRUDENCE model projections of changes in European climate by the end of the century. Clim. Change 81:7-30

Déqué, M., Somot, S., Sanchez-Gomez, E., Goodess, C.M., Jacob, D., Lenderink, G. And Christensen, O.B. (2011). The spread amongst ENSEMBLES regional scenarios: regional climate models, driving general circulation models and interannual variability. Clim. Dyn. Doi: 10.1007/s00382-011-1053-x

Kjellström, E., Nikulin, G., Hansson, U., Strandberg, G. and Ullerstig, A., (2011), 21st century changes in the European climate: uncertainties derived from an ensemble of regional climate model simulations. Tellus, 63A(1), 24-40. DOI: 10.1111/j.1600-0870.2010.00475.x

van der Linden P, Mitchell JFB (eds) (2009) ENSEMBLES: climate change and its impacts: summary of research and results from the ENSEMBLES project. Met Office, Hadley Centre, Exeter

Projected changes in Baltic Sea upwelling from an ensemble of RCP scenario simulations

Christian Dieterich, Germo Väli, Semjon Schimanke and H.E. Markus Meier

Swedish Meteorological and Hydrological Institute, Norrköping, Sweden (christian.dieterich@smhi.se)

1. Abstract

Regional downscaling of various SRES and RCP scenarios has been conducted for the North Sea and Baltic Sea region within the KLIWAS program. We analyze and discuss projected changes in sea surface temperature, wind and heat fluxes with respect to upwelling in the Baltic Sea from an ensemble of scenarios with the SMHI coupled atmosphere-ice-ocean model RCA4-NEMO. Intensified and more frequent upwelling in coastal areas of the Baltic Sea will impact on a wide range of topics of the Baltic Sea system.

2. Introduction

Climate change scenarios with global models do not represent regional processes adequately enough to permit an analysis of regional effects of possible changes in the Baltic Sea region. Dynamical downscaling with regional climate models allows for a consistent projection of climate change in the Baltic Sea region and for a closer look at regional phenomena like coastal upwelling. Upwelling in the Baltic Sea has been identified to play a potential role for algae bloom forecast, fisheries, weather prediction and tourism (Lehmann and Myrberg, 2008).
Sea surface temperature in the Baltic Sea is expected to increase between 1 and 4 degrees depending on the Representative Concentration Pathways (RCP) and on the season. An analysis of Lehmann et al. (2012) has shown that the upwelling frequency in the upwelling regions along the southeastern Swedish coast has increased by up to 30% within the period 1990 - 2009. We aim to verify whether upwelling will occur more frequently under projected changes of the regional climate during this century.
To this end we ran an ensemble of scenarios with the SMHI coupled atmosphere-ice-ocean model RCA4-NEMO (Dieterich et al., 2013, Wang et al., 2013).

3. Experimental Setup

The experiments discussed in the following sections have been carried out with the SMHI coupled atmosphere-ice-ocean model RCA4-NEMO. It consists of the RCA4 atmosphere model in a model domain covering the Northeast Atlantic and Europe and the NEMO setup for the North Sea and Baltic Sea (Dieterich et al., 2013). RCA4-NEMO is a fully coupled atmosphere-ice-ocean model, where the different components are coupled every 3 hours using the Oasis3 coupler. The coupler does exchange the surface temperatures of open water and sea ice together with the ice fraction and ice albedo to the atmosphere model. From the atmosphere the ice-ocean model receives the momentum fluxes and pressure at the surface, the shortwave and non-solar heat fluxes and the freshwater fluxes due to the evaporation - precipitation. For the experiments discussed here the river discharge was prescribed using results from an E-HYPE simulation driven by a downscaled ERA-interim reanalysis (Lindström et al., 2010). To approximate the expected increase in river discharge in the Bothnian Sea and the Bothnian Bay an artificial trend of 10% per century has been added for the years 2008 - 2099 to the climatological seasonal cycle derived from the E-HYPE simulation. For the initial years 1961 - 1979 of the scenario experiments the climatological seasonal cycle of the river discharge was prescribed.
An ensemble is analyzed that consists of two different RCP scenarios from two different GCMs. This yields four different trajectories for the possible evolution of the climate in the Baltic Sea region. The GCMs that are applied on the open boundaries of the atmosphere and the ice-ocean model are the MPI-ESM-LR and the EC-Earth. Both of these CMIP5 models ran the two RCP scenarios 4.5 and 8.5 that have been downscaled using RCA4-NEMO.

4. Results

All four scenarios show an increase of Baltic Sea SST for the current century (Figure 1). On average the summer SST increases by 2 degrees from 1970 to 2099 int the RCP 4.5 scenarios. The RCP 8.5 scenarios show a somewhat larger increase of around 3 degrees.

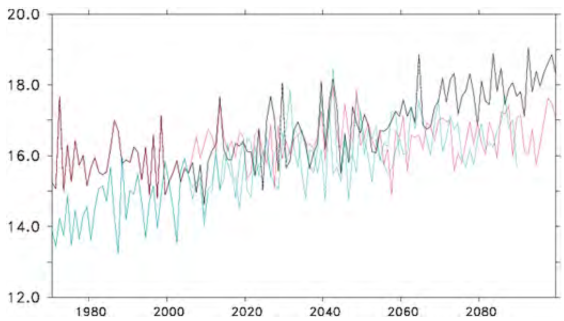


Figure 1: Baltic Sea summer SST for the period 1970 - 2099. Ensemble members are MPI-ESM-LR RCP8.5 (black), MPI-ESM-LR RCP4.5 (red), EC-Earth RCP8.5 (green), EC-Earth RCP4.5 (blue).

The modeled changes in sea surface temperature are not uniformly distributed in the Baltic Sea. The summer SST in the middle and at the end of the century changes most pronounced in those areas that have been identified as typical upwelling areas by Bychkova et al. (1988). There is a tendency for the upwelling areas along the Swedish south and east coasts and the Finnish south coast to produce more intense or more frequent upwelling (Figure 2). In the middle of the century the SST has increased by 1 degree on average. In the upwelling areas that are favored by strong westerlies the SST has actually decreased compared to the reference period. On the eastern side of the Baltic Sea and on the Estonian coast of the Gulf of Finland SST increased more rapidly than on average and those upwelling areas seem to have been weakened. The same principal picture emerges towards the end of the century although the SST signals of the upwelling areas are masked somewhat on the backdrop of the overall increase in SST of 2 degrees.

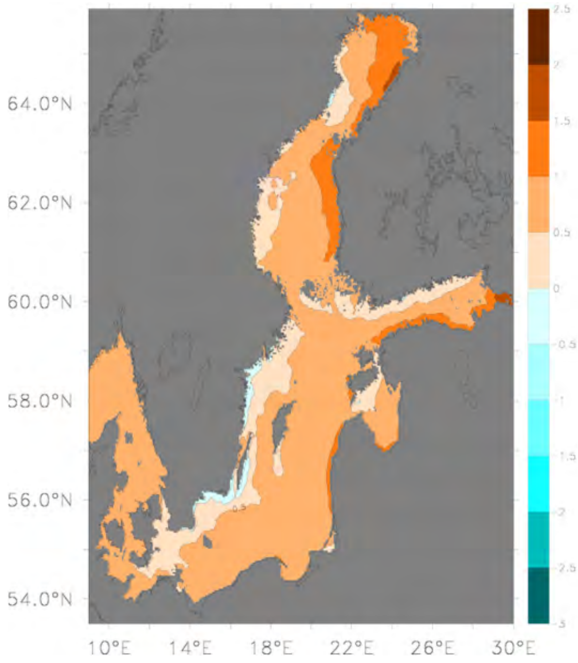


Figure 2: Ensemble mean summer SST [degree C] difference between the two climatological periods 2020 - 2049 and 1970 - 1999.

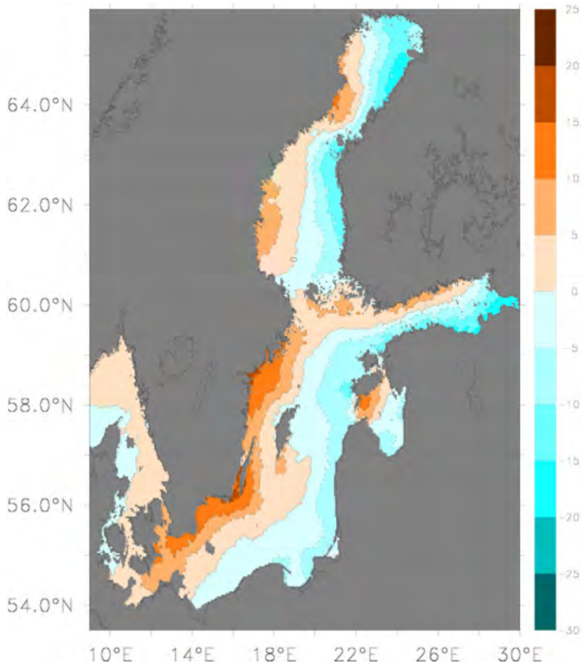


Figure 3: Ensemble mean summer net heat flux [W/m^2] difference between the two climatological periods 2020 - 2049 and 1970 – 1999.

In our coupled atmosphere-ice-ocean model we observe the net surface heat flux between atmosphere and ocean change in ways consistent with the SST patterns. Figure 3 shows the increased heat loss over the intensified upwelling areas on the western side of the Baltic Sea and a decreased heat loss along the eastern side of the Baltic Sea.

5. Discussion

Upwelling in the ocean does have obvious consequences on vertical and indirectly on lateral nutrient transports and does affect the marine ecosystem directly. Pronounced changes in upwelling intensity also have effects on the overlying atmosphere. The changes in net heat flux of up to +- 20 W/m^2 in our model simulations give rise to the expectation that the atmosphere model component of the coupled model will experience a local feedback through changes in local surface fluxes that have been caused initially by a change of the large-scale position of the storm track.

Acknowledgment

This work has been funded by the KLIWAS program. KLIWAS is funded by the German Federal Ministry of Transport, Building and Urban Development (BMVBS).

References

Bychkova, I., S. Viktorov, D. Shumakher (1988) A relationship between the large-scale atmospheric circulation and the origin of coastal upwelling in the Baltic, Meteorologiya i Gidrologiya, 10, pp. 91-98

Dieterich, C., S. Schimanke, S. Wang, G. Väli, Y. Liu, R. Hordoir, L. Axell, A. Höglund, H.E.M. Meier (2013) Evaluation of the SMHI coupled atmosphere-ice-ocean model RCA4_NEMO, SMHI-Report, RO 47, pp. 76

Lehmann, A., K. Myrberg (2008) Upwelling in the Baltic Sea - A review, J. Mar. Systems, 74, Supplement, pp. S3-S12

Lehmann, A., K. Myrberg, K. Höflich (2012) A statistical approach to coastal upwelling in the Baltic Sea based on the analysis of satellite data for 1990-2009, Oceanologia, 54, 3, pp. 369-393

Lindström, G., C. Pers, J. Rosberg, J. Strömqvist, B. Arheimer (2010) Development and testing of the HYPE (Hydrological Predictions for the Environment) water quality model for different spatial scales, Hydrology Research 41, 3-4, pp. 295-319

Wang, S., C. Dieterich, R. Döscher (2013) The simulation of present and future climate variability over Baltic Sea area with new SMHI atmosphere-ocean-ice coupled model RCA4_NEMO, 7th Study Conference on BALTEX

The influence of regional climate change on the local wave climate and the longshore sediment transport at the German Baltic Sea Coast

Norman Dreier[1], Christian Schlamkow[2] and Peter Fröhle[1]

[1] Institute of Institute of River and Coastal Engineering, Hamburg University of Technology, Germany (norman.dreier@tuhh.de)
[2] Chair of Geotechnics and Coastal Engineering, University of Rostock, Germany

1. Introduction

Sediment-transport processes along the coast are one of the main forces for the morphological development of the coastline. The processes are influenced by the meteorological (wind) and hydrodynamical conditions (e.g. currents, waves and water levels) at the coast and can be divided into two groups: i) long-term processes for average conditions and ii) short-term processes for extreme events.

The average wind- and wave conditions at a mean sea-level are effecting long-term morphologic changes of the coastline like e.g. coastal erosion and deposition (longshore transport). The changes may also have consequences for the maintenance of shipways within coastal areas.

On the other hand side, under storm conditions, short-term extreme water levels and waves can have significantly effects on e.g. the erosion of a sandy beach or artificial flood-protection dune (crossshore transport).

Aim of this paper is the presentation of a method to estimate possible consequences of climate change on the morphological development of sandy coasts and on the functional design of coastal protection measures. This is exemplarily done at some locations of the German Baltic Sea. Possible changes of the average wind- and wave conditions within the study area are known from previous investigations.

In this study future changes of the average wind conditions (near-surface average wind velocities and directions) on the basis of regional climate change scenarios will be discussed for selected locations along the German Baltic Sea coast.
On the basis of the changes in wind conditions, the changes of the average wave conditions (average significant wave heights and directions) are assed. Finally, possible changes of the local long-shore sediment transport capacities (both directional and net-sediment transport capacities) are estimated from changes of the local wave climate.

2. Data and Methods

The determination of the climate change signal of the sediment transport capacities bases on dynamical downscaled wind data from the regional circulation model.

Table 1. Cosmo-CLM model runs (remark: 'x' denotes no experiment).

20th century observed anthropogenic forcing	**21st century forced by emission scenario A1B**	**21st century forced by emission scenario B1**	**transient time series of wind parameter**
C20_1	A1B_1	X	C20_1+A1B_1
C20_1	x	B1_1	C20_1+B1_1
C20_2	A1B_2	X	C20_2+A1B_2
C20_2	x	B1_2	C20_2+B1_2
C20_3	x	X	x

Figure 1. Locations of the study area at the German Baltic Sea Coast.

Cosmo-CLM (Rockel *et al.*, 2008) which has been forced by the global atmosphere-/ocean-ice-model ECHAM5/ MPI-OM. Climate data from different Cosmo-CLM model runs are available from the CERA climate data archive (Lautenschlager *et al.*, 2009). The climate variability of the 20th century (1960-2000) is represented through 3 independent realisations (C20_1, C20_2 and C20_3) as compiled in Table 1. For the modelling of the future climate, only the first two of the climate model runs for the 20th century were continued and forced by the SRES (Nakićenović *et al.*, 2000) scenarios A1B (global economic) and B1 (global environmental), resulting in 4 independent realisations. The realisations for the past and the future have been combined to 4 transient time series (cp. Table 1) of near surface wind conditions (10 m above surface) covering a period from 1960-2100. For the calculation of the wave climate we are using wind-wave-correlations that have been derived from measured wind and waves for three locations at the German Baltic Sea Coast (Fröhle and Fittschen, 1999). Figure 1 shows the locations which have been used in this study: Warnemünde (cp. Figure 1 right), Travemünde (Bay of Lübeck, cp. Figure 1 bottom) and Westermarkelsdorf (Island of Fehmarn/Bay of Kiel, cp. Figure 1 top).

3. Changes of average wind conditions

For the assessment of future changes in wind, wind data for different time periods, each with durations of 30 years, from the Cosmo-CLM model were extracted at grid points close to the locations of the study area. The changes of the wind conditions were analysed by calculating the frequency of occurrence and average values for the wind velocities and directions using the future scenarios 2050 (2021-2050) and 2100 (2071-2100) and comparing them to values for the control period 1971-2000.

At all 3 locations it became clear that due to shifts of the frequency distributions the average wind velocity is going to increase in the future and that the average wind direction is changing to more westerly directions. Maximum changes of up to +4% for the average wind velocity and up to +11° for the average wind direction have been found (location Westermarkelsdorf) to the end of the 21st century compared with actual conditions (1971-2000).

4. Changes of average wave conditions

From the 4 transient time series of wind conditions (cp. Table 1) long-term time series of wave parameters (significant wave height, mean wave period and direction) are calculated. This has been done, using a hybrid approach that combines wind-wave-correlations and numerical wave simulations at each location. The time series of wave parameters where finally analysed over time periods of 30 years, comparing the average values for the scenario 2050 (2021-2050) resp. 2100 (2071-2100) to the control period 1971-2000.

The changes of the average wind conditions can be linked to changes of the average wave conditions depending on the alignment of the coast towards westerly wind directions. Regarding the wave heights it can be concluded that for locations exposed to westerly winds (e.g. locations Warnemünde and Westermarkelsdorf) the average significant wave height can increase up to +7% to the end of the 21st century compared with actual conditions. At the same time the average wave direction is changing to more westerly directions (up to 8°).

A contrary development, with a small decrease of the average wave height (-1%), was found for the location of Travemünde in the middle of the second half of the 21st century (2041-2070). In contrast to the other locations of this study, the location of Travemünde is exposed to north-easterly winds and the average wave direction changes towards more easterly directions (up to 6°).

5. Changes of Longshore sediment transport

On the basis of the long-term time series of wave parameters we used the shoreline change model GENESIS (Hansen & Kraus, 1989) to calculate long-term time series of the local longshore sediment transport capacities (both directional and net-transport). The model was set up, using the actual form of the coastline and measured sediment parameters (mean grain diameter) at the different locations.

The changes of the transport capacities where analysed within time periods of 30 years, comparing the values for the scenario 2050 (2021-2050) resp. 2100 (2071-2100) to the control period 1971-2000.

The spatial pattern of the changes of the average wave conditions can also be linked to the spatial pattern of change of the long-shore sediment transport. At locations exposed to westerly winds (e.g. locations Warnemünde and Westermarkelsdorf) both the directional sediment transport capacity in the direction where the wind is blowing to and the net-sediment transport capacity are increasing. Maximum increases of the net-sediment transport capacity up to +57% (e.g. location Westermarkelsdorf; cp. Figure 2) were found in the second half of the 21st century. At the same time, the directional sediment transport capacity where the wind is blowing from is decreasing at these locations.

Due to different changes of the average wave conditions at locations exposed to easterly winds, both the local directional and the net-sediment transport capacities are going to decrease down to 22% in the second half of the 21st century (e.g. location Travemünde; not shown here).

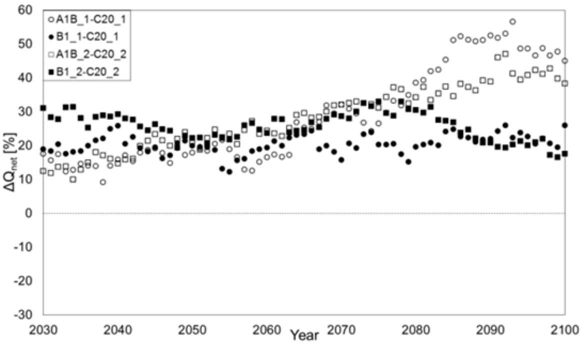


Figure 2. Change of net-transport capacity over time periods of 30 years for different transient runs of the climate change scenarios A1B and B1 compared to the control period (1971-2000); Westermarkelsdorf

6. Summary

Significant changes of regional wind conditions induced from global climate change can have significant effects for the functional and the constructional design of coastal and flood protection structures at the German Baltic Sea Coast. Comparatively small changes of the average wind conditions towards higher wind velocities (+2% to +4%) and more westerly directions can be directly connected to the changes of the average wave heights (-1% to +7%) and waves from westerly directions becoming more dominant.

Due to the changing wave climate the local longshore sediment transport characteristics are affected significantly (-22% to +57% change of net-transport capacity) what has to take into consideration for the functional design of future coastal protection measures like e.g. beach-nourishments, nearshore breakwaters or jetties.

References

Fröhle, P., Fittschen T. (1999) Assessment of short-term directional wave measurements with respect to long-term statistical evaluations. Proc. 5th Int. Conf. on Coastal and Port Engineering in Developing Countries (COPEDEC V), (Cape Town, South Africa), 1005-1016.

Hanson, H., and Kraus, N. C. (1989) GENESIS: Generalized model for simulating shoreline change, Report 1: Technical reference, Tech. Rep. CERC-89-19, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Lautenschlager, M., Keuler, K., Wunram, C., Keup-Thiel, E., Schubert, M., Will, A., Rockel, B. and Boehm, U. (2009) Climate Simulation with COSMO-CLM. Climate of the 20th Century run no.1-3, Scenario A1B run no.1-2, Scenario B1 run no.1-2 , Data Stream 3: European region MPI-M/MaD. World Data Centre for Climate

Nakićenović, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., La Rovere, E.L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Raihi, K., Roehrl, A., Rogner, H.-H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N. and Dadi, Z. 2000. Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, 599pp.

Rockel, B., Will, A. and Hense, A. (eds.) 2008. Special Issue: Regional circulation modelling with COSMO-CLM (CCLM). Meteorologische Zeitschrift, Vol. 17.

Towards a reconstruction of palaeoclimate: Research in the southeast Baltic Sea region during 2011-2013

Olga Druzhinina[1], Yury Kublitsky [2] , Dmitry Subetto [2] and Liudmila Syryh [2]

[1] Faculty of Geography and Geoecology, I. Kant Baltic Federal University, Kaliningrad, Russia (olga.alex.druzhinina@gmail.com)
[2] Faculty of Geography, A. Herzen State Pedagogical University, S-Petersburg, Russia

1. Introduction

The processes of settling by southeastern Baltic primitive tribes against the background of environmental changes were studied since 2009 (the projects ‘The Evolution of the Baltic Sea and the Stages of the Earliest Human Settlement in the Southeast Baltic’, “Evolution of environment of the Southeast Baltic on the border Pleistocene – Holocene and the Stages of the Earliest Human Settlement, RFBR). Aims of the investigations are to obtain new archaeological and palaeogeographic data (variability of climate, vegetation and geological, geomorphological and hydrological processes over the last ~13000 years), and to approach the reconstruction of the Late Glacial and Holocene climate and landscapes as the natural basis of settling processes in the southeastern Baltic Sea.

2. Methods

Methods of research include:

1. The complex palaeogeographic analysis of lake and bog deposits, using data for reconstruction of climate and in-continental hydrological net fluctuations, changes of vegetation
2. Archaeological prospecting and excavations, studying of key archaeological sites within palaeogeographic approach
3. C14, AMS, OSL dating
4. Geological and geomorphological studies for the reconstruction of ancient relief and topography

3. Studying area

From 2011, paleogeographic studies have taken place in a group of small lakes of Vishtynetskaya highland (Kaliningrad region, RF), and include drilling and sampling of bottom sediments of Kamyshovoe lake, one of the most interesting hydrological objects of this territory. Comparisons of palaeogeographic characteristics of this lake with the ones of moraine hills of Lithuania and Poland indicates that the reservoir may be one of the oldest in the region, and its formation should be related directly to deglaciation processes of the Vishtynetskaya highland territory.

4. Results

The obtained samples confirm the assumption about the relative age of the lake. Sediment cores are presented by both stages: late glacial and the column of Holocene sediments. Sediment cores were obtained with a total capacity of about 10 meters; 200 samples are in the process for complex palaeogeographic analysis - magnetic susceptibility, pollen, diatoms and analysis of isotopes (δ18O, δ13C), AMS, 14C dating. For the present moment, preliminary results of the analysis of magnetic susceptibility and radiocarbon dating of part of samples have been obtained. The earliest dating for now (LU-6980) has been received from a depth 830-840 sm from water surface (8740+-160). Complete data are expected in the end of 2013. In the end it will be possible to reconstruct the Late Glacial and Holocene climate and the landscapes of the southeastern Baltic territory.

Baltic Sea wave conditions under climate change scenarios

Nikolaus Groll[1], Birgit Hünicke[1] and Ralf Weisse[1]

[1] Institute of Coastal Research, Helmholtz Center Geesthacht, Geesthacht, Germany (nikolaus.groll@hzg.de)

1. Introduction

Anthropogenic climate change may cause long-term changes in wind, wave and storm surge conditions in the Baltic Sea which could have significant impacts on coastal, on- and offshore activities and human safety. The knowledge of the possible range of future changes is essential for long-time planning of infrastructure and for developing adaptation strategies. Such possible future changes in the Baltic Sea wave conditions are estimated with the spectral wave model WAM.

2. Model setup

The wave model WAM (4.5.3) is forced with wind fields which were regionalized by the regional atmosphere model (RCM) CCLM with a resolution of about 18km x 18km. The CCLM itself was forced by simulations with the general circulation model (GCM) ECHAM5/MPI-OM. Additionally, simulated sea ice coverage is incorporated as it influences the fetch and the wave heights. The grid for the Baltic Sea has a resolution of 0,05°x0,075° (lat/lon).

Two 20th century simulations (1961 to 2000) with different initial conditions from the GCM/RCM simulations (provided by the Max-Planck Institute of Meteorology, Hamburg) are followed by two IPCC scenario simulations (A1B and B1) from 2001 to 2100 respectively (Figure 1).

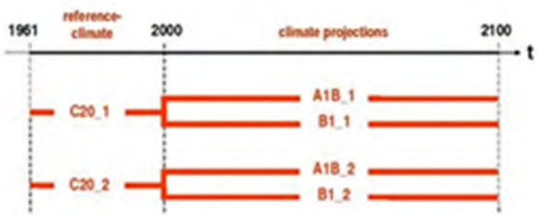


Figure 1. Schematic illustration of the ensemble setup

3. Wind climate

Generally, all four future climate projections show an increase of extreme wind speeds (here in terms of the 99 percentiles) toward the end of the 21th century compared to the reference climate.

For example, Figure 2 shows the difference between the 30yr average of the yearly 99 percentile for the period 2071-2100 of the A1B_1 simulation relative to 1961-1990. The largest increase up to +0.7 m/s can be found in the southern Baltic Sea; this corresponds to an increase of about 5% relative to the reference period. Not only changes in the wind speed are important but also changes in the wind directions can influence the wave climate.

Again all four projections show a shift toward more westerly direction during strong winds (not shown).

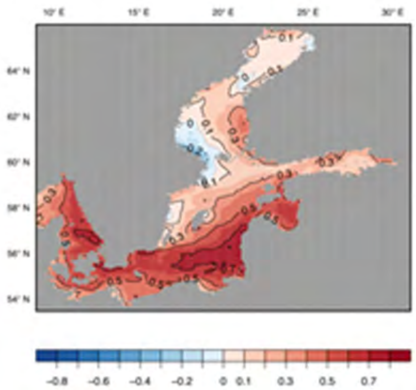


Figure 2. Difference of the yearly 99 percentile wind speed [m/s] for the scenario simulations A1B_1 2071-2100 compared to the reference period 1961-1990

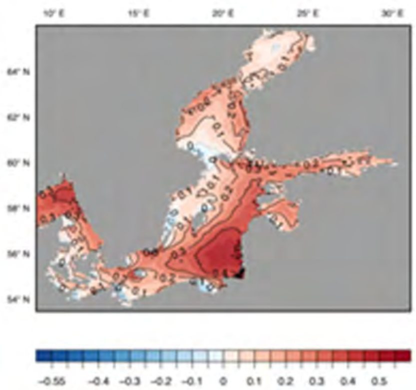


Figure 3. Difference of the yearly 99 percentile wave height [m] for the scenario simulations A1B_1 2071-2100 compared to the reference period 1961-1990

4. Wave climate

The resulting wave climate shows also a general increase in the 99 percentile significant wave height in all four projections. For instance, in the A1B_1 simulation the wave height increases up to 0,5 m in the south-eastern Baltic Sea (Figure 3).

However due to the shift to more frequent westerly winds a decrease of wave height in some regions, especially near several eastern coastlines, is evident.

How a two-way online coupled model system impacts regional climate simulations

H. T. M. Hagemann, B. Rockel and B. Geyer

Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, Geesthacht, Germany (Ha.Hagemann@hzg.de)

1. Introduction

This study introduces a two-way online coupled system COSTRICE from three models of atmosphere, ocean and sea ice (CCLM, TRIMNP and CICE, respectively) using the coupler OASIS version 3 for regional climate simulations over Baltic Sea, North Sea and vicinity regions.

Differences between stand-alone simulations of the regional climate model COSMO-CLM (CCLM) and coupled runs of COSTRICE are analyzed to investigate impacts of the coupling on regional climate simulations.

2. Models

Physically, COSTRICE is a two-way online coupled model system developed at Helmholtz-Zentrum Geesthacht, Germany to reproduce interactions and feedbacks amongst atmosphere, ocean and sea ice for regional climate simulations. Technically, COSTRICE is a combination of the regional atmosphere model CCLM with the regional ocean model TRIMNP and the Los Alamos sea ice model CICE using the coupler OASIS3 (Fig. 1). The atmospheric model used in the current study is the non-hydrostatic regional climate model CCLM (Consortium for Small-scale Modeling model in CLimate Mode, Rockel et al., 2008) version cosmo_4.8_clm11 developed by COSMO [http://www.cosmo-model.org] and the CLM-community [http://www.clm-community.eu]. The ocean model TRIMNP used for the coupled system is the “Nested and Parallel” version of the non-hydrostatic regional ocean model developed at Helmholtz-Zentrum Geesthacht, Germany, on the basis of the TRIM3D (Tidal Residual and Intertidal Mudflat Simulations in 3 Dimensions) model of University of Trento, Italy (Casulli and Cattani, 1994). The sea ice model CICE is the Los Alamos sea ice model version 4.1 from Los Alamos National Laboratory, US [http://oceans11.lanl.gov/trac/CICE].

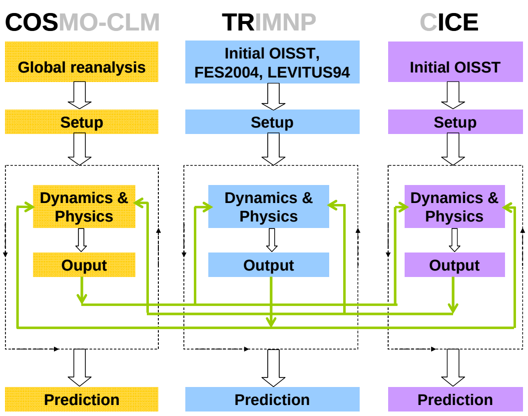


Figure 1. Schematic of the coupled system COSTRICE.

The three models are coupled through the coupler OASIS3 (The Ocean Amosphere Sea Ice Soil model version 3 of CERFACS, France) [http://oasis.enes.org]. In Figure 1, dashed boxes describe time loops in each component model. OASIS3 couples component models via green routes.

3. Experiments

A stand-alone run STERAi and a coupled run CPERAi are set up to investigate impacts of the coupling on regional climate simulations over Baltic Sea and North Sea regions (Fig. 2) for a case study of 1997-2002. In both cases, CCLM is setup with a horizontal grid mesh size of 50 km and 32 vertical hybrid levels, the running time step of 300 seconds and the domain covers the whole Europe. In STERAi, CCLM is driven by the 6-hourly ERA-interim reanalysis data as initial and lateral boundary conditions. While in CPERAi, skin temperature of a grid box that is provided to CCLM every 3 hours is the combination of sea surface temperature SST of TRIMNP and sea ice skin temperature of CICE based on sea ice area. For none matching areas between the two domains of CCLM and TRIMNP, the ERA-interim reanalysis SST is used.

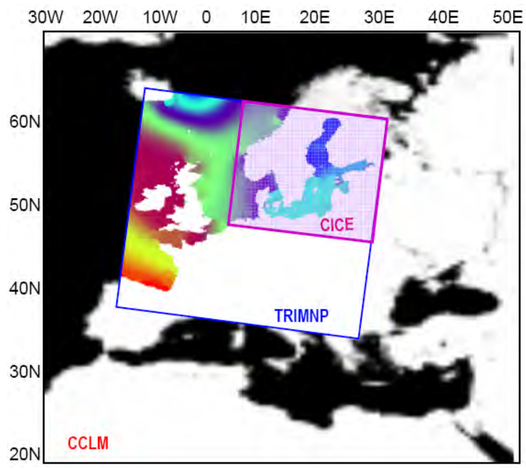


Figure 2. Domains for the atmosphere (CCLM), ocean (TRIMNP) and sea ice (CICE) models.

In CPERAi, TRIMNP is setup with a horizontal grid mesh size of 12.8 km and 50 vertical layers and is driven by 1-hourly atmospheric state variables (near surface pressure, wind, temperature, humidity, air density, cloud fraction), the lowest atmospheric level height, and fluxes (precipitation, snow, short and long wave radiation, and heat) of CCLM. CICE runs with the same horizontal resolution as TRIMNP but only over Baltic Sea and the Kattegat Bay of North Sea. CICE requires the SST, salinity, currents, ocean surface slope, freezing/melting potential energy from TRIMNP and in turn pays back to TRIMNP the water and ice temperature, ice concentration, fresh water flux, ice to ocean heat flux, short wave flux through ice to ocean, and ice stress components. TRIMNP exchanges data with CICE every 3 hours. The time steps of TRIMNP and CICE are both 240 seconds. The first simulation month (January 1997) is considered as “spin-up" time before the two-way coupling starts. The first year 1997 is disregarded when evaluating skills of the model system.

4. Results

In general, despite of some cold biases over North Sea and North Atlantic Ocean in winter, COSTRICE reproduced well SSTs over the considered regions compared to the high resolution reanalysis data OISST of NOAA [http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.OISST/.version2/.AVHRR/]. In summer, biases are smaller over Baltic Sea and North Sea where the interactions and feedback between atmosphere and ocean are taken into account. In winter, although sea ice concentration of COSTRICE is mostly underestimated over the sea ice covered areas Bothnian Bay and Bothnian Sea compared to NOAA AVHRR data, variation and distribution of sea ice concentration are well simulated. Hence, skin temperature which is the combination of sea water surface temperature from TRIMNP and sea ice skin temperature and sea ice area from CICE is in good agreement with the monthly temperature from NOAA and ERA-interim reanalysis data sets. Therefore, the monthly mean of near surface air temperature of CPERAi is similar to the stand-alone one.

However, feedback of ocean skin temperature has influence on precipitation simulations of CCLM. For example, differences of monthly mean precipitation for summer (JJA) 1998-2002 between the two experiments and reanalysis data WATCH are displayed in Figure 3. WATCH data is the daily time series of ECMWF reanalysis data where the monthly means are corrected with GPCC precipitation data and a gauge under-catch correction according to Weedon et al. (2011). Compared to WATCH, STERAi mostly overestimates rainfall over Baltic catchment, especially over Norway and Sweden, and underestimates rainfall over Poland and some areas to the right. Source of the strong wet bias in CCLM may be associated with the combination of North Atlantic Oscillation (NAO) and high topography along the Norway's coastline.

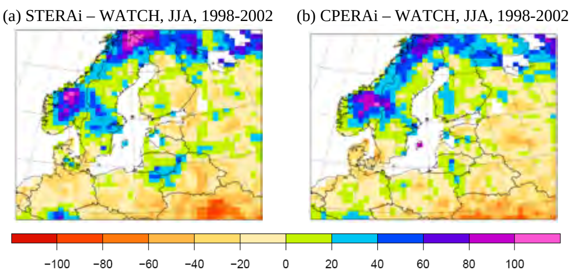


Figure 3. Difference (%) of monthly mean precipitation for JJA 1998-2002 of STERAi (a) and CPERAi (b) compared to WATCH reanalysis data.

NAO is captured well by stand-alone and coupled run when monthly averaged mean sea level pressure fields of the two experiments are compared to ERA-interim. However, in Figure 4a, NAO is more intensified in stand-alone run (for example July 1998) leading to more rainfall to Northern Europe and less to further south areas. The change of circulation even affects central Russia causing dry biases. In the coupled version (Fig. 4b) the high over North Atlantic Ocean is reduced and the low over Norwegian Sea is increased leading to the less wet bias over Bergen, Norway and Kiruna, Sweden in CPERAi. The low over Northern Russia is also increased to reduce wet biases and the part over central Russia is decreased to reduce dry bias.

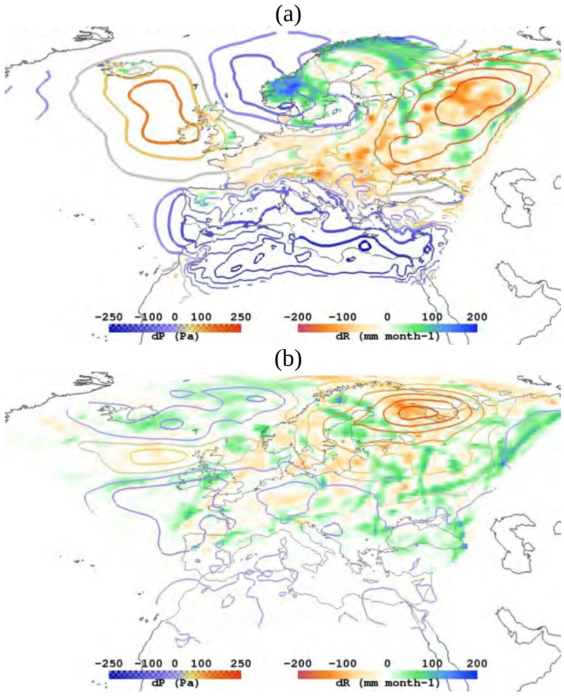


Figure 4. Difference of monthly mean precipitation (mm/month, shaded) and mean sea level pressure PMSL (hPa, contours) for July 1998 between STERAi and reanalysis data (a) and between CPERAi and STERAi (b).

5. Conclusions

COSTRICE has capability to reproduce SST and sea ice over the Baltic Sea and the North Sea. However, simulation of SST over North Sea is affected by Atlantic Ocean that needs longer spin-up time. The interactions and feedback among three major components of the climate system implemented in the coupling process lead to a more reasonable climate simulations over Baltic Sea and North Sea. The coupling has impacts on simulated precipitation not only over the Baltic Sea catchment but also over adjacent areas via circulation. However, a more robust conclusion will be made after the assessment of a long term simulation.

References

Casulli, V. and Cattani, E. (1994) Stability, accuracy and efficiency of a semi-implicit method for three dimensional shallow water flow, Computers Math. Applic., Vol. 27, pp. 99–112.

Rockel, B., Will, A., Hense, A. (Editorial) (2008) Special issue Regional climate modelling with COSMO-CLM (CCLM), Meteorologische Zeitschrift, Vol. 17, No. 4, pp. 347-348.

Weedon, G. P., and Coauthors (2011) Creation of the WATCH Forcing Data and Its Use to Assess Global and Regional Reference Crop Evaporation over Land during the Twentieth Century. J. Hydrometeor, Vol. 12, pp. 823–848.

Variability and trends in daily minimum and maximum temperatures and in diurnal temperature range in Lithuania, Latvia and Estonia

Jaak Jaagus[1], Agrita Briede[2] and Egidijus Rimkus[3]

[1] Department of Geography, Institute of Ecology and Earth Sciences, University of Tartu, Estonia (jaak.jaagus@ut.ee)
[2] Department of Geography, University of Latvia, Riga, Latvia
[3] Department of Hydrology and Climatology, Vilnius University, Lithuania

1. Introduction

The Baltic Sea region can be characterized by a significant climate warming during the last decades. For practical purposes, daily mean temperature is not as important as daily maximum and minimum temperatures. It is natural that daily extreme temperatures have similar trends as daily mean temperature but there are certain peculiarities.

In the global scale, it is found that minimum temperature has increased generally faster than maximum temperature during the period of the intense climate warming after 1950 (Vose et al., 2005). Consequently, the diurnal temperature range (DTR) has decreased in the major part of continental areas. DTR has a slightly negative trend also in the Baltic Sea region during 1950-1993 (Easterling et al. 1997).

Long-term changes in time series of monthly mean maximum and minimum temperatures in Fennoscandia during 1910-1995 were thoroughly analysed by Tuomenvirta et al (2000). Linear trends calculated for 1950-1995 revealed an increase of maximum temperature by 0.07 K per decade and of minimum temperature by 0.17 K per decade, which resulted in statistically significant decrease in DTR by 0.07 K per decade. All these changes were observed in winter and spring, not in summer and autumn.

The main objective of this research is to analyse variability and trends in time series of daily minimum and maximum temperature and DTR in the three Baltic countries during 1951-2010. We have emphasised to the analysis of seasonal differences in the trends. Thereby, we assume that maximum as well as minimum temperatures have increased significantly and minimum temperature has increased much more than maximum temperature. Consequently we hypothesize that daily temperature range has decreased.

2. Data and methods

Daily minimum and maximum temperature measured at meteorological stations were used for the analysis in this study. Diurnal temperature range (amplitude) is calculated as a difference between maximum and minimum temperatures. The main period 1951-2010 is used. This is the longest continuous temperature series for which data from a number of stations are available. The total number of the used stations was 47 while 16 of them were from both Lithuania and Latvia and 15 from Estonia. The data are obtained from the Estonian Meteorological and Hydrological Institute, Latvian Environment, geology and meteorology centre and Lithuanian Hydrometeorological Service. The stations were located more or less evenly over the study area (Fig. 1).

We take into account that the properties of maximum and minimum air temperatures as well as of daily temperature range are clearly different in the coastal zone and in the hinterland. Therefore, we grouped and analysed separately maritime and continental stations. The number of maritime stations in Estonia was 7, in Latvia – 4 and Lithuania – 2.

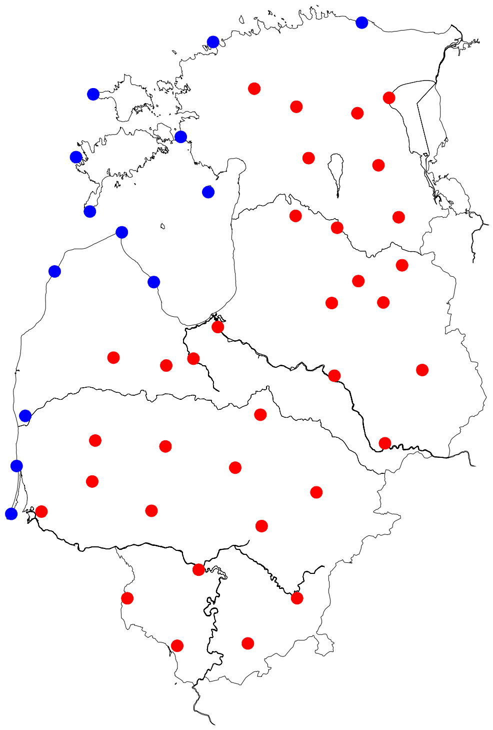


Figure 1. Location map with maritime (blue) and continental (red) stations.

The problem of data homogeneity is crucial in trend analyses. We selected only these stations for analysis where no inhomogeneities were detected in time series. A number of stations with long time series were omitted due to relocations. We assume that our time series are homogeneous, i.e. they don't contain artificial breaks. Nevertheless, there might be some factors, for example, growing of trees in the neighbourhood of a meteorological station that can influence on the local thermal conditions and thereby on the homogeneity of temperature series.

We have used all together time series of four monthly variables: mean maximum temperature, highest maximum, mean minimum and lowest minimum temperature. Their mean values and standard deviations are calculated for the all stations.

Maximum and minimum temperatures are not always normally distributed. A clear negative asymmetry is typical for winter temperatures while a slight positive asymmetry is observed in daily maximum temperature for summer and late spring. Therefore, the trend analyses are realised using the non-parametric Mann-Kendall test. Trends are considered statistically significant on $p<0.05$ if the MK statistic is 1.96 or higher. The trend slopes are calculated using the Sen's method.

3. Results and discussion

Daily maximum and minimum temperatures as well as DTR in the Baltic countries are influenced by two main large-scale factors – latitude and the Baltic Sea. Generally, in the southern locations, i.e. in Lithuania temperature is higher and in the northern locations, in Estonia, maximum and minimum temperatures are lower. But the influence of the Baltic Sea plays an important role in temperature regime minimising DTR.

The average temperature difference between Lithuania and Estonia has been 1-2 K while it was the highest in spring in case of maximum temperature in maritime stations and in winter in case of minimum temperature in continental stations, and the lowest in midsummer. The maritime stations have higher maximum temperatures in autumn and winter, and lower values in spring and summer in comparison with the continental stations. Minimum temperature is higher in maritime stations during the whole year. Differences in minimum temperature between the maritime and continental stations are the highest during winter season reaching up to three degrees or even higher. The typical peculiarities of maritime climate revealed in the highest magnitude in the West-Estonian archipelago.

The lowest diurnal temperature amplitudes have been observed in the Estonian maritime stations and the highest in the Estonian continental stations. This difference is remarkably smaller in Latvia and Lithuania, probably due to the absence of stations on islands with totally maritime conditions. The highest mean temperature ranges revealed in May, June and July, the lowest ones in November and December. The territorial pattern on DTR demonstrates much higher values in the continental regions and lower values at the maritime stations.

The highest maximum temperature in the Baltic counties – 36.8°C – was measured at Varėna, southern Lithuania, in 13 July 1959. Absolute temperature maxima in January have Lithuania. The lowest minimum temperatures in the study area during the 60 years were recorded at Daugavpils, south-eastern Latvia (-43.2°C) and Utena, eastern Lithuania (-42.9°C) on 1 February 1956. The absolute minima at the coastal stations of Estonia were much higher not dropping below -30°C.

Mean annual maximum temperature has increased in the Baltic countries by 0.3 K per decade during 1951-2010. It has been a bit higher in Estonia than in Latvia and Lithuania. Among months statistically significant trend was detected in March, April, May, July and August, and in the maritime stations also in February (Fig. 2). Absolute maximum temperatures have increased in all countries in February and March, in Estonia and Latvia also in April and August.

Mean annual minimum temperature has also increased by the same 0.3 K in the average during the 60 years. The strongest change was observed from January to March but at some regions also in April, May, July and August (Fig. 3). Absolute minimum temperature has the highest trend in March and at some regions also in April, July and some other months.
Few statistically significant trends revealed for DTR. Mostly positive trends were found for April and May while negative trends were detected in some stations in January, February, March and June (Fig. 4). Consequently, the preliminary assumptions of decreasing DTR were not approved.

The trends were more or less similar at the three countries. Generally, the warming trend has been a bit stronger in the northern part of the study region (Estonia) than in the other parts. In many cases, trend values for the continental regions are higher than in the maritime stations.

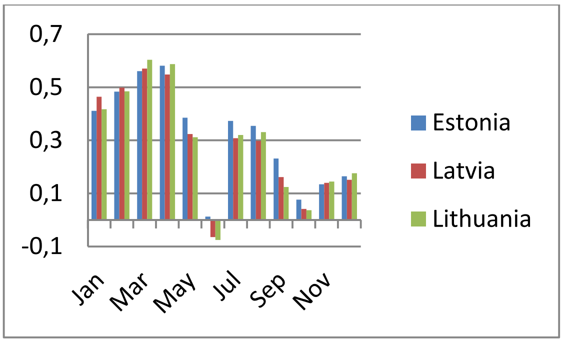


Figure 2. Trend values (K/decade) for monthly mean maximum temperature.

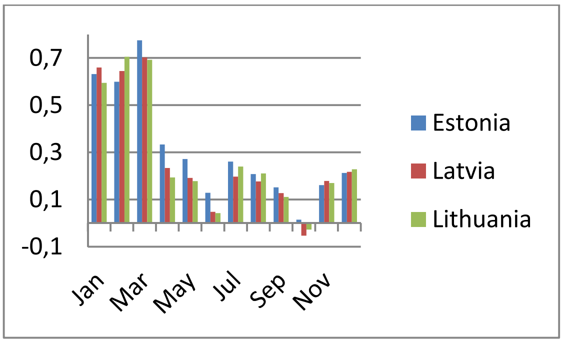


Figure 3. Trend values (K/decade) for monthly mean minimum temperature.

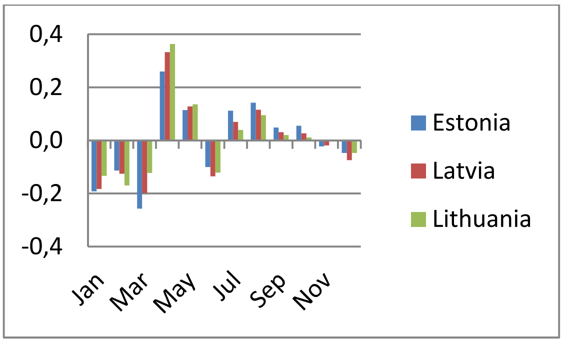


Figure 4. Trend values (K/decade) for monthly mean DTR.

References

Easterling D, Horton B, Jones P, Peterson T, Karl T, Parker D, Salinger J, Razuvayev V, Plummer N, Jameson P, Folland C (1997) Maximum and minimum temperature trends for the globe. Science, 289, 2008–2074.

Tuomenvirta H, Alexandersson H, Drebs A, Frich P, Nordli PØ (2000) Trends in Nordic and Arctic temperature extremes and ranges. J Climate, 13, 977–990.

Vose RS, Easterling DR, Gleason B (2005) Maximum and minimum temperature trends for the globe: an update through 2004. Geophys Res Lett, 32(L23822). doi:10.1029/2005GL024379.

Diurnal variability of water vapour in the Baltic Sea region according to NCEP-CFSR and BaltAn65 reanalyses

Erko Jakobson[1,2], Hannes Keernik[1,2], Andres Luhamaa[2,3], Hanno Ohvril[2]

[1] Tartu Observatory, Tõravere, Estonia (erko.jakobson@ut.ee)
[2] Institute of Physics, University of Tartu, Estonia
[3] Estonian Meteorological and Hydrological Institute, Tallinn, Estonia

1. Introduction

Water vapour is unquestionably the most essential component of the Earth's atmosphere. It is contributing averagely about 60% of the natural greenhouse effect (Kiehl and Trenberth, 1997; Maurellis and Tennyson, 2003), being the resource for precipitation in the lower troposphere and playing a critical role in many chemical reactions. Therefore, its quantity must be known precisely to understand, associate and forecast meteorological processes. On the other hand, temporal as well as spatial variability of water vapour occur such a fine scales, that resolving it adequately presuppose observing systems with high sampling resolution in space and time (Anthes, 1983; Bengtsson et al., 2003). Assimilating information from several databases, numerical weather prediction models and reanalyses are important tools for monitoring changes in water vapour content.

In this paper, we determine summer average diurnal cycle in precipitable water PW, and also the atmospheric layers responsible for this cycle, using two atmospheric reanalyses.

2. Data

Global atmospheric reanalysis model of the National Center of Environmental Predictions Climate Forecast System Reanalysis (NCEP-CFSR) (Saha et al., 2010) and regional reanalysis model BaltAn65 (Luhamaa et al., 2010), based on HIRLAM version 7.1.4, were used for this study. BaltAn65 obtained boundary fields from ECMWF ERA-40 global reanalyses.

NCEP-CFSR horizontal resolution is 0.5 degrees, while BaltAn65 resolution is 0.1 degree. Data from 1979 to 2010 from NCEP-CFSR and from 1979 to 2005 from BaltAn65 was analysed.

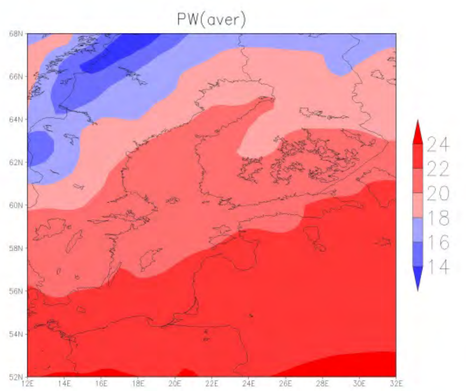


Figure 1. Precipitable water PW (mm) summer (JJA) average for 1979 – 2010 from NCEP-CFSR.

3. Results

NCEP-CFSR summer average precipitable water has clear latitudinal dependence (Fig. 1) with orographic effect on Scandinavian Mountains, but no influence of surface type. The region average of precipitable water was 22.8 mm, though local extreme values varied through the summer even one magnitude – from 4.5 mm to 51 mm.

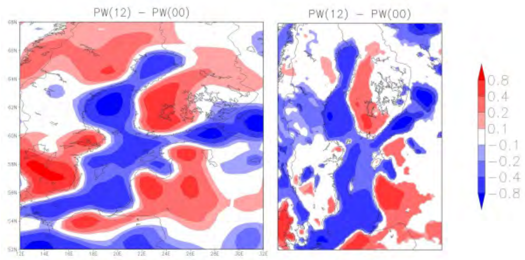


Figure 2. Difference in precipitable water PW (mm) (PW_{12UTC} – PW_{00UTC}) in summer (JJA). Left panel – NCEP-CFSR for 1979 – 2010. Right panel – BaltAn65 for 1979 – 2005.

Statistically significant differences in precipitable water are shown on Fig. 2 for both models. Diurnal cycle above the Baltic Sea and above land has opposite behaviour according to both models – above sea is averagely more water vapour at 00UTC, above land at 12UTC. According to NCEP-CFSR, the whole region average precipitable water is at 12 UTC 0.4 mm higher than at 00UTC, though regional maximum differences were even more than 2 mm in both directions.

Specific humidity and temperature 00, 06, 12 and 18 UTC vertical cross-sections differences from the average values from NCEP-CFSR (Fig. 3) show fundamental differences between results above sea and land. BaltAn65 patterns were similar (not shown). Above sea there is less humidity at 12 and 18, above land below 950 hPa at 12 and above 925 hPa at 06 and somewhat at 00. Above land the temperatures are higher at 18 and 12 and lower at 06 and 00. Above sea is temperature diurnal cycle delayed about 6 hours, compared to cycle above land, with higher temperatures at 18 and 00 and lower temperatures at 06 and 12, though the delay fades out above about 850 hPa.
The summer mean diurnal variation in the specific humidity profile fade out ($\Delta < 0.1$ g/kg) above 700 hPa (3010 m), while in the temperature vertical profile it fade out ($\Delta < 0.5$ ºC) above 850 hPa (1460 m). This shows that though the vertical changes in water vapour and temperature are closely coupled, humidity diurnal variations reach much higher.

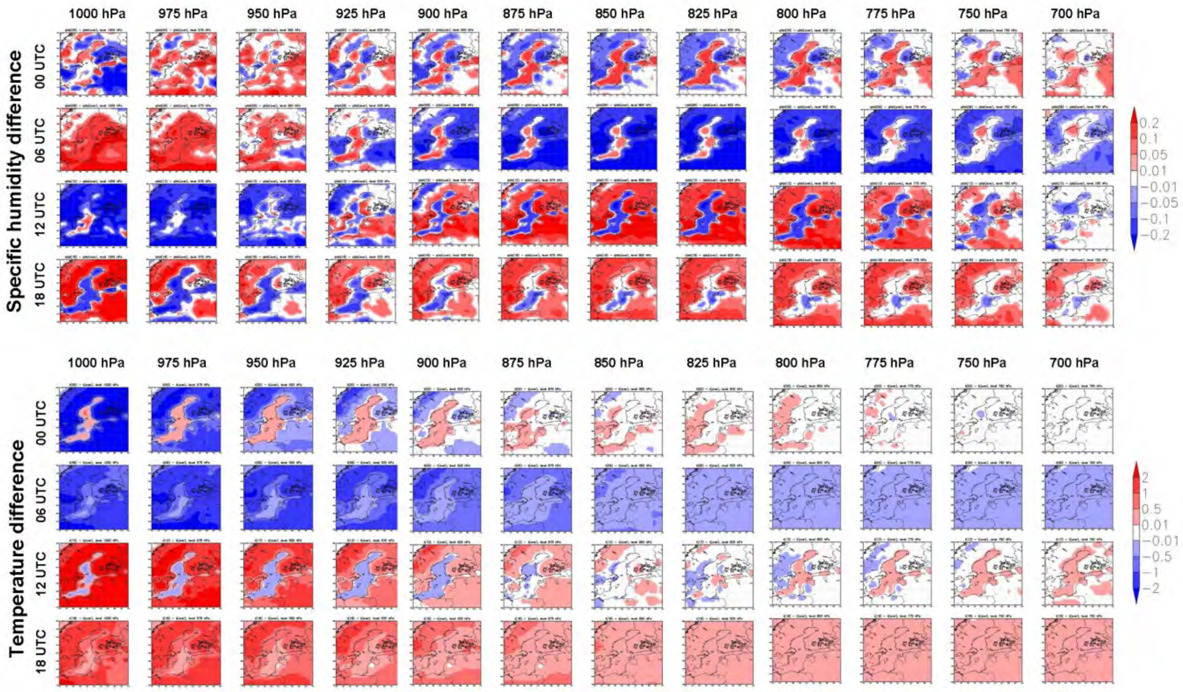


Figure 3. Upper panel – specific humidity (g/kg) at 00, 06, 12 and 18 UTC minus average specific humidity. lower panel – temperature (ºC) at 00, 06, 12 and 18 UTC minus average specific humidity. rows – times; columns – pressure levels.

4. Conclusions

Summer average diurnal variations in the precipitable water, specific humidity and temperature are primarily affected by under laying surface type – sea or land. The main inducers above sea are sea breeze at daytime with descending airflow and land breeze at night with ascending airflow.

Above land:

- Temperature diurnal cycle is controlled by solar energy diurnal cycle with minimum temperature at 06 UTC and maximum at 18 UTC in the whole profile.
- Specific humidity diurnal cycle is controlled by both temperature and relative humidity. Above 950 hPa (540 m) is the cycle coherent with temperature cycle, but below 950 hPa is diurnal maximum at 06 UTC due to high relative humidity and minimum at 12 UTC due to low relative humidity.
- Precipitable water values at 12 UTC are mostly higher than 00 UTC ones, though there are some regions above land with vice versa behavior.

Above sea:

- At 00 UTC is relatively warmer because of heating by descending dry adiabatic airflow; at 12 UTC is relatively colder because of cooling by ascending wet adiabatic airflow.
- Specific humidity diurnal cycle is controlled by ascending humid airflow at 00 and 06 UTC and descending dryer airflow at 12 and 18 UTC. At 12 UTC below 1000 hPa (110 m) is still more humidity.
- Precipitable water values at 12 UTC are clearly lower than 00 UTC ones, due to higher specific humidity at 00 UTC above 950 hPa (540 m). This finding is opposite to our previous study based on 10 year GPS-measurements at Visby station on Gotland Island, where PW values at 12 UTC exceeded 00 UTC ones.

References

Anthes R.A. (1983), Regional models of the atmosphere in middle latitudes, Mon. Wea. Rev., 111, 1306-1335.

Bengtsson L., Robinson G., Anthes R., Aonashi K., Dodson A., Elgered G., Gendt G., Gurney R., Jietai M., Mitchell C., Mlaki M., Rhodin G., Silverstrin P., Ware R., Watson R., Wergen W. (2003), The use of GPS measurements for water vapor determination, Bull. Am. Meteorol. Soc., 84, 1249-1258.

Jakobson E., Ohvril H., Elgered G. (2009), Diurnal variability of precipitable water in the Baltic region, impact on transmittance of the direct solar radiation, Boreal Environment Research, 14, 45-55.

Kiehl J.T., Trenberth K.E. (1997), Earth's Annual Global Mean Energy Budget, Bull. Am. Met. Soc., 78, 197-208.

Luhamaa A., Kimmel K., Männik A., Rõõm R. (2010), High resolution re-analysis for the Baltic Sea region during 1965–2005 period, Clim. Dyn., 36, 727-738.

Maurellis A.N., Tennyson J. (2003), The climatic effects of water vapour, Physics World, pp. 29-33.

Saha S., et al. (2010), The NCEP Climate Forecast System Reanalysis, Bull. Am. Met. Soc., 91(8), 1015-1057.

Trends in tropospheric humidity and temperature over Estonia and Finland derived from radiosonde measurements

Hannes Keernik[1,2], Erko Jakobson[1,2] and Hanno Ohvril[1]

[1] Institute of Physics, University of Tartu, Estonia (hannes.keernik@ut.ee)
[2] Tartu Observatory, Tõravere, Estonia

1. Introduction

Global climate variability and warming has been widely debated topic for many years all over the world. Comprehensive studies have been made also for the Baltic Region, for example by Jaagus (2006) and Tuomenvirta (2004). Research by Jaagus involved surface air temperature (T_s) trend analyses during the years 1951–2000 in Estonia. Statistically significant increasing trends in T_s were detected in January, February, March, April and May (annual trend 0.2–0.35°C decade^{-1}). Similar study for Finland was conducted by Tuomenvirta, who reported annual T_s trend 0.08°C decade^{-1} for the 20th century. For the period 1976–2000, the trend was as much as 0.81°C decade^{-1}.

These warming trends at surface refer to the exponential increase of the integrated column water vapour (precipitable water, PW). Using radiosonde data from 50 stations around the world for 1973–1990, Gaffen et al. (1992) established a relationship between monthly T_s and PW by an equation of the form $\ln(PW) = A + BT_s$, with linear correlation coefficient $r = 0.94$. The latter is even higher for stations poleward of 20° latitude. In addition, the correlations between these two characteristics increase when comparing yearly averages, since mean values over a longer period give rise to uniformity in the vertical humidity profile.

On contrary to T_s, tropospheric temperature and humidity trends over the Baltic Region are investigated considerably less. In this paper, we discuss the variations and trends in PW, specific humidity (SH) and temperature over Estonia (Harku) as well as Finland (Sodankylä, Jokioinen and Jyväskylä) by means of Vaisala RS80, RS90 and RS92 radiosondes.

2. Data processing

All data were retrieved from a freely accessible web site of the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html). Raw radiosonde message was used to identify the type of sonde. Two different datasets obtained with Vaisala RS80 and RS9x generations (RS90 and RS92) have not been united, because of the bigger RS80 dry bias than newer versions of Vaisala sondes (Smit et al., 2013; Wang and Zhang, 2007).

Radiosonde data from four stations were used:

- Harku (59.38 N, 24.58 E), 1999–2012, 4928 soundings. RS9x used for all period.
- Jokioinen (60.81 N, 23.50 E), 1982–2012, 10 934 soundings. RS9x used since 2005.
- Jyväskylä (62.40 N, 25.68 E), 1982–2012, 10 946 soundings. RS9x used since 1998.
- Sodankylä (67.36 N, 26.65 E), 1982–2012, 10 974 soundings. RS9x used since 2000.

Only measurements at 00 UTC were used, except over Jyväskylä, where due to the shift of launching time, since 1997 soundings at 06 UTC were used instead. Radiosonde profiles were vertically linearly interpolated with the step of 500 m from ground. Monthly means at all levels were calculated by averaging at least 10 measurements. By this condition, the highest level available for trend calculations was determined. Linear regression analysis is applied for the detection of trends. All trends are considered to be statistically significant at 95% confidence level. Anomalies and trends over stations are calculated from average profile measured by same type of radiosonde (RS80 or RS9x).

3. Trends at surface and above

By analyzing annual anomalies of SH (Fig. 1) and temperature (not shown) during 1982–2012, high positive anomalies at higher altitudes around 1982–1984 are revealed. It is followed by the coldest – although, not "driest" – period around 1984–1987. For all stations in Finland, annual anomalies of SH appear to be the most negative during 1993–1994 (also resulting in the lowest annual PW values in Fig. 2). The late 1990s are relatively warm and moist, the same tendency is evolving in recent years.

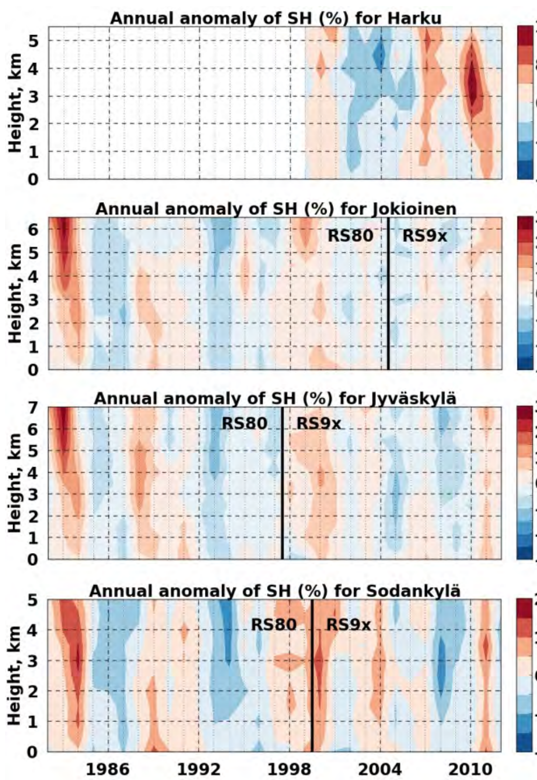


Figure 1. Annual anomalies of specific humidity for all four stations. From 1999 to 2012 over Harku, all measurements were made using RS9x. For stations in Finland, sonde transition from RS80 to RS9x is marked as black vertical line. Anomalies are calculated from the mean of data obtained by the same type of radiosonde (RS80 or RS9x).

For Harku, the data record is relatively short. Therefore we were not able to identify any statistically significant trends in annual T_s and PW (Fig. 2). However, monthly SH, temperature as well as relative humidity up to 5.5 km have been considerably increased from July to September, reflecting a positive trend in PW in September (2.6 mm decade^{-1}).

In Finland, from 1982 to 2012, there have been positive annual T_s trend for two stations, Jyväskylä and Sodankylä (1.0°C decade^{-1} and 0.5°C decade^{-1}, respectively). Increasing T_s trends, well in agreement with Tuomenvirta, are present mostly in summer (JJA) and autumn (SON). Because of discontinuities related to sonde sensor evolution, trends in annual PW for two separated time series were not found.

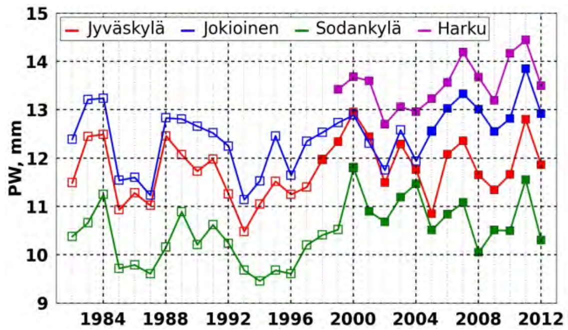


Figure 2. Annual PW values over Jyväskylä, Jokioinen, Sodankylä as well as Harku. Empty and filled squares denote RS80 and RS9x measurements, respectively.

Although, lengths of time series derived from RS80 measurements differ from station to station, decreasing trends in monthly PW in May are notable for all stations in Finland (from –0.6 to –2.3 mm decade^{-1}). In addition, increases of monthly PW calculated from earlier records are similar in January between three stations, significant trend detectable only over Sodankylä (0.8 mm decade^{-1}). For recent time series obtained with RS9x, the most significant decrease in PW is observable from 1998 to 2012 in July over Jyväskylä (–3.1 mm decade^{-1}).

Nevertheless, trends in monthly PW are not necessarily reflected in statistically significant trends in SH profiles, and *vice versa*, since the value of PW is most affected by magnitude of SH changes at the lower tropospheric levels, as exemplified by Sodankylä's case (Fig. 3). Temperature and SH show significant decreasing trends in February and increasing trends in June for almost the whole profile. However, PW is significantly increased in January (0.8 mm decade^{-1}) and decreased in May (–1.5 mm decade^{-1}) due to the greater changes in these months.

In conclusion, while annual T_s during the research period in two of four stations has significantly increased, there is no strong evidence of increase in annual PW over stations observed, probably due to the discontinuities in the time series. However, many monthly PW trends were discovered, the most notable in May, when decreasing trend calculated from earlier datasets applies to all stations in Finland. The further work includes homogenizing different datasets measured by RS80 and RS9x through applying correction proposed by Miloshevich et al. (2001).

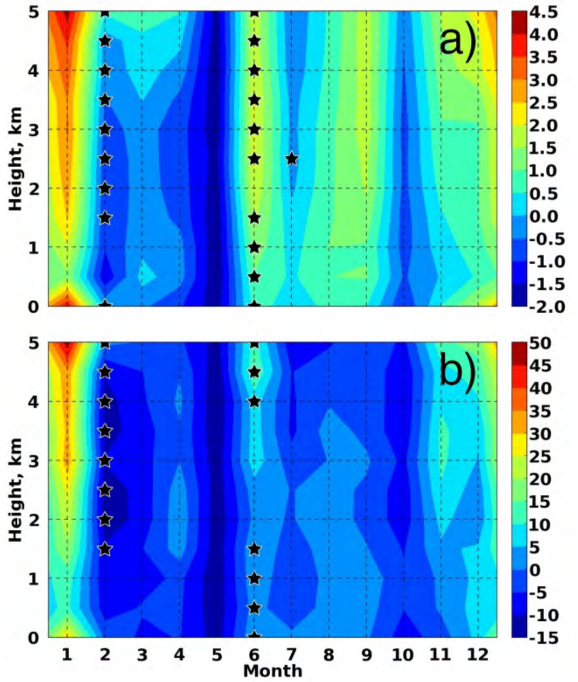


Figure 3. Example of trends in monthly a) temperature (°C decade^{-1}) and b) specific humidity (% decade^{-1}) over Sodankylä, 1982–1999. Statistically significant trends at the 95% confidence level are marked with stars.

Acknowledgement

This research was supported by European Social Fund's Doctoral Studies and Internationalisation Programme DoRa, which is carried out by Foundation Archimedes.

References

Gaffen, D., Elliott, W., Robock, A. (1992). Relationships between tropospheric water vapor and surface temperature as observed by radiosondes, *J. Geophys. Res.*, 97, 18,185–18,193.

Jaagus, J. (2006). 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.

Miloshevich, L. M., Vömel, H., Paukkunen, A., Heymsfield, A. J., Oltmans, S. J. (2001). Characterization and correction of relative humidity measurements from Vaisala RS80-A radiosondes at cold temperatures, *J. Atmos. Oceanic Technol.*, 18, 135–156.

Smit, H., Kivi, R., Vömel, H., Paukkunen, A. (2013). Thin film capacitive sensors, Monitoring Atmospheric Water Vapour, ISSI Scientific Report Series, Vol. 10, part 1, 11–38.

Tuomenvirta, H. (2004). Reliable estimation of climatic variations in Finland, Finnish Meteorological Institute, Contributions 43, 82 p.

Wang, J., Zhang, L. (2008). Systematic errors in global radiosonde precipitable water data from comparisons with ground-based GPS measurements, *J. Climate*, 21, 2218–2238.

A new generation of regional climate model scenarios for the Baltic Sea area

Erik Kjellström, Grigory Nikulin, Patrick Samuelsson and Colin Jones

Swedish Meteorological and Hydrological Institute, Norrköping, Sweden (erik.kjellstrom@smhi.se)

1. Introduction

Uncertainties in future climate change are related to external forcing, model formulation and natural variability. A way to handle these uncertainties is to perform several simulations constituting an ensemble. As part of the Coordinated Regional Downscaling EXperiment (CORDEX), the Rossby Centre has produced a large number of RCM simulations at 50km resolution for Europe. Here, a total of 18 different climate change simulations are presented. This relatively large RCM ensemble can be used to address uncertainties at the local to regional scale due to choice of GCM (in total 9) and external forcing (2 different emission scenarios). The objective of the study is to assess future climate change in the Baltic Sea area for the time period 1961-2100. We also discuss differences in the climate change signal between the coarse-scale GCMs and the RCM.

2. The regional climate model RCA4

Since RCA3 (Samuelsson et al., 2011), RCA has undergone both technical and physical changes. The new model version, RCA4, have some changes in the land and surface description of the model including a new global physiography data set including Gtopo30 orography, ECOCLIMAP land-use and soil information (Masson et al., 2003). In addition, a new lake model (FLake) has been implemented (Samuelsson et al., 2010) and a river routing scheme.

Modifications in the atmospheric part of the model include introduction of a numerically more stable turbulent kinetic energy (TKE) scheme (Lenderink and Holtslag, 2004) into the original CBR (Cuxart et al., 2000) scheme. At the same time the variables diffused in the TKE scheme were switched from dry (temp, humidity, liquid water) to moist conservation (liquid water potential temp and total water) following Grenier et al. (2001). Treatment of convection has been adjusted by switching the deep and shallow convection schemes from the standard Kain-Fritsch scheme (Kain and Fritsch, 1990) to the Bechtold-KF scheme (Bechtold et al., 2001). A few additional modifications including dilute CAPE profile for calculating the CAPE closure have also been implemented (Jiao and Jones, 2008). Finally, the threshold relative humidity for cloud formation was adjusted and the representation of cloud SW relflectivity and LW emissivity was modified to account for in-cloud cloud-water heterogeneity, loosely following Tiedtke (1996).

3. The RCA4 ensemble

RCA4 has been forced by nine different GCMs under two different emission scenarios for the experiments described here. The GCM runs are from the CMIP5 (Coupled Model Intercomparison Project Phase 5) as listed in Table 1. Apart from different formulation the GCMs have been operated at different horizontal resolution, ranging from c. 125 to 300 km at the equator. For all GCMs two emission scenarios were downscaled. These are the RCP (Representative Concentration Pathway) scenarios RCP4.5 (Thomson et al., 2011) and RCP8.5 (Rihai et al., 2011).

Table 1. List of CMIP5 GCMs that have been used to provide boundary conditions for the RCA4 runs presented here.

No	Modelling Centre	Model name
1	Canadian Centre for Climate Modelling and Analysis	CanESM2
2	Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	CNRM-CM5
3	EC-EARTH consortium	EC-EARTH
4	NOAA Geophysical Fluid Dynamics Laboratory	GFDL-ESM2M
5	Met Office Hadley Centre	HadGEM2-ES
6	Institut Pierre-Simon Laplace	IPSL-CM5A-MR
7	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5
8	Max Planck Institute for Meteorology	MPI-ESM-LR
9	Norwegian Climate Centre	NorESM1-M

4. Simulated future climate change

Figure 1 shows the change in wintertime precipitation in 2041-2070 compared to the reference period 1971-2000. It is clear that the signal in RCA4 largely follows that in the GCMs and that there is an increase in the entire region. The figure also illustrates that although there is a spread between the different simulations indicating uncertainty the results are relatively robust as almost all simulations show an increase. It can also be noted that the simulated climate change signal in RCA4 differs in some details from that in the GCMs as a result of the higher resolution.

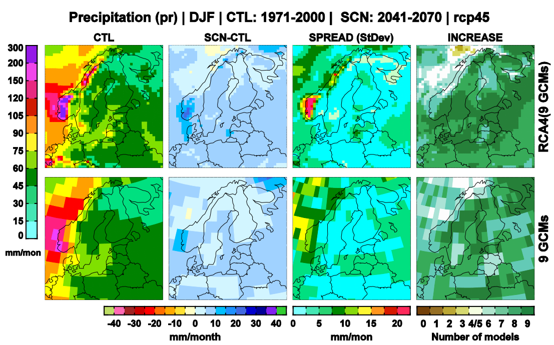


Figure 1. The simulated winter (DJF) change in precipitation.

Changes in both temperature and precipitation are shown for a part of the Baltic Sea area in Figure 2. Here it is seen that there is a gradual increase in both temperature and precipitation as simulated by RCA4 in both seasons. It is clear that the choice of emission scenarios gets more important with time. For these particular variables the scenarios show about equally strong climate change in the first time period (2011-2040) while the RCP8.5 scenario leads to a stronger change compared to RCP4.5 in the mid and even more so at the end of the century. As an example of this we note that the RCP8.5 scenario gives about equally strong climate change at the mid of the century (2041-2070) as what the RCP4.5 scenario shows 30 years later.

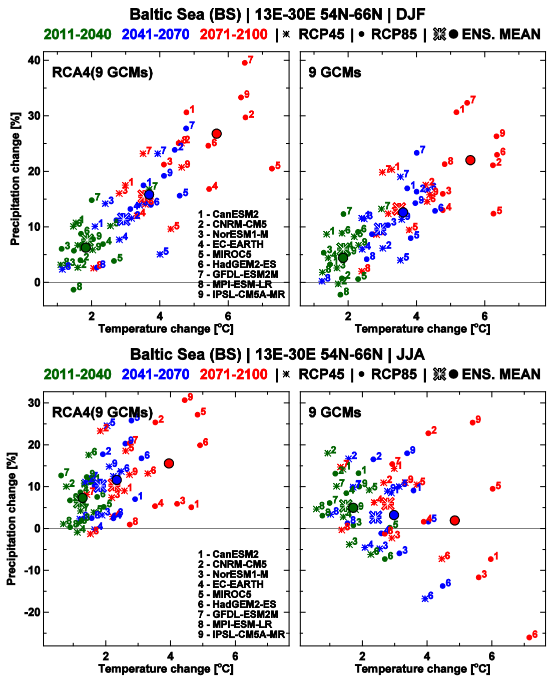


Figure 2. Simulated change in winter (top) and summer (bottom) temperature and precipitation in RCA4 (left) and in the corresponding GCMs (right). Results are shown for three time periods and two emission scenarios for all individual simulations as well as for the ensemble means.

Figure 2 also reveals some differences between the climate change signal in RCA4 and the underlying GCMs as RCA4 generally produces a larger positive (or smaller negative) change in precipitation compared to that in the GCMs. This is most evident in summer.

5. Summary and conclusions

A large ensemble of RCM simulations at 50km resolution are presented for the Baltic Sea region. Strong, gradually increasing, climate change signals are seen in both temperature and precipitation. The simulated climate change signal in the RCM generally follows that in the GCMs although with some notable exceptions. First, there are some small-scale structures to the climate change signal related to the higher horizontal resolution. Secondly, there are also some differences in how the RCM responds to a certain change – here exemplified by the stronger increase in precipitation compared to the GCMs.

Acknowledgements

We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups (listed in Table 1 of this paper) for producing and making available their model output.

References

Bechtold, P., Bazile, E., Guichard, F., Mascart, P. and Richard, E. (2001), A mass-flux convection scheme for regional and global models. Q.J.R. Meteorol. Soc., 127: 869–886.

Cuxart, J., Bougeault, P. and Redelsperger, J.-L. (2000), A turbulence scheme allowing for mesoscale and large-eddy simulations. Q.J.R. Meteorol. Soc., 126: 1–30.

Grenier, H. and Bretherton, C.S. 2001: A Moist PBL Parameterization for Large-Scale Models and Its Application to Subtropical Cloud-Topped Marine Boundary Layers. Mon. Wea. Rev., 129, 357–377.

Jiao, Y. and Jones, C., 2008: Comparison Studies of Cloud- and Convection-Related Processes Simulated by the Canadian Regional Climate Model over the Pacific Ocean. Mon. Wea. Rev., 136, 4168–4187

Kain, J.S. and Fritsch, J.M. 1990. A One-Dimensional Entraining/Detraining Plume Model and Its Application in Convective Parameterization. J. Atmos. Sci., 47, 2784–2802.

Kjellström, E., Nikulin, G., Hansson, U., Strandberg, G. and Ullerstig, A., 2011. 21st century changes in the European climate: uncertainties derived from an ensemble of regional climate model simulations. Tellus, 63A(1), 24-40.

Lenderink, G. and Holtslag, A. A. M. (2004), An updated length-scale formulation for turbulent mixing in clear and cloudy boundary layers. Q.J.R. Meteorol. Soc., 130: 3405–3427.

Masson, V., Champeaux, J.-L., Chauvin, F., Meriguet, C. and Lacaze, R., A global database of Land Surface Parameters at 1-km Resolution in Meteorological and Climate Models. Journal of Climate, 16, 9, 1261- 1282, 2003.

Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N. and Rafaj, P., 2011. RCP 8.5—A scenario of comparatively high greenhouse gas emissions. Climatic Change 109:33–57.

Samuelsson, P., E. Kourzeneva, and D. Mironov, 2010: The impact of lakes on the European climate as simulated by a regional climate model. Boreal Env. Res., 15, 113-129.

Samuelsson, P., Jones, C., Willén, U., Ullerstig, A., Gollvik, S., Hansson, U., Kjellström, E., Nikulin, G., Wyser, K., 2011. The Rossby Centre Regional Climate Model RCA3: Model description and performance. Tellus, 63A(1), 4-23.

Thomson, A.M., Calvin, K.V., Smith, S.J., Kyle, G.P., Volke, A., Patel, P., Delgado-Arias, S., Bond-Lamberty, B., Wise, M.A., Clarke L.E. et al., 2011 RCP4.5: a pathway for stabilization of radiative forcing by 2100. Climatic Change 109:77–94.

Regional aspects of climate in the southeast Baltic region in connection with global changes

Evgeny V. Krasnov, Galina M. Barinova, Dara V. Gaeva

Baltic Federal University of Immanuel Kant, Russia (ecogeography@rambler.ru)

1. Regional climate in the light of global changes

Global climate trends cannot be understood without a real regional differentiation, not only today, but also in ancient times (Barinova, 2002; Barinova et al., 2004). In most Russian regions, general warming is faster than in other countries (Estimational report, 2008). Maximum warming is set between 50 and 55° N. To the South, positive trends in surface air temperature are less distinct (Kasimov and Klige, 2012). In winter, the warming is more noticeable at high latitudes and climate zones shift northward, which will be accompanied by a transformation of agricultural, forest and taiga geosystems. This paper focuses on air temperature and precipitation variations in the southeast Baltic region.

2. The peculiarities of air temperature and precipitation variations

The regional climate warming was established on the base of regular observations at several coastal meteorological stations (Königsberg –Kaliningrad, Rostock-Warnemünde). For example, the average air temperature in Kaliningrad from 1979 to 1998 was about 7.5°C (up to 0.8°C higher than 20 years before). On Fig. 1, air temperature fluctuations in Kaliningrad and Rostock from 1949 to 2010 are seen. Deviations of average yearly air temperature from the mean (1961-1990) were calculated separately for Kaliningrad (7.2°) and Rostock – Warnemünde (8.4°).

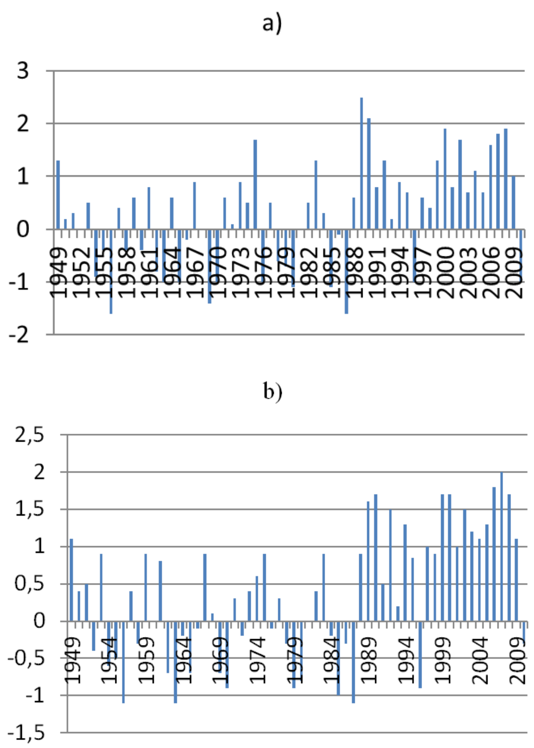


Figure 1. - Deviations of the average annual air temperature from 1949 to 2010. a) Kaliningrad, b) Rostock-Warnemünde

Interannual fluctuations of precipitations are possible to characterize as short-periodical processes. The highest precipitation in Kaliningrad (1214 mm/y) and Rostock (789 mm/y) was detected in 2007, but in 2006, the quantity of precipitations was two times less. In 1980-2009, an increase of the annual sum of precipitation comparatively to the mean was observed three times more than in 1949-1979.

For 60 years (1950-2010), the rate of warming in certain months varied considerably. Positive trends with increasing temperature 1.5-2.0°C was calculated for spring (especially in March). December typically shows a weak negative trend (Fig. 2.).

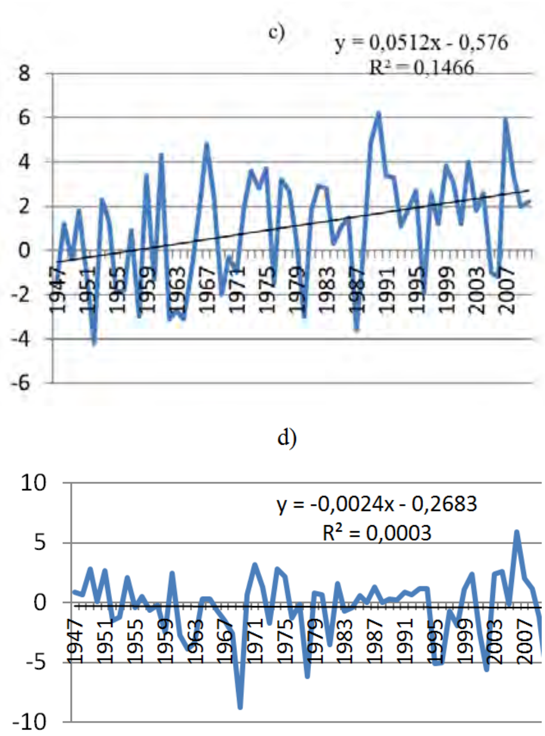


Figure 2. Long-term seasonal trends of average air temperature in Kaliningrad region c) March, d) December.

Thus, the greatest contribution to the increase of annual air temperature is in the spring and summer.

3. Adaptation effects of regional climate change

Tendency of climate change: Average temperature (spring 1.5-2.0°C) and precipitations (year 17%) increase, and temperature fluctuations also increase. In Winter there is a stronger thawing and in spring a stronger freezing.

Probable Consequences: Reduction of the heating period (2-3 days), growth of expenses for air conditioning in the summer. Increase fire risk in the forest. Frequency of floods decrease. Improving the productivity of agriculture, crop and livestock. Changes in the structure of land.

Regional environmental risks increase which are related with atmospheric deposition of heavy metals and other pollutants, not only from local sources, but first of all from Poland and more western countries (Barinova, Koroleva, Krasnov, 2012).

Soil erosion and water logging processes, increasing of groundwater level. Increase in the population morbidity (respiratory and circulatory). New methods of control and prevention infectious and parasitic diseases development.

Strategies of adaptations: New standards of construction and operation of buildings, usage of fertilizers and chemical substances for plant protection. Monitoring icing of electrical power lines, roads. Breeding, new varieties of crops and breeds of animals. New methods and techniques to struggle parasitic organisms and diseases. Selection of appropriate varieties and crops. Reclamation and restoration of forests, people health promotion (campsites, tourism, promotion of healthy lifestyles etc.

4. Conclusion

Global climate change with regional peculiarities threatens poses new threats such as floods, draught and forest fires, moisture periods etc. They are likely to be repeated more often and become destructive. All these events may be considered as a manifestation of the global trend. On the other hand, the warm season becomes longer almost everywhere in Russia, and the consumption of fuel and oil products should be reduced.

In the light of the peculiarities of regional climate change, we would like to create adaptation strategies of sustainable development for middle and longer periods.

References

Barinova G. Kaliningrad District. Climate. Yantarny Skaz Publ. H. – Kaliningrad, 196.p., 2002.

Barinova G., Krasnov E., Zotov S., Borzenkova I. Change of climate in the Baltic sea region last one thousand years: history of research// Proceedings of VII Intern. Congress on oceanography History. Part II Kaliningrad State University Publ. H. – Kaliningrad, pp. 393-396, 2004.

Barinova G., Koroleva Yu., Krasnov E. Indicative Modeling and spatial Evaluation of Air Pollution Risk// In: Horst Kremers, Alberto Susini (eds) Risk Models and Applications Collected Papers. CODATA – Germany e.V. , Berlin, pp. 23-34, 2012.

Kasimov N., Klige P. The main factors of modern global changes of natural environment// In: Kasimov N. (ed) Modern global changes of natural environment. Part 3. Factors of global changes Sci. World Publ. H – Moscow, pp. 11-40, 2012.

Estimational Report on Climate change and its Consequences in the Russian Federation territory. Rosgidromet Publ. H. – Moscow, 227 p., 2008.

Sea level variations of the Baltic Sea in response to climate variability for the period 1970-2010

Andreas Lehmann[1], Wilma Huneke[1], Klaus Getzlaff[1] and Kai Myrberg[2]

[1] GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany (alehmann@geomar.de)
[2] Finnish Environmental Institute/Marine Research Centre, Helsinki, Finland

1. Introduction

Sea level (SL) changes in the Baltic Sea are dominated by internal, short-term variations which are mostly caused by the ephemeral nature of the atmospheric conditions. Tides are small and their amplitude decreases from western to northern and eastern parts of the Baltic Sea. Short-term sea level changes are superimposed by seasonal and inter-annual variations. For long-term periods, land uplift and sea level changes due to climate change needs to be taken into consideration.

The climate variability of the period 1970-2010 of the atmospheric conditions over the Baltic Sea area has been previously analysed by Lehmann et al. (2011), and the general response of the Baltic Sea hydrography has been described by Getzlaff et al. (2011).

Here we focus on sea level changes due to climate variability on decadal scales. Changes in the Baltic Sea level can be seen as the sum of global, regional and local effects. Global climate change contributes through global seal level rise due to thermal expansion and increase in the ocean mass from land based sources of ice. Regional changes are caused by thermal and halosteric effects, changes in wind, surface pressure and ocean circulation. Local effects are due to changes in river runoff and wind extremes.

2. Data and methods

The study is based on hourly sea level records at Landsort and Warnemünde and on monthly mean SL timeseries provided by the PSMSL dataset. Furthermore, daily sea surface heights with spatial very high resolution are extracted from a hydrodynamical model of the whole Baltic Sea for the period 1970-2010. Detailed statistical analysis is applied to obtain information about temporal trends, changes in seasonal, annual and spatial sea level variability including extremes.

The numerical model used in this study is a general three-dimensional coupled sea ice-ocean model of the Baltic Sea (BSIOM, Lehmann & Hinrichsen 2000). At present, the horizontal resolution of the coupled sea-ice ocean model is 2.5 km, and in the vertical 60 levels are specified, which enables the top 100 m to be resolved with levels of 3 m thickness. The model domain comprises the Baltic Sea, including the Kattegat and Skagerrak. The coupled sea ice-ocean model is forced by realistic atmospheric conditions taken from the Swedish Meteorological and Hydrological Institute (SMHI Norrköping, Sweden) meteorological database (Lars Meuller, pers. comm.), which covers the whole Baltic drainage basin on a regular grid of 1 x 1° with a temporal increment of 3 hours. The database consists of synoptic measurements interpolated on the regular grid using a two-dimensional univariate optimum interpolation scheme. This database, which for modelling purposes is further interpolated onto the model grid, includes surface pressure, precipitation, cloudiness, air temperature and water vapour mixing ratio at 2 m height and geostrophic wind. Wind speed and direction at 10 m height are calculated from geostrophic winds with respect to different degrees of roughness on the open sea and near coastal areas (Bumke et al. 1998). BSIOM forcing functions, such as wind stress, radiation and heat fluxes were calculated according to Rudolph and Lehmann (2006). At the western boundary, a simplified North Sea basin is connected to the Skagerrak to provide characteristic North Sea water masses resulting from different forcing conditions. Low frequency sea level variations in the North Sea/Skagerrak are calculated from the BSI (Baltic Sea Index; Novotny et al. 2006).

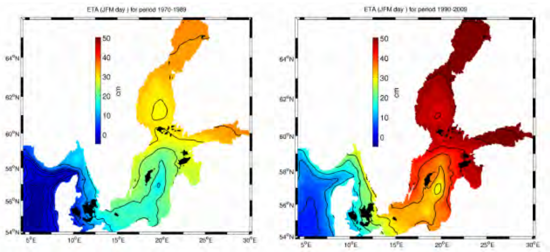


Figure 1. Mean sea level (JFM) for the period 1970-1989 (left) and 1990-2009 (right), based on BSIOM SSE daily means.

3. Results

BSIOM has been run for the period 1970-2010. Daily mean fields of sea surface elevation (SSE) have been extracted from the model and form the basis for the subsequent analysis. Generally, PSMSL data from different stations along the Baltic Sea coast and corresponding monthly mean sea levels of BSIOM are highly correlated (R>0.8). Thus BSIOM is able to reproduce sea level variations for the period 1970-2010 realistically (Novotny et al. 2006).

Lehmann et al. (2011) have demonstrated that a seasonal shift of strong westerly wind events from autumn to winter occurred over the Baltic Sea between the two periods 1970-1989 and 1990-2009. The mean sea level for JFM for the two periods reflects this change (Fig. 1). The shift occurred unidirectional over the whole Baltic area which suggests a change in the prevailing westerly wind situation.

However, the first and second EOF of the winter (JFM) averaged sea level elevation for both periods are very similar (Fig. 2). The first EOF represents unidirectional sea level variations (explained variance of > 80%). This variation is strongly correlated to the NAOI and BSI. Especially, north of the island Gotland there are changes in the amplitude of the sea level variations visible, partially related to changes in the barotropic circulation.

The second EOF represents sea level variations related to internal basin modes and in- and outflow conditions.

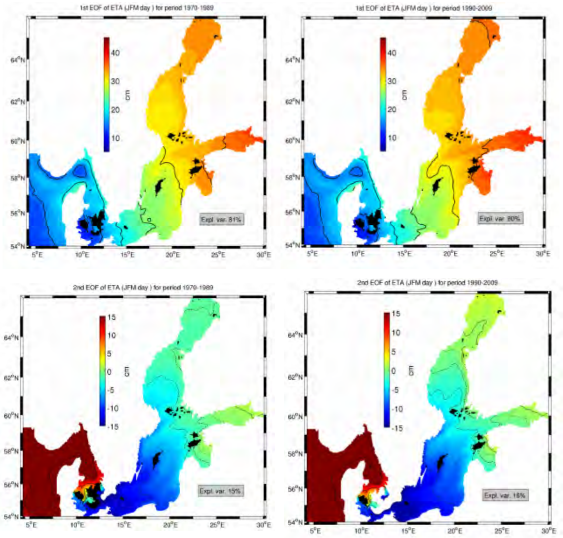


Figure 2. First and second EOF of winter (JFM) averaged daily SSEs BSIOM model output. Left panels for the period 1970-1989, right panels for the period 1990-2009.

4. Conclusions

The mean sea level shows a positive trend of about 2-3 mm/year. Over the studied period there is a warming trend in SST of about 0.4 C°/decade and a decrease in mean salinity of about 0.12 psu/decade. This corresponds to a general increase of the mean sea level over the studied period of about 8.6 mm by thermosteric and 25.7 mm by halosteric effects.

Changes in the atmospheric circulation are accompanied by corresponding changes in the mean sea level. On decadal time scales we found a shift in strong wind events from autumn to winter with a corresponding shift in seasonal sea level variability at Landsort (Baltic Proper) of about 100 mm. A change in the annual cycle of the mean sea level at Warnemünde could also be observed which inter alia was characterized by a shift of the minimum sea level from spring to summer.

References

Bumke, K., Karger, U., Hasse, L. Niekamp, K. 1998. Evaporation over the Baltic Sea as an example of a semi-enclosed sea. Contr. Atmos. Phys., 71(2), 249-261.

Getzlaff, K., Lehmann, A., Harlaß, J.. 2011. The response of the general circulation of the Baltic Sea to climate variability. BALTEX Newsletter No. 14., 13-16.

Lehmann, A., Hinrichsen, H.-H. 2000. On the thermohaline variability of the Baltic Sea. J. Marine Syst., 25 (3-4), 333-357.

Lehmann, A., Getzlaff, K., Harlaß, J. 2011. Detailed assessment of climate variability in the Baltic Sea area for the period 1958 to 2009. Climate Res., 46 (2), 185-196.

Novotny, K., Liebsch, G., Lehmann, A., Dietrich, R. 2006. Variability of Sea Surface Heights in the Baltic Sea: An Intercomparison of Observations and Model Simulations. Marine geodesy, 29, 113-134.

Rudolph, C., Lehmann, A. 2006. A model-measurements comparison of atmospheric forcing and surface fluxes of the Baltic Sea. Oceanologia, 48(3), 333-380.

Reanalysis vs. regional climate modelling for the Baltic Sea region

Andres Luhamaa, Marko Zirk, Piia Post

Institute of Physics, University of Tartu, Estonia (andres.luhamaa@ut.ee)

1. Introduction

The purpose of this study is the further analysis of the regional reanalysis BALTAN65+ (Luhamaa et.al 2011) and the comparison against the regional climate model RCA4. BALTAN65+ is a regional reanalysis performed with numerical weather prediction model HIRLAM, which contains all major parameters that are available from any numerical weather prediction model and where observations are assimilated with 6 hour interval. Period for the reanalysis is 1965-2005 and horizontal resolution is 11km. The regional climate model RCA4 is used with EURO-CORDEX domain, which is larger than BALTAN65+, but has similar horizontal resolution. RCA4 is also based on HIRLAM and thus the main dynamical and physical features of both models should be similar, making their comparison more reasonable than, for example, comparing reanalysis with point observations.

The current study focuses on values of precipitation and near surface air temperatures. Spatial distributions and distributions of extremes are compared from three different sources: BALTAN65+ and RCA4 simulations results and the observed values from Estonian meteorological stations.

2. Expected results

It has been shown by Post and Päädam (2011) that observed precipitation extremes are similar to the ones in BALTAN65+. Comparison of modeled precipitation from BALTAN65+ and RCA4 regional model output will give a fair estimation of regional models ability to simulate regional aspects of precipitation and if its results will be useful in studies of future precipitation estimations.

References

Luhamaa, Andres; Kimmel, Kaarel; Männik, Aarne; Rõõm, Rein (2011). High resolution re-analysis for the Baltic Sea region during 1965–2005 period. Climate Dynamics, 36, (3-4), 727 - 738.

Post, P.; Päädam, K. (2011). Eesti sademete ekstreemumite muutlikkuse analüüs jaamade ning BaltAn65+ järelanalüüsi andmete põhjal. Jaak Jaagus (Toim.). Publicationes Instituti Geographici Universitatis Tartuensis, Tartu Ülikooli Kirjastus, 109, 7 - 22.

Multi-model estimates of sea ice cover changes in the Baltic Sea by 2090

Anna Luomaranta[1], Jari Haapala[1], Kimmo Ruosteenoja[1], Kirsti Jylhä[1], Hilppa Gregow[1] and Ari Laaksonen[1,2]

[1] Finnish Meteorological Institute, Helsinki, Finland (jari.haapala@fmi.fi)
[2] University of Eastern Finland

1. Introduction

The variability of the sea ice cover in the Baltic Sea is an indicator of climate change and fluctuations in northern Europe. In a warming climate, the winter ice cover of the Baltic Sea will face changes that can affect the environment and the human activities in the region.

Projections of sea ice cover changes can be made either by numerical sea ice models (Omstedt and Nyberg 1995, Haapala and Leppäranta 1997, Haapala et al. 2001, Meier et al. 2004), or using a statistical methods to correlate sea ice variability and atmospheric changes (Tinz 1996, Jylhä et al. 2008). The statistical approach cannot capture real physical linkages of the components of the climate system, but requires very little computing resources compared to the numerical models and is thus a feasible tool for producing probability estimates of ice cover changes based on several atmospheric scenarios.

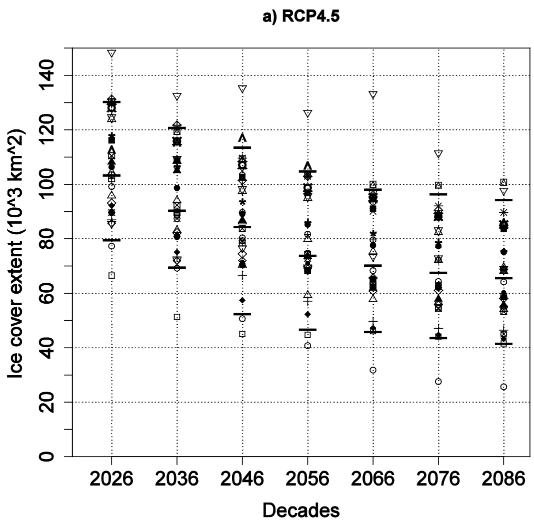
In this study we assess the future changes in the Baltic Sea ice cover by the 2080s, compared to the period 1971-2000. We focus mainly on the temporal variations in the annual maximum ice cover extent and on the 30-year average of the annual maximum fast ice thickness.

2. Material and methods

Our research data consists of the observed annual maximum ice cover extent in 1951-2011, together with observed and projected future November-March mean air temperature along the coastline of the Baltic Sea within 53 to 67 °N and 14 to 31 °E. The projected changes in temperature were derived from simulations performed with 28 global climate models participating in Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al. 2012). Two greenhouse gas scenarios were used: RCP4.5 and RCP8.5. The future temperatures were constructed employing a delta method.

In order to assess changes in the ice cover extent, we first fitted a regression model between the observations of ice cover and air temperature. Using the projected future coastal winter temperature as an input to this model, the frequency distributions for maximum sea-ice cover extent for seven future decades (from 2021-2030 to 2081-2090) were then estimated.

The average maximum fast ice thickness for each decade was assessed based on the Stefan's law that applies the yearly cumulative sum of air temperatures below 0°C. This winter-frost sum was in turn calculated both as a multi-model mean and separately for each of the 28 models. However, the method used in assessing the ice thickness does not take into account the snow layer on top of the ice cover. Snow acts as an effective insulator, thus slowing down the growth of ice thickness. Therefore, the calculated ice thicknesses are systematically overestimated by about 10-20 cm (Leppäranta 1993).



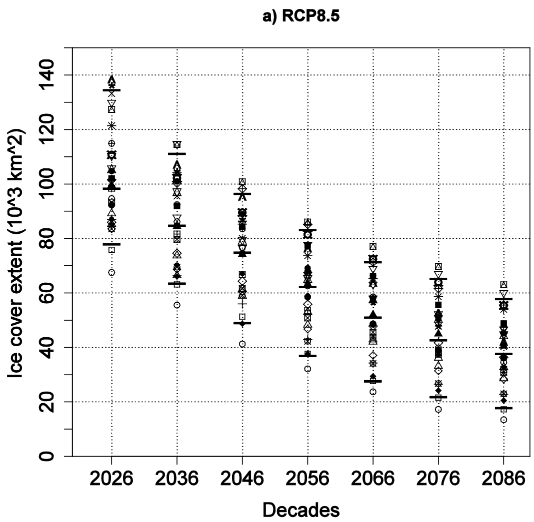


Figure 1. The median value of the maximum ice cover extent in the individual models in each future decade. The short horizontal lines show the median values and the 5th and the 95th percentiles of all the medians: a) RCP4.5 scenario, b) RCP 8.5 scenario

3. Results

According to our analysis, both the maximum ice cover extent and the probability of severe and average ice winters will decrease. In the RCP4.5 scenario, the medians in the frequency distributions of the maximum ice cover extent vary among the models from 66.5 to 148.4 $\times 10^3$ km^2 in 2021-2030 and from 25.7 to 100.8 $\times 10^3$ km^2 in 2081-2090 (Fig. 1a). In RCP8.5, the corresponding range among the models is smaller and the decrease of the maximum ice cover extent is faster (Fig. 1b).

The average maximum fast ice thickness was assessed only in coastal sea areas. The ice thickness decreases in both scenarios. In RCP4.5, in a typical winter the southern and southwestern parts of the Baltic Sea are projected to be ice-free by the end of the century. The largest thickness in 2081-2090 is found in the Bay of Bothnia, being locally over 60 cm. In RCP8.5, most of the Baltic Sea remains ice-free during the average winter at the end of the century, and the seasonal maximum in the Bay of Bothnia is about 40 cm.

References

Haapala, J., Leppäranta, M. (1997): The Baltic Sea ice season in changing climate. Boreal Environment Research, 2, 93-108.

Haapala, J., Meier, M., Rinne, J. (2001): Numerical investigations of future ice conditions in the Baltic Sea. Ambio, 30 (4-5), 237-244.

Jylhä, K., Fronzek, S., Tuomenvirta, H., Carter, T.R., Ruosteenoja, K. (2008): Changes in frost, snow and Baltic sea ice by the end of the twenty-first century based on climate model projections for Europe. Climatic Change, 86, 441-462.

Leppäranta, M. (1993): A Review of Analytical Models of Sea-Ice Growth. Atmosphere-Ocean,31.

Meier, H.E.M., Döscher, R., Halkka, A. (2004): Simulated distributions of Baltic sea-ice in warming climate and consequences for the winter habitat of the Baltic ringed seal. Ambio, 33, 249-256.

Omstedt, A., Nyberg, L. (1996): Response of Baltic sea ice to seasonal, interannual forcing and climate change. Tellus, 48A, 644-662.

Tinz, B. (1996): On the relation between annual maximum extent of ice cover in the Baltic Sea level pressure as well as air temperature field. Geophysica, 32(3), 319-341.

Taylor, K.E., Stouffer, R.J., Meehl, G.A. (2012): An Overview of CMIP5 and the experiment design. Bull. Amer. Meteor. Soc., 93, 485-498, doi:10.1175/BAMS-D-11-00094.1.

Features of climate change on the territory of the Republic of Belarus

Victor Melnik, Elena Komarovskaya

Republic Hydrometeorological Center, Minsk, Republic of Belarus (mel@hmc.by)

1. Introduction

Through most of the 20th century until the end of the 80s, short-term periods of warming in Belarus were alternated by periods of cooling that were of similar magnitudes and durations. Unprecedented warming (by both, duration and intensity) began in 1989 by the winter temperature rise. The warming has continued during the next years, including the last few years. An important peculiarity of the current warming is not only in its unprecedented duration, but also in higher temperatures which during the past 20 years (1989 to 2010) exceeded on average climatic norms by 1.1ºC. Out of the 20 warmest years since the post-war period (1945), 16 years occurred in the 1989-2010 period (Figure 1).

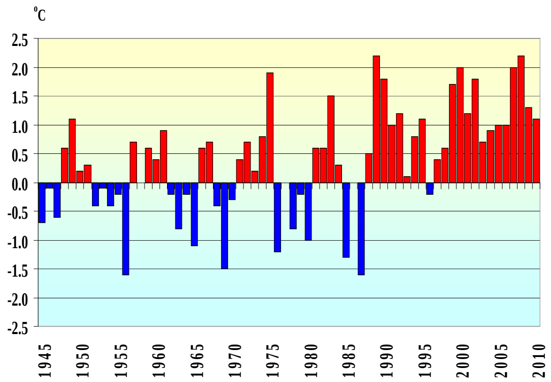


Figure 1. Deviations of annual surface air temperature area-averaged over Belarus from climatic norm (long-term mean value of 5.8 °C) for the 1945-2010 period

2. The main results of the study

As a result of climate change (warming) since 1989 we observe:

- the period with snow cover has decreased by 10-15 days
- a tendency toward an increase of duration of no-frost period (4-7 days);
- an increase of the duration of the vegetative period (by 10-12 days) and its heat supply (degree-days; by 150-200 ºC);
- a change on borders of agro climatic areas, and in the south of Polesiye a new warmer agro climatic area was formed. The shortest and warmest winter season and the longest and warmest vegetation period are distinctive features of this new agro climatic zone within Belarus (Melnik et al, 2010).

Analysis of rainfall shows a slight decrease in precipitation mainly in the southern, ameliorated part of the country. In the northern part a slight increase in precipitation is noted. On average, it is fair to say that the amount of precipitation changed slightly during last two decades of warming on the territory of Belarus.

Over the last twenty years during the warm season, precipitation shortfall is noted in April, June, and especially in August - Rainfall was 91%, 93% and 88% of normal respectively. A bit more than normal level of precipitation was observed in February, March and October.

Changes of the main climatic characteristics over the last two decades of regional (and global) warming (1989-1998 and 1999-2008 compared to norms defined by WMO as the mean values for 1961-1990) have the following features. For the last decade (1999-2008) a specific change of the surface air temperature seasonal cycle is observed. Temperature decrease in winter months (except December) was accompanied by a noticeable growth of the summer and autumn surface air temperatures. This gives the grounds to claim a warming shift for summer and autumn months (including December). May temperature remained practically unchanged and air temperature increases in April can pose a threat for thermophilous crops because of May frosts (Melnik et al. 2010, 2011).

Nationwide, in Belarus the second decade of the warming period (1999-2008) was warmer than the first decade (1989-1998) by 0,5ºC (Table 1).

Table 1. The average annual surface air temperature in Belarus for the last two decades

Climatic norm, ºC for the 1961-1990 period	The nationwide average annual surface air temperature, ºC for the period			
	1989-1998	1999-2008	1989-2008	1989-2010
5,9	6,7	7,2	6,9	7,0

Annual precipitation over the past decades has not significantly changed (Table 2). However, we noted

- a noticeable increase in rainfall over the last decade (1999-2008) compared to the climate norm (1961-1990) in January-March, and October,
- a slight increase (4.5%) in May, July, and August, and
- a significant rainfall decrease rainfall in June and September (Melnik et al. 2011).

Table 2. The average annual precipitation in Belarus for the last two decades

Climatic norm, mm, for the period 1961-1990	The mean of average annual precipitation, mm, for the period			
	1989-1998	1999-2008	1989-2008	1989-2010
632	657	638	647	659

The river runoff in the Baltic Sea Basin (Zapadnaya Dvina, Neman) over the last period of climate warming changed ambiguously. Runoff formation occurred according to the precipitation regime. Average annual runoff became larger at the rivers of the Zapadnaya Dvina Basin: at large and medium-size rivers by 14 to 20% and at small streams by 9 to 25%. Runoff decrease in this period occurred at large and medium-size rivers of the

Neman Basin - from 3 to 8%, and at small river basins- changes practically did not happen. A share of winter runoff in annual distribution within the Zapadnaya Dvina River Basin has significantly increased. A somewhat smaller increase was noted within the Neman River Basin. A share of summer and autumn runoff at the rivers of the Zapadnaya Dvina Basin increased compared to the period prior to 1989. Spring runoff was reduced for all rivers by 12 to25% due to the reduced snowpack at the beginning of freshet (Danilovich et al. 2007).

Scenario assessments of climatic changes based upon general circulation model simulations for different periods of the century in most cases give the greatest change (increase) in seasonal surface air temperatures in the winter season (Loginov, 2008). It is difficult to project future changes of surface air temperature and precipitation, but it should be noted that the warming that has begun in the end of the 20th century on the territory of the Republic of Belarus has ambiguous features. Therefore, continuous monitoring of climate change requires the constant study.

3. Conclusions

Results of the research show that in Belarus there were several features of change in the main climatic characteristics over the last two decades of warming, 1989-1998 and 1999-2008 (compared to the norms adopted by WMO as the 1961-1990 mean values). Nationwide, the second decade of the warming period (1999-2008) was warmer than the first by 0. 5 ºC. Over the last decade (1999 - 2008) a shift to the warmer second half of the year (June through December) is observed. Share of winter runoff in the annual runoff distribution within the Zapadnaya Dvina River Basin has significantly increased. A somewhat smaller increase was noted within the Neman River Basin. Due to a non-linear nature of the ongoing and projected changes, continuous monitoring of climate change is required.

References

Danilovich I.S. and Trofimova L.B. (2007) Influence of atmospheric circulation on water regime of the rivers of Belarus during winter and spring seasons, Natural resources, No 1, pp. 39-46.

Loginov V.F. (2008) Global and Regional Climate Changes: Causes and Consequences, 496 pp.

Melnik V.I. and Komarovskaya E.V. (2010) Climate changes and measures for adaptation of branches to these changes in the Republic of Belarus. Materials of constantly operating seminar at the Parliamentary Meeting of the Union of Belarus and Russia concerning construction of the Union State: The center of the system analysis and strategic researches of National Academy of Sciences of Belarus, pp.169-176.

Melnik V.I. and Komarovskaya E.V. (2011) Features of climate change on the territory of the Republic of Belarus for the last decades. Scientific and methodical ensuring of activity on environmental protection: problems and prospects, pp.77-84.

Introducing the coupled atmosphere-ocean system: COSMO-CLM and NEMO for the North and Baltic Seas

Trang Van Pham[1], Jennifer Brauch[2], Barbara Frueh[2] and Bodo Ahrens[3]

[1] Biodiversity and Climate Research Center, Senkenberg, Germany (trang.pham-van@dwd.de)
[2] German Meteorological Service, Germany
[3] Goethe University Frankfurt, Germany

1. Introduction

The coupled atmosphere-ocean-ice system is studied to assess the impact of the North and Baltic Seas on climate of central Europe. The regional atmosphere model COSMO-CLM is coupled to the regional ocean model NEMO.

Due to the differences in domain areas, grid sizes, time steps between COSMO-CLM and NEMO, an interface model, OASIS 3, is used to interpolate and exchange data between the atmosphere and ocean models. Fields exchanged between the two models are: effective precipitation, atmospheric wind stress, solar and non-solar radiations, sea level pressure, sea surface temperature and fraction of sea-ice.

2. Component models

COSMO-CLM (Böhm et al., 2006; Rockel et al., 2008) used in this study is a non-hydrostatic regional climate model, versioned cosmo4.8_clm11. The model is set up based on the CORDEX Europe domain with a horizontal grid size of 25km (0,22 degree); 232 x 226 grid cells; 40 vertical layers. The time resolution of COSMO-CLM used here is 150 seconds. For the lateral boundaries, the 6-hourly ERA-Interim reanalysis data (Dee et al., 2011) are used.

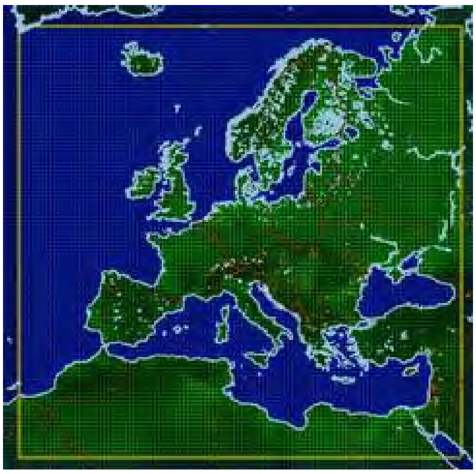


Figure 1. CORDEX domain for COSMO-CLM model (http://www.medcordex.eu/cordex_domains_250610.pdf)

NEMO-ocean model (Madec, 2008) with ice module, versioned 3.3, is set up for North and Baltic Seas with the horizontal grid space of 2'; 619 x 523 grid cells and 56 vertical layers; the time step of NEMO is 600 seconds. The adjustment to the North and Baltic Seas is provided by Sweden's Meteorological and Hydrological Institute (SMHI), Sweden.

Simulation period of stand-alone models or coupled models are both from 1979 to 2010.

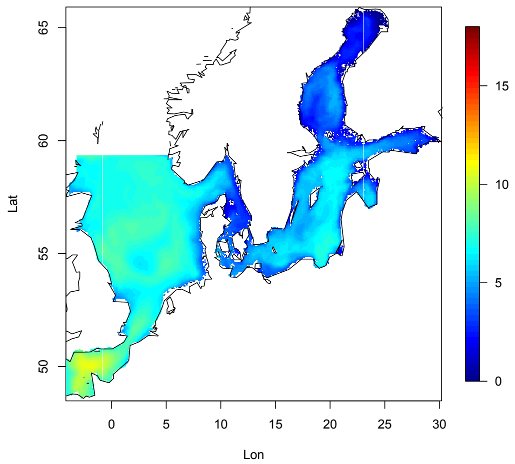


Figure 2. Domain North and Baltic Seas of the NEMO-Baltex model

3. Coupled system

The atmosphere and ocean models are coupled via the coupler OASIS3 (Valcke, 2006). At the interface, effective precipitation, atmospheric wind fluxes, solar and non-solar radiations are sent from COSMO-CLM to NEMO; and sea surface temperature and fraction of ice are sent from NEMO to COSMO-CLM. The interpolation method used in OASIS 3 is distance weighted. These fields are exchanged between two models every 3 hours.

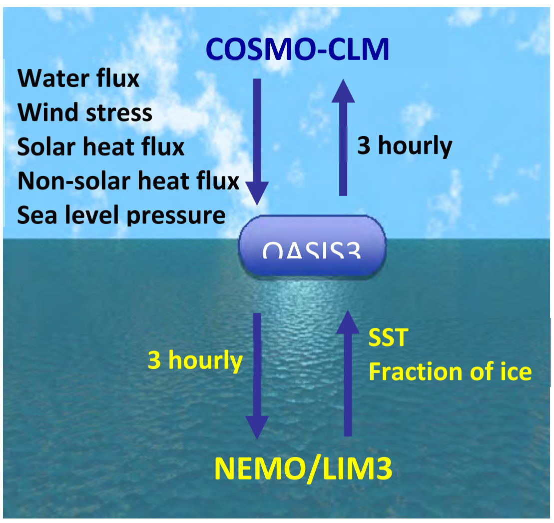


Figure 3. Coupled atmosphere and ocean models

4. Results

The first results from the coupled models show a slight increase (from 0.5 to 2 degree) of 2m temperature in central Europe compared with the stand-alone atmosphere model. In the South West of Europe, temperature tends to be lower in coupled system.

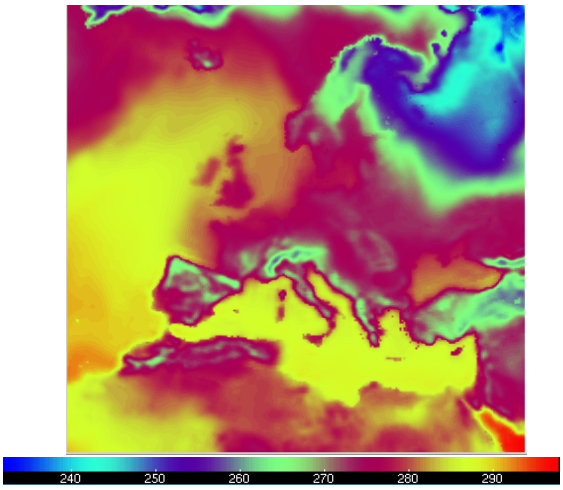


Figure 4. Mean temperature at 2 meter (degree Kelvin) in January 1989 – Result from coupled COSMO-CLM and NEMO model

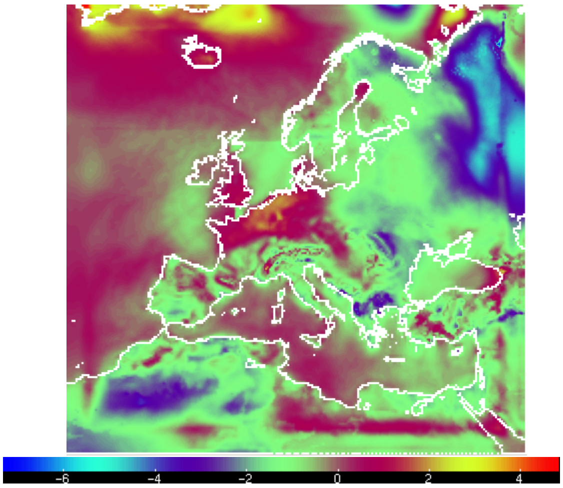


Figure 5. Difference in mean temperature at 2 meter between coupled models and COSMO-CLM in January 1989

Over the North and the Baltic Seas, the coupled system shows noticeable changes in sea surface temperature (SST) and sea surface salinity (SSS). In comparison with the ocean stand-alone run, the difference varies from -15 to 5 degree Celsius regarding SST, and from -10 to 25 PSU regarding SSS. Larger differences are found near the coast and around the junction of North and Baltic Seas.

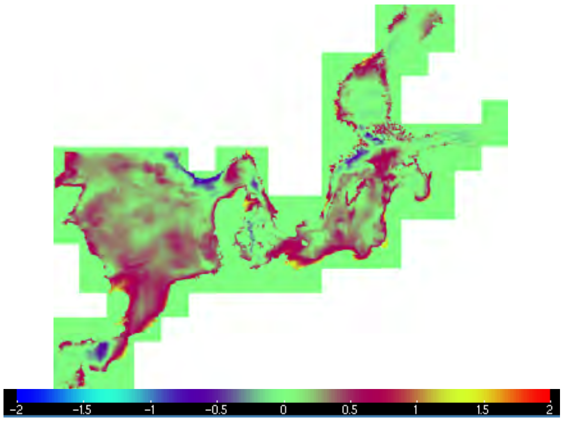


Figure 6. Difference in mean SST in the North and Baltic Seas between coupled models and NEMO in January 1989

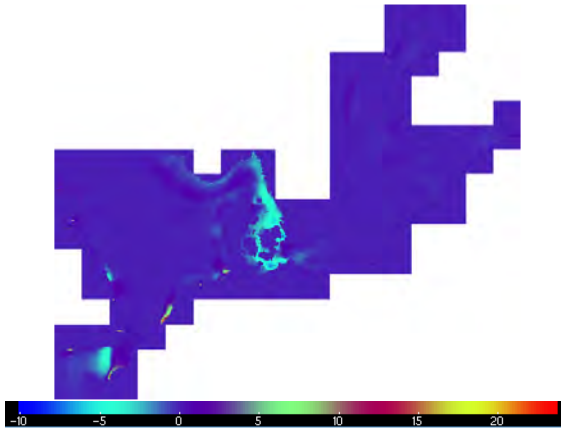


Figure 7. Difference in mean SSS in the North and Baltic Seas between coupled models and NEMO in January 1989

5. Conclusion

Coupled COSMO-CLM and NEMO models show a noticeable difference from the stand-alone model results. More evaluations are planned to assess the magnitude and distribution of the differences.

References

Böhm U., M. Kücken, W. Ahrens, A. Block, D. Hauffe, K. Keuler, B. Rockel, A. Will (2006) CLM - the climate version of LM: Brief description and long-term applications, COSMO Newsletter, Vol. 6, COSMO.

Dee, D., S. Uppala, A. Simmons, P. Berrisford, P. Poli, S. Kobayashi, U. Andrae, M. Balmaseda, G. Balsamo, P. Bauer, P. Bechtold, A. Beljaars, L. van de Berg, J. Bidlot, N. Bormann, C. Delsol, R. Dragani, M. Fuentes, A. Geer, L. Haimberger, S. Healy, H. Hersbach, E. Holm, L. Isaksen, P. Kallberg, M. Kohler , M. Matricardi, A. McNally, B. Monge-Sanz, J. Morcrette, B. Park, C. Peubey, P. de Rosnay, C. Tavolato, J. Thepaut, F. Vitart (2011) The ERA-Interim reanalysis: configuration and performance of the data assimilation system, Quarterly Journal of the Royal Meteorological Society, Vol 137, pp.553-597

Madec G. (2008) “NEMO ocean engine", Note du Pole de modélisation, Institut Pierre-Simon Laplace (IPSL), France, No 27 ISSN No 1288-1619

Rockel,B., A. Will, A. Hense (2008) Regional climate modeling with COSMO-CLM (CCLM), Meteorologische Zeitschrift, Vol. 17, No. 4, pp. 347-348

Valcke S. (2006) OASIS3 User Guide (prism_2-5), CERFACS Technical Report TR/CMGC/06/73, PRISM Report No 3, Toulouse, France, 60 pp

New historical climate data of the southern Baltic Sea coasts

Gudrun Rosenhagen and Birger Tinz

German Meteorological Service, Deutscher Wetterdienst, Hamburg

1. Background

The current discussion on climate change goes along with a revival of interest in all sorts of historical climate information. Seewetteramt of Deutscher Wetterdienst in Hamburg houses a huge archive of historical handwritten journals of weather observations. The archive comprises not only the data collected by Deutscher Wetterdienst of the last decades, but builds up on the archive of the German Marine Observatory, Deutsche Seewarte, which existed from 1875 to 1945. It includes millions of marine data records from ships, buoys and light vessels the oldest going back to the 18^{h} century and historical data from more than 1500 land stations in overseas. Among those journals a considerable amount of original observations sheets from the southern Baltic coasts exists which has been until recently almost unnoticed: The observations of the signal stations along the southern Baltic coasts. Signal stations were positioned close to the shore to warn sailors near the coasts of severe weather (see Fig. 1).

Figure 1. Signal station Leba (Poland; Picture: Archive Deutscher Wetterdienst Hamburg)

2. Data description

The archive of the signal stations of Deutscher Wetterdienst in Hamburg consists of hundreds of handwritten journals with weather records of the 123 year's period starting in 1877 and ending in 1999. As the wind conditions are of particular interest to the sailors, all records contain values of wind force and wind direction, but there are specifications of the weather conditions and visibility and before 1940 also of sea level pressure and precipitation and in some cases of sea state. Most stations reported 3 to 9 times per day, the pressure was usually measured at least once per day and the precipitation twice. In stormy days, observation frequencies were often increased.

The number of the stations changed throughout the years with a maximum of nearly 100 stations in 1940 (see Fig. 2).

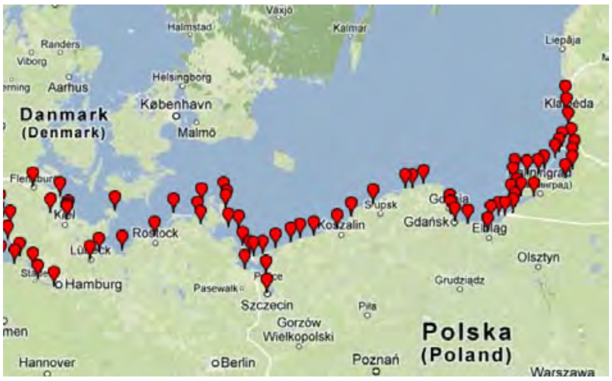


Figure 2. Signal stations with weather observations in the year 1940 of the German Marine Observatory Hamburg (Google maps)

3. Status and outlook

It is planned to digitize and quality check all handwritten journals. Until now, the handwritten data and metadata of the period 1969 to 1999 have been digitized. The data and metadata will be integrated in the climate data bank of Deutscher Wetterdienst and, if the station is nowadays positioned in Denmark, Poland, Russia or Lithuania, immediately forwarded on electronic data processing media to the National Meteorological Service of the respective country. All digitized data will be freely accessible to all interested scientists.

The digitized data are a valuable source of historical information for climate investigations of the southern coasts of the Baltic Sea.

References

Tinz, B., Rosenhagen, G, Gloeden, W., Mächel, H. (2011): German initiative: Rescue of world-wide historical data. 4th ACRE - EURO4M - ERACLIM Meeting September 21st-23rd, de Bilt, Netherlands

Observed changes and variability of atmospheric parameters in the Baltic Sea region during the last 200 years

Rutgersson[1], A., Jaagus[2], J., Schenk[3], F., Stendel[4], M.

[1] Department of Earth Sciences, Uppsala University, Sweden (anna.rutgersson@met.uu.se)
[2]University of Tartu, Estonia (jaak.jaagus@ut.ee)
[3]Helmholtz-Zentrum, Geesthacht, Germany (Frederik.Schenk@hzg.de)
[4]Danish Climate Centre, Danish Meteorological Institute, Copenhagen, Denmark (mas@dmi.dk)

1. Introduction

The climate of the Baltic Sea region is strongly influenced by variations of large-scale atmospheric circulation patterns over the North Atlantic. The zonal pressure gradient (NAO) over the North Atlantic and the position of the Icelandic Low and Azores High mainly relate to variations of atmospheric parameters like wind, temperature and humidity in the region. The climate of the Baltic Sea shows a strong seasonal cycle, but also large inter-annual to multi-decadal variability. It is important to understand and describe potential long-term changes and variability of atmospheric parameters as they can be a signature of a changing climate on a global or regional scale. Such changes would have large impacts on important hydrological, oceanographic and biogeochemical processes in the region. This includes the obvious importance of precipitation and temperature for the run-off, relation between atmospheric circulation patterns and sea level and sea ice, storm frequency with Baltic Sea mixing and marine ecosystems and numerous other impacts. The presentation is partly based on the BACC II review (BACC, 2013) and aims at presenting the observed changes and variability of atmospheric parameters during the last 200 years. It also points at key uncertainties and limitations in the knowledge of the atmospheric forcing of the Baltic Sea region. Focusing on the period of last 200 years, results rely on relatively robust in-situ measurements in contrast to earlier periods where the information is mainly obtained by proxy-data.

2. Period and data

The Baltic Sea area is relatively unique with a dense observational network covering an extended time period. A network of stations measuring continuously with relatively good accuracy was developed since the middle of the 19th century with few stations starting already in the middle of the 18th century. Satellites were introduced in 1978 which significantly improved data coverage with higher resolutions in space and time. With a much higher data coverage in recent decades, this section is divided into two periods, long term data with more or less well developed synoptic stations and the last decades being characterized by the availability of satellite data and sounding systems.

3. Large scale circulation patterns

The atmospheric circulation in the European/Atlantic sector plays an important role for the regional climate of the Baltic Sea basin (Hurrell, 1995; Slonosky et al., 2000, 2001; Moberg and Jones, 2005; Achberger et al., 2007). It can be described mainly by the North Atlantic Circulation (NAO), the zonality of the atmospheric flow and of the blocking frequency. The first mode of a principal component analysis of winter sea-level pressure variability is the NAO which in winter shares a close correlation with atmospheric and marine state variables of the Baltic Sea (where a positive index indicates mild and wet winters and a negative index indicates cold and dry winters). Figure 1 shows the winter NAO index for 1823 to 2012. The strongly positive NAO phase in the 1990s can be seen as part of multi-decadal variations comparable to those at the beginning of the 20th century rather than a trend towards more positive values.

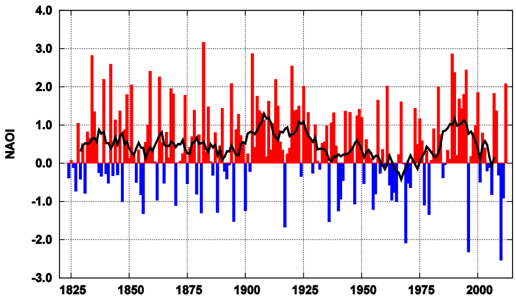


Figure 1; NAO index for boreal winter (DJFM) 1823/1824-2011/2012 after Jones et al. (1997) updated in BACC (2013).

There are also indications from some studies that weather types are more persistent in last decades than in earlier decades. For all weather types (both zonal, meridional, or anticyclonic), an increase of persistence on the order of 2 to 4 days is found from the 1970s to the 1990s. This increase may be reflected by an increase in the occurrence of extreme events.

4. Wind climate

Variations in the wind climate over the Baltic Sea region are closely related to the atmospheric circulation over the North Atlantic. Here, the number of deep cyclones (core pressure < 980 hPa) in winter (DJFM) reached a minimum in the early 1970s and clearly increased in the following decades reaching their maximum around the last decade of the 20th century (Lehmann et al. 2011). In the same time, a continuous shift of storm tracks towards the NE regionally increased the impact and number of storms over N-Europe and i.e. the Baltic Sea in recent decades in winter and spring, but decreased in autumn.

Long-term wind and storm indices in contrast do not show any clear change. In this context, it can thus be concluded that the wind climate shows large decadal variability rather than robust trends over Northern Europe. Different storminess measures in Figure 2 agree, showing increased storminess in the 1880s and 1990s with an unusual calm period around the 1960-70s and a return to average in recent years. The number of deep lows partly fail to clearly show the calm conditions. Only the summer wind climate over the Southern Baltic Sea shows a slight negative long-term trend.

5. Surface air temperature

Northern hemisphere mean surface air temperature increased about 0.08K per decade from 1861 to 2010 (CRUTEM4v). The linear increase for the Baltic Sea region is slightly higher for the same period. Linear trends of the annual mean temperature anomalies during 1871-2011 were 0.11 K per decade north of 60° N and 0.08 K per decade south of 60° N in the Baltic Sea Basin.

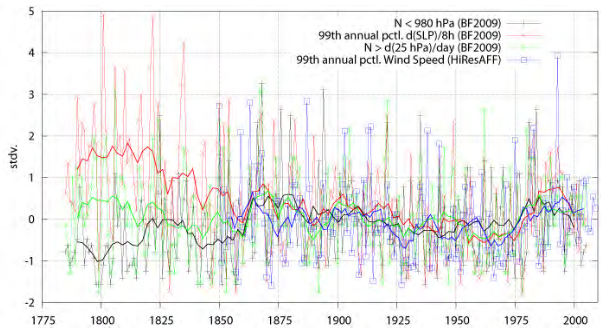


Figure 2: Storminess indices of the annual number of deep lows (N<980 hPa), the 99th percentile of pressure tendency per 8h, the annual number of days exceeding a pressure tendency of 25 hPa for the station of Stockholm 1785-2005 (Bärring and Fortuniak 2009) compared to the reconstructed annual 99th percentile of wind speeds in the vicinity of Stockholm 1850-2009 from HiResAFF (Schenk and Zorita 2011, 2012). From BACC (2013)

The temperature increase is, however, not linear but accompanied by large (multi-)decadal variations dividing the 20th century into three main phases: warming in the beginning of the century until the 1930s, later cooling until 1960s and another distinct warming during the last decades of the time series (see Figure 3). All seasonal trends are positive and significant at the 0.05 level, except winter temperatures north of 60°N (due to the large variability). The largest trends are observed in spring (and winter in the southern part of the area) and the smallest in summer. Also the seasonal trends are higher in the northern area ("polar amplification"), compared to the southern area.

6. Open questions

There are a number of open questions related to changes in atmospheric parameters during the last 200 years

- Distant controls of circulation changes; Is there a relation between less ice in the Arctic and low winter temperatures in the northern European regions, as is suggested by e.g. Overland and Wang (2009)?
- Extreme events; are there any trends in occurrence of extreme events concerning precipitation, wind and temperature? Present studies include quite few data, and it is difficult to draw any statistically significant conclusions.
- Does the novel 20th century reanalysis (Compo et al., 2011) provide realistic long-term trends e.g. in case of storminess since 1871?

7. Conclusions

Variations and trends of atmospheric parameters during the last 200 years can be summarized as:

- Circulation – northward shift of storm tracks and increased cyclonic activity in recent decades with increased persistence of weather types.
- Wind - no long-term trend, but considerable variations on (multi-)decadal timescale.
- Temperature – continued warming, in particularly during spring and stronger over northern regions (polar amplification).

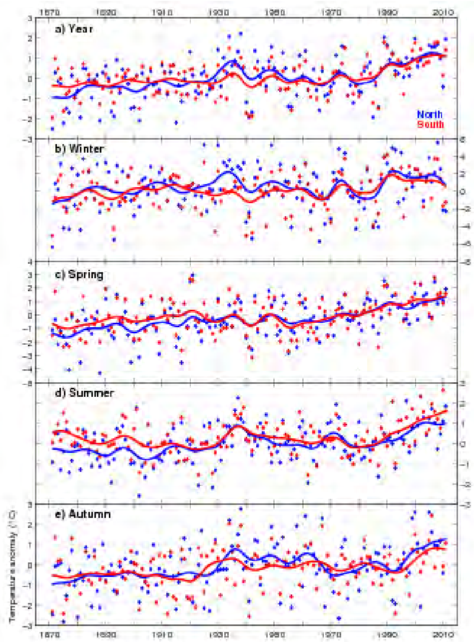


Figure 3: Annual and seasonal mean near-surface air temperature anomalies for the Baltic Sea Basin 1871-2011, taken from the CRUTEM3v dataset (Brohan et al. 2006). Blue colour represents the Baltic Sea basin north of 60°N, and red colour to the south of that latitude. The dots represent individual years, and the smoothed curves variability on timescales longer than 10 years.

References

Achberger, C., J.E. Box and D. Chen, 2007: Nordic region, in: Arguez, A. (ed.): State of the Climate 2006. Bull. Amer. Met. Soc. 88, S104-S106.

Bärring, L. & K. Fortuniak (2009): Multi-indices analysis of southern Scandinavian storminess 1780–2005 and links to interdecadal variations in the NW Europe–North Sea region. Int. J. Climatol. 29: 373–384.

Brohan, P et al, 2006: Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850.

Compo, G., et al., 2011: The twentieth century reanalysis project. Quarterly Journal of the Royal Meteorological Society, 137 (654), 1-28.

Hurrell, J.W., 1995: Decadal trends in the North Atlantic Oscillation – regional temperatures and precipitation. Science 269, 676-679.

Lehmann, A., Getzlaff, K. & J. Harlaß (2011): Detailed assessment of climate variability in the Baltic Sea area for the period 1958 to 2009. Clim. Res. 46: 185–196.

Moberg, A. and P.D. Jones, 2005: Trends in indices for extremes in daily temperature and precipitation in central Europe. Int. J. Climatol. 25, 1149-1171.

Overland, J.E. and M. Wang, 2010: Large-scale atmospheric circulation changes are associated with the recent loss of Arctic sea ice. Tellus 62A, 1-9

Schenk, F. and E. Zorita (2012): Reconstruction of high resolution atmospheric fields for Northern Europe using analog-upscaling. Clim. Past, 8, 1681-1703

Slonosky, V.C., P.D. Jones and T.D. Davies, 2000: Variability of the surface atmospheric circulation over Europe, 1774-1995. Int. J. Climatol. 20, 1875-1897.

Slonosky, V.C., P.D. Jones and T.D. Davies, 2001: Atmospheric circulation and surface temperature in Europe from the 18th century to 1995. Int. J. Climatol. 21, 63-75.

Spatiotemporal climate variations and trends over the Baltic Sea since 1850

Schenk, F.[1,2] and Zorita, E.[2]

[1] Linné Flow Centre, Department of Mechanics, Royal Institute of Technology (KTH), Stockholm, Sweden (freddyschenk@web.de)
[2] Institute for Coastal Research, Department of Paleoclimate, Helmholtz-Zentrum Geesthacht, Geesthacht, Germany

1. Introduction

The climate of Northern Europe and the Baltic Sea region is characterized by strong variations on daily to multi-decadal timescales. The last up to six decades have faced clear changes such as strong seasonal warming trends, a northeast shift and strong increase in the number of deep cyclones (<980 hPa) with increased wind speeds over the Baltic Sea in winter to spring (Lehmann et al., 2011).

As these spatiotemporal changes are often interpreted as a potential harbinger of future climate change, we use the novel reconstructions of High Resolution Atmospheric Forcing Fields (HiResAFF) (Schenk and Zorita, 2012) to reflect changes of pressure, wind and temperature in the context of long-term variations since 1850.

Magnitudes and spatial patterns of reconstructed regional temperature trends are compared on seasonal basis with available gridded observations. Additionally, trends are estimated over land and sea areas for the period 1850-2009. Latitudinal differences in regional warming trends are studied in the context of polar amplification.

The dominating large-scale atmospheric circulation e.g. in terms of spatiotemporal variations of deep cyclones are studied over Northern Europe and linked to variations of the NAO. As a regional imprint, we assess variations and potential trends in the mean seasonal wind climate and storminess in comparison with well established wind and storm indices.

2. Data and Methods

We use homogeneous and physically consistent daily fields with a horizontal resolution of 0.25°x0.25° (~25 km) from HiResAFF (Schenk and Zorita, 2012) covering Northern Europe over the period 1850-2009. Daily pressure and monthly temperature observations since 1850 and high-resolution atmospheric fields from a short regional climate model simulation are used to reconstruct the full gridded fields over the last 160 years. Long-term station data and gridded observations are used to test the co-variability and consistency of regional trend patterns.

3. Temperature

Due to the large variability i.e. over northern latitudes of Scandinavia, trends are not very robust in winter and hence depend on the considered time period. The very warm 1920s in the northern domain lead to negligible long-term warming trends in winter in CRU TS 3.10 and HiResAFF in the period 1901-2009 whereas spring and autumn show strong warming trends. With exception of underestimated spring warming, centennial trends of HiResAFF are consistent with CRUTEM3 over the Baltic Sea catchment (BACC, 2008) for 1871-2004 with strongest warming in spring, followed by winter and autumn and little warming in summer. With exception of summer, warming trends for 1850-2009 in HiResAFF are slightly lower but more robust than for the shorter period since 1871 or 1901 HiResAFF suggests that winter warming (Fig. 1) is now stronger for the extended period since 1850 while spring shows stronger trends since the 1880s.

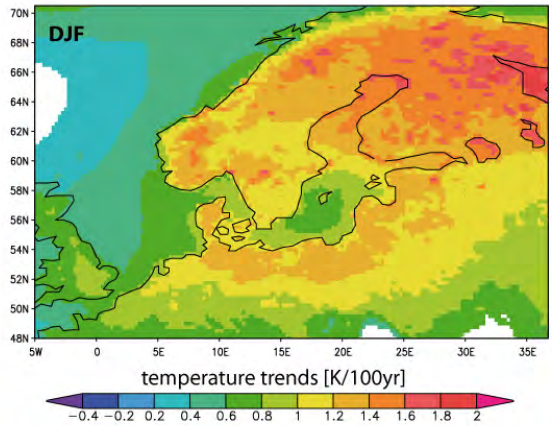


Figure 1. Centennial seasonal near-surface temperature trends for winter 1850-2009 from HiResAFF (Schenk and Zorita, 2012). Non-significant trends (p<0.05) in white.

The reconstructed seasonal and annual near-surface temperature trends [K/100yr] for the period 1850-2009 are shown for different regions and additionally over land and sea areas separately (Tab. 1). Note stronger near-surface warming trends over the Baltic Sea surface in summer relative to land areas. This is due to preceding warming trends in spring.

Table 1. Weighted field averages of seasonal and annual air temperature (2 m) trends [K/100yr] over land and sea for different regions from HiResAFF for the period 1850-2009. Non-significant trends (p<0.05) are indicated by italics.

[K/100yr]	Northern Europe 1850-2009		
Season	All	Land	Sea
ANN	0.63	0.70	0.53
DJF	0.94	1.12	0.70
MAM	0.76	0.90	0.56
JJA	0.22	*0.18*	0.28
SON	0.69	0.70	0.66

[K/100yr]	Baltic Sea region 1850-2009			
Season	All	60-70°N	50-60°N	Sea
ANN	0.74	0.92	0.61	0.70
DJF	1.21	1.38	1.00	1.09
MAM	0.96	1.15	0.83	0.80
JJA	*0.17*	0.37	*0.05*	0.33
SON	0.72	0.91	0.59	0.74

Consistent with the phenomenon of polar amplification, northern latitudes exhibit clearly stronger warming trends than regions south of around 60° N (Tab. 1). This leads to a stronger latitudinal temperature gradient over the Baltic Sea in all seasons with exception of recent decades in winter (Fig. 2). 51-yr running decadal trends for regions north and south of the Baltic Sea show relatively homogeneous variations with exception of winter.

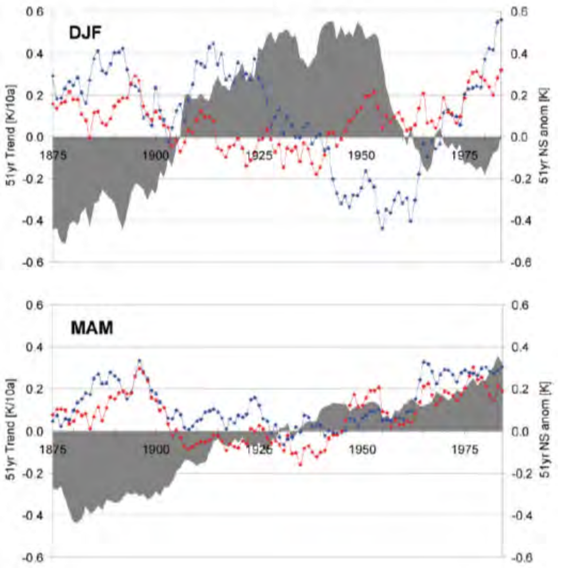


Figure 2. Deviations of 51-yr running latitudinal temperature gradients (gray) from the long-term mean NS gradient and running 51-yr decadal trends north (blue) and south (red, 48°-52° N, 20°-30° E) of the Baltic Sea for winter and spring.

4. Pressure and Wind

In agreement with well established pressure-based storm indices like Stockholm (Bärring and Fortuniak, 2009, see Fig. 2 in Rutgersson et al., this issue) or NE-Atlantic and North Sea (Krueger et al., 2013), no robust long-term trends are found over these areas. However, HiResAFF points to regional differences in the wind climate. For instance, the very stormy period of the 1880s found over the NE-Atlantic and North Sea is partly less pronounced over the central to northeastern Baltic Sea compared to the 1990s (Fig. 3).

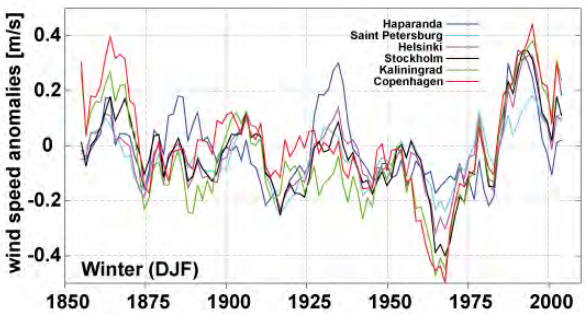


Figure 3. 11yr running seasonal mean wind speed anomalies relative to the long-term mean selected for different locations in winter 1850-2009 from HiResAFF.

The strong increase and NE shift of deep lows since the 1970s in NCEP/NCAR reanalysis (Lehmann et al., 2011) is confirmed by the reconstruction. An analysis of the annual number of deep cyclones in HiResAFF suggests that the peak in the 1990s is unprecedented in the period 1850-2009. This period coincides with a strong increase in 31-yr running correlations of wind speeds (and sea-level variations) over the Baltic Sea region with the NAO. This is in agreement with previous studies (e.g. Matulla et al., 2007) about the non-stationary link between NAO and wind indices.

5. Conclusion

Generally high reconstruction skills regarding high- and low-frequent variations and trends of HiResAFF provide confidence into a realistic analysis of regional long-term changes in the climate over Northern Europe. The meteorological fields have also been successfully used to drive ecosystem simulations of the Baltic Sea since 1850 (Gustafsson et al., 2012; Meier et al., 2012).

The atmospheric analysis shows, that the strongest reconstructed seasonal long-term warming trends since 1850 of HiResAFF are now found in winter in contrast to shorter periods since 1871 or 1901, where in agreement with BACC (2008) spring shows clearly stronger warming trends with non-significant ($p<0.05$) warming in winter north of 60° N. Latitudinal differences in multi-decadal seasonal warming trends show partly no continuous polar amplification over time although on average an increasing north-south temperature gradient is evident with exception of recent decades in winter.

The very stormy period of the 1880s found over the NE-Atlantic and North Sea is partly less pronounced over the central to northeastern Baltic Sea compared to the 1990s with exception of the southern and western region. The region-wide rough wind climate of the 1990s coincides with unprecedented high numbers of deep lows north of 60° N in this period. Running correlations between wind and NAO attain only recently very high levels.

References

BACC Author Team (2008): Assessment of Climate Change for the Baltic Sea Basin. In: Regional Climate Studies, 474 pp., Berlin/Heidelberg.

Bärring, L. and Fortuniak, K. (2009): Multi-indices analysis of southern Scandinavian storminess 1780–2005 and links to interdecadal variations in the NW Europe–North Sea region. Int. J. Climatol. 29, 373-384.

Gustafsson, B.G., Schenk, F., Blenckner, T., Eilola, K., Meier, HEM, Müller-Karulis, B., Neumann, T., Ruoho-Airola, T., Savchuk, O.P., and Zorita, E. (2012): Reconstructing the Development of Baltic Sea Eutrophication 1850–2006. AMBIO, 41, Number 6, 534-548.

Krueger, O., Schenk, F., Feser, F. and Weisse, R. (2013): Inconsistencies between long-term trends in storminess derived from the 20CR reanalysis and observations. J. Climate, 26, 868-874.

Lehmann, A., Getzlaff, K. and Harlaß, J. (2011): Detailed assessment of climate variability in the Baltic Sea area for the period 1958 to 2009. Clim. Res., 46, 185-196.

Matulla, C., Schoener, W., Alexandersson, H., von Storch, H. and Wang, X.L. (2007): European Storminess: Late 19th century to present. Clim. Dyn. 31, 125-130.

Meier, H.E.M. et al. (2012): Comparing reconstructed past variations and future projections of the Baltic Sea ecosystem - first results from multi-model ensemble simulations. Environ. Res. Lett., 7, 034005.

Rutgersson, A., Jaagus, J., Schenk, F. and Stendel, M. (2013): Observed changes and variability of atmospheric parameters in the Baltic Sea region during the last 200 years. In: this issue

Schenk, F. and Zorita, E. (2012): Reconstruction of high resolution atmospheric fields for Northern Europe using analog-upscaling. Clim. Past, 8, 1681-1703.

Future climate change A1B scenario downscaling - Results for the Baltic and North Sea

Dmitry V. Sein[1], Uwe Mikolajewicz[1], Matthias Groeger[1], Ernst Maier-Reimer[1] and Daniela Jacob[1,2]

[1] Max Planck Institute for Meteorology, Hamburg, Germany (dimitry.sein@zmaw.de)
[2] Climate Service Center, Hamburg, Germany

1. Model setup

The REgional atmosphere MOdel **REMO** (Jacob, 2001) with 37km resolution is coupled to the global ocean – sea ice – marine biogeochemistry model **MPIOM/HAMOCC** (Marsland et al., 2003) with increased resolution on the North-West European Shelves (up to 4 km in the German Bight). The coupled domain includes Europe, the North-East Atlantic and part of the Arctic Ocean (Fig.1). The models are coupled via the **OASIS** coupler. The coupling procedure is similar to those described in Aldrian et al., (2005) but some additional processes were taken into account. We included into the coupled system the sea ice (Mikolajewicz et al., 2005), terrestrial hydrology and ocean biogeochemistry. In addition, the ocean model was run with ocean tides and better representation of the diurnal cycle (one hour coupled time step). The last two modifications make one of the major differences from the ECHAM5/MPIOM IPCC simulations, where the diurnal cycle and tidal dynamics were neglected. The ocean tidal forcing was derived from the full ephemeridic luni-solar tidal potential. The global Hydrological Discharge model **HD**, which calculates river runoff (0.5º horizontal grid resolution), is coupled to both the atmosphere and ocean components. Exchange of fields between ocean and atmosphere takes place every hour.

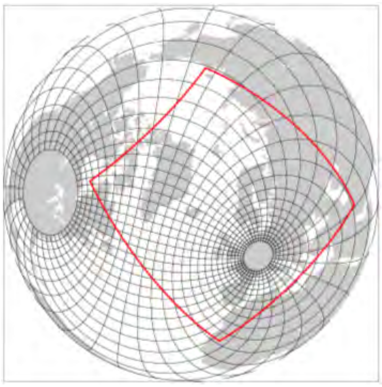


Figure 1. Grid configuration: the red "rectangle" indicates the coupled domain (REMO model) black lines indicate the grid of the MPIOM/HAMOCC. For the ocean/sea ice grid only every 15th line is shown.

Lateral atmospheric and upper oceanic boundary conditions outside the coupled domain were prescribed using NCEP/NCAR reanalysis for the hindcast simulations as well as ECHAM5/MPIOM C20 20-th century and A1B scenario data (the total simulation period was 1920-2100) for corresponding scenario downscaling. After the validation runs with NCEP/NCAR reanalysis the model was spun-up for the period 1920-2000. Then the **scenario** run (21st century) and in parallel a **control** run (20th century forcing) were carried out.

2. Hindcast simulations forced by NCEP/NCAR reanalysis: Comparison with observational data

The Simulated climatological sea surface temperature in the North Sea and the western part of the Baltic Sea is in a good agreement with observational climatologies (Fig.2). In the eastern part of the Baltic Sea, i.e. Gulf of Bothnia and Gulf of Finland, SST is underestimated by about 2K. This is mainly it is caused by a cold bias in the atmospheric model in this region, which is a subject of further investigations.

The largest disagreement of sea surface salinity with observational data occurs around Denmark, in the Gulf of Finland and at the Norwegian coast. Both vertical and horizontal resolutions of the ocean model are not sufficient enough for a realistic representation of the physical processes in these regions. The strong model bias in the Wadden Sea is a consequence of the coarse vertical resolution. The dipole structure of salinity bias along the Norwegian cost is caused by relatively "smooth" modeled Baltic water outflow. The strong observed meandering of this outflow (Johannessen et al., 1989) and a consequent increased horizontal mixing with North Sea water is not resolved in our MPIOM setup.

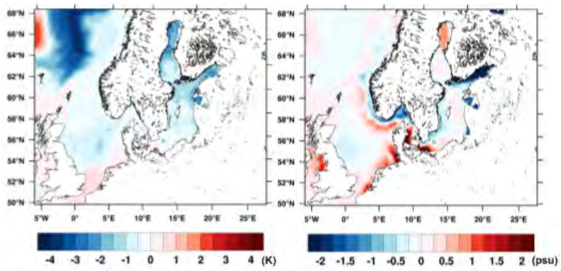


Figure 2. 1980-2000 mean SST (left) and SSS (right) difference: model – GDEM climatology (Carnes, 2009).

One of the most complicated tasks in the modeling of the water circulation in the Baltic and the North Seas is the representation of their exchange through the Danish straits. We realize that vertical resolution ca. 10 m and horizontal ca. 10 km is not sufficient to exactly reproduce the high frequency dynamics, associated with the pulse-like Baltic – North Sea water exchange through the small straits. Nevertheless, the modeled salinity of the Baltic is in relatively good agreement with the observational data. As we do not use any kind of fresh water flux correction or salinity restoring in this region, this indicates that the total exchange was in balance with precipitation and river runoff into the Baltic Sea.

3. Climate change: Precipitation and river runoff

The predicted large scale changes in precipitation are similar to those simulated by ECHAM5/MPIOM (Fig.3), but due to higher atmospheric resolution in REMO they differ in small scale features, in particular in Northern Europe. The stronger precipitation increase during winter time together with corresponding warming and reduction of snow cover leads to substantial increase of Baltic river runoff from November to March.

In general, the increase of precipitation in the Baltic Sea catchment causes an increase of mean river runoff in this region up to 20%.

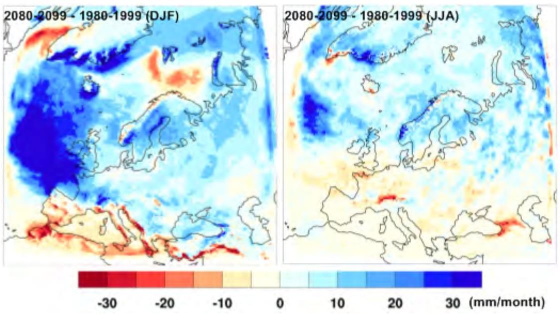


Figure 3. Changes in precipitation

4. Climate change. Sea surface temperature, salinity and sea level changes.

To analyze the climate changes in the Baltic and the North Sea regions we provide a comparison between two last decades of the 20th and 21st century. The warming of the North Sea (ca. 2K) is in a quite good agreement with the global ECHAM5/MPIOM IPCC A1B simulations. The simulated SST change in the Baltic by the end of the 21st century is much higher reaching up to 4K in its northernmost part (Fig.4).

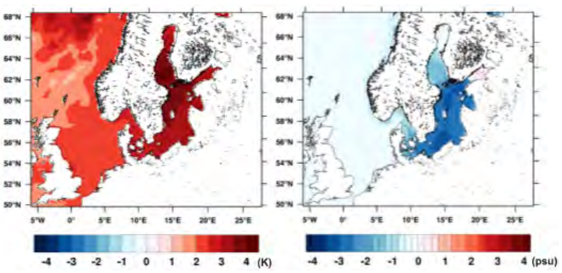


Figure 4. Mean SST (left) and SSS (right) change: 2080-2099 – 1980-1999

One of the most important "added value" in our IPCC scenario downscaling is a representation of salinity changes into the Baltic Sea. Almost all the global AO GCMs involved in IPCC scenario runs are to coarse to simulate realistic salinity in this region providing just a fresh water there. As a result, they do not show the changes in Baltic water salinity and subsequent changes in density and stratification. In our case we obtain a relatively strong freshening (by ca. 3 – 3.5 psu) at the end of 21st century. The main reason for this freshening is the simulated increase of winter precipitation in the Baltic Sea catchment area. While the water outflow is limited by the exchange "capacity" of the Danish straits, the increase of the river runoff tends to store more fresh water into the Baltic, causing its continuous freshening.

Considering the North Sea, our simulations do not show significant changes in sea surface salinity in this region as there is a vigorous water exchange with the open Atlantic.

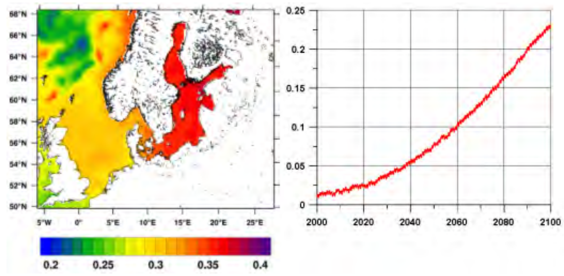


Figure 5. 2080-2099 – 1980-1999 mean sea level change (left) and global steric sea level change (right)

The simulated sea level change consists of the "global part", caused by the thermal expansion of the global ocean (steric change) and its local changes. The mean steric sea level rise estimation is about 2 mm/year (Fig.5) which is in a reasonable agreement with observations and global ECHAM5/MPIOM simulations. Note, that our model does not include glaciers melting, missing the eustatic sea level changes due to corresponding increase of the ocean volume. According to present day estimations it means that we underestimate the current global sea level rise for about 1.5 mm/year (Nerem et al. 2010).

5. Conclusions

The most pronounced changes corresponding to downscaled IPCC A1B scenario projection for the North European shelves were obtained in the Baltic Sea. Global warming will affect the Baltic Sea primarily through an enhancement of the hydrological cycle which delivers more moisture from the tropics towards the poles. The resulting increase of precipitation over the Baltic Sea catchment area leads to substantial increase of the river runoff which is much stronger than in surrounding areas. Sea level changes in the Baltic Sea are therefore much more pronounced then in the North Sea.

References

Aldrian, E., D.V.Sein, D.Jacob, L.D.Gates and R.Podzun (2005) Modelling of Indonesian Rainfall with a Coupled Regional Model. Climate Dynamics **25**, pp. 1–17

Jacob, D. (2001) 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, **77**, 1-4, 61-73

Johannessen, J.A., E. Svendsen, S. Sandven, O.M. Johannessen and K. Lygre, (1989) Three-Dimensional Structure of Mesoscale Eddies in the Norwegian Coastal Current. J. of Physical Oceanography, **19**, pp.3-19

Marsland,S.J., H. Haak, J.H. Jungclaus, M. Latif and F. Roeske, (2002) The Max-Planck-Institute global ocean/sea ice model with orthogonal curvilinear coordinates, Ocean Modelling, **5**, No. 2, pp. 91-126

Mikolajewicz.,U., D.V.Sein, D.Jacob, T.Kahl, R.Podzun, T.Semmler (2005) Arctic sea ice variability with a coupled regional atmosphere-ocean-sea ice model. Deutsche Meteorolog. Zeitschrift, 14 (16), 793-800

Nerem R.S., D. P. Chambers, C. Choe and G. T. Mitchum (2010) Estimating Mean Sea Level Change from the TOPEX and Jason Altimeter Missions, Marine Geodesy, 33:S1, 435-446

Lessons from the almost seven decades of visual wave observations from the eastern Baltic Sea coast

Tarmo Soomere, Maris Eelsalu, Katri Pindsoo and Mihhail Zujev

Wave Engineering Laboratory, Institute of Cybernetics at Tallinn University of Technology, Estonia (soomere@cs.ioc.ee)

1. Wave climate and its changes

A variety of changes in the marine climate, from alterations in the wind speed, direction or gustiness up to shortening of the ice season, may lead to associated changes to the wave properties. Identification of such changes is a major challenge for many regions of the World Ocean as the instrumentally measured wave time series are relatively short (normally not exceeding 20–30 years) and data observed from ships have a low coverage in domains not visited by regular ship traffic (Gulev et al., 2003).

In this paper we describe several key developments in the quantification and understanding of wave fields in the Baltic Sea basin derived from long-term regular visual wave observations from the eastern coast of the Baltic Sea.

2. Visually observed wave data from the eastern Baltic Sea coast

The Baltic Sea is one of the few water bodies where systematic visual wave observations have been performed from numerous hydrometeorological stations of the former USSR using the same routine starting from the mid-1940s. As in several locations the observations are still carried on, the resulting records of wave properties on the eastern Baltic Sea coast provide an exceptionally long temporal coverage (Zaitseva-Pärnaste et al., 2011).

The resulting data sets have several obvious shortages (such as an element of subjectivity, a poor spatial and temporal resolution, transformation of wave fields in the nearshore, extensive gaps, etc.). There is thus need for much more complicated pre-processing of the observed wave data than standard meteorological variables such as pressure, temperature, or wind. In spite of these deficiencies large pools of visually observed data from ships adequately reflect the basic wave features in the open sea (Gulev and Hasse, 1998). Even if the single values of, e.g., wave height or direction, have been modified in the process of refraction or wave breaking in the nearshore, the data filed during a long time and using the same routine still contain precious information about the changes in the wave properties (and implicitly about the associated forcing factors), and are extremely useful to reconstruct long-term patterns in changes of wave properties (Gulev et al., 2003; Gulev and Grigorieva, 2006).

During the last years the data sets of wave properties have been digitised and processed for eight observation sites (work on two sites is in progress) covering almost the entire eastern Baltic Sea coast from the Curonian Spit up to the eastern part of the Gulf of Finland (Fig. 1). This stretch covers about a half of the sedimentary coasts of the Baltic Sea. Even more importantly, the temporal coverage of these data has been recently extended back to almost seven decades (from 1946 onwards) using the high correlation between the observed wave height in physical units (metres) and the observed qualitative sea state (Soomere, 2013).

The visually observed data first confirmed the intuitively obvious features of the Baltic Sea wave fields such as a relatively mild overall wave regime (long-term significant wave height in the nearshore well below 1 m), much shorter typical wave periods (4–6 s in the open sea, 3–5 s in the nearshore) than in the open ocean, high temporal variability in the wave properties, strong seasonal signal, modest values of extreme wave heights and the presence of two-peak structure of the directional distribution of wave propagation directions that obviously follows the similar structure of moderate and strong winds (Soomere and Räämet, 2011).

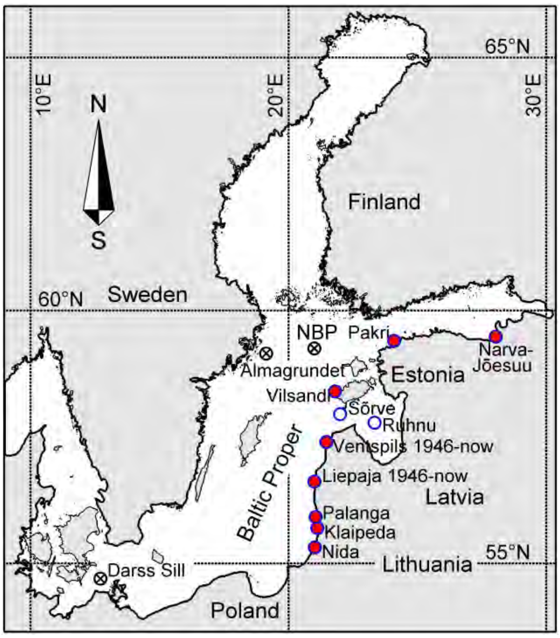


Figure 1. Visual wave observation sites on the eastern coast of the Baltic Sea, date from which have been digitised (filled circles) or currently under reconstruction (empty circles), and locations of long-term instrumental measurements (crossed circles).

3. Wave climate changes derived from observations

The analysis of the entire data set of visually observed wave properties has revealed several highly interesting properties of the Baltic Sea wave climate on a decadal scale. First of all, the data clearly demonstrates that the wave height in the Baltic Sea does not have any clearly defined long-term trend. The longest (sub)trends persist for about three or four decades. Instead, the wave activity (interpreted, e.g., as the annual mean wave height) has extensive decadal-scale, mostly aperiodic variations at almost all observation sites. The amplitude of these variations is remarkable: the annual mean wave height may change by a factor of two at sites open to the Baltic Proper.

The most interesting feature, recently identified from a reconstruction of the long-term course of the wave intensity back to the 1940s (Soomere, 2013) is the long decreasing phase in the wave intensity from the mid-1940s until about 1970. This process seems to be present along the entire eastern coast of the Baltic Sea. As no existing wave simulations cover such a long time span, the validity of this conclusion needs further analysis. Still, such an ultimate decrease, by almost a factor of two on average, in the wave intensity over three decades is consistent with a substantial decrease in the storminess over these decades in the entire Baltic during the first half of the 20th century (cf. Alexandersson et al., 2000). Although the exact magnitude of this decrease may be somewhat overestimated by observers, the presented data very likely represents a major gradual change in the Baltic Sea wave fields in the 20th century.

A comparison of the visually observed data with recent numerical hindcasts and instrumentally measured data has also revealed a highly nontrivial spatial pattern of decadal variations in the Baltic Sea. While the overall wave intensity in the entire Baltic Sea basin has experienced no considerable changes since the 1970s, the local wave climate has undergone significant changes. For example, a remarkable increase in the wave intensity occurred in the northern Baltic Proper during the 1990s. Changes with a comparable (but slightly smaller) amplitude evidently occurred in the south-eastern and south-western parts of the sea (Zaitseva-Pärnaste et al., 2011; Soomere et al., 2012). The overall long-term course in the observed wave height suggests that these variations in the wave activity were a short-term phenomenon. It is likely that the Baltic Sea is now in the phase characterized by a relatively moderate level of the average wave height in the Baltic Sea.

While it is commonly accepted that variations in the wave height are a key driver of coastal processes, changes in the wave periods or approach directions may become decisive at certain occasions, for example, in the impact of waves in the nearshore and at the coast. Such variations are particularly important in micro-tidal seas such as the Baltic Sea, where waves are the major driver of coastal processes. In addition, the data from such water bodies provides a unique possibility to identify the related changes to the meteorological patterns (that are usually masked by swell on the open ocean coasts). A substantial rotation of the predominant wave propagation direction has been reported for the eastern Gulf of Finland, Zaitseva-Pärnaste et al., 2011), with possibly serious consequences to the coastal evolution (Ryabchuk et al., 2011). Interestingly, this rotation has not been resolved by the WAM model forced by geostrophic winds (Soomere and Räämet, 2011).

4. Concluding remarks

The use of wave observations made from coastal sites is intrinsically problematic for the reconstruction of the wave properties offshore because the results inherently reflect a multitude of processes of wave transformation in the nearshore. They still often carry invaluable (and frequently underestimated) information about the wave fields. In particular, they form a unique source for highlighting and tracking the long-term changes to the wave fields.

While the discussed extensive variations in the wave height in the 1990s can be explained by a concentration of a large part of centres of cyclones crossing the Baltic Sea in the middle of the Bothnian Sea (Bärring and von Storch, 2004) or by a short-time increase in the storminess (Alexandersson et al., 2000), the changes before 1970 apparently have been caused by some larger-scale phenomenon. Most of the reconstructions of wind speed over the Baltic for this period reveal some increase in the wind intensity rather than decrease (e.g. Pryor and Barthelmie, 2003). As the Baltic Sea has a strongly elongated shape, a considerable increase or decrease in wave height may be caused, for example, by a systematic rotation of the predominant direction of strong winds. Such a seeming rotation of the wind rose at a single observation site may be caused by a variation in the trajectory of cyclones. For an observer this process is reflected as a change in wave approach directions.

Acknowledgements

This study was supported by the project "Science-based forecast and quantification of risks to properly and timely react to hazards impacting Estonian mainland, air space, water bodies and coasts" (TERIKVANT, 2012–2014) and forms a part of activities of the Estonian Centre of Excellence in Non-linear Studies CENS, both financed from the European Regional Development Fund. We thank the Estonian Meteorological and Hydrological Institute, the Centre of Marine Research, Klaipėda, Lithuania, and the Latvian Environment, Geology and Meteorology Centre for providing access to the original observation diaries and/or files, and L. Kelpšaitė, M. Viška and M.Org for their efforts to digitize the diaries.

References

Alexandersson H., Tuomenvirta H., Schmith T., Iden K. (2000) Trends of storms in NW Europe derived from an updated pressure data set. *Clim. Res.*, Vol. 14, No. 1, pp. 71–73.

Bärring L., von Storch H. (2004) Scandinavian storminess since about 1800. *Geophys. Rev. Lett.*, Vol. 31, Art. No. L20202.

Gulev S.K., Grigorieva V.G. (2006) Variability of the winter wind waves and swell in the North Atlantic and North Pacific as revealed by the voluntary observing ship data. *J. Clim.*, Vol. 19, No. 21, pp. 5667–5685.

Gulev S.K., Hasse L. (1998) North Atlantic wind waves and wind stress fields from voluntary observing ship data. *J. Phys. Oceanogr.*, Vol. 28, pp. 1107–1130.

Gulev S.K., Grigorieva V.G., Sterl A., Woolf D. (2003) Assessment of the reliability of wave observations from voluntary observing ships: Insights from the validation of a global wind wave climatology based on voluntary observing ship data. *J. Geophys. Res.*, Vol. 108, No. C7, Art. No. 3236.

Pryor S.C., Barthelmie R.J. (2003) Long-term trends in near-surface flow over the Baltic. *Int. J. Climatol.*, Vol. 23, No. 3, 271–289.

Ryabchuk D., Leont'yev I., Sergeev A., Nesterova E., Sukhacheva L., Zhamoida V. (2011). The morphology of sand spits and the genesis of longshore sand waves on the coast of the eastern Gulf of Finland. *Baltica*, Vol. 24, No. 1, pp. 13–24.

Soomere T. (2013) Extending the observed Baltic Sea wave climate back to the 1940s. *J. Coast. Res.*, Special Issue No. 65.

Soomere T., Räämet A. (2011) Spatial patterns of the wave climate in the Baltic Proper and the Gulf of Finland. *Oceanologia*, Vol. 53, No. 1-TI, pp. 335–371.

Soomere T., Weisse R., Behrens A. (2012) Wave climate in the Arkona Basin, the Baltic Sea. *Ocean Sci.*, Vol. 8, No. 2, pp. 287–300.

Zaitseva-Pärnaste I., Soomere T., Tribštok O. (2011) Spatial variations in the wave climate change in the eastern part of the Baltic Sea. *J. Coast. Res.*, Special Issue No. 64, pp. 195–199.

Climate change and local trends in longer air temperature time series of the Baltic region

Andres Tarand

Tallinn, Estonia (andres.tarand@gmail.com)

1. Introduction

The long time series of air temperature or precipitation usually belong to bigger towns, which often are situated in the coastal zone. It means that two kinds of climate mesoscale processes – the impact of the sea (not changing very much during centuries) and urban impact – have their role in air temperature observations results. In principle the phenomenon is well known but in practice complicated because global trend, impact of the sea in coastal zone and urban impact have all the same magnitude.

In our presentation time series of Helsinki, St Petersburg, Riga, Stockholm, Tallinn and Tartu are used as basic data. Among these time series Riga presents the case with no homogenization althouge observations have been located in 7 different places. Tartu time series have their beginning in 1821 and were reconstructed up to 1866 by Meitern (1992). As Tartu time series are only one in the Baltic states which was working without gaps in the time of the world wars, the data have been analized by many authors: Jaagus (1999), Kärner and Meitern (2006), Sits and Post (2006). Tallinn time series were reconstructed by Tarand (2003) and due to many reorganizations of stations net was here important to reduce air temperature observations to one point. In St Petersburg where meteorological obsevations started at the beginnig of 18th century the continuous series began in 1804 and observations have been provided all the time on Vassily island with one replacement of observation place in 1933. Stockholm and Helsinki both have meteorological stations which have been working all the time at the same place. Careful treatment of Stockholm´s data is given by Moberg (1996) in his doctoral thesis. Helsinki`s corrected time series are published by Heino (1994).

2. Impact of the Baltic Sea

Generally the mesoscale impact of the sea is observable within 20-kilometers zone from the average coastal line and is mostly a function of wind direction. In the case of air temperature the most rapid change happens within the zone of first kilometer. In summer time the average horizontal gradient of seawind in midday is 0.4°C/km and in winter (sea without ice) around the day -0.1°C/km. Tarand (1986). For determination of that gradient we used the profile between Helsinki and Tallinn (80 km) with 8 meteorological stations (4 in Helsinki and 4 in Tallinn) on different distance relative to average coastal line. For correction of Tallinn time series also the average differences from parallel observations (all in all five cases in 116 years) were used . This kind of corrections like we implemented in the case of Tallinn are strictly climatological and could not be implemented precisely for reconstruction of temperature individual years.

3. Urban heat island

Before the satellites registering landscape (townscape) surface temperature there were two ways of mapping urban heat island. The first is using stationary observations and second organizing special temporary network or/and car-routes. However, all possibilites could be combined. An example of first possibility is Tartu where in 1929-1939 the Meteorological Observatory worked in town and Raadi station 4 km from the centre to NE on agricultural landscape. Then in the town with 50000 inhabitants the average maximum value of heat island in winter was near to 1°C and annual mean in observatory 0.5°C. As an example of combined methods implemented in Tallinn in the 1970s (400000 inh.) the average maximum value was 1.5°C in winter. As it was generalized decades ago with the growth of towns maximum of heat island does not rise over 2°C but the area of heat island is growing corresponding to expansion of artifical surfaces and leak of energy produced by man. That is the key issue of urban impact to the temperature trend values which should be managed individually to every time series. Hereby one cannot derive the urban impact only from general indeces of growth (population, industry) but more important are the changes near to observation place (3 km radius).

4. Results

If somebody from broader audience tries to follow climate change as represented on Fig.1 he would be amazed. Helsinki and Tallinn are situated in world-wide prospect at the same place and on the level of annual mean temperatures are really correlated very well (0.99). A climatologist, however, knows that a distance about 100 km in direction from South to North means some tenths of centigrades lower mean air temperature but not the opposite as it happened in the period 1911-1940. That was just the period of Helsinki rapid growth. Heino (1994) gives the role of urban effect for that time as 0.7-0.8°C in annual mean. Later on the urban effect for Helsinki-Kaisaniemi station is stabilized. On Fig.2 the trends of whole period 1850-1999 for Helsinki and Tallinn are presented. The trend in Helsinki has been constantly bigger and as Tallinn time series in that period practically does not have urban impact we can conclude that for hundred years the urban heat island has its role

0.4°C and natural warming 0.8°C. On the Fig.3 one can follow the same process of rapid growth of air temperature in Stockholm in the second half of the 19th century (not to compare with Riga´s unhomogenized curve) and in St Petrsburg first at the beginning of 20th century. That was noticed in then Leningrad Observatory (not by curves but the building- sites coming closer) and from 1933 the new observation place was founded. But townscape development after WW2 has been even more active and starting from the 90s of the last century the climate of St Petersburg is a little warmer than in Tallinn. It is, though, just the urban climate. The calculated trend about the difference between St Petersburg and Tallinn has the same value as that of Helsinki-Tallinn.

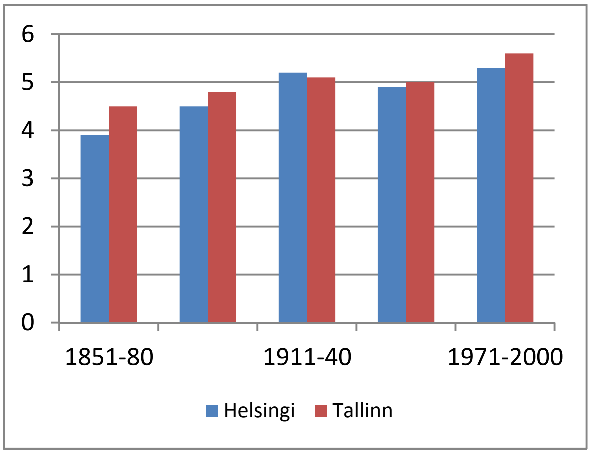


Figure 1. Annual average air temperature of 30-year periods in Tallinn and Helsinki

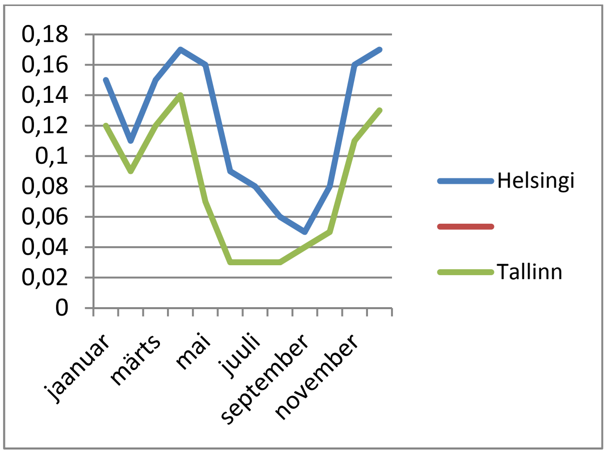


Figure 2. Trend of mean air temperature in 1850-1999

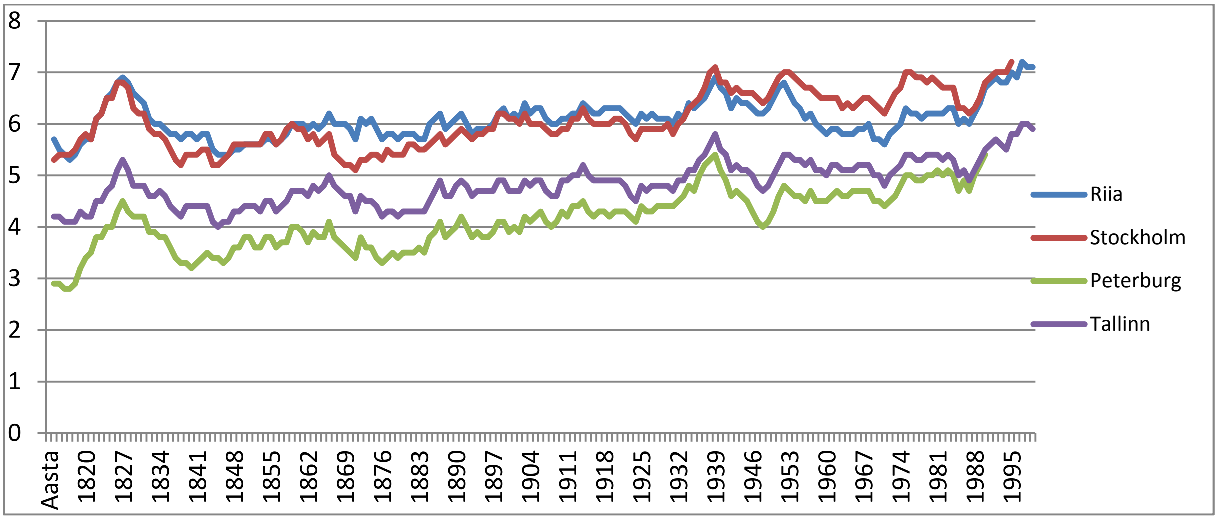


Figure 3. Average air temperature (10-years smoothed) in four Baltic Sea towns

Simulated halocline variability in the Baltic Sea during 1961-2007

Germo Väli[1,3], Markus Meier[1,2] and Jüri Elken[3]

[1] Swedish Meteorological and Hydrological Institute, Norrköping, Sweden (germo.vali@smhi.se)
[2] Department of Meteorology, Stockholm University, Sweden
[3] Marine Systems Institute, Tallinn University of Technology, Estonia

1. Abstract

Salinity and halocline depth variations in the Baltic Sea during 1961-2007 are studied using a three-dimensional ocean circulation model. Significant interannual and interdecadal variations in the halocline depth are found, together with identified periods characterized either by shallow (1970-1975) or deep halocline (1990-1995). The model simulation indicates that the mean surface salinity in the Baltic Sea is mainly controlled by the accumulated river runoff, while the below halocline salinity in the Baltic proper (which comprises Bornholm and Gotland basins) is dependent also on the mean zonal wind stress. The halocline depth and strength in the Baltic Sea is significantly affected by the mean zonal wind stress, while the impact of runoff is smaller. The horizontal ventilation of the halocline in the eastern Gotland Basin which is of utmost importance for the Baltic Sea nutrient cycling is significantly larger during periods with deepened halocline opposite to physical intuition. Decadal variations in volume transports between different regions of the Baltic proper are to great extent controlled by mean zonal wind stress but in some regions by runoff as well.

2. Introduction

The Baltic Sea is a brackish sea with an estuarian-like circulation characterized by (a) water exchange through the Danish Straits, (b) elongated multi-basin bottom topography and coastline (c) river discharge, and (d) atmosphere-ice-ocean interaction (*e.g. Mälkki and Tamsalu*, 1985).

Spatial salinity variations in the Baltic Sea are quite high. Typical estuarine gradients are present in the upper layers but the central part of the sea (named as Baltic Proper) has also persistent strong salinity stratification: halocline lies on about 60 – 80 m depth and deep salinities range up to 14 g/kg in the Gotland Deep (Matthäus, 1984).

Both observations (Elken et al., 2006) and model simulations (Meier, 2007) indicate large variations of the halocline depth in the Baltic Sea. The climatologically averaged seasonal differences of the halocline depth in the model simulations exceed more than 30 m, whereas the observed differences in the northern Baltic Proper exceed 20 m.

3. Materials and methods

Halocline depth

Halocline depth is defined as the location of the maximum of the first vertical derivative of the salinity:

$$H_{halocline}(x,y) = H\left(\max\left\{\frac{\Delta S(x,y,z)}{\Delta z}\right\}\right)$$

where $S(x,y,z)$ is the monthly mean salinity at the horizontal location x,y and the depth z (>0).
In this study, we focus only on changes in the perennial halocline of the Baltic Sea. In order to exclude the seasonal halocline with strong salinity gradients close to the surface, we follow the approach that the permanent halocline in the Baltic Sea is located deeper than 30 m and does not appear in areas with depths less than 50 m.

Time-series

Monthly mean distributions of the forcing fields and the oceanographic response fields appear to contain high degree of variance due to seasonal and year-to year changes. Following Meier and Kauker (2003), the low-pass filtered series with a cut-off period of four years describe well the interdecadal variations.

4. Results

The monthly mean halocline depth in the Baltic Sea (stations BY15 and BY31) underwent remarkable interannual variations (more than 30 m) during 1961-2007 (Fig. 1). Also the low pass filtered halocline depth showed significant interannual variations.

In particular, the smoothed halocline variations exceeded 20 m in both stations. A deep halocline period is identified during 1990-1995 in both stations, whereas the deepening occured sligthly earlier in the Landsort Deep (BY31). Similarily, a shallow halocline period is identified during 1970-1975.

Similar features are seen also in other stations of the Baltic Proper (e.g. BMP1, BY27, BY29). An exception was the Bornholm Basin (BY5, not shown), where the halocline is controlled by the Slupsk Sill overflow; the low-pass filtered halocline depth remained close to 55 m and did not show any significant decadal variability.

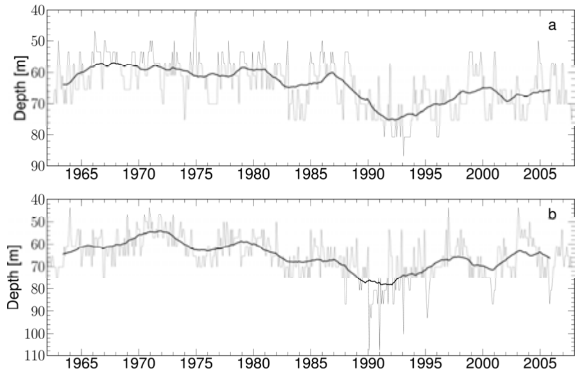


Figure 1: The monthly mean simulated halocline depth (thin line) in BY15 (a) and BY31 (b) with corresponding 4-year mean (thick line).

The decadal variability of halocline depth is to great extent controlled by the decadal variations of total accumulated runoff to the Baltic Sea (Fig. 2) and mean zonal wind stress (Fig. 3), whereas the impact of mean zonal wind stress appears slightly larger. In general, the halocline depth is increased during periods (a) with larger freshwater input and (b) with more frequent westerly winds.

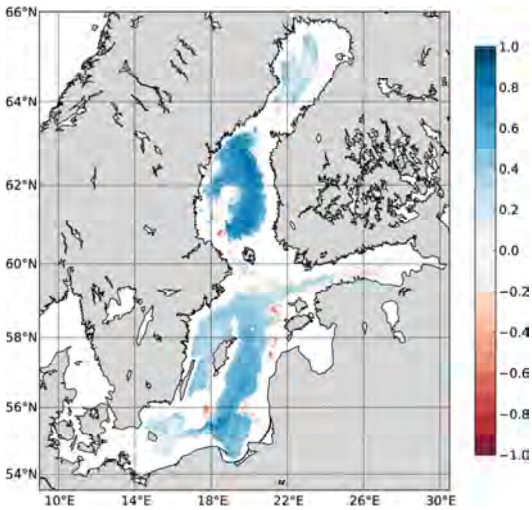


Figure 2: The correlation between the halocline depth and accumulated runoff to the Baltic Sea.

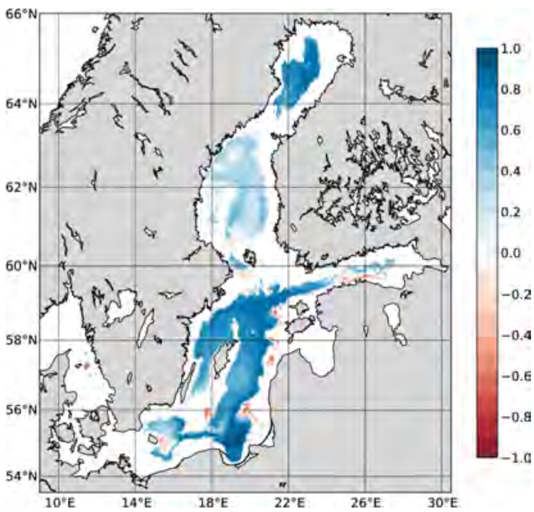


Figure 3: The correlation between the halocline depth and mean zonal wind stress.

The physical response of the Baltic Sea to the increased halocline depth is seen as a larger halocline ventilation of the Baltic Sea (Fig. 4). The ventilation of the halocline is calculated as the volume transport in depth range 60-150 m through transect between Gotland and Latvia with center located at BY15.

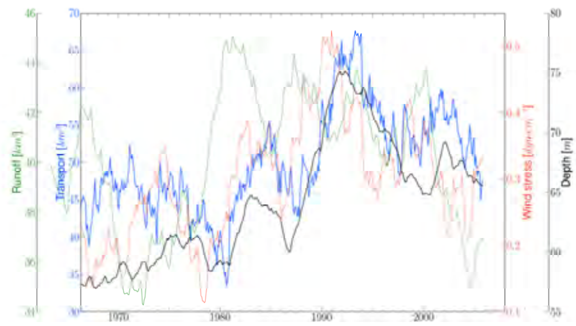


Figure 4: The low-pass filtered time-series of halocline depth (black bold line), halocline ventilation (blue bold line), runoff (green thin line) and mean zonal wind stress (red thin line).

5. Summary and conclusions

The halocline depth in the Baltic proper has large interannual variations (more than 20m), while the seasonal variations exist only in specific locations, which are affected the most by the forcing.

A shallow halocline period with larger salinity gradients for the Baltic Sea during 1970-1975 and a deep halocline period with smaller salinity gradients during 1990-1995 can be distinguished from both the simulated time-series and observations.

The halocline depth and strength in the Baltic is strongly dependent on the westerly winds, which increase the depth and reduce the strength. The effect of the accumulated river runoff to the halocline depth in the Baltic proper is lower compared with the wind field.

The ventilation of the halocline in the eastern Gotland basin and mean halocline depth are strongly correlated. The largest ventilation occurs during the deep halocline period. Shallow halocline period is characterized with the ventilation rate lower than the mean.

References

Elken, J., P. Mälkki, P. Alenius, and T. Stipa (2006), Large halocline variations in the northern Baltic proper and associated meso- and basin-scale processes, *Oceanologia*, *48 (S)*, 91–117.

Matthäus, W. (1984): Climatic and seasonal variability of oceanological parameters in the Baltic Sea, Beiträge zur Meereskunde, 51, 29-49

Meier, H.E. M. (2007), Modeling the pathways and ages of inflowing salt- and freshwater in the Baltic Sea, *Estuarine Coastal and Shelf Science*, *74*, 610–627.

Meier, H.E. M., and F. Kauker (2003), Modeling decadal variability of the Baltic Sea: 2. role of freshwater inflow and large-scale atmospheric circulation for salinity, *Journal of Geophysical Research*, *108*, 10.1029/2003JC001799.

Mälkki, P., and R. Tamsalu (1985), Physical features of the Baltic Sea, *Tech. Rep. 252*, Finnish Marine Research.

Assessment of regional climate variability and change using ECA&D and E-OBS

G. van der Schrier, E.J.M. van den Besselaar, R. Leander and A.M.G. Klein Tank

Royal Netherlands Meteorological Institute, De Bilt, The Netherlands (schrier@knmi.nl)

1. The European Climate Assessment & Dataset

The European Climate Assessment & Dataset (ECA&D) project presents information on changes in weather and climate extremes and provides the daily dataset needed to monitor and analyse these extremes. ECA&D was initiated by EUMETNET's European Climate Support Network in 1998 and has been growing steadily since. Currently, ECA&D is receiving data from 61 participants for 62 countries and the ECA dataset contains nearly 37000 observations for 12 elements at 7847 meteorological stations throughout Europe, the Mediterranean and the Middle East. Recently, Sweden, Finland and Germany substantially increased the number of stations provided to ECA&D. With the relatively dense station networks provided by the Baltic states, the land area surrounding the Baltic Sea is one of the regions in Europe with the highest station density in ECA&D. ECA&D is accessible via www.ecad.eu and concepts and calculations are documented on those web pages and by Klein Tank et al. (2002) and Klok & Klein Tank (2008).

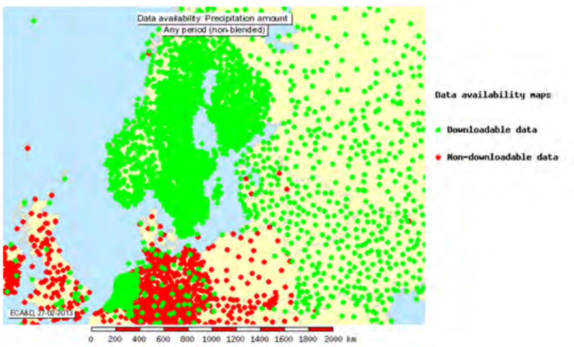


Figure 1. Station density for stations providing daily precipitation sums. The green dots represent stations for which the daily data can be downloaded from the ECA&D web pages. The red dots are the stations for which the daily data is not downloadable via ECA&D and must be obtained via the relevant National Meteorological Service.

2. The gridded E-OBS dataset

Based on the ECA&D station data, gridded data for daily maximum, daily minimum and daily averaged temperature, daily precipitation sum and daily averaged sea-level pressure are calculated. This data spans the period from January 1st 1950 to June 30, 2012 (version 7.0) and is updated with preliminary files until the end of each month The gridded dataset is referred to as E-OBS and comes in four different grid flavours, of which the 0.25 x 0.25 degree grid is the finest. The calculation of E-OBS is documented by Haylock et al. (2008) and van den Besselaar et al. (2011).

Due to the high-density station network in the circum-Baltic area, both ECA&D and E-OBS can be used to investigate specific events, like the winter storm of January 2005 (named Edwin or Gudrun by the Norwegian weather service, see figure below for precipitation over the area on 8 January 2005) and to assess regional climate variability and change. The climate change indices provided in ECA&D are excellent tools for such assessments describing various characteristics of climate change (both changes in the mean and the extremes). A core set of 26 indices follows the definitions recommended by the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI). Many of these indices relate to climate, and in particular, climate extremes relevant for hydrology.

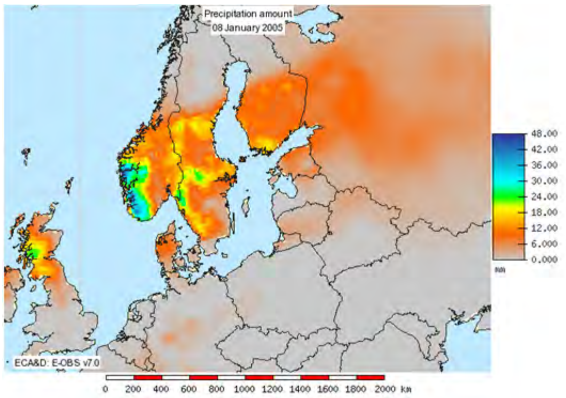


Figure 2. E-OBS precipitation amount for 8 January 2005. The winter storm Erwin, also known as Gudrun by the Norwegian weather service, hit northern Europe with violent winds and excessive rains from Ireland to Russia on 7-9 January 2005, killing at least 17 people and severely disrupting traffic and damaging infrastructures.

3. New developments

Next to the introduction to ECA&D and E-OBS, the presentation will focus on new developments within E-OBS. The first of these developments relate to a modified algorithm to calculate the gridded data, enhancing the internal consistency between the E-OBS datasets and giving an improved representation of extremes. Another development concerns the calculation of the climate change indices from the gridded E-OBS data (rather than on the station-based data only) on an operational basis. This facilitates assessments of interesting climate events, like the warm November 2011 month.

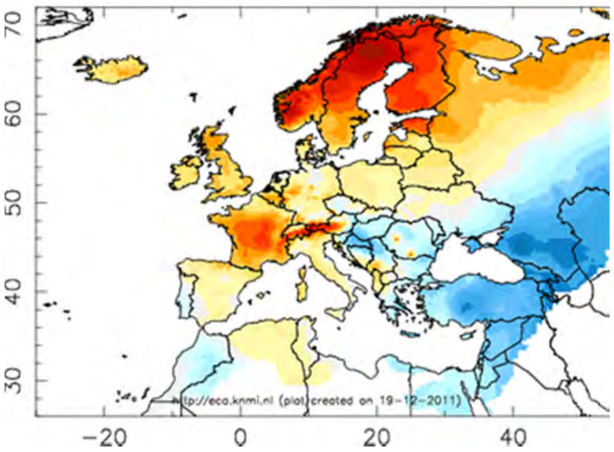


Figure 3. Maximum temperature averaged over November 2011 as anomaly with respect to the 1981-2010 climatology based on the E-OBS dataset.

References

Haylock, M.R.,Hofstra, N., Klein Tank, A.M.G., Klok, E.J., Jones, P.D. and New, M. (2008) A European daily high-resolution gridded data set of surface temperature and precipitation for 1950-2006, J. Geophys. Res. (Atmospheres), 113, pp. D20119, doi:10.1029/2008JD010201

Klein Tank, A. M. G. et al. (2002) Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment, Int. J. Climatol., 22, pp. 1441-1453 Data and metadata available at http://www.ecad.eu

Klok, E.J. and Klein Tank, A.M.G. (2008) Updated and extended European dataset of daily climate observations, Int. J. Climatol. 29, pp. 1182-1191, doi:10.1002/joc.1779

van den Besselaar, E.J.M. and Haylock, M.R. and van der Schrier, G. and Klein Tank, A.M.G., (2011) A European daily high-resolution observational gridded data set of sea level pressure, J. Geophys. Res. (Atmospheres), 116, pp. D11110, doi:10.1029/2010JD015468

Long-term variations of simulated sediment transport along the eastern Baltic Sea coast as a possible indicator of climate change

Maija Viška and Tarmo Soomere

Institute of Cybernetics, Tallinn University of Technology, Tallinn, Estonia (maija@ioc.ee)

1. Introduction

The eastern coasts of the Baltic Sea mainly consist of relatively soft and easily erodible sediment and are sensitive to large hydrodynamic loads. These coasts develop mostly under the influence of wave action. Recent studies show that large variations in wave properties (like the average significant wave height and wave height in extreme storms) have occurred in certain domains during last decades (Soomere and Räämet, 2011). It is natural to expect that these variations are reflected in the intensity or even direction of coastal processes. As many sedimentary coasts of the Baltic Sea are very dynamic and therefore sensitive to changes in the wave properties, they serve as good indicators of the (wave) climate change (Eberhards, 2003).

2. Methods and data

The longest connected domain of sedimentary coasts of the Baltic Sea stretches from the Sambian Peninsula (Kaliningrad region) up to Pärnu Bay (Estonia). Alongshore variations in sediment transport along this system and long-term trends in the potential net and bulk transport in its selected subsections (Fig. 1) are reconstructed using numerical simulations of the Baltic Sea wave climate for 1970–2007.

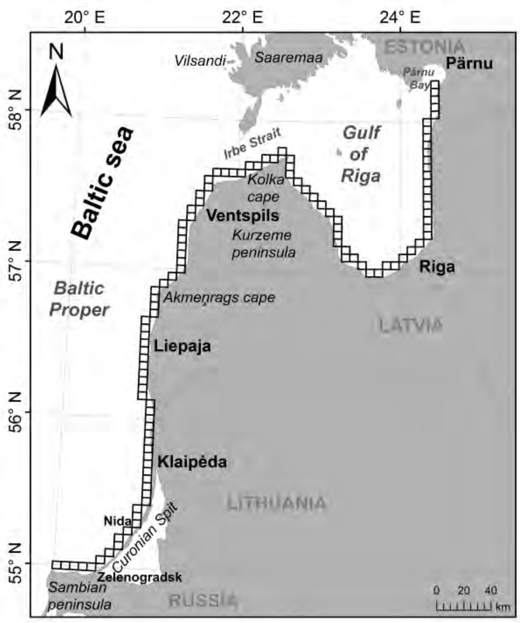


Figure 1. Study area at the eastern coast of the Baltic Sea. Small boxes in the nearshore show the wave model grid cells, from which values have been used in the analysis

Wave properties with a resolution of about 5.5 km have been simulated using the WAM model driven by adjusted geostrophic winds from the Swedish Meteorological and Hydrological Institute (Soomere and Räämet, 2011). The sediment flux in about 6 km long coastal sections is evaluated using the Coastal Engineering Research Centre (CERC) wave energy flux model and a fixed grain size of 0.17 mm (Viška and Soomere, 2012). The spatial pattern of the simulated net transport contain several persistent divergence and convergence areas that separate regions with oppositely directed net sediment flux and correspond to the most likely erosion and accumulation regions (Soomere and Viška, 2013). A highly persistent area of divergence of net transport and thus a likely erosion domain exists at the Akmenrags Cape. Its presence suggests that sediments usually do not pass this cape. Consequently, it is likely that the eastern coast of the Baltic Proper hosts two almost separated sedimentary compartments in the contemporary wave climate. For this reason we divide the eastern coast of the Baltic Proper into two compartments in the analysis below.

3. Bulk and net potential alongshore transport

The pattern of long-term and interannual variations of the bulk transport over the entire study area (Fig. 1) shows relatively large short-term variability, evidently reflecting the difference in storminess in subsequent years. There are three interesting features.

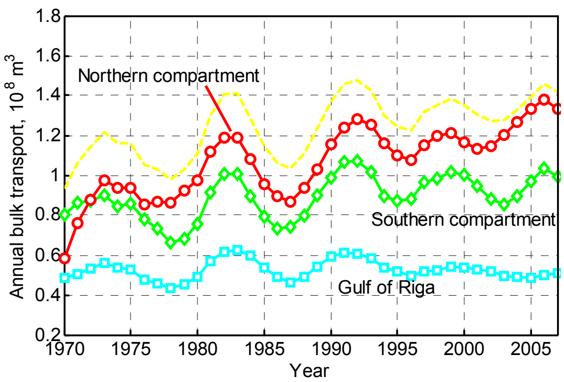


Figure 2. Bulk sediment transport integrated over three sections of the eastern Baltic Sea coast: red circles – from the Sambian Peninsula to Akmenrags Cape (the southern compartment); cyan squares – from the Akmenrags Cape to the Kolka Cape (the northern compartment), green rhombi – from the Kolka Cape to Pärnu Bay. All values are smoothed over three subsequent years. The yellow line shows a half of the transport over the entire eastern Baltic Sea coast.

First of all, this transport increases considerably, by about 25% by the end of the simulated time interval compared to its typical values in the 1970s.

Secondly, the increase is mostly concentrated along the eastern coasts of the Baltic Proper and does not become evident in the Gulf of Riga.

Thirdly, the overall course of the bulk transport reveals clearly identifiable, almost periodically occurring cycles with a typical time interval between the low and high values about 10 years. The amplitudes of the cycles are close to the typical values of interannual variations of this measure of transport.

The overall increase in the transport rate matches well the increase in the wind speed over the northern Baltic Proper (Räämet and Soomere, 2011). As no cyclic course is evident in the long-term behaviour in the wind speed, the decadal variations in the overall bulk transport rate apparently are associated with changes to the wind and wave propagation directions. As the both the directional distribution of winds and waves have two-peak structure in the study area (Viška and Soomere, 2012), even a small variation in the balance of the frequency of occurrence of south-western and north-north-western winds may lead to substantial changes in the bulk sediment transport rate.

The long-term variations of the overall net potential transport do not follow those for the bulk transport (Fig. 3). Instead of a gradually increasing trend of the bulk transport, the net transport relatively rapidly increased in the 1970s and 1980s and decreased with essentially the same rate since the mid-1990s. Interannual variability of net transport is even higher then bulk transport but the variations do not have such a clear cyclic nature as the bulk transport. The typical time scale between periods of high and low net transport varies from 10 to 20 years.

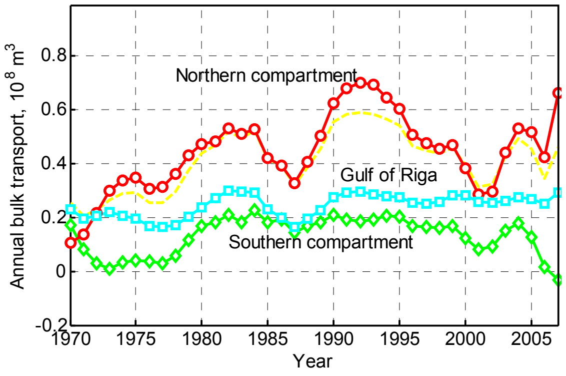


Figure 3. Net sediment transport integrated over three sections of the eastern Baltic Sea coast. Notations are the same as for Fig. 2.

4. Sediment transport in different compartments

The overall course of the annual values of the bulk sediment transport and its decadal variations for single compartments have almost perfect match in all three compartments variations except for the Gulf of Riga where this quantity is almost constant since the year 1995. The bulk potential transport rate is much lower in the Gulf of Riga than in Baltic Proper part. Interestingly, its rate practically does not change over the simulation interval.

A surprising feature is that the relative magnitude of the net transport in the Gulf of Riga considerable exceeds the similar rate for the bulk transport along the eastern Baltic Sea coast. While the bulk transport along the coasts of the Gulf of Riga is about a half of that along the southern part of the eastern Baltic Proper coast and less than 1/3 of that along the northern sections of the coasts of the Baltic Proper, the net transport in the Gulf of Riga even exceeds the level of net transport along the southern part of the coast of the Baltic Proper.

Another unexpected feature is that the values of net sediment transport for single compartments have very limited match of their decadal variation. There is a certain similarity between their courses from the mid-1970s until about the beginning of the 1990s and around the turn of the millennium. In particular, the processes in the Gulf of Riga seem to behave quite differently from those along the coast of the Baltic Proper.

5. Concluding remarks

The presented material first reveals that the reaction of sedimentary coasts to changes in the wind and wave climate may be extremely complicated. There is already some evidence that the properties of wave fields not exactly follow the trends and decadal variations in the wind fields. The analysis of the changes along different coastal compartments adds one more feature to this picture. In essence, it suggests that changes in the wind and wave properties and the reaction of sedimentary coasts to these may have radically different nature at the coasts of the Baltic Proper and in sub-basins of the Baltic Sea.

While in the 20th century storm waves have impacted the long stretch of the eastern coast of the Baltic Proper from the Sambian Peninsula up to the Kolka Cape in a basically similar manner, the situation has changed at the turn of the millennium: storms that impact the coasts of the Baltic Proper have less impact on the Gulf of Riga and vice versa. Although it may be hypothesized that this peculiarity reflect certain changes in the trajectories of storm cyclones crossing the Baltic Sea, its nature obviously needs much more detailed studies of changes to the wind and wave properties in this area.

Differently from the coasts of the southern Baltic Proper, the coasts of the Gulf of Riga develop under much lower wave activity concentrated in clearly shorter waves and thus providing substantially less wave energy to shape the coast. As a result, the coasts in this gulf evidently are still far from the equilibrium and thus host higher net transport even under relatively low waves.

Acknowledgements

The underlying research was supported by the targeted financing by the Estonian Ministry of Education and Research (grant SF0140007s11), Estonian Science Foundation (grant No 9125) and the European Union via a support to the Estonian Centre of Excellence CENS from the European Regional Development Fund and by the DoRa international PhD studentship for M.Viška. The authors are deeply grateful to Alexander von Humboldt Foundation for supporting their research stay in the Institute for Coastal Research, Geesthacht in 2011.

References

Eberhards G. (2003) The sea coast of Latvia, University of Latvia, Riga (in Latvian).

Räämet A., Soomere T. (2011) Spatial variations in the wave climate change in the Baltic Sea. *J. Coast. Res.*, Special Issue No. 64, pp. 240–244.

Soomere T., Viška M. (2013) Simulated sediment transport along the eastern coast of the Baltic Sea. *J. Mar. Syst.*, doi 10.1016/j.jmarsys.2013.02.001

Viška M., Soomere T. (2012) Hindcast of sediment flow along the Curonian Spit under different wave climates. In: Proceedings of the IEEE/OES Baltic 2012 International Symposium "Ocean: Past, Present and Future. Climate Change Research, Ocean Observation & Advanced Technologies for Regional Sustainability," May 8–11, Klaipėda, Lithuania. IEEE 7 pp. doi 10.1109/BALTIC.2012.6249195

Soomere T., Räämet A. (2011) Spatial patterns of the wave climate in the Baltic Proper and the Gulf of Finland. *Oceanologia*, Vol. 53, No. 1-TI, pp. 335–371.

Simulation of present and future climate variability over the Baltic Sea area with the new SMHI atmosphere-ocean-ice coupled model RCA4_NEMO

Shiyu Wang, Christian Dieterich and Ralf Döscher

Swedish Meteorological and Hydrological Institute, Norrköping, Sweden (shiyu.wang@smhi.se)

1. Introduction

The Baltic region not only includes the Baltic sea itself, also includes its drainage area. To predict the Baltic climate change, the coupled regional atmosphere-ocean model is the useful tool for this purpose. Döscher (2002) developed coupled atmosphere-ice-ocean model with full fluxes coupling. The Baltic Sea is interactively coupled. This coupled system is free of drift and suitable for long-term climate studies (Kjellström, 2005). However, Baltic Sea as a semi-enclosed brackish sea, the water and salt exchange between North Sea and Baltic Sea plays an important role on the physical and ecological processes for this region. Therefore, it is vital to include whole drainage basin of Baltic Sea as well as North Sea within coupled model system. Previous studies either only focus on the Baltic Sea region or the integration period was still short or the model resolution was coarse. To fulfill these gaps and provide effect tool for the Baltic Sea regional climate change study under different climate scenarios, the objective of this study is to development a new regional atmosphere-ocean-ice coupled model for the Baltic Sea and North Sea regions and apply this model to investigate the climate change variability over Baltic Sea area.

2. Description of coupled model and methodology

With the motivation to improve the prediction of climate change impacts, and assess the energy budget and water cycle over North Sea and Baltic Sea region, a new high resolution regional atmosphere-ocean coupled model RCA4_NEMO has been developed in this study, which consists of Rossby Center new regional climate model RCA4 (Samuelsson, 2011), regional ocean model NEMO 3.3.1, sea ice model LIM3 and river routing model CaMa_Flood 3.0(Yamazaki, 2011). The regional atmosphere model RCA4 runs in a horizontal resolution of 0.22° on a rotated latitude-longitude grid with 40 vertical levels covering Europe (Figure 1). NEMO runs in a resolution of 2minutes with 56 vertical levels and CaMa Flood runs in a resolution of 15 minutes. The active coupling region covers the Baltic Sea and North Sea . The coupling among RCA4 , NEMO and CaMa_Flood are carried out using OASIS3 coupler developed by CERFACS. This two way coupled system exchanges heat, freshwater, momentum fluxes, no-solar heat flux derivative from atmosphere to ocean, and receives SST, sea ice concentration, sea ice temperature and sea ice albedo from NEMO model for the coupling area. The atmosphere-ocean coupling frequency is set to 3 hours. To provide river runoff for NEMO, the river runoff from CaMa_Flood is sent to NEMO at daily frequency.

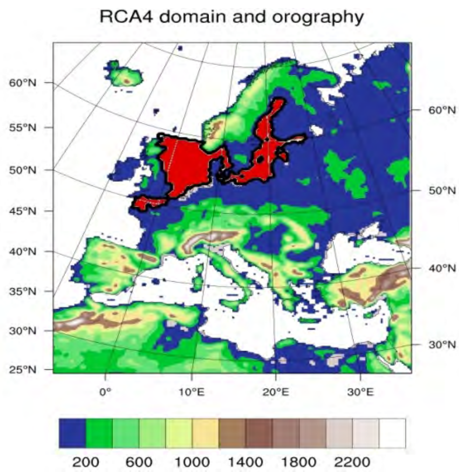


Figure 1 Orography in the RCA4 model domain (Unit: metres) and red region is the ocean domain and active coupling area.

3. Model Evaluation and simulated climate change under different climate scenarios

To examine the reliability of this coupled model system, firstly, this coupled model is validated in a hindcast experiment from 1979-2008 driven by ECMWF ERA-Interim data without flux correction. Comparing to uncoupled version and observations, this coupled model system can realistically simulate the present climate. The improvement on the atmosphere is minor, but there is still some improvement for certain parameters. Figure 2 shows the 30-year mean 2m temperature in spring from coupled, uncoupled and observations. RCA4 usually has cold bias, particularly in the west Europe. The difference between the coupled run and uncoupled run indicates that the cold bias has been improved over East Scandinavia and Baltic Sea coast region and the bias ranges between ±0.5° for the whole domain.

Comparing to NEMO standalone run, the improvement for the ocean model is more pronounced, particularly for SST and salinity. This 30-year long-term simulation shows that this coupled system is free of climate drift and suitable for climate change impact study under different climate scenarios at high resolution.

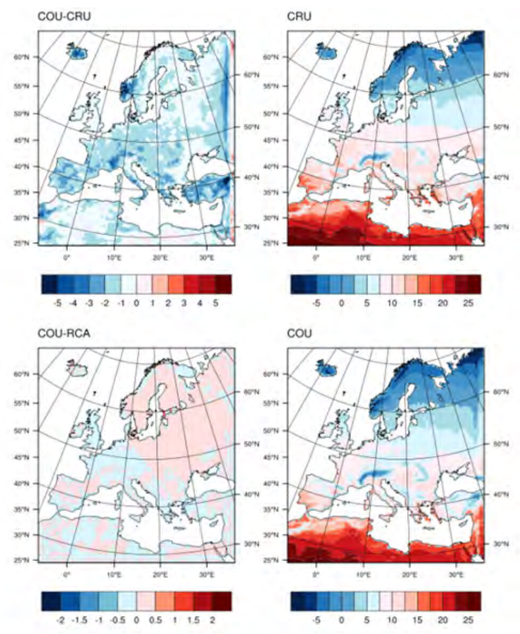


Figure 1 2m temperature in MAM from coupled, uncoupled, and observations between 1979-2008(CRU: observation, COU:coupled results,RCA:uncoupled results,COU-CRU: difference between coupled and observation,COU-RCA: difference between coupled and uncoupled runs)

To study the future climate change in Baltic Sea region, two CMIP5 emission scenarios rcp4.5 and rcp8.5 are downscaled. The boundary data from EC-EARTH model are used to drive this regional coupled model system. Both simulations are run from 1950 to 2100. All the simulation results will be analyzed in this study.

References

Döscher R., Willen U., Jones C., Rutgersson A., Meier H.E.M., Hansson U. and Graham L.P.(2002)The development of the regional coupled ocean-atmophere model RCAO, Boreal Environment Research, 7, 183-192

Kjellström E., Döscher R., and Meier H.E.M (2005) Atmospheric response to different sea surface temperatures in the Baltic Sea: coupled versus uncoupled regional climate model experiments, Nordic Hydrology, 36,4-5, 397-409

Samuelsson P. et al. (2011) The Rossby Centre Regional Climate model RCA3: model description and performance, Tellus, 63A, 4-23

Yamazaki D., Kanae S., Kim H. and Oki T. (2011) A physically based description of floodplain inundation dynamics in a global river routing model,Water Resources Research,47, W04501, doi:10.1029/2010 WR009726

Detecting acceleration in long time series of Baltic Sea level

Eduardo Zorita and Birgit Hünicke

Institute for Coastal Research, Helmholtz-Zentrum Geesthacht, Germany (eduardo.zorita@hzg.de)

1. Introduction

Climate change projections for the 21st century indicate an acceleration of the observed global rate of sea-level rise, which presently hovers over 3 mm/year, having attained a mean 20th century value of about 1.6 mm/year. The IPCC highest projections of global sea-level rise by 2100 AD relative to present of 59 cm (IPCC AR4) and about 80 cm including polar ice dynamics require a substantial increase in that rate of sea-level. The question arises of whether this required acceleration can be already detected in long time series of sea-level observations. Some tide gauges in the Baltic Sea report the longest series available so far (e.g. the Stockholm series) , so that they provide a long background of mostly natural variability of rates of sea-level rise to be compared to the most recent rates.

However, the concept of acceleration and its statistical definition and application for a time series is not straight forward. In this contribution, we explore several possible definitions of acceleration of sea-level rise and apply them to the Stockholm series.

2. Stockholm Sea-level series

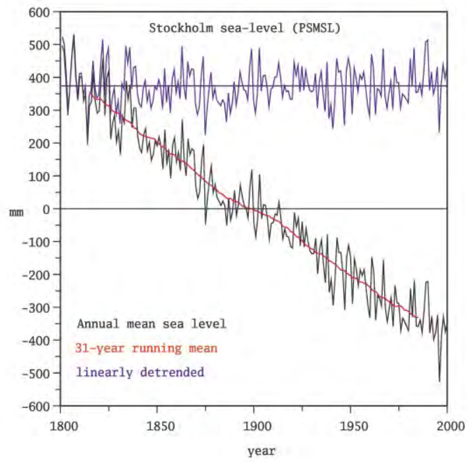


Figure 1. Time series of annual mean sea-level at Stockholm, smoothed with a 31-year running mean and linearly de-trended over the whole period

Figure 1 displays the annual mean sea-level series in Stockholm from the Permanent Service for Mean Sea Level (PMSL). The strong downward trend partly reflects the land up-lift caused by the Glacial Isostatic Adjustment after the last Glacial Maximum, but the trend would also contain the contribution of global sea-level rise caused by anthropogenic climate forcing. Visually, a slowing down of the sea-level decline can be observed in the last 30-years, which would be indicative of a stronger influence of the anthropogenic forcing.

By linearly de-trending the time series, any influence of the anthropogenic forcing should be highlighted by a tendency of sea-level values to be above the long-term trend. However, this is difficult to see in practice: the last 30-years do not appear particularly different from the rest.

3. Acceleration

The acceleration of sea-level rise could be defined as an tendency of the first time-differences to become larger: increasing dh/dt or in time series context h(t+1)-h(t). The series of first time differences of the annual sea-level in Stockholm, however, does not display a tendency of larger values in the recent decays (Figure 2).

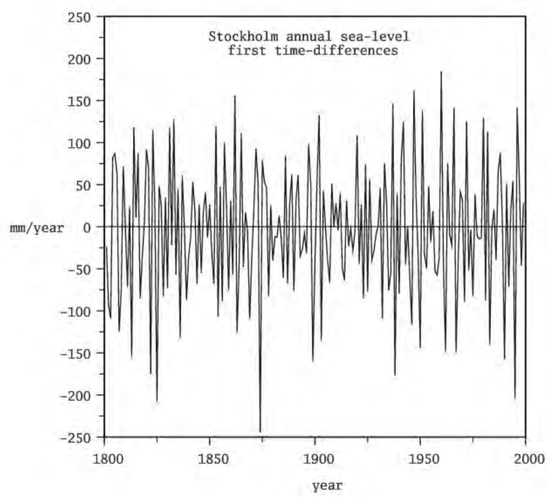


Figure 2. Time series of the first time differences, h/t+1)-h(t), of the Stockholm annual sea-level.

Another definition of acceleration is provided via a change of the gliding linear trends computed of a period of a few decades. Figure 3 displays these gliding linear trends. The series of gliding trends clearly exhibits a long-term positive trend. It attains an average value of about 5 mm/year, in agreement with estimations of the Glacial Isostatic Adjustment, the trends tend to be smaller at the beginning of the period and stronger at the end. Overall the *acceleration* amounts to + 0.007 mm/year^2. Is this trend statistically significant? The answer to these question is rather subtle, since the statistical significance of a trend of a time series where their individual values are not independent, as here, cannot be evaluated with standard methods of ordinary least squares. A direct application of ordinary leas squares would indicate that the acceleration is statistically significant at the 95% level. A further question is, however, that the acceleration is uniformly distributed throughout the whole period 1800-2000 and not more evident in the last decades. Additionally, the periods in which the gliding trends attain their highest value are not the recent decades, but the decades centered in the year 1900 AD.

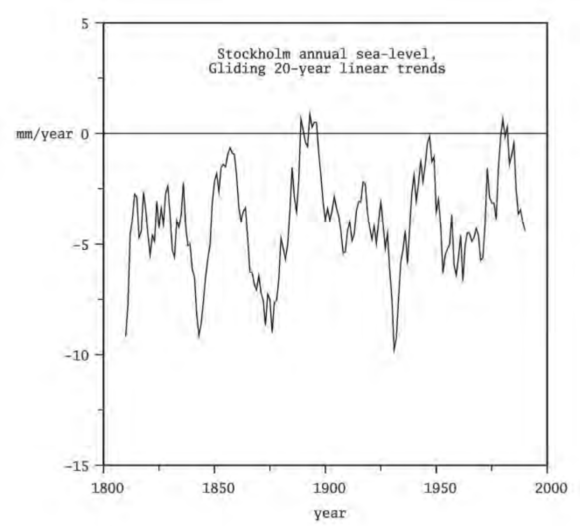


Figure 3. Gliding linear trends of the annual mean Stockholm sea-level calculated in 20-year moving windows with Ordinary Least Squares fit.

A more formal test of statistical significance of the time series displayed in Figure 3 results in a non-significant long-term trend. This test is based on Monte Carlo surrogate series constructed by scrambling the Fourier series (Ebusizaki, 1997)

4. Conclusions

The answer to the question of whether or not sea-level time series display a statistical significance acceleration is not completely clear and depends on the exact meaning of the term acceleration that the researcher has in mind, and also on the possible attribution of the causes of the acceleration. Taking long time series of sea-level in the Baltic Sea, it will be discussed under which circumstances the acceleration can be considered physically and statistically significant.

References

Ebusizaki, W (1997) A method to estimate the statistical significance of a correlation when the data are serially correlated. J. of Climate 10, 2147-2153

Topic C

Provision of improved tools for water management, with an emphasis on extreme hydrological events and long term changes

From BALTEX research to adaptation to climate change – A Swedish perspective

Sten Bergström

Swedish Meteorological and Hydrological Institute, Norrköping, Sweden (sten.bergstrom@smhi.se)

1. Background

In the early days of BALTEX the hydrological modeling community, characterized by simple but robust engineering tools, was confronted with the climate researchers and their more sophisticated models. This started a vivid and fruitful discussion which, among other things, led to that first full scale hydrological model for the entire catchment of the Baltic Sea (Graham and Bergström, 2000; Graham and Jacob, 2000). From a hydrologists point of view this was the start of a new process, where understanding of the possibilities and limitations of climate modeling became an important asset. This was to prove very useful in the adaptation projects to come.

In Sweden adaptation to climate change became an issue after the launch of the final report by the Swedish Commission on Climate and Vulnerability (2007). The commission identified risks in the metropolitan areas of Stockholm and Gothenburg and the two big lakes Mälaren and Vänern and River Göta älv where particularly addressed. But before that climate impacts on the hydrological upgrading of Swedish dam safety assessments was in focus since the arrival of new guidelines for design floods in 1990. These guidelines are now updated and since 2007 it is prescribed that climate change shall be considered in dam safety assessments in Sweden (Svensk Energi et al., 2007).

2. Methodology

The technique used for hydrological adaptation to climate change has been to use global climate modelling results which have been downscaled dynamically for the regional scale. However, already in the first applications of this kind within the BALTEX research programme, it was realized that the downscaled data had to be corrected for bias in one way or another. Initially the simple delta-change technique was used, but it has now become standard to use the more advanced Distribution Based Scaling (DBS) approach (Yang et al., 2010*)* in the interface between the regional climate model and the hydrological model. This means that two meteorological variables, precipitation and temperature, from climate model projections are adjusted by scaling factors before being used for hydrological simulations to make the output from the regional climate model statistically comparable to observations.

Another lesson learned is that it is necessary to use an ensemble of regional climate simulations. It has now become standard practice to use at least some ten different regional climate scenarios (normally 12-16). This gives at least some feeling for uncertainties and helps avoiding that the decision makers categorically rely upon one single result.

The hydrological model has so far been the HBV model in most applications (Bergström, 1995). This rather traditional model has proved to be useful for many roles, including that of simulating impacts on hydrology from a changing climate on a variety of scales (see for example Andréasson et al., 2004).

3. Hydropower in the forefront

Hydropower is extremely important in the Nordic countries, so no wonder that the power industry very early showed interest in climate change and its potential consequences. Already in the 1990's a joint Nordic project on the effects of climate change on hydropower was carried out (Saelthun et al., 1998) and since then joint Nordic-Baltic efforts have been made within the Climate and Energy project (Fenger, 2007) and the subsequent Climate and Energy Systems project (Thorsteinsson & Björnsson, 2012).

The progress of the Swedish research on climate and design floods was closely monitored by the Swedish committee on climate change and dam safety. The committee delivered its final report in 2011 (Svenska Kraftnät et al., 2011). This meant that representatives from national authorities, the hydropower industry and the mining industry jointly proposed a methodology to be used to account for climate change in dam safety assessments, partly with its roots in BALTEX. This technique has set a new standard and is also used in areal planning and for the development of infrastructure in metropolitan areas.

4. Big cities, big lakes, big problems

In 2007 the Swedish governmental Commission on Climate and Vulnerability had identified the growing metropolitan areas and the big lakes as particularly vulnerable to climate change. This had previously been underlined by several flood incidents in the year of 2000, the wettest year on record in Sweden so far. Since 2007 a number of studies have been carried out or are ongoing to address this problem.

The risks for sea level rise and its combination with high river flow and even extreme short term rainfall has made the issue still more complex. The latter was emphasized by the disastrous rainstorm in Copenhagen on July 2, 2011. If it can happen in Copenhagen it can certainly happen almost anywhere in Sweden!

In Stockholm the outlet structure and the whole regulation scheme of Lake Mälaren are now subjects to reconsideration and reconstruction. As the new conditions are planned to prevail for about 100 years, climate change cannot be neglected in this process. Climate factors which have to be considered are changes in inflow from rivers, sea level rise, isostatic rebound of land and possible change in the wind climate causing denivellation of the lake and extreme sea level episodes. The margin between the average sea level and the level of the lake is as close as 70 cm. And this lake offers drinking water for two million people.

The system of Lake Vänern, River Göta älv and the city of Gothenburg constitutes the most complex problem of adaptation to climate change in Sweden. Lake Vänern is the largest lake in the European Union (size 5650 $km^{2)}$ and Gothenburg at the outlet of the river into the sea is the second largest city in Sweden. The whole area is characterized by near-shore exploitation and thus increasing exposure to flooding. A flood event in 2001 revealed that clearly.

The River Göta älv is used for water supply, for hydropower production and for navigation. It is also a flood prone area which geologically is one of the most unstable in Sweden with high risks for big landslides along the banks. Finally, climate simulations seem to rather consistently point out the Swedish west coast as more affected by a warmer climate than other parts of the country.

The most recent infrastructural project, which is subject to climate change adaptation considerations, is a new planned railway tunnel under the city of Gothenburg, with two underground railway stations. Here rising sea levels are considered in the planning phase. Other issues are possible changes in extreme rainfalls and the future risks for flooding from the nearby River Mölndalsån that might put this project at risk.

5. Final comments

The years passed since the BALTEX initiative in the early 1990s have shown a remarkable development from intense discussions on meteorology, hydrology and oceanography in attempts to understand each other's approaches to science, to today's real life adaptation to climate change. The BALTEX programme has meant a lot in this process. It has also helped in the development of the scientific profile of SMHI and contributed to the broadening our international network.

Looking forward, there are a few issues which have emerged in the work on adaptation of our society to a changing climate and which are still unsolved. The use of regional climate simulations and downscaling techniques has become standard. This has facilitated the use of ensembles of scenarios, a way that is also favored by the scientific community. However, in real life applications, guidance as to which climate scenarios to use is now needed. The way we work today suffers from inconsistencies and a biased selection of scenarios, as we use practically all available regional scenarios.

A second and, as it seems, everlasting issue is how to handle evapotranspiration in a changing climate. Compared to air temperatures and precipitation very little efforts have been spend on evapotranspiration, even though it constitutes as much as half the annual precipitation in Sweden.

A third issue is sea level rise. It is a myth that this is compensated by isostatic uplift of land in a country like Sweden. This is not the case in the south (for example the city of Malmö or even Gothenburg) and as far north as in Stockholm scenarios of sea level rise have to be considered in new developments along the shore lines. And the cities are growing fast. So, sea level rise impacts around the Baltic Sea is a scientific field where BALTEX could contribute and deliver important societal support.

Acknowledgements

The author is grateful to all colleagues and partners who have participated in the process of adaptation to climate change in Sweden. Special thanks go to the members of Swedish committee on climate change and dam safety and the steering groups of the connected research projects. I also want to recognize the BALTEX scientific community for its impact in the early days of this process, when we took the first steps from climate simulations to impact studies on water resources.

References

Andréasson, J., Bergström, S., Carlsson, B., Graham, L. and Lindström, G. (2004). Hydrological change – climate change impact simulations for Sweden. Ambio, 33, 228–234.

Bergström. S. (1995) The HBV Model. In. Singh, V.P. (ed.). Computer Models of Watershed Hydrology. Water Resources publications, Highlands Ranch, Colorado, pp. 443-476.

Fenger, J. (ed.) (2007) Impacts of Climate Change on Renewable Energy Sources – their Role in the Nordic Energy System. Nord 2007:003. Nordic Council of Ministers, Copenhagen.

Graham, L.P. and Bergström, S. (2000) Land surface modeling in hydrology and meteorology – Lessons learned from the Baltic Basin. Hydrological and Earth System Sciences. 4(1), 13-22.

Graham, L.P. and Jacob, D. (2000) Using large-scale hydrologic modeling to review runoff generation processes in GCM climate models. Meteorologische Zeitschrift, Vol. 9, No. 1, 49-57.

Saelthun, N.R., Aittoniemi, P., Bergström, S., Einarsson, K., Jóhannesson, T., Lindström, G., Ohlsson, P-E. Thomsen, T., Vehviläinen, B. and Aamodt, K. O. (1998) Climate change impacts on runoff and hydropower in the Nordic countries. Final report from the project "Climate Change and Energy Production" Report TemaNord 1998:552, Oslo.

Svenska Kraftnät, Svensk Energi, SveMin and SMHI (2011). Dammsäkerhet och klimatförändringar. Slutrapport från Kommittén för dimensionerande flöden för dammanläggningar i ett klimatförändringsperspektiv (in Swedish, Dam safety and climate change. Final report from the committee on spillway design in a climate change perspective).

Svensk Energi, Svenska Kraftnät and SveMin (2007). Swedish Guidelines for Design Flood Determination for Dams – New edition 2007.

Swedish Commission on Climate and Vulnerability (2007) Sweden facing climate change – threats and opportunities. Final report from the Commission on Climate and Vulnerability, Swedish Government Official Reports, SOU 2007:60. Stockholm.

Thorsteinsson, T. and Björnsson, H. (eds.) (2012). Climate Change and Energy Systems - Impacts, Risks and Adaptation in the Nordic and Baltic countries. TemaNord 2011:502, Nordic Council of Ministers, Copenhagen .

Yang, W., Andréasson, J., Graham, L.P., Olsson, J., Rosberg, J and Wetterhall, F. (2010) Distribution-based scaling to improve usability of regional climate model projections for hydrological climate change impacts studies. Hydrology Research, 41 (3-4): 211-229.

The impacts of climate change and nutrient reduction measures on river discharge and nutrient fluxes to the Baltic Sea

Chantal Donnelly and Berit Arheimer

Swedish Meteorological and Hydrological Institute, Norrköping, Sweden (chantal.donnelly@smhi.se)

1. Introduction

A significant uncertainty regarding future climate change in the Baltic Sea region is how discharge and nutrients to the Baltic Sea will change in a future climate (Meier et al. 2006). Changes in discharge to the Baltic Sea are of particular interest when considering changes to salinity levels in the sea while changes to nutrient fluxes have implications for the sea's unique ecosystem, including the occurrence of eutrophication.

To reduce eutrophication of the Baltic Sea, all nine surrounding countries have agreed upon reduction targets in the HELCOM Baltic Sea Action Plan (BSAP). To support the implementation of these targets requires process based modeling tools for which model resolution is sufficient to resolve the local effects of remedial measures. Furthermore, to determine the effects of climate change on any potential remedial measures requires an approach in which all climate dependent hydrological and nutrient processes are explicitly accounted for. This study attempts to address these requirements.

2. Data and Methods

To provide such a tool for analysis of water and nutrient fluxes from the Baltic Sea catchment, the HYPE model was set up and applied for the region (Balt-HYPE). The HYPE model is a semi-distributed, process based hydrological model and nutrient model which simulates hydrological fluxes on a daily time-step in coupled subbasins. Readily available, regional and global databases were used to set up the Balt-HYPE model including topography, precipitation, temperature, land use, soil-type, agricultural management, wastewater effluents and atmospheric deposition over the entire model domain with a median resolution of 325 km^2 for 5128 subbasins.

New to this study is that transient estimates of discharge to the Baltic Sea are made using bias-corrected RCM outputs. Bias correction was made using the distribution based scaling method (DBS, Yang et al. 2010) which aims to reproduce the distribution of both normal and extreme precipitation events whilst retaining as much information as possible from the raw climate model outputs. This is the first time this method has been applied for bias correction over a large region.

The Balt-HYPE model was then used for experimenting with land-based remedial measures and future climate projections to quantify the impacts of these on water and nutrient loads to the Baltic Sea. The procedure for these experiments is shown in Fig. 1 (Arheimer et al. 2012). A mini ensemble consisting of 5 different downscaled climate projections was simulated. The climate projections were driven by varying GCMs, initial conditions, resolutions and emissions scenarios. Three different remedial scenarios were tested. Finally, the model was also used to provide an estimate of the proportions of the sources of nutrients to the Baltic Sea based on today's conditions.

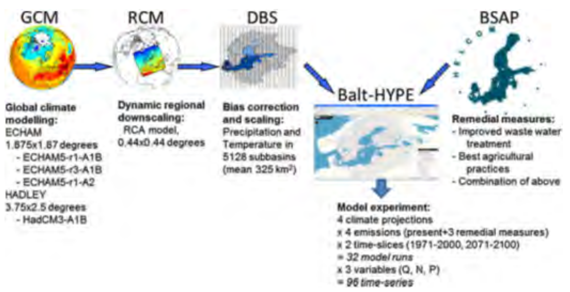


Figure 1. Procedure for model experiments on climate change and remedial measures impact on discharge and nutrient fluxes to the Baltic Sea (Arheimer et al. 2012)

3. Results

All projections indicate increases in average discharges to the Baltic Sea by the end of the century. These increases ranged from 108 to 2171 m3/s or 1 % to 14 % of the reference period discharge (Table 1) with an ensemble average of + 8 %. The seasonal dynamics of discharge to the Baltic Sea are expected to change considerably compared to today's pattern for all projections. In general, winter discharge to the Baltic Sea increases while summer discharge decreases. The spring flood peak is reduced for all scenarios. This is partly due to decreased snow storage and earlier snow melt as a result of the higher temperatures, particularly in the north, but also due to changes in the seasonal precipitation distribution.

Table 1. Simulated mean annual discharge to the Baltic Sea for the reference period (1971 to 2000), a future period (2071 to 2100) and the simulated change in discharge for each scenario.

Description	Mean Discharge (m^3/s) 1971-2000	Mean Discharge (m^3/s) 2071-2100	Change in Q (m^3/s)	Change in Q (%)
RCA3E5A1B$_3$	15541	15648	108^	1 %
RCAOE5A1B$_3$	14584	15075	491^	3 %
RCAOE5A1B$_1$	14890	16717	1827	12 %
RCAOH3A1B	14647	16391	1744	12 %
RCAOE5A2	15278	17449	2171	14 %
Ensemble	Mean		1268	8 %

The simulations of nutrient loads indicate that a future climate may reduce the inflow of N but slightly raise the inflow of P to the marine basins; however, some of the climate projections indicated the opposite. If the adleyA1B projection were to eventuate, the Balt-HYPE model suggests that the HELCOM target for N reduction ould be fulfilled for the Baltic proper by the impact of climate change alone by 2100. Nevertheless, the spatial variation is large within countries and within river basins and on the local scale increases in N concentrations are also seen. The seasonal distribution of nutrient concentrations to the Baltic Sea also changed considerably with the seasonal variation of Nitrogen concentrations reduced, as was the seasonal variation of Phosphorous concentrations.

The experiments with combinations of remedial measures and climate change in the Balt-HYPE model indicate that there is a possibility to reach all the BSAP targets in the future for most marine basins by the end of this century (Fig. 2). For N, the impact of climate change is of the same order as the expected reduction from remedial measures, according to the results of the model experiment. For P, there is a higher probability to reach BSAP targets than for N. Thus, climate effects need to be accounted for when estimating the long-term effects of the BSAP

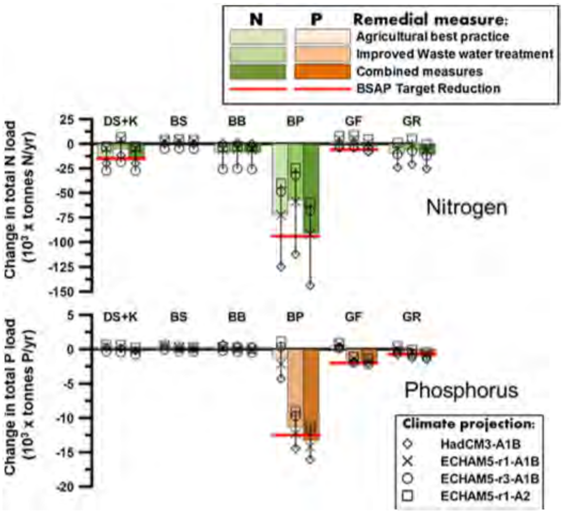


Figure 2. Combined Effect of future climate change and remedial measures to each marine basin of the Baltic Sea. (Arheimer et al. 2012)

Finally, the apportionment of nutrients to their sources (Fig. 3) based on today's climate and management conditions indicates that agriculture contributes just over half of the N load to the Baltic Sea, with the remainder coming from forestry, rural households, urban WWTPs and other sources. For P, most of the load could be equally attributed to contributions from agriculture, urban WWTPs and rural households. Poland was shown to be the largest contributor of N and P to the Baltic Sea, followed by Sweden then Russia. For the first time, this source apportionment shows the contributions of non-coastal countries Ukraine and Belarus to Baltic nutrient loads, which is estimated at 2 % and 6 % respectively, for both N and P.

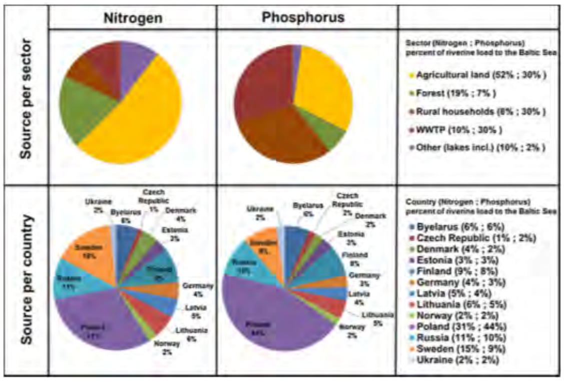


Figure 3. Source apportionment based on societal sector and country, using the Balt-HYPE model (Arheimer et al. 2012)

There are many uncertainties involved in such a complex chain of data transfer among different analysis tools as presented in this experiment. Uncertainties can be divided into internal uncertainties which come from the methodology of the study and external uncertainties which arise from not being able to predict anthropogenic behaviour in the future (i.e. emissions scenarios, land-use scenarios). Both sources of uncertainty are considered and discussed within this study with suggestions for improvements to the model calibration across the domain and processes for simulating the long-term variation in N and P stored in the soil deemed most necessary.

4. Conclusions

Results from a mini-ensemble of 5 simulations driven by various climate projections indicated that discharge to the Baltic Sea is likely to remain similar or increase by up to 15 %, however, the magnitude of change lies within the predictive uncertainty of the hydrological model so conclusions regarding the magnitude of change are not recommended. Averaged across the whole basin, increased discharges to the Baltic Sea in winter and decreased discharges in summer are likely at the end of this century. It was shown that climate change effects need to be considered when estimating the long-term effects of remedial measures on nutrient fluxes to the Baltic Sea. The model results suggest that the total load to the Baltic Sea may decrease for N and increase for P in the future. The experiment indicates that impact of climate change may be of the same order of magnitude as the expected N reductions from the measures simulated.

References

Yang W, Andreásson J, Graham LP, Olsson J, Rosberg J, Wetterhall F (2010) Distribution-based scaling to improve usability of regional climate model projections for hydrological climate change impacts studies. Hydrol Res. 41(3–4), 211-228

Meier HEM, Kjellström E, Graham LP (2006) Estimating Uncertainties of projected Baltic Sea salinity in the late 21st century. Geophys Res Lett. 33: 4pp.

Yang W, Andreásson J, Graham LP, Olsson J, Rosberg J, Wetterhall F (2010) Distribution-based scaling to improve usability of regional climate model projections for hydrological climate change impacts studies. Hydrol Res. 41(3–4), 211-228

Simulation of annual maximum runoff in a river catchment with a spatial weather generator and climate change scenarios

Leszek Kuchar[1,2], Slawomir Iwanski[1], Leszek Jelonek[2], Wiwiana Szalinska[2]

[1]Department of Mathematics, University of Environmental and Life Sciences, Wroclaw, Poland (Leszek.Kuchar@gmail.com)
[2]Institute of Meteorology and Water Resources, Wroclaw Branch, Wroclaw, Poland

1. Introduction

One of the key problems of future hydrology is the impact of climate change on catchment, runoff response, and prediction of extremes (Barnet et al., 2004; Bergstrom et al., 2001; Christensen et al. 2004; Müller-Wohlfeil et al., 2000; Prudhomme et al., 2002). Daily runoff simulations, particularly annual maximum runoff in the Kaczawa river catchment for future climate conditions given by different scenarios, are presented in this paper.

2. Methodology

The scheme of runoff simulations in the Kaczawa river catchment for future climate conditions given by different scenarios are presented in the Figure below.

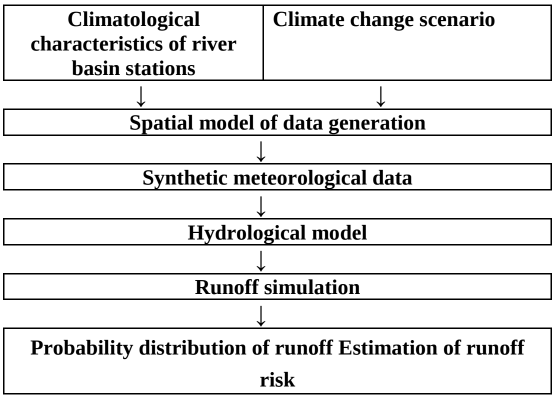


Figure 1. Estimation of runoff in river basin using generated data and climate scenario.

On basis of a 28-year data series (1981-2008) for 16 stations of meteorological network within or around the Kaczawa river catchment, basic climatological characteristics required by weather generator are computed (Iwanski and Kuchar, 2003; Kuchar, 2004; Wilby, 2007). Then, spatial correlations between variables and stations are added to the characteristics (Kuchar, 2004; Khalili et al., 2007).

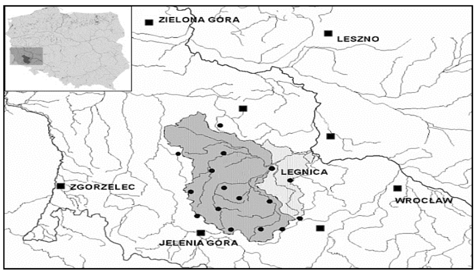


Figure 1. The Kaczawa river catchment (left side tributary of the Odra River, area of 1807 km^2, main sit: Legnica 51°13'N, 16°14'E) with meteorological stations (●).

Next, on the basis of information coming from three climate change scenarios (GISS, GFDL and CCCMA) for years 2060-2080 basic climatological characteristics were modified (Kuchar, 2004; Wilks, D.S., 2010). Then, spatial weather generator SWGEN is used to produce 500 years of synthetic data on potentially possible weather course, 16 stations, the given time horizon and scenario. The year 2000 as the background of the potential changes in catchments runoff is used together with 500 years of synthetic data.

The SWGEN model generates precipitation by means of the first-order Markov chain to determine the occurrence of wet/dry days, and then for the amount of rainfall multidimensional two-parameter gamma distribution (Iwanski and Kuchar, 2003):

$$(\Gamma_m(\alpha_1,\beta_1), \ldots, \Gamma_m(\alpha_k,\beta_k))$$

where m is the number of months (m=1,…,12) and k is the number of locations, while daily values of solar radiation (SR), temperature maximum (T_{max}) and minimum (T_{min}) are considered as a multidimensional time series AR(1) in the following form:

$$X_t = \Phi_m \cdot X_{t-1} + \varepsilon_t$$

where X_t and X_{t-1} are vectors (m × 1) of normalized values for all three variables for day t and t-1, ε_t is a vector (m × 1) of independent random components normally distributed with vector of mean equal to zero and matrix of covariance Σ_m, and Φ_m (for m=1, …, 12) is a matrix of parameters (Iwanski and Kuchar, 2003).

In the next stage, generated data were applied to hydrological rainfall-runoff model NAM to simulate runoff for closing water-gauges (MIKE 11, 2003). The catchment runoffs are evaluated with a different temporal step (one day, five days and ten days). The obtained outflows for various simulations are characterized by probability distribution functions. Three parameter gamma probability distribution is used as the best distribution fitting the monthly outflow, and Pareto pdf for daily maximum outflow within the year (considered in this paper), (Iwanski and Kuchar, 2003; Walpole et al., 2002).

3. Results

The simulations of daily runoff in the Kaczawa river catchment were done at discharge point in Piętnica. The number of simulations were determined by the time of horizon (2040, 2060, 2080 and 2000 as a background), three climate change scenarios (GISS, GFDL and CCCMA), and number of generated years (500) for each case, with total of 5000 (3x3x500+500) years. The NAM model computed for a given year, a daily outflow at discharge point, and maximum value was chosen to estimate parameters of density function.

It means that the parameters of Pareto probability distribution were estimated for 10 (3x3+1) combinations, based on 500 computed runoff each.

As an example, Figure 3 presents graphs of density function of maximum daily runoff at discharge point at Piątnica for present conditions (year 2000) and CCCMA, GFDL, and GISS scenarios for 2080, while Figure 4 shows graphs of pdf of maximum daily runoff at the same discharge point for GISS scenario, and lead time 2040, 2060 and 2080.

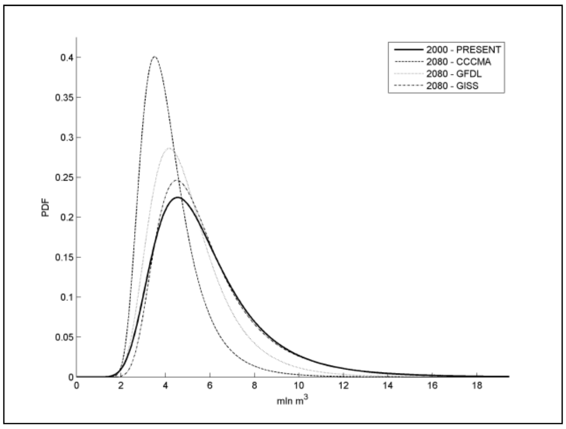


Figure 3. Pareto pdf of maximum daily runoff on the Kaczawa River at discharge point Piątnica and different climate scenario - simulation for 2080.

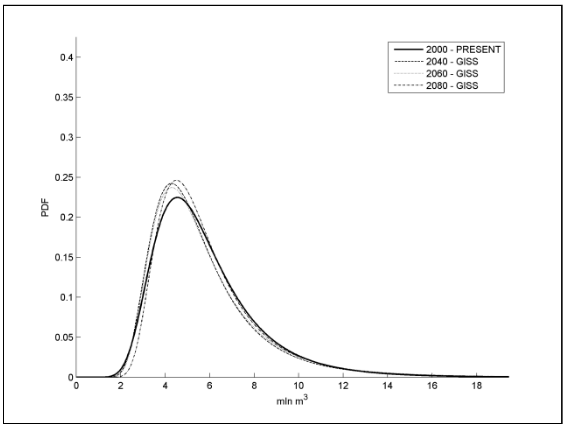


Figure 4. Pareto pdf of maximum daily runoff on the Kaczawa River at discharge point Piątnica for GISS climate scenario, and different lead time.

In addition, for a given probability distribution of river runoff moment characteristics, confidence intervals and critical regions were computed.

4. Conclusions

The application of spatial weather generator SWGEN combined with hydrological rainfall-runoff model (NAM) and climate change scenario, gives various possibilities to study changes in the river catchment coming up to 60–80 years. The probability distribution of the river runoff gives detailed information on the moment characteristics, confidence intervals and critical values. It is an important tool for a decision support system. In case of maximum daily outflow in the Kaczawa River, the catchment shows significant changes depending on the climate change scenario and time to lead.

References

Barnett T., Malone T., Pennell W., Stammer D., Semtner B., Washington W., The effects of climate change on water resources in the west: introduction and overview, Clim. Change, 62, 1–11, 2004.

Bergstrom S., Carlsson B., Gardelin M., Lindstrom G., Pettersson A., Rummukainen M., Climate change impacts on run-off in Sweden-assessments by global climate models, dynamical downscaling and hydrological modeling, Clim. Res., 16, 101–112, 2001.

Christensen N.S., Wood A.W., Voisin N., Lettenmaier D.P., Palmer R.N., Effects of climate change on the hydrology and water resources of the Colorado river basin, Clim. Change, 62, 337–363, 2004.

Iwanski S., Kuchar L., Spatial generation of daily meteorological data, Acta Scientiarum Polonorum - Formatio Circumiectus, 2 (1), 113-121, 2003 (in Polish).

Khalili M., Leconte R., Brissette F., Stochastic multi-site generation of daily precipitation data using spatial autocorrelation, J. Hydrometeorol., 8(3), 396–412, 2007.

Kuchar L., Using WGENK to generate synthetic daily weather data for modelling of agricultural processes, Math. Comp. Symul., 65, 69-75, 2004.

MIKE 11, A modelling system for Rivers and Channels, User Guide, DHI Water and Environment, 2003.

Müller-Wohlfeil D.I., Bürger G., Lahmer W., Response of a river catchment to climate change: application of expanded downscaling to northern Germany, Clim. Change, 47, 61–89, 2000.

Prudhomme C., Reynard N., Crooks S., Downscaling of global climate models for flood frequency analysis: where are we now?, Hydrol. Processes, 16, 1137–1150, 2002.

Walpole R.E., Myers R.H., Myers S.L., Ye K., Probability and statistics for engineers and scientists, Prentice Hall, 7th Ed., New Jersey, 2002.

Wilby R.L., A daily weather generator for use in climate change studies, Environ. Modelling and Software, 22 (12), 1705–1719, 2007.

Wilks D.S., Use of stochastic weather generator for precipitation downscaling, Climate Change, 1, 898–907, 2010.

Improved tools for river flood preparedness under a changing risk in Poland

Zbigniew W. Kundzewicz

Institute of Agricultural and Forest Environment, Polish Academy of Sciences, Poznań, Poland (zkundze@man.poznan.pl) and Potsdam Institute for Climate Impact Research, Potsdam, Germany (zbyszek@pik-potsdam.de)

1. River flooding in Poland

River flooding is the most destructive natural peril in the Baltic Sea Basin in general and in Poland in particular. Most of Poland is located in basins of two large rivers – the Vistula and the Odra, with sources in the highland areas and emptying into the Baltic Sea. Flood risk and preparedness became matters of broad concern, following the dramatic floods in Poland in 1997 and 2010, when national flood losses were estimated to reach the level of billions of Euros and the topic made it to cover stories.

2. Spatial-temporal characteristics of flood risk

The highest river flood risk areas are south of the 51°N parallel (therein the Carpathians, the southern part of the Sudetes, and the central part of the Bug River basin). Catastrophic river floods of regional extent occur in Poland, on average, every 6.5 years (Kundzewicz et al., 2012). Typically, the two periods of high river flow in Poland are: spring (related to the snowmelt and ice melt) and summer (with intense precipitation). Floods caused by advective and frontal precipitation covering large areas are typical in most of the upper Vistula basin. Most severe floods, in terms of flood fatalities and material damage, have occurred in large river valleys and particularly in urban areas protected by embankments. When a very large flood comes, levees may fail to withstand the water mass and break, so that adjacent areas are inundated.

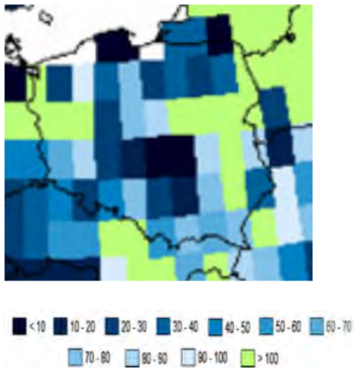
3. Observations and projections

Precipitation has increased at most stations and decreased at some stations in Poland, but many changes are not statistically significant. There has been a pronounced, but not ubiquitous, increasing tendency in the intensity of rainfalls. However, the inter-annual variability is very strong. Changes are evident in the seasonality of precipitation, such as decrease of the ratio of summer precipitation to winter precipitation and also in the proportion of liquid to solid phase in winter precipitation. The frequency of synoptic weather patterns that are likely to lead to intense precipitation and floods has been on the rise.

There has been an increasing number of local floods in urban areas (flash floods), including large towns, caused by intense rainfall, when the capacity of the urban sewer systems is too small, or there is an obstruction of the outflow because of a flood wave in the river.

The flood damage potential has considerably increased. Increasing flood exposure results from human encroachment into floodplains and economic development of flood-prone areas. The assets at risk from flooding are enormous, and growing, with the wealth of the nation.

Projections for the future illustrate the possibility of increasing flood hazard in much of the country (Fig. 1), due to increasing frequency and amplitude of intense precipitation and increasing frequency of "wet" circulation patterns. On the other hand, snowmelt flood hazard is expected to decrease.



Recurrence interval (return period) of today's 100-year flood (i.e. flood with a recurrence interval of 100 years during the period 1961–1990) at the end of the 21st century (2071–2100), in case of scenario SRES A1B (cf. Kundzewicz et al., 2010).

4. Flood defenses and preparedness systems

Flood defenses in the Vistula basin include embankments of approx. 4700 km in length, protecting an area of about 5300 km^2. The flood protection system in the Odra basin consists of embankments, weirs, reservoirs (including dry flood protection reservoirs), relief channels, and a system of polders. However, total capacity of water storage reservoirs in Poland is only 6% of the mean annual runoff. Flood preparedness system includes also non-structural measures, e.g. forecast-warning component. Since uncertainty in projections for the future is large, precautionary attitude should be taken when planning adaptation. There is no doubt that better accommodation of extremes of present climate variability augurs better for the future climate, subject to change.

5. Ongoing public dispute

This contribution informs of the ongoing public dispute, related to flood preparedness and of the progress in implementation of the EU Floods Directive in Poland. Debate on flood preparedness plan for the basin scale of the Upper Vistula, where most flood damages have occurred in historic times, is also reviewed.

References

Kundzewicz, Z. W., Dobrowolski, A., Lorenc, H., Niedźwiedź, T., Pińskwar, I., Kowalczak, P. (2012) Floods in Poland. In: Kundzewicz, Z. W. (ed.) Changes in Flood Risk in Europe, Special Publication No. 10, IAHS Press, Wallingford, Oxfordshire, UK., Ch. 17, 319-334.

Kundzewicz, Z. W., Lugeri, N., Dankers, R., Hirabayashi, Y., Döll, P., Pińskwar, I., Dysarz, T., Hochrainer, S., Matczak, P. (2010) Assessing river flood risk and adaptation in Europe—review of projections for the future. Mitig. Adapt. Strategies for Global Change 15(7), 641 - 656.

Causes and rates for erosion caused by the January 2012 storm surge on the accumulative Polish dune coast

Labuz T.A.

Institute of Coastal and Marine Sciences, Szczecin University, Szczecin, Poland (labuztom@univ.szczecin.pl)

1. Introduction

The Polish coast is 500 km long and mainly exposed on N direction. It is aligned and composed by loose material (sand, till or peat, mainly). Almost 85% is built by sandy aeolian deposits and covered by different dune types. Among them only 35% show accumulative tendencies. Such soft coasts are strongly threatened nowadays by storm surges (Łabuz, Kowalewska-Kalkowska 2011, Łabuz 2012) and human impact. There is a need of short term field measures of coastal changes for prediction and calculation of land loss.

2. Methods and aims of the study

This paper presents issues of foredunes mapping, which is part of research conducted along whole Polish coast under project FoMoBi (www.fomobi.pl), financed by National Centre for Research and Development (NCBiR).

Methods of the field research are: i) field leveling as profiles across coastal forms, ii) surface measurements in plots 5x5 m of the embryo dunes on the upper beach and on larger areas 200 m along foredune ridge as 3D leveling using GPS RTK base and in future iii) ground laser scanning. Laboratory computation depends on measuring relief changes on the base of profiles and surfaces comparison. There are some indicators of relief changes used as (Fig.1): foredune base and ridge or edge movements, foredune height and dune base width, beach width and height, height and dynamics of embryo dunes on the beach. Dynamics layer is a graph that is showing relief changes in short time periods. The comparison of it gives height changes, that can be used for sand volume computation. Profiling is a cheaper and faster method of research also helpful during storm surges events. DTM models can give more accurate data especially in settlement areas.

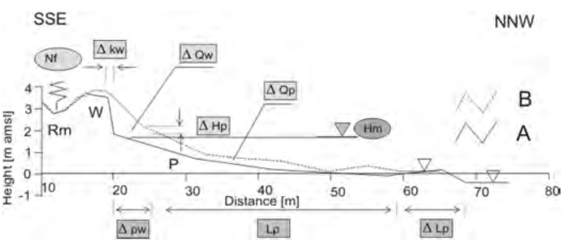


Figure 1. The measured parameters of the coast profile, Rm – interdune runnel, W- foredune, P – beach, B - profile before storm, A - profile after storm, Δpw- foredune foot changes, Δkw- foredune ridge edge changes, ΔHp - beach height changes, ΔLp - beach width changes, Lp - beach width, ΔQw - sand volume changes in foredune (per 1 m wide profile), ΔQp - sand volume changes in beach (per 1 m wide profile), Hm - storm sea level, Nf - wave run-up (max. 3.5 m)

3. The January 2012 storm surges characteristics

On the non-tidal Baltic Sea, short-term sea level variations mainly induced by meteorological forcing are main threat for coastal areas (Łabuz, Kowalewska-Kalkowska 2011). Each autumn-winter period is expected one or two storm surges with water level exceeding up to 2 m amsl. During such surge, waves are reaching land up to 3.5 m amsl.

There were two storm surges in January 2012. Each after another (on 6 and 14 January) have had double force that hit on soft south Baltic Sea coast, one after another. The meteorological and hydrological description of this storm surges was based on the data provided by the Harbour Master's Offices along Polish coastline. Sea waves developing by strong winds from NNW to NW direction were able for washout of many coastal areas. In Świnoujście, on west Polish coast sea level reached 1.3 m amsl with 1.5 m high waves exceeding land up to 3 m (Fig.2). On east coast (Vistula Sandspit) water reached up to 4 m amsl. Middle coast, mainly on Łebska, Wicko Sandspits or on Hel Peninsula water exceded up to 3.5 m amsl.

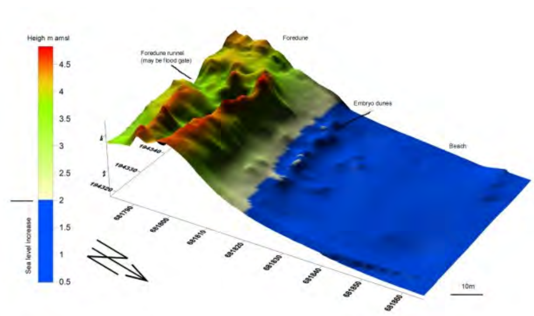


Figure 2. The DTM example of washed out beach and aeolian forms by sea level rise up to 2 m amsl

4. Coast erosion rate

Whole coast sections exposed on west direction was threatened by described events. Dune sections so far accumulative one, shoved foot dune erosion with rate from 2 to 6 m (sic!). This is from 2 to 4 times more than annual retreat rate of Polish coast. Sand volume washed on mainly threatened sections of the coast was bigger than 1.5m^3 per each square meter of the dune ridge. On lower sections of the coast were formed washover fans entering lowland up to 200 m from beach: Hel Peninsula, Karwia Sandspit). Mouths of channels connecting lakes with sea were rebuild and enlarged by wave pressing in to the lakes.

5. Reasons of erosion

The calculated changes in sand volume indicated that the greatest decrease in sediment on the dune and beach occurred in the coast sections with exposition perpendicular to developed storm surges. The dunes sand balance was negative due to a considerable lowering of the beach caused firstly by deflation (onshore strong winds 12-16 m/s) and secondly by abrasion. In places where beach was lower than 2 m amsl erosion was two times heavier than in other places. Additional factor causing annual erosion is negative sand balance on the beach. Due to that dunes and beaches are not able to rebuild during calm season. Low and narrow beaches do not prevent dune dykes against erosion.

6. Conclusions

The 06 and 14 January 2012 storm surges were one of the most severe surges at the south Baltic Sea coast. Their destructive force was caused by following one sure after another. Coast weakened and strained by one surge was affected by second one increasing in erosion rate. Described storm induced significant erosion of the dune shore even on so far accumulative part of coast. The size of coastline erosion and retreat depends both on the sea surge height and its duration, as it was stated in last field research (Łabuz 2012).

Data from the realized studies are useful for different time scale comparison as vectors, volumes or 3D pictures. The presented studies are covering almost 20% of dunes on the Polish coast. The idea of using simple research methods follows from the need to move quickly along the coast in order to register the changes caused by the occurred phenomenon (eg. the storm surges or heavy wind action).

References

Łabuz TA (2012) Coastal Response to Climatic Changes: Discussion with Emphasis on Southern Baltic Sea, Landform Analysis, Vol. 21, pp. 43-55

Łabuz T A, Kowalewska-Kalkowska H, (2011) Coastal erosion caused by the heavy storm surge of November 2004 in the southern Baltic Sea. Climate Research, Special Issue, Vol. 48, pp. 93-101

An emergency communication system against hydrosphere and atmosphere threats for the Baltic Sea and the Polish coastline: The role of new media in warning of extreme hydrological and marine hazards

Łukasz Legutko, Aleksander Plygawko, Mieczyslaw Ostojski

Institute of Meteorology and Water Management - National Research Institute (IMGW-PIB)

1. Introduction

The Institute of Meteorology and Water Management - National Research Institute (IMGW-PIB) has based its activities on the study of atmospheric phenomena, including over 90 years research on the developments in the hydrosphere. IMGW-PIB combines the fields of science such as meteorology, hydrology and oceanography and on a regular basis it monitors the Baltic Sea environment using the extensive network of measuring apparatus. Within the research IMGW-PIB carries out regular measurements of physical, chemical and radiochemical parameters of the Baltic Sea environment and the coastal atmosphere. It also studies the processes of change and trends occurring in the environment.

The work of skilled IMGW-PIB specialists has resulted in an early warning system development against extreme hydrological hazards, designed and constantly improved, including warnings for the Baltic Sea and the coastal zone. The early warning system consists of such elements as:

- IMGW Hydrological Monitor;
- Websites (pogodynka.pl, bałtyk.pogodynka.pl, zagle.pogodynka.pl);
- SMS early warning system
- Mobile apps.

In addition, the education on the risks posed by hydrosphere and atmosphere plays a very important role. An example of educational activities are Sailing Meteorology Schools that have been organized each year since four years now.

2. Early warning systems

IMGW-PIB Monitor

The monitor was designed to present and visualize hydrological data and products calculated and created by the Polish Hydrological and Meteorological Service. It works in the web technology to ensure operation with the necessity of unrestricted access to data from any computer or mobile device with the internet access. The Monitor is an information platform providing real-time data in the uniform format for all national services and decision-makers at all levels who are responsible for making decisions for Baltic Sea in the emergency situations such as floods, hurricanes, storms.

Access to the data is provided from two types of map of Poland layers (statistics based on river basins of major rivers and topographic maps of the area). The Monitor gives the ability to move around the map and to present data from a specific station of a particular part of Poland or that of the Polish basin, which we are interested in. To meet hydrological purposes the Monitor shows real-time water level data from the telemetry sensors and those collected by the observers. The Monitor operates also a special unit to review official warnings published by the National Research Institute and the flood wave prediction model along with water level inflowing the Baltic Sea.

www.Pogodynka.pl.

Pogodynka.pl is the main IMGW-PIB information service on broad meteorological, hydrological and marine issues.

www.Bałtyk.pogodynka.pl: Bałtyk.pogodynka.pl is a specialist web portal dedicated to the Baltic Sea. It includes such items as:

- Monitoring service of the Baltic Sea pollution;
- Cruise reports;
- Weather forecasts for major regions of the Baltic Sea and the Polish zone;
- Meteorological and hydrological warnings for the Baltic Sea regions and the Polish offshore zone. The hydrological forecasts in addition to protect flowing waters, cover also the Polish Baltic Sea territorial waters and the coast of the Polish Republic.
- Map of the Baltic Sea ice cover which shows the current ice conditions in the Baltic Sea. It graphically complement the information included in the Ice Bulletin and is released twice a week during normal and mild winters or daily during severe winters. Using international codes and symbols that are consistent with the WMO (World Meteorological Organization) terminology and ice codes, a type of ice is presented, its distribution and concentration as well as ice deformation processes (shafts, cracks, ice buildup and crowding). The Ice Map includes also additional information on ice thickness, location and operation of icebreakers. The Ice Map is transferred along with other products (Ice Bulletins and reports) to national and international users.

The Ice Bulletin contains encrypted information according to the Baltic Ice Key on icing and shipping conditions in the Baltic Sea observation areas, information about the work and activities of icebreakers and navigation restrictions in individual regions. ABSBTBKB Baltic Ice Key is used to provide information about icing of ports, waterways and selected coastal areas and sections of the sea routes in the Baltic and the nearest North Sea.

www.Żaglepogodynka.pl: It is a tailored weather portal designed specificially for fans of water and sea sports. It presents forecasts and warnings for sailors. In addition, it plays an educational role through clear getting familiar with the maritime issues. Sailing and weather warnings as well as weather guide for sailors are also included.

SMS text messages

A tailored system, which through SMS channel provides forecasts for the Baltic Sea and its coastal zone to the users as well as specialist meteorological and hydrological warnings for the above mentioned areas.

Mobile Apps
Designed for a quick and easy access to meteorological data for each device with the web access. Mobile Apps display information on the rivers states, hydrological warning for particular regions, Baltic Sea water temperature and radar maps.

3. Education

IMGW-PIB within its educational activity organizes classes in the Sailing Meteorology School. They are conducted in the form of workshops, lectures and exercises using weather maps and film screenings. This allows sailors to meet with people watching the safety of navigation.

4. Summary

The use of new media in the early warning system has become indispensable for ensuring safety and proper behavior of the public in emergency situations caused by natural disasters. IMGW-PIB watching this trend for a few years has been effectively implemented new technologies to educate and warn the public against extreme events in the hydrosphere and atmosphere. Understanding the specifics of coastal areas it creates tailored products which make the information for people at the coast or in the sea clear and useful.

Flood frequency on the rivers in the Belorussian part of the Baltic Sea basin and cyclonic activity

Irina Partasenok and Ryhor Chekan

Republic Hydrometeorological Center, Minsk, Republic of Belarus (irina-danilovich@yandex.ru)

1. Introduction

Studying of the mechanisms of runoff formation and the follow-up use of revealed relationships for prevention of negative consequences of natural disasters are the major tasks of hydrological environment management and sustainable development. Runoff is a complex process and its formation is influenced by many factors that can be divided into meteorological (quantity and intensity of precipitation, surface air temperature, especially in winter) and terrestrial (surface conditions, type of ground and vegetation and etc.). Precipitation is a major factor that supplies rivers with water in the Baltic Sea Basin within the territory of Belarus and variability of annual precipitation totals controls the formation of water resources. The intra-annual distribution of precipitation is the most difficult characteristic to forecast. It was established, that cyclones from the Atlantic Ocean cause precipitation on the territory of the Russian Plain (Babkin, 1999) and over Belarus as well. These cyclones travel large distances, bring water vapor from the ocean and more humid maritime areas and control water resources of the nation. That's why the aim of this investigation was to estimate cyclones characteristics and effects of their passing through the Belarus territory on the water budget of the region. In particular, we are interested in origin of extreme phenomena on the rivers.

2. Data and methods

The data of the cyclones trajectories, received by automatic tracking according to archives reanalysis NCEP/NCAR or ECMWF (Rudeva et al. 2007), have been used in the research. Frequency and intensity of cyclones during the 1948-2007 period that influenced hydrometeorological conditions of Belarus have been estimated. Calculation of cyclones frequency and their trajectories in the domain 20-65^{o} N and 5-45^{o} E was selected. The domain borders are expanded from the borders of Belarus by 1000 km in each direction.

Climatic data include annual and winter sums of precipitation and the maximum values of snow water equivalent; hydrological data are represented by maximum discharges of spring floods. Additionally, the information about the floods frequency on the Belorussian rivers within the Baltic Sea Basin has been generalized (i.e., their nationwide average was calculated).

The standard methods of descriptive statistics have been used for the estimation of cyclones frequency and their temporal distribution. Estimates of long-term cyclone dynamics (trends) were made using Mann-Kendall trend test and quantified by linear trends.

To characterize the impact of cyclonic activity on climatic and hydrological variables, we used Pearson, Spearmen and Kendall correlations, and factor analysis.

3. Relationship between cyclonic activity and hydrometeorological conditions in Belarus

Analysis of the cyclones which passed through the territory of Belarus during the last 60 years shows a gradual decrease of their numbers - from 260-270 to 220-230 per year (by average mean 255) (Figure 1). The highest values were observed within study region in the 1950-1970 period.

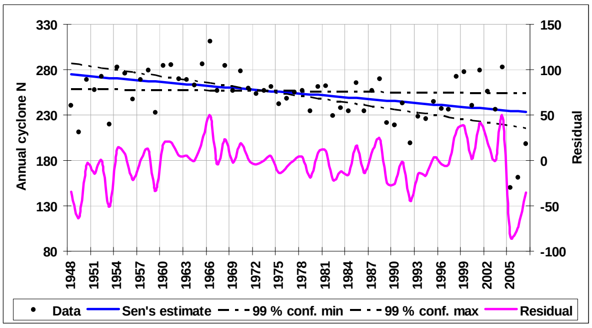


Figure 1. Dynamics of cyclones passed through the territory of Belarus (results of Mann-Kendall Trend Test)

The dynamics of precipitation totals is characterized by the alternation of prolonged wet and dry periods. The connection between cyclone frequency and winter precipitation is quite low. Coefficients of any type correlation do not exceed 0.4. A weak positive trend of winter precipitation totals is observed despite of a negative trend of cyclones' count (Figure 2). It could be explained by hypothesis that cyclones originated from different regions of the Atlantics cause different hydrometeorological conditions in Belarus and the length of stay of certain cyclone types can increase. We have to further investigate these assumptions.

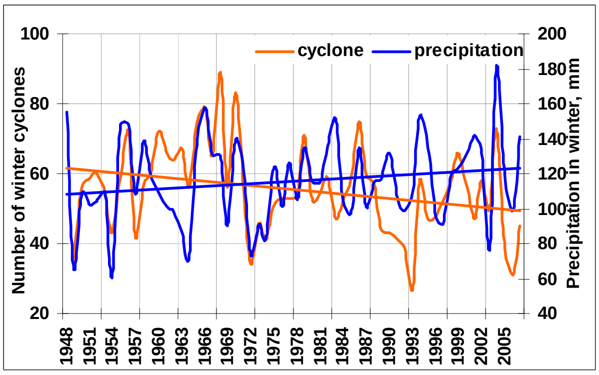


Figure 2. Dynamics of cyclones and precipitation in winter (December through February)

4. Distribution of dangerous phenomena on the rivers of the Belorussian part of the Baltic Sea Basin

Floods during spring snowmelt and infrequent rain-caused floods are considered as the most dangerous natural disaster on the rivers of Belarus by the spatial extent and possible damage. The frequency of floods fluctuates depending on hydrometeorological conditions and physiographic characteristics of each river basin. In the Zapadnaya Dvina (Daugava) Basin, floods were observed at 1878, 1929, 1941, 1951, 1956; in the Neman Basin in 1886, 1931, in the Muhavets Basin -in 1974 (winter flood), 1979гг. (Goldberg, 2002). Analysis of long-term data of the dangerous phenomena shows that the greatest frequency of floods of various gradations was in the 1950-1970 period. It can be explained by prevalence of meridional circulation processes in the atmosphere during this period. The period was characterized by an increase in total number of cyclones (for a year and for seasons) which defined hydrometeorological conditions of the Belarus. It should be noted, that during this period the increase of "southern" cyclones frequency was observed. These cyclones bring considerable precipitation, strengthening of wind, snowstorms and promote formation of high water-accumulation in snowpack before the spring snowmelt.

Since 1970, we observe a decrease in the flood frequency and maximum discharge during spring snowmelt (Figure 3). It is connected with transformation of the atmospheric processes to more frequent zonal types (according to the Wangengheim-Girs classification; cf., Girs 1974) and increase of the frequency of “western” cyclones in the winter season (on the background of the annual decrease in their quantity). During the last decades, this cyclone distribution change has caused a small growth of the cold season precipitation but also an increase of the occurrence of winter thaw periods (McBean et al. 2005).

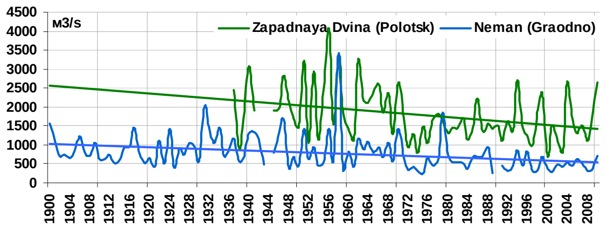


Figure 3. Maximum discharge during spring floods on two major rivers in the Belorussian part of the Baltic Sea Basin

Precipitation of the cold season does not accumulate as a snow or ice cover, and is spent as water from melted snow. That is why the intra-annual distribution of the runoff has considerably changed: the winter discharges have increased and the spring discharges have decreased (Danilovich et al. 2007). As a result, the water-supply in snowpack is exhausted before the beginning of spring snowmelt and there are no conditions for flood occurrence.

5. Summary

Analysis of cyclonic activity during the past 60 years shows the largest number of cyclones defining hydrometeorological conditions of Belarus in 1950-1970. During this period the greatest number of spring floods caused by snowmelt on the rivers of Belarus is also noted. Since 1970, a decrease in the total number of cyclones has been observed. However, an increase in quantity of the “western” cyclones during the winter season has led to some precipitation increase during the cold period and to prevalence of thaws. The thaws interfered with accumulation of snowpack before the beginning of a spring snowmelt and promoted decrease in the number of floods on the rivers of Belarus during last decades.

References

Babkin V. (1999) Global factors of runoff formation of the rivers of Russian plain, Modern problems of hydrometeorology, pp.101−114.

Danilovich (Partsenok) I. and Trofimova L (2007) Influence of atmospheric circulation on water regime of the rivers of Belarus during winter and spring seasons, Natural resources, No 1, pp. 39-46.

Girs, A.A. (1974) Macrocirculation method of long-range forecasts. Gidrometeoizdat, Leningrad, 488 pp.

Golberg M. (ed.) (2002) The dangerous hydrometeorological phenomena on territory of Belarus. The reference book. pp. 89-132.

McBean and Co-Authors (2005) Arctic Climate Impact Assessment (ACIA); Impacts of a Warming Arctic. Overview Report. Hassol SJ (ed). Cambridge University Press, Cambridge, United Kingdom, 140 pp.

Rudeva I. and Gulev S. (2007) Climatology of the cyclone size characteristics and their changes during the cyclone life cycle. Monthly Weather Review, Vol. 135, No. 7, pp. 2568-2587.

Characteristics of cyclones causing extreme sea levels in the Northern Baltic Sea

Piia Post[1] and Tarmo Kõuts[2]

[1] Institute of Physics, University of Tartu, Tartu, Estonia (piia.post@ut.ee)
[2] Marine Systems Institute, Tallinn University of Technology, Estonia

1. Introduction

Sequences of similar weather patterns may cause different kind of extreme environmental events as droughts in case of anticyclones or devastating wind-storms and floods in case of extra-tropical cyclones in Europe (Mailier et al. 2006). These hazards carry along the largest economic loss or even loss of lives. The same reason, series or packages of cyclones, force the extreme storm surges in the coastal sea.

The sea level fluctuations in the Northern Baltic Sea are predominantly meteorologically forced as there are no remarkable tides there (Suursaar et al. 2011). After the cyclone Erwin (or Gudrun) passed the Baltic Sea in 2005 January 8-9, causing nearly in all Northern Baltic coastal measurement sites highest historical sea levels, studies about extreme sea levels as well as sea level regime generally has grown. Ülo Suursaar with coauthors have written a series of articles about the temporal variability of single storm surges, their correlations with wind and wave storms, large-scale atmospheric circulation, modeled sea level rise and storm risks (Suursaar el al. 2010, 2011 if to mention two of them). One of their conclusions is that all extreme storms – storm surges in the coastal waters of Estonia occurred because the center of intensive and fast moving cyclone propagated to the north from the Scandinavian Peninsula over the Gulf of Finland. Roughly the same idea is presented by Averkiev and Klevannyy (2010), who have mathematically modeled water levels in the Baltic Sea to find the most dangerous trajectories and velocities of passing cyclones for extreme sea-level events at different locations on the coast. We call their approach a conceptual model. As in our disposal was a database of Northern Hemispheric cyclones, from where it is possible to find the appropriate characteristics of cyclones, therefore we tried to control the validity of their conceptual model. We examined the two most extreme events of storm surge in Pärnu more closely to detect similar properties of not only single cyclones, but series of cyclones that had generated high sea levels.

2. Data and methods

In this paper we used extreme sea level events for years 1948-2010 from two Estonian sites: Pärnu (Gulf of Riga) and Tallinn (Gulf of Finland) and tried to characterize the cyclones that have possibly generated sea level extremes. For preliminary analysis of extreme sea level events we chose 20 highest sea level values from both stations, altogether 31 events, as 9 of the days were the same for both sites. The sea-level was at least +100cm and +150cm above the mean level in Tallinn and Pärnu, respectively, during these 20 extreme events. Due to river delta, high sea levels in Pärnu are naturally higher. Two most extreme sea level events for Pärnu have occurred in October 1967 and January 2005, see Fig 1 for more detailed temporal variability of both cases. Values of these extremes were +250cm and +275cm, respectively, in 1967 and 2005.

Averkiev and Klevannyy (2010) simulated extreme sea level events for entire Gulf of Finland using hydrodynamic model of the Baltic Sea BSM6 with meteorological forcing from HIRLAM (SMHI). They used cyclone Erwin as a prototype of a "dangerous cyclone", as almost all sea level measurement stations in observed region registered historical maximum levels during its overpass. Averkiev and Klevannyy (2010) found dangerous values of following cyclones properties: cyclone track as a straight line in the longitude belt 10°–30°E, approximated by linear equation ($y=p1\cdot x+p2$), velocity (v_{max}) and geographic coordinates of the cyclone center (y_{max}, x_{max}) at the moment of its maximum deepness. For Pärnu these parameters are presented in Table 1.

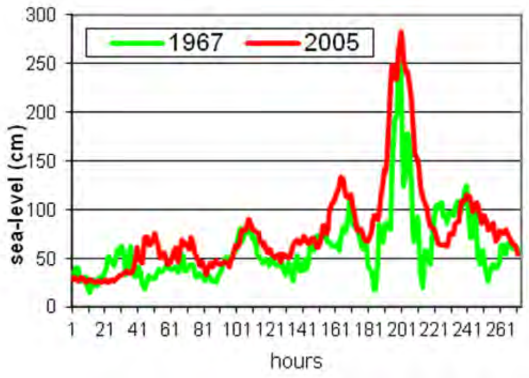


Figure 1. The sea level changes with time for two extreme storm surges. The maximum occurrence time of both events has been coincided.

Table 1. Dangerous characteristics of cyclones for Pärnu sea level from the model of Averkiev and Klevannyy (2010) and as from track data of the two most extreme storm surge events.

Parameter	*Model*	*Oct 1967*	*Jan 2005*
$p1$,	0.304,	0.256,	0.016,
$p2$	51.96	53.90	58.87
v_{max} (km/h)	59.3	86.6	52.7
y_{max},	59.5°N,	57.0°N,	61.2°N,
x_{max}	24.8°E	11.8°E	18.9°E

We validated sensitivity of cyclones characteristics for these 31 extreme sea level cases from 1948-2010. We used data about coordinates, time, velocity and sea level pressure (SLP) values of low pressure centers, found from the database of cyclones described by Gulev et al. (2001). This database consists of cyclone tracking output of the 6-hourly NCEP/NCAR reanalysis (Kalnay et al 1996) SLP fields using the software of Grioriev et al (2000).

First we separated cyclones lasting at least 48 hours, that attained the minimum air pressure value (<1000 hPa) in the region 10°-30°E, 50-70°N. Then, we approximated trajectories of these cyclones with a straight line in the longitude belt from 0°E till 6h after the lowest pressure attained. Cutting the cyclone track from both ends offered us better estimation of the cyclone direction in the area of interest as cyclone often turned steeply just after the moment of the maximum deepness. Using this linear approximation it was easier to make comparisons and group the cyclone tracks.

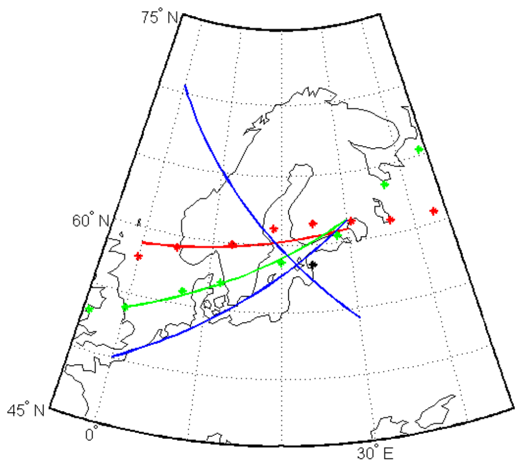


Figure 2. Truncated trajectories of cyclones that have caused extreme sea levels in Pärnu: Oct 18, 1967 (green points and line) and Jan 9, 2005 (red points and line). Two blue lines bound the sector for cyclone trajectories of all other cyclones that caused at least +150cm sea levels in Pärnu.

3. Results

We analyzed the variability of cyclone tracks that might cause high sea level events in Pärnu and Tallinn. First of all we noticed that cyclones passed the Baltic Sea and caused these 31 extreme events in 1948-2010 were not exclusively deep and that there was no obvious correlation between the minimum air pressure of the cyclones and the extreme sea level value. In both sites, Pärnu and Tallinn, on January 8-9 2005 was registered the highest sea level since 1948 (also historical, since 1923 in Pärnu and 1842 in Tallinn). Suursaar et al (2009) classify Erwin/Gudrun as most significant storm since 1966 that passed the Estonian territory, but from the viewpoint of atmospheric pressure, it is only the 12th (with minimum pressure of 957.4 hPa). At the same time Erwin/Gudrun could be called as explosive cyclone or bomb, by the definition of Bergeron (Roebber, 1984), with maximum Normalized Deepening Rate (NDP) of -24.5 hPa/24h during its first day of existence. The second highest storm surge from Oct. 18 1967, was caused by much longer cyclone, with min pressure of 968.3 hPa. For 1967 Oct cyclone, the NDP was -20.9/24h, also a very high value.

Data of real cyclones characteristics compared to by Averkiev and Klevannyy (2010) modeled values are presented in Table 1 and Fig 2. Cyclones which caused these two extreme sea level events in 1967 and 2005, tend to have smaller meridional component of velocity than proposed by Averkiev-Klavannyy conceptual model. However, taking into account other less extreme events, then this conceptual model predicted the propagation vector well inside the possible data-sector. The same was valid for latitude of the cyclone center at the moment of its maximum deepness, only the real cyclones tended to have their deepest point about 10 degrees to west compared to Averkiev-Klevannyy conceptual model value.

Suursaar et al (2010) concluded that these two events in Pärnu appear as outliers or elements of other population if to compare with other maximum values. What means that there should be some other reason for the extremely high sea levels as cyclones of these two most extreme sea level events were not the most extreme ones. We supposed that actual cause for extreme sea levels was not that much the certain parameters of a single cyclone, but properties of a sequence of cyclones passing the Baltic Sea that had certain (in some extent similar) trajectories with certain periodicity in given time span. From Fig 1 six sea level maxima could be detected in about 10 successive days for both, 1967 and 2005 cases. If to compare the cyclone series at the time of 1967 and 2005 storm surge events just looking at the trajectories, then the 2005 year series were more clearly distinguishable. There were 4 cyclones in the area that arose after each other and had quite similar propagating direction. At the time of 1967 Oct. event, evolution of cyclones is not so clearly evident. Still, common feature for both events was two very long (in time and space) cyclones generated over the western part of the Atlantic Ocean at latitude about 40°N. Second of these cyclones was generated after the highest sea level moment, what refers to the possible serial clustering of cyclones, induced by the time-varying effect of large-scale atmospheric factors on individual cyclone tracks (Mailier et al, 2006). We plan to quantify the serial clustering of these cyclones and show that during these extreme sea level events cyclones cluster more than expected by chance.

References

Averkiev, A.S, Klevannyy, K.A. (2010) A case study of the impact of cyclonic trajectories on sea-level extremes in the Gulf of Finland, Continental Shelf Research, 30, 707-714.

Grigoriev, S., Gulev, S.K. and Zolina, O. (2000) Innovative software facilitates cyclone tracking and analysis, EOS 81.

Gulev, S.K., Zolina, O. and Grigoriev, S. (2001) Extratropical cyclone variability in the Northern Hemisphere winter from the NCEP/NCAR reanalysis data. Climate Dynamics, 17, 795-809.

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., Jenne, J., Joseph, D. (1996) The NCEP/NCAR 40-Year Reanalysis Project. Bull. Amer. Meteorol. Soc., 77, 437-472.

Mailier, P. J., Stephenson, D. B., Ferro, C. A. T. and Hodges, K. I. (2006) Serial clustering of extratropical cyclones. Mon.Wea. Rev. 134, 2224–2240.

Roebber, Paul J. (1984) Statistical Analysis and Updated Climatology of Explosive Cyclones. Mon. Wea. Rev., 112, 1577–1589.

Suursaar, Ü., Jaagus, J. Kullas, T. and Tõnisson, H. (2011) Estimation of sea level rise and storm surge risks along the coast of Estonia, Baltic Sea – a tool for coastal management. Littoral 2010, doi.org/10.1051/litt/201112005.

Suursaar, Ü. Kullas, T., Szava-Kovats, R. (2010) Wind-and wave storms, storm surges and sea level rise along the Estonian coast of the Baltic Sea. Ravage of the Planet II. Book Series: WIT Transactions on Ecology and Environment, 127, 149-160.

Precipitation – Too much or too little for potato growth

Triin Saue[1,2] and Jüri Kadaja[1]

[1] Department of Agricultural Engineering and Technology, Estonian Research Institute of Agriculture, Saku, Estonia
[2] Marine Systems Institute, Tallinn University of Technology, Estonia

1. Introduction

Soil moisture is one of the most important stress factors for vegetation and crop yield and the most limiting factor for crop production in the world. Management of water resources is much more crucial and a more universal problem than any of the other factors of the environment. Inadequate and variable water supply has a negative impact on crop production in any climatic region. Most studies on water stress are focused on deficiencies of soil water. However, in moderate climates, including the Baltic Sea area, the water limiting on crops often works as a two-side process – yields are impended by both periods of water deficit and excess that are brought about by irregular rainfall.

Long term experimental studies of the effect of water stress cannot be easily conducted, thus the task was addressed to a crop model.

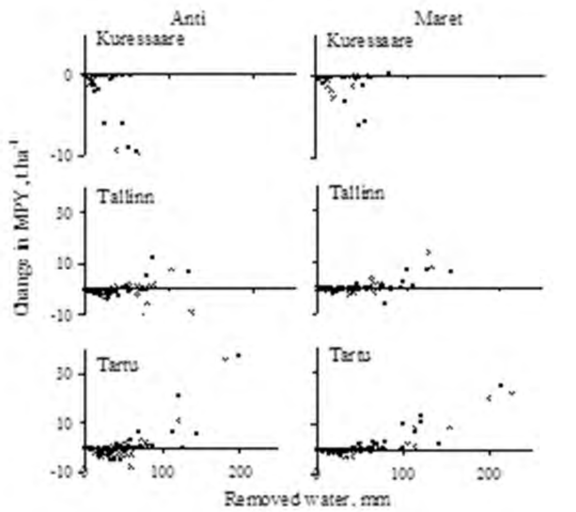


Figure 1. Relation between added water and change in MPY for the early variety 'Maret' (right) and late variety 'Anti (left) in three Estonian locations. Infiltration is included. **indicates statistically significant relation (p<0.001)

2. Data and methodology

To calculate the effect of water limiting, alternative water balance scheme was added to a potato production model POMOD (Sepp and Tooming 1991, Kadaja and Tooming 2004). The model is based on the concept of maximum plant productivity and computes meteorologically possible yields (MPY) – maximum yield conceivable under the existing irradiance and meteorological conditions with optimal soil fertility and agrotechnology (Kadaja and Tooming 2004). Those calculations use observed meteorological data and thus the yield is originally limited by both water shortage and excess. MPY series were calculated for three Estonian locations: Tartu (continental climate) for 1901-2011, Tallinn (sub-continental) for 1920-2011 and Kuressaare (marine) for 1923-2011. For each of series, four model runs were conducted: a) yield was limited by both water shortage and excess; b) water deficit was calculated and the amount of "missing" water was added as irrigation; c) excess water was calculated and removed; d) two-side water regulation. Additional set of runs was implemented for all the same cases, where account of infiltration and natural run-off (hereinafter referred together as infiltration) was omitted. Water shortage was reached, when sol moisture content fell under the lower limit of the optimal range of the productive water supply. Water excess was detected, when sol moisture content overcame the field capacity. Total water deficit or excess was calculated for the whole growing season.

3. Results

As expected, the most benefit was achieved by two-side water regulation: average MPY increased by 7 to 27% and by 14 to 25%, for infiltrated and non-infiltrated soil, respectively (Table 1). Those yield changes are all statistically reliable (at least $p<0.05$).

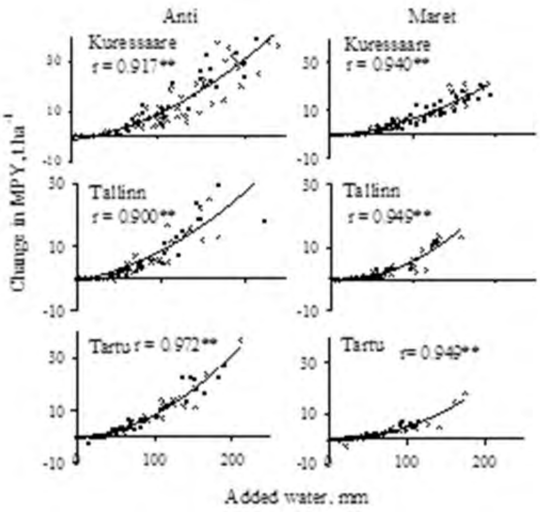


Figure 2. Relation between removed water and change in MPY for the early variety 'Maret' (right) and late variety 'Anti (left) in three Estonian locations. Only the years are included, when there was excessive water. Infiltration is included.

The elimination of water shortage also gave positive results in all cases. The yield increase by irrigation reached from 3% to 27% for different varieties and localities. In all localities more benefit from the irrigation was achieved for the late variety, and when infiltration was included, the yield change was statistically significant for the late variety in all locations. Irrigation proved the most valuable in dry Kuressaare, where almost 30% of yield increase was calculated for the late variety. Also the increase of early variety was significant in Kuressaare, and, in the calculatios without the effect of infiltration, irrigation caused significant yield change only in Kuressaare, where existing conditions are dry and mean yields are the lowest compared to other locations.

For drainage, the situation looks quite different in different locations (Figure 2). In Kuressaare, there is no considerable relationship between removed water and MPY change, and the outcome is mostly negative. In continental stations, there occur both years with positive and negative effect of drainage, especially for the late variety. For the early variety the positive results are much higher than negative.

4. Discussion

Results indicate that under existing conditions, the benefit from irrigation is considerable, while the effect of drainage is expressed only in conditions of restricted infiltration and natural run-off. However, in some cases, especially in Tartu, where the precipitation amounts are higher in May and June, the highest losses of yield were met in years with excessive water. The average impact of drainage is diminished by years when effect of drainage is negative due to increasing water deficit during a following dry period. In more than half of the years (in Tartu 70–80% of the years) crops suffer from both water shortage and excess. The highest is the effect of irrigation in Kuressaare, getting in May and June only as 58% of precipitation in Tartu, and arises due to it from the last place to the most productive one. Need for irrigation was absent in Kuressaare only in 3–4 years from 89.

Although there is no definite understanding, how the precipitation patterns will change in Estonia, most climate change scenarios indicate an increase in annual precipitation (Jaagus 2006, Saue and Kadaja 2011). Also, the extreme precipitation events have already become more intense, together with a decrease in wet days (Post and Päädam 2011), leading to more frequent drought periods and more intense flooding rainfalls (Tammets 2007, 2010). Thus the need for more detailed water limiting studies is in the air.

Table 1. Average change in MPY (%), when water limiting is removed from one or both sides and corresponding amount of added/removed water (mm) per growing period for two varieties and three locations.

Variety	Location	Mean MPY ($t\ ha^{-1}$)	Irrigation		Drainage		Two-way treatment		
			Change in MPY (%)	Added water (mm)	Change in MPY (%)	Removed water (mm)	Change in MPY (%)	Added water (mm)	Removed water (mm)
			With infiltration						
Anti	Tallinn	55.1	9.0*	58	-0.3	28	10.1*	66	32
	Tartu	55.7	8.2*	54	1.5	37	11.6*	66	42
	Kuressaare	50.7	27.4*	117	-1.1	8	27.4*	120	13
Maret	Tallinn	41.2	4.6	40	1.0	33	6.5*	47	37
	Tartu	38.1	3.3	34	3.1	41	7.3*	43	46
	Kuressaare	37.9	18.5*	93	-0.7	10	18.6*	96	15
			Without infiltration						
Anti	Tallinn	51.9	7.4	50	7.0	50	16.9*	61	57
	Tartu	52.1	7.2	47	9.1*	59	19.2*	64	67
	Kuressaare	51.6	24.5*	110	-1.3	18	25.2*	115	25
Maret	Tallinn	38.5	3.8	36	8.6*	57	14.1*	44	64
	Tartu	35.8	2.8	31	10.1*	64	14.4*	42	70
	Kuressaare	38.0	17.2*	89	-0.3	21	18.1*	92	28

* indicates statistically significant change in MPY ($p<0.05$ detected by the Dunnett comparisions test).

When infiltration was included (which is the "normal" situation), drainage of excess precipitation resulted in a quite marginal and opposite-directed change in average yield. Without infiltration, the benefit of drainage was 7-10% in Tallinn and Tartu and the result remained slightly negative for Kuressaare. From drainage the benefit was overall higher for early variety. The average need for irrigation water was between 30-40 mm for the early and 45-60 mm for the late variety in continental locations, being over two times higher for insular Kuressaare. In continental stations the need for drainage was around 40-50 mm per growing period for both varieties in addition to infiltration (about 10-15 mm more without it). In Kuressaare, the mean amount of excessive precipitation was only 8-10 mm, and there was no water to remove in about 70% of the years. And even then its removal is negative in most cases because of a following dry period. The relation between change in MPY and added water was strong ($p<0.001$ in all locations and both varieties) for the case of water deficit calculations (irrigation) (Figure 1). The relation is best describable with the second order polynomial curve.

References

Jaagus J (2006). 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, pp 77–88.

Kadaja J, Tooming H (2004). Potato production model based on principle of maximum plant productivity, Agric Forest Meteorol, 127, 1-2, pp 17–33.

Post P, Päädam K. (2011). Changes in Estonian precipitation extremes according to the observational and BaltAn65+ reanalysis data. In: Jaagus J (Ed). Publicationes Instituti Geographici Universitatis Tartuensis, Tartu Ülikooli Kirjastus, pp 7–22.

Saue T, Kadaja J (2011). Possible effects of climate change on potato crops in Estonia. Boreal Environment Research, 16, pp 203–217.

Sepp J, Tooming H. (1991) Productivity resources of potato, Gidrometeoizdat, Leninrad [in Russian, with English abstract]

Tammets T (2007). Distribution of extreme wet and dry days in Estonia in last 50 years. Proc. Estonian Acad. Sci. Engineering, 13, pp 252–259.

Tammets T (2010). Estimation of extreme wet and dry days through moving totals in precipitation time series and some possibilities for their consideration in agro-meteorological studies. Agronomy Research, 8, pp 433–438.

'Stormy' circulation types of COST 733 classifications in Estonia

Mait Sepp

Department of Geography, University of Tartu, Estonia (mait.sepp@ut.ee)

1. Introduction

423 different classifications of atmospheric circulation types were created by COST 733 Action for Baltic Sea region. Some prior information on how those classifications describe 'regular' meteorological variables is needed to decide which classifications may be suitable for analyzing complex environmental phenomena's as stormy weather. Unfortunately, COST 733 Action does not give such information on the circulation type (CT) level.

2. Data and methods

Here, 47 classifications, containing all together 433 CTs, from the COST 733 cat. 2.0 domain 05 (Baltic Sea region) were analyzed to distinguish 'stormy' CT-s (SCT) in case of Estonia. For this purpose, wind speed data from three Estonian meteorological stations – Jõhvi, Lääne-Nigula and Võru were compared to classifications including nine CT-s and representing the optimisation method family (methods CAP, CKM, NNW, PXK, SAN and SOM). The period of analysis was 1966-2001, i.e. 13,149 days.

The following parameters were defined for every station: windless day – day, when the wind speed V≤4 m/s on all times of measurement. Stormy day - day, when V≥10 m/s on at least one measurement. Storm day - day, when V≥15 m/s on at least one measurement.

The percentage of days when windless, stormy or storm days occurred and the probability of their occurrence was calculated for each CT. According these indicators, we can distinguish a SCT – in case of this type, the probability of the occurrence of a stormy day must increase the probability of the occurrence of a windless day.

3. Results

Results of the analysis demonstrate that there are 1-2 (up to 4) SCTs per most classifications. All in all, there were 63 CTs per 47 classifications that could be called ‘stormy’. Each classification contained 1-2 CTs that could be called ‘storm types’ and 4-5 CTs that are ‘windless types’.

There were no significant differences in the distribution of CTs in classes of wind speed. The main difference is based from the distribution of wind speeds measured at meteorological stations: while in Lääne-Nigula there were 58 and in Jõhvi 39 storm days during the observed period, there were only 2 storm days in Võru. While the percentage of windless days in Jõhvi and Lääne-Nigula was ca 45%, it was 75% in Võru. However, the CTs that are windless in Võru are also windless in Lääne-Nigula and Jõhvi.

Differences were seen in classification methods and to some extent also in the initial data used in classifying. For example, classifications that belong in the NNW family have no SCTs. The 12 classifications from the PXK family share only 5 SCTs between themselves. Classifications, whose CTs have been determined to last 4 days, usually have only 1 SCT.

Almost half of the SCTs represent a situation, where a low is located in the north-east of Estonia. A third of SCT cases represent situations, where there is a low pressure area north of Estonia and a high pressure area south of Estonia.

4. Conclusions

Atmospheric circulation classifications analysed here, have certain limitations as tools for studying stormy weather events. If SCTs are observed individually, the probability that a stormy day would occur in case of the specific SCT is relatively low – ca 30% on an average. An average of a third of storm days occurs during SCTs. But when observed by classifications, the SCTs include ca 50% of stormy days and up to 75% of storm days. There are classification families which CTs cover stormy days more precisely then other ones. Those ‘better’ families are CAP, CKM, SAN and SOM. On the other hand, analyze showed that stormy and even storm days may occur almost in every CT. This refers to the fact that storms and stormy weather themselves are highly diverse natural phenomenon.

Towards flood assessment over Eurasian watersheds using RCM and river flow routing algorithm

Elena Stafeeva and Igor Shkolnik

Regional Climate Modeling Laboratory, Department of Dynamic Meteorology, Voeikov Main Geophysical Observatory, Saint-Petersburg, Russia (stafeeva@main.mgo.rssi.ru)

The evidence of modeling projections of climate change impacts on floodings is important for water resources and flood assessment by decision-makers. Climate projections provided by global and regional climate modeling systems (GCM/RCM) usually feed the impact models. However, challenges in representing dangerous hydrological events over the river catchments suggest that decisions must be made depending on the degree of realism of mean and extreme runoff simulation by an RCM at daily (hourly) resolution. Given an RCM simulated surface and groundwater inflow to rivers, the river flow routing model can compute flow and volume of water everywhere across watersheds taking into consideration thousands of reaches. In this study the river flow routing model has been developed and applied to 20 years (1981-2000) MGO RCM daily runoff simulation for northern Eurasia driven by the three different reanalyses (ERA-40, NCEP-DOE and JRA). The reanalyses differ to some degree in their representation of observed moisture fluxes and regional water budget suggesting that more credible response of RCM simulated hydroclimate can be obtained using ensembles of historical runs. The quality of model simulated annual runoff and its variations at daily to interannual resolution is evaluated through comparison of RCM-driven river flow routing model output against river discharge observations across 15 watersheds of northern Eurasia.

Precipitation extremes projections for Poland for the period 2021-2050

Joanna Wibig

Department of Meteorology and Climatology, Lodz University, Lodz, Poland (zameteo@uni.lodz.pl)

1. Introduction

At the moment there is a consensus concerning global warming and the increase of temperature in the Central Europe and Poland. However much less is known about the hydrological response to warming trend. In northern Europe the precipitation totals have been increasing and in the southern Europe the decrease of precipitation has been observed. In the middle latitudes there is a wide zone with small changes and tendency to higher amounts of rain in cold half of the year and lower in a warm part of the year. However even in the regions where precipitation totals are not supposed to increase, the highest daily totals can become more extreme, because of the higher water holding capacity of the warmer air.

The aim of present study is to make projections of precipitation extremes in a future climate in Poland, compare projections obtained using different methods and evaluate the uncertainty of results.

2. Methods

Generally GCM's projections give climate information in very low resolution and it is not applicable in impact studies in regional or local scale. RCMs are used to downscale from the GCM's scale to the regional one. Ten RCM simulations were used in this study with spatial resolution around 25 km, emission scenario A1B and driven by six different GCM simulations (Table 1). For all cases 30-year control climate simulations for the reference period 1971-2000 were compared with 30-year simulations covering the scenario period 2021-2050. All simulations were made within ENSEMBLES project.

Table 1. List of used RCM simulations.

Inst.	GCM	RCM	References
KNMI	ECHAM5-r3	RACMO	van Mejigaard et al. 2008
SMHI	ECHAM5-r3	RCA	Kjellström et al. 2005
SMHI	BCM	RCA	
SMHI	HadCM3Q3	RCA	
METNO	HadCM3Q0	HIRHAM	Haugen & Haakensatd 2006
METNO	BCM	HIRHAM	
DMI	APREGE	HIRHAM	Christensen et al 1996
DMI	BCM	DMI-HIRHAM5	
DMI	ECHAM5-r3	DMI-HIRHAM5	
ICTP	ECHAM5-r3	RegCM	Georgi & Mearns, 1999

Outputs of RCMs are subject to systematic biases. So transfer methods should be used to obtain the data possible to use in impact models.

One of such methods is distribution based scaling approach. Refined Yang et al. (2010) version was applied. Scaling factors were obtained on monthly scale for each percentile from 1 to 99 using the empirical distribution functions.

Three other methods were based on delta approach. In the first case, the distribution related change factors were obtained separately for each month and each percentile from 1 to 99. In this approach there is no change in the number of days with precipitation (Lenderink et al., 2007). In the other cases the delta change approach was used to obtain new number of precipitation days as well as mean monthly precipitation totals and their standard deviations only. Weather generators were used to obtain the distribution of daily totals. In both remaining cases the first order Markov chain was used to decide whether the day is dry or wet and the gamma and mixed exponential distributions were used to predict the daily totals (Wilks and Wilby, 1999).

3. Data

Daily precipitation totals measured at 40 stations in Poland obtained from the Institute of Meteorology and Water Management were used in this study. Data cover the reference period 1971-2000. The location of stations is shown on figure 1. Precipitation data were used to obtain gridded precipitation records in Poland. A grid covered the area from 12 to 24 E and from 48 to 55N with a resolution of 0.25° both in longitude and latitude. Daily precipitation totals in each grids point were calculated as an average from values in the circle of 100 km centred at the grid point. Days with precipitation amounts lower than 0.1 mm were assumed to be dry (r=0.).
Such set of gridded data was used to obtain the bias in the first method, and as an observed dataset of precipitation altered by delta change factors to obtain the future (scenario) in all other methods. This dataset was also used to estimate the weather generator parameters.

Figure 1. Localization of meteorological stations with daily precipitation totals.

Daily precipitation totals from all simulations shown in Table 2 from the reference period 1971-2000 and scenarion period 2021-2050 were also used to obtain projections for future.

4. Comparison and uncertainty assessment

Different sources of uncertainty were evaluated:

Uncertainty related to driving GCM: when results obtained for the same RCM with lateral boundary conditions taken from different GCM.

Uncertainty related to RCM: when the same GCM output was used as lateral boundary conditions in different RCMs. Uncertainty related to transfer method: when projections of future were prepared on the basis of the same RCM experiment using different transfer methods.

Comparison of all resulting projections enable an assessment of the most probable projection and its range.

Acknowledgements

This work was supported by the Polish National Science Centre under contract UMO-2012/05/B/ST10/00945. This analysis has been made possible thanks to simulations made under ENSEMBLES project (http://ensemblesrt3.dmi.dk/).

References

Christensen JH, Christensen OB, Lopez P, van Mejigaard E, Botzet M (1996) The HIRHAM4 regional atmospheric climate model, Scientific report DMI, Copenhagen, Report 96-4 Available at DMI, Langbyvej 100, DK-21000 Copenhagen Ø, Denmark

Giorgi F, Mearns LO (1999) Introduction to special section: regional climate modeling revisited. J Geophys Res (Atmospheres), 104, pp. 6355-6352

Haugen JE, Haakensatd H (2006) Validation of HIRHAM version 2 with 50 and 25 km resolution. RegClim general technical report, 9. pp. 159-173

Kjellström E, Bärring L, Gollvik S, Hansson U, Jones C, Samuelsson P, Rummukainen M, Ullersig A, Willen U, 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

Lenderink G, Buishand A, van Deursen W (2007) Estimates of future discharges of the river Rhine using two scenario methodologies: Direct versus delta approach. Hydrol Earth Syst Sci 11, pp 1143-1159

Van Mejigaard E, van Ulft LH, van de Berg WJ, Bosveld FC, van den Hurk BJJM, Lenderink G, Siebesma AP (2008) The KNMI regional atmospheric model RACMO, version 2.1, KNMI publication: TR-302, 43 pp

Yang W, Andréasson J, Graham LP, Olsson J, Rosberg J, Wetterhall F (2010) Distribution-based-scaling to improve usability of regional climate model projections for hydrological climate change impacts studies. Hydrol Res, 41, pp 211-229

Wilks DS, Wilby RL (1999) The weather generation game: a review of stochastic weather models, Prog Phys Geogl, 23, pp. 329-357

.

Maximum sea levels at selected stations of the Baltic Sea coast

Tomasz Wolski[1], Bernard Wiśniewski[2]

[1]University of Szczecin, Institute of Marine and Coastal Sciences, Poland, (natal@univ.szczecin.pl)
[2]Maritime University of Szczecin, Institute of Marine Navigation, Poland

1. Introduction

Fluctuations in sea levels present an important geophysical, oceanographic, and climatological problem. Sea level fluctuations change the water depth and substantially affect the location of important shore components, and thus may contribute to coastal erosion and the landward shift of the shoreline. A considerable part of sedimentological effects on the shore is generated by long-term (on the scale of years or decades) changes in sea level. It is of utmost importance to monitor sea level fluctuations, so that processes and effects in the coastal zone are understood, their adverse consequences are adequately forecast, and if possible appropriate preventive measures are taken.

The purpose of this research is to show examples of maximum sea levels in the Baltic Sea on the basis of long-term observations series of a few gauges stations. These gauges stations are located on the Polish, German, Danish, Swedish, Finnish and Estonian coasts of the Baltic Sea.

2. Materials and methods

The analyzed data are hourly values of sea levels. Observation sea levels serieswere obtained from Bundesamt für Seeschifffahrt und Hydrographie (Germany), Danish Meteorological Institute (Denmark), Swedish Meteorological and Hydrological Institute (Sweden), Finnish Meteorological Institute (Finland), Estonian Meteorological and Hydrological Institute (Estonia) and Institute of Meteorology and Water Managment (Poland).

In this paper, the sea level observationsare related to one tide gauge zero, benchmark to Normaal Amsterdams Peil (NAP).

In the present work we have analysed the number of storm surges for the period 1950-2010. To define storm surges, a sea levelvalue of ≥ 70 cm from the local gauge zerowas prescribed (Majewski et al. 1983,Wiśniewski and Wolski 2009).

To determine the level of 100-year and 1000-year return time surges, the Gumbel distribution was fitted to the observations and the parameters of the distribution were estimated by the maximum likelihood method. The Gumbel's distribution is double exponential and described by the formula (Gumbell E.J. 1958):

$$f\ (x)\ =\frac{1}{\hat{a}}\,e\left[-\frac{x-\hat{b}}{\hat{a}}-e\left(-\frac{x-\hat{b}}{a}\right)\right]$$

where:

â- scale parameter (it determines dispersion of the distribution along x- axis),

$\hat{b}$ - location parameter (it determines location of the distribution on x-axis)

In this paper, a Kolmogorv test is applied to test whether or not the observations can be described by the Gumbel distribution. The number of storm surges at selected gauge stations in the Baltic Sea is shown in Figure 1.

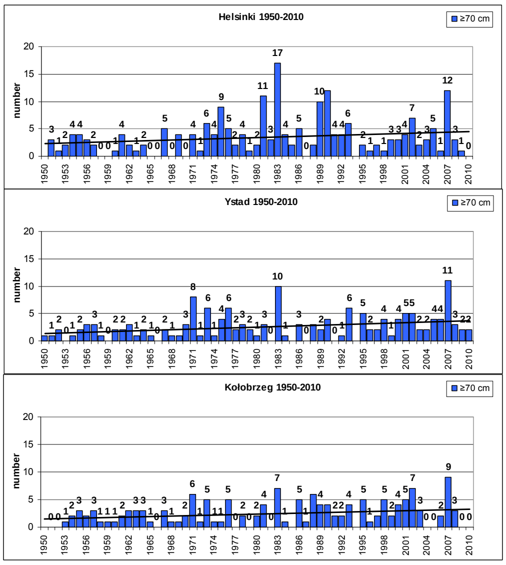


Figure 1. Number of storm surges on the selected Baltic coast (defined as sea level ≥ 70 cm from the reference gauge)

3. Results

From Figure 1 one can observe that the number of storm surges in the past 60 years on the Baltic Sea coast steadily grows. In the period 1950-2010 the number of storm surges has been increasing in Helsinki: from 2.3 to 4.5 storm annual average, in Ystad from 1.4 to 3.7storm annual average and in Kołobrzeg from 1.5 to 3.3 storm annual average.A significant increase of the amount of storm surges during the period 1950-2010 in the Baltic coast may be evidence of an increased intensity of the low-pressure systems from the North Atlantic.

Analysing time series of sea level is important to determine long-term probabilistic forecasts of annual maximum sea levels. They are called theoretical sea levels that may occur once a certain number of years such as once every 200 years, 100 years or 50 years.In this work we determine the theoretical value of sea levels for the selected gauge station of the period 1889-2006 based on the Gumbel distribution, whose parameters are estimated with the maximum likelihood method (Table 1).

Table 1. Theoretical maximum sea levels [cm] and probability of their occurrence at selected gauge stations of the period 1889-2006

T (years)	**P (%)**	***Gauge station***			
		Ystad	Stockholm	Świnoujście	Kołobrzeg
1000	0.1%	183.0	134.7	223.5	238.2
500	0.2%	172.8	126.7	209.5	222.7
200	0.5%	159.4	116.0	190.9	202.3
100	1%	149.1	108.0	176.8	186.8
50	2%	138.9	99.9	162.6	171.3
20	5%	125.2	89.1	143.7	150.6
10	10%	114.6	80.8	129.1	134.5
5	20%	103.6	72.1	113.9	117.8
4	25%	99.8	69.1	108.8	112.2
3.33	30%	96.7	66.6	104.4	107.4
2	50%	86.9	58.9	90.9	92.6
1.33	75%	76.6	50.8	76.8	77.1
1. 25	80%	74.5	49.2	73.9	73.9
1.11	90%	69.2	45.0	66.5	65.8
1.01	99%	59.1	37.0	52.5	50.1

Table 1shows that the height of extreme sea level with return periods of 100 years (probability of 1%, once per century) is lowest in Stockholm (108 cm above zero local gauge). This results from the location of this gauge station away from the open sea. For the other gauge stations, the 100-year annual maximum sea level is significantly higher: 149 cm in Ystad, 177 cm in Świnoujście and 187 cm in Kolobrzeg. These estimations did not differ significantly from the values calculated by other authors for the Southern Baltic Sea (Wróblewski 1992, Jednorał et al. 2008,Wiśniewski and Wolski 2009).

4. Summary

The present work characterizes the changes and the course of maximum sea levels at selected locations at the Baltic Sea coast, on the basis of long-term observational series. Increasing numbers of storm surges in the Baltic Sea may be due to climate change, the NAO index or local wind conditions (Ekman 2009, Johansson et al. 2004, Suursaar et al. 2007).

The height of maximum annual sea level with a 100-year return period found in the present study for the selected stations depends on the location and the distance from the open sea.

The probability of occurrence of high sea levels estimated in this work for selected Baltic Sea gauges stations (ports) can be used in the design of coastal hydro-engineering infrastructure, coastal zone managing, and the planning of inundation areas during storm and flood events.

Acknowledgements

Thanks to national meteorological and hydrological institutes of Baltic Sea states, SMHI, FMI, DMI, BSH, EMHI, IMGW, for providing the sea level data.

The work was financed by the research project of the National Center for Science, Poland No. 2011/01/B/ST10/06470.

References

Majewski A., Dziadziuszko Z., Wiśniewska A. (1983) Monografia powodzi sztormowych 1951–1975.Wyd. Komunikacji i Łączności, Warszawa, pp. 216

Wiśniewski B., Wolski T. (2009) Katalogi wezbrań i obniżeń sztormowych poziomów morza oraz ekstremalne poziomy wód na polskim wybrzeżu. Wyd. Akademia Morska Szczecin, pp. 158

Gumbell E.J. (1958) Statistics of Extremes. Columbia University Press

Wróblewski A. (1992) Analysis and forecast of long-term sea level changes along the Polish Baltic Sea coast, Part I. Annual sea level maxima. Oceanologia, No. 33, pp. 65-85

Jednorał T., Sztobryn M., Miłkowska M., (2008) Zastosowanie modelu statystyk pozycyjnych do prognozowania ekstremalnych poziomów Morza Bałtyckiego w polskiej strefie brzegowej. Inżynieria Morska i Geotechnika, no 5, pp. 257–263

Ekman M. (2009) The Changing Level of the Baltic Sea Turing 300 Years: A Clue to Understanding the Earth . Summer Institute for Historical Geophysics, Aland Islands.

Johansson M., Kahma K., Boman H., Launiainen J. 2004 - Scenarios for sea level on the Finnish coast. Boreal Environment Research 9. p. 153–166

Suursaar Ü, Kullas T., Kuusik T., (2007) Possible changes in hydrodynamic regime in the Estonian coastal waters (the Baltic Sea) as a result of changes in wind climate. Journal of Coastal Research. SI 50, pp. 247 – 252.

Estimation of the peak outflow from natural lakes within the Neva river basin

Sergey Zhuravlev

Saint-Petersburg State University, Chair of hydrology, Saint-Petersburg, Russia (hydromod@gmail.com)

1. Introduction

Lakes are the main natural factor of the peak runoff decreasing within the Neva river basin. The main objective of this study is to estimate peak runoff reducing due to lake flood regulation.

The study area is the Neva river basin and the watersheds of the lakes that situated in its boundaries. Six lakes of different surface area (from 6.4 to 17700 km^2) and watershed area (from 95 to 276000 km^2) were selected.

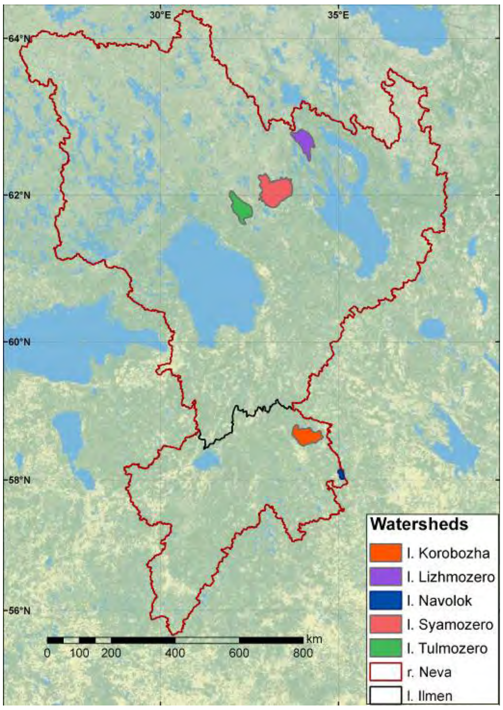


Figure 1. The scheme of the Neva river basin, showing the location of the watersheds used in this study.

2. Material and methods

The process of lake routing is described with following equations:

$$\frac{dW}{dt} = \frac{Q_{\text{in.},t} + Q_{\text{in.},t+\Delta t}}{2} - \frac{Q_{\text{out.},t} + Q_{\text{out.},t+\Delta t}}{2} - E(S,t) + P(S,t)$$

in which W is the water storage volume, Q_{in} is the lake inflow, Q_{out} is the lake outflow, S is lake surface area, and

$$H - H_0 = aQ^n$$

in which $H - H_0$ is the water depth above the datum of zero outflow, Q is the outflow discharge, a and n the parameters that depend on the area and shape of the lake.
The examples of rating curves are shown on the figure 2. The relationships between rating curves parameters of lakes and their morphometric characteristics are discussed in Jeng and Yevdjevich (1966) and Zhuravlev (2011).

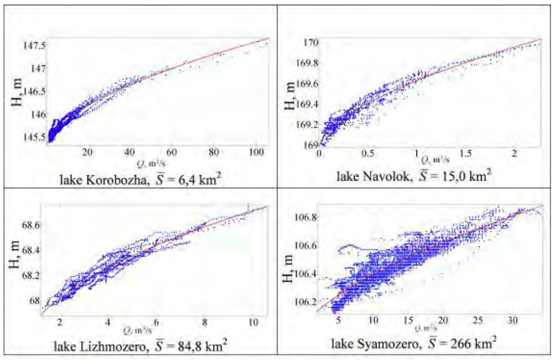


Figure 2 Rating curves for lakes Korobozha, Navolok, Lizhmozero and Syamozero. Daily data on lake levels, outflow evaporation from water surfaces and precipitation from 1970 to 2010 were obtained. After that the regulation coefficients $\alpha_{\max} = M_{\text{in},\max} / M_{\text{out},\max}$ were estimated for every lake.

3. Results and discussion

Preliminary results show that the peak flow reducing due to lake flood control fluctuates from 10% to 85%. The maximum value of $\alpha_{\max}$ appertains to the lake without any other lakes in its watershed boundaries. The quite low value of $\alpha_{\max}$ of the Ladoga is explained by artificially regulated inflow.

Table 1. Characteristics of lake inflow, outflow and regulation coefficients

River/lake	$M_{\text{in},\max}$, l/(s·km^2)		$M_{\text{out},\max}$, l/(s·km^2)		$\alpha_{\max}$	
	Mean	Abs. max.	Mean	Abs. max.	Mean	Abs. max.
Neva/ Ladoga	22	28	10	12	2.2	2.3
Lizhma/ Lizhmozero	59	84	13	20	4.5	4.2
Tikhomandrica/ Navolok	153	216	23	43	6.7	5.0
Syapsya/ Syamozero	44	71	15	21	2.9	3.4
Uver'/ Korobozha	55	105	52	102	1.1	1.03
Volkhov/ Ilmen	54	90	22	26	2.5	3.5

References

Jeng, R. I., and Yevdjevich, V. M., Colorado State University Hydrology Papres №14 (August 1966), "Stochastic properties of lake outflows", 21 pp.

Zhuravlev S.A. Model-based estimation of lake runoff regulation.Vestnik St. Petersburg University. Ser. 7. 2011. Issue 4. P. 111–115.

Topic D

Biogeochemical cycles in the Baltic Sea basin and transport processes within the regional Earth system under anthropogenic influence

Urban snow and snowmelt runoff inorganic pollution and its impact on the receiving river in the city of Brest, Belarus

Ina Bulskaya[1], Alexander Volchek[2]

[1] Brest State University Named After Pushkin, Brest, Republic of Belarus (inabulskaya@gmail.com)
[2] Brest State Technical University, Brest, Republic of Belarus

1. Introduction

The urban environment differs from the natural and is characterized by significant presence of impervious surfaces and a large number of sources of pollution. Impervious surfaces do not permit rain and snowmelt infiltrate into the soil, forming significant amounts of surface runoff and thus alter natural hydrology. While the rain surface runoff is a common subject of investigation in many countries, the snowmelt urban runoff has been paid little attention to (Buttle et al. 1998). During the winter period (from November to March) in countries with moderately continental climate due to the snow cover presence, not only typical sources of pollution (e.g. litter and rubbish from streets, soil and pavement erosion, vehicle emissions, aerosols and emissions from industry) contribute to surface runoff contamination, but also such factors as winter weather characteristics (periods of snow fall and snow melt, intensity of snow fall, duration of dry periods), road de-icing composites constituents, pattern of street cleaning, salting and snow removal etc.

The aim of this paper is to study snow and snowmelt runoff inorganic constituents on the urbanized territories and to point out components that can present a potential environmental threat. According to this, concentrations of inorganic ions such as chlorides, phosphates, nitrates and ammonium, heavy metals as well as suspended solids (SS) were measured in samples of snow, snow layer and snowmelt runoff.

2. Materials and methods

Three sample points with different functions typical for urbanized territories were chosen in the city of Brest for the evaluation of inorganic pollutants in snow and snowmelt. Samples of snow were taken during the snowfall periods in clean plastic vessels; snow was melted and analyzed during 24 hours. Samples of snow layers were taken at the same points in clean plastic vessels, discarding the very top snow layer, melted and analyzed the same way that the snow samples. The samples of snowmelt effluents were taken in the ends of drainage pipes that carry effluent from target points to the river Muhavets.

SS were measured by the gravimetric method. Chlorides were measured by titrimetric method. Nitrates, phosphates and ammonium were measured by the photometric method. Heavy metals were measured by AAS.

3. Results and discussion

According to the primary results obtained in our study, several components can cause a potential environmental impact. SS and chloride ions are the primary pollutants both in snow from the snow layer and snowmelt. This is due to the de-icing of streets and roads which is accomplished with sand and sodium chloride mixture. Average concentrations of SS and chlorides are several times bigger than national regulation values. Concentrations of SS and chlorides follow the similar variation and most probably depend on the street cleaning and icing pattern.

Ammonium and phosphate ions average concentration in snowmelt runoff also exceed the national regulation levels values. Discharge of the effluent with elevated level of nutrients (e.g. ammonium and phosphates) can contribute to eutrophication effects.

Moreover, suspended solids can absorb pollutants on their surface and then release them after getting to receiving water stream and cause long-term polluting effects.

4. Conclusions

The surface runoff formed during snow melting periods can carry a significant burden of pollutants that can cause long-term environmental effects on water bodies, if the runoff is drained into the water body without treatment. If the drainage system has an old design (with no treatment facility), all pollutants are transported to the receiving waters. In Brest, a significant percent of surface runoff is drained to the Muhavets river which falls into Western Bug, and thus such runoff can contribute to transboundary element transport.

References

Buttle, J.M., Xu F. (1988) Snowmelt runoff in suburban environments, Nordic Hydrology, Vol. 19, pp. 19-40

Tsihrintzis, V.M., Hamid R. (2001) Modeling and management of urban stormwater runoff quality: a review, Water Recourses Management, Vol. 11, pp. 137-164

Суйкова, Н.В., Брянская Ю.Б., Боровков В.С. (2012) Свойства мелкодисперсных техногенных наносов и их влияние на русловой процесс и самоочищение речной воды, Водные ресурсы, Т. 39, № 2, с. 186-194.

Щукин, И.С., Мелехин А.Г. (2012) Качественный состав поверхностного стока с территории г. Перми, Вестник ПНИПУ. Урбанистика, № 4, с. 110-118.

Influence of DOM on the CO_2 pressure in the Gulf of Bothnia surface water

Moa Edman[1] and Leif G. Anderson[2]

[1] Department of Earth Sciences: Oceanography, University of Gothenburg, Sweden (moa.edman@gvc.gu.se)
[2] Department of Chemistry and Molecular Biology, University of Gothenburg, Sweden

1. Introduction

Current modeling efforts in the Baltic Sea cannot realistically reproduce the nutrient balance in the northern Baltic Sea Basins; the Bothnian Sea and the Bothnnian Bay, see Omstedt et al. (2012) and Eilola et al. (2011). This affects the quantity of modeled primary production and thus many biogeochemical rates in a fully coupled biogeochemical model.

It has serious implications for our endeavor to use models as tools in understanding the dissolved CO_2 system in these areas, and understand the possible future impact by anthropogenic forcing factors such as eutrophication, acidification and so forth. As these areas have been shown to be sensitive to changes in the inorganic carbon system (Omstedt et al. 2010), this is a major concern.

It now seems apt to move away from modeling primary production as dependent on inorganic nutrients and expand models to handle organic speciation of both nutrients and carbon.

As a first step we investigate the effects of increased net production by adding organic N (nitrogen) and P (phosphorus) as an available nutrient sources to a dinoflagellate plankton group and bacteria (cyanobacteria).

We further experiment with the parameterization of maximum growth rates, limiting factors, sinking velocities, ability to utilize nutrient from different pools, respiration rates and susceptibility to mortality, all of which are dependent on temperature, and therewith at the heart of the models seasonal biogeochemical patterns. We want to capture the key functions of natural plankton communities by allotting the three phytoplankton functional groups different niches in the ecosystem.

In this study we aim to reproduce the characteristic biogeochemical signatures in mean vertical profiles and the mean seasonal surface variation in the Eastern Gotland Basin, the Bothnian Sea and the Bothnian Bay. The results are evaluated by objective skill metrics to assess the model skill.

This presentation is part of the BALTEX PhD projects aiming for improved understanding of acidification of coastal waters with reference to the Baltic Sea-Skagerrak marine system.

2. Available measurement data

We use the total amount of N and P as indicators of correct nutrient conditions, and use the NO_3+NH_4 and HPO_4 constituents, together with the biological pCO_2 seasonal fingerprint, as indicators of correct biogeochemical modeling.

Data is acquired from SMHI and cruises preformed during the Bonus+ Baltic-C project (see fig. 1). The SHARK measurements are used to construct mean vertical profiles and mean seasonal variations in surface waters, while the Baltic-C data acts as an independent, second data-set which add confidence to the monitoring data.

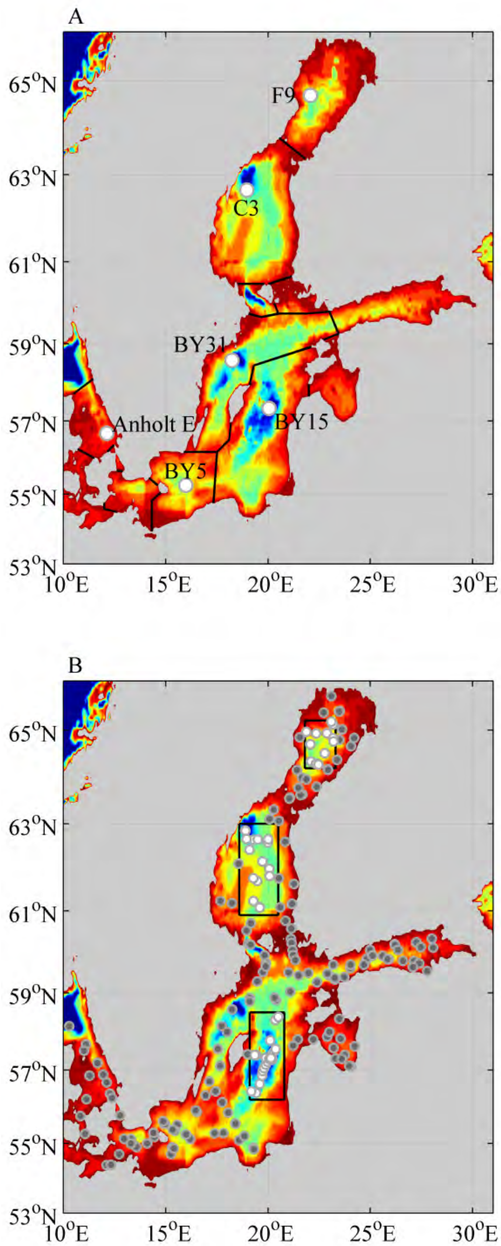


Figure 1. Maps of the Baltic Sea. A) The six sampling locations chosen from the SHARK-database are indicated with white dots and the 13 sub-basins used in the model are indicated by black lines. B) Data acquired during cruises preformed within the Baltic-C project is indicated with dots (grey and white). Black boxes enclose the data which is used in this study (white dots).

3. Modeling dissolved organic matter

Dissolved organic matter (DOM) is introduced to the model. Modeled DOM is divided into DOP (dissolved organic phosphorus), DON (dissolved organic nitrogen), DOCt (dissolved organic carbon of a terrigenous origin) and DOCm (dissolved organic carbon of a marine origin). This brings riverine organic matter as a nutrient source to the plankton community and also enables realistic recycling of matter within the euphotic zone, see Fig. 2.

Effectively, this exploits a new nutrient pool and enhances the modeled biological production. This is especially important in the phosphate deprived northern basins, but also improves the pCO_2 seasonal cycle in other Baltic Sea basins.

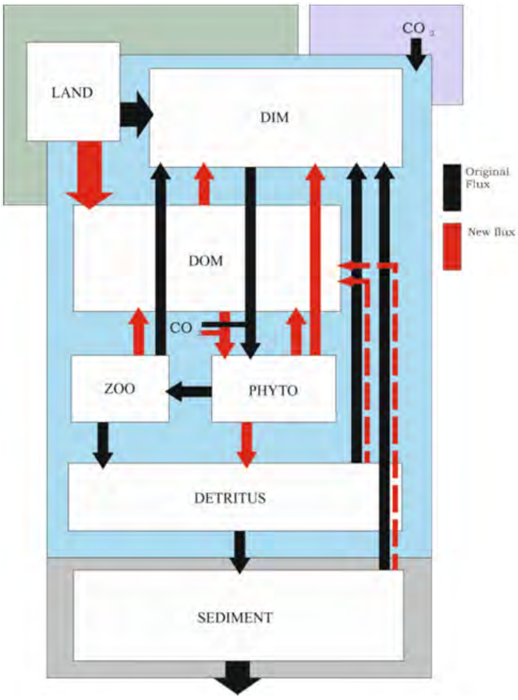


Figure 2. Schematic illustration of matter transformation between the marine pools with or W/O taking DOM into consideration.

Concentrations of dissolved organic N and P are forced from land with the difference between the total concentrations and inorganic fractions. The resulting DON and DOP pools are degraded into inorganic nutrient, the rate depending on temperature and substrate, but also used to sustain the dinoflagellates and cyanobacteria during summer when the inorganic concentrations are low.

Land derived DOC forcing is taken from CSIM scenario data (Omstedt et al. 2012) and degraded at a slower rate than in situ produced marine DOC.

4. Results

This study investigates the different roles of the functional phytoplankton groups in reproducing a realistic seasonal surface variation of nutrient species and carbon species alike, in the Eastern Gotland basin, the Bothnian Sea and the Bothnian Bay. The results show improved model skill in general, especially in recreating the timing of biological drawdown of CO_2 in the Bothnian Bay. Up-to-date results will be shown during the presentation.

5. Conclusions

Important information about proper parameterization of phytoplankton abundance and production in numerical models can be gained by modeling efforts to simultaneous produce realistic variation of total nutrient properties, its inorganic species and the dissolved CO_2 system. To get correct seasonal timing and durability of the biological drawdown of CO_2, and the assimilation and redistribution of nutrients, the dissolved organic fractions need to be considered.

References

Eilola, K., B. G. Gustafsson, I. Kuznetsov, H. E. M. Meier, T. Neumann, and O. P. Savchuk. (2011) Evaluation of biogeochemical cycles in an ensemble of three state-of-the-art numerical models of the Baltic Sea., J. Mar. Syst., 88, pp. 267–284

Omstedt, A., Edman, M., Anderson, L., G., and H., Laudon (2010) Factors influencing the acid-base (pH) balance in the Baltic Sea: A sensitivity analysis. Tellus B, 62B, 280-295.

Omstedt, A., Edman, M., Claremar, B., Frodin, P., Gustafsson, E., Humborg, C., Hägg, H., Mörth, M., Rutgersson, A., Schurgers G., Smith, B., Wällstedt, T. and A. Yurova (2012) Future changes in the Baltic Sea acid-base (pH) and oxygen balances, Tellus B, 64B, 19586

Tracing terrestrial DOC in the Baltic Sea – A 3D model study

F. Fransner[1], C. Humborg[2,3] , H.E.M. Meier[4], C.M. Mörth[2,5] and J. Nycander[1]

[1] Institute of Meteorology, Stockholm University, Stockholm, Sweden (filippa@misu.su.se)
[2] Department of Applied Environmental Science, Stockholm University, Stockholm, Sweden
[3] Baltic Nest Institute, Stockholm Resilience Center, Stockholm University, Stockholm, Sweden
[4] Swedish Meteorological and Hydrological Institute, Norrköping, Sweden
[5] Department of Geological Sciences, Stockholm University, Stockholm, Sweden

The fate of terrestrial organic matter in the marine environment and what role it plays in the carbon cycle is of great interest as rivers bring huge amounts of it each year to coastal seas. With global warming and an increased river runoff this discharge is expected to increase, therefore, it is important to understand the dynamics of the terrigenous carbon in the marine environment. In this study we have focused on the path of terrestrial dissolved organic carbon (DOC_{terr}) in the Baltic Sea. This was done by comparing results from a 3D circulation model, where DOC_{terr} had been released into the Baltic Sea with the surrounding rivers, with samples of stable carbon isotope observations separating DOC with marine and terrestrial origin, respectively. From this we could draw some conclusions regarding the magnitude of the processes affecting the removal of DOC_{terr} from the water column and its potential effect on the inorganic carbon system of the Baltic Sea.

Simulations of eutrophication scenarios using the current and an improved version of ERGOM

Rene Friedland[1], Thomas Neumann[1], Gerald Schernewski[1,2]

[1] Leibniz Institute for Baltic Sea Research (IOW), Germany, (rene.friedland@io-warnemuende.de)
[2] Coastal Research and Planning Institute, Klaipeda University, Lithuania

1. Climate change and the Baltic Sea action plan: Model simulations on the future of the western Baltic Sea

We applied the biogeochemical model ERGOM to simulate the consequences of Climate Change as well as the combination of Climate Change with nutrient load reductions according to the Baltic Sea Action Plan (BSAP) on the Baltic Sea ecosystem.

According to the simulations, Climate Change will cause an increase of the water temperature up to 3 K and a salinity decrease of 1.5 PSU until 2100. However, the implementation of the BSAP will have much stronger effects on the ecosystem. The model suggests that the western Baltic Sea will shift from a nitrogen (N) towards a phosphorus (P) limited system. As a consequence, N-fixation will strongly decrease. The same applies to nutrient-concentrations in winter, denitrification as well as detritus and chlorophyll concentrations in summer. The availability of N in summer, the Secchi depth and the oxygen saturation will increase. Our simulations suggest that the full implementation of the BSAP will cause imbalances in the Baltic Sea over decades before a new system state will be reached.

2. Effects of an improved ERGOM

The current versions of the Baltic Sea‘s biogeochemical models – although broadly used for climate change or eutrophication scenario simulations – contain many shortcomings. In the second part of the talk some improvements of IOW‘s ecosystem model ERGOM will be presented, e.g. the effect of a finer horizontal resolution in the western Baltic Sea or the influence of a more detailed allocation of freshwater and nutrient inputs from land.

References

R. Friedland, T. Neumann, G. Schernewski (2012) Climate change and the Baltic Sea action plan: Model simulations on the future of the western Baltic Sea, Journal of Marine Systems, Vol. 105–108, pp. 175-186, DOI: 10.1016/j.jmarsys.2012.08.002.

Land cover-climate interactions in the past for the understanding of current and future climate change: The LANDCLIM project

Marie-José Gaillard[1], Anna-Kari Trondman[1], Jed O. Kaplan[2], Anneli Poska[3], and Gustav Strandberg[4]

[1] Department of Biology and Environmental Science, Linnaeus University, Kalmar, Sweden (marie-jose.gaillard-lemdahl@lnu.se
[2] ARVE Group, Ecole Polytechnique Fédérale de Lausanne, Station 2, 1015 Lausanne, Switzerland
[3] Department of Earth and Ecosystem Sciences, Lund University, Sölvegatan 12, 223 62 Sweden
[4]Swedish Meteorological and Hydrological Institute, 60176 Norrköping, Sweden

1. Introduction

There is today a general understanding on the need of powerful climate models for societies to be informed on the current climate and its possible development in the future. Knowledge on possible scenarios of climate change is required for setting up alternative strategies to avoid catastrophes that might endanger environment and human life. Climate models help us to understand the climate system as a whole and to envisage our future. However, although climate models do exist since many decades, they have not ceased to get better, and still can become better. A way to improve climate models is to test them over long time-periods in the past, i.e. run the model for centuries and millennia back in time and compare the results with reconstructions of pas climate based on geological data. Vegetation (land cover), climate (natural) and human-induced, is an inherent part of the climate system. It exerts biogeochemical (affecting sources and sinks of greenhouse gases, aerosols, pollutants and other gases) and biophysical (affecting heat and water fluxes, wind direction and magnitude) feedbacks on the atmosphere. These feedbacks are either positive, amplifying changes or variability in climate, or negative, attenuating variability and slowing trends in climate. Carbon cycle feedbacks have received particular attention, but biophysical interactions between the land surface and atmosphere have been less studied although they can be of comparable importance at the regional scale. Therefore, the incorporation of dynamic vegetation into climate models to account for feedbacks and refine global change projections is a current priority in the global climate modeling community (e.g. van der Linden and Mitchell, 2009).

In this context, there is a growing need for descriptions of vegetation/land-cover in the past at continental to global scales for the purpose to test, evaluate and improve dynamic vegetation and climate models. The development of databases of human-induced changes in land cover based on historical records, remotely-sensed images, land census and modeling (e.g. Klein-Goldewijk et al., 2010; Kaplan et al., 2009; Olofsson and Hickler, 2008; Pongratz et al., 2008) has been informative to evaluate the effects of anthropogenic land-cover changes on the past climate. However, these datasets show inconsistent estimates of land cover during key time periods of the past (Gaillard et al., 2010). Therefore, the development of tools to quantify and synthesize records of vegetation/land cover change based on e.g. pollen data is essential to evaluate model-based scenarios and to improve their reliability. Until recently it was not possible to translate pollen records from lake sediments or bog peat into vegetation abundance, e.g. percentage cover of plants. A pollen-vegetation model (REVEALS – Regional Estimates of VEgetation Abundance from Large Sites) that makes it possible to translate fossil pollen data into vegetation cover was developed by Sugita (2007). The REVEALS model provides better estimates of the regional vegetation/land-cover changes, and in particular open, herb-dominated areas, than the traditional pollen percentages and earlier attempts at correcting or calibrating them. REVEALS thus allows a more robust assessment of past human-induced land cover in quantitative terms at regional- to continental-spatial scale.

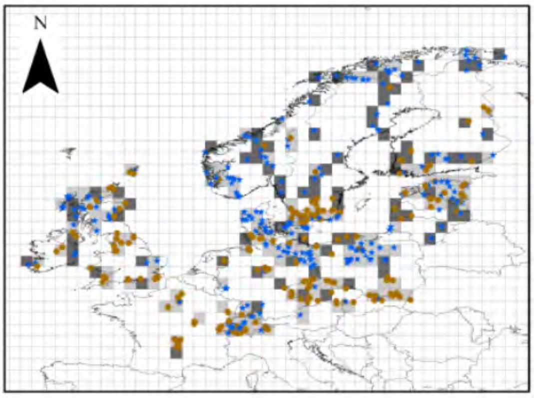


Figure 1. Study area of the LANDCLIM project, common 1°x1° grid and location of the sites with pollen records. The dark grid-cells include 1-2 sites which often implies less reliable REVEALS estimates. Modified from Trondman et al. (2013, soon submitted).

2. The LANDCLIM project

The LANDCLIM (LAND cover – CLIMate interactions in NW Europe during the Holocene) project and research network were sponsored during the years 2009-2011 by the Swedish [VR] and Nordic [NordForsk] Research Councils, respectively, and is sponsored since 2010 by the Swedish strategic research area ModElling the Regional and Global Earth system, MERGE. LANDCLIM has the overall aim to quantify human-induced changes in regional vegetation/land-cover in northwestern and western Europe North of the Alps (Figure 1) during the Holocene (the last 11 500 years) with the purpose to evaluate and further refine a dynamic vegetation model (LPJGUESS, Smith et al., 2001) and a regional climate model (RCA3, Samuelsson et al., 2010), and to assess the possible effects on the climate development of two historical processes, i.e. climate-driven changes in vegetation and human-induced changes in land cover, via the influence of forested versus non-forested land cover on shortwave albedo, energy and water fluxes. The relationship between this effect and the biochemical effect of forest versus openland for the CO2 balance is not known at present. Accounting for land surface changes may be particularly important for regional climate modeling, as the biophysical feedbacks operate at this scale. The aims of the LANDCLIM project are achieved by applying a model-data comparison scheme (Figure2).

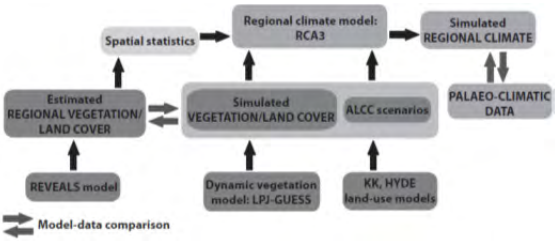


Figure 2. Model-data comparison scheme of the LANDCLIM project. The REVEALS model is used to estimate land cover from pollen data for 10 plant functional types (PFTs) and 5 time windows of the Holocene - modern time, 200 BP, 500 BP, 3000 BP and 6000 BP, as well as for the entire Holocene at 20 selected sites. The REVEALS estimates are then compared to the LPJGUESS simulations of potential vegetation and with the ALCC scenarios of Kaplan et al. (2009) (KK10) and Klein-Goldewijk et al. (2010; HYDE). The alternative descriptions of past land-cover are then used in the regional climate model RCA3 to study the effect of anthropogenic land-cover on climate. The climate model- simulated climate is finally compared to reconstructions of past climate based on other proxies than pollen. Modified from Trondman et al. (2013, submitted).

3. Material and methods

For the data-comparison approach, see the caption of Figure 2. The pollen-based REVEALS estimates of land cover are based on over 600 pollen records extracted from the European (EPD) Pollen Database (EPD), Czech Pollen Database (PALYCZ) and Alpine Pollen Database (ALPADABA), or obtained directly from the authors. All pollen data (including pollen-morphological taxonomy and nomenclature) and chronologies were carefully checked for correctness and consequence. LPJGUESS was run for the 5 selected time windows of the Holocene (Fig. 2, caption) and the entire Holocene at the same selected sites as the 20 Holocene pollen records. RCA3 was run for modern time, 200 BP and 6000 BP with two alternative land cover, i.e. LPJGUESS simulated land-cover and the KK10 scenarios.

4. Results

The REVEALS estimates demonstrate that the study region was characterized by larger areas of human-induced openland than pollen percentages suggested, and that these areas were already very large by 3000 BP (Fig. 3). The KK10 scenarios were found to be closer to the REVEALS estimates than the HYDE scenarios (Kaplan et al., 2013, submitted). LPJGUESS simulates potential climate-induced vegetation and, therefore, the model outputs differ from the REVEALS estimates as the latter include human-induced vegetation. The results from the RCA3 runs at 200 BP and 6000 BP using the LPJGUESS and KK10 land-cover descriptions indicate that past human-induced deforestation did produce a decrease in summer temperatures of >0 - 1.5°C due to biogeophysical processes, and that the degree of decrease differed between regions; the effect of human-induced deforestation on winter temperatures was shown to be more complex (Strandberg et al., 2013, submitted).

5. Conclusions

Human-induced open land-cover such as cultivated fields and grazing land may have produced a significant decrease in summer temperatures already from 3000 BP and mitigated the general human-induced increase in temperatures since AD 1850 due to increased CO_2 in the atmosphere. The positive property of forests as CO_2 sinks is well known. But afforestation (i.e. planting forest) may also have the opposite effect of warming the climate through biogeophysical processes. Careful studies on land cover-climate interactions are essential to understand the net result of all possible processes related to anthropogenic land-cover change so that relevant landscape management can be implemented for mitigation of climate warming.

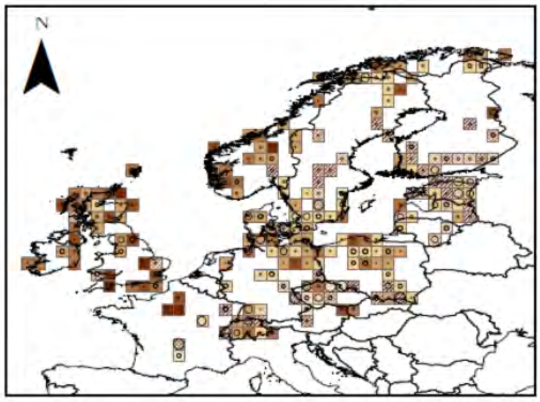


Figure 3. Cover of the PFT Grassland (Cyperaceae, *Filipendula*, *Plantago lanceolata*, *Plantago montana*, *P. media*, Poaceae, *Rumex* p.p. /*Rumex acetosa*-t) at 3000 BP. Modified, Trondman et al. (submitted). The darker the color, the higher the % cover.

References

van der Linden, P. and Mitchell, J. F. B. (2009) ENSEMBLES project, Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK, 160 pp.

Klein Goldewijk, K., Beusen, A., and Janssen, P. (2010) The Holocene, 20, 565–573.

Kaplan, J., Krumhardt, K., and Zimmermann, N. (2009) Quaternary Sci. Rev., 28, 3016–3034.

Kaplan, J., Krumhardt, K., Trondman, A.-K., Gaillard, M.-J., et al. (2013) Submitted to Global Change Biology.

Olofsson, J. and Hickler, T. (2008) Veg. Hist. Archaeobot., 17, 605–615.

Pongratz, J., Reick, C., Raddatz, T., and Claussen M. (2008) Global Biogeochem. Cy., 22, GB3018, doi:10.1029/2007GB 003153.

Samuelsson, P., Gollvik, S., Hansson, U., Jones, C., Kjellström, E., et al. (2010) Tellus A, , 63A(1), 4-23. DOI: 10.1111/j.1600-0870.2010.00478.x.

Smith, B., Prentice, I. C., and Sykes, M. T. (2001) Global Ecol. Biogeogr., 10, 621–637.

Strandberg et al. (2013) Submitted to Climate of the Past.

Trondman, A.-K., Gaillard, M.-J., Sugita, S., Mazier, F. et al. (2013) Submitted to Global Change Biology.

Impact of the emissions of the international sea traffic on the airborne deposition to the Baltic Sea and concentrations at the coastline

Marke Hongisto

Finnish Meteorological Institute, Helsinki, Finland (marke.hongisto@fmi.fi)

The estimates of atmospheric deposition of various anthropogenic contaminants to the Baltic Sea (BS) are very important due to the poor ecological state of this vulnerable, semi-closed, shallow sea with brackish water. The EMEP Western Centre estimates on annual basis the airborne load of oxidized and reduced nitrogen to the BS for HELCOM, and the Eastern Centre calculates deposition of heavy metals over the area, both reporting the results in a 50 km grid. In addition several Nordic research institutes have evaluated the atmospheric deposition to the BS. Among others, the dispersion of nitrogen and sulphur compounds during the period 2006-2011 has also been studied with the chemistry-transport model Hilatar (Hongisto, 2003) over Europe with around 17 km, 0.15^{o} grid, and over the Baltic Sea with 0.08^{o} - 0.068^{o} (~ 7 km) resolution using a specific Baltic Sea ship emission inventory originally presented in Stipa e.a. 2007. In this paper the role of the ship emissions on the sulphur and nitrogen deposition and concentrations at the coastal sites over the period studied are presented.

1. Materials and methods

The chemistry-transport model Hilatar uses the 6^{th} hour predictions of the operational version of the HIgh Resolution Limited Area Model (Unden et al.,2002), run at the Finnish Meteorological Institute (FMI) since 1990 with different parameterizations. Since March 2012 the European reference HIRLAM has 65 vertical layers and 0.068^{o} horizontal resolution, in this work the finest resolution of the European model was 0.15^{o}, and for the BS model the horizontal resolution was 0.08^{o} (2006-200711) and 0.068^{o} since then.

The main numerical methods and parameterizations of Hilatar are described in Hongisto 2003. The model uses acid compound chemistry with nitrogen, sulphur and ammonium compounds or chemically inert module for particles. Over Europe Hilatar has used the 50-km EMEP- emission inventory. For the 2011 simulations it has been changed to the TNO MACC 2007 inventory with around 10 km resolution. The MACC emissions have been scaled to the year 2010 values by using the annual country emissions reported to EMEP. For stack sources in Finland we use the National VAHTI emissions and for North-West Russian an updated own inventory. In the current paper we also compare how the use of different inventories affects the deposition. Model validation results against measurements are presented in Hongisto (2003, 2011 and 2012) and in references within them. For concentrations some validation is presented in Figure 1. In spring the underestimation of the concentrations reflects difficulties in estimating the mixing height and stability over a cold sea.

2. Preliminary results

The simulations with the MACC emissions and those for the year 2011 are still in process, however the share of the ship emission over the previous years has been partly analyzed.

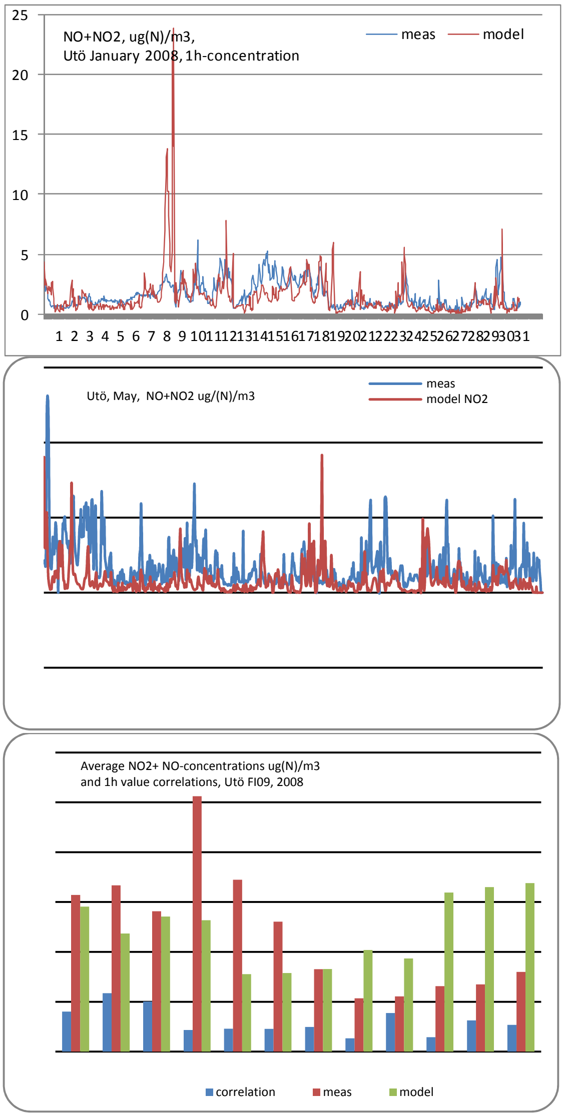


Figure 1. Model-measurement inter-comparison: examples of 1h NOx ($NO+NO_2$) concentrations in winter and spring, and monthly NOx-concentrations and correlation

In Figure 2 the total deposition of oxidized nitrogen (NOy) and the ship-emission originated deposition are presented. The ship-emission oriented share of the total deposition was 4-7 % in late spring and winter (OND-JF), 22-30 % in May- July and 11-16 % in Mars-April and August-September 2008. The wet deposition share varied between 44-65 % of the total NO_y-deposition in 2008. The share of the ship-oriented deposition was higher in dry months when wet deposition was smaller. 2009 the share of the ship emission oriented deposition of the monthly NOy-deposition varied between 3 and 27 %, as presented in Fig. 2.

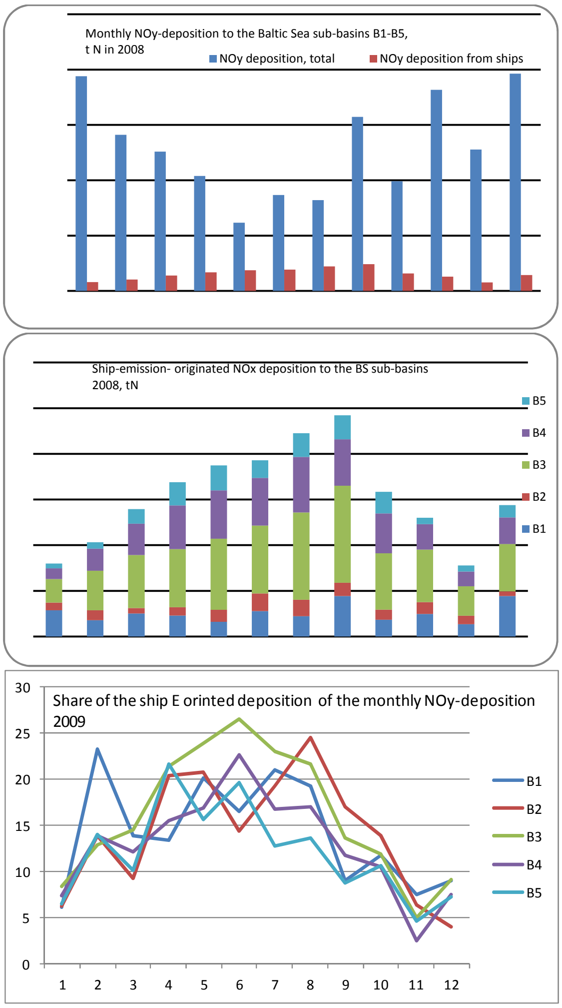


Figure 2. Monthly deposition of oxidized nitrogen to the Baltic Sea in 2008 caused by all European and ship emissions, the ship emission oriented deposition to the various BS sub-basins and the share of the ship emission oriented deposition of the monthly NOy-deposition in different BS sub-basibs in 2009. B1: the Bothnian Sea and Bay, B2: Gulf of Finland, B3: Northern Baltic Proper, B4: Southern Baltic Proper, B5: Kattegatt and the Belt Sea.

In Fig. 3. the geographical distribution of the ship-emission originated deposition of oxidized nitrogen and oxidized sulphur are presented. The sulphur deposition is deposited much closer to the ship lanes. In the presentation differences between the years in 2006-2011, reasons to inter-annual variation and the possible trend of ship emission originated depositions and concentrations are discussed.

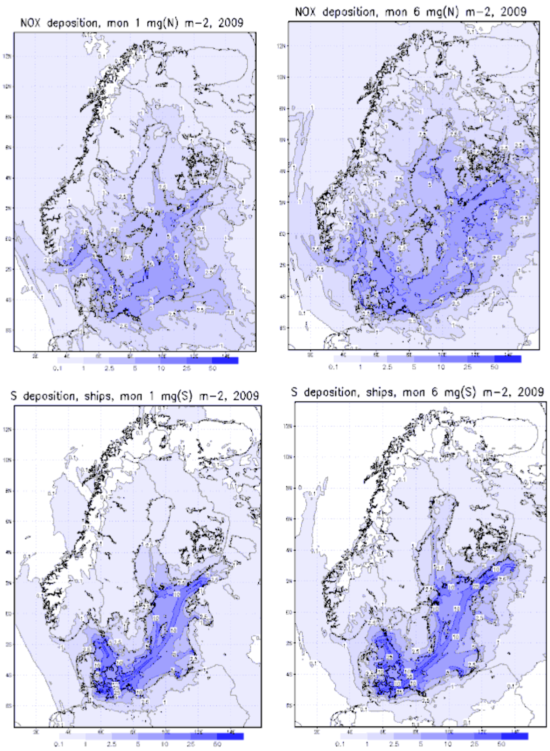


Figure 3. Ship-emission oriented oxidezed nitrogen and sulphur deposition in January and June 2009, mg S or N m^{-2}.

References

Hongisto M., 2003. Modelling of the transport of nitrogen and sulphur contaminants to the Baltic Sea Region. FMI Contributions No- 40, Helsinki 2003, 188 p. http://lib.hut.fi/Diss/2003/isbn9512264811/index.html

Hongisto M., 2012. Origin and possible effects of episodic nutrient deposition events over the Baltic Sea. IJEP, Int. J. Environment and Pollution, Vol. 50, Nos. 1/2/3/4, 2012. pp. 293-307

Hongisto, M., 2011. Variability of the marine boundary layer parameters over the Baltic Sea sub-basins and their impact on the nitrogen deposition. Oceanologia, 53 (1-T1) pp. 391-413.

MACC, 2011. MACC Euriopean emission inventory for the Years 2003-2007. TNO report TNO-060-UT-2100-00588. www.tno.nl

Stipa T., Jalkanen J-P., Hongisto M., Kalli J and Brink A., 2007. Emissions of NOx from Baltic shipping and first estimates of their effects on air quality and eutrophication of the Baltic Sea. ISBN:978-951-53-3028-4.

Unden e.a., 2002. HIRLAM-5 Scientific Documentation. HIRLAM-5 project, 144 p.

Will the growing season have changed in Poland by the end of the 21st century? Intra- and multi-model projections

Joanna Jędruszkiewicz

Department of Meteorology and Climatology, University of Lodz, Łódź, Poland (jjedruszkiewicz@gmail.com)

1. Introduction

The agriculture is the area of economy that is highly sensitive to climate change. According to IPCC (2007) a large differentiation of the potential impact on crop yield in Europe is expected (positive in the north and negative in the south). In order to achieve the most reliable knowledge about changes in agriculture, a detailed spatial assessment should be done. An increasing number of studies, based on phenological, satellite and climatological studies (Linderholm 2006), have reported on shifts in timing and length of the growing season. Furthermore the timing of spring events such as budding, leafing and flowering, is mainly regulated by temperatures after the dormancy is released. This study gives consideration to influence of the climate change on growing season in Poland in 21st century on the basis of the regional climate models projections. The shifts in the beginning and end dates of the growing season have been analyzed as well as its duration. Moreover the differences between regional climate model projections have been examined.

2. Data and methods

Daily mean 2-meter temperature (T_{2m}) from seven regional climate models for A1B scenario were obtained for two scenario period 2021-2050 (S1) and 2071-2100 (S2). Five of all models: HIRHAM[1] (Norwegian Meteorological Institute), HIRHAM5 (Danish Meteorological Institute), RegCM3 (International Centre for Theoretical Physics), RCA (Swedish Meteorological and Hydrological Institute), RACMO2 (Royal Netherlands Meteorological Institute) data were collected from the ENSEMBLE project (http://ensemblesrt3.dmi.dk), the CLM data form the Max-Planck Institute (http://cera-www.dkrz.de) and the WRF data assimilated by Department of Meteorology and Climatology, University of Lodz that was previously developed among the NCEP/NCAR and other institutes (http://www.wrf-model.org/index.php). The control 40 station T_{2m} data were acquired from the Institute of Meteorology and Water Management, National Research Institute.

Before any analysis was set out, the simulated T_{2m} data for scenario S1 and S2 had been corrected. The correction was based on quantile mapping method. It was so called "distribution-based" bias correction described in more details by Déqué (2007) and Piani et al. (2010).

The meteorological growing season (MGS) was determine on the Huculak and Makowiec (1977) method basis. A beginning of the MGS is considered as the earliest day with T_{2m} equal or higher than 5°C, which gives the beginning for such cumulative deviation from the 5°C that until the end of the first half-year do not reach negative values. On the other hand, the end of the MGS is a date preceding the day when the is T_{2m} equal or lower than 5°C and give the beginning for such cumulative deviation from the 5°C that until the end of the year do not reach positive values. Furthermore the duration of the growing season is the difference between the end and the beginning of the MGS. This method assumes the homogeneity of the daily mean temperature series.

3. Growing season based on multi-model projections

Typically, the growing season in Poland begins at the earliest in the west and south west (beginning of march) and at the latest in the north east and mountain region (april). On the contrary the end of the MGS at the earliest appear in the east and south part of the country (last decade of September) and at the latest in the Oder Valley region (beginning of November).

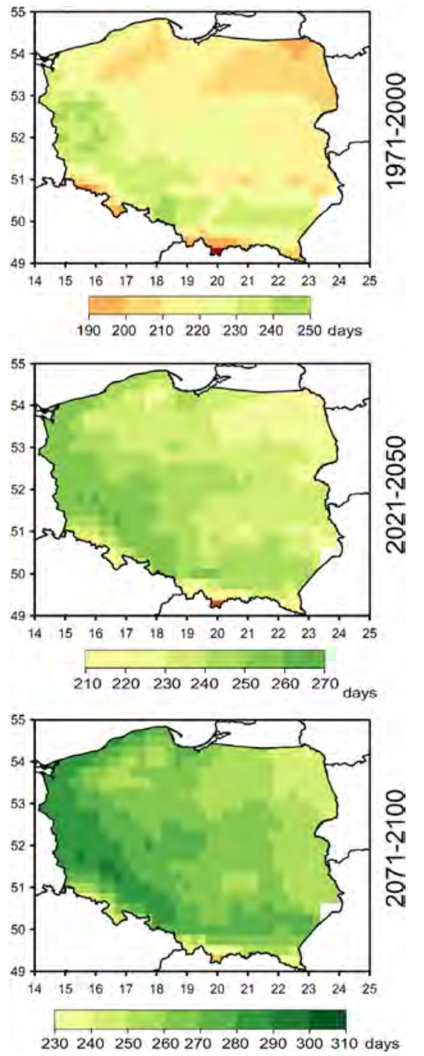


Figure 1. Multi-model projections of the meteorological growing season in control period (1971-2000) and scenario periods (2021-2050 and 2071-2100).

[1] Available data only for the S1 scenario

Although future changes in growing season are prominent in every aspect, the most pronounced are for the MGS end dates shift. By the end of the 21st century growing season end dates will have been subjected to approximately month delay. Once, the end of MGS is predicted to be shifted forward, the beginning of MGS will be moved backward of about three weeks. Due to the spring warming the plant growth will begin around 8-18th February in the west and 10-20th March in the east and mountain region. As a consequence of that the length of the growing season will be extended.

In general the shortest observed MGS duration was below 190 days in the far northeast of Poland, Sudeten and Carpathian Mountains (Fig. 1). In Central Poland the growing season was around 220-230 days and the longest in Oder Valley more than 230 days. In the future scenario the spatial distribution of the growing season length remain similar. Nonetheless the duration will be extended. According the multi-model projection, by the 2021-2050, the MGS will have been longer of a month on NE Poland and three weeks in W and SW Poland. Furthermore, by the end of 21st century the growing season will have been longer of about 40-50 days in the northeast and more than two months in the northwest, west and southwest Poland.

4. Intra-model projection

For 2021-2050 period the seven analyzed models projections have revealed quite good agreement with no significant differences between model in the beginning and end dates of the growing season. On the contrary, considerable intra-models variation have been projected for the 2071-2100 period. The most extreme projections of the beginning dates are presented for HIRHAM5 and RegCM3 model (differences less than a month) and the end dates are for RegCM3 and CLM models (more than a month). Furthermore, the length of the growing season is not as diversified as the above mention dates (only in the west up to 20 days). The RegCM3 is the only exception with the longer MGS length of 20-50 days than average.

5. Conclusion

Increased temperatures in the 21st century will certainly have large agriculture consequences in Poland, while some species will benefit from warmer and longer growing season (e.g. maize), the others will lose (e.g. potatoes and wheat). Moreover, the acceleration of the vegetation cycle might have a negative consequences for grain filling and quality. The perennial crops are also at risk of the phenological phases shifts, because they have a less opportunity to adapt to the new plant calendar. Changes in the timing and length of the growing season may not only have far reaching consequences for plant and animal ecosystems, but persistent increases in MGS may lead to long-term increase in carbon storage and changes in vegetation cover which may affect the climate system.

Acknowledgements

Present work was funded by Polish National Science Centre under grant N N306 602040 (2011-2013).

References

Déqué, M., (2007) Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: Model results and statistical correction according to observed values, Global and Planetary Change, 57, pp. 16-26

IPCC, (2007) Europe [in:] Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, pp. 541-580

Linderholm, H.W., (2006) Growing season changes in the last century, Agricultural and Forest Meteorology, 137, pp. 1-14.

Huculak, W., M., Makowiec, (1977) Determination of the meterological growing season on the annual observation basis. Zesz. Nauk. SGGW, 25, pp. 65–72 (in polish)

Piani, C., J. O., Haerter, E., Coppola, (2010) Statistical bias correction for daily precipitation in regional climate models over Europe, Theor Appl Climatol, **99**, pp. 187-192

Anthropogenic sources of nutrient pollution as a cause of degradation of the Baltic Sea and sustainable wastewater management for its prevention

Edyta Kiedrzyńska[1, 2,] *, Marcin Kiedrzyński[3], Magdalena Urbaniak[1, 2], Artur Magnuszewski[4] and Maciej Zalewski[1,2]

[1] International Institute of the Polish Academy of Sciences, European Regional Centre for Ecohydrology under the auspices of UNESCO, 3 Tylna Str., 90-364 Lodz, Poland. *e-mail: edytkied@biol.uni.lodz.pl
[2] University of Lodz, Faculty of Biology and Environmental Protection, Department of Applied Ecology, 12/16 Banacha Str., 90-237 Lodz, Poland.
[3] University of Lodz, Faculty of Biology and Environmental Protection, Department of Geobotany and Plant Ecology, 12/16 Banacha Str., 90-237 Lodz, Poland.
[4] Warsaw University, Faculty of Geography and Regional Studies, Institute of Physical Geography Krakowskie Przedmieście 30, 00-927 Warsaw, Poland.

1. Introduction

Anthropogenic sources of nutrient pollution are the main cause of the still increasing eutrophication and occurrence of toxic cyanobacteria blooms in the Baltic Sea. It is caused by the inflow of large loads of Total Phosphorus (TP) and Total Nitrogen (TN) (HELCOM, 2011) from sewage treatment plants (STPs), which discharge poorly treated wastewater (WW) via rivers to the sea. According to BSAP (2007), about 75% of the nitrogen load and at least 95% of the phosphorus load enter the sea via rivers or as direct waterborne discharges.

The total input of nutrients to the Baltic Sea amounted to 638 000 tonnes (t) of TN and 28 400 t of TP in 2006. Poland discharged the largest amount of phosphorus (36%, 10 224 t TP) and nitrogen (24%, 153 120 t TN) from all the Baltic countries (Knuuttila, 2011) and therefore, it is critical to decrease the emission of nutrients from STPs to rivers and in consequence also riverine P and N loads to the Baltic Sea. The activities of the Baltic countries aiming to reduce the degradation of the Baltic Sea and to achieve a good ecological status should primarily rely on the quantification of pollutants from point sources in individual catchments and understanding of the migration process along the river continuum, and then on the sustainable management of water resources, both on the local, regional and transborder scale.

The research was carried out in the Pilica River catchment, which is 9258 km^2 in area and is located in central Poland (Fig. 2). The Pilica River (342 km long) is the biggest left-bank tributary of the Vistula River. The Vistula River is the second (after the Neva) longest river (1092 km) draining into the Baltic and according to Buszewski et al. (2005) is one of the most polluted rivers in Europe. The Vistula and Pilica Rivers traverse some of the most industrialized and polluted areas in Europe, especially in Silesia.

The aim of the research was to evaluate the role of STPs located within the Pilica River catchment in nutrient transfer to the Pilica River along the entire length from the source to the estuary into the Vistula River. Furthermore, the objective was to develop effective methods to reduce the outflow of pollutants from STPs by applying the solutions based on ecohydrology and phytotechnologies (Zalewski 2000; Kiedrzyńska et al. 2008; Kiedrzyńska and Zalewski 2012).

2. Material and methods

Physicochemical monitoring of the Pilica River was conducted at 6 sites from the upland (site R1) to the lowland estuary to the Vistula River (site R6) between 2010 and 2012 (Fig. 1). Monitoring of wastewater (WW) was conducted at the outlets of 17 sewage treatment plants (S1-S7), which were divided into three size categories: class I: 0 – 1 999; class II: 2 000 – 9 999, class IV: 15 000 – 99 999 of the population equivalent (p.e.).

Total phosphorus (TP) was determined by the ascorbic acid method (Greenberg et al., 1992). Total nitrogen (TN) was analysed using the persulphate digestion method (HACH 1997). Water samples for soluble forms of nutrients, e.g. soluble reactive phosphorus (SRP), NO3-, NO2-, NH4+, were analysed with the Ion Chromatography System (DIONEX, ICS 1000).

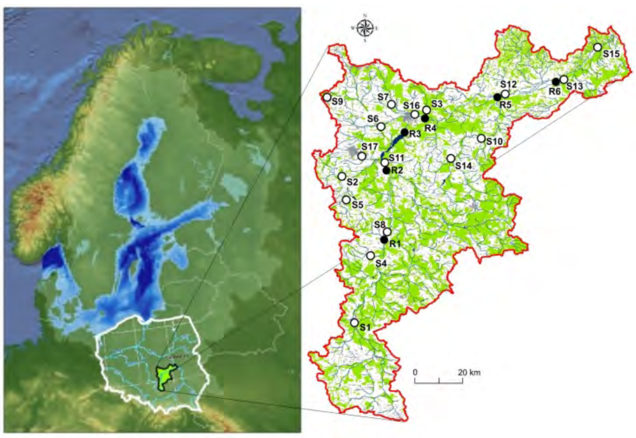


Figure 1. Location of the Pilica River catchment (central Poland) compared to other countries of the Baltic Sea catchment and location of riverine (R1 − R6) and STPs monitoring sites (S1 – S17).

3. Results

The results indicate significant pollution of the Pilica River by nutrients along its entire length. Analysis of point sources of pollution in the Pilica River catchment indicates that wastewater is not sufficiently treated. Concentrations of phosphorus and nitrogen exceeds the legal limit several times. According to the Polish standards (in accordance with the Regulation of the Minister of Environment of 24 July 2006) and Wastewater Directive (91/271/EEC), concentrations in the effluent from STPs shall not exceed

- class I (<2 000 p.e.) − 5 TP mg dm^{-3} and 30 mg dm^{-3} TN
- class II (from 2 000 to 9 999 p.e.) − 2 mg TP dm^{-3} and 15 mg dm^{-3} TN

- class IV (from 15 000 to 99 999 p.e.) − 2 mg TPdm^{-3} and 15 mg dm^{-3} TN

Reduction of nutrients concentrations in the wastewater flowing out of STPs should be one of the main objectives of the sustainable water management in river basins. This is especially important in the Pilica River catchment due to a large load of wastewater outflow from industrial, municipal and domestic STPs (Fig. 2)

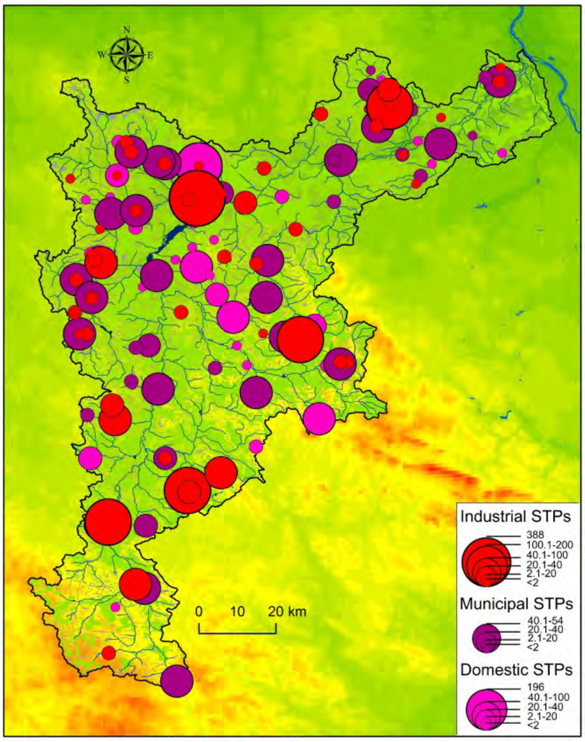


Figure 2. Location and wastewater outflow from industrial, municipal and domestic STPs in the Pilica River catchment in 2010.

It most difficult for small STPs to maintain the standards of nutrients concentrations in the wastewater and due to the large number of such STPs in the Pilica River catchment, they are discharging a significant load of nutrients directly to the Pilica River or its tributaries. Large STPs, despite having more advanced technology to capture nutrients and being most effective, discharge the largest loads of nutrients as a consequence of large outflows.

4. Wastewater management

Sustainable Wastewater (WW) Management in a catchment should be based on the principle "think globally act locally" and include the top down – bottom up approach for point sources pollution reduction and management to minimize the environmental contamination hazard and to improve water quality in rivers and the Baltic Sea (Fig. 3).

As evidenced by the research, sustainable WW management should focus both on large cities and small towns, because they are a major threat to the water purity. In order to reduce the outflow of pollution from STPs and to increase the efficiency in phosphorus and nitrogen capturing, it is necessary to develop a model of system solutions based on the concept of ecohydrology and phytotechnologies. Innovative technologies, such as biochemical filtration zones, geotextiles, hydrobotanical wastewater treatment utilizing the most efficient macrophyte species, should also be used in these systems. This kind of effective solution is being developed with good results for STP in the Rozprza town (central Poland).

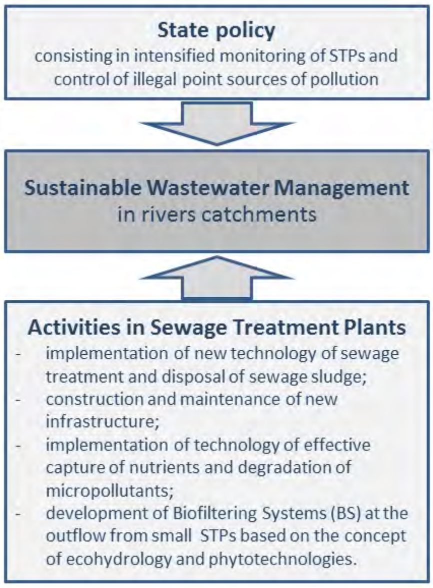


Figure 3. Top down – Bottom up approach towards integrated wastewater management in rivers catchments.

Acknowledgments

The research was funded by the Polish Ministry of Science and Higher Education, Project - NN305 365738 'Analysis of point sources pollution of nutrients, dioxins and dioxin-like compounds in the Pilica River catchment and draw up of reclamation methods'.

References

Buszewski, B., Buszewska, T., Chmarzyński, A., Kowalkowski, T., Kowalska, J., Kosobucki, P., Zbytniewski, R., Namieśnik, J., Kot–Wasik, A., Pacyna, J., Panasiuk, D., 2005. The present condition of the Vistula river catchment area and its impact on the Baltic Sea coastal zone. Regional Environmental Change 5, 97–110.

Greenberg, A.E., Clesceri, L.S., Eaton, A.D., 1992. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington.

HACH, 1997. Water analysis handbook. pp. 1309.

HELCOM, 2011. The Fifth Baltic Sea Pollution Load Compilation (PLC-5) Baltic Sea Environment Proceedings No. 128.

Kiedrzyńska, E., Wagner-Łotkowska, I., Zalewski, M., 2008. Quantification of phosphorus retention efficiency by floodplain vegetation and a management strategy for a eutrophic reservoir restoration. Ecological Engineering 33, 15-25.

Kiedrzyńska, E., Zalewski, M., 2012. Water Quality Improvement Through an Integrated Approach to Point and Non-Point Sources Pollution and Management of River Floodplain Wetlands. In: Voudouris, K., Voutsa, D., (eds). Ecological Water Quality – Water Treatment and Reuse. INTECH pp. 325-342.

Knuuttila, S., 2011. Fifth Baltic Sea Pollution Load Compilation (PLC-5). Baltic Sea Environment Proceedings No. 128.

Zalewski, M., 2000. Ecohydrology – the scientific background to use ecosystem properties as management tools toward sustainability of water resources. In: Zalewski, M., (ed.). Ecological Engineering. Journal on Ecotechnology 16: 1-8.

Biotic responses to post-glacial climate change in the Baltic Sea area

Evgeny V. Krasnov, Galina M. Barinova and Anna Yu. Romanchuk

Immanuel Kant Baltic Federal University, Kaliningrad, Russia (ecogeography@rambler.ru)

1. Introduction

The post-glacial Holocene has been characterized by global climate change, the Earth's crust isostatic movement, marine transgressions and regression fluctuations. These processes are clearly manifest in the Baltic Sea region, which is reflected primarily in the reactions of coastal ecosystems and their biota. According to previous data (Gudelis 1976), the history of this recent basin it very short (only the post-glacial Holocene). But now we know that older marine mollusc assemblages with *Portlandia arctica* was leaved in time of the Minde-Riss (Pleistocene) transgression. This cold-water basin replaced the warmer Eems Sea with the boreal species *Mytilus edulis*. During its maximum extent, wide straits to the Atlantic Ocean existed in the west and to the White Sea in the north. Possibly the arctic-boreal bivalves *Cardiidae* entered the Baltic Sea waters during this interglacial stage. According to Blazhchishin (1998), marine conditions in the Baltic Sea basin existed even during the time of Wurm glaciation.

2. The post-glacial history

From the degradation of the last glacial cover and the formation of several fresh-water lakes (13-14 thousand years ago), the post-glacial stage of this area began with the Billingen interstage (12,7 thousand years ago), and the south Baltic lake started to form. Studies of Late Quaternary sediments showed evidence of penetration of salt water in the basin, reflected in increasing boron content and increasing salinity of pore waters. Brackish-water fauna in large numbers did not have time to develop, but continued to exist in the form of local communities. In the cold North of the Baltic Sea waters, there are nowadays species characteristic of the Arctic zone: *Amphipods*, *northern mysids*, etc (Table 1).

Table 1: Figures of temperature, salinity and Baltic Sea level range in post-glacial stages

Stage	Temperature °C	Salinity ‰	Sea level m
Modern Sea	**+ 17,0**	up to **8,0**	**0,0**
Litorina Sea	up to **20,0**	**8,0- 15,0**	from - **4,0** up to + **3,0**
Ancillus Lake	up to **10,0**	**0-3,0**	**-20,0**
Yoldia Sea	**14,0- 15,0**	**5,0-7,0**	from**-10,0** up to + **2,0**
Baltic Glacial Lake	**7,0-8,0**	**0-3,0**	from + **2,0** up to - **26,0**

Temperature and salinity was determined by using stable isotopes of oxygen ($^{18}O/^{16}O$) and carbon ($^{13}C/^{12}C$) ratios. The level of BGL during the Billingen accident fell by 26 meters and caught up with sea level (Nielsson 1970). A Mid-Swedish Strait Baltic basin began to penetrate the water of the Atlantic with *Yoldia arctica*. Only after 300 years they had reached the Finland costs when the Yoldia Sea was formed. The transgression peaked at 8200-8400 years ago, above the level of the ocean. In connection with the raising of Fennoscandia, the sea gradually turned into a freshwater Ancylus lake (with *Ancylus fluviatilis*). Ice-free regions were inhabited by the arctic and subarctic vegetation: dwarf birch, willows, mosses and lichens.

The initial phase of the Atlantic (Flanders) transgression generally started by the appearance of diatoms *Mastogloia*. The end of this phase and the beginning of the next phase corresponds to the regression, when sea level was 20 m lower than today. Maximum sea levels of the Litorina Sea (3-4 m higher than at present) occurred in times of the climatic optimum - about six thousand years ago. The average annual temperature in the Baltic was 2-3°C higher than today and there was more precipitation. The highest species diversity of molluscs, characterizing this time, was found in regions of northern Lithuania (Damusyte 2002). Numerous *Cerastoderma edule, C. glaucum, C. crassum* together with *Macoma calcarea, M. baltica, Mytilus edulis* and others lived in the brackish-water basin at a depth of 5-10 m.

After this period, the vegetation in the Arctic started to become more thermophilic. Firstly, pine and birch forests, and later oak, lime, hazel, elm and other leaf-bearing species occurred which have reached the maximum spread by 5 - 7 thousand years ago (Yuspina 2007).

During the climatic optimum, vegetation zones moved north by about 400 km, when the area of glaciers in the mountain areas of Norway, Iceland, Spitsbergen and in the Alps were strongly reduced. During a cooling about two thousand years ago, broad leaved forest species of pine and birch spread in the area around Baltic Sea, which is still present. Short-term fluctuations occurred against a continuing cooling, giving way to warmer and drier of climate in the cold and damp century.

During the 8th to 12th centuries, grape-growing areas shifted to northern Germany and even Latvia. In the middle of the 13th century, there was cooling again, which continued until the second half of the 19th century. In Europe, the number of years with hard winter, summer droughts, storms, rains and floods increased. In the last quarter of the 19th century a steady rise in temperature began. Herring, cod and other fish species that were previously hardly found in the Barents Sea, were objects of intensive fishing. In the Gulf of Finland, mackerel was found, and in the western part of the Baltic Sea some new species of fishes were caught.

3. Modern biotic responses

A recent decrease of species diversity, estimated from subfossil bivalves mollusk shells washed onto beaches during storms, indicates the deterioration of environmental conditions comparable with the climatic optimum. Significant fluctuations in bivalves biodiversity, associated with the seasonal changes of temperature and hydrodynamic characteristics of water masses was observed (Romanchuk and Ponomareva, 2010). Using the percentage of damaged bivalves it was possible to judge the intensity of the sea force and, thus, the strength of storms. In the Curonian Lagoon, phytoplankton biomass in 1990-2000 increased by more than an order of magnitude compared with 1950, and an increase of *Cyanobacteria* by the factor of 3 (during 1986 to 1989) and even 7 from 1990 to 2000 was observed (Aleksandrov and Dmitrieva, 2006).

References

V.K. Gudelis, E M. Emelyanov Eds: Geology of Baltic Sea, Vilnius, 1976. - 384 p.

Blazhchishin A.I. Palaeogeography and Evolution of Late Quaternary Sedimentation in the Baltic Sea. - Kaliningrad: Yantamy Skaz, 1998. - 160 p.

Nielsson E. On Late- Quaternary history of Southern Sweden and the Baltic basin // Baltica, v.4, Vilnius, 1970. - P. 11-31.

Damysyte A. Fossil mollusks of the Baltic sea, Lithuanian coast // The Seventh Marine Geological Conference, "The Baltic", April 21-27, 2002, Kaliningrad, Russia, Abstracts. - P. 27.

Yuspina L.F. Reflection of early Holocene events in spore- pollen spectra of bottom sediments of the Baltic Sea // Vestnik of Immanuel Kant State University of Russia, 2007, №1. - P. 21-31.

Romanchuk A., Ponomareva E. Methods of assessing coastal marine waters quality: current state and perspectives // Vestnik of Immanuel Kant State University of Russia, 2010, №1. – P. 77-82.

Aleksandrov S., Dmitrieva O A. Primary production and marcers of phytoplankton as criterias eutrophication of Curonian Bay of Baltic Sea // Water Resources. 2006. T. 33, №1. - P. 104-110.

The role of the terrestrial dissolved organic matter mineralization for the acid-base system of the Baltic Sea

Karol Kulinski[1,2], Bernd Schneider[2], Karoline Hammer[2] and Detlef Schulz-Bull[2]

[1] Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland (kroll@iopan.gda.pl)
[2] Leibniz Institute for Baltic Sea Research, Warnemuende, Germany

1. Introduction

The concentrations of dissolved organic matter (DOM), expressed as DOC, are 3-5 times higher in the Baltic Sea water than those observed in the open ocean. This is due to high internal production and to high input from land by river runoff as well. Rivers supply the Baltic Sea with ca. 908 Gmol of carbon annually. More than 37% of this amount (341 Gmol C yr^{-1}) consists of organic carbon (Kulinski and Pempkowiak, 2011). Although the loads of terrestrial dissolved organic matter (tDOM) are well quantified in the Baltic Sea its fate and pathways are still poorly characterized. However, studies of other coastal regions indicate that tDOM may partially be mineralized in the estuarine mixing zone (e.g. Anderson et al., 2009; Letscher et al., 2011) and may modify the total alkalinity (A_T) of seawater (e.g. Cai et al., 1998; Hernandez-Ayon et al., 2007). Both processes which lead to an increase of pCO_2 and consequently to a decrease in pH, were subject of our investigations. Here we focus on the kinetics of the tDOM mineralization that control the increase in total CO_2 (C_T) and thus the changes in the acid-base system of the Baltic Sea.

2. Methods

The samples for this study were collected in the mouths of rivers Vistula and Odra from board of r/v Oceania in May 2012. At both stations 160 L of river water were transferred to pre-cleaned HDPE containers and pre-filtered onboard through the GF/F glass fibre filters (pre-combusted at 450 ºC for 8 h). Using an ultrafiltration technique based on a tangential flow filtration system (PALL), the tDOM fractions with molecular weight ranges larger than 1 kDa and 0.5 kDa - 1 kDa were extracted. At the beginning of the ultrafiltration and after each twofold reduction of the extract volume (up to volumetric enrichment factors of 16) sub-samples were taken for the determination of DOC, pH, C_T and A_T. Based on the obtained results, the organic alkalinity (A_{org}) was determined for both rivers as the difference between measured A_T and that calculated from pH and C_T. This facilitated an estimate of the mean dissociation constants of the tDOM acidic groups.

To determine the tDOM mineralization kinetics in seawater, tDOM extracts were used to perform incubation experiments. tDOM extracts were added to seawater taken at a coastal station in the Mecklenburg Bight and incubated at room temperature (20ºC) in the dark. During the experiment the concentrations of C_T, O_2 and DOC were measured in the incubated samples after 1, 2, 3, 5, 9, 20, 34 and 65 days. At the same time control samples were analyzed which consisted only of seawater and were handled at the same conditions as those enriched with tDOM. This allowed us to separate the influence of the marine DOM decomposition in the samples from that of the added tDOM and thus to assess the kinetics of the tDOM mineralization.

3. Results

The results obtained from the incubation experiment confirm that mineralization of the tDOM takes place in seawater. The changes of the C_T and O_2 concentrations which reflect the mineralization process are presented in Fig. 1. After 65 days the total decrease of tDOC concentrations amounts to 9 % and 11 % for Vistula and Odra rivers, respectively. The mineralization rates found within the study differed for different tDOM sources and molecular weight fractions. However, assuming a first order kinetic and thus relating the logarithmic rates to the tDOC concentrations, yielded similar mineralization rate constants (*k*) that amounted to $11 \cdot 10^{-4}$ day^{-1} and correspond to a half-life time ($T_{1/2}$) of tDOM of 630 days. The only exception from this was the tDOM fraction larger than 1 kDa collected from the Vistula river, which mineralized with a *k* of $8 \cdot 10^{-4}$ day^{-1} corresponding to $T_{1/2}$ of 866 days. Similar calculations were performed for the control samples containing only seawater in order to describe the kinetics of marine DOM mineralization. The obtained results suggest that two clearly distinguishable mineralization phases exist for the seawater DOM that contains both autochtonous and terrestrial DOM. Rapid mineralization lasted for about 5 days with a *k* of $157 \cdot 10^{-4}$ day^{-1} ($T_{1/2}$=44 days) followed by a slower mineralization with *k* and $T_{1/2}$ comparable to those found for tDOM.

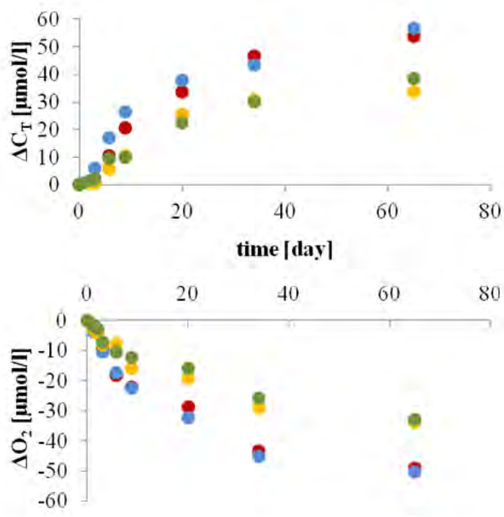


Figure 1. C_T concentration increase (ΔC_T) and O_2 concentration decrease (ΔO_2) as a consequence of tDOM mineralization during the incubation experiment. Symbols correspond to the different rivers and molecular weight fractions of tDOM. (> 1 kDa: red and blue, 0.5 – 1.0 kDa: yellow and green for Vistula and Odra, respectively).

4. Conclusions

The results obtained by our studies indicate that the input of tDOM affects both the structure and functioning of the Baltic Sea acid-base system. There are two major pathways of the tDOM influence detected: (i) modification of the seawater alkalinity caused by the input of organic alkalinity related to the tDOM load and (ii) mineralization of tDOM in seawater - both resulting in a pCO_2 increase and a pH decrease. Biogeochemical modeling is required to quantify these effects for the Baltic Sea as a whole and to estimate the consequences of higher tDOM inputs in a warmer climate. The results of our investigations are considered as first steps to accommodate biogeochemical models with process parameterizations that facilitate a comprehensive description of the acid-base system in the Baltic Sea and to simulate future developments.

Acknowledgements

The research was held at the Leibniz Institute for Baltic Sea Research, Warnemuende, within the framework of the postdoctoral fellowship of K. Kulinski financed by the Polish Ministry of Science and Higher Education (grant no. 654/MOB/2011/0).

References

Anderson L.G., Jutterström S., Hjalmarsson S., Wåhlström I., Semiletov I.P. (2009) Out-gassing of CO_2 from Siberian Shelf seas by terrestrial organic matter decomposition. Geophysical Research Letters, 36, L20601, doi:10.1029/2009GL040046.

Cai W.J., Wang Y.C., Hodson R.E. (1998) Acid-base properties of dissolved organic matter in the estuarine waters of Georgia, USA. Geochimica et Cosmochimica Acta, 62, pp. 473-483.

Hernandez-Ayon J.M., Zirino A., Dickson A.G., Camiro-Vargas T., Valenzuela-Espinoza E. (2007) Estimating the contribution of organic bases from microalgae to the titration alkalinity in coastal seawaters. Limnology and Oceanography-Methods, 5, pp. 225-232.

Kulinski K., Pempkowiak J. (2011) The carbon budget of the Baltic Sea. Biogesciences, 8, pp. 3219-3230.

Letscher R.T., Hansell D.A., Kadko D. (2011) Rapid removal of terrigenous dissolved organic carbon over the Eurasian shelves of the Arctic Ocean. Marine Chemistry, 123, pp. 78-87.

Simulations of future sulphur and nitrogen deposition over the Baltic Sea drainage basin using meteorological data from three regional climate projections

Joakim Langner and Magnuz Engardt

Swedish Meteorological and Hydrological Institute, Sweden (Joakim.langner@smhi.se)

We use a regional model of atmospheric chemistry and transport to investigate trends in sulphur and nitrogen deposition over Europe during the first half of the 21st century. To assess changes due to climate change, the off-line deposition model was operated with meteorology from a regional climate model simulating present and future climates. The sensitivity of the deposition calculations to uncertainties in the climate predictions was explored by using output from three different climate projections. Changes in anthropogenic air pollution emissions in Europe were extracted from the RCP4.5 emission inventory. The modeling systems were evaluated by comparing modelled precipitation, deposition and concentrations during a reference period with observations collected during a similar period. We conclude that the deposition of sulphur and nitrogen containing species will mainly be governed changes in European emissions of these species over the period 2000 to 2050. Uncertainties in air pollution emission projections limit our ability to accurately determine future deposition of acidifying and eutrophying species. If future emissions follow the pathway of the RCP4.5 scenario, Europe can expect significantly lower deposition of sulphur and oxidised nitrogen in 2050 compared to 2000. For reduced nitrogen large areas of western Europe will receive considerably more deposition in 2050 than in 2000 due to feedback of decreased sulphur concentrations on the turnover time of reduced nitrogen. Climate and emission changes alter the physical and chemical environment of the atmosphere, affecting the species atmospheric lifetime and the patterns of deposition. Climate change results in decreased wet deposition of sulphur and reduced nitrogen leading to increased turnover time of these species. Climate and emission changes lead to decreased turnover times of reduced nitrogen but increased turnover times of sulphur and oxidised nitrogen. These relations are likely leading to altered source--receptor relations in the future.

Modelling the extent of hypoxia and anoxia in the Baltic Sea for the period 1970-2010

Andreas Lehmann[1], Hans-Harald Hinrichsen[1], Klaus Getzlaff[1] and Kai Myrberg[2]

[1] GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany (alehmann@geomar.de)
[2] Finnish Environmental Institute/Marine Research Centre, Helsinki, Finland

1. Introduction

The Baltic Sea, one of the largest brackish water ecosystem of the world, suffers frequently from hypoxia and anoxia. The permanent halocline prevents vertical convection during winter time to ventilate deep waters in deeper layers. Variations in oxygen conditions are influenced by several mechanisms. The most crucial process for renewal of oxygen-depleted water masses are major Baltic Inflows which transports highly saline and oxygenated water masses to the deep basins of the Baltic Sea. Eutrophication led to enhanced primary production and degradation of suspended organic matter by bacteria with increased oxygen consumption during past decades. Climate warming affects large-scale oxygen conditions by decreased oxygen solubility and increased respiration rates. A decline in oxygen conditions has generally a negative impact on marine life in the Baltic Sea. Besides other abiotic conditions such as temperature and salinity, the extent of species distributions is determined by the level of oxygen conditions, which defines a major habitat requirement to which species' physiology is suited. Threshold levels of oxygen often form the physiological preferences for the distribution of adult as well as of early life stages of several species. Thus, a better description of evolution of oxygenated, hypoxic and anoxic areas is particular required when studying oxygen-related processes such as habitat utilization of spawning fish, survival rates of their eggs as well as settlement probability of juveniles. To describe the spatial and temporal evolution of the oxygen concentration in the Baltic Sea over the period 1970-2010, we applied a high resolution 3D-hydrodynamical model of the whole Baltic Sea (BSIOM) coupled with a simple pelagic and benthic oxygen consumption model (OXYCON). Model results have been verified by CTD measurements of GEOMAR and HELCOM data provided by ICES.

2. Data and methods

The numerical model used in this study is a general three-dimensional coupled sea ice-ocean model of the Baltic Sea (BSIOM, Lehmann and Hinrichsen 2000). At present, the horizontal resolution of the coupled sea-ice ocean model is 2.5 km, and in the vertical 60 levels are specified, which enables the top 100 m to be resolved with levels of 3 m thickness. The model domain comprises the Baltic Sea, including the Kattegat and Skagerrak. The coupled sea ice-ocean model is forced by realistic atmospheric conditions taken from the Swedish Meteorological and Hydrological Institute (SMHI Norrköping, Sweden) meteorological database (Lars Meuller, pers. comm.), which covers the whole Baltic drainage basin on a regular grid of 1 x 1° with a temporal increment of 3 hours. The database consists of synoptic measurements interpolated on the regular grid using a two-dimensional univariate optimum interpolation scheme. This database, which for modelling purposes is further interpolated onto the model grid, includes surface pressure, precipitation, cloudiness, air temperature and water vapour mixing ratio at 2 m height and geostrophic wind. Wind speed and direction at 10 m height are calculated from geostrophic winds with respect to different degrees of roughness on the open sea and near coastal areas (Bumke et al. 1998). BSIOM forcing functions, such as wind stress, radiation and heat fluxes were calculated according to Rudolph and Lehmann (2006).

The oxygen consumption model (OXYCON, Hansen and Bendtsen 2009; Jonasson et al. 2012) considers one pelagic oxygen sink and two benthic sinks due to microbial and macrofaunal respiration. Pelagic and benthic oxygen consumption is modelled as a function of temperature and oxygen concentration. The consumption rates for different areas are adjusted to the mean annual primary production in the different sub-basins of the Baltic Sea. At the sea surface the oxygen flux is based on the oxygen saturation concentration determined from surface temperature and salinity.

For comparison of simulated oxygen distributions with observations, oxygen data for the whole Baltic Sea ICES subdivisions (SD21-32; Fig. 1), were compiled from the ICES oceanographic database of depth-specific CTD (conductivity, temperature, depth) and bottle measurements. From the database, all available oxygen values were selected between 1970 and 2009. Data were subsequently aggregated to obtain monthly means per year and per 5-m depth stratum. For a comparison of the model output with highly spatially resolved CTD data, a second data set was available. This data set consists of observations based on routine research cruises in different parts of the western and central Baltic (SD 21-28) between April 2002 and August 2010 carried out mainly by GEOMAR. The physical parameters (salinity, temperature, and oxygen) of the water column were obtained from a CTD/O_2 system. The most frequently observed area was the Bornholm Basin, with a horizontal resolution of the station grid of about 10 nm.

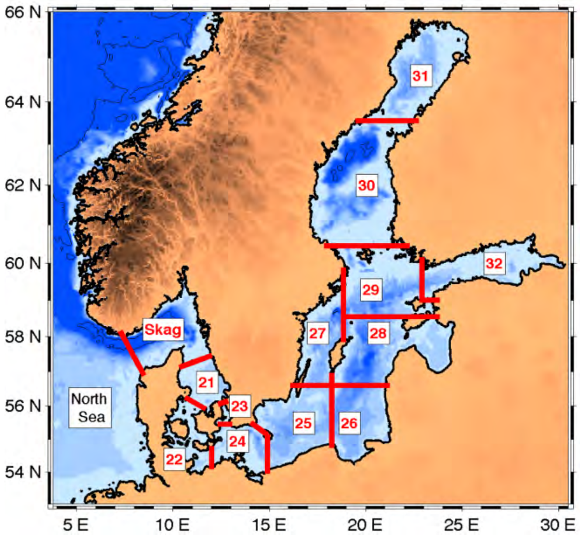


Figure 1. Baltic Sea with ICES subdivisions.

3. Results

BSIOM has been run for the period 1970-2010. Daily mean fields of temperature, salinity and oxygen have been extracted from the model and form the basis for the subsequent analysis. Figure 2 shows the comparison of simulated and observed profiles of temperature, salinity and oxygen of the ICES subdivision 25. The mean and natural variability range is very well captured by BSIOM. The shape of profiles is very well reproduced. A much harder test is shown in Fig. 3 where CTD measurements of one hydrographic survey (July 2006) are compared with model data. It should be noted that the initial conditions of BSIOM have been constructed from earlier model runs which most closely resembled the hydrographic conditions of winter 1970.

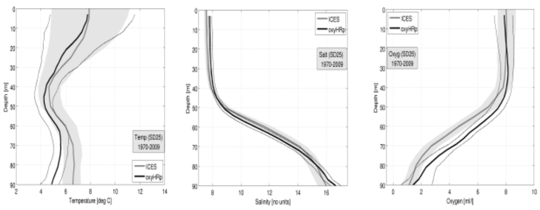


Figure 2. 0.1, 0.5 and 0.9 quantiles of temperature, salinity and oxygen profiles for subdivision 25 for the period 1970-2009 based on ICES monthly database and BSIOM model output.

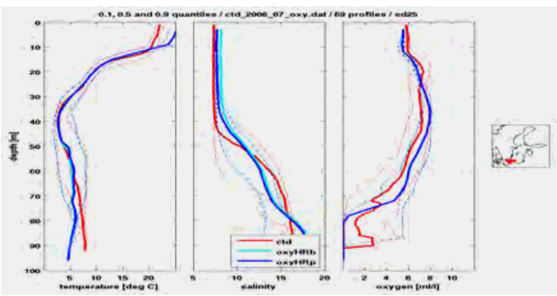


Figure 3. 0.1, 0.5 and 0.9 quantiles of temperature, salinity and oxygen profiles for subdivision 25, in July 2006 based on GEOMAR CTD-measurements and BSIOM model output.

After initialization, no further adjustment has taken place. The development of the hydrographic conditions of the Baltic Sea is only due to atmospheric forcing, runoff and the western boundary conditions.

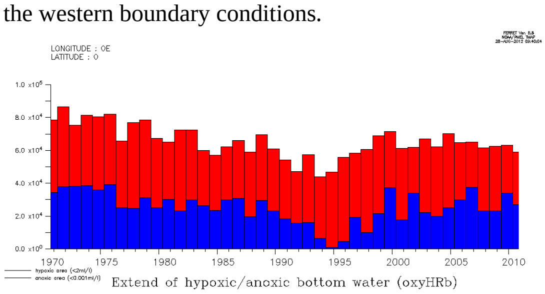


Figure 4. Extent of hypoxic (red) and anoxic (blue) bottom water in the Baltic Sea for the period 1970-2011.

The maximum extent of hypoxic and anoxic conditions is displayed in Figure 4. There is a high inter-annual variability with smallest hypoxic and anoxic areas occurring after the major inflow in 1993. Compared to observational assessments, the determination of hypoxic and anoxic areas is based on daily mean values and the full model resolution which is about 2.5 km

4. Conclusions

The Baltic Sea is subject to major temporal and spatial variability in important abiotic variables, e.g. temperature, salinity, oxygen concentration and nutrients, which drive bottom up and top down food web processes. However, many species are believed to exist at the limit of their physiological tolerance, in areas and habitats that do not represent their marine or fresh water origin. Thus, the implementation of the OXYCON submodel into our modeling framework suggests its applicability to perform sensitivity analyzes of oxygen-related spatial habitat distributions under multiple combinations of natural and anthropogenic drivers (climate change, eutrophication, new species introductions) and might help to test hypotheses, providing results of fundamental importance to Baltic Sea ecosystem management.

References

Bumke, K., Karger, U., Hasse, L. Niekamp, K. 1998. Evaporation over the Baltic Sea as an example of a semi-enclosed sea. Contr. Atmos. Phys., 71(2), 249-261.

Hansen, J.L.S., Bendtsen, J. 2009. Effects of climate change on hypoxia in the North Sea – Baltic transition zone, IOP. C. Ser. Earth Environ. Sci., 6, Copenhagen, Denmark, 10-12 March 2009, 302016.

Jonasson, L., Hansen, J.L., Wan, Z., She, J. 2012. The impacts of physical processes on oxygen variations in the North Sea-Baltic transition zone. Ocean Sci., 8, 37-48.

Lehmann, A., Hinrichsen, H.-H. 2000. On the thermohaline variability of the Baltic Sea. J. Marine Syst., 25 (3-4), 333-357.

Rudolph, C., Lehmann, A. 2006. A model-measurements comparison of atmospheric forcing and surface fluxes of the Baltic Sea. Oceanologia, 48(3), 333-380.

The Gulf of Finland Year 2014 - 'Clean Gulf of Finland ahead of time'

Myrberg, K [1,2] and Kostamo, K[1]

[1]Finnish Environment Institute/Marine Research Centre, Mechelininkatu 34a, FIN-00251 Helsinki, Finland (kai.myrberg@ymparisto.fi)
[2]Department of Geophysics, Klaipeda University, Herkaus Manto 84, LT-92294 Klaipeda, Lithuania

Background

Co-operation between Finnish Russian and Estonian scientists began already in the 1955 to protect the marine environment of the Gulf of Finland, when the collaboration between Finland and the Soviet Union was agreed on and established. The actual trilateral collaboration was initiated in 1968 by scientists, predominantly from Leningrad and Tallinn, who suggested a joint working group focusing on the effects of harmful substances in the Gulf of Finland and the functioning of the marine systems that regulate processes in the area. The first thematic year was organized in 1996. It was obvious already at that time that even though scientifically sound datasets could not be acquired due to differences in for example sampling and monitoring methodology, some actions to stop the deterioration of the sea area would have to be implemented immediately. The trilateral cooperation during 1996 created a platform for investigations such as joint expeditions, analyzing the collected data and publishing joint scientific articles and reports

Research

Research during The Gulf of Finland Year 2014 will provide an excellent opportunity for all three riparian countries to produce coherent information for the implementation of the HELCOM Baltic Sea Action Plan, the EU's Marine Strategy Framework Directive and Habitats Directive, as well as EU's Baltic Sea Region Strategy. The main goal of all these strategies is to protect the marine nature and improve, if necessary, its status. The strategies are based on the sustainable use and development of the marine area (ecosystem-based maritime spatial planning), which requires basic knowledge on its environmental values (*e.g.*, the theme year's research themes: biological and geological diversity, fish and fisheries, ecosystem resilience) as well as human activities (*e.g.*, fisheries, maritime traffic). Thus the main aim of the theme year, production of subregionally comprehensive datasets regarding eutrophication, hazardous substances, biodiversity and maritime safety, as well as on, *e.g.*, the effects of climate change on the environment, will provide valuable background data for all stakeholder groups involved.

Eutrophication. The GoF year will provide a collation of existing *datasets/literature review* from all three countries regarding eutrophication and its effects on biota. Furthermore, an extensive Finnish-Estonian-Russian field survey campaign will be arranged. The monitoring survey will produce information on the status of the GoF and enable the assessment of the state of the marine area on a more precise level that has been previously achieved. The survey campaign will also be a first step towards implementation of a trilateral monitoring programme for the GoF. Prior to the joint monitoring in 2014, a three-lateral intercalibration experiment will be carried out in summer 2013.

Hazardous substances. The theme year will provide spatial analyses of the distribution of hazardous substances. Furthermore, estimations on threshold levels impairing the various components of the ecosystems will be produced. In addition, the possibility to use new technologies in monitoring the status of the biota will be investigated.

Biological diversity. The Gulf of Finland year will provide information on the distribution of species, habitats and biodiversity hotspots along with comprehensive datasets of geological diversity and various environmental parameters. Additionally, new methods will be developed to study the status and distribution of BD (remote sensing, DNA-barcoding)

Maritime activities. In order to prevent accidents and to increase the preparedness in case of oil spills, the theme year will increase cooperation among the three countries in maritime operations. This will be achieved by developing the winter navigation system and by providing more information on winter conditions directly to ships. Furthermore, common exercises, *e.g.*, maritime navigation simulator experiments, will be carried out.

The results of the theme year – the Gulf of Finland Declaration

All of the results will be applied to produce the second Gulf of Finland declaration, which will present the most essential actions which should be taken to improve the state of the GoF. Furthermore, the declaration will provide knowledge for political decision making process in questions related to the implementation of HELCOM BSAP, international and national legislations. Thus, the declaration will enhance the possibilities of reaching a good environmental status in the GoF ahead of the set target year 2021. The results of the theme year will be reported as policy briefs, popular reports and articles, scientific publications, lectures and seminars to reach the various stakeholder groups.

Influence of coastal upwelling on the Air-Sea exchange of CO_2 in a Baltic Sea basin

Maria Norman, Sindu Raj Parampil, Anna Rutgersson and Erik Sahlée

Department of Earth Sciences, Uppsala University, Uppsala, Sweden (maria.norman@met.uu.se)

1. Abstract

Four upwelling events along the east coast of Gotland are analyzed using in situ measurements and satellite data. There is a significant difference in magnitude between measured and calculated fluxes of CO_2 during upwelling. This discrepancy can at least partly be explained by the fact that the partial pressure of CO_2 in the water is not representative for the flux footprint area during the wind directions favorable for upwelling. The carbon budget is calculated during upwelling and compared to fictitious cases representing scenarios without upwelling. It is found that the effect of upwelling is reduced uptake or increase emissions of CO_2 by 19-250%. A rough estimate shows that the whole Baltic Sea annual uptake could decrease by approximately 25% when including costal upwelling.

2. Introduction

Coastal upwelling is a commonly occurred phenomenon along coastlines where cold nutrient rich water is lifted to the surface from within or below the thermocline. The concentration of CO_2 generally increases with depth in the water column, and hence upwelling results in a higher CO_2 concentration at the sea surface. In the Baltic Sea the life time of an upwelling event is a couple of days up to one month, and at some regions it occurs as frequent as 25-30% of the time (Lehmann et al. 2012; Gidhagen 1987).

The global oceans are an important sink of CO_2, and to be able to model the future climate it is important to have knowledge of all the processes influencing the air-sea exchange processes. The air-sea exchange of CO_2 is mainly controlled by the difference of partial pressure, pCO_2, between water and air. Other controlling factors are the solubility and the rate at which CO_2 is transferred across the air-sea interface, often referred to as the transfer velocity. Upwelling influences the pCO_2 at the water surface, and hence the air-sea exchange of CO_2 can also expect to be affected, since an increased pCO_2 at the sea surface (pCO_{2w}) will decrease a downward flux, increase an upward flux, or even turn a downward flux upward.

Although the global oceans act as a net sink, on a regional scale an ocean can be either a source or a sink. Previous studies show that the Baltic Sea is either a small sink or a small source of CO_2; Norman et al. (2013a) found that the Baltic Sea is a net sink of 0.22 mol m^{-2} yr^{-1}, while Kulinski and Pempowiak (2012) concluded that the Baltic Sea is a source of 0.25 mol m^{-2} yr^{-1}. Norman et al. (2013a) used a Baltic Sea model (Omstedt et al. 2009) to estimate the carbon budget. This model do not include upwelling, hence the estimated uptake might be overestimated.

In this study (Norman et al. 2013b) four upwelling events are selected using in situ measurements of wind direction, wind speed and pCO_{2w} at the Östergarnsholm site, which is situated on a small flat island off the east coast of Gotland. Daily average satellite data of sea surface temperature (SST) is also used to investigate the horizontal scale of the upwelling. The aim is to analyze the air-sea exchange during upwelling, and to estimate the impact of upwelling on the carbon budget.

3. Results

The selected upwelling events are two July periods in 2005 and 2007, and two October periods in 2008, with various lengths from 8 to 17 days. For the four upwelling events, CO_2 fluxes are calculated using a standard bulk formula and compared with directly measured fluxes. The transfer velocity is calculated according to Nightingale et al. (2000), and compared with the measured transfer velocity where measured fluxes are used. Figure 1a) shows calculated and measured fluxes during part of one upwelling event in July 2005. Calculated and measured transfer velocity during the same period is shown in Figure 1b). During this period the fluxes are directed downward, and there is an evident difference in magnitude between calculated and measured fluxes. Furthermore, the magnitude of the fluxes decreases during the upwelling event, as can be expected when the difference in the pCO_2 between water and air decreases. The measured transfer velocity show significantly higher values than the calculated, and also the transfer velocity decrease during upwelling. The differences between calculated and measured fluxes and transfer velocity, is partly attributed to the fact that pCO_{2w} is not measured in the flux footprint area during south- to southeasterly winds.

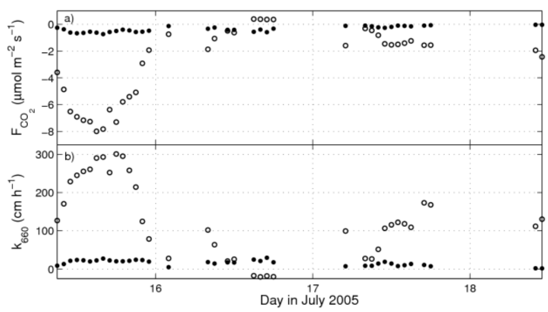


Figure 1. a) Fluxes calculated using a standard bulk formula (dots), measured fluxes (circles); b) Transfer velocity calculated according to Nightingale et al. (2000) (dots), Measured transfer velocity using measured fluxes (circles), during part of one upwelling event in July 2005.

For an upwelling event during October 2008, the same pattern with a large difference in magnitude between calculated and measured fluxes and transfer velocity can be seen (Figure 2a and b). In addition, during this period CO_2 fluxes were measured on two levels, 10 and 26 m height. The fluxes measured on the higher level show somewhat better agreement with the calculated fluxes. For these data the footprint area is larger compared to the lower lever flux estimates, and thus it is more likely that the heterogeneity in the surface is captured.

Furthermore, the CO_2 budget during the upwelling events is estimated, and for that purpose the area and of the upwelling region and the pCO_{2w} is needed. The satellite data of SST is used to define the area of upwelling during each event. A detection method based on SST anomaly and distance from the coast is applied. Figure 3 is an example of calculated fluxes using this technique. On the maps of the Gotland region there are colors where upwelling is detected, and the colors represent the magnitude of the flux.

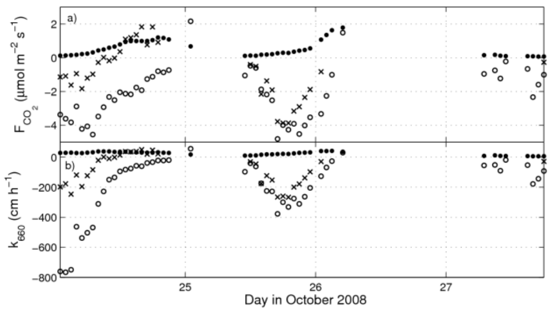


Figure 2. a) Fluxes calculated using a standard bulk formula (dots), measured fluxes at 10 m (circles), measured fluxes at 26 m (crosses); b) Transfer velocity calculated according to Nightingale et al. (2000) (dots), Measured transfer velocity using measured fluxes at 10 m (circles), Measured transfer velocity using measured fluxes at 26 m (crosses), during part of one upwelling event in July 2005.

During the four upwelling events there is a strong correlation between SST and pCO_{2w}. This correlation is used to estimate pCO_{2w} using satellite SST in the upwelling region. To study the effect of upwelling, the CO2 uptake or emission during upwelling is compared with a scenario without upwelling. To calculate the budget without upwelling SST and pCO_{2w} is linearly interpolated between the time before and after the upwelling event.

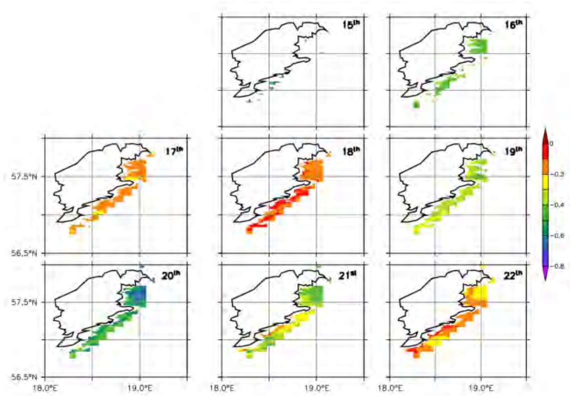


Figure 3. The colored area shows estimated fluxes of CO_2 in the area surrounding Gotland. The fluxes are estimated using satellite SST and the relation between SST and pCO_{2w}. The magnitude is indicated by the colorbar (μmol m^{-2} s^{-1}).

The effect of upwelling for the two July periods results in a decreased CO_2 uptake of 5.0 and 5.4 Gg, respectively. This corresponds to a relative decrease of 19% and 59%, respectively. During the October periods the emissions increase due to the upwelling by 15.4 and 23.4 Gg, respectively. The corresponding relative increases are 211% and 250%, respectively. This makes the region off the east coast of Gotland less of a sink of CO_2.

To study the impact of upwelling for the whole Baltic Sea, a rough estimate can be done by estimating the area affected by upwelling and assuming a certain frequency of upwelling in time. Such a rough estimate is done using the result for the region on the east coast of Gotland with the result that upwelling could decrease the annual uptake by approximately 25%.

References

Gidhagen L (1987) Coastal upwelling in the Baltic Sea – satellite and in situ measurements of sea-surface temperatures indicating coastal upwelling, Estuar Coast Shelf Sci, 24., 4., pp. 449-362

Kuliński K, Pempowiak J (2012) Carbon Cycling in the Baltic Sea, Springer-Verlag, Berlin and Heidelberg, pp. 129

Lehmann A, Myrberg K, Höflich K (2012) A statistical approach to coastal upwelling in the Baltic Sea based the analysis of satellite data for 1990-2009, Oceanologia, 54., 3., pp. 369-393

Nightingale PD, Malin G, Law CS, Watson AJ, Liss PS, Liddcoat ML, Boutin J, Upstill-Goddard RC (2000) In situ evaluation of air-sea gas exchange parameterizations using novel conservative and volatile tracers, Global Biogeochem Cycles, 14., 1., pp. 373-383

Norman M, Rutgersson A, Sahlée S (2013a) Impact of Improved Air-Sea Gas Transfer Velocity on Fluxes and Water Chemistry in a Baltic Sea Model, J Marine Syst, 111-112., pp. 175-188

Norman M, Parampil S, Rutgersson A, Sahlée S (2013b) Influence of Coastal Upwelling on the Air-Sea Exchange of CO_2 in a Baltic Sea Basin, Submitted

Omstedt A, Gustavsson E, Wesslander K (2009) Modelling the uptake and release of carbon dioxide in the Baltic Sea surface water, Cont Shelf Res, 29., 7., pp. 870-885

Modelling the interaction between eutrophication, acidification and climate change in the Baltic Sea

Omstedt, Anders and Moa Edman

Department of Earth Sciences, University of Gothenburg

1. Introduction

Coastal seas, such as the Baltic Sea, link the continents to the ocean by means of fresh water and matter fluxes. The coupling is complex and illustrates the interconnection between human activity and physical, chemical, and biological processes in the whole drainage basin. This can be exemplified by the spread of anoxic bottom water in coastal seas, which is closely linked to both riverine nutrient load and stagnation periods. Changes due to deoxygenation, marine acidification, and climate change may have severe implications for carbon and nutrient cycles, as well as for marine ecosystems. The CO_2 and O_2 dynamics (Figure 1) are central to these changes and crucial for the marine biogeochemical cycles and for the ecosystem health. The connection between eutrophication, acidification and climate change is through primary production and mineralization of both organic matters from the sea and from land.

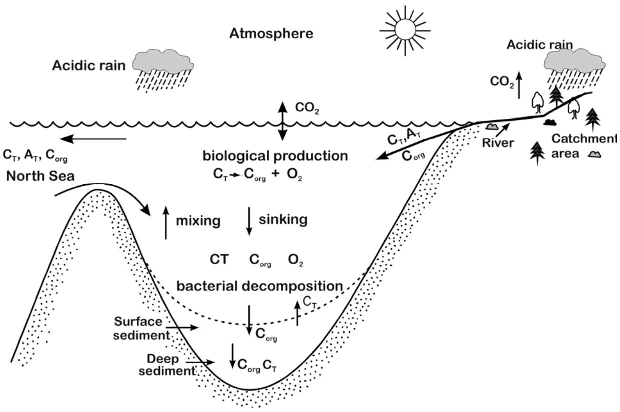


Figure 1. Sketck of main the processes active in the CO_2-O_2 system (from Omstedt et al, 2009).

2. Modelling the Baltic Basin CO_2-O_2 system

In some recent modeling efforts developed within the BONUS+ program Baltic-C a new coupled land-sea carbon model for the Baltic Sea and its drainage basin has been developed. The model system involves two land surface models, i.e. LPJ-GUESS and CSIM and one Baltic Sea model, i.e. PROBE-Baltic The model design was set up as shown in Fig. 2. All three models are forced by the downscaled climate data according to the chosen scenario narratives.

A selection of IPCC-SRES narratives, together with climate model simulations based on these, was adopted as the basic scenario framework of the present study. Twelve GCM scenarios, downscaled for the Baltic Sea Basin using the RCA3 RCM, were chosen to span the possible future climate development of the twenty-first century and to accommodate uncertainty in the nature of the global climate system (represented by three GCMs), natural climate variability (represented by three ensemble members for the ECHAM5 GCM), and the future course of socio-economic development (represented by three GHG emission scenarios).

Three scenario runs started from ECHAM but use different land cover assumptions and nutrient loads. One of these runs was defined as business as usual with A2 emissions (BAU-A2), a second run was defined as a medium scenario (medium-A1B), and a third run the most optimistic scenario with nutrient loads according to the Baltic Sea Action Plan (BSAP; HELCOM, 2007) and the B1 emission scenario (BSAP-B1). Due to severe biases in the GCM's in the water and heat balances bias corrections were also introduced.

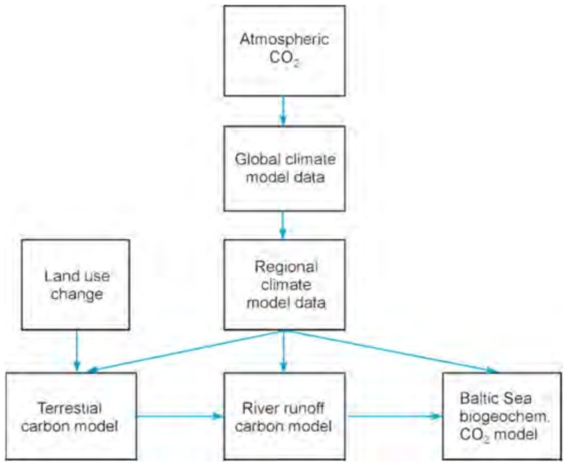


Figure 2. Sketch of the model system including a terrestrial carbon model (LPJ-Guess), river runoff carbon model (CSIM), and a Baltic Sea carbon model (PROBE-Baltic). The drainage basin and Baltic Sea models are forced by using global climate models downscaled by one regional climate model (from Omstedt et al., 2012).

3. Future changes under global warming

The scenario response of pH and oxygen concentrations along a longitudinal Baltic Sea transect is examined in Figs. 3 and 4. These figures show the current state and the changes that result from both the BSAP-B1 and BAU-A2 scenario narratives. Fig. 3 shows that acidification will occur at most depths in both the BSAP-B1 and BAU-A2 scenarios, with the most pronounced pH drops occurring in the surface waters, the Åland Sea deep water, and the intermediate or deep waters of the northern basins. The small pH variation in Kattegat deep water is due to the lateral conditions in the model that assume constant values in the deeper parts of the Kattegat and should be ignored. In both the BSAP-B1 and BAU-A2 scenarios, the Baltic Proper deep water is the least affected by acidification.

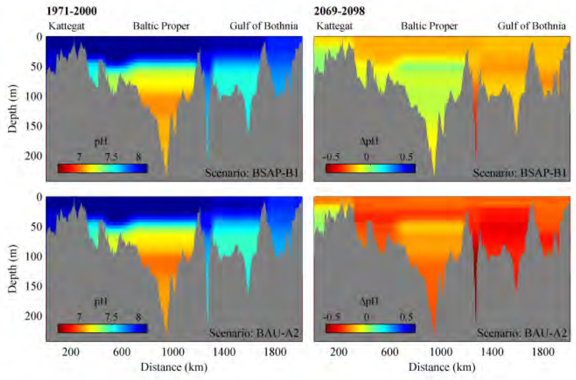


Figure 3. Current pH (1971-2000) and scenario pH changes (2069–2098) along a Baltic Sea transect for the BSAP-B1 and BAU-A2 scenarios (from Omstedt et al., 2012).

The corresponding oxygen concentration results are depicted in Fig. 4. The BSAP-B1 scenario causes only minor changes in the oxygen concentrations in the Baltic Sea as a whole, and with increasing oxygen concentrations in the deeper parts of the Baltic Proper. These increases are caused by lessened hypoxic and anoxic conditions during stagnation periods due to lower nutrient concentrations.

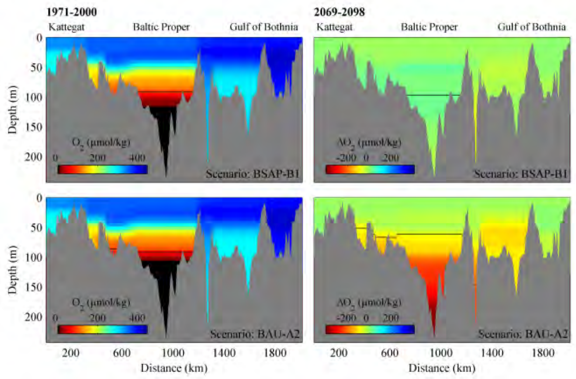


Figure 4. Current O_2 concentration (µmol kg^{-1}) (1971-2000) and scenario O_2 changes (2069–2098) along a Baltic Sea transect for the BSAP-B1 and BAU-A2 scenarios. The limit for hypoxic water (set as 90 µmol kg^{-1}) is indicated by the black line (from Omstedt et al., 2012).

In the BAU-A2 scenario, the most pronounced reductions in oxygen concentration (Fig. 4) occur in the intermediate and deep layers in the Baltic Proper, Åland Sea and Bothnian Sea. In the Baltic Proper, the change is caused by a growing anoxic water volume, which shifts the redox cline upwards, and an increased oxygen debt in the deepest volume. The oxygen reductions in the Bothnian Sea will not cause hypoxic conditions, but the volume will be deprived of almost half its oxygen content (–150 µmol kg^{-1}). The reduced pH decrease in the Baltic Proper bottom-water volume (Fig. 3) is caused by the interaction between the O_2 and CO_2 systems. In the BSAP-B1 case, the bottom-water pH had begun to level out early due to lessened CO_2 deep-water accumulation, caused by the nutrient reductions in the narrative. Continued acidification from CO_2 emissions in BSAP-B1 is balanced by the recovery of deoxygenated water volumes until the emission signal also levels out. In the BAU-A2 scenario, acidification prevails throughout the modelled period; however, the effect is somewhat counteracted in anoxic bottom waters by alkalinity generation (Edman and Omstedt, 2013), which dampens the effect of increased CO_2 accumulation. The result is net acidification in Baltic Proper bottom water as well in BAU-A2, though the pH decrease is less pronounced than in the surface waters.

4. Summary and Conclusions

It is most likely that the carbon dioxide in the atmosphere will increase in the coming decades and that climate warming will continue with implication on several aspects that are related to the heat balance. With increasing temperatures the water balance will also be influenced through changes in precipitation and evaporation. For the Baltic Sea drainage basin we expect more precipitation in north and less in south, which may have large effects on the salinity as well as the biogeochemical cycles. Changes in nutrient cycles are much due to the development of agriculture practice and food consumption and may increase the nutrient load in the future. Increased temperatures and CO_2 concentrations will also change the carbon cycle and increased transports of organic carbon from land into the sea. Future expected anthropogenic climate changes in heat and water cycles, nutrient and carbon cycles indicate increased threats to the marine ecosystems implying a strong need for management efforts both related to regional nutrient emission reductions and global CO_2 emission reductions.

References

Edman, M., and Omstedt, A. (2013). Modeling the dissolved CO_2 system in the redox environment of the Baltic Sea. Limnol. Oceanogr., 58(1), 2013, 74-92

Omstedt, A., Edman, M., Claremar, B., Frodin, P., Gustafsson, E., Humborg, C., Mörth, M., Rutgersson, A., Schurgers, G., Smith, B., Wällstedt, T., and Yurova, A. (2012). Future changes of the Baltic Sea acid-base (pH) and oxygen balances. Tellus B, 64, 19586, http://dx.doi.org/10.3402/tellusb.v64i0,19586.

Omstedt, A. , Gustafsson, E. and K., Wesslander, (2009). Modelling the uptake and release of carbon dioxide in the Baltic Sea surface water. Continental Shelf Research 29, 870-885. DOI: 10.1016/j.csr.2009.01.006

Remote sensing algorithms for sea surface CO_2 in the Baltic Sea

Gaëlle Parard, Anna Rutgersson and Sindu Raj Parampil

Department of Earth Sciences, Uppsala University, Uppsala, Sweden (gaelle.parard@geo.uu.se)

1. Introduction

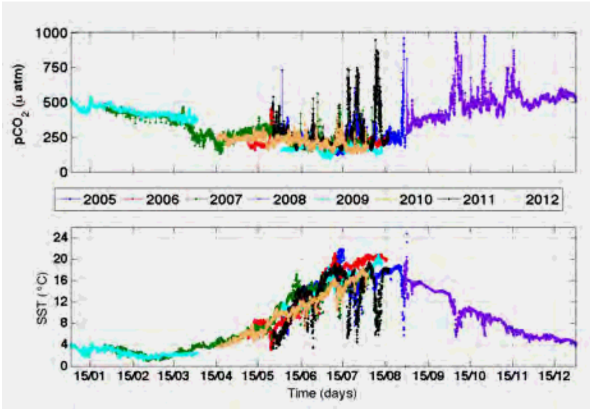
Carbon dioxide is the most important anthropogenic green house gas, the global emissions of CO_2 from fossil fuel combustion and cement production were of 9.5 ± 0.5 PgC yr^{-1} in 2011 (Le Quéré et al., 2012). One important sink is the ocean CO_2 uptake, which absorbed 26% of the anthropogenic emission, 2.5±0.5 PgC yr^{-1} (Le Quéré et al. 2012; Global Carbon Project 2012). The uncertainty of this estimation is still significant and in the ocean the partial pressure of CO_2 (pCO_2) is mostly estimated from a sparse network of surface observations in space and in time. The impact of the pCO_2 variability is not well known in all oceans. Furthermore, at local scale, strong variations can be due to upwelling events or biological activities. For example in the Baltic Sea upwelling events is commonly observe along coastline during spring and summer and can considerably affect the air-sea CO_2 flux. To estimate the CO_2 flux in all Baltic Sea accurately, it is necessary to know the pCO_2 variability. The goal of our work is to develop and validate remote sensing based method for estimating pCO_2 in Baltic Sea. In first part, we work on data of pCO_2 mooring near the coast to construct relationship with satellite data and after apply this at the Baltic Sea scale.

2. Data

Time series measurements:

The existing field station Östergarnsholm, east of Gotland is based on a micrometeorological tower to investigate the air-sea exchange water, heat energy and CO_2 between the surface and the atmosphere. In addition to the tower, two buoys are deployed at 1 km (buoy A) and 4 km from the coast (Buoy B). Buoy A at 57.45°N, 18.98°E, closer to the coast, measures Sea Surface Temperature (SST) and pCO_2 at 4 m depth semi-continosly since 2005 (Rutgersson et al., 2008).

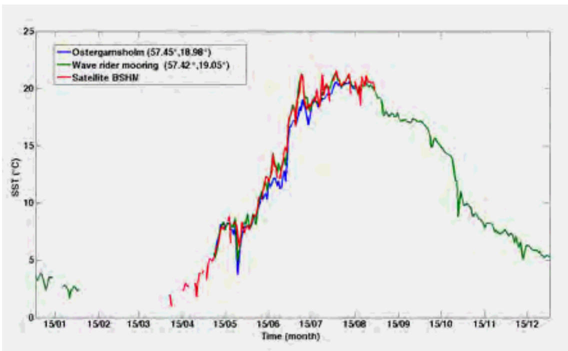
The pCO_2 data measured on this mooring have a seasonal cycle with values between November to March higher than atmospheric value (~390 **μatm**) (Figure 1). During the warmer period, the values are lower than atmospheric value but some events (few days) are really high with values exceeding 700 **μatm** and correlate with low SST values. These periods are characteristic of upwelling events near Gotland, which take place between May and October (Norman et al., in prep; Lehmann et al, 2012).



Top: pCO_2 measurement. Bottom: SST measurement at the Östergarnsholm Buoy A. Buoy B, 57.42 °N, 19.05°E (Directional Wave Rider buoy) gives wave information and also measures SST at 1 m depth (Figure 2). The signal from the two temperature sensors are very close except during upwelling events, where the SST at 4 m is reduced more than at 1 m. This difference is due to the distance from the upwelling events.

Satellite measurements:

The remote sensing SST for the period 2005–2011 is taken from the Advanced Very High Resolution Radiometer (AVHRR), onboard the National Oceanic and Atmospheric Agency (NOAA) satellites. The German Federal Maritime and Hydrographic Agency Hamburg processes the raw data from two satellites using the TeraScan software (Siegel et al., 1994). The mean daily average of SST at the two mooring were compared to the SST remote sensing data (figure 2), there are a strong correlation between the data from the mooring and the remote sensing SST of 0.98. The upwelling events are seen in the remote sensing data as on the mooring data.



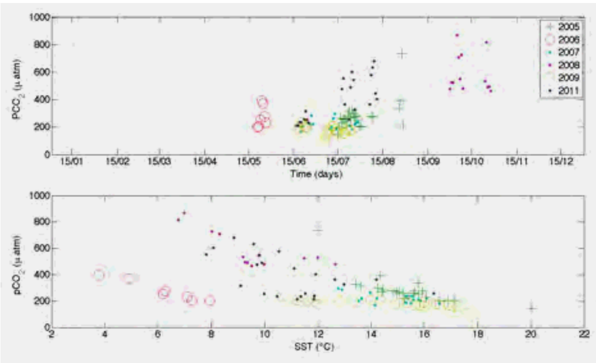
Mean daily SST from Östergarnsholm mooring measurement in blue, from the wave rider mooring in green, BSH satellite SST in red, for the year 2006.

3. Results and conclusions

During November to March the pCO_2 measuring show strong correlation with SST measurements with a positive relationship between pCO_2 and SST which correspond to the thermodynamical effect defined by Takahashi et al, 1993 in ocean. We have typically this relationship during the winter months, the pCO_2 variations follow the SST variations with an increase of 3,98%/°C, which is close to the thermodynamic relationship of 4,23%/°C.

During the spring-summer period, we have two types of relationship. The first correspond at the period without upwelling events, which also correspond to lower pCO_2 value during the upwelling events (figure 3). The slope is near zero and seems a mixed of SST-pCO_2 relationship during winter and during high pCO_2 during upwelling events.

During the upwelling, where we observe the stronger value of pCO_2, they have strong negative slope in the SST-pCO_2 relationship.



Upwelling events period from 2005 to 2011 top) pCO_2 signature bottom) pCO_2 in function of SST measurement.

The negative slope is observed more at the end of the upwelling season. It could be several reasons for these two types of slope: the mixed layer depth and the strength of the upwelling. We observe in temperature profile in Baltic Sea from SMHI a strong annual and monthly variation of the mixed layer depth in the area. This can explain the different signature of the upwelling events. The satellite SST maps around the mooring show clearly when the upwelling events take place. We observe that for some upwelling periods, observed on mooring data, the mooring is not clearly in the upwelling, which can explain the difference of pCO_2 value observed for each event.

References

Le Quéré, C. et al. (2012) The global carbon budget 1959–2011, Earth Syst. Sci. Data., 5., pp. 1107-1157

Global Carbon Project (2012) more information, data sources and data files at www.globalcarbonproject.org

Rutgersson A., M. Norman, B. Shneider, H. Pettersson, E. Sahlée. (2008) The annual cycle of carbon-dioxyde and parameters influencing the air-sea carbon exchange in the Baltic Proper. , J. Mar. Syst., 74., pp. 381-394

Norman M., S. Raj Parampil, A. Rutgersson and E. Sahlée. (in prep) Influence of coastal upwelling on the Air-Sea gas exchange of CO_2 in a Baltic Sea bassin.

Lehmann, A., K. Myrberg, and K. Höflich, (2012) A statistical approach to coastal upwelling in the Baltic Sea based on the analysis of satellite data for 1990-2009 Oceanologia, 54 (3).pp. 369-393.

Siegel, H., Gerth, M., Rudloff, R., Tschersich, G., (1994). Dynamic Features in the Western Baltic Sea investigated using NOAA-AVHRR data. Ocean Dynamics, 3., pp.191-209.

Takahashi, T., J. Olafsson, J. G. Goddard, D. W. Chipman, and S. C. Sutherland (1993), Seasonal variation of co2 and nutrients in the high-latitude surface oceans: A compar- ative study., Global Biogeochemical Cycles, 7 (4), 843–878.

Energy flows, production and filtration activity of mollusks in the salinity gradient of estuaries of the southern Baltic Sea

Dmitry Philippenko

University of Turku, Finland (dmiphi@utu.fi)

Introduction

Mollusks – is one of the dominant groups of invertebrate animals in freshwater and marine benthic communities with a high speed of biomass production. There is a considerable importance of bivalve mollusks in organic matter transformation and sediment accumulation in water bodies due to its filter feeding type (Møhlenberg and Riisgård 1978, Filgueira et al. 2011). Current study was aimed at the research of mollusk settlements structure and its functional changes (energy flows, production and filtration rate) along the salinity gradient in estuaries of the southern Baltic.

Materials and methods

Study area was located in the German coast of the Baltic Sea (fig. 1). Materials were collected by the grab from April to September 2011 in three estuarine water bodies (Darss-Zingst bodden chain, Rugen lagoon, Salzhaff bay) at the depth from 0.3 to 6.2 m. Data on biomass and density of mollusks were used to compute energy flows, which were calculated as a cumulative value of production (P) and respiration (R). Total respiration was calculated by the exponential equation:

$$R = Q_1 \cdot 24 \cdot OC \cdot \gamma^{-1}$$

where Q_1 – oxygen consumption, (mg O_2 h^{-1}), OC – oxy-caloric coefficient (14,2 J mgO_2^{-1}), γ – temperature adjustment. Oxygen consumption coefficients for mollusks were obtained from the literature (Arakelova 1986). Efficiency coefficient (K_2) of energy consumption for species was estimated as a relation of production to energy flow (Alimov, 1989). Based on a relation of filtration rate (l ind^{-1} h^{-1}) to biomass, data on filtration activity of filter feeding bivalve *Mya arenaria* L. were calculated according to an equation (Riisgård and Seerup 2003):

$$F = 4{,}76 \cdot W^{0{,}71}$$

Filtration efficiency of *M. arenaria* was based by the values of its primary production utilization and water purification from suspended organic matters.

Figure 1. Study area in the southern Baltic Sea

Results

The mollusk community *Hydrobia ulvae* + *Mya arenaria* was prevailing in studied estuaries and distributed among the most of sites of waterbodies. Most of species were found under water salinity, higher than 5 psu. Salinity level of 5 psu was a low boundary of marine and brackish (with marine origin) mollusks species distribution in studied estuaries. Positive correlation between quantitative characteristics of mollusk settlements (density, biomass) and water salinity was estimated ($r = 0.65$, $p < 0.0001$ and $r = 0.83$, $p < 0.0001$).

Values of species production were lowest in the DCBZ estuary with the lowest salinity, where *H. ulvae* (9.2 kJ m^2) and *M. arenaria* (9.3 kJ m^2) created up to 91 % of the total production during the vegetation season. In more saline water areas (Rugen lagoon and Salzhaff bay) production values belonged mainly to *M. arenaria* (19.4 kJ m^2) and *H. ulvae* (16.7 kJ m^2) correspondingly. Total production, respiration and efficiency coefficients (K_2) of energy consumption in estuaries increased along the salinity gradient (Table 1).

Table 1. Values of the total production, respiration and K_2 coefficients of mollusks in estuaries during the vegetation season.

Estuary	Salinity, psu	P, kJ m^2	R, kJ m^2	K_2
DZBC	4.6	32.7	91.4	0.15
Rugen lagoon	8.2	59.6	167.1	0.23
Salzhaff bay	10.1	190.2	543.9	0.26

There is a significant positive correlation between total mollusk production and water salinity ($r = 0.99$, $p < 0{,}01$) in contrast with correlation between primary production and mollusk production, which was significant negative ($r = –0.97$, $r < 0.05$) (fig. 2-3). This fact can be determined by the critical salinity (horogalinicum) influence on the production process within the examined salinity range.

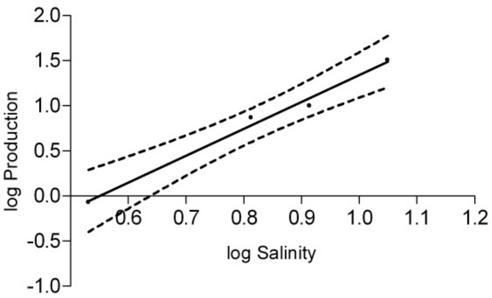


Figure 2. Correlation between the total mollusk production and the water salinity (log scale, CI = 95 %).

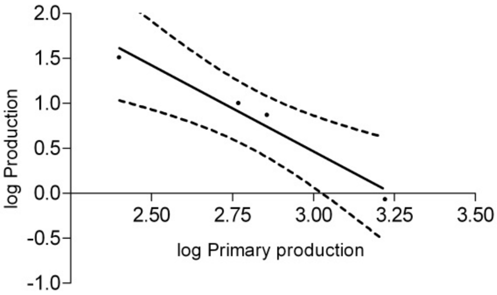


Figure 3. Correlation between the total mollusk production and the primary production of estuaries (log scale, CI = 95 %).

Estimated values of the filtration rate of bivalve *M. arenaria* revealed capability in range from 2.4 to 14.5 % of primary production consuming by this mollusks in the southern Baltic estuaries. Mean daily filtration coefficient (l mgO_2^{-1}) by *M. arenaria* was 66.5 ± 7.8 l mgO_2^{-1}. Calculation of filtration efficiency of the whole *M. arenaria* settlements revealed their ability to filter on average 2.4 ± 1.1 m^3 of water per square meter of the bottom (tab. 2). During vegetation season mollusks can purify approximately 380.6 ± 165.3 m^3 of the water in the estuaries, while removing up to 558,9 ± 65,7 g of the suspended organic matters.

Table 2. Filtration activity of *Mya arenaria* in estuaries of the southern Baltic Sea: F – filtration rate, Q – filtration coefficient, DF – daily filtration, SF – seasonal filtration.

Estuary	F, l d^{-1}	Q, l mgO_2^{-1}	DF, $m^3\ m^{-2}$	SF, $m^3\ m^{-2}$
DZBC	6.9	57.5	1.03	150.9
Rugen lagoon	7.2	76.6	2.81	492.4
Salzhaff bay	179.4	65.6	3.41	511.5

Therefore, main functional characteristics of mollusk settlements (energy flow, production, respiration, bivalve filtration rate) in Baltic Sea estuaries significantly increased along the salinity gradient.

Acknowledgements

Author thanks Prof. G. Graf and his research group from University of Rostock (Germany) for providing of this research. Also author thanks Dr. Sven Dahlke (University of Graifswald, Germany) for the field work and organization of expeditions to mentioned water bodies. Curent research was financially supported by Deutsche Bundesstiftung Umwelt (DBU), project # 30011/314.

References

Alimov A. (1989) Introduction to production hydrobiology, 152 p. (in Russian).

Arakelova E. (1986) Exchange rate of gastropod mollusks, Proc. Zool. Inst., 148, pp. 71-85 (in Russian).

Filgueira R., Rosland R., Grant G. (2011) A comparison of scope for growth (SFG) and dynamic energy budget (DEB) models applied to the blue mussel (*Mytilus edulis*), J. Sea Res., 66, pp. 403-410.

Møhlenberg F., Riisgård H. (1978) Efficiency of particle retention in 13 species of suspension feeding bivalves, Ophelia, 17 (2), pp. 239-246.

Riisgård H., Seerup D. (2003) Filtration rates in the soft clam *Mya arenaria*: effects of temperature and body size, Sarsia, 88 (6), pp. 416-428.

Atmospheric phosphorus load to the Baltic Sea – An approach for the estimation in the Finnish sea area

Tuija Ruoho-Airola[1], Seppo Knuuttila[2] and Jussi Vuorenmaa[2]

[1] Finnish Meteorological Institute, Helsinki, Finland (tuija.ruoho-airola@fmi.fi)
[2] Finnish Environment Institute, Helsinki, Finland

In the HELCOM Baltic Sea Action Plan (BSAP) (HELCOM 2007), maximum allowable nutrient inputs to the Baltic Sea and country wise allocated reduction targets for the HELCOM contracting parties are given. Both waterborne and airborne loads should be taken into account in the implementation and revision of the country allocation of nutrient reductions of the BSAP, but the information of the atmospheric phosphorus (P) deposition to the Baltic Sea is insufficient. The relative importance of the airborne P load has even increased because of the strong decline in the waterborne P load during the recent decades.

For the BONUS ECOSUPPORT project, a reconstruction of the nutrient input to the Baltic Sea was compiled for 1850–2006 (Ruoho-Airola et al. 2012). Published estimates of the P deposition for the Northern Europe ranged between 5 and 40 kg km^{-2} y^{-1}. In the absence of more detailed information, a constant deposition value of 15 kg km^{-2} y^{-1} was assumed after 1970. Both the BSAP and the ECOSUPPORT work demonstrate that there is a pressing need to update and define the estimate of the atmospheric P deposition to the Baltic Sea.

For the estimation of the atmospheric P load into the Finnish sea area, bulk deposition measurements have been performed at the station Tvärminne, southwestern coast of Finland. In 2010-2012, the total P deposition in Tvärminne was ca. 10 kg km^{-2} y^{-1}. Recently, new measurements at the EMEP station Utö in the Finnish Archipelago Sea near the Baltic Proper has been started. Utö is a small rocky island without any arable land, so the local anthropogenic P emissions are low. We will present the first results of the P deposition measurements at Utö. Also an analysis of the Tvärminne monitoring data will be presented and compared to results from other stations around the Baltic Sea.

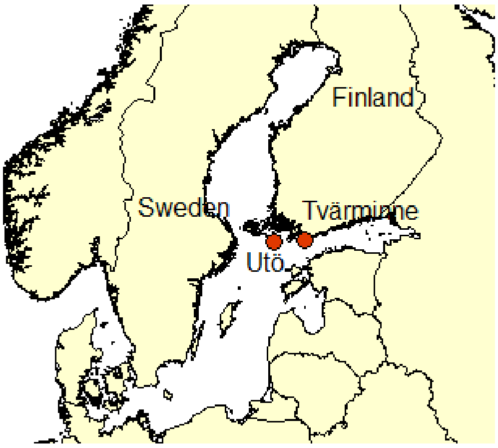


Figure 1. Monitoring stations Utö and Tvärminne.

References

HELCOM 2007. Baltic Sea Action Plan. Helsinki. ISBN 978-952-92-3231-4.

Ruoho-Airola T., Eilola, K., Savchuk O.P., Parviainen M. and Tarvainen V. 2012. Atmospheric nutrient input to the Baltic Sea for 1850-2006: a reconstruction from modeling results and historical data. AMBIO 41: 549-557.

Estimates of possible changes in indicators of eutrophication of the Baltic Sea under different scenarios of climate change and nutrient loads

V. Ryabchenko[1], M. Molchanov[1], A. Isaev[2], T. Eremina[2], O. Savchuk[3] and R. Vankevich[2]

[1] St.Petersburg Branch, P.P. Shirshov Institute of Oceanology, Russia (vla-ryabchenko@yandex.ru)
[2] Russian State Hydrometeorological University, St.Petersburg, Russia
[3] Baltic Nest Institute, Resilience Centre, Stockholm University, Sweden

1. Introduction

The purpose of this study is to estimate possible changes in eutrophication status of the Baltic Sea which are due to scenarios of climate change and nutrient loads in the 21st century. The estimation is based upon a recent version of St. Petersburg Baltic Eutrophication Model (SPBEM).

2. The coupled hydrodynamic-ecosystem model

SPBEM includes 3D hydrodynamic ocean-sea ice module (Neelov et al. (2003); Myrberg et al. (2010)) and biogeochemical cycles (BGC) module (Savchuk, (2002)). The BGC module describes nutrient cycling in the coupled pelagic and sediment sub-systems and contains 12 pelagic (zooplankton, diatoms, cyanobacteria, flagellates, nitrogen, phosphorus and silica detritus, ammonium, nitrite + nitrate, phosphate, silicate and dissolved oxygen) and 3 sediment (benthic nitrogen, phosphorus and silica) state variables. The current model version has horizontal resolution 5 nm, vertical step is 2m in the upper 100-meters and 5m below 100m.

3. Set-up of simulations

Two climate change scenario simulations have been used to force the SPBEM for the period 1961-2100. The forcing was calculated applying a dynamical downscaling approach using the regional climate model RCAO, Rossby Centre Atmosphere Ocean model (Döscher et al. (2002)). The lateral boundary data was from two GCMs, ECHAM5/MPI-OM from the Max Planck Institute for Meteorology in Germany and HadCM3 from the Hadley Centre in the UK. HadCM3 and ECHAM5 simulations were both forced with the A1B greenhouse gas emission scenario. Nutrient loads from land vary in accordance with the following two scenarios. In the reference scenarios (REF) concentrations of nitrogen and phosphorus in rivers, precipitation and point sources are assumed constant after 2007 and equal to their average values in the modern period (1995 to 2002). In the scenario according to Baltic Sea Action Plan (BSAP) the concentrations of nutrients in rivers linearly decrease from 2007 to 2020 by 17% for nitrogen and 35% for phosphorus and after 2020 remain unchanged. Atmospheric N and P depositions are described similarly and for the same period (from 2007 to 2020) are reduced by 50%. River run-off for future periods was calculated using a statistical model for 5 different basins (Gulf of Bothnia, the Bothnian Sea, Gulf of Finland, the Central Baltic, Kattegat), based on the difference of precipitation minus evaporation for land obtained from RCAO (Meier et al. (2012)). River loads are calculated as the product of the concentrations of nutrients and the river water discharge. The sea level at the open boundary in the Kattegat is calculated using a statistical model based on the meridianal difference of atmospheric pressure over the North Sea (Meier et al. (2012)). Results are reported for two 30 year periods (1970-200 and 2071-2100).

4. Results

The following indicators of eutrophication were considered: mean winter surface layer dissolved inorganic nitrogen and phosphorus, mean summer surface layer chlorophyll-a, mean late summer near-bottom dissolved oxygen and mean annual Secchi disk depth. Results are reported for two 30 year periods (1970-200 and 2071-2100).

According to the ECHAM5 driven REF scenario simulation, the possible climate change in this century will cause the growth of the near-surface temperature in the Baltic region, the increase in river run-off and water temperature in the Baltic Sea, especially in its surface layer (by 1.6 ^{0} C in summer), decrease (by about 1 ‰) in sea surface salinity. These changes in the hydrological regime will have a significant impact on the marine ecosystem of the Baltic Sea. In the warming climate and maintaining the current level of concentration of nutrients in the external loads on the Baltic Sea, areas of anoxia and hypoxia will grow by the end of this century compared to their modern values (in 3 and 1.5 times, respectively). The deterioration of the aeration of the sea will be accompanied by growing winter concentrations of nitrate (by 1.7 mmol N m^{-3}) and phosphate (by 0.3 mmol P m^{-3}) in the surface layer, an increase in mean annual biomass (by 22%) and primary production (by 37%) of phytoplankton. Secchi disk depth, characterizing the transparency of water, will be reduced by 0.4m. Water quality, characterized by the above environmental indicators, will deteriorate compared to current conditions. It is important to note that calculated changes in eutrophication indicators in two REF runs (ECHAM5 driven and HadCM3 driven) for the sea as a whole and for individual stations turned out to be different. The main reason for greater changes in HadCM3 driven simulation is higher water temperature in this run. In fact, higher water temperatures are projected to (1) reduce oxygen concentrations in the water column due to lower solubility of oxygen in warmer water and (2) accelerate organic matter mineralization and oxygen consumption. Greatly expanding anoxia will increase phosphorus release rates from the sediments, and amplify the phosphorus recycling which will reduce the removal of phosphorus from the ecosystem. Also expanding of anoxia cause increase rate of denitrification process and decrease nitrogen in the deep water. Together with an accelerated pelagic recycling loop, this will intensify primary production and increase phytoplankton biomass and chlorophyll-a.

According to the ECHAM5 driven BSAP scenario simulation, nutrient load reduction suggested in BSAP will not lead to any fundamental changes in the water quality in the end of this century. Namely, areas of anoxia and hypoxia are increased, respectively, by 68 and 19%, winter surface concentrations of nitrate and phosphate are reduced, respectively, by 0.5 mmol N m^{-3} and 0.03 mmol P m^{-3}, biomass and primary production of phytoplankton are increased respectively by 3.5% and 27%, Secchi disk depth is reduced by 0.2m. The resulting estimates are qualitatively consistent with the estimates obtained in the ECOSUPPORT project (http://www.baltex-research.eu/ecosupport/downloads/BONUS_125_ECOSUPPORT_Final_Report.pdf). Analysis of biogeochemical fluxes in the Baltic Sea implemented in ECOSUPPORT and this study showed that climate warming, leading to an increase in water temperature and a decrease in oxygen content in the sea, enhances release of phosphorus from the sediments, reduces the intensity of denitrification and increases nitrogen fixation. These natural mechanisms, to some extent, may oppose the proposed measures to combat excessive nutrient loads.

References

Döscher, R., U. Willén, C. Jones, A. Rutgersson, H. E. M. Meier, U. Hansson, and L. P. Graham (2002). The development of the regional coupled ocean-atmosphere model RCAO, Boreal Environ. Res., Vol.7, pp.183–192.

Meier, H.E.M., R. Hordoir, H. C. Andersson, C. Dieterich, K. Eilola, B. G. Gustafsson, A. Höglund, S. Schimanke (2012). Modeling the combined impact of changing climate and changing nutrient loads on the Baltic Sea environment in an ensemble of transient simulations for 1961–2099. Clim. Dyn. DOI 10.1007/s00382-012-1339-7.

Myrberg, K., Ryabchenko, V., Isaev, A., Vankevich, R., Andrejev, O., Bendtsen, J., Erichsen, A., Funkquist, L., Inkala, A., Neelov, I., Rasmus, K., Rodriguez Medina, M., Raudsepp, U., Passenko, J., Söderkvist, J., Sokolov, A., Kuosa, H., Anderson, T. R., Lehmann, A. & Skogen, M. D. (2010). Validation of three-dimensional hydrodynamic models of the Gulf of Finland. Boreal Env. Res., Vol. 15, pp. 453–479.

Neelov I.A., T.A. Eremina, A.V. Isaev, V.A. Ryabchenko, O.P. Savchuk, R.E.Vankevich (2003). A simulation of the Gulf of Finland ecosystem with 3-D model. Proceedings Estonian Academy of Science. Biology. Ecology, Vol. 52, pp. 347-359.

Savchuk O.P. (2002). Nutrient biogeochemical cycles in the Gulf of Riga: scaling up field studies with a mathematical model. J. Mar. Syst., Vol. 32, pp. 253-280.

Ten years of CO_2 measurements on a cargo ship reveal new insights and knowledge gaps in the Baltic Sea net community production

Bernd Schneider and Bernd Sadkowiak

Leibniz Institute for Baltic Sea Research Warnemünde, Germany (bernd.schneider@io-warnemuende.de)

1. Introduction

Investigations of the surface water CO_2 system were performed which mainly aimed at the quantification of the net community production and its relationship to the availability of nutrients. They are thus closely related to the eutrophication of the Baltic Sea. Measurements of the CO_2 partial pressure (pCO_2) are an ideal tool for such studies since the production and mineralization of organic matter are accompanied by the consumption and release of CO_2, respectively. Furthermore, due to the slow equilibration with atmospheric CO_2, the biological signal is conserved for a long time in the surface water and facilitates a quantitative assessment of the processes in question.

2. Methods

A fully automated pCO_2 measurement system was deployed in summer 2003 on cargo ship "Finnpartner" in cooperation with the Finnish Algaline Project. The measurements were based on equilibration of surface water with air and infrared CO_2 detection in the equilibrated air (Schneider et al., 2006). The ship commutes at 2 – 3 day intervals between Helsinki and Lübeck, and in some years also visited regularly Gdynia. The spatial resolution of the data that is given by the ship`s speed and the response time of the measurement system, amounts to 1 – 2 nautical miles. The measurements were interrupted for about 1.5 years in 2006/2007 when another ship ("Finnmaid") took over the line.

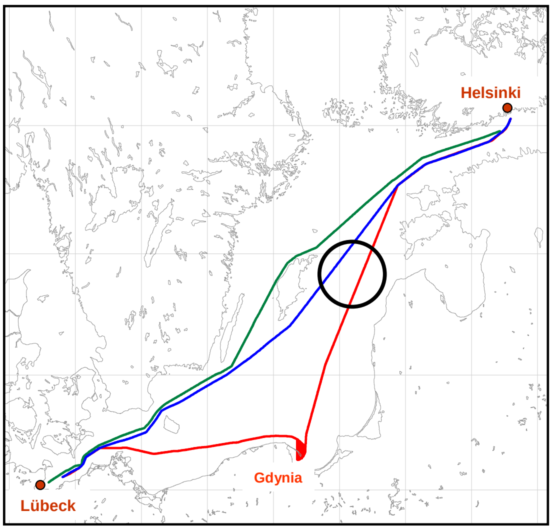


Figure 1. Routes of cargo ship FINNMAID. The black circle indicates the area for which the mean CO_2 partial pressures (Fig. 2) and total CO_2 concentrations (Fig. 3) were calculated.

3. Seasonality of the pCO_2

Mean pCO_2 for each transect during 2004 – 2011 were calculated for the northeastern Gotland Sea (encircled area in Fig. 1) and plotted as a function of the julian day in Fig. 2. The data show a pronounced seasonality that is controlled by an interplay between biological production, vertical mixing and, to a minor degree, on temperature.

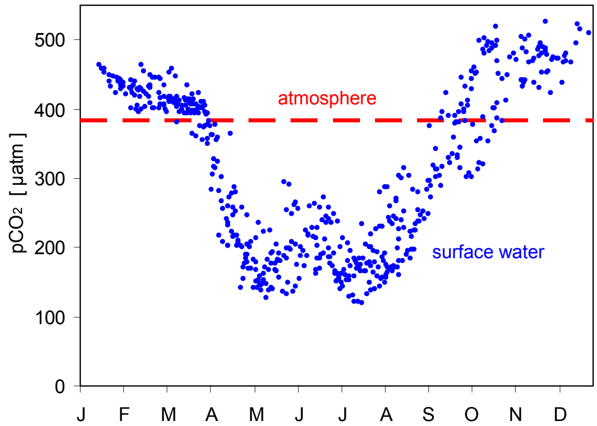


Figure 2. Seasonality surface water CO_2 partial pressures, pCO_2, in the northeastern Gotland Sea during 2004 – 2011, and mean atmospheric pCO_2 during this time span.

During late autumn and winter deep mixing transports CO_2 to the surface and causes a pCO_2 that exceeds the atmospheric CO_2 and makes this region a source for atmospheric CO_2. A sudden drop of the pCO_2 below the atmospheric level occurs with the onset of the spring plankton bloom and the surface water becomes a sink for atmospheric CO_2. The minimum is observed by mid-May and the pCO_2 starts again to increase until mid-June. This is due to the rising temperature while regenerated production takes place which has only a minor effect on the CO_2 budget. A second pCO_2 minimum is observed in July and reflects another major bloom event that is based on nitrogen fixation. In the following weeks the pCO_2 is increasing mainly due to deep mixing and goes finally again beyond the atmospheric value. Balancing uptake and release of CO_2 by gas exchange indicated that the central Baltic Sea is a weak sink for atmospheric CO_2.

4. Net community production

Based on the pCO_2 data the seasonal changes in total CO_2 (C_T) were calculated which together with estimates of the CO_2 gas exchange yielded the net community production. These calculations were facilitated by the fact that calcifying plankton is virtually absent in the central Baltic (Schneider et al., 2009). The sharp drop of C_T that occurred in all years in almost the same week by the end of March, displayed the start of the spring bloom (Fig. 3). The C_T decrease continued until mid-May although nitrate was already entirely depleted in all years by mid-April (Fig. 3, first dashed line). This indicates the continuation of the net community production since concurrently also the excess phosphate that was left after the nitrate depletion, continued to decrease. Hence, a nitrogen source must exist to sustain the post-nitrate production. Since the atmospheric deposition is by far too small to cause short term effects, it was speculated that either dissolved organic nitrogen was used for production or that early nitrogen fixation took place despite the low water temperatures at the end of April and beginning of May.

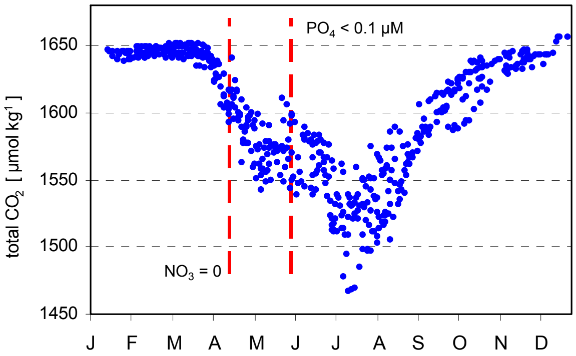


Figure 3. Seasonality of the total CO_2 calculated from the pCO_2 data for 2004 – 2011. The dashed lines indicate the dates of nitrate and phosphorus depletion.

However, both hypotheses could not be substantiated by field measurements. But an analysis of data for total nitrogen and phosphorus concentrations in the eastern Gotland Sea (Swedish National Monitoring Program, SMHI) showed that total nitrogen increased after the nitrate depletion whereas total phosphorus decreased continuously since the start of the spring bloom due to sedimentation (Fig. 4). These findings point to an external nitrogen source such as nitrogen fixation (Schneider et al., 2009).

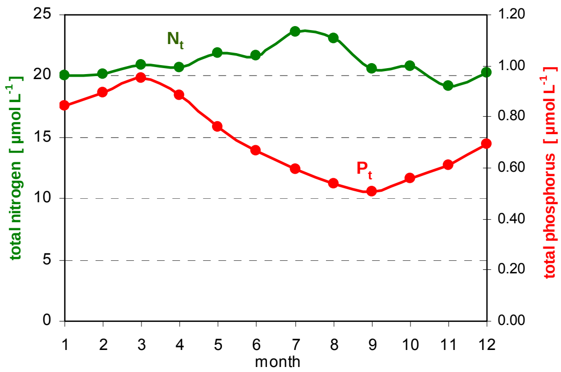


Figure 4. Mean seasonality of the total nitrogen and total phosphorus during 2003 – 2012 at station BY15 in the eastern Gotland Sea (Swedish National Monitoring Programme, SMHI).

During the time span from mid-May to mid-June the C_T did not show a clear trend. This indicates that the organic matter production was mainly based on regenerated production during which the nutrients and carbon are recycled within the trophic layer.
The second distinct drop of C_T was observed by mid-June when the mid-summer production based on nitrogen fixation started. The minimum occurred in general in July and showed strong interannual variations with regard to the minimum levels. However, these do not necessarily reflect variations of the integrated production and of nitrogen fixation in the trophic layer. It was shown that the C_T minima were confined to a shallow water layer of about 2 m – 3 m and occurred only during extremely calm weather conditions that resulted in high temperatures at the immediate water surface. Finally, the phosphorus supply for production during nitrogen fixation must be considered. Since phosphate was almost completely consumed at the beginning of the nitrogen fixation period in the beginning of June (Fig. 3, second dashed line) there is clearly a phosphorus shortage during the nitrogen fixation period. However, the lack of phosphorus is obviously not limiting nitrogen fixation and the organic matter production. As a result, C/P and N/P ratios occur that may exceed the corresponding Redfield ratios by a factor of up to four (Larsson et al., 2001; Schneider et al., 2003).

5. Conclusions

The chronology and intensity of the net community production can be traced by high resolution measurements of the surface water CO_2 partial pressure. It was shown that the traditional view concerning the production control by the winter nutrient concentrations applies only conditionally to the Baltic Sea. This refers in particular to the post-nitrate production that requires a nitrogen source which is possibly based on early “cold” nitrogen fixation in April/May. Furthermore, the data indicate that the mid-summer production fuelled by nitrogen fixation is not controlled and limited by the phosphate surplus after the spring bloom.

References

Larsson, U., Hajdu, S., Walve, J., Elmgren, R. (2001) Baltic Sea nitrogen fixation estimated from the summer increase in upper mixed layer total nitrogen, Limnol. Oceanogr., 46, 811 – 820.

Schneider, B., Nausch, G., Nagel, K., Wasmund, N. (2003) The surface water CO_2 budget for the Baltic Proper: a new way to determine nitrogen fixation, J. Mar. Sys., 42, 53 – 64.

Schneider, B., Kaitala, S., Maunula, P. (2006) Identification and quantification of plankton bloom events in the Baltic Sea by continuous pCO_2 and chlorophyll *a* measurements, J. Mar. Sys., 59, 238 – 248.

Schneider, B., Kaitala, S., Raateoja, M., Sadkowiak, B. (2009) A nitrogen fixation estimate for the Baltic Sea based on continuous pCO_2 measurements on a cargo ship and total nitrogen data, Cont. Shelf Res., 29, 1535 – 1540.

Climate change responses of the large aquatic ecosystems in the Baltic Sea basin

Andrey N. Sharov, Larisa E. Nazarova, Tamara N. Polyakova, Nadezhda A. Berezina

Northern Water Problems Institute, Karelian Research Centre of the Russian Academy of Sciences, Russia (sharov_an@mail.ru)

1. Introduction

Freshwater ecosystems are among the most vulnerable to climate change. Spatio-temporal heterogeneity of structural and functional parameters of plankton and benthos of large lakes in the Baltic Sea basin formed depending on a number of global factors in the first place, such as climate variability and human impact. Climate variability can directly or indirectly affect the population dynamics of aquatic organisms and their geographical distribution. In the Baltic Sea basin, climate change will be reflected primarily on the ice cover duration. Responses of biological communities to the climate variability are much more complex and difficult to recognize than the responses of physical components, especially in the case of large ecosystem with long period of water exchange. We illustrate that on example of large European lake, situated in the eastern Baltic Sea basin, Lake Onega (Figure 1).

Figure 1. Lake Onega is second of the largest lake in the Europe (lake area 9890 km^2, volume 280 km^3, mean depth 30 m, maximum depth 120 m).

The main purpose of this paper is to analyze the regional meteorological parameter variability, physical changes and biotic communities dynamics over the last 50 years in the Lake Onega. To identify common global and regional patterns of climate change in Lake Onega region we used Databases of the Northern Water Problems Institute and Roshydromet (Federal Service for Hydrometeorology and Environmental Monitoring) and also data about North Atlantic Oscillation (NAO) from website http://www.cgd.ucar.edu for about 50 years (Figure 2).

2. Climate change trends

Climatic changes during this period include reduction in the ice cover period duration on Lake Onega, increases in both air temperatures and sunshine duration. The duration of the ice-free period in Petrozavodsk Bay of Lake Onega increased to an average of 227 days/year, which is 12 days longer than the average value of the second half of the 19th century by the early onset of spring (Atlas of Lake Onega 2010). The intensity of the warm spring water determines the beginning of the vegetation season and somatic and reproductive growth biotic populations, which further affect the overall structural and functional organization of the whole ecosystem.

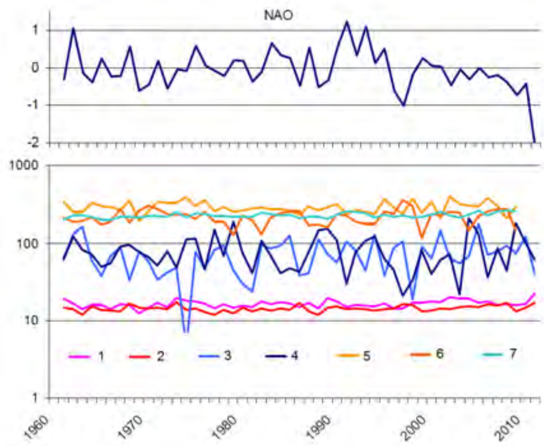


Figure 2. Dynamic of the annual climatic data in 1960-2012 (Petrozavodsk weather station). 1 - air temperature in July, C°; 2 - air temperature in August, C°; 3 - precipitation in July, mm; 4 - precipitation in August, mm; 5 - sunshine duration in July, hour; 6 - sunshine duration in August, hour; 7 – Ice free period, day.

Trend of increasing water temperatures, duration ice-free period were marked also for different small lakes in Finland, Sweden, Norway and north-western Russia (Finland `s Fifth National Communication, 2010; Efremova et al. 2010). The effect of climate change for Lake Ecosystem cannot be expressed in the term of mean annual temperature, but the duration of the "biological summer" mainly determines the start possibilities for aquatic organisms production and its value. Thus, life cycles and distribution of species are changed as a result of climate variability and may be differed between lakes.

3. Biological responses to climate change

Analysis of long-term observations in species composition, seasonal and annual dynamics in abundance and biomass of plankton including phytoplankton and zooplankton in Lake Onega revealed that current trend to an increase in their average value, despite on the high seasonal and spatial variability. Phytoplankton biomass varies throughout the year from 0.1 to 5 g/m^3, with a maximum in early summer. Zooplankton is also characterized by seasonal variations with maximum species diversity and abundance in July. Spatial heterogeneity of zooplankton was especially noted in shallow water areas (littoral zone and bays), where it reached 100-150 thousand ind./m^3 and above 3 g/m^3. In the central part of Lake Onega, the these values were low, 0.01-0.02 thousand ind./m^3 and 0.1 g/m^3 (Atlas of Lake Onega 2010).

Climate influences on the seasonal dynamics of zooplankton and phytoplankton, determining their taxonomical structure and a complex of the species prevailing in terms of biomass and productivity.
Zoobenthos in the deep part of the lake is characterized by low species diversity and consists mainly of oligochaetes and glacial relict crustaceans. Mean abundance and biomass of macrozoobenthos in the deep waters of Lake Onega were maximally 4,5 ± 0,8 thousand ind./m^2 and 6,7 ± 1,1 g/m^2, respectively, while in littoral zone (3- 8 m) they reached 11,8 ± 1,7 thousand ind./m^2 and 11,8 ± 1,5 g/m^2. There is a trend to increase of biomass of zoobenthos for last 50 years, which is primarily related not only to climate changes but also to local eutrophication. For example in Petrozavodsk and Kondopoga bays maximum abundance and biomass (up to 41 10^3 thousand ind./m^2 and 58.0 g/m^2) were recorded in last decades.

Climate change, as warming, together with the creation of canal-river networks and shipping increase facilitated the rapid distribution and introductions of some aquatic species of plant and animals, including thermophilic species from the southern basin (Ponto-Caspian and Mediterranean seas) to the north, including Baltic Sea basin (Berezina, 2007). In the case of Lake Onega, the main changes were found in the macrozoobenthos in coastal areas where invasive species of amphipod *Gmelinoides fasciatus* successfully established more than ten years ago. This has led to an increase in the total biomass of benthic and significant changes in community structure.

4. Correlation of biological and climatic parameters

In analyze the relationships between physical parameters and the biological characters we used the nonparametric Spearman rank correlation. Significant correlation between physical parameters of climate changes (ice cover duration, the air temperature, NAO index) and biomass of macrozoobenthos was found only for shallow (10-15 m) and relatively unpolluted areas of Lake Onega. Significant positive correlation was found between the biomass of the zoobenthos and the average annual one-year lag of the NAO index (Figure 3).

NAO is a large-scale atmospheric processes determining climate variability in the Northern Hemisphere. Under positive index prevailing strong westerly winds warm, moist air to the north of the European continent, this is particularly evident in the winter. Thus, the relatively warm weather throughout the year enhances zoobenthos biomass a year. Early spring (high NAO index in winter) leads to an increase in the growing season, the intense heating of the water displacement of the seasonal cycles and increase the performance of Production of aquatic organisms. Zoobenthos biomass in August have positive correlation with winter NAO ($r = 0.64$, $p < 0.01$) and with ice cover duration ($r = 0.51$, $p < 0.02$). Sunshine duration in August is in inverse proportion to the Rainfall ($r = -0.77$, $p < 0.01$) and is positive correlated ($r = -0.78$, $p < 0.01$) with the chlorophyll a concentration.

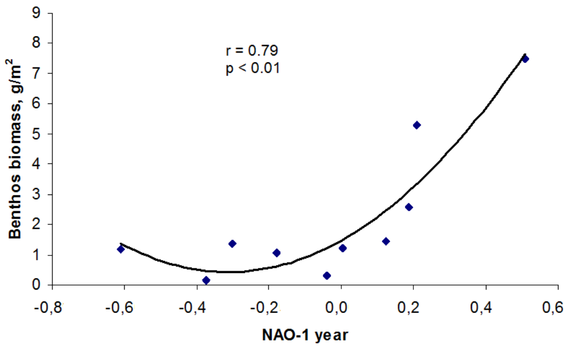


Figure 3. Relation between Lake Onega benthos biomass (15 m station) and annual NAO index (r - Spearman rank correlation coefficient).

Relationships between climatic variables (index of NAO, the temperature, the duration of ice cover and solar light) and biological indicators show a marked influence of climatic fluctuations in the lake ecosystem. However, the eutrophication and pollution in local areas much more impact on aquatic organisms compared to climate variability.

5. Conclusion

Thus, in the Baltic Sea basin there are climate changes that may lead to the transformation of the structural and quantitative characteristics of aquatic communities. Climate change will impact primarily on the ice cover duration. This may influence the length of the growing season and the seasonal cycles of aquatic organisms. At the same time, we found no significant correlation between climatic variables and the plankton biomass due to strong seasonal variations and other factors on the ecosystem of Lake Onega. Anthropogenic impacts (eutrophication) increases productivity and variability of planktonic and benthic communities. Deeper part of Lake Onega is characterized by high stability. The most significant response of aquatic organisms to climate change can be expected in the littoral zone.

References

Atlas of Lake Onega. Ans. Ed. NN Filatov, Petrozavodsk Karelian Research Centre, 2010.152 p.

Berezina N. A. Invasions of alien amphipods (Crustacea: Amphipoda) in aquatic ecosystems of North-Western Russia: pathways and consequences // Hydrobiologia. 2007, № 590. P 15-29.

Efremova T.V., Zdorovennova G.E., Palshin N.I. Ice conditions of lakes in Karelia // Water environment: learning for sustainable development. Petrozavodsk: Karelian Research Centre, 2010. P. 31-40.

Finland`s Fifth National Communication under the United Nations Framework Conventions on climate change. Helsinki, 2010. 282 p.

Regime Shifts and Trends in the Baltic Sea area: A statistical approach

Adolf Konrad Stips[1] and Madis-Jaak Lilover[2]

[1] Joint Research Centre, European Commission, Ispra, Italy (adolf.stips@jrc.ec.europa.eu)
[2] Marine Systems Institute, Tallinn University of Technology, Tallinn, Estonia

1. Introduction

During the 1980s air and sea surface temperature started to increase in the Baltic Sea area. Sea ice broke up earlier and overall ice coverage declined. This resulted in a longer growing season and in increases in phytoplankton biomass as well as changes in the zooplankton and fish communities. These changes are often considered to represent a regime shift in the ecology of the central Baltic Sea, which according to Alheit et al. (2005) could be caused by a related sign change in the North Atlantic Oscillation (NAO).

The aim of this investigation is to inspect relevant physical and ecosystem variables for trends and structural breakpoints in the concerned time series. We therefore use documented statistical methods that include confidence tests at the 5% error probability.

2. Method and data

To estimate structural breakpoints in time series regression models we apply the method developed by Bai and Perron (2003). This method is implemented in the statistical software **R** package *strucchange*. An introduction to the method with examples is presented in Zeileis et al. (2003). The **R** statistical software and the mentioned package can be freely downloaded from the Comprehensive R Archive Network (CRAN, http://cran.r-project.org/).

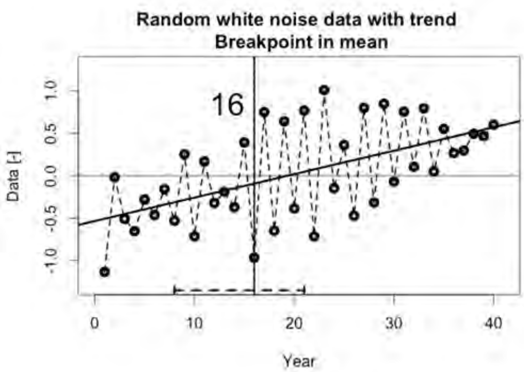


Figure 1. Breakpoint identified at year 16 in a 30 years time series of data with a significant trend of 0.05 and white noise added.

When applying this statistical method to data generated so that they have a significant linear trend and added white noise than in most cases a significant breakpoint is detected. An example of such data is given in Figure 1, presenting a 40 year time series with a trend of 0.05[-]/year. Doing 10000 Monte Carlo simulations we found that time series with a significant trend do have in about 90% of the cases also a significant breakpoint (actually caused by the locally changing mean as a consequence of the trend). To exclude such spurious breakpoints resulting from the applied methodology, data with a significant trend must therefore be detrended before doing the analysis.

To compare our results with the results and conclusions from Alheit et al. (2005) this new study is mainly based on the data used in that article. These data sets comprise annual temperature maximum in the halocline (55-70 m of the Bornholm Basin, Station K2), Phytoplankton spring biomass in the Bornholm Basin (Station K2) and the Gotland Basin (Station K1), Diatom and dinoflagellate biomass in the Gotland Basin (Station J1), Silicate concentration in the Bornholm Basin (Station K2) and Gotland Basin (Station K1), biomass anomalies of Acartia spp., in the Gotland Sea and the Gdansk Deep, abundance of cod and sprat in the central Baltic Sea. Here only some selected results can be presented.

For the North Atlantic Oscillation index we used the version from the Climatic Research Unit of the University of East Anglia http://www.cru.uea.ac.uk/cru/data/, see also Hurrell (1995).

3. Results

As a first example the biomass of the phytoplankton spring bloom is presented in Figure 2 (data already detrended). Applying the breakpoint analysis to the original data a breakpoint at 1987 (±2) is detected. But these data have a significant increasing trend of 38 (±25) mg m^{-3}/year and subtracting that trend also does remove the previously found breakpoint.

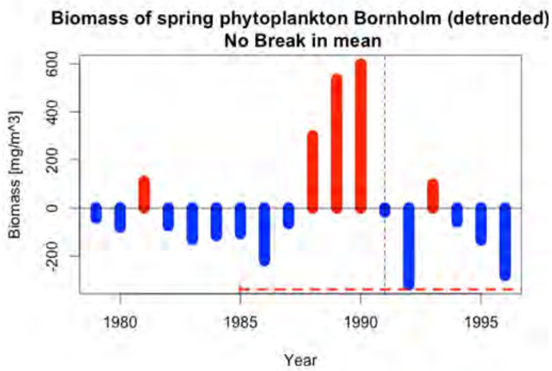


Figure 2. Spring phytoplankton in the Bornholm Basin of the Central Baltic Sea detrended. After removing the significant trend no breakpoint can be identified.

The second example is the biomass anomaly of sprat in the Gotland Sea, presented in Figure 3 (data already detrended). Applying the breakpoint analysis to the original data a breakpoint at 1992 (±2) is detected. But sprat biomass anomaly does have a significant increasing trend of 10 (±4.7) [-]/year and subtracting that trend also does remove the previously found breakpoint, as can be seen in Figure 3.

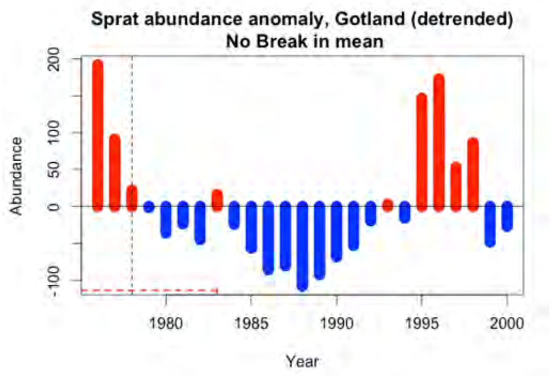


Figure 3. Sprat abundance in the Gotland Basin of the Central Baltic Sea. After removing the significant trend no breakpoint can be identified.

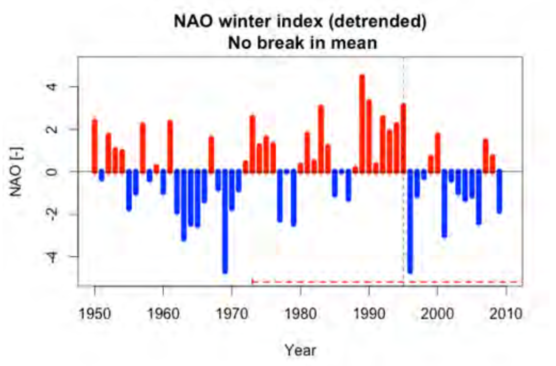


Figure 4. North Atlantic Oscillation . After removing the significant trend no breakpoint can be identified.

Finally, the supposed cause of the proposed regime shift in the Baltic Sea the NAO index is scrutinized. The NAO time series from 1950 to 2005 does have a just significant increasing trend of 0.041 (±0.03) per year. The breakpoint analysis of the original data does result in a breakpoint at 1971 (±9) which is corresponding to the most significant sign change in this time series. As the linear trend in the NAO data is significant we must remove it before the breakpoint analysis. The result of this analysis is presented in Figure 4. The structural change test does not provide any significant breakpoints in the time series mean of the NAO index.

4. Discussion

Most of the investigated time series do exhibit a statistical significant linear trend. As a result of this trend the straightforward application of a structural breakpoint test does lead to many false detections of such breakpoints. But testing these time series for structural breakpoints after removing the linear trend did reveal only for some investigated variables the existence of a breakpoint in the 70-80ties of the last century. In contradiction to the seemingly well established "regime shift" hypothesis in the Baltic Sea no clear breakpoint can be identified in many physical variables and also not in most ecosystem variables including fish. Finally, also the proposed reason for the supposed ecological regime shift in the Baltic Sea, the change of the NAO sign at around 1987, is not statistically significant. This invalidates the proposed causal chain leading from a NAO sign change to a hypothesized regime shift, as both events are failing to pass rigorous statistical tests.

5. Conclusions

In summary we conclude that the Baltic Sea regime shift does remain a hypothesis and most physical and ecosystem time series data from the Baltic Sea region are statistically best described by a linear trend and not by a regime shift.

The underlying dynamics of a system cannot be revealed by a pure statistical analysis. Statistics can help us to question or support our hypothesis but advanced geophysical and ecosystem modeling is needed to understand the system dynamics.

References

Alheit, J. et al. (2005). Synchronous ecological regime shifts in the central Baltic and the North Sea in the late 1980s. *ICES Journal of Marine Science*, Vol. **62**, pp. 1205-1215.

Bai, J. and Perron, P. (2003). Computation and Analysis of Multiple Structural Change Models. *Journal of Applied Econometrics*, Vol. **18**, pp. 1-22.

Hurrell, J. W. (1995). Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. *Science*, Vol. **269**, pp. 676-679.

Zeileis, A. et al. (2003). Testing and Dating of Structural Changes in Practice. *Computational Statistics and Data Analysis*, Vol. **44**, pp. 109-123.

The Submarine Groundwater Discharge as a carbon source to the Baltic Sea

Beata Szymczycha and Janusz Pempkowiak

Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

1. Introduction

The Baltic Sea used to be characterized as an autotrophic semi-enclosed brackish sea (Thomas et al., 2004). No submarine groundwater discharge (SGD) was taken into account though. This work reports results on quantification of SGD as a source of carbon flux to the Bay of Puck, Southern Baltic Sea. The data are then scaled up to the entire Baltic Sea using the measured carbon concentrations and the literature derived SGDs.

2. Materials and Methods

The study area was situated in the Puck Bay, a shallow part of the Gulf of Gdansk (southern Baltic Sea). The reported study was a continuation of earlier investigations reported by Szymczycha et al. (2012). Seepage water sampling points were selected at sites characterized by low salinity of sediment porewater. The DIC and DOC analysis were carried out in a 'HyPerTOC'analyser using the UV/persulphate oxidation method and NDIR detection (Kuliński and Pempkowiak, 2008) The recovery was equal to 97.5 ± 1 %. The precision assessed as RSD was better than 1.5%. DIC and DOC fluxes via SGD to the study area were calculated as a product of groundwater fluxes and concentrations of DIC and DOC.

3. Results

In general, salinity and pH of porewater decreased with depths while DIC and DOC concentrations increased with sediment depths. The salinity profiles are explained by intrusion of seawater into the sediments (Szymczycha et al., 2012). The annual averages of DIC (n=13) and DOC (n=13) concentrations in groundwater were equal to 64.5 ± 10.0 mg C l^{-1} and 5.8 ± 0.9 mg C l^{-1}. The SGD is equal to 16 dm^3/m^2 d. The annual carbon discharges to the Baltic Sea, and to the selected areas of the sea are presented in Table 1. The DIC and DOC fluxes carried with the SGD to the Baltic Sea equal 283.6 ± 44.0 kt yr^{-1} and 25.5 ± 2.2 kt yr^{-1}, respectively. The SGD derived carbon loads represent some 10% of the load discharged to the sea with river run-off.

When the SGD carbon loads are supplemented to the Baltic carbon budget, the status of the sea set as 'marginally heterotrophic' (Kuliński and Pempkowiak, 2011), turns into firmly heterotrophic.

Table 1. Submarine groundwater discharge and associated carbon fluxes to the Baltic Sea Sub-Basins and the Baltic Sea

Study Area	SGD ±SD $km^3\ yr^{-1}$	Carbon Concentrations ± SD mg l^{-1}		Carbon Fluxes ± SD kT yr^{-1}		Source
		DIC	DOC	DIC	DOC	
The Baltic Sea	4.40±ND*	64.5±15.0	5.8±0.5	283.8±44.0	25.5±2.2	This study (SGD rate based on Peltonen, 2002)
The Polish and German coast	1.90±ND	64.5±15.0	5.8±0.5	122.6±19.0	11.0±1.0	This study (SGD rate based on Peltonen, 2002)
The Gulf of Gdańsk	0.06±ND	64.5±15.0	5.8±0.5	3.9±0.6	0.3±0.03	Szymczycha et al, 2013
The Puck Bay	0.03±ND	64.5±15.0	5.8±0.5	1.9±0.2	0.2±0.002	Szymczycha et al, 2013
The Gulf of Finland	0.60±ND	64.5±15.0	5.8±0.5	38.7±6.0	3.5±0.3	Szymczycha et al, 2013

References

Kuliński, K. and Pempkowiak J.(2011) The carbon budget of the Baltic Sea, Biogeosciences, 8, 3219–3230.

Peltonen K. (2002) Direct groundwater flow to the Baltic Sea. Nordic Council of Ministers, Temanord., Copenhagen, 78 pp.

Szymczycha, B., Vogler, S., Pempkowiak, J. (2012) Nutrients fluxes via Submarine Groundwater Discharge to the Bay of Puck, Southern Baltic. Science Total Environemnt, 438, 86–93

Szymczycha, B., Szczepańska A., Maciejewska A., Pempkowiak J. (2013) SGD as carbon source to the Baltic. Biogeosciences, submitted

Thomas, H., Bozec, Y., Elkalay, K., and de Baar, H. J. W (2004): Enhanced Open Ocean Storage of CO2 from Shelf Sea Pumping, Science, 304, 1005-100.

Transport of PCDD/PCDF along the Pilica river continuum under different hydrological conditions – A possible impact on the Baltic Sea environment

Magdalena Urbaniak[1,2], Edyta Kiedrzyńska[1,2], Marek Zieliński[3] and Maciej Zalewski[1,2]

[1] European Regional Centre for Ecohydrology u/a UNESCO, Poland (m.urbaniak@unesco.lodz.pl)
[2] Department of Applied Ecology, University of Lodz, Poland
3 Nofer Institute of Occupational Medicine, Lodz, Poland

1. Introduction

Export of micropollutants to rivers and coastal zones driven by human-related activities is one of the major problems in river catchments and coastal marine ecosystems (Kannan et al. 2003; Hilscherova et al. 2003; Koh et al. 2004; Saphoznikova et al. 2005; Urbaniak et al. 2010).

Poland is one of the nine countries situated in the catchment area of the Baltic Sea, which greatly contributes to it pollution. The Polish territory is almost entirely located in the catchment area of the Baltic Sea (99.7%) (PCSO 2011). The total area of Poland is 312 679 km^2 making it the 9th largest country in Europe and the 6th most populous member of the European Union. The average number of persons per 1 km^2 amounts to 123 (ca. 1 082 in cities, and 51 in rural areas), which is the highest rate among the countries of the Baltic Sea catchment. This generates a large amount of municipal and industrial wastewater and rainwater. Moreover, Poland is predominantly an agricultural country, where agricultural lands in 2011 accounted for 60.3%. This contributes to water runoff containing fertilizers, pesticides and organic contaminants which entered the rivers and are transported trough river continuum up to the Baltic Sea.

Among various substances transported through the river water, the Persistent Organic Pollutants (POPs) including PCDDs (polychlorinated dibenzo-p-dioxins) and PCDFs (polychlorinated dibenzofurans) pose a serious threat to aquatic ecosystems. Chemically, these compounds belong to a group of halogenated aromatic hydrocarbons and are characterised by high toxicity. Moreover, their long life in the environment, the ability to accumulate in soils and sediments, and in aquatic and terrestrial food chains make them a long-term threat to the environment and humans. They have been recorded in the Polish rivers, reservoirs and lakes (Urbaniak et al. 2010, 2012ab; Konieczka at al. 2005; Rodziewicz et al. 2004; Kannan et al. 2003; Kowalewska et al. 2003) and consequently in abiotic and biotic compartments of the Baltic Sea (HELCOM, 2002; 2003).
Considering above, prevention of Baltic Sea pollution and achievement its good ecological status should primarily rely on the understanding of the processes of migration of given micropollutants and their quantification in individual catchments.

Therefore, the main objective of this study was to quantify the transfer of PCDDs/PCDFs along the Pilica River continuum under different hydrological conditions in order to estimate the load of analyzed compounds to the Vistula River – the second biggest river within the Baltic Sea catchment.

2. Materials and methods

The Pilica River (Figure 1) is one of the most significant and the longest left-hand tributaries of the Vistula River, which flows into the Vistula at the 457 km of the river course. The overall length of the Pilica River is 342 km with the total catchment area of 9 258 km^2.

Eleven towns are located along the river length, including the biggest ones: Tomaszow Mazowiecki – with 65 375 inhabitants and strong textile, ceramics, machinery, metal and leather industry, Nowe Miasto − with 3 885 inhabitants, Bialobrzegi – with 7 328 inhabitants and Warka with 11 035 inhabitants and strong brewery and fruit and vegetable industry. All of mentioned cities are located in the lower section of the river.

The water samples from the Pilica River were collected three times: in spring of 2010 (high water flow; flood period), in summer of 2010 (stable water flow) and in summer of 2012 (low water flow). The samples were taken from 5 stations located along the river continuum, including 2 points situated above (no. 2) and below (no. 3) the Sulejow Reservoir (Figure 1).

The river samples were collected 100-150 m above the Sewage Treatment plants (STPs) outlets to the Pilica River in order to obtain representative, well-mixed samples which reflect the river pollution at the given sampling point.

Samples were purified and analysed for 17 2,3,7,8-substituted congeners of PCDDs and PCDFs using HRGC-HRMS and isotope dilution method described earlier by Urbaniak et al., (2012b).

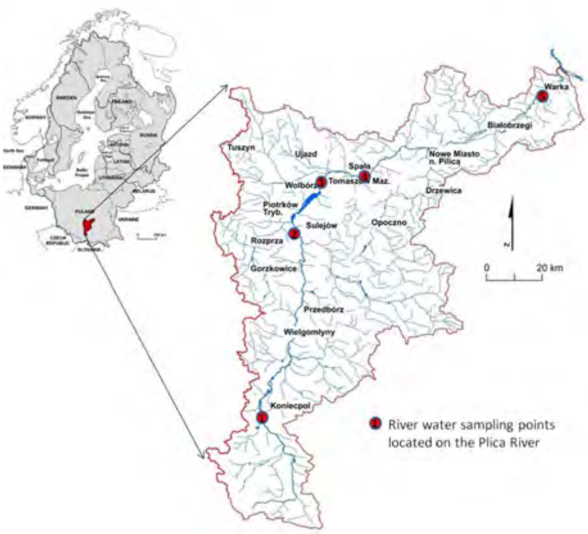


Figure 1. Location of river water sampling points along the Pilica River continuum.

3. Results and discussion

The total concentration of 17 2,3,7,8-substituted PCDDs/PCDFs showed that during a high water flow observed for the period of spring flooding in 2010 the river water samples were heterogeneous with values ranging from 21.78 pg/L to 47.85 pg/L. The samples collected at the stable water flow during the summer season of 2010 were characterised by lower concentrations comparing to the previous period as the obtained values ranged from 15.50 pg/L up to 38.89 pg/L. The lowest concentrations were obtained during the low water flow in summer 2012 with the minimum and maximum concentration of 15.40 pg/L and 21.34 pg/L, respectively.

The obtained results showed also that the average total concentration of PCDDs/PCDFs calculated for all sampling points decreased together with decrease of river water flow as following: 33.57 pg/L, 28.31 pg/L and 18.72 pg/L for high, stable and low water flow periods, respectively. Similar situation was observed for TEQ concentration with the highest values noted for period of high water flow (4.21 pg TEQ/L), medium during the stable hydrological conditions (3.64 pg TEQ/L) and the lowest during low water stage (0.99 pg TEQ/L). These results suggest that during high water flow despite the point sources of pollution like STPs outlets which constantly derived PCDDs/PCDFs into the river recipients, the important role play diffuse sources of pollution related mostly to the agricultural and urban runoff.

Moreover, samples collected at the high water flow illustrated an increase in the total and TEQ concentration along the first two sampling points (no. 1 and no. 2). This situation can be linked to the input of the analyzed compounds from STPs located within this part of the Pilica catchment, as well as to the runoff of pollutants from the surrounding agricultural fields together with the flooding waters. The decrease in the total and TEQ concentrations below the Sulejow Reservoir may result from the deposition and burial of the analysed micropollutants in the sediments and biota of the reservoir. The further increase in the total and TEQ concentration at the last sampling points may be again related to the discharges from the STPs as well as to the surface runoff from the catchment following the intensive rains. Additionally, the higher total and TEQ concentration in the samples collected from the downstream section of the Pilica River (no. 4 and 5) can be related to a larger drainage area and consequently the higher pollution level of this part of the river.

The samples collected at the stable and low flows in turn showed different pattern with decreasing of total and TEQ concentration along the first three sampling points and the increase at the 4^{th} and 5^{th} site. The reason of such situation is threefold: 1) the self-purification of the river at its upper section (sampling points no. 1 and 2); 2) the burial of PCDDs/PCDFs in the Sulejow Reservoir; and 3) the impact of the biggest cities and STPs within the Pilica catchment (sampling points no. 4 and 5).

The obtained results calculated in order to obtain the annual load of total and TEQ PCDDs/PCDFs concentration into the Vistula river ranged between 28.69 to 51.45 g/year for total and 1.52 to 6.45 g/year for TEQ concentration. The achieved loads in comparison to the other worldwide data are several times lower (Ko and Baker, 2004; Liu et al., 2008) and thus suggest the low impact of the Pilica discharges on the quality of the Vistula River and the Baltic Sea environment.

Acknowledgements

The research was supported by the Polish Ministry of Science and Higher Education, Project: N N305 365738 “Analysis of point sources pollution of nutrients, dioxins and dioxin-like compounds in the Pilica River catchment and draw up of reclamation methods”.

References

HELCOM, 2002. Environment of the Baltic Sea Area 1994-1998. Baltic Sea Environment Proceedings No. 82B, 216 pp.

HELCOM, 2003. The Baltic Marine Environment 1999-2002. Baltic Sea Environment Proceedings No. 87, 48 pp.

Hilscherova, K., Kannan, K., Nakata, H., Yamashita, N., Bradley, P., Maccabe, J.M., Taylor A.B. &Giesy J.P. 2003 Polychlorinated dibenzo-p-dioxin and dibenzofuran concentration profiles in sediments and flood-plain soils of the Tittabawssee River, Michigan. Environmental Science and Technology37, 468–474.

Kannan k., Kober J.L., Khim J.S., Szymczyk K., Falandysz J., Giesy J.P., 2003. Polychlorinated biphenyls, polycyclic aromatic hydrocarbons and alkylphenols in sediments from the Odra river and its tributaries, Poland. Toxicol. And environ. Chem.., 85,(4-6), 51-60

Ko F-Ch., and Baker J.E., 2004. Seasonal and annual loads of hydrophobic organic contaminants from the Susquehanna river basin to the Chesapeake Bay. Marine Polution bulletin 48, 840-851.

Koh, C.H., Khim, J.S., Kannan, K., Villeneuve, D.L., Senthilkumar, K.&Giesy, J.P. 2004 Polychlorinated dibendibenzo-p-dioxins (PCDDs), dibenzofurans (PCDFs), biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) and 2,3,7,8-TCDD equivalents (TEQs) in sediments from the Hyeongsan River, Korea. Environmental Pollution123, 489–501.

Konieczka P., Lisinger Th.P., Zygmunt B., Namieśnik J., 2005. Determination of PCBs in river sediment samples – proficiency test for selected Polish laboratories. Accred. Dual. Asur. 10, 241-251.

Kowalewska G., Konat-Stepowicz J., Wawrzyniak-Wydrowska B., Szymczyk-Żyła M., 2003. Transfer of organic contaminants to the Baltic in the Odra Estuary. Mar. Pollut. Bull. 46, 703-718.

Liu Y., Peng P., Li X., Li X., Zhan S., Ren M., 2008. Polychlorinated dibenzo-p-dioxins and dibenzofurants (PCDD/Fs) in water and suspended particulate matter from Xijiang River, china. Journal of Hazardous Materials 152, 40-47.

PCSO 2011 Polish Central Statistical Office. Demographic Yearbook 2011.

Rodziewicz M., Kaczmarczyk A., Niemirycz E., 2004. Polychlorinated biphenyls in the Sediments of the Odra River and its Tributaries. Pol. J. Environ. Stud. 13, 203–8.

Sapozhnikova Y., Zubcov E., Zubcov N., Schlenk D., 2005. Occurrence of pesticides, polychlorinated biphenyls (PCBs), and heavy metals in sediments from the Dniestr River, Moldova. Arch. Environ. Contamin. Toxicol. 49, 439-488.

Urbaniak M., Kiedrzyńska E and Zalewski M., 2012a. The role of a lowland reservoir in the transport of micropollutants, nutrients and the suspended particulate matter along the river continuum. Hydrology Research 43(4), 400-411.

Urbaniak M., Skowron A., Frątczak W., Zieliński M., Wesołowski W., 2010.Transport of polychlorinated biphenyls in urban cascade reservoirs: levels, sources and correlation to the environmental conditions. Polish J. Environ. Stud., vol. 19, no. 1, 201-211.

Urbaniak M., Skowron A., Zieliński M. & Zalewski M. 2012b. Hydrological and environment al conditions as key drivers for spatial and seasonal changes in PCDD/PCDF concentrations, transport and deposition along urban cascade reservoirs. Chemosphere, 88, 1358–1367.

Migration, retention and leaching of PCBs in soil fertilized with sewage sludge

Magdalena Urbaniak[1,2], Mariusz Szewczyk[2], Wojciech Tołoczko[3] and Maciej Zalewski[1,2]

[1] European Regional Centre for Ecohydrology u/a UNESCO, Poland (m.urbaniak@unesco.lodz.pl)
[2] Department of Applied Ecology, University of Lodz, Poland
3 Department of Soil Science and Geoecology, University of Lodz, Poland

1. Introduction

Recently, there has been an increasing interest in the pathways of pollutants migrating in soils fertilized with sewage sludge (Wilson et al., 1997; Litz and Muller-Wgener, 1998; Madsen et al., 1999; Molina et al., 2000; Hesseloe et al., 2011; La Guardia et al., 2001). The use of sewage sludge as a fertilizer is widespread (McLachlan et al., 1996). The amount of sludge used for agricultural purpose in Germany is 25% and in Sweden up to 90% (McLachlan et al., 1996). Nevertheless, numerous studies have proved that sludge contains apart from nutrients also PCBs, which produce mutagenic, carcinogenic, immunotoxic as well as developmental and reproductive effects in living organisms. This imply problems with further use of such contaminated sludge for agricultural purposes. After application of sludge it is present in relatively thin layer on the soil surface. Nevertheless, due to high persistence of PCBs, its supplementation of the soil sludge fertilization must lead to increased soil contamination. This in turn imply the risk for water bodies as intensive rainfalls and floods scour the surface layer of such contaminated soil and transport it via rivers up to the Baltic Sea. This thesis is confirmed by research of Liu et al., (2008) conducted on the Xijiang River catchment. The authors demonstrated that soil is the dominant source of PCDDs/PCDFs in the river water.

Considering the above, the aim of this work was to evaluate the mobility and retention of PCBs in the soil fertilized with different doses of sewage sludge and with its mixture with CaO. Leachability of sludge-borne PCBs and nutrients was analyzed in order to evaluate groundwater contamination risk.

2. Materials and methods

The cylindrical PCV columns were used for evaluation of PCBs mobility. The length of each column was 650 mm with the internal diameter of 100 mm. On the side of each tube at altitudes of: 0, 50, 100, 150, 200, 250, 350 and 450 mm, a 8-9 mm diameter holes were drilled. This allowed soil sampling from the appropriate depth, without affecting the structure of the soil profile.

The column experiment was conducted in five triplicate variants:

1) control – soil;
2) soil fertilized with sewage sludge in dose of 62.5 ton/ha (dw);
3) soil fertilized with sewage sludge in dose of 62.5 ton/ha mixed with 40% of CaO (dw);
4) soil fertilized with sewage sludge in dose of 187.5 ton/ha (dw);
5) soil fertilized with sewage sludge in dose of 187.5 ton/ha mixed with 40% of CaO (dw).

The experiment was carried on for 15 days. After this time the soil was sampled for analysis of PCBs.

Leachate samples for analysis of PCBs and nutrients (total nitrogen – TN and total phosphorus – TP) were collected daily, starting 24 hours after the initial application of 300 mL of distilled water. This procedure was repeated daily. A dose of 300 mL of water applied for 15 days was calculated to reflect the annual rainfall of 562.5 mm, which is closest to the typical annual rainfall for Lodz region (Central Poland) amounted to 572 mm.

PCBs contents in soil and leachete samples were analyzed using PCB Rapid Assay kit and the results were confirmed by HRGC/HRMS based on method described by Urbaniak et al., (2012). TP concentration was analyzed with the addition of the oxidizing decomposition reagent Oxisolv (Merck) with the Merck MV 500 Microwave Digestion System and determined by the ascorbic acid method (Greenberg et al. 1992). TN was analyzed using the persulphate digestion method (HACH 1997).

3. Results and discussion

The obtained results of soil analysis showed the increasing PCBs concentration together with increasing sewage sludge dose. The lowest average concentration was obtained for control samples (98.418+/-34.155 µg/kg); the highest for samples of the highest sewage sludge dose mixed with CaO (136.856+/-22.277 µg/kg). The obtained results showed also that the highest PCB concentrations were noted in the bottom layer of the soil (350-450 mm). The increased concentrations were also observed in the surface layer of the soil (0-100 mm). This may be connected with migration of some part of applied PCB from soil surface through its profile together with the vertical migration of applied water.

The results of leachete samples demonstrated several times lower concentrations of PCB ranging from 0.331 µg/L up to 0.423 µg/L, with higher values in samples fertilized with sewage sludge in dose of 187.5 ton/ha mixed with 40% of CaO (dw). The achieved data demonstrated also the increase of PCB concentration in time in the control samples and the decrease in the samples fertilized with sewage sludge and sewage sludge with CaO. The highest concentration was noted on the second day of experiment.

In case of TN and TP the obtained results showed that the maximum values were noted in leachete coming from soil fertilized with the highest dose of sewage sludge mixed with CaO (59.920 µg/L and 1.210 µg/L, respectively). The same dose used without CaO demonstrated several times lower TN and TP concentrations (9.510 µg/L and 0.540 µg/L, respectively).

The results of the experiment show that application of sewage sludge and water in quantity reflecting the annual rainfall of 562.5 mm stimulated leaching the most mobile chemical compounds like TN and TP. The leaching of PCBs was minimal as these compounds exhibit hydrophobic character and in consequence are not transported with water. Thus the majority of them were retained in the soil profile.

Acknowledgements

Scientific research has been carried out as a part of the projects: „Innovative recourses and effective methods of safety improvement and durability of buildings and transport infrastructure in the sustainable development" financed by the European Union from the European Fund of Regional Development based on the Operational Program of the Innovative Economy.

References

Greenberg, A.E., Clesceri, L.S., Eaton, A.D. 1992 Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington.

HACH, 1997 Water analysis handbook. Hach Company, pp. 1309.

Hesselsoe, M., Jensen, D., Skals, K., Olesen, T., Moldrup, P., Roslev, P., Mortensen, G.K., Henriksen, K., 2001. Degradation of 4-nonylphenol in homogeneous and nonhomogeneous mixtures of soil and sewage sludge. Environ. Sci. Technol. 35, 3695–3700.

La Guardia, M.J., Hale, R.C., Harvey, E., Mainor, T.M., 2001. Alkylphenol ethoxylate degradation products in land-applied sewage sludge (Biosolids). Environ. Sci. Technol. 35, 4798–4804.

Litz, N., Muller-Wegener, U., 1998. The influence of surfactants applied by sewage sludge on the behaviour of atrazine and PAHs in semiarid soils. Z. Pflanzenerna¨hr. Bodenk. 161, 255–259.

Liu Y., Peng P., Li X., Li X., Zhan S., Ren M., 2008. Polychlorinated dibenzo-p-dioxins and dibenzofurants (PCDD/Fs) in water and suspended particulate matter from Xijiang River, china. Journal of Hazardous Materials 152, 40-47

Madsen, L.P., Thyme, J.B., Henriksen, K., Moldrup, P., Roslev, P., 1999. Kinetics of di-(2-ethylhexyl)phthalate mineralization in sludge-amended soil. Environ. Sci. Technol. 33, 2601–2606.

McLachlan M.S., Horstmann M., Hinkel M., 1996. Polychlorinated dibenzo-p-dioxins and dibenzofurans in sewage sludge: sources and fate following sludge application to land, Sci. Total Environ. 185, 109-123.

Molina, L., Dıaz-Ferrero, J., Coll, M., Martı´, R., Broto-Puig, F., Comellas, L., 2000. Study of evolution of PCDD/F in sewage sludge-amended soils for land restoration purposes. Chemosphere 40, 1173–1178.

Urbaniak M., Kiedrzyńska E and Zalewski M., 2012. The role of a lowland reservoir in the transport of micropollutants, nutrients and the suspended particulate matter along the river continuum. Hydrology Research 43(4), 400-411, doi:102166/nh.2012.108

Wilson, S.C., Alcock, R.E., Sewart, A.P., Jones, K.C., 1997. Persistence of organic contaminants in sewage sludge-amended soil, a field experiment. J. Environ. Qual. 26, 1467–1477.

Influence of temperature on the long-term spring diatom development in the Baltic Sea

Norbert Wasmund, Günther Nausch and Rainer Feistel

Leibniz-Institute for Baltic Sea Research, Seestr. 15, D-18119 Warnemünde, Germany (norbert.wasmund@io-warnemuende.de)

Trends in spring diatom development in the western and central Baltic Sea were tested on the basis of the HELCOM data set from 1979 to 2011. As sporadic phytoplankton sampling cannot record phytoplankton blooms completely, the magnitude of diatom growth during spring was estimated by silicate consumption. The spring diatom biomass decreased suddenly at the end of the 1980s in the Baltic Proper but not in the neighbouring western Baltic area. A strong negative correlation between the minimum water temperature and the magnitude of the diatom growth in the southern Baltic Proper confirms that diatom growth has decreased after mild winters, when motile phytoplankton, such as dinoflagellates and *Mesodinium rubrum*, may form blooms instead of diatoms. Silicate shortage did not occur in the Baltic Proper. It is discussed if decreased convective mixing or increased grazing pressure may be the cause for the absence of diatom blooms after mild winters.

1. Introduction

Diatom spring blooms are important primary producers in marine ecosystems. Substantial changes in their intensity may have consequences for the food chain and may indicate changes in the driving environmental forces. In the southern Baltic Proper, diatom spring blooms have almost disappeared in the late 1980s and were more or less replaced by dinoflagellates. This change was related to milder winters (Wasmund et al. 1998). As key copepod and fish species were influenced at the same time, this change can be considered as a regime shift (Alheit et al. 2005).

Diatom blooms last only a few weeks and may be overlooked in low-frequency monitoring programmes. An alternative to the biomass calculation by microscopical observation is the estimation of diatom growth on the basis of the silicate consumption (Wasmund et al. 1998).

The aim of this study was to update the long-term analysis of Wasmund et al. (1998) to the year 2011 and to extend the data base by considering larger areas in the separate Baltic basins instead of single central stations. It will be checked if the expected trends are related to temperature. Differences between the sea areas are identified and explained.

2. Method

Common data taken in the frame of the international monitoring programme of the Helsinki Commission (HELCOM), which were provided by the ICES data bank, were used. Water samples were taken at standard stations by rosette samplers from different water depths and analysed according to the stipulated HELCOM methodology (HELCOM, 2008). Only data from the surface water (0-10 m depth) were considered.

3. Results

Only the results from the regions of most extreme observations are presented in this Abstract (Fig. 1): (a) Kiel Bight, a shallow transitional water in the western Baltic Sea, (b) the southern part of the Eastern Gotland Basin near the station BMP K1 (55°33'N, 18°24'E).

The maximum silicate concentration of winter/spring is shown as the upper line bordering a grey area. The difference between maximum and minimum silicate concentration, reflecting the consumption, is shown as columns. It is assumed that silicate consumption is strongly related to diatom growth as no other process and no other plankton component consumes silicate. The development of the annual minimum temperature in winter/spring is added as a line.

In Kiel and Mecklenburg Bight, strong diatom spring blooms occur every year. They tend to exhaust the silicate reserves almost completely.

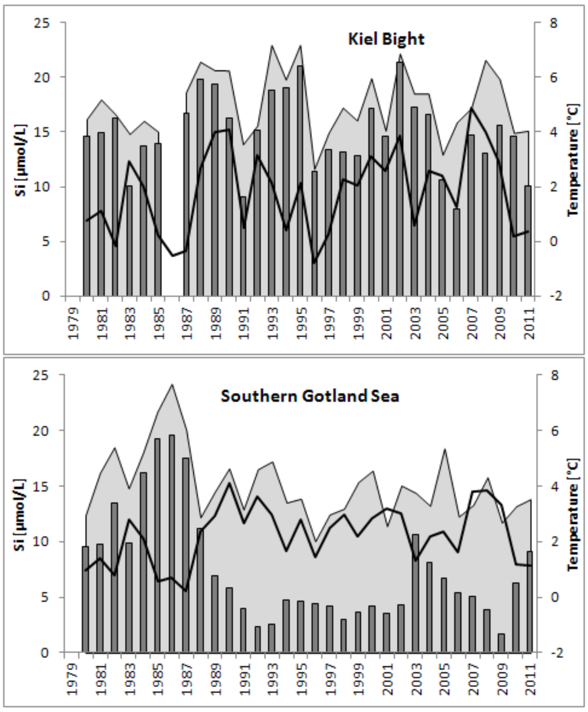


Figure 1. Development of pre-bloom silicate concentra-tions (shaded area), consumption of silicate during the spring bloom (bars) and minimum temperature (bold curve) in the two sea regions (Wasmund et al., 2013).

Further to the east, where a perennial halocline exists at about 70 m depth, the diatom spring bloom intensity declines and silicate reserves were never used up after 1988, when minimum water temperature was strongly increasing.

The relationship between annual minimum water temperature and silicate consumption in spring is shown in

Fig. 2. A strong negative correlation (p<0.01) between these parameters exists in the Southern Gotland Sea, whereas in the Kiel Bight no significant linear relationship (p=0.05) between these parameters could be found.

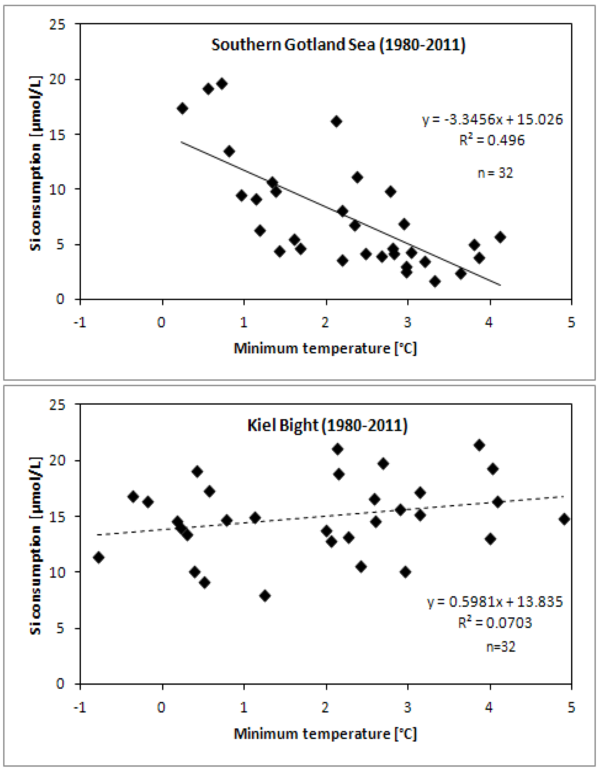


Figure 2. Relationship between annual minimum water temperature and silicate consumption in spring in the different sea regions. Mean values of the upper 10 m were used. Dashed regression line indicates insufficient significance, R^2 = coefficient of determination. Figure extracted from Wasmund et al. (2013).

4. Discussion

The dependency of the diatom bloom intensity on the strength of the preceding winter in the southern Baltic Proper, but not in the western Baltic remains elusive and may have different reasons.

Originally, Wasmund et al. (1998) had hypothesised that different vertical mixing regimes were responsible. During cold winters, when the water temperature falls below the temperature of the density maximum, deep convective mixing occurs, whereas the water column stays thermally stratified in mild winters. Diatoms need the deep circulation for seeding and development. However, as observational data show, strong wind events cause deep mixing also in mild winters, refuting the thermal-mixing hypothesis.

Presently we are in favour of an alternative “feeding hypothesis”. Gaedke et al. (2010) described that edible phytoplankton (mainly diatoms) is indirectly strongly temperature-sensitive via grazing. Higher temperatures stimulate zooplankton more than phytoplankton. Copepods, which may feed selectively on large-celled diatoms, develop earlier after mild winters and may control the diatom bloom as their occurrence (April-May in the Baltic Proper) matches better. In the shallow western Baltic, diatoms appear very early (late February to early April) independent of the temperature regime. A mismatch between diatom and copepod occurrence occurs there generally and diatoms may grow without significant grazing pressure.

References

Alheit, J., Möllmann, C., Dutz, J., Kornilovs, G., Loewe, P., Mohrholz, V. and Wasmund, N. (2005) Synchronous ecological regime shifts in the central baltic and the north sea in the late 1980s. ICES J. Mar. Sci., 62, 1205-1215.

Gaedke, U., Ruhenstroth-Bauer, M., Wiegand, I., Tirok, K., Aberle, N., Breithaupt, P., Lengfellner, K., Wohlers, J. and Sommer, U. (2010) Biotic interactions may overrule direct climate effects on spring phytoplankton dynamics. Global Change Biology, 16, 1122-1136.

HELCOM (2008) Manual for marine monitoring in the combine programme of helcom, part C. Annex C-2: Hydrographic and hydrochemical variables. http://www.helcom.fi/groups/monas/CombineManual/AnnexesC/en_GB/annex2/.

Wasmund, N., Nausch, G. and Matthäus, W. (1998) Phytoplankton spring blooms in the southern baltic sea - spatio-temporal development and long-term trends. J. Plankton Res., 20, 1099-1117.

Wasmund, N., Nausch, G. and Feistel, R. (2013) Influence of temperature on the long-term spring diatom development in the Baltic Sea. J. Plankton Res. 35: 393-406.

Special Session

Finalised BONUS+ projects

Advanced modeling tool for scenarios of the Baltic Sea ECOsystem to SUPPORT decision making (ECOSUPPORT, 2009-2011)

H. E. M. Meier[1, 2] and ECOSUPPORT[3] co-workers

[1] Swedish Meteorological and Hydrological Institute, Sweden (markus.meier@smhi.se)
[2] Stockholm University, Department of Meteorology, 10691 Stockholm, Sweden
[3] www.baltex-research.eu/ecosupport

1. Rationale of ECOSUPPORT

The ECOSUPPORT project (www.baltex-research.eu/ecosupport) addressed the urgent need for policy-relevant information on the combined future impacts of climate change and industrial and agricultural practices in the Baltic Sea catchment on the Baltic Sea ecosystem. ECOSUPPORT provides a multi-model system tool to support decision makers. The tool is based upon scenarios from a coupled atmosphere-ice-ocean-land surface model for the Baltic Sea catchment area, marine physical-biogeochemical models of differing complexity, a food web model, statistical fish population models, economic calculations, and new data detailing climate effects on marine biota. The ECOSUPPORT concept includes the following steps: (i) assessing the predictive skills of the models by comparing observed and simulated past climate variability (i.e. quantification of model uncertainties) and analyzing causes of observed variations; (ii) performing multi-model ensemble simulations of the marine ecosystem for 1850-2100 forced by reconstructions of past climate and by various future greenhouse gas emission and air- and riverborne nutrient load scenarios (ranging from a pessimistic *business-as-usual* (BAU) to the *most optimistic case* (Baltic Sea Action Plan - BSAP)); (iii) analyzing projections of the future Baltic Sea ecosystem using a probabilistic approach accounting for uncertainties caused by biases of regional and global climate models (RCMs and GCMs), lack of process description in state-of-the-art ecosystem models, unknown greenhouse gas emissions and nutrient loadings, and natural variability; (iv) assessing impacts of climate change on the marine biota (e.g. effects of ocean acidification), biodiversity and fish populations (with focus on cod, sprat and herring); (v) generating a free-access data base of scenario model results and tools to access the database; and (vi) disseminating the project results to stakeholders, decision makers and the public using inter alia the GeoDome concept. Hence, within ECOSUPPORT a multi-stressor approach was applied, calculating the combined effects of changing climate, nutrient loads from land and atmosphere and fisheries on the Baltic Sea ecosystem. In addition to a Baltic Sea wide assessment, local-scale impacts of changing climate on coastal areas (with focus on the Gulf of Finland, Vistula Lagoon, and the Polish coastal waters) were studied.

2. Selected key results

The Baltic Sea models applied in ECOSUPPORT are capable of simulating past climate variations and eutrophication since 1850 (e.g., Eilola et al. 2011; Meier et al. 2012b), building confidence that the models are able to simulate future changes caused by climate and nutrient load scenarios realistically. In the ECOSUPPORT transient scenario simulations (1960-2100) water temperature and ice cover were projected to significantly increase and decrease, respectively (e.g. Meier et al. 2011; 2012a; 2012b). Warming would enforce the stability across the seasonal thermocline.

All scenario simulations suggest decreased salinity and reduced stability across the permanent halocline due to increased, spatially integrated runoff from land. No clear tendencies in salt water transport changes were found. However, the uncertainty in salinity projections is very likely large due to considerable biases in atmospheric and hydrological modeling. It was found that sea-level rise has greater potential to increase surge levels in the Baltic Sea than does increased wind speed.

Despite the high uncertainties involved, which are due to model shortcomings and unknown future scenarios of external nutrient loads (Fig.1), results of scenario simulations suggest that climate change may reinforce oxygen depletion (e.g. Meier et al., 2011), increase phytoplankton biomass in general and cyanobacteria biomass in special (e.g. Hense et al., 2013), and reduce water transparency and biodiversity (due to decreased salinity) (e.g. Meier et al., 2012a).

Further, we found that in future climate, cod biomass may decrease and sprat biomass may increase assuming present day estimates of sustainable fishing (e.g., Niiranen et al. 2013). However, all food web and fish population models indicate that the level of cod fishery is important for determining the cod stock size also in the future, independent of the climate scenario used. For details the reader is referred to http://www.baltex-research.eu/ecosupport/publications.html and references therein.

3. Research needs

The systematic assessment of models within ECOSUPPORT emphasizes also future research needs. For instance, the role of the coastal zone for biogeochemical cycling (e.g. nutrient retention, bioavailability of nutrients) in the Baltic Sea is poorly understood and the performance of models in the northern Baltic Sea (Bay of Bothnia and Bothnian Sea) needs to be improved. Salt water inflows should be addressed in more detail to resolve why there is a decrease in inflows in present climate and to better account for the smaller inflows in the models. Climate to land use to socio-economy interaction and feedbacks should be further studied. More plausible nutrient load scenarios consistent with large-scale socioeconomic developments based upon the IPCC Fifth Assessment Report (http://www.ipcc.ch) are needed. The multi-stressor approach should be further developed. In addition to warming, freshening, de-oxygenation, eutrophication, and overfishing also the impact of acidification, invasive species and pollutants on the Baltic Sea ecosystem should be considered. Finally, climate change impacts should be included into the BSAP load reduction scheme review based upon the information from spatially and temporally highly resolved modeling.

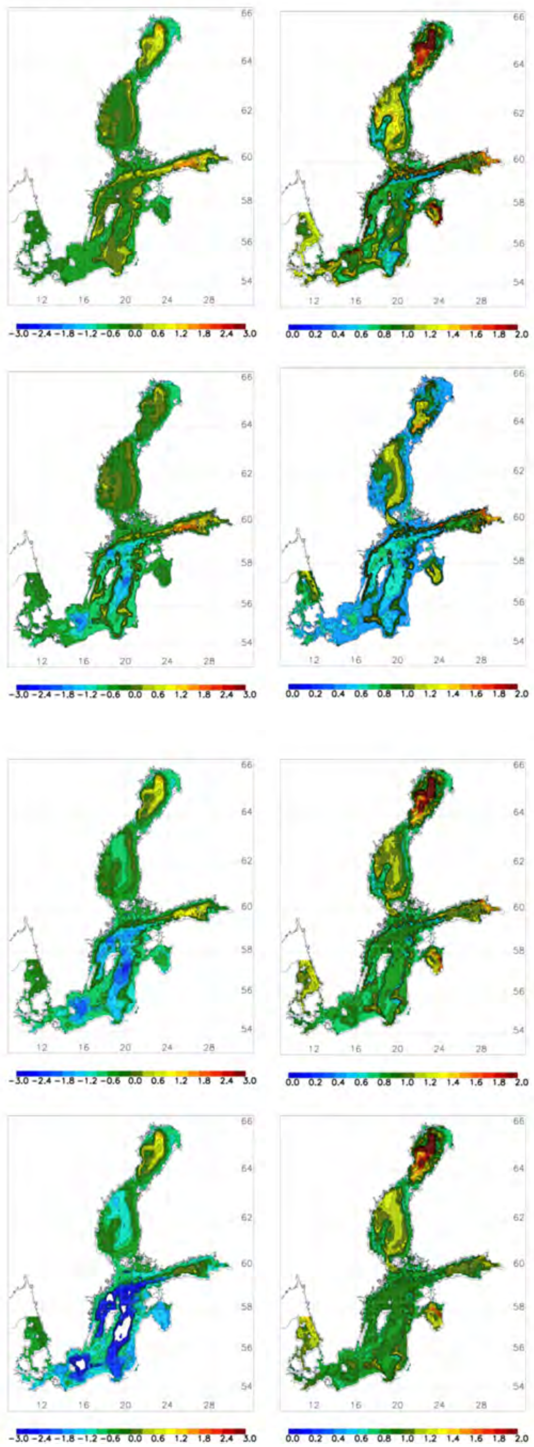


Figure 1. Ensemble mean (left panels) and ratio between biogeochemical model and GCM caused variances (right panels) of summer bottom oxygen concentration changes between 2070-2099 relative to 1978-2007 in four nutrient load scenarios (BSAP, CLEG, REF, BAU). For details see Meier et al. (2012a).

Acknowledgements

The research presented in this study was part of the project ECOSUPPORT (Advanced modeling tool for scenarios of the Baltic Sea ECOsystem to SUPPORT decision making) and has received funding from the European Community's Seventh Framework Program (FP/2007-2013) under grant agreement no. 217246 made with BONUS, the joint Baltic Sea research and development program, and from the Swedish Environmental Protection Agency (SEPA, ref. no. 08/381). Additional support came from the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS) within the projects “Impact of accelerated future global mean sea level rise on the phosphorus cycle in the Baltic Sea” (grant no. 214-2009-577) and “Impact of changing climate on circulation and biogeochemical cycles of the integrated North Sea and Baltic Sea system” (grant no. 214-2010-1575) and from the Baltic Ecosystem Adaptive Management program (BEAM, 2010-2014) funded by the Swedish government, as part of its Strategic Research Initiative on Marine Environmental Research. Further, we are in great debt to all institutes and individuals that kindly provided their data to the Baltic Environmental Database (BED) at the Baltic Nest Institute (http://nest.su.se/bed).

References

Eilola, K., B.G. Gustafson, I. Kuznetsov, H.E.M. Meier, T. Neumann, O. P. Savchuk, 2011: Evaluation of biogeochemical cycles in an ensemble of three state-of-the-art numerical models of the Baltic Sea during 1970-2005. J. Marine Systems, 88, 267-284, doi:10.1016/j.jmarsys.2011.05.004

Hense, I., H. E. M. Meier, and S. Sonntag, 2013: Projected climate change impact on Baltic Sea cyanobacteria. Climatic Change, doi:10.1007/s10584-013-0702-y (published on-line 19 February 2013)

Meier, H.E.M., H.C. Andersson, K. Eilola, B.G. Gustafsson, I. Kuznetsov, B. Müller-Karulis, T. Neumann, O. P. Savchuk, 2011: Hypoxia in future climates: A model ensemble study for the Baltic Sea Geophys. Res. Lett., 38, L24608

Meier, H. E. M., B. Müller-Karulis, H. C. Andersson, C. Dieterich, K. Eilola, B. G. Gustafsson, A. Höglund, R. Hordoir, I. Kuznetsov, T. Neumann, Z. Ranjbar, O. P. Savchuk, and S. Schimanke, 2012a: Impact of climate change on ecological quality indicators and biogeochemical fluxes in the Baltic Sea - a multi-model ensemble study. AMBIO, 41(6), 558-573, doi:10.1007/s13280-012-0317-y

Meier, H. E. M., H. C. Andersson, B. Arheimer, T. Blenckner, B. Chubarenko, C. Donnelly, K. Eilola, B. G. Gustafsson, A. Hansson, J. Havenhand, A. Höglund, I. Kuznetsov, B. MacKenzie, B. Müller-Karulis, T. Neumann, S. Niiranen, J. Piwowarczyk, U. Raudsepp, M. Reckermann, T. Ruoho-Airola, O. P. Savchuk, F. Schenk, J. M.Weslawski, and E. Zorita, 2012b: Comparing reconstructed past variations and future projections of the Baltic Sea ecosystem - first results from multi-model ensemble simulations. Environ. Res. Lett., 7, 034005, doi:10.1088/1748-9326/7/3/034005

Niiranen, S., J. Yletyinen, M. M. Tomczak, T. Blenckner, O. Hjerne, B. MacKenzie, B. Müller-Karulis, T. Neumann, and H. E. M. Meier, 2013: Combined effects of global climate change and regional ecosystem drivers on an exploited marine food web. Global Change Biology, submitted.

Methane cycling in shallow sediments and the overlying water column of the Baltic Sea: A synopsis of the project *BALTIC GAS* (BONUS+)

Gregor Rehder[1], Volker Brüchert[2], Daniel Conley[3], Timothy Ferdelman[4], Henrik Fossing[5], Wanda Gülzow[1], Jørn Bo Jensen[6], Zygmunt Klusek[7], Laura Lapham[8,9] ,Nikolay Pimenov[10], Pierre A.G. Regnier[11], Michael Schlüter[12], Volkhard Spiess[13], Bo Barker Jørgensen[8], and the BALTIC GAS science team[14]

[1] Department of Marine Chemistry, Leibniz Institute for Baltic Sea Research Warnemünde, Germany (gregor.rehder@io-warnemuende.de)
[2] Department of Geology and Geochemistry, Stockholm University, Sweden
[3] Department of Geology, Lund University, Sweden
[4] Max Planck Institute for Marine Microbiology, Bremen, Germany
[5] National Environmental Research Institute, Aarhus University, Denmark
[6] Geological Survey of Denmark and Greenland, Copenhagen, Denmark
[7] Institute of Oceanology, Polish Acadamey of Sciences, Sopot, Poland
[8] Center for Geomicrobiology, Aarhus University, Denmark
[9] Center for Environmental Science, University of Maryland, Solomons, U.S.A.
[10] Winogradsky Institute of Microbiology, Russian Academy of Sciences, Moscow, Russia
[11] Department of Earth Sciences, Utrecht University, The Netherlands, and Free University of Brussels, Belgium
[12] Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany
[13] Department of Geosciences, University of Bremen, Germany
[14] http://balticgas.au.dk/

1. Geological Setting, Approach, and Research Rationale

The Baltic Sea is an ideal natural laboratory to study the methane cycle in the framework of diagenetic processes. With its brackish character and a gradient from nearly marine to almost limnic conditions, a strong permanent haline stratification leading to large vertical redox gradients in the water column, and a sedimentation history which resulted in the deposition of organic-rich young post-glacial sediments over older glacial and post-glacial strata with very low organic content, the Baltic is an ideal site to study the role of a variety of key parameters and processes for the methane cycle.

Within the BONUS + Project "BALTIC GAS", scientists from twelve partner institutions from six nations investigated the methane cycle of the Baltic Sea through investigations in all major basins. These studies included the fate of methane from its genesis and accumulation in shallow sediments, the oxidation in the upper metres of the seafloor and at the sediment surface, the cycling and turnover of the evading gas in the water column, and finally, its loss to the atmosphere by air-sea exchange and bubble-mediated transport. The major objectives were to

(1) quantify and map the distribution and flux of methane in the Baltic Sea, including fluxes within the sediment, at the sediment-water interface and at the water-air boundary
(2) analyse the controls on the relevant key biogeochemical processes,
(3) integrate seismo-acoustic mapping with geochemical profiling,
(4) model the dynamics of Baltic Sea methane in the past (Holocene period), present (reaction-transport models), and future (predictive scenarios), and
(5) identify hot-spots of gas and potential future methane emission in the Baltic Sea.

The latter two objectives were motivated by the fact that the input of organic material and temperature at the seawater-sediment boundary are key controls for methane formation, thus making the methane cycle sensitive to eutrophication and regional climate change. This presentation gives an overview of some of the major findings and highlights of the project.

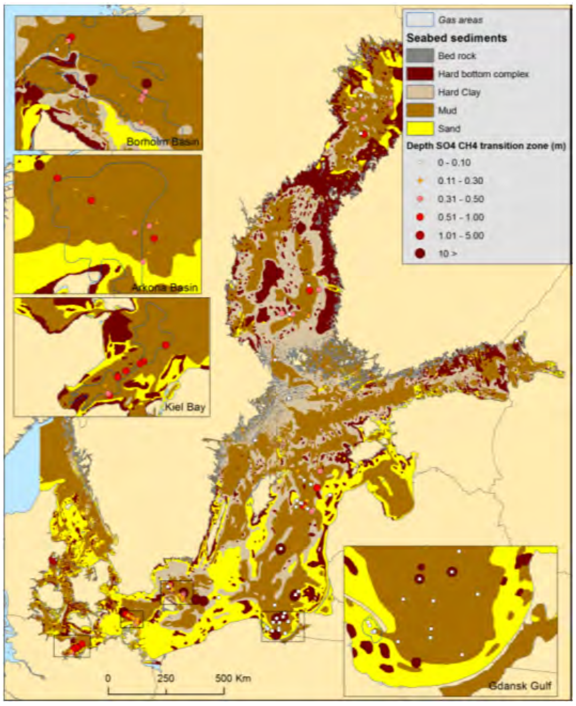


Figure 1. Spatial distribution of measured depths (m) of the sulfate-methane transition zone (symbols) overlying a map of major Baltic Sea sediment types (adopted from Al-Hamadi and Recker, 2007). Concomitant presence of both sulfate and methane was predominantly observed in muddy sediments with a SMTZ median value of about 0.35 m, caused by a high content of particulate organic matter and thus increased production of methane.

2. Scientific Highlights

Based on data mining and an extensive new data base on free gas, dissolved methane concentrations and related parameters, maps of the distribution of free gas as well as the depth of the sulfate-methane transition zone (SMTZ), and subsurface methane flux have been created (Fig.1).

- Hot-spots of methane outgassing from the sediment, often accompanied by pockmarks on the seafloor found by multibeam bathymetry, have been detected and mapped in several areas of the Baltic Sea, in particular in the Polish and Russian sectors (Pimenov et al., 2010, Ulyanova et al., 2012). Gas ebullition has also been observed in the major inshore study site, the eutrophied Himmerfjärden. In contrast, ebullition of free gas is of minor importance for the methane flux from the seabed to the water column in the major basins, even in regions characterized by muddy sediments and the presence of shallow gas.
- Based on analysis of an extensive data set gathered prior to the project, the methane distribution in the water column across all major basins was assessed. This demonstrated the confinement of high methane concentrations in the open Baltic Sea to the anoxic basins, and a strong limitation for the flux towards the atmosphere caused by biogeochemcal processes within the pelagic redoxcline (Schmale et al., 2010).
- Supported by the large geophysical and geochemical data base compiled by BALTIC GAS, a transient reaction-transport model was developed to understand the past and present methane cycle in the Baltic seabed and the accumulation of gas (Mogollón et al., 2011; Mogollón et al., 2012). The model results explain quantitatively how gas in the seabed is controlled by the thickness of Holocene mud, which is the main modern source of methane.
- Long-term monitoring of methane in the surface water throughout the central Baltic Sea by a continuously running system mounted on a ferry commuting between Travemünde, Gdynia and Helsinki at so far unprecedented resolution has revealed the seasonal dynamics and geographical distribution of methane (Gülzow et al., 2013, Fig.2).

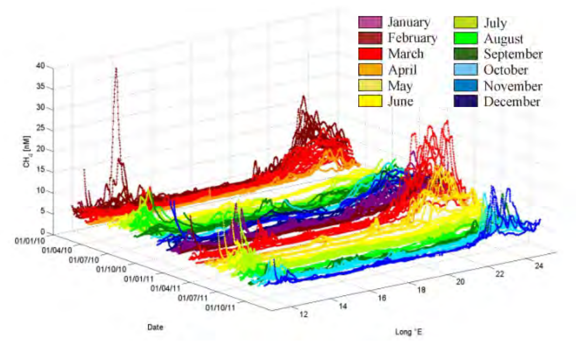


Figure 2. Methane surface concentrations (nmol/l) between Lübeck and Helsinki for the years 2010-2011 as obtained from the installation on the ferry ship Finnmaid (Gülzow et al., 2013, extended dataset shown here), revealing seasonal patterns as well as episodic phases of high methane flux to the atmosphere.

- Model predictions of future methane fluxes and the potential for accelerating gas emissions from the seabed suggest a large resilience of the biogeochemical processes towards the breakdown of methane. This finding could not have been predicted without the large amount of new data used to verify the model and has been a key result of the project. The general model forecast is that the predicted temperature increase (1-2 °C) and salinity drop in the Baltic Sea, together with an unchanged level of eutrophication, would not lead to a dramatic increase in the gas ebullition from the sediments during this century.

3. Technological Milestones

The approach of BALTIC GAS also resulted in the development of new technologies and techniques, including:

- the implementation of continuous measurements of sea surface methane concentrations using off axis integrated cavity output spectroscopy on a ship of opportunity (Gülzow et al., 2011)
- the use of low frequency multibeam acoustic data for the 2-D detection of shallow gas deposits (Schneider v. Deimling et al., 2013 in press).
- advanced seismo-acoustic methods to quantify the gas volume in sediments as well as the vertical extent of the gassy layer.

Acknowledgements

BALTIC GAS received funding from the European Community's Seventh Framework Program (FP7/2007–2013) under grant agreement Nr.217246 made with the joint Baltic Sea research and development program BONUS. We are particularly indebted to the skillful support of captains and crews of the various research vessels during the extensive work at sea.

References

Al-Hamdani, Z. and Reker, J. (eds.) (2007) Towards marine landscapes in the Baltic Sea. BALANCE Interim Report No 10, GEUS.

Gülzow, W., G. Rehder, B. Schneider, J. Schneider von Deimling & B. Sadkowiak (2011) A new method for continuous measurement of methane and carbon dioxide in surface waters using off-axis integrated cavity output spectroscopy (ICOS): An example from the Baltic Sea. Limnology and Oceanography Methods, 9, 176-184.

Gülzow, W., G. Rehder, J. Schneider von Deimling, T. Seifert & Zs. Tóth (2013) One year of continuous measurements constraining methane emissions from the Baltic Sea to the atmosphere using a ship of opportunity. Biogeosciences 10, 81-99.

Mogollón, J. M., A. W. Dale, I. L'Heureux, & P. Regnier (2011) Impact of seasonal temperature and pressure changes on methane gas production, dissolution, and transport in unfractured sediments, J. Geophys. Res., 116, G03031, doi:10.5194/bg-9-1915-2012

Mogollón, J. M., A. W. Dale, H. Fossing & P. Regnier (2012) Timescales for the development of methanogenesis and free gas layers in recently-deposited sediments of Arkona Basin (Baltic Sea). . Biogeosciences, 9, 1915-1933.

Pimenov, N. V., M. O. Ulyanova, T. A. Kanapatsky, P. A. Veslopolova, V. V. Sigalevich & V. V. Sivkov (2010) Microbially mediated metahne and sulfur cycling in pckmark sediments of the Gdansk Basin, Baltic Sea. *Geo-Marine Letters,* 30**,** 105-130.

Schmale, O., J. Schneider von Deimling, W. Gülzow, G. Nausch, J. J. Waniek & G. Rehder (2010) Distribution of methane in the water column of the Baltic Sea. *Geophysical Research Letters,* 37**,** L12604.

Schneider von Deimling, J., W. Weinrebe, Zs. Tóth, H. Fossing, R. Endler, G. Rehder & V. Spieß (2013, inpress) A low frequency multibeam assessment: Spatial mapping of shallow gas by enhanced penetration and angular response anomaly. *Marine and Petroleum Geology***,** http://www.sciencedirect.com/science/article/pii/S0264817213000482.

Ulyanova M., Sivkov V., Kanapatskij T., Sigalevich P., Pimenov N. (2012) Methane fluxes in the southeastern Baltic Sea. Geo-Marine Letters. 32, 535 - 544. DOI: 10.1007/s00367-012-0304-0.

Baltic-C: Modeling and experimental approaches to unravel the Baltic Sea carbon (CO_2) cycle and its response to anthropogenic changes

B. Schneider[1], A. Omstedt[2], C. Humborg[3], J. Pempkowiak[4], M. Pertillä[5], A. Rutgersson[6], and B. Smith[7]

[1]Baltic Sea Research Institute, Germany
[2]Department of Earth Sciences, University of Gothenburg, Sweden
[3]Baltic Nest Institute, Stockholm University, Sweden
[4]Institute of Oceanology, Polish Academy of Sciences, Poland
[5]Finnish Meteorological Institute, Finland
[6]Department of Earth Sciences, Uppsala University, Sweden
[7]Department of Physical Geography and Ecosystem Science, Lund University, Sweden

http://www.baltex-research.eu/baltic-c

1. Rationale and objectives

Eutrophication is related to the autochthonous and/or allochthonous input of organic carbon mainly into the surface water (Nixon, 1995). Its increase during the last century was mainly attributed to enhanced inputs of nutrients and is considered as a major threat to the Baltic Sea ecosystem because it accelerates oxygen depletion and potentially the formation of hydrogen sulphide in deeper water layers. Furthermore, production and mineralization of organic matter are connected with the consumption and release of CO_2, respectively, and thus control the seasonal cycle of the pH. However, the pH is also affected by the atmospheric CO_2 which increased by more than 40 % during the last two centuries. This has caused a pH decrease of 0.15 in the Baltic Sea provided that no other counteracting processes had occurred. Baltic-C was aiming at establishing a model framework that addresses both eutrophication and acidification by simulating the Baltic Sea carbon/CO_2 and oxygen system and its possible future development under the influence of a changing climate and at other anthropogenic activities.

2. The approach

To estimate the inputs of biogeochemically relevant substances from land into the Baltic Sea, the Catchment Simulation Model, CSIM, (Mörth et al., 2007) was used. It was extended by a weathering component and provided input data for nutrients, total CO_2 and alkalinity for different environmental scenarios. By connecting the CSIM with the dynamic vegetation-ecosystem model, LPJ-GUESS, (Smith et al., 2001) also the input of organic carbon into the Baltic Sea could be simulated. Regarding the atmospheric imprint on the Baltic Sea biogeochemistry, estimates were performed for the atmospheric deposition of nutrients and acidic substances and alternative parameterizations of the CO_2 gas exchange transfer velocity were investigated (Rutgersson et al., 2011).

In addition to the modeling of the biogeochemical forcing from land and the atmosphere, the simulation of the Baltic Sea carbon/CO_2 and O_2 system was supported by a comprehensive field measurement programme and the analysis of data obtained mainly from monitoring programmes. Automated CO_2 partial pressure measurements were performed and used to determine the timing and intensity of the net community production (Schneider et al., 2009). The mineralization of organic matter in deeper water layers was studied by investigations of the CO_2 accumulation during several research cruises (e.g., Beldowski et al., 2010). The latter studies were complemented by the analysis of sediment cores which included the determination of the reflux of inorganic and organic carbon into the water column (Kulinski and Pempkowiak, 2011). Finally, considerable effort was put on the compilation of alkalinity data for a multitude of rivers discharging into the Baltic Sea.

3. Major results

Coupled to the catchment model and taking into account the gathered data, a biogeochemical model was developed (PROBE-Baltic, Omstedt et al., 2012) to simulate the Baltic Sea carbon/CO_2 and oxygen system and to delineate scenarios based on climate change projections and other anthropogenic alterations. It was shown that enhanced nutrient loads will increase the extension of hypoxic and anoxic areas. However, eutrophication will not dampen the Baltic Sea acidification, but only amplify the seasonal pH cycle due increased production and mineralization of organic matter. The magnitude of future pH changes are mainly controlled by atmospheric CO_2 concentration provided that no changes in the alkalinity inputs will occur. However, the latter may happen as a consequence of climate change induced changes in the hydrological cycle.

References

Beldowski, J., Löffler, A., Schneider, B. and Joensuu, L., 2010. Distribution and biogeochemical control of total CO_2 and total alkalinity in the Baltic Sea. J. Mar. Sys., 81, 252 – 259.

Kulinski, K. and Pempkowiak, J., 2011. The carbon budget of the Baltic Sea. Biogeosciences, 8, 3219 – 3230.

Omstedt, A., Edman, M., Claremar, B., Frodin, P., Gustafsson, E., Humborg, C., Hägg, H., Mörth, M., Rutgersson, A., Schurgers, G., Smith, B., Wällstedt, T. and Yurova, A., 2012. Future changes in the Baltic Sea acid-base (pH) and oxygen balances. Tellus B, 64, 19586, doi:10.3402/tellusb.v64i0, 19586.

Mörth, C.-M., Humborg, C., Eriksson, E., Danielsson, A. and Medina, R., 2007. Modeling riverine nutrient transport of the Baltic Sea: a large scale approach. Ambio, 36, 124 – 133.

Rutgersson, A., Smedman, A. and Sahlee, E., 2011. Oc- eanic convective mixing and the impact on air-sea gas transfer velocity. Geophys. Res. Lett., 38, DOI:10.1029/2010GL045581.

Schneider, B., Kaitala, S., Raateoja, M. and Sadkowiak, B., 2009. A nitrogen fixation estimate for the Baltic Sea based on continuous pCO_2 measurements on a cargo ship and total nitrogen data. Cont. Shelf Res., 29, 1535 – 1540.

Smith, B., Prentice, I.C., and Sykes, M.T., 2001. Representation of vegetation dynamics in modelling terrestrial ecosystems: comparing two contrasting approaches within European climate space. Glob. Ecol. Biogeogr., 10, 621 – 637.

Baltic Way: Towards the use of ocean dynamics for pollution control

Tarmo Soomere

Wave Engineering Laboratory, Institute of Cybernetics at Tallinn University of Technology, Estonia (soomere@cs.ioc.ee)
http://wavelab.ioc.ee/bonus-balticway

1. Introduction

The ever increasing impact of the marine industry on vulnerable sea areas such as the Baltic Sea, and especially the increase in risks associated with potential oil pollution, calls for novel methods for mitigating beforehand the impact of such risks on vulnerable areas. The aim of the research in the BONUS BalticWay framework was to develop methods for preventive reduction of such offshore environmental risks that are initially caused by the maritime industry and further transported by various metocean drivers to the coasts. The underlying idea is to characterise systematically the damaging potential of different sea areas in terms of the potential current- and wind-driven transport to vulnerable regions if faced by an oil spill or other pollution. This way, by placing maritime activities in the safest offshore areas, the consequences of potential accidents can be minimised before they occur (Soomere and Quak, 2007).

2. The essence of the technology

Traditionally risks of maritime industry are associated with possible accidents (ship collisions or grounding, etc.) that may lead to loss of lives or property, or to environmental pollution. The management of the related environmental risks has been traditionally focussed on small areas around the installation or the ship in question.

However, the technological progress has led to a new paradigm in the treatment of such risks and many by-products such as exhaust emissions or external noise are no more located in small areas. The amounts of oil spills or other harmful substances (e.g., debris, plastic litter) potentially released to the sea have increased to a level that are of acute danger to the ecosystem or to society, even in seemingly remote and safe locations (Pichel et al., 2007). Especially the currents can transport different impacts over hundreds of kilometres and may provide extremely large risks to some regions over a substantial time period.

The approach used to develop the technology described in this note is based on a smart use of the existence of semi-persistent patterns of currents and winds which affect considerably pollution propagation as well as drift of various items such as vessels without propulsion, rescue boats or lost containers. These patterns make the probability of transport of various substances or objects from different open sea areas to vulnerable sections (such as spawning, nursing or also tourist areas) highly variable. For certain areas of reduced risk this probability is relatively small and directing activities to these areas would appear to be feasible as well with very limited additional costs.

3. Solving the inverse problem

The problem of identification of such areas of reduced risk is a variation of the inverse problem of pollution propagation. An approximate solution to this problem is constructed by means of statistical analysis of a large number of Lagrangian trajectories or Eulerian propagation patterns of pollution particles. The method contains an eddy-resolving circulation model (ideally combined with an oil drift and fate model), a scheme for the tracking of Lagrangian trajectories, a technique for the calculation of quantities characterising the potential of different sea areas to supply adverse impacts, and routines to construct the optimum fairway (Andrejev et al., 2011; Soomere et al., 2011).

The entire approach is intrinsically based on certain statistical features of current-induced transport. The importance of statistical methods in marine design and operation is now generally acknowledged. Since their outcome is not always explicit, one of the major challenges implicitly addressed by the research team consists in further developing methods and technology for the use of statistical information in solving dynamical problems. These methods allow identifying a number concealed features of transport which can be inferred neither from theoretical analysis nor from even massive measurements.

4. Optimum fairways

A commonly used measure to quantify environmental risks is the probability of the valuable areas being hit by pollution. It is straightforward to associate with each offshore point, the probability of oil transport from this site to a certain vulnerable area. Its sensible use implicitly requires the setting of a (propagation) time scale over which this probability is counted (Andrejev et al., 2011). Doing so naturally leads to a complementary quantity that can equally well characterise the potential of pollution released at a particular sea point to pose danger to the nearshore: the average time it takes for the pollution to reach the valuable area (e.g., the nearshore). This measure, called alternatively particle age or residence time, is similar to commonly used water age (Deleersnijder et al., 2001). It naturally characterizes the cost of consequences from another viewpoint: the longer time pollution remains in the open sea, the larger fraction of it will be weathered or may be removed before it hits a vulnerable spot.

Once a map of the probabilities of coastal hits (or particle age) has been constructed, the optimum locations for potentially dangerous activities (areas of reduced risk) are the minima for the probabilities or the maxima for the particle age. The obvious practical outcome is the possibility to plan (or redirect) dangerous activities into such areas. These maps are, however, of much larger practical importance. They may serve as the basis for various engineering solutions, decision support systems and preventive methods for the environmental management of shipping and offshore activities.

There is a variety of different measures and approaches to define the optimum fairway or location of other potentially dangerous activities. The ‘fair way’ of dividing the risks equally between the opposite coasts (Soomere et al., 2010) is a local solution that does not normally provide the minimum level of risk for the entire water body. Another approximate solution for the environmentally safest sailing line is to route the ships along the minima of the probability of the transport of pollution to vulnerable areas (Andrejev et al., 2011). Alternatively, one can benefit from a choice of the sailing line that provides a systematic increase in the time it takes for the adverse impact to reach a vulnerable area. The use of the maxima for this time for this purpose (Andrejev et al., 2011) is equivalent to buying extra time to combat the leak while the spill travels to the coast.

5. Applications

Several versions of this technology have been applied to different regions of the Baltic Sea under the assumption that all coastal areas have an equal value. Optimized fairways have been identified for the Gulf of Finland (Andrejev et al. 2011), south-western Baltic Sea and Danish Straits (Lu et al., 2012), and for the entire Baltic Sea (Lehmann et al., 2013) based on the properties of current-driven Lagrangian transport. In the Gulf of Finland the use of the optimum fairway would decrease the probability of coastal pollution by 40% or increase the average time of reaching the pollution to the coast from 5.3 to about 9 days (Andrejev et al., 2011). An equivalent solution in terms of Eulerian transport has been found for the fairway crossing the Baltic Proper and the Gulf of Finland (Höglund and Meier, 2012).

The climatologically valid spatial patterns of hits to the nearshore not always lead to the best solution. The optimum fairways in the south-western Baltic Sea vary substantially depending on the presence of the inflow and outflow conditions rather than on the particular season (Lu et al., 2012). In the Gulf of Finland, the probabilities for the hit to different parts of the nearshore and the ability of different sections of the fairway to provide coastal pollution have extensive seasonal variability. Not unexpectedly, the potential impact of the fairway is inversely proportional to its distance from the nearest coast. A short section of the fairway to the south of Vyborg and a segment to the west of Tallinn are the most probable sources of coastal pollution. The most frequently hit coastal areas are short fragments between Hanko and Helsinki, the NE coast of the gulf to the south of Vyborg, and a longer segment from Tallinn to Hiiumaa on the southern coast of the gulf (Figure 1).

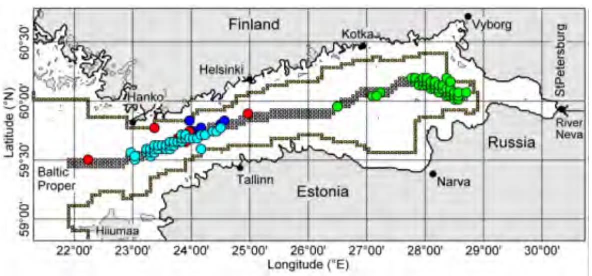


Figure 1. Interconnections between the most frequently hit areas and the origin of the pollution particles stemming from the major fairway in the Gulf of Finland (Viikmäe and Soomere, 2013). The link between the nearshore areas and the origin is depicted by using the same colour. Graphics by B. Viikmäe.

In reality, the value of different offshore and coastal areas may considerably vary. The largest value can be associated with marine protected areas (MPA). A study addressing the possibilities of this technology to better protect the MPAs in the Gulf of Finland revealed that, not surprisingly, the number of hits to the MPA almost linearly decreases with distance from the fairway (Delpeche-Ellmann and Soomere, 2013). The potential pollution released during a ship accident and further carried by currents may affect MPAs at very large distances. Typically, a fairway section of about 125 km long (covering about 1/3 of the about 400 km long gulf) may serve as a source of pollution for each MPA. The largest MPA (in the Eastern Gulf of Finland) may receive pollution from about a 210 km long section (covering about 1/2 of the entire length of the gulf). This result once more suggests that the problem of environmental management of maritime activities has a clear global dimension.

Acknowledgements

The BalticWay team joined the efforts of eight research groups in five countries: Institute of Cybernetics at Tallinn University of Technology, (coordinating partner) and Laser Diagnostic Instruments from Estonia, Danish Meteorological Institute, Finnish Environment Institute, Institute for Coastal Research, HZG Geesthacht and Leibniz Institute of Marine Sciences at the University of Kiel from Germany and Department of Meteorology, University of Stockholm and Swedish Meteorological and Hydrological Institute from Sweden. The research was jointly supported by the funding from the relevant national funding agencies and European Community's Seventh Framework Programme (2007–2013) under grant agreement n° 217246 made with the joint Baltic Sea research and development programme BONUS+.

References

Andrejev O., Soomere T., Sokolov A., Myrberg K. (2011) The role of spatial resolution of a three-dimensional hydrodynamic model for marine transport risk assessment. *Oceanologia*, Vol. 53, pp. 309–334.

Deleersnijder E., Campin J.-M, Delhez E.J.M. (2001) The concept of age in marine modelling. I. Theory and preliminary model results. *J. Mar. Syst*., Vol. 28, pp. 229–267.

Delpeche-Ellmann N.C., Soomere T. (2013) Investigating the Marine Protected Areas most at risk of current-driven pollution in the Gulf of Finland, the Baltic Sea, using a Lagrangian transport model. *Mar. Pollut. Bull*., Vol. 67, No. 1-2, pp. 121–129.

Höglund A., Meier H.E.M. (2012) Environmentally safe areas and routes in the Baltic Proper using Eulerian tracers. *Mar. Pollut. Bull*., Vol. 64, pp. 1375–1385.

Lehmann A., Hinrichsen H.-H., Getzlaff K. (2013) Identifying potentially high risk areas for environmental pollution in the Baltic Sea. Under review in *Boreal Environ. Res.*

Lu X., Soomere T., Stanev E., Murawski J. (2012) Identification of the environmentally safe fairway in the South-Western Baltic Sea and Kattegat. *Ocean Dyn*., Vol. 61, No. 10, pp. 1669–1680.

Pichel W.G., Churnside J.H., Veenstra T.S., Foley D.G., Friedman K.S., Brainard R.E., Nicoll J.B., Zheng Q., Clemente-Colon P. (2007) Marine debris collects within the North Pacific Subtropical convergence zone. *Mar. Pollut. Bull*., Vol. 54, No. 8, pp. 1207–1211.

Soomere T., Quak E. (2007) On the potential of reducing coastal pollution by a proper choice of the fairway. *J. Coast. Res.*, Special Issue No. 50, pp. 678–682.

Soomere T., Andrejev O., Sokolov A., Myrberg K., 2011. The use of Lagrangian trajectories for identification the environmentally safe fairway. *Mar. Pollut. Bull.*, Vol. 62, No. 7, pp. 1410–1420.

Soomere T., Viikmäe B., Delpeche N., Myrberg K. (2010) Towards identification of areas of reduced risk in the Gulf of Finland. *Proc. Estonian Acad. Sci*., Vol. 59, No. 2, pp. 156–165.

Viikmäe B., Soomere T. (2013) Spatial pattern of hits to the nearshore from a major marine highway in the Gulf of Finland. Under review in *J. Mar. Syst.*

Special Session

On the Future Programme and International Cooperation

The GEWEX Hydroclimatology Panel

Jan Polcher[1], Jason Evans[2], Sam Benedict[3]

[1] Laboratoire de Météorologique du CNRS, Paris, France (jan.polcher@lmd.jussieu.fr)
[2] Climate Change Research Centre, University of New South Wales, Sydney, Australia
[3] International GEWEX Project Office,

1. Introduction

The Global Energy and Water Exchanges (GEWEX) Hydroclimatology Panel (GHP) held its third meeting at the University of New South Wales (UNSW), Sydney, Australia. Drs. Jason Evans and Matt McCabe hosted the Panel at the UNSW Centre of Excellence for Climate System Science. Dr Jason Evans, who was confirmed as GHP Co-Chair at the meeting, joined Jan Polcher, GHP Co-Chair, to welcome over 25 international participants. The Panel focused on results since the last meeting; continued restructuring of science elements; and establishment of plans for GHP's contribution to the climate research challenges and questions posed for the next phase of GEWEX.

Following the Panel's last meeting in October 2011, the GHP simplified its structure into two main core activities; namely, all of the Regional Hydroclimate Projects (RHPs), including four potentially new regional studies under consideration for RHP status; and Cross-cutting projects that are research topic based. Current/proposed cross-cutting projects include, Extremes (including drought and high frequency precipitation), Water and Energy Exchanges Studies, High Elevations science, and seasonal streamflow forecasting. The Global Data Centers for precipitation, river runoff and lakes/reservoirs (GRDC, GPCC and Hydrolare, respectively) are affiliated activities under GHP auspices for GEWEX.

2. Regional Hydroclimate Projects (RHPs)

Figure 1 summarizes the status of the Regional Studies most recently associated with GHP. By applying new criteria, approved earlier by the GEWEX Scientific Steering Group (SSG), in evaluating the RHPs and their contributions to GEWEX, the Panel was able to assign the designations (Former, Current, Prospective) noted in the Figure. The Panel agreed to maintain links to the former studies through its Web Page and will send letters of appreciation to the persons who were key in, recently, guiding these activities through their successful closing phases. Application of the new criteria also allowed the Panel to validate the continuation of four studies and confirm their end dates, for future planning purposes (BALTEX-2013, NEESPI-2014/15, MAHASRI-2015 and HyMeX-2016). Of the Studies designated as "Prospective", the Saskatchewan River Basin was shown to be the most mature in its planning and is expected to be endorsed by the Panel as an Initiating (I) RHP shortly. These actions were endorsed by the GEWEX SSG.

3. GHP Cross-cut Projects

The concept of the Cross-cut Projects, as the second core element of GHP, with the RHPs, was carried over from the precursor to GHP in GEWEX. The goals of the Cross-cut activities were established at the meeting to be to: (i) Generate interactions between RHPs, (ii) Maintain links with completed RHPs, (iii) Advance the GHP contributions to the GEWEX grand science questions, (iv) Address issues of common concern with the other GEWEX Panels and WCRP projects.

The Panel specified that: Cross-cut Projects should be for 2-3 years but can be renewed, that concepts for such projects needed to be addressed in short proposals that follow a prescribed template with specifics related to the

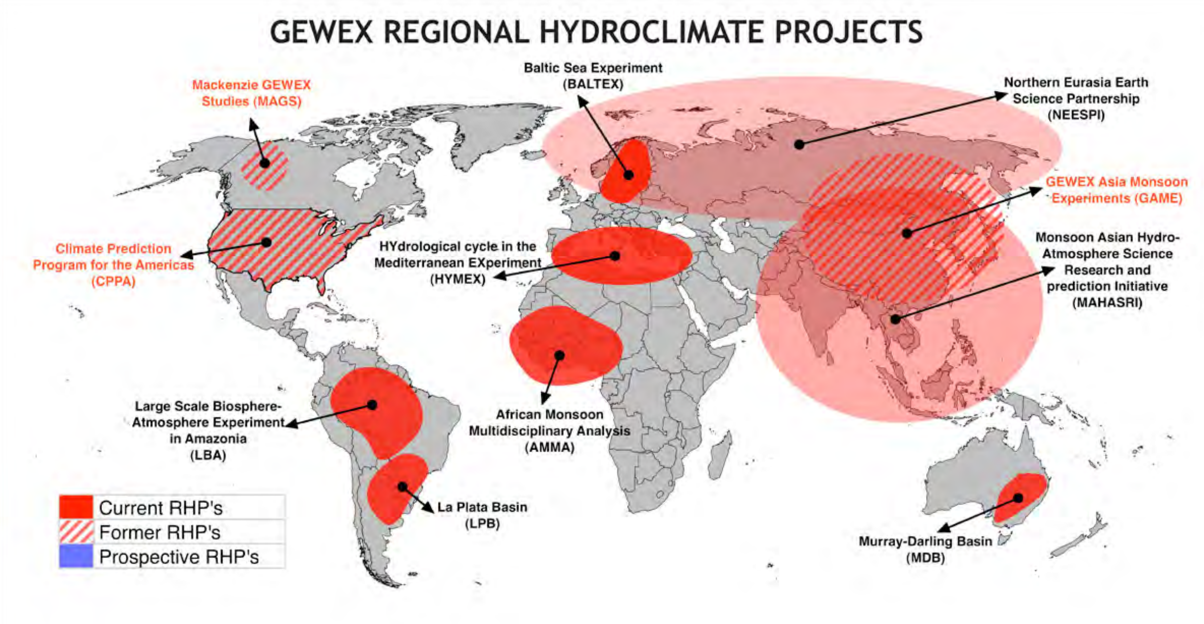


Figure 1. Status of the GHP Regional Hydroclimate Projects (RHPs).

science objectives, the relationship to the RHP's and the Grand Science Questions, and the implementation process. A researcher or team will need to be identified as the lead and will report progress of the initiative at the time of the quarterly panel phone conferences and at the annual GHP meeting. Once the Panel agrees that a proposal has reached a significant level of momentum steps can be taken to broaden participation in the project within GEWEX and other related communities.

Two Cross-cut proposals were formally submitted to GHP at the meeting, namely, one on Short time-scale precipitation extremes and a second on Droughts. Other potential cross-cut projects were also discussed at the meeting that are now being identified in the Panel's Cross-cut Projects framework, including on High-elevation precipitation; Climate change and water resources; Hydrological seasonal forecasting that would interact with the Working Group on Seasonal to Interannual Predictions (WGSIP) and the Hydrologic Ensemble Prediction EXperiment (HEPEX); Regional modeling that would interact with the Coordinated Regional Climate Downscaling Experiment (CORDEX); LSM validation that would connect to the GEWEX Land Atmosphere System Study (GLASS); and Validation of global data sets to be undertaken in concert with the GEWEX Data and Assessments Panel (GDAP).

4. GHP's strategy to address the GEWEX Grand Science Questions (GSQs)Headline

The Panel accepted the charge from the GEWEX Scientific Steering Group (SSG) to develop a strategy for addressing the GSQs within the context of its core activities. During this aspect of the discussion the Panel agreed that the GSQs pose issues that are central to the regional activities of GHP and noted that being responsive to the these topics had been made part of the new criteria for reaching full RHP status. In addition the Cross-cuts were being developed to focus the attention of the GHP community on the issues raised by the GSQs and to enable assessments to be carried out across regions. The Panel accepted the action to encourage regional studies in areas that could yield results of special importance to the GSQ science foci. Figure 2 provides an overview of the GHP strategy for responding to the GSQs.

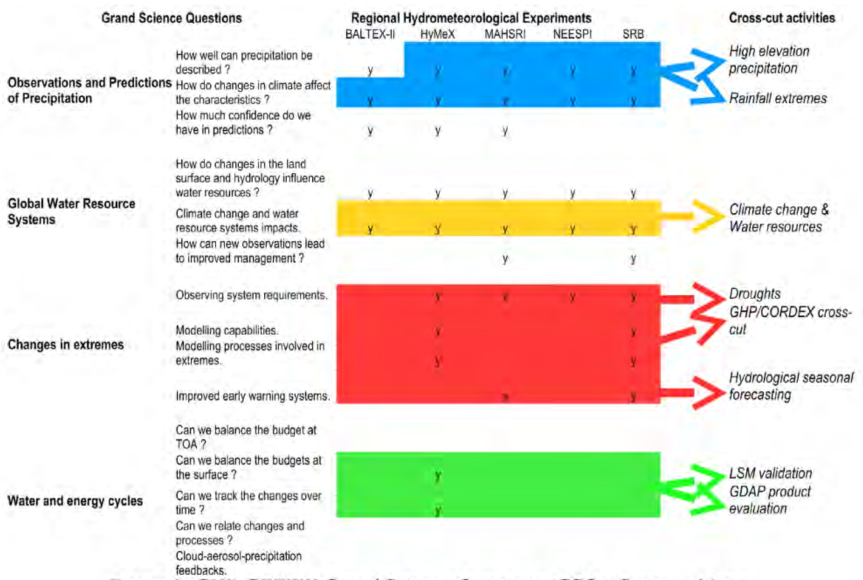


Figure 2. GHP GEWEX Grand Science Questions (GSQs) Strategy Matrix

5. Further outcomes

Earlier, the Panel had honored Dr. Dennis Lettenmaier' request to step down as Co-Chair of GHP, due to other commitments. The Panel also formally acknowledged Dr Eric Wood's request to step down as lead for the Hydrologic Applications (HAP) element of GHP. The Panel commended Drs Lettenmaier and Wood for their contributions to GHP and the broader aspects of GHP and GEWEX. As part of the strategy to preserve the most successful facets of HAP, following Dr Wood' departure, seasonal hydrologic forecasting has been identified as a GHP Cross-cut. The future of other HAP-related activities is still under consideration by the Panel.

To be responsive to the GEWEX SSG Rapporteur's Report for GHP, the Panel will consider the development of a Cross-cut project to address the continuing need for high quality data and products being made available to the GHP and broader communities. This includes not just raw data but, for example, integrated water and energy budget term products within the RHP regions. In addition, GHP will look for opportunities to cooperate with and benefit from Future Earth and global impacts communities. The Panel will also keep open options to work with the WCRP Working Group on regional climate. Because it was recognized that it was important to better understand the progress and requirements with regard to hydrological modeling, the Panel agreed to attempt to summarize this knowledge across the RHPs and Cross-cuts. In this context, the action was accepted to undertake a synthesis in the form of an article in an appropriate Publication (e.g. BAMS, EOS, etc.).

6. Summary

The GEWEX SSG Rapporteurs for GHP noted in their Report that "…it has been a good but challenging year for GHP…". By choosing to focus on a more narrow set of science questions with regional, cross-cutting features it has been possible to simplify the organizational structure. This transition has been proceeding very well so that in another year or so GHP should be fully functioning in a more responsive mode of operation. However, the completion of several RHPs and uncertain steps of some new ones create challenges to GHP to help foster such activities, particularly those in geographic regions, which are currently not fully represented in GEWEX, such as Africa, South America and the Caribbean. GHP's support of an African regional study associated with the Lake Victoria Basin and its effort to hold its 2013 meeting in South America may act as a catalyst to re-energize the GHP-related community in those regions.

Future Earth: Research for Global Sustainability

Martin Visbeck

GEOMAR Helmholtz Centre for Ocean Research Kiel and Kiel University, Germany; Member of the Executive Group of the Future Earth Transition Team (mvisbeck@geomar.de)

Future Earth is a 10-year international research programme initiated by the International Council of Science (ICSU) and the International Social Science Council (ISSC) which will provide the knowledge required for societies to face the challenges posed by global environmental change and to identify opportunities for a transition to global sustainability (see also www.icsu.org/futureearth).

Future Earth will address issues critical to poverty alleviation and development such as food, water, energy and human security, governance, tipping points, economic implications of inaction and action, natural capital, technological transformations including a low-carbon economy, the sustainable use and conservation of biodiversity, lifestyles, ethics and values with an increased regional emphasis.

Recent foresight exercises on the challenges facing Earth system research and its funding converged on the need for a step change. More knowledge fields need to be engaged, bringing both disciplinary and interdisciplinary excellence; the close collaboration with stakeholders across the public, private and voluntary sectors to encourage scientific innovation and address policy needs is essential. So Future Earth will establish new ways to produce research in a more integrated and solutions-oriented way. Future Earth will support science of the highest quality, integrate the natural and social sciences, as well as engineering, the humanities and law. Research in Future Earth will be co-designed and co-produced (see Figure 1) by academics, governments, business and civil society, encompass bottom-up ideas from the wide scientific community, be solution-oriented, and inclusive of existing international Global Environmental Change projects and related national activities.

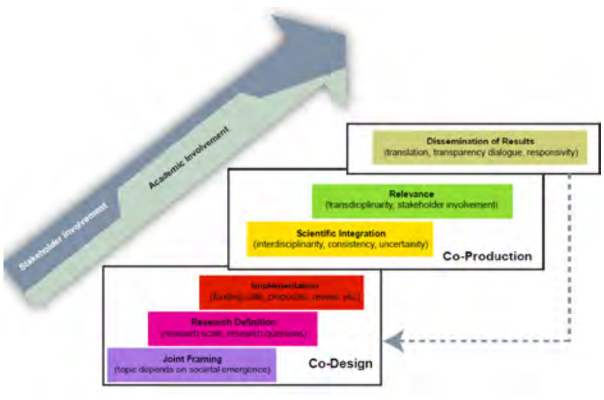


Figure 1. The co-design of research topics and co-production of scientific knowledge (Mauser et al., submitted to Current Opinion in Environmental Sustainability).

1. The conceptual framework of Future Earth

The conceptual framework for Future Earth (see Figure 2), which will guide the formulation of research themes and projects, recognises that humanity is an integral part of the dynamics and interactions of the Earth system. It also encompasses the crossscale spatial and temporal dimensions of the social-environmental interactions and their implications for global sustainability.

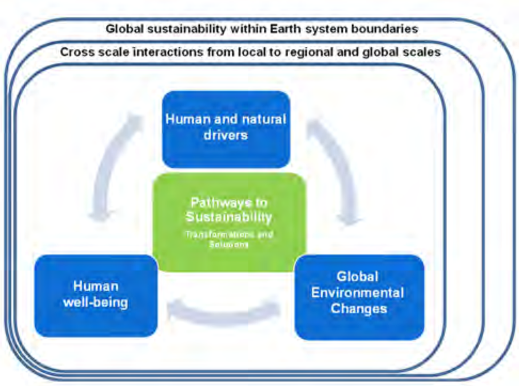


Figure 2. Schematics of Future Earth conceptual framework.

The conceptual framework illustrates the fundamental interconnections between natural and human drivers of change, the resulting environmental changes and their implications for human wellbeing within the Earth system boundaries. These interactions take place across a range of time and spatial scales, and are bounded by the limits of what the Earth system can provide. This fundamental, holistic, understanding is the basis for the identification of transformative pathways and solutions for global sustainability.

2. The initial research themes

The conceptual framework guides Future Earth research towards addressing key research challenges, expressed as a set of three broad and integrated research themes:

Dynamic Planet
Understanding how planet Earth is changing due to natural phenomena and human activities through intensified and novel research on mapping, understanding and projecting global change processes and interactions between social and environmental changes across scales. The Future Earth research emphasis will be on observing, explaining, understanding, projecting Earth environmental and societal trends, drivers and processes and their interactions; anticipating global thresholds and risks.

Global Development
Providing the knowledge for sustainable, secure and fair stewardship of food, water, biodiversity, health, energy, materials and other ecosystem functions and services. The emphasis of Future Earth research will be on determineng

the impacts of human activities and environmental change on human well-being, people and societies through integrated social-environmental research and the identification of sustainable solutions.

Transformations toward Sustainability
Understanding transformation processes and options, assessing how these relate to human values, emerging technologies, and economic development pathways, and evaluating strategies for governing and managing the global environment across sectors and scales. The emphasis of Future Earth research will be on solutionoriented science that enables societal transitions to global sustainability, such as how to anticipate, avoid and manage global environmental change through research on transformative pathways and scenarios, innovation pathways, and what institutional, economic, social, technological and behavioural changes can enable effective steps towards global sustainability and how these changes might best be implemented.

These research themes will be the main organisational units for Future Earth research. They will build on the success of existing Global Environmental Change (GEC) programmes and projects.

3. Future Earth cross-cutting capabilities

Addressing the proposed integrated research themes will depend on core capabilities such as observing networks, high performance computing, Earth system models, data management systems and research infrastructures. These capabilities are essential to advance the science of global environmental change and translate it into useful knowledge for decision making and sustainable development.
Many of these capabilities lie beyond the boundaries of the Future Earth initiative, residing in national and international observing systems, modelling centres, training programs, and disciplines. It will be important that Future Earth works in partnership with the providers of these capabilities for mutual benefit.

4. Future Earth education and capacity building

Future Earth will partner with programmes and networks that already work in the educational sector to ensure rapid dissemination of research findings and support science education at all levels. Targeted audiences will include primary, secondary and tertiary education and engagement with youth through social networks. Approaches will include online education, engagement with media, science and technology centres, and use of existing GEC research programmes that support graduate and post-graduate education. Future Earth has identified capacity building as a basic principle of all its activities and will develop a multi-tiered exercise in scientific capacity building, with both explicit capacity building activities and capacity building that occurs as a by-product of its many activities. Future Earth dedicated capacity building activities will include generating a strong international network of scientists committed to international interdisciplinary and trans-disciplinary research, with a particular focus on early-career scientists, and the development of institutional capacity, including developing functional regional nodes and international networks..

5. Future Earth governance and support

The governance structure of Future Earth embraces the concept of co-design. It involves a *Governing Council* responsible for setting the strategic direction of the programme supported by co-equal engagement and science committees. The *science committee* will provide scientific guidance, ensuring quality of the research and suggest new projects. The *engagement committee* will provide leadership and strategic guidance on involving stakeholders throughout the entire research chain from co-design to dissemination and ensure that Future Earth produces the knowledge that society needs. An *Executive Secretariat* which will perform the day-to-day management of Future Earth, ensuring the coordination across themes, projects and regions.

Future Earth is supported by the *Science and Technology Alliance for Global Sustainability* that is responsible for establishing Future Earth and will promote and support its development as its scientific sponsors. Its members are the International Council for Science (ICSU), the International Social Science Council (ISSC), the Belmont Forum, the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP), the United Nations University (UNU), and the World Meteorological Organization (WMO) in an observer capacity. The Alliance will work with the Governing Council and Executive Director of Future Earth to secure new and enhanced sources of funding. Already, the Belmont Forum has launched in 2012 a new open and flexible process to support international collaborative research actions through annual multi-lateral calls to support environmental research. This will require the strengthening of funding bases for disciplinary and trans-disciplinary research and coordination activities.

Future Earth will build upon and integrate the existing Global Environment Change Programmes – such as the World Climate Research Programme (WCRP) International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP), DIVERSITAS, and the Earth System Partnership (ESSP).
Current GEC programmes have national committees in several countries such as Germany, Switzerland, Sweden or Japan, that ensure that the international initiatives can be strategically linked with national research communities and priorities. Germany, as one of the first countries globally, has successfully finished the transition from a National Global Change Committee to a National Future Earth committee in March 2013 (see also www.dkn-future-earth.org). National committees will be asked to play a vital role in implementing Future Earth at the national level.

References

Mauser W., Klepper G., Rice M., Schmalzbauer B., Hackmann H., Leemans R., Moore H.: Transdisciplinary global change research: the co-creation of knowledge for sustainability. Submitted to Current Opinion in Environmental Sustainability, 2013.

Special Session

GEWEX Regional Hydroclimate Projects

La Plata Basin RHP: Rethinking the design of adaptation strategies

E. Hugo Berbery[1], Jean-Philippe Boulanger[2], Elvira Gentile[3] and Sandro Schlindwein[4]

[1] Earth System Science Interdisciplinary Center, University of Maryland, USA (berbery@atmos.umd.edu)
[2] LOCEAN, UMR CNRS/IRD/UPMC, France
[3] University of Buenos Aires, Argentina
[4] Federal University of Santa Catarina, Florianópolis, Brazil

1. Introduction

The Regional Hydroclimate Project for La Plata Basin (LPB) was recently completed. Initially conceived as a physically based research with a main interest in downscaling approaches to link climate and hydrology, it evolved into a multidisciplinary project to include studies of vulnerability and adaptation strategies for land-use, agriculture, and rural development. LPB objectives were addressed through the development of international research networks, with CLARIS LPB, a Europe-South America Network for Climate Change Issues and Impact Assessment, being the main contributor.

2. Land Use/Land Cover Changes in LPB

Vast areas of the La Plata Basin have experienced human-induced changes in land cover and management practices of crop-systems due to the continuous expansion of agriculture. These changes in land cover may impact the ecosystem-climate feedbacks in unknown ways. A large effort in LPB was to seek a better understanding of the impacts of ecosystem changes on the regional climate. The regional climate of the La Plata basin is sensitive to extensive changes in land cover, and those changes are highly non-linear.

3. CLARIS-LPB

The CLARIS LPB project was born with a “climate-sciences” perspective where the climate change impact problem would be simulated by a chain of models. Final outputs offer an ensemble of possible futures from which a decision making process could be derived to support the design of adaptation measures. However, the design of adaptation strategies is a human (social) issue, based on the current vulnerability of the system of interest, including all its components (social, economic, environmental). For this reason a systems approach was adopted to deal with all the complexity in the process of developing adaptation strategies. The collaboration with stakeholders became fundamental to understand the vulnerability of the system of interest, to show the climate change impacts and to reflect together on the paths that could be taken in order to reduce its vulnerability and to initiate the adaptation process.

4. After LPB

The presentation will discuss the evolution of LPB through the years to become more responsive to production and societal needs, and how its legacy is feeding new multidisciplinary initiatives in climate services and ecosystem services in the region.

Northern Eurasia Earth Science Partnership Initiative (NEESPI) in the past two years

Pavel Ya. Groisman[1] and Richard G. Lawford[2]

[1] University Corp. for Atmospheric Research at NOAA/NCDC, Asheville, North Carolina, USA (pasha.groisman@noaa.gov)
[2] International GEWEX Project Office, Washington, District Columbia, USA

1. Introduction

The Northern Eurasia Earth Science Partnership Initiative, or NEESPI, is a currently active program of internationally-supported Earth systems science research, which has as its foci issues in Northern Eurasia that are relevant to regional and global scientific and decision-making communities. NEESPI is an interdisciplinary program of internationally-supported Earth systems and science research that addresses large-scale and long-term manifestations of climate and environmental changes.

The NEESPI Study Area (Figure 1) includes: the former Soviet Union, northern China, Mongolia, Fennoscandia, and Eastern Europe. This part of the globe is undergoing significant changes – particularly those changes associated with a rapidly warming climate in this region and with important changes in governmental structures since the early 1990s and their associated influences on land use and the environment across this broad expanse. How this carbon-rich, cold region component of the Earth system functions as a regional entity and interacts with and feeds back to the greater Global system is to a large extent unknown. Thus, the capability to predict future changes that may be expected to occur within this region and the consequences of those changes with any acceptable accuracy is currently uncertain.

Figure 1. NEESPI logo. It shows also the NEESPI study domain and its major land cover types.

One of the reasons for this lack of regional Earth system understanding is the relative paucity of well-coordinated, multidisciplinary and integrating studies of the critical physical and biological systems. By establishing a large-scale, multidisciplinary program of funded research, NEESPI has been aimed at developing an enhanced understanding of the interactions between the ecosystem, atmosphere, and human dynamics in Northern Eurasia. Specifically, the NEESPI strives to understand how the land ecosystems and continental water dynamics in Northern Eurasia interact with and alter the climatic system, biosphere, atmosphere, and hydrosphere of the Earth.

2. From conception to present days

Eight years ago Northern Eurasia Earth Science Partnership Initiative (NEESPI) was launched with the release of its Science Plan (http://neespi.org). This web site contains the NEESPI history, presentations at the NEESPI past conferences, the NEESPI Science Plan (260 pp.) and its Executive Summary (18 pp.; also dubbed in 2007 as a refereed publication in the Special NEESPI issue of “Global and Planetary Change”). The NEESPI Science Plan includes elements of WCRP, IGBP, IHDP и DIVERSITAS. Gradually, the Initiative was joined by numerous international projects launched in EU, Russia, the United States, Canada, Japan, and China. NEESPI duration ~ 12 years (started in 2004). Throughout its duration, NEESPI served and is serving as an umbrella for more than 155 individual international research projects (Figure 2). Currently, the total number of the ongoing NEESPI projects (as on January 2013) is 48 and has changed but slightly compared to its peak (87 in 2008; Figure 3). More than 700 scientists from more than 200 institutions of 30 countries worked or are working under the Initiative umbrella. Recently, we queried the NEESPI Principal Investigators and found that more than 75 PhD Theses devoted to Northern Eurasia studies were defended during the life of the Initiative.

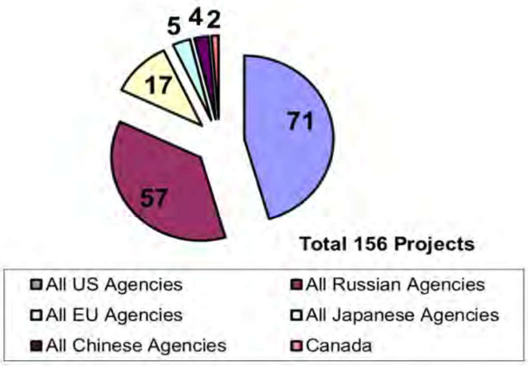


Figure 2. Completed and ongoing NEESPI Projects by country (or group of countries) sorted by funding source.

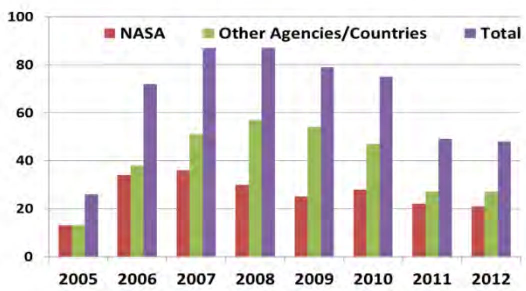


Figure 3. Active NEESPI Projects per year.

3. NEESPI Outreach

During the Mega-Project life, more than 1,100 papers and 26 books were published. The past 24 months were extremely productive in the NEESPI outreach. NEESPI leadership organized six Open Science Sessions at the major Geoscience Unions/Assembly Meetings (EGU, JpGU, and AGU) and six International Workshops. The programs of three of these Workshops (in Tomsk, Yoshkar Ola, and Irkutsk, Russia) included Summer Schools for early career scientists. More than 320 peer-reviewed papers, books, and/or book chapters were published or are in press since January 2011 (this list was still incomplete at the time of preparation of this abstract). In particular, a suite of 25 peer-reviewed NEESPI articles was published in the Forth Special NEESPI Issue of "Environmental Research Letters" (ERL) http://iopscience.iop.org/1748-9326/focus/NEESPI3 (this is the third ERL Issue). In December 2012, the next Special ERL NEESPI Issue was launched http://iopscience.iop.org/1748-9326/focus/NEESPI4.

Northern Eurasia is a large study domain. Therefore, it was decided to describe the latest findings related to its environmental changes in several regional monographs in English. Four books on Environmental Changes in the NEESPI domain were published by the University of Helsinki (Groisman et al. 2012), Akademperiodyka (Groisman and Lyalko 2012), and Springer Publishing House (Gutman and Reissell 2001; Groisman and Gutman 2013) being devoted to the high latitudes of Eurasia, to Eastern Europe, and to Siberia. We expect that one more book devoted to East Asia (Chen et al. 2013) will be published simultaneously by Higher Education Press and De Gruyter Publ. House in Beijing and Berlin respectively prior to commence of this Meeting.

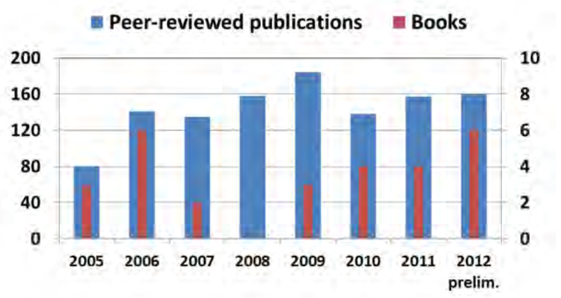


Figure 4. Dynamic of the NEESPI publications by year.

4. Content of the presentation at the Conference

In this presentation, the description of the NEESPI Program will be complemented with an overview of the results presented in the latest our books:

- *Arctic Land Cover and Land Use in a Changing Climate: Focus on Eurasia*
- *Earth System Change over Eastern Europe*
- *Regional Environmental Changes in Siberia and Their Global Consequences;*
- *Dryland East Asia: Land Dynamics amid Social and Climate Change* and
- The future of the Initiative will be discussed.

References

Chen, J., S. Wan, J. Qi, G. Henebry, M Kappas, and G. Sun (eds.) 2013: Region of East Asia: Land Dynamics amid Social and Climate Change. Beijing: Higher Education Press and Berlin: De Gruyter. (in press).

Groisman and Gutman (eds.) 2013: Environmental Changes in Siberia: Regional Changes and their Global Consequences. Springer, Amsterdam, The Netherlands, 357 pp. doi:10.1007/978-94-007-4569-8

Groisman, P.Ya. and V.I. Lyalko (eds.) 2012: Earth Systems Change over Eastern Europe. Akademperiodyka, Kiev, The Ukraine, 488 pp. ISBN 978-966-360-195-3.

Groisman, P.Ya., A. Reissell, and M. Kaukolehto (eds.) 2012: Proceedings of the Northern Eurasian Earth Science Partnership Initiative (NEESPI) Regional Science Team Meeting devoted to the High Latitudes. Report Series in Aerosol Science, No. 130, Helsinki, Finland, 153 pp.

Gutman, G. and A. Reissell, eds., 2011: Arctic land cover and land use in a changing climate: Focus on Eurasia. VI, Springer, Amsterdam, The Netherlands, 306 pp.

Key References

Groisman, P.Ya., and S.A. Bartalev, 2007: Northern Eurasia Earth Science Partnership Initiative (NEESPI): Science plan overview. Global and Planetary Change, 56, issue 3-4, pp. 215-234.

Groisman, P.Ya., and 27 Co-Authors, 2009: The Northern Eurasia Earth Science Partnership: An Example of Science Applied To Societal Needs. Bull. Amer. Meteorol. Soc., 90, pp. 671-688.

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.

No. 39: Minutes of 21st Meeting of the BALTEX Science Steering Group held at Kuressaare, Saaremaa, Estonia, 3 June 2007. September 2007.

No. 40: Minutes of 22nd Meeting of the BALTEX Science Steering Group held at SMHI, Norrköping, Sweden, 23-25 January 2008. May 2008.

No. 41: 2nd International Lund RCM Workshop: 21st Challenges in Regional-scale Climate Modelling. Lund University, 4-8 May 2009. Workshop Proceedings. Editors: Burkhardt Rockel, Lars Bärring and Marcus Reckermann. 292 pages, April 2009.

No. 42: International Conference on Climate Change – The environmental and socio-economic response in the southern Baltic region. University of Szczecin, 25-28 May 2009. Conference Proceedings. Editors: Andrzej Witkowski, Jan Harff and Hans-Jörg Isemer. 140 pages, May 2009.

No. 43: Minutes of 23rd Meeting of the BALTEX Science Steering Group held at Finnish Meteorological Institute, Helsinki, Finland, 12 - 14 January 2009. July 2009.

No. 44: BALTEX Phase II 2003 – 2012 Revised Objectives. A Summary Amendment to the BALTEX Phase II Science Framework and Implementation Plan. 23 pages. November 2009.

No. 45: Minutes of 24th Meeting of the BALTEX Science Steering Group held at the University of Riga, Riga, Latvia, 16 - 18 November 2009. March 2010.

No. 46: Sixth Study Conference on BALTEX, Miedzyzdroje, Wolin, Poland, 14 - 18 June 2010. Conference Proceedings. Editor: Marcus Reckermann and Hans-Jörg Isemer, 182 pages. June 2010.

No. 47: Minutes of 25th Meeting of the BALTEX Science Steering Group held at the Hotel Amber Baltic, Międzyzdroje, Poland, 13 June 2010. September 2010.

No. 48: SurBACC 2010. A survey of the perspectives of climate scientists concerningclimate change and climate science in the Baltic Sea basin. Author: Dennis Bray. 82 pages, October 2010.

No. 49: Minutes of 26th Meeting of the BALTEX Science Steering Group held at the University of Gothenburg, Sweden, 24-25 November 2010. March 2011.

No. 50: A survey of the perceptions of regional political decision makers concerning climate change and adaptation in the German Baltic Sea region. Authors: Dennis Bray and Grit Martinez. September 2011.

No. 51: Minutes of 27th Meeting of the BALTEX Science Steering Group held at the Baltic Sea Research Institute Warnemünde, Germany, 29-30 September 2011. December 2011.

No. 52: Minutes of 28th Meeting of the BALTEX Science Steering Group held at the Marine Systems Institute, Tallinn University of Technology, Estonia, 5 September 2012. December 2012.

No. 53: Seventh Study Conference on BALTEX, Borgholm, Öland, Sweden, 10 - 14 June 2013. Conference Proceedings. Editor: Marcus Reckermann and Silke Köppen, 190 pages. June 2013.

Copies are available upon request from the International BALTEX Secretariat.