BALTEX

Baltic Sea Experiment

World Climate Research Programme / Global Energy and Water Cycle Experiment
WCRP GEWEX

First Study Conference on BALTEX

Visby, Sweden
August 28 - September 1, 1995

Conference Proceedings

Editor : A. Omstedt

International BALTEX Secretariat
Publication No. 3
August 1995

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Editor :
Anders Omstedt
SMHI, Norrköping, Sweden

PREFACE

The First Study Conference on BALTEX has been arranged at Visby on the island of Gotland in the central part of the Baltic Sea in August 1995. Five intensive conference days offer many opportunities to learn much about the energy and water cycle in the Baltic Sea drainage basin. The conference will provide good possibilities for interdisciplinary discussions and thus will be a most stimulating Study Conference. The conference has been organized by the International BALTEX Steering Committee, the Swedish National Committee for the IGBP and WCRP of the Royal Swedish Academy of Sciences and the Swedish Meteorological and Hydrological Institute.

In the present proceedings the contributions of the invited lecturers as well as abstracts of other participants are published. I wish to thank all those who have contributed to the conference. In the local organization and scientific committees: Sven Bergström, Ulf Högström, Irene Johansson, Lennart Bengtsson, Zdzislav Kaczmarek, Pentti Mälkki, Ehrhard Raschke and Evgenij Zaharchenko. Thanks also to Gun Sigurdsson and Anneli Arkler for lots of practical support and enthusiasm.

I thank Hans-Jörg Isemer for arranging the publication of the proceedings as a BALTEX Secretariat report. Financial support for the printing of the proceedings through GKSS Research Centre, Geesthacht, Germany, is gratefully acknowledged.

Norrköping, August 1995

Anders Omstedt

Editor, SMHI

The Hydrological Cycle in Climate and Weather Prediction

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Abstract

The ability of the ECHAM4 model to simulate the hydrological cycle of the atmosphere is investigated. It is found that the validation is severely hampered by the large uncertainty of the observational data. It is tried to minimize the problem by using a wide range of observational data such as different types of satellite and in-situ data and by using river run-off data from large catchment areas. Mostly the simulation by the model lies within the range of realizations of climatological estimates, although some limitations, such as insufficient precipitation in summer over middle and high latitude land areas can be determined. Radiation balance, including cloud forcing is in general agreement with ERBE data, but problems remain over ocean areas west of California, Chile and Namibia where the model underestimates the boundary layer stratiform clouds, thus leading to insufficient cloud cooling in these areas.

The BALTEX program, together with other GEWEX sub-programs, are likely to play a very important role in further modelling improvements in particular for the smaller scale weather systems, which are so important for the hydrological cycle. Of particular importance in BALTEX is the possibility to validate the hydrological processes over large ocean-type water bodies which will help develop better parameterization schemes for remote ocean areas, where detailed observational studies are not feasible.

1. Introduction

The total amount of water on the Earth amounts to some 1400 million km^3. Of this is 1370 million km^3 stored in the oceans, 24 million km^3 in glaciers and roughly 4 million km^3 on land, mainly as interstital water in rocks and sediments. The estimated global annual hydrological cycle is estimated to some 500 thousand km^3, which means that the averaged residence time of a water molecule in the Earth´s hydrological system is some 3000 years. Only a very short part of this time, 6-8 days, is spent in the atmosphere. Nevertheless, the role of the atmosphere is fundamental since it is only due to atmospheric processes, that water can be transported from its sources to its sinks. The total amount of water in the Earth´s atmosphere measures about 0.25 % of the total mass of the atmosphere or 14 thousand km^3. Even this is a sizeable amount of water, in fact equivalent to about two thirds of the total amount of water of the Baltic Sea.

The role of water in the climate system is of fundamental importance for a number of reasons. The release of latent heat is of the order of 90-100 Watts/m^2 and is thus the single most important factor in heating the atmosphere. The amount of heat is equal to 25% of the amount of heat reaching the Earth from the sun. Water vapour is the dominating greenhouse gas and contributes to the warming of the Earth by more than 20 °C (Kondratyev and Moskalenko, 1984).

The indirect effect of water in the atmosphere is also of major importance for the climate of the Earth, through the creation of clouds and through the changing of the surface albedo as a consequence of snow and ice on the ground. The overall effect of clouds is a net cooling of the atmosphere by some 20 Watts/m^2. Finally, precipitation and evaporation over ocean areas change surface salinity and hence vertical mixing in the oceans. Some areas, such as the North Atlantic, appear in particular to be very sensitive in this respect.

The ability of a realistic representation of the hydrological cycle is of particular importance for climate change. It seems reasonable to require of a climate model, in order for us to obtain confidence in the way the hydrological cycle may change in a future climate, such as a climate with a much higher concentration of greenhouse gases than the present one, that it, in a realistic way, can represent the hydrological processes in the present climate. Possible changes in the hydrological processes, such as a modified cloud and water vapour feedback or changes in the position of the storm tracks or even the statistical distribution of precipitation in time and space, are likely to have more far reaching effects on society than changes in the temperature.

The purpose of this paper is to review some aspects of modelling the hydrological by numerical models of the atmosphere. As we will see, numerical models are remarkably good in reproducing the large scale features of the hydrological cycle and in some respects as good as we presently can observe precipitation and other components of the hydrological cycle.

My presentation will fall into three parts. In the first part I will present some recent result from our climate modelling work in Hamburg. In the second part I will discuss the serious problem of validation due to the fractal structure of precipitation. What are the data sets today? How good are they? What will GEWEX bring? In the final part, I will discuss how the BALTEX program will contribute towards furthering our understanding of these questions.

2. The hydrological cycle in the ECHAM4 model

The ECHAM4 climate model is the latest atmospheric general circulation model developed at the Max Planck Institute for Meteorology in Hamburg, in cooperation with other European climate groups (Roeckner et al., 1995). It constitutes a major change to the previously used atmospheric general circulation model (Roeckner et al., 1992) and its main features are described in Roeckner et al., 1995 and Chen et al., 1995). Major efforts have been put towards a better representation of the hydrological cycle and in this paper we will concentrate the evaluation on the models ability of representing hydrological processes. In the following we will concentrate the discussion of results from a T42, 19 level model, but other integrations with higher and lower horizontal resolution as well as with higher vertical resolution have been undertaken and will be considered in forthcoming papers. In the experiments described here, the model has been integrated for 14 years using the observed sea surface temperature data for the period 1979-1993. Data for CO_2 etc has been selected in agreement with the AMIP project (Gates 1992).

Figure 1 summarises the global annual hydrological cycle. Data are provided separately for the marine and continental atmosphere. Observational estimates are from Baumgartner and

Reichel (1975) and from Chahine (1992). Data on net snow accumulations on landices and glaciers are from Bromwich (1990). Units are given in 10^3 km^3/year or 10^{15} kg/year.

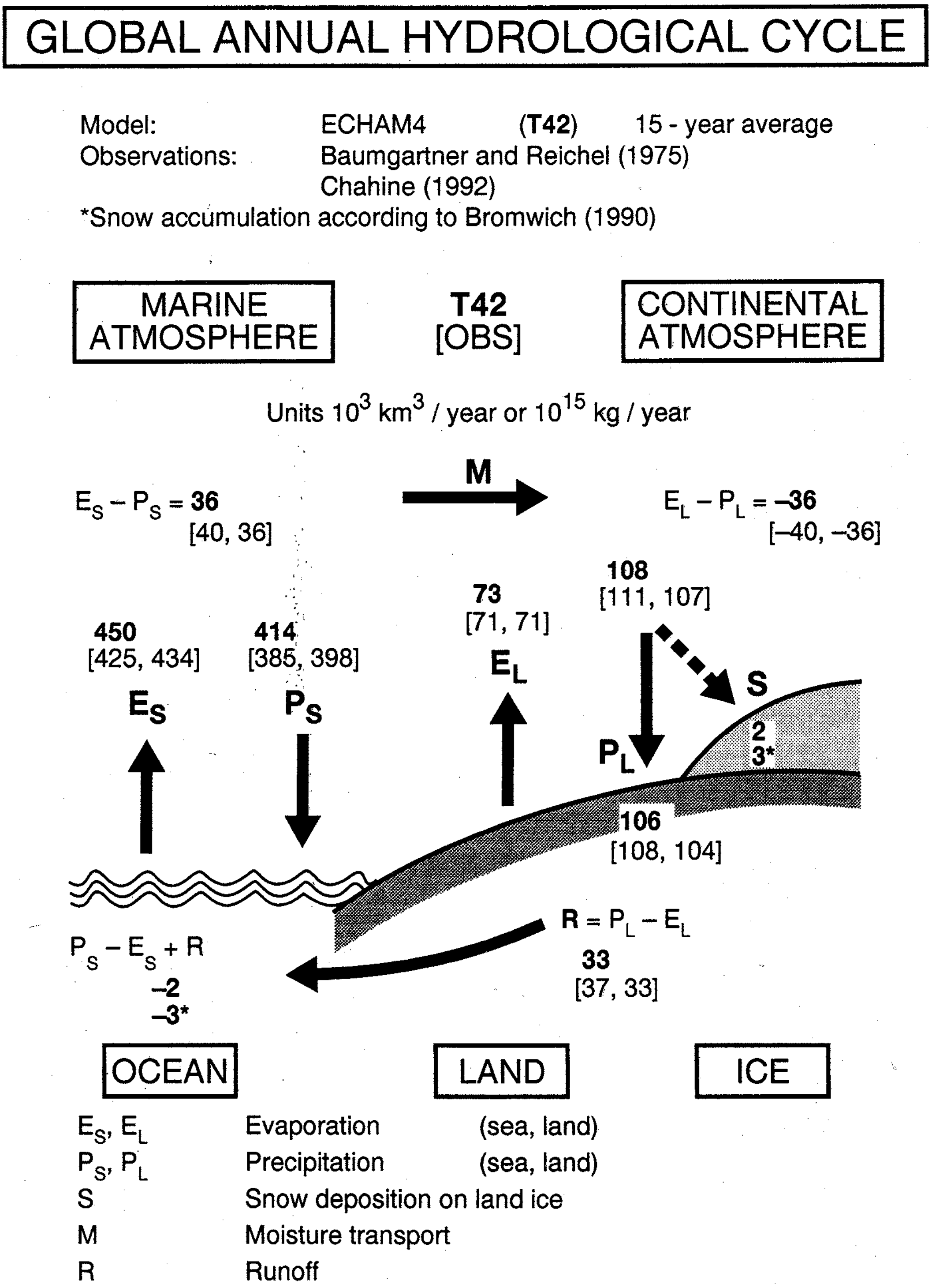


Figure 1: Global annual hydrological cycle for the marine and continental hemisphere respectively. Upper figure averaged results from 15 years from ECHAM4. Lower figures, empirical estimates from Baumgartner and Reicher (1975) and Chahine (1992). Snow accumulation according to Bromwich (1990). Units are given in 10^3 km^3/year or 10^{15} kg/year.

The simulated hydrological cycle over oceans is about 5 % higher than the observational estimates, while data for land areas falls within the two estimates or are very close to the observational data. It is presently not possible to say whether the simulated data for the oceans are incorrect, since no reliable independent observations are presently available. However validation against other types of observations, tropospheric winds, cloud cover etc. (Chen et al., 1995), suggests that the Walker circulation is somewhat too intense, which may explain the high evaporation which mainly occurs over tropical oceans. With respect to precipitation over land, it is interesting to note that precipitation over land is three times higher than the net moisture transport from the oceans in good agreement with observations, demonstrating that the model handles the secondary hydrological circulation over land rather well. Moisture transport from ocean to land is presently not independently calculated. Accumulation of snow on glaciers is lower than the observational estimates, but also here observational data are unreliable and probably only known within ± 20% (Giovanetto et al. 1992).

Figure 2 shows the simulated and the climatological estimated precipitation (Legates and Wilmott, 1990) in zonal averages over land for the boreal winter and summer respectively. The agreement is very good, except for the Southern Hemisphere in Dec-Feb around 30 S, where the simulation has a much broader maximum than the climate estimate, and along the coast of Antarctica where the climate estimate by Legates and Wilmott (1990) appears to be unrealistically high.

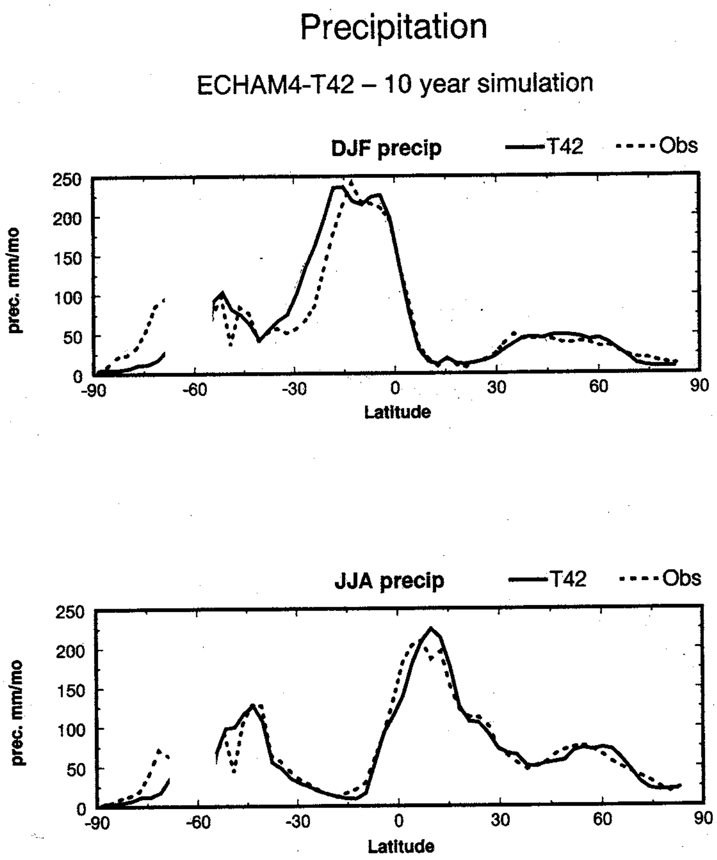


Figure 2: Zonally averaged precipitation over land for Dec./ Jan. / Feb, above and Jun./ Jul. / Aug. below. Full lines show the simulate results from ECHAM4 and the dashed results climate estimate from Legates and Wilmott (1990) Units are mm precipitation/month.

Finally, in Figure 3 we show a comparison with the ECMWF predicted global precipitation calculated for all forecasts between day 2 and day 3 from the ensemble of all such forecasts between 1 May 1990 and 30 April 1991, a time with a practically frozen forecasting system at ECMWF (Klinker, 1992, pers inf.). Bengtsson (1991) has suggested that the precipitation calculated between day 2 and day 3 from the ECMWF forecasts, at least for the operational model at ECMWF at this time, is probably the best possible estimate, since at this time in the forecast, the spin up has been significantly reduced and the model systematic errors are still quite small.

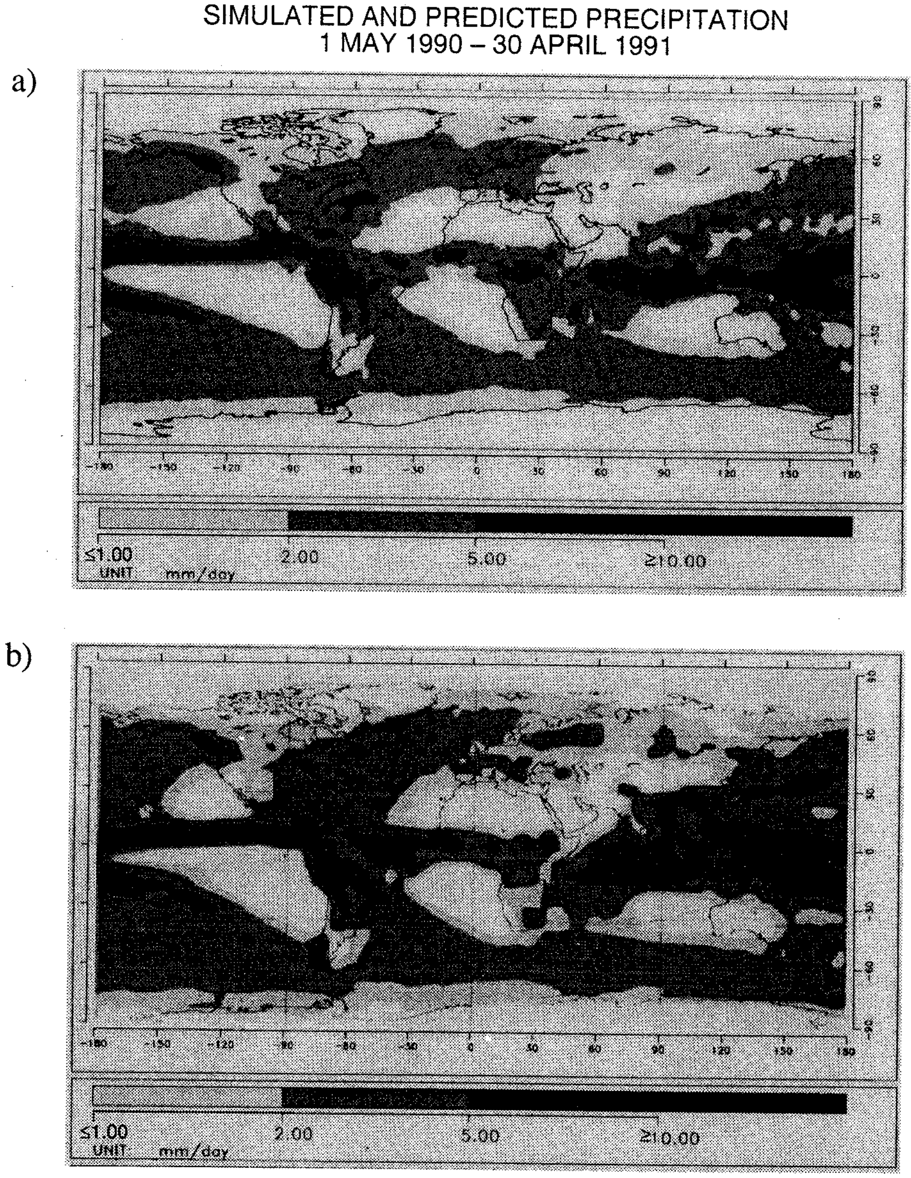

SIMULATED AND PREDICTED PRECIPITATION
1 MAY 1990 – 30 APRIL 1991

Figure 3: (a) Simulated precipitation with the ECHAM4 model for the period 1 May 1990 to 30 April 1991. SST data according to Reynolds (pers comm). (b) Ensemble forecasts averaged for the predicted precipitation between day 2 and day 3 of all daily forecasts from the ECMWF operational model for the same period (Klinker, pers comm.). Units mm precipitation/day. Isolines are given for 1, 2, 5 and 10 mm/ day.

This comparison can only be seen as a tentative validation, since during the short span of one year, the simulated precipitation, albeit constrained by the observed SST, in some areas can deviate considerably from another equally likely realization of the state of the atmosphere. Nevertheless there is a considerable agreement in the large scale features of the precipitation patterns. It is particularly interesting to note the high agreement in precipitation over ocean areas. The tropical precipitation, as indicated by the isolines of 5 and 10 mm precipitation per day is more confined in the ECHAM simulation, presumably a consequence of a tendency to generate a somewhat overactive tropical circulation. Precipitation over the extra-tropical land areas on the other hand is weaker in the simulation. Whether this is due to systematic effects or to insufficient sampling can not be determined, although other evaluation studies of ECHAM4 indicate underestimated precipitation over extra-tropical land areas during summer and an overestimation during winter.

A special problem in the validation of precipitation is the fine scale structure of precipitation. As has been convincingly shown by Bergeron (e.g. 1960, 1970), even over relatively flat land areas in "undisturbed" synoptic conditions such as typical warm front precipitation at high latitudes in late autumn with no marked diurnal cycle, precipitation patterns are influenced markedly by very small natural obstacles (less than 10 m high). This fractal nature of precipitation creates a practically unsolved sampling problem. Alternative ways to estimate large scale precipitation is by calculating river run off or the water level in lakes with no or with known discharged conditions. Such a validation technique has been developed (Sausen et al., 1991) and Figure 4 shows the result from such a comparison.

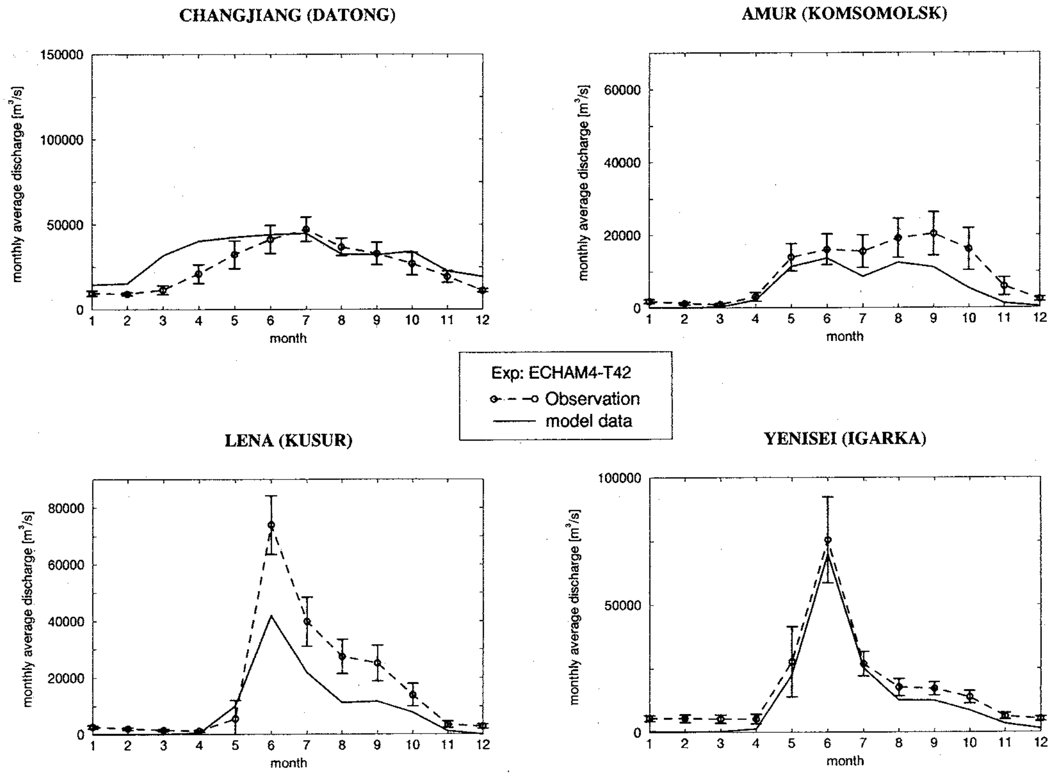


Figure 4: Calculated (full lines) and measured (dashed lines) river run off data at four major rivers. Vertical bars indicate interannual variability. Calculations are averaged over 10 years, measured river flow over 30 years or longer. Units are given in m^3/ sec.

The observed data represents averaged conditions over some 30 years and the parallell bars shows the maximum and minimum value for each month. The river run off incorporate not only precipitation but evaporation, soil percolation, snow melt and river flow velocity. In the present study information on soil percolation is based on available data for soil structure. River run off has been calculated from detailed orographic maps. Although there are considerable differences, which at least partly are due to insufficient horizontal resolution, there are also agreements in particularly qualitative ones, such as the sharp maximum in the river run off in Lena and Yenisei in June mainly due to the rapid snow melt during this month. However, great care must be taken to this type of validation due to the fact that many rivers are heavily regulated, due to hydroelectric dams or to to large scale agricultural irrigation projects. Some of the Swedish rivers into the Baltic Sea for example have a minimum flow in early summer due to regulation, instead of the typical maximum flow in an unregulated river.

3. Validation of cloud and radiation

Chen et al. (1995) have undertaken a comprehensive validation of cloud and radiation in the ECHAM4 model and we will here only summarize some of their results. Table 1 and Table 2 summarize the radiation balance at the top of the atmosphere (TOA) and at the surface (SFC).

Global annual mean radiation budget (TOA)

Radiative flux	ECHAM4 T42	ERBE Hartmann (1993)	Units
Incoming shortwave	341	341	W/m^2
Outgoing shortwave	104	101	"
Albedo	30.6	29.8	%
NET shortwave	237	240	W/m^2
Outgoing longwave	235	234	"
NET radiation	2	6	"
Outgoing SW (clear)	56	53	"
Albedo (clear)	16.3	15.6	%
NET SW (clear)	286	288	W/m^2
Outgoing LW (clear)	264	264	"
NET radiation (clear)	22	24	"
SW cloud forcing	-49	-48	"
LW cloud forcing	29	30	"
NET cloud forcing	-20	-18	"

Table 1: Global annual mean radiation budget at the top of the atmosphere (TOA). Calculated data are averaged over 15 years, ERBE data refers to the period 1985-89 (Hartmann 1993). Units are given in Watts/m^2.

The global annual mean radiation budget at the top of the atmosphere, Table 1, agrees within the accuracy of the measurements from ERBE (Hartmann, 1993). This is also the case for the cloud forcing with a simulated net cloud forcing of -20 Watts/m^2. A closer examination of the geographical distribution of the cloud forcing show larger discrepencies with the ERBE data. Boundary layer stratiform clouds are still underestimated west of California, Chile and Namibia giving rise to an underestimation of the short wave cloud forcing in this area, and clouds of all types are overestimated for the tropically active areas in particular over Indonesia generally providing a stronger than the observed net cloud forcing in this area. We will discuss this further below. Table 2 shows the total radiative fluxes at the ground as well as the fluxes in clear air. The downward long wave radiation, according to the GEBA dataset (Ohmura and Gilgen, 1993), is probably still underestimated, although it has been increased by some 11 Watts/m^2 compared to the previous ECHAM3 model (Roeckner et al., 1992) by the incorporation of the effect of water vapour continuum (Giorgetta and Wild, 1995). The underestimation of the downward longwave radiation leads to a generally reduced net radiation at the ground, thus providing a slight deficit for the forcing of sensible of latent heat fluxes at the ground. The role of the clouds for the net radiation at the ground amounts to a reduction of 46 Watts/m^2.

Global annual mean radiation budget (SFC)

Radiative Flux	ECHAM4 T42	ERBE ISCCP GEBA	Units
Downward shortwave	171	170-173	W/m^2
Upward shortwave	23	22-28	"
Albedo	13.6	12.7-16.5	%
NET shortwave	148	142-157	W/m^2
Downward longwave	344	344-357	"
Upward longwave	397	389-397	"
NET longwave	-53	-(40-46)	"
NET radiation	95	102-105	"
Downward SW (clear)	248		"
Upward SW (clear)	34		"
Albedo (see above)	13.6		%
NET SW (clear)	214		W/m^2
Downward LW (clear)	324		"
Upward LW (see above)	397		"
NET LW (clear)	-73		"
NET radiation (clear)	141		"
SW cloud forcing	-66		"
LW cloud forcing	21		"
NET cloud forcing	-46		"

Table 2: Same as for table 1 but for the conditions at the surface (SFC)

The simulated globally averaged cloudiness amounts to ca. 60%, Figure 5. The annual variation is small, with a minimum in the boreal summer. Observed data sets vary between 56 and 62% with a tendency to a maximum during the boreal summer. There is in general a reduction in clouds (mainly convective clouds) over land during the summer, probably related to insufficient convective forcing. This is probably also the reason why precipitation is underestimated over land in summer, particularly at middle and high latitudes.

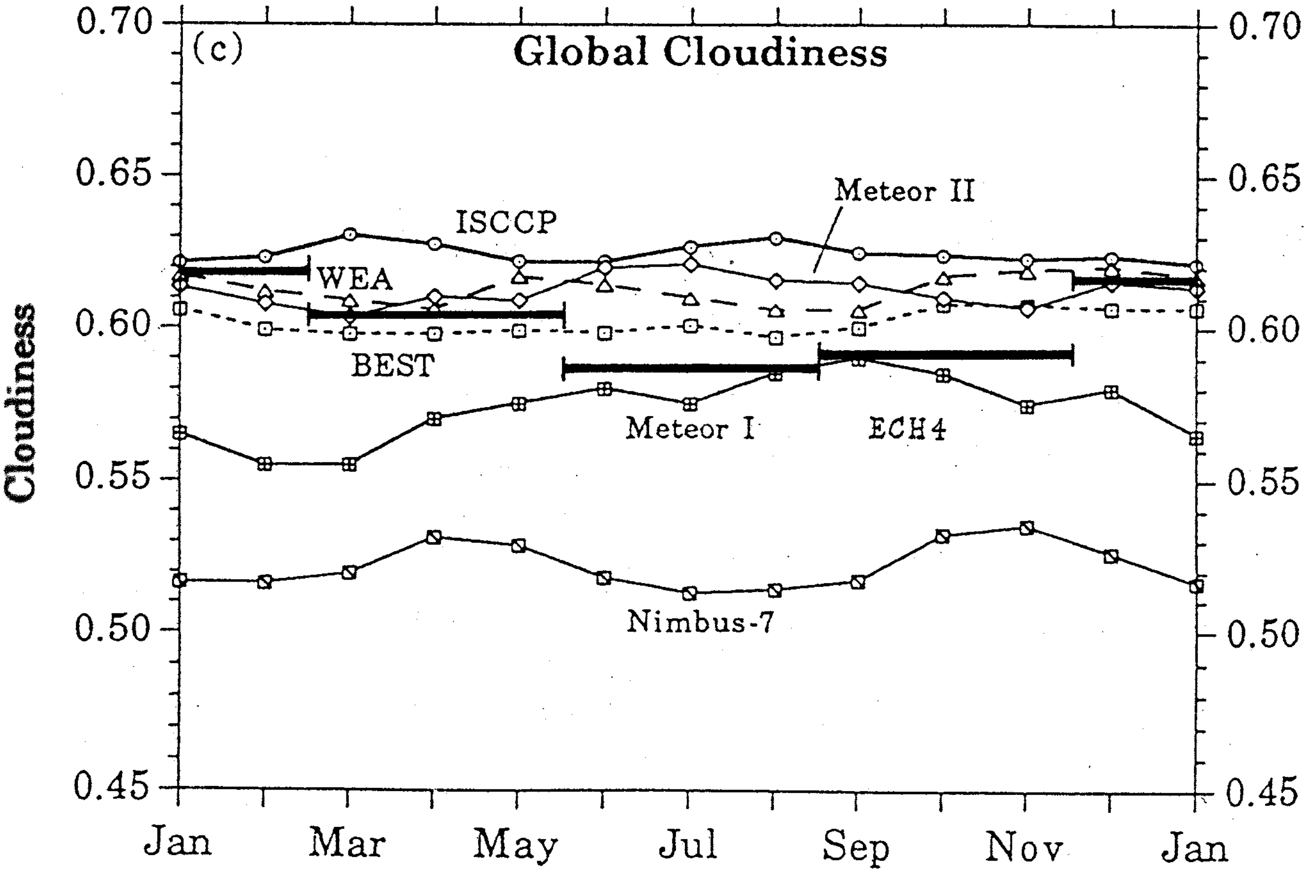
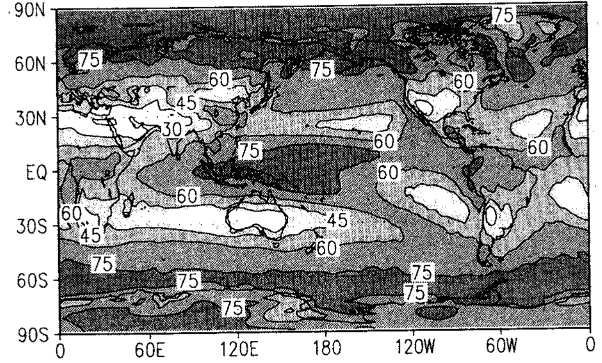


Figure 5: Calculated and observed global cloudiness. For ECHAM 4 seasonally averaged, for observations every months. Annual cycle of cloudiness from ground-based observations of Beryland and Strokina (BEST) (1975, 1980) and Warren et al. (WEA) (1986, 1988) and from satellite-based observations of Nimbus 7, The International Satellite Cloud Climatology Project (ISCCP), Meteor I and Meteor II. From Mokhov and Schlesinger (1994).

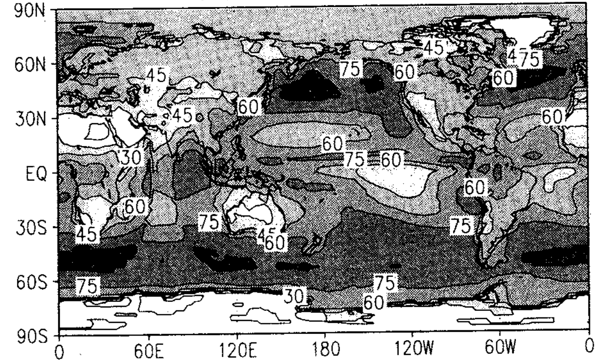
In Figure 6 we compare the annual mean total cloud cover with two sets of observed data, satellite cloud data, ISCCP data (Schiffer and Rossow, 1983) for the years 1983-90 and a surface cloud climatology (Hahn et al., 1994). Reliable satellite data is not available over the landices and close to the poles. Surface observational data is mainly lacking over the southern oceans and over Antarctica. The satellite and the surface dataset are generally in broad agreement. However, over the southern oceans the area of densest clouds can be found at about 50 °S while in the surface based data set, the densest clouds are more around 60 °S. Similarly the surface based data set has more clouds over Canada and Siberia, than the satellite one. It is likely in this case that some cloud types over high latitude land areas in the satellite data set apparently have been interpreted as snowcover. Here clearly the land based data are more reliable. The reason to the latitude difference at the Southern Hemisphere is not very clear. It is interesting to note, though, that the model generated clouds are more in agreement with the surface based data set. There are also differences in the intensity of the cloud cover and it is found that the satellite data set in general has a more intense cloud cover in the storm tracks over the Northern Hemisphere.

ANNUAL MEAN Total Cloud Cover

(a) ECHAM4 (79–93)



(b) ISCCP (83–90)



(c) Cloud climatology from surface (82–91) Hahn et al. 1994

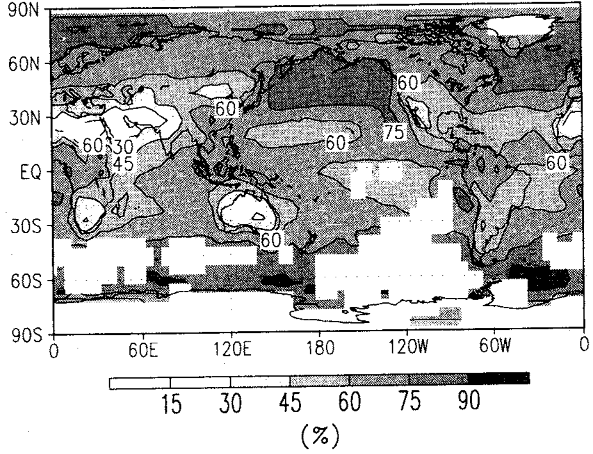


Figure 6: Annual mean total cloud cover. (a) From ECHAM4, (b) from ISCCP for the years 1983-90 and (c) surface cloud climatology from Hahn et al. (1994). Units are given in %.

The systematic errors of the model can be seen in the Tropics. Here in the area of ascending motion the model has more widespread and heavy cloudiness than in the observed data, while in areas of descending motion the cloudiness is much lower in the model than in the observations. This can be clearly seen over the Southern Indian Ocean. As has been discussed by Chen et al. (1995), the most likely reason to this is an overactive Walker circulation in the model, presumably caused by a too efficient convective parameterization (Nordeng, 1994).

4. What can we learn from BALTEX?

The previous sections have clearly demonstrated the fundamental problem we have in both modelling and observing the hydrological cycle. The key issue is the fractal character of practically all issues related to the hydrological cycle. Precipitation can vary significantly over distances of a few kilometers as was so convincingly demonstrated in the many studies by Bergeron (1970), Figure 7. The same is true for clouds as well, as any observation of the sky does remind us about. Evaporation has also a very small scale variability and so has all kinds of surface conditions, such as river run off and the percolation of water into the soil. In spite of all these difficulties there are equally clear indications that the large scale aspects of the hydrological cycle has a well organised structure if we only consider it over large enough areas and over long enough time spans.

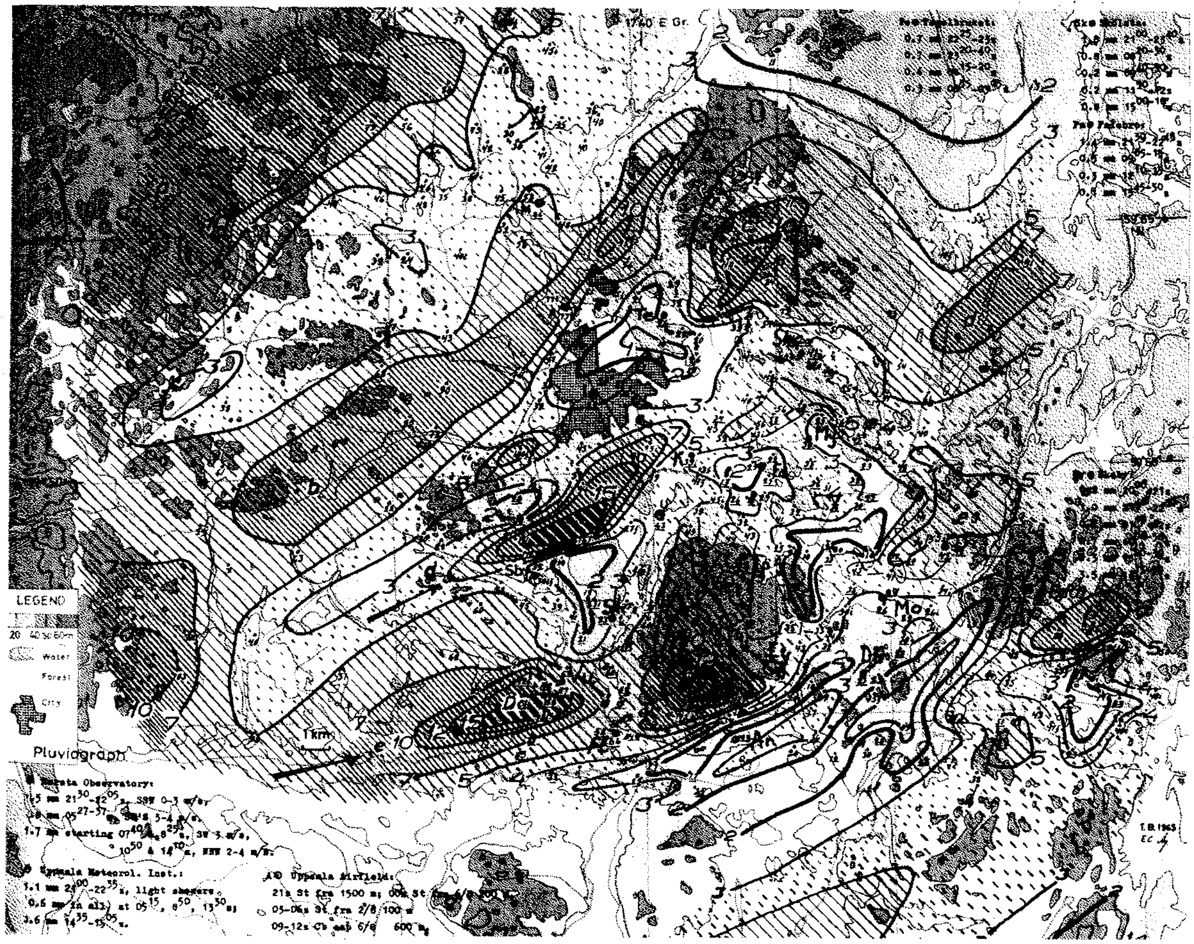


Figure 7: Rainfall distribution during 24 hours (24.6. 18h - 25.6 18h 1962) for a precipitation measurement experimentation area around Uppsala, Sweden. Analysed by T. Bergeron. From Dahlström (1981).

The hydrological cycle is namely strongly constrained by the large scale convergence of water vapour. When this condition is unfavourable, precipitation is not possible. However, where it occurs, precipitation is mostly locally redistributed due to orographic features and to the generation of small scale transient weather systems from convective clouds to meso-scale meteorological systems. Similarily, we know from the positive experience of conceptual hydrological models (Bergström, 1976, 1992) that river run off from large complex catchment areas can be calculated with high accuracy from observations of precipitation and surface temperature. An individual tuning, though, of each basin is required, but that can be accomplished with a relatively small number of parameters and is valid for the typical condition which normally occurs in a given catchment area. All this is telling us that we are dealing with a problem which is predictable in its large scale aspects, but impredictable in its details. The key issue is one of parameterization, that is to express the subgrid-scale processes in terms of the large scale variables.

The GEWEX research program has outlined a number of subprograms in different parts of the world, having vastly different types of hydological processes. The Baltic Sea with its huge drainage basin may be considered as an ideal area for a study of the hydrological processes at high latidudes, encompassing both a typical temperate and boreal climate. Furthermore, it has an important marine component and will create a possibility for the determination of precipitation and evaporation over a large water body.

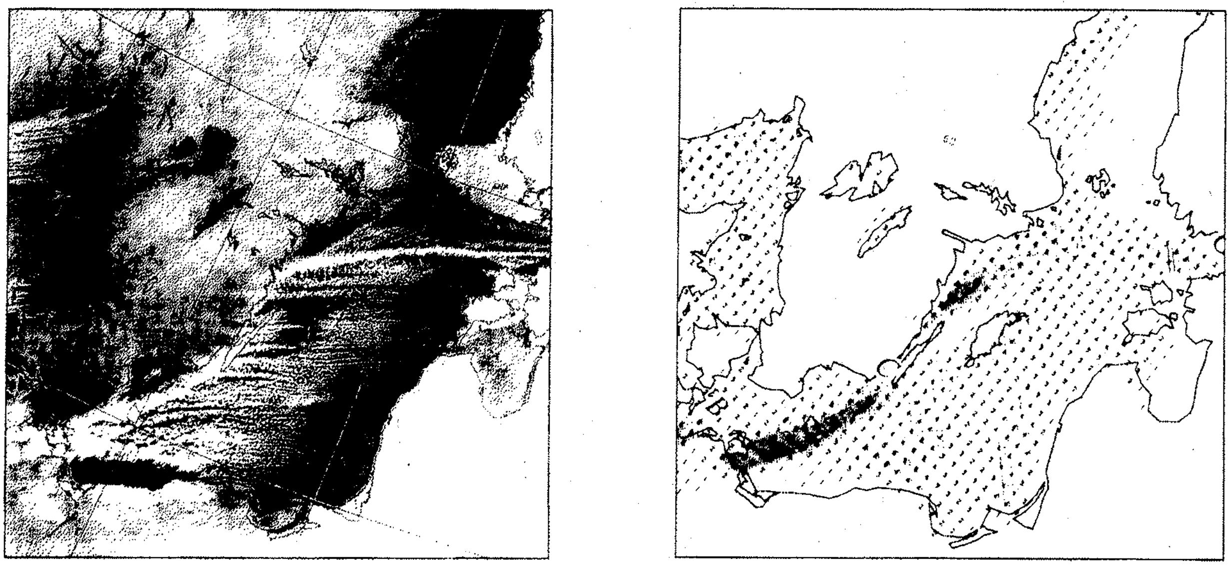


Figure 8: Satellite observed and predicted snow showers for a weather situation with very cold arctic area over the Baltic Sea, 11 Jan. 1987. The prediction is a 18 hours forecast with the HIRLAM model with an horizontal resolution of 20 km. At this high resolution, even the clouds forming over the the lakes in central Sweden and the dissolving clouds downwind of the island of Gotland are correctly predicted as can be seen from the satellite image. (Andersson and Gustafsson, 1994).

The key scientific aspect of BALTEX will be to undertake an energy and water balance for the whole Baltic Sea domain. This will require modelling with advanced high resolution models, capable of resolving meso-scale eddies and systems of organised convection. Of particular importance will be to investigate the relative role of sub-synoptic systems for the hydrologiccal cycle. Presently we do not know the relative importance of such small scale organised motions for the water and energy processes. An example of such a feature is the organised convective systems typically occuring when cold arctic air invades the area during the winter. Figure 8 shows such an episode in January 1987 which successfully has been reproduced in a model experiment by Andersson and Gustafsson (1994). During this episode, stations around the south eastern coast of Sweden obtained huge amount of snow in a short period of time. The air-sea interactions were intense, with a total atmospheric heat transfer (sensible and latent heat) of up to 1000 Watts/m^2, Figure 9.

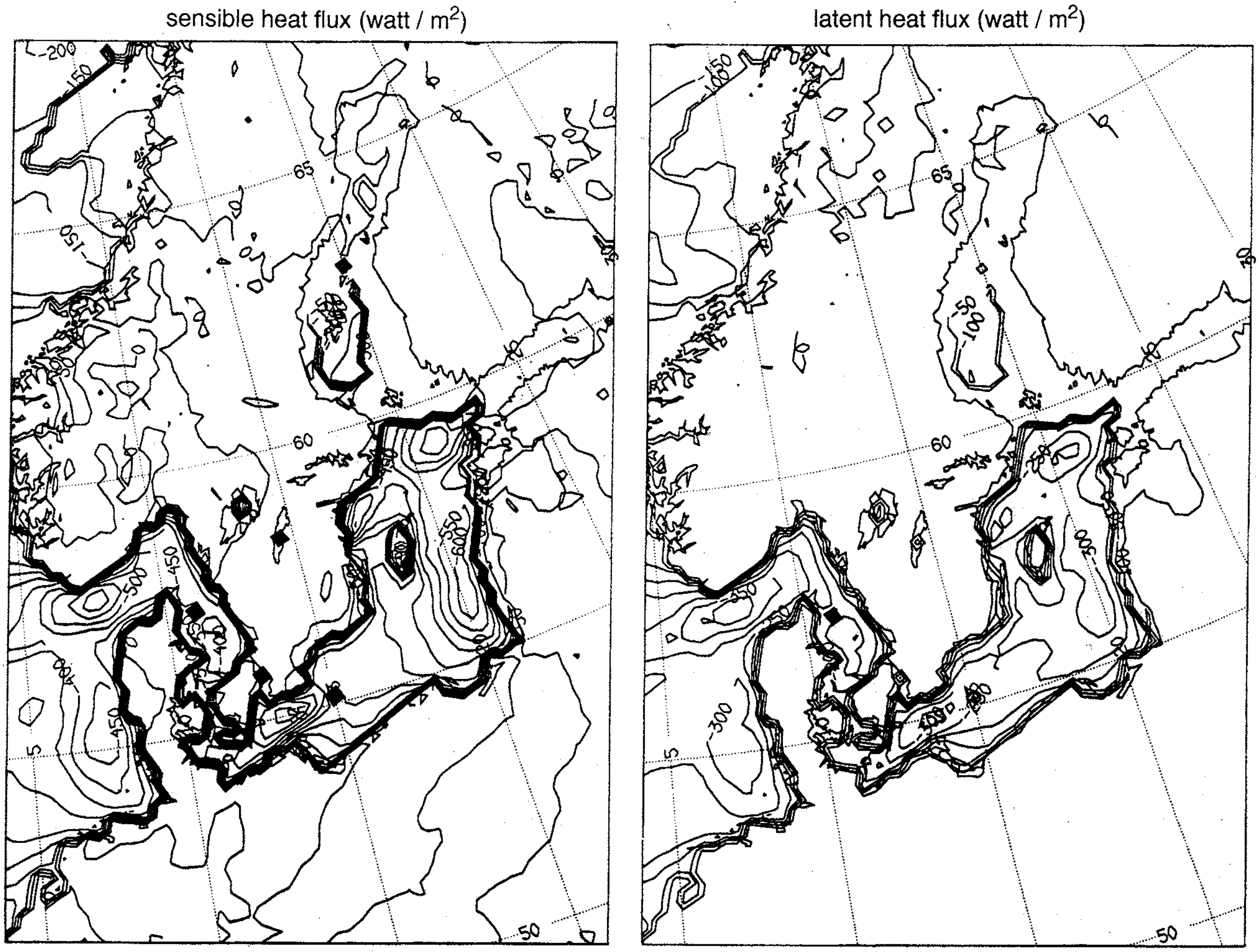


Figure 9: Predicted sensible (a) and latent heat fluxes(b) for the same weather situation as in Figure 8. Note the sharp limits in the fluxes at the ice boundaries. At the very low air temperatures in this weather situation, generally below -20 °C over the whole area, the sensible heat fluxes are about twice as large as the latent heat fluxes. The maximum heat fluxes amount to almost 1000 Watts/m^2. (Gustafsson, 1994, pers. inf.).

Precipitation over ocean areas is very poorly known due to the great difficulties in measuring precipitation at sea. Over the Baltic Sea the combination of high resolution modelling, satellite and radar measurements, supported by special in-situ observations will make it possible to improve this understanding in a significant way. The same is true for evaporation and heat fluxes over the water, quantities which presently are insufficiently known. The Baltic Sea is exposed to violent storms during practically all seasons and has often weather conditions which are typical for the North Atlantic and during winter even Arctic type conditions. We can therefore anticipate that the knowledge gained during BALTEX will be applicable over other ocean areas, where detailed combined observational and modelling studies are not feasible.

5. Conclusions

We have presented some recent results of the simulation of the hydrological cycle by means of a newly developed general circulation model at the Max Planck Institute for Meteorology in Hamburg. It is found that the validation of the model is severely hampered by the large uncertainty of the observational data. There are considerable differences between estimates of precipitation from OLR and from SSM/I data as well as between the satellite and in-situ observations. Cloud cover estimates from the satellite data sets, such as ISCCP data set, differs considerably from cloud cover estimates from surface synoptic data in particular over high latitude land areas. Over many areas the difference between the two different cloud cover estimates is larger than the difference to the model results. It is tried to minimize the problem by using a wide range of observational data such as different types of satellite and in-situ data and by using river run-off data from large catchment areas. Mostly the simulation by the model lies within the range of realizations of climatological estimates, although some limitations, such as insufficient precipitation in summer over middle and high latitude land areas can be determined. Radiation balance, including cloud forcing is in general agreement with ERBE data, but problems remain over ocean areas west of California, Chile and Namibia where the model underestimates the boundary layer stratiform clouds, thus leading to insufficient cloud cooling in these areas.

An improved understanding of the hydrological cycle will require an in depth evaluation of precipitation and cloud processes on small and medium scales, in addition to the large scale global programs. Such studies require a full integration of observational and modelling activities of the kind which is being planned for the BALTEX program. The fractal structure of the different components of the hydrological cycle will in principle exclude a complete physical understanding of all details. This means that the emphasis must continue to be on the comprehensive modelling aspects leading to methods of parameterization which are able to incorporate the effects of organized meso-scale systems. An increased modelling resolution is clearly here a very strong priority and the observational programs should in turn be driven by the modelling work.

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HYDROLOGY AND HYDROENERGETICS OF THE BALTIC DRAINAGE

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ABSTRACT

The annual precipitation, evaporation and runoff of the Baltic Drainage were estimated to be 728, 449 and 279 mm, respectively. As taken over the whole drainage area, the average annual ranges of snow, lake and underground water storages are equivalent to 100, 25 and 85 mm, respectively.

The annual heat energy required to maintain evaporation from the Baltic Sea and its drainage was estimated to be 2.46 x 10^{21} J. Of this energy, 21% is consumed by evaporation from the sea and 5% by lake evaporation.

The amount of energy required to melt all the snow falling on the Baltic Drainage amounts to 0.12 x 10^{21} J per year. This is 1.5 times the annual absorption of thermal energy by the lakes, and eight times the energy required to melt lake ice.

The energy used by the 80 million people of the Baltic Drainage area would be sufficient to melt all the lake ice in a mild winter. The hearts of these people pump blood at the rate of 8000 m^3 s^{-1}, half of the mean runoff into the Baltic.

TWO WATER PARCELS

The most pristine river basin within the Baltic Drainage is located in the northeastern extremity, as a finger pointing towards the White Sea.

The Ileksa Basin with an area of 3950 km^2, comprises forests, wetlands, lakes – all with the common feature that human impact has always been minimal. The forests have never been cut, and wetlands have developed in complete tranquility since the Ice Age.

Today a national park, established in 1991, covers most of the Ileksa Basin. Extensions of the park area have been planned; at the same time there is a risk of unauthorized timber cutting within the park itself.

Let one cubic metre of water flow into the Ileksa River near its source, Lake Kalgazinskoye. When does this water enter the Baltic?

If the water parcel flows the shortest way, it should travel 700 km before reaching the Baltic. However, it has to be mixed in seven lakes, two of which are the largest in Europe. The average residence time of inflowing water in both of these lakes, Ladoga and Onega, is about 12 years (Data Book 1991).

Fig. 1 shows the destiny of the water parcel by assuming a complete mixing in each of the seven lakes. After 20 years, about 40% of the volume of the parcel has reached the Baltic. Some 30% has evaporated, most of this loss occurring from the shallow upstream lakes in the two first summer seasons. The rest, another 30%, will still be part of the water storage of Lakes Onega and Ladoga, two decades later.

Let another cubic metre of water enter the uppermost source creek of River Vistula in the Carpathian Mountains. It has to travel a distance of 1100 km to the Baltic, but practically no lakes delay its journey. One month later, a clear majority of the water molecules has reached the Baltic. A minority has evaporated or been used for farming and by riverside communities.

The average retention time of the rivers in the Baltic Drainage is much closer to that of the Vistula than to that of the Ileksa. The true delay of water precipitating on land is naturally much longer than the retention time within watercourses.

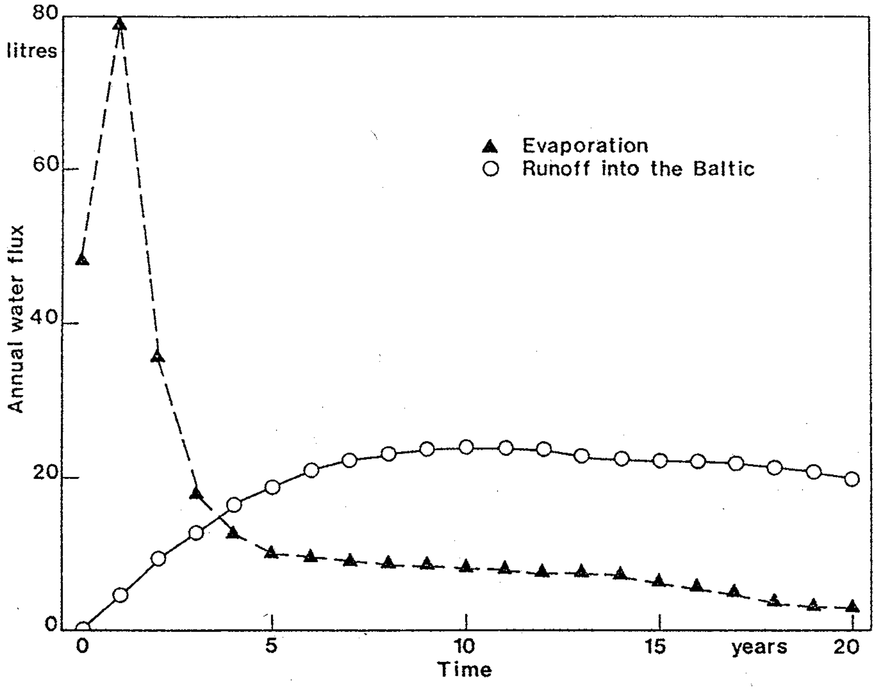

Fig. 1. Annual evaporation and annual runoff into the Baltic from a 1000 litre water parcel entering the Ileksa River.

WATER BALANCE OF THE BALTIC DRAINAGE

The runoff into the Baltic has been analysed thoroughly for the years of 1950–90 (Bergström & Carlsson 1993). The annual average for this period, including inflow into the Danish Sounds and Kattegat, was 15 306 $m^3 s^{-1}$, which is equivalent to 8.85 $l s^{-1} km^{-2}$, 4 830 $km^3 a^{-1}$ or 279 mm a^{-1}.

The total area of the Baltic Drainage was measured from a digitized map. Including the basins flowing into the Danish Sounds and Kattegat the area is 1 732 000 km^2. The contributions of different counties are as follows (%): Sweden 25.3, Russia 18.7, Poland 17.8, Finland 17.5, Belarus 4.9, Lithuania 3.8, Latvia 3.7, Estonia 2.6, Denmark 1.7, Germany 1.5, Ukraine 0.9, Slovak Republic 0.8 and Norway 0.8 (Sucksdorff 1995).

The accuracy of the runoff calculations can be considered good. Data from altogether about 200 discharge stations have been used, representing 86% of the total drainage basin. Runoff from the remaining areas has been estimated on the basis of specific runoff for neighbouring stations (Bergström & Carlsson 1993). Strong coastal gradients of precipitation may induce some uncertainty in these estimates.

The direct groundwater inflow into the Baltic is still largely unknown. Along the shoreline of Finland and most of Sweden, this component is probably insignificant. In the contrast, the contribution of coastal aquifers in Poland and in the Baltic countries should be investigated.

The ten largest river basins are as follows:

River	Basin area (km^2)	Mean flow ($m^3\ s^{-1}$)
Neva	281 000	2 460
Vistula	194 400	1 065
Odra	118 900	573
Neman	98 200	632
Daugava	87 900	659
Narva	56 200	403
Kemi	51 400	562
Göta	50 100	574
Torne	40 100	392
Kymi	37 200	338

These ten basins are shown in Fig. 2. They account for 59% of the total area, and their flow amounts to 50% of the total runoff of the Baltic Drainage.

The true precipitation and actual evapotranspiration of the Baltic Drainage have not been estimated accurately. At least in Sweden and Finland, water balances have been analysed for the period of 1961–90 (Brandt *et al.* 1994, Hyvärinen & Solantie 1995). Authors of these reports, however, have a realistic understanding of the problems encountered in precipitation corrections, and of other uncertainties.

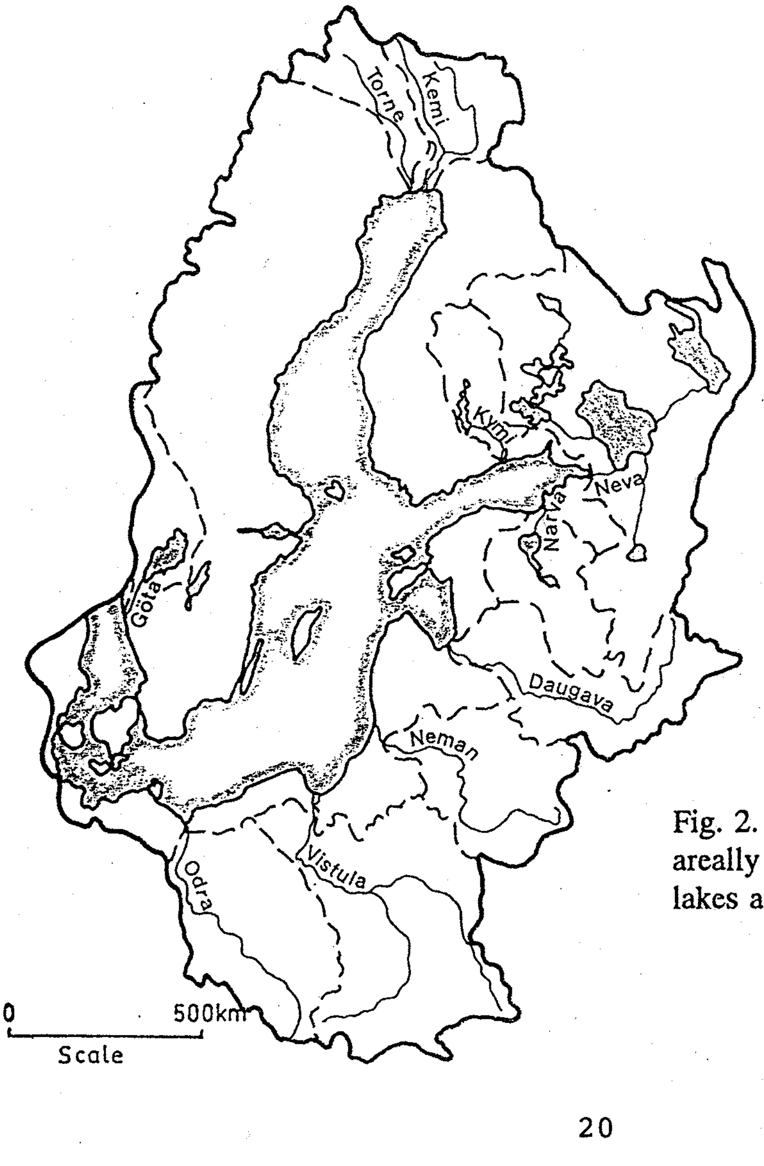

Fig. 2. The Baltic Drainage with the ten areally largest river basins. The ten largest lakes are also shown.

An approximate water balance of the Baltic Drainage can be compiled on the basis of various national and international sources. Precipitation data are abundant, and estimates of actual evapotranspiration have been presented for major river basins (e.g. UNESCO 1978, Petrova & Terzhevik 1992).

Fig. 3 shows the mean monthly values of the water balance components of the whole Baltic Drainage. The annual estimate of corrected precipitation is 728 mm, actual evaporation being 449 mm and runoff 279 mm. The rainiest month is August (82 mm), while evapotranspiration is greatest in June (96 mm) and runoff in May (38 mm).

The annual inflow hydrograph of the Baltic is relatively flat; the greatest monthly runoff is only 2.2 times the lowest value. This is an obvious consequence of the different hydrologic regimes spreading over the area. For instance, Rivers Vistula and Odra often have their highest flood peak in winter months, when many of the northern rivers have their minimum flows.

To make a comparison between two vital flow phenomena, the hearts of the 80 million people living in the Baltic Drainage pump blood at the rate of 8000 $m^3 s^{-1}$. If all of these people would simultaneously perform a hard physical work, their blood pumping could easily double, thus reaching the mean inflow into the Baltic.

The areal distribution curves of runoff and evaporation are shown in Fig. 4. The tenth having the highest specific runoff generates 20% of the total runoff, while the opposite extreme tenth generates only 5%. By far the largest runoff values, in excess of 1000 mm a^{-1}, occur in the two mountain ranges bordering the Baltic Drainage: the Scandic and Carpathian Mountains. In the middle of the Polish plains annual runoff is only 50 – 100 mm (UNESCO 1978).

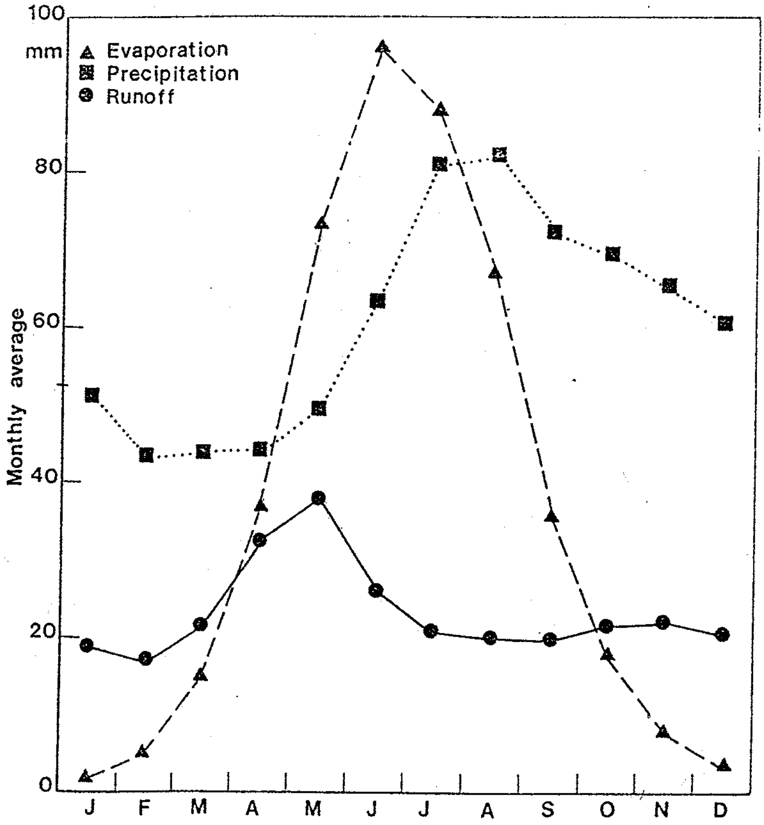

Fig. 3. The average monthly water balance of the Baltic Drainage.

It is interesting to compare the evaporation from the Baltic Drainage with that of the Baltic Sea itself (Fig. 5). When 74 mm evaporates from the drainage area in May, the evaporation from the Baltic lingers near the annual minimum of 10 mm. In January, the cold land surface has a minimal vapor flux, while 44 mm evaporates from the Baltic - more than in July. Even in absolute amounts the Baltic evaporates more in November–February than its drainage. The area of the sea is one quarter that of the drainage.

The total energy required to maintain the total evaporation is about 2.46×10^{21} J a^{-1}. Of this energy, 21% is consumed by evaporation from the Baltic itself and 5% by lake evaporation. The total energy requirement is seven times the annual energy use of mankind. The energy use of the 80 million people living in the Baltic Drainage is equivalent to the energy involved in the evaporation from the Lake Onega.

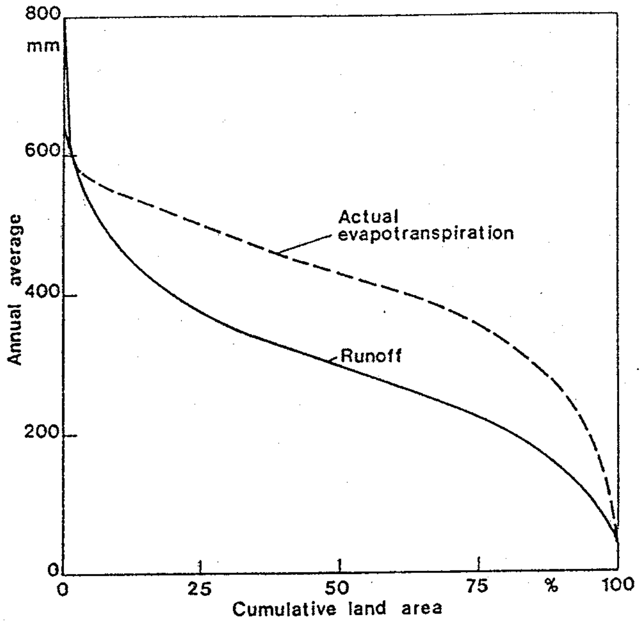

Fig. 4. The areal distribution curves of runoff and actual evapotranspiration of the Baltic Drainage.

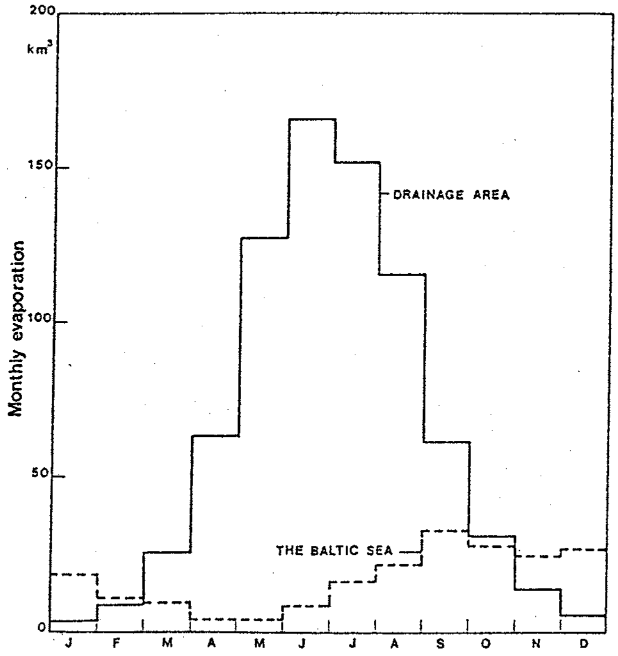

Fig. 5. The average monthly evaporation from the Baltic Sea and its drainage.

STORAGE COMPONENTS

Three seasonally varying storages have a considerable influence on the monthly water balances of the Baltic Drainage:

- the snow cover
- lakes and reservoirs
- underground water (soil moisture and groundwater)

The two first terms can be calculated with reasonable accuracy, and the third can be estimated from the monthly water balance equation. The result is obviously inaccurate, because it contains the errors of all the other components.

Fig. 6 summarises the snow conditions of the Baltic Drainage. The total areally averaged snowfall is 210 mm a^{-1}, 29% of annual precipitation. The absolute amount of snowfall is highest in December, 42 mm, the relative amount in January, 78%.

Snowmelt rates are by far highest in March–May, but a considerable amount of thawing occurs throughout the snow season. Therefore, the average water equivalent of snow on the whole Baltic Drainage barely reaches 100 mm on 1st April, although accumulated snowfall by that date is 160 mm.

The monthly changes of the total water volume of lakes and reservoirs in the Baltic Drainage was estimated on the basis of water level observations and various inventories (e.g. Dysenius & Nilsson 1994, Kuusisto 1992, Kaufmana 1990). This component is dominated by the strong and regular variation in Swedish and Finnish lakes, with a considerable human enhancement by regulation. In Lakes Ladoga and Onega, the seasonal water level variation is relatively slight. In contrast, the absolute water volume of Lake Ilmen varies strongly, the range being almost as wide as that of Lake Ladoga, although the average volume of the latter is a hundred times greater.

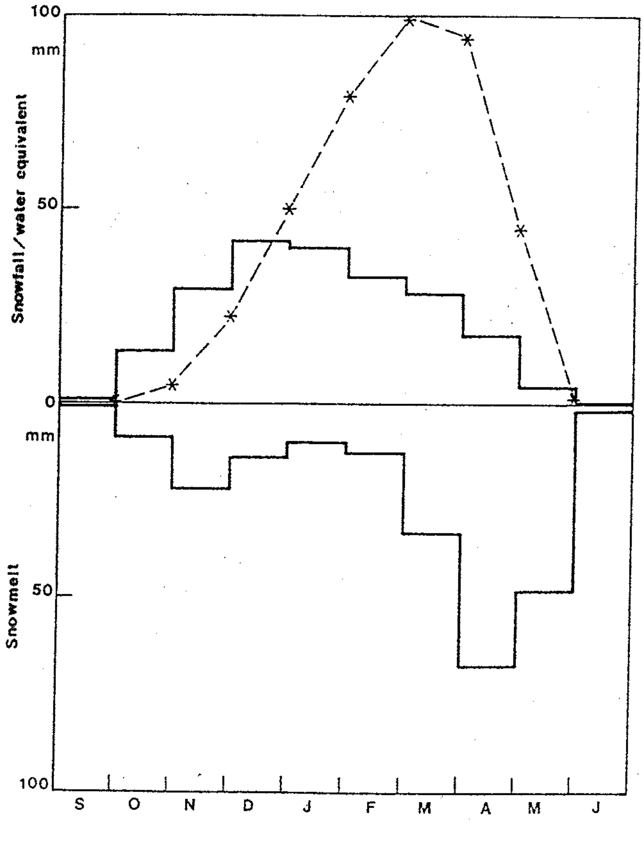

Fig. 6. Monthly snowfall, snowmelt and cumulative water equivalent of snow in the Baltic Drainage.

Because of the different rhythms of the Baltic rivers, the total monthly variations of lake volume remain rather modest (Fig. 7). The largest increase, in May, amounts to only 35 km³, equivalent to 20 mm over the whole Baltic Drainage. In July–September and January–March, the storage declines by 5...10 km³ per month.

The change of underground storage ΔG has been estimated from the equation

$$\Delta G = P - (E + Q + \Delta S + \Delta L)$$

where P = corrected precipitation
E = actual evapotranspiration
Q = runoff
ΔS = change of snow storage
ΔL = change of lake volume

According to Fig. 7, the underground storage is increased during nine months and depletes during only three months, from May to July. The greatest depletion, almost 60 mm, occurs in May.

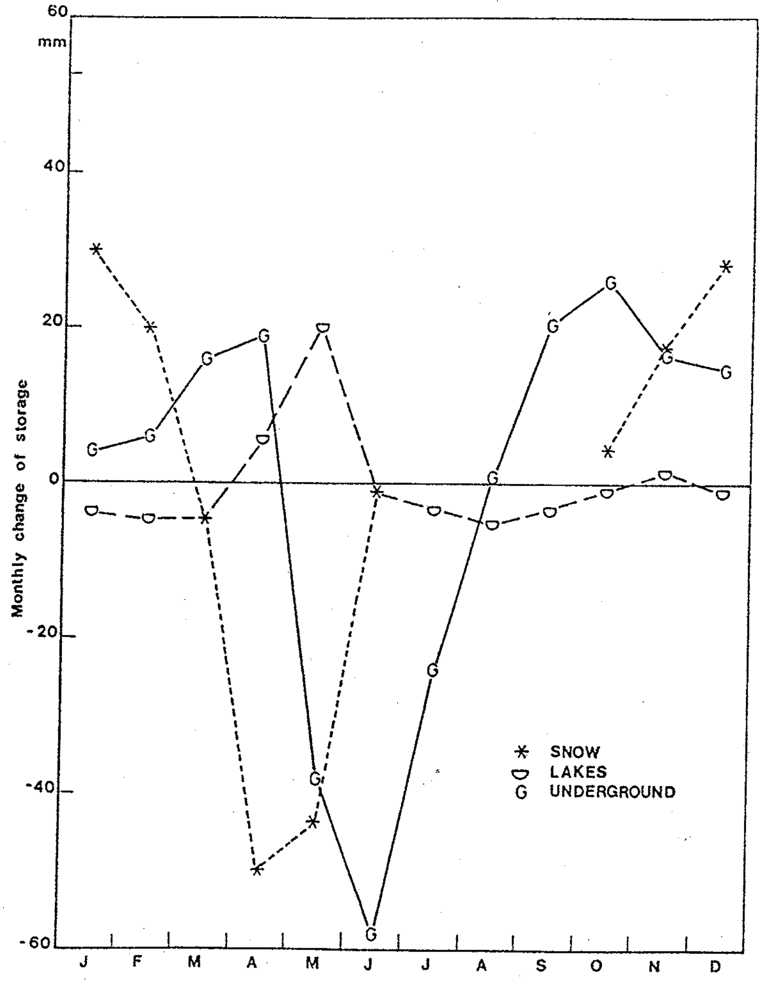

Fig. 7. Monthly changes of water stored in snow cover, lakes and underground in the Baltic Drainage. All values are given as the depth of the water layer over the whole area (1.73 x 10^6 km²).

LAKES

The Baltic Drainage has about 80 lakes with a surface area exceeding 100 km^2. The number of lakes larger than 1 km^2 totals almost 10 000; of them 4300 are located in Sweden and 2300 in Finland. The total area of all the Baltic lakes is estimated to be 123 000 km^2 and their volume 2110 km^3.

Table 1 contains data on ten largest lakes in the Baltic Drainage. Five of them are located in the Neva River basin, all the others being in different basins. Altogether these ten lakes make up 40% of the area and as much as 73% of the volume of all Baltic lakes. Lake Ladoga alone contains 43% of all the fresh surface water in the Baltic Drainage.

Table 1. The ten largest lakes in the Baltic Drainage.

Lake	Area (km^2)	Depth (m) Mean	Depth (m) Max	Volume (km^3)	Residence time (a)	Shoreline length (km)
Ladoga	18 130	50	230	908	12	1 570
Onega	9 890	28	120	280	12	1 810
Vänern	5 648	27	106	153	9.0	1 940
Greater Saimaa	4 380	12	82	53	3.0	14 850
Peipsi	4 300	6	15	25	2.3	
Vättern	1 912	39	128	74	56	642
Ilmen	1 350[1]	7[1]	12[1]	9.4[1]	0.7	
Mälaren	1 140	11.9	61	13.6	2.2	1 410
Päijänne	1 116	16.2	95	18.1	2.3	2 248
Pielinen	960	9.4	60	9.0	1.5	1 372

[1] considerable annual variation; e.g. areal range 600 ... 2100 km^2, mean depth range 3 ... 11 m.

There are only a few large lakes in the southern river basins of the Baltic Drainage. However, the largest lake in Poland, Lake Sniardwy, has an area of 110 km^2, and the total Polish lake area is over 8000 km^2. The largest lake in the German part of the Baltic Drainage is Lake Müritz, 117 km^2 (Data Book 1989).

Most of the lakes in the Baltic Drainage are shallow. The median depth on the lake volume curve is 16 m; only Lake Ladoga has a considerable water volume (45 km^3) deeper than 100 m (Petrova & Terzhevik 1992). Because the water surface of all the largest lakes is below the elevation of 100 metres (Lake Ladoga only 5 m), almost half of the total water volume is beneath sea level (Fig. 8).

The seasonal variation of the total lake volume is 40–50 km^3. This is only 30–40% of the cumulative annual volume variation of individual lakes. The decadal variation, also considering lakes individually, amounts to 200–300 km^3.

The annual amounts of energy involved in lake evaporation in the Baltic Drainage is 14×10^{19} J. This is about the same as energy required to melt all snow from the entire area. The energy required to melt lake ice, equivalently released in the formation of ice, is one tenth of the lake evaporation energy. The annual absorption of thermal energy of lake water is 7.6×10^{19} J, of which 81% is stored in May–July and 95% lost in September–December (Fig. 9).

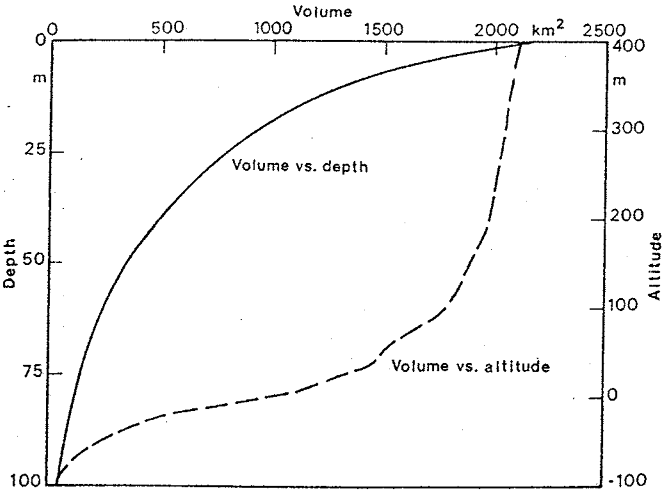

Fig. 8. The distribution curves of the lake volume in the Baltic Drainage as functions of depth and altitude from sea level.

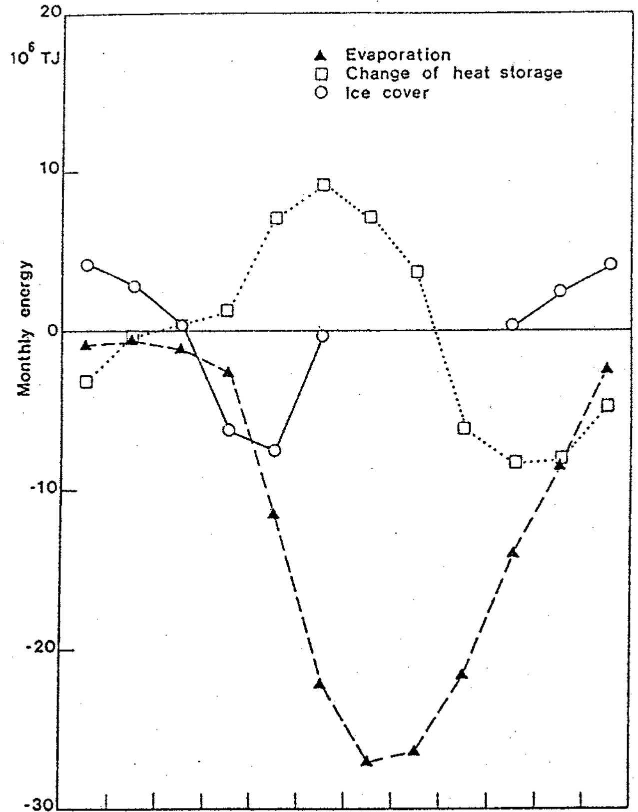

Fig. 9. Monthly amounts of energy required or released in processes of lake evaporation, change of heat storage and formation/melting of the ice cover.

LAND AND SOIL

Forests cover about 54% of the land area of the Baltic Drainage. Agricultural land use amounts to 26%, built-up land to 4% (ECE 1993).

Wetlands are a hydrologically important feature of the Baltic Drainage. Depending on the definition used, they account for 15–25% of the total land area. A considerable proportion of wetlands has been drained and is today classified as forests or agricultural lands.

Detailed data on land use, vegetation and soils will be important to several BALTEX-subprograms. An essential element to receive this data will be the BGIS project, started in January 1995. This project includes e.g. the mapping of land cover and soil types over the whole Baltic Drainage. A digital terrain model and drainage basin subdivision shall also cover the entire area (EDC 1994).

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THE LARGE-SCALE VERTICAL CIRCULATION OF THE BALTIC SEA

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Abstract

In this paper some basic features of the physical oceanography of the Baltic Sea are described. The large-scale vertical circulation, taking place in a huge basin with a vast, narrow and shallow connection to the ocean, is of a type encountered in diffusive, stratified filling-boxes. Freshwater is supplied at the sea surface and waters of higher salinity at greater depths. A rather homogeneous mixture of these waters flows out of the box. The dynamics of the Baltic filling-box is complicated by a number of factors. Firstly, the water exchange across the shallow entrance sills is mainly forced by the weather-related changing sealevel outside the Baltic, giving the water exchange an event-like character and making greater inflows lasting several weeks unpredictable. Secondly, the inflowing waters, being mixtures of low-saline Baltic Sea surface water and salty sea water, span a wide range in salinity depending on a varying degree of recirculation of Baltic surface water in the entrance area. Thirdly, the inflowing waters form a suite of pools of stratified deepwater in the Baltic Sea, connected by dense, gravity forced bottom currents. Fourthly, the dense bottom currents entrain ambient water, whereby their volume flow increases and salinity decreases, until having attained the density of the ambient water whereafter they are interleaved into the Baltic filling-box. Fifthly, the vertical (diapycnic) mixing in the deepwater pools, transporting sea salt upwards, is known only quantitatively but should by different mechanisms ultimately be driven by the wind.

Solar radiation causes buoyancy fluxes of different kinds through the sea surface that together with wind-forced mixing cause a vertically and seasonally varying stratification in the upper layers. The well-mixed surface layer reaches in late autumn and winter down to the perennial halocline whereby some deepwater is eroded. A few new results are communicated. The established estimate of evaporation from the Baltic Sea seems to be high by some 20-25 percent. Freshwater buoyancy from river runoff seems to be distributed over the open sea in pulses, probably by advection of density fronts. This may be of importance for the timing of the establishment of the seasonal pycnocline in spring.

Introduction

The Baltic Sea is one of the major estuaries on earth with a net long-term freshwater supply amounting to about 15,000 m^3s^{-1} and a surface area inside the entrance sills of about 370,000 km^2. Topographically the Baltic estuary has the character of a fjord, with a broad-crested sill located in the mouth. The Belt Sea occupies the crest of the sill. On the oceanic side of the Belt Sea is the shallow Kattegat which, particularly in the eastern part, deepens towards the Skagerrak. On the Baltic side is the Arkona Sea, the westernmost part of the Baltic Sea. In oceanographic literature the Belt Sea and Kattegat, with a total surface area of ca. 42,000 km^2, are often considered to belong to the Baltic Sea. The Sjælland Island splits the flow between Kattegat and the Arkona Sea into two branches, one through the relatively short and partly quite shallow Öresund and the other through a longer channel system constituted by the parallel Great and Little Belts, separated by the Fyn Island, coupled in series with the Fehmarn Belt (Fig. 1). The sill depths of Fehmarn Belt (Darss Sill) and the Öresund are only 18 and 8 metres respectively.

In the vast shallow area in the mouth, outflowing Baltic surface water ($\sim$8 psu) is mixed with quite saline Skagerrak water ($\sim$33 psu) that fills up Kattegat beneath the surface layer. The mixture forms surface layers in Kattegat and the Belt Sea, typically 10-15 m in thickness and of relatively low salinity. However, the salinity of the surface water varies in response to the recent history of in- and outflows and wind-induced mixing and there is a north-south gradient with increasing salinity towards the Skagerrak. Thus, Kattegat and the Belt Sea usually store large amounts of low-saline water in their surface layers (Fig. 2). The circumstance that the thicknesses of these layers are approximately equal to the sill depths of the straits usually implies an efficient blocking of direct inflow of saline Kattegat deepwater to the Baltic Sea. This is one of the major reasons why the salinity of the Baltic Sea is comparatively low.

Using an extremely simple model, where the Baltic Sea is connected to the Kattegat by narrow and shallow channels with frictionally balanced barotropic flow, the flow through the Belt Sea and Öresund and the horizontal mean sea level in the Baltic Sea may be computed astonishingly well when the model is driven exclusively by the observed sea level in Kattegat, see Witting (1954), Stigebrandt (1980) and Omstedt (1990). This clearly shows that the water exchange across the entrance sills of the Baltic Sea is essentially driven by the fluctuating sea level in Kattegat. If the freshwater supply to the Baltic Sea is accounted for in the model, the results change slightly but systematically such that outflows from the Baltic are strengthened and prolonged and inflows are weakened and shortened. However, it should be made very clear that even if the freshwater supply to the Baltic Sea has only a minor effect upon the volume flow through the entrance straits it has a major influence upon the salinity, not only in the Baltic Sea but also in the Belt Sea and Kattegat as described above.

The exchange of salt and water of the Baltic Sea is evidently determined by the salt stratification and the current field on the boundary to the Belt Sea/Öresund. The salinity of the water forced into the Baltic Sea varies quite much, depending upon the previous history of outflows of low-saline Baltic surface water and diapycnic mixing with underlying saltier water in the Belt Sea and Kattegat as described above. In order to compute the volume flow and salinity of the inflow to the Baltic Sea one obviously needs a model that is capable of computing not only volume flows but also the vertical and horizontal salinity distributions in the Belt Sea and Kattegat. Already relatively simple baroclinic models, using only a rough partition of water masses into a few model boxes,

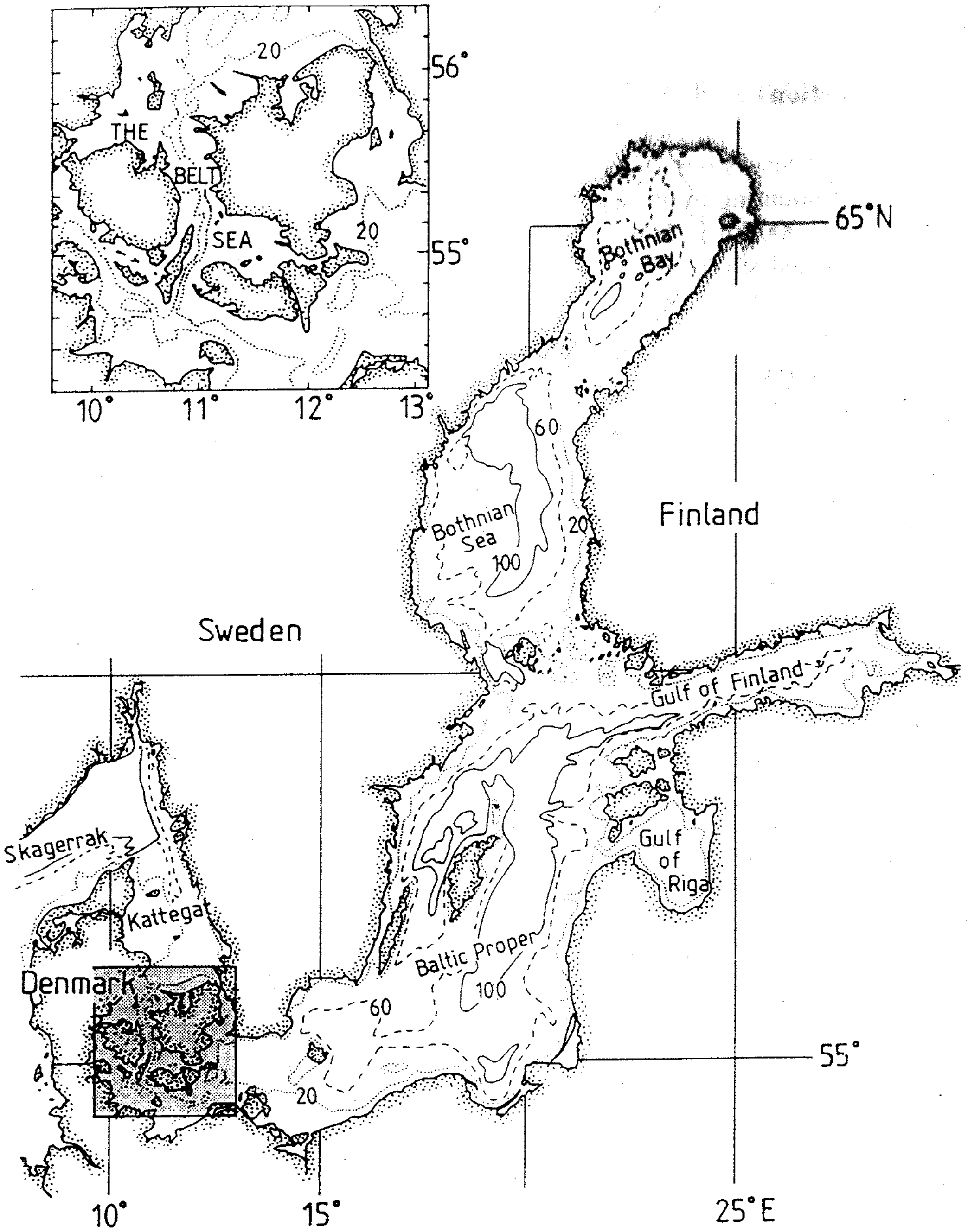

Fig. 1 Bathymetric map of the Baltic Sea.

combined with a barotropic model are able to compute quite realistic inflows.

A smoothed version of the distribution of mean inflows among different salinities computed by such a model is shown in Fig. 3. The most salient feature is that the inflows are distributed over a large range of salinities. Flows contributing to the high salinity end of the distribution occur only very seldom. The classical description of the inflow of salt to the Baltic Sea, due to Knudsen (1900) and others, is an inflow of 15,000 m^3s^{-1} of water of constant salinity (17.4 psu). The fact that the flow rate and salinity of water flowing into the Baltic Sea indeed vary quite much is extremely important for the hydrographical state of the Baltic Sea deepwater because only waters of high salinity are dense enough to penetrate down into and replace the water in the deepest portions of the Baltic proper. Since such inflows are only rarely occurring the deepest deepwater in the Baltic Sea may become stagnant for long periods whereby anoxic conditions develop as described by Fonselius (1969), Fonselius et al. (1984) and others (Fig. 4).

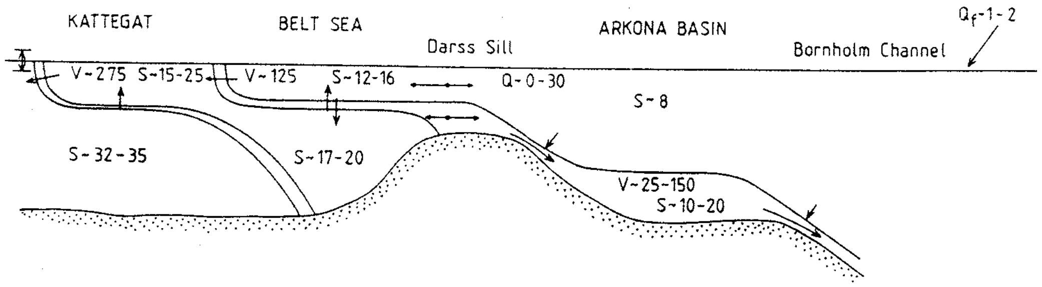

Fig. 2 Typical flows (Q; $km^3 day^{-1}$) and volumes (V; km^3) and salinities (S; psu) of water masses in the Baltic entrance area.

The circumstance that the salinity of inflowing water is determined by the prevailing salinity of the Kattegat and Belt Sea implies that the salinity $S_ö$ of the surface layer of the Baltic Sea is controlled by the factors that forces the dynamics of Kattegat and the Belt Sea. The steady state response of $S_ö$ to permanent changes of the forcings, as computed by a model, are shown in Fig. 5. It appears that $S_ö$ is most sensitive to changes of the freshwater supply to the Baltic Sea and the barotropic forcing. The sensitivity to changes of the regional wind over the entrance area and the salinity of the Skagerrak water seems to be much less.

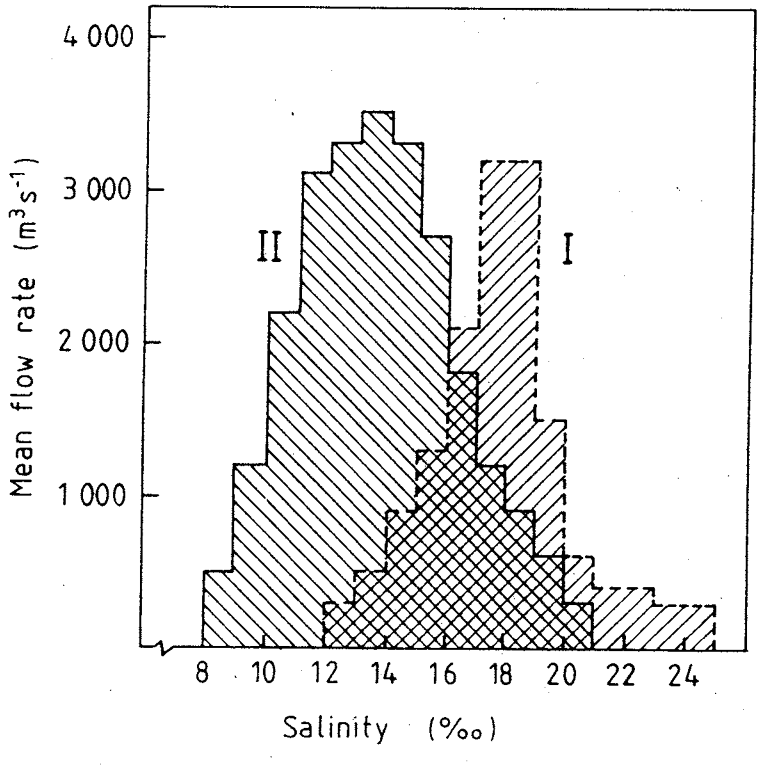

Fig. 3 The distribution of inflows among different salinities at the entrance sills (I) and in the Arkona Sea (II). The distribution I is a smoothed version of model computations (Stigebrandt, 1983) and II is a slightly smoothed version of a distribution computed from historical hydrographical data (Stigebrandt, 1987b).

The inflowing water is denser than the Baltic surface water why the flow takes the shape of a gravity forced dense bottom current, typically 5-10 metres in thickness in the

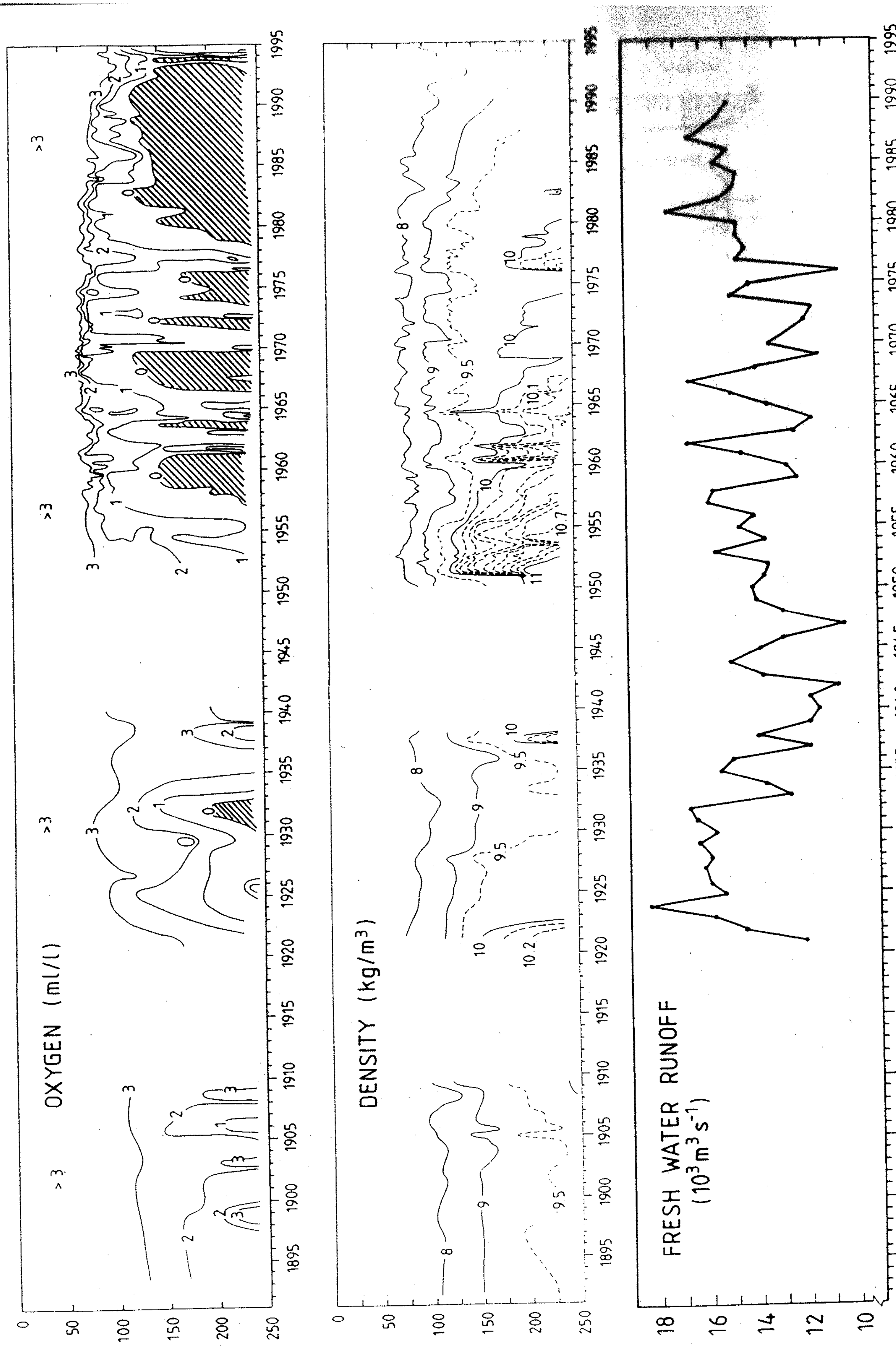

Fig. 4 The development of the density and oxygen in the Gotland Basin in the period 1895-1994 and runoff of freshwater from land in the period 1921-49 (Mikulski, 1982) and 1950-1990 (Bergström and Carlsson, 1993).

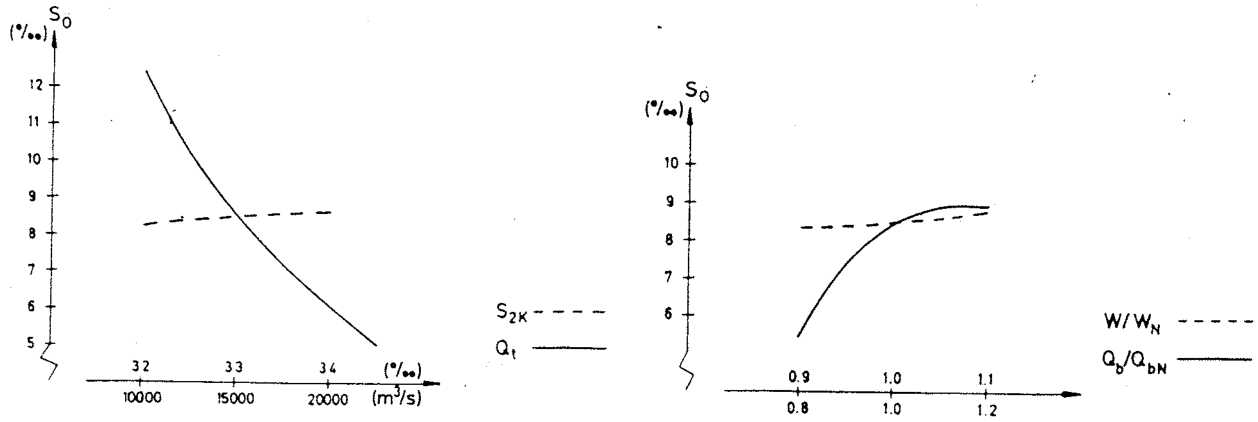

Fig. 5 The steady-state response of the surface salinity $S_{Ö}$ of the Baltic proper to permanent changes of the total freshwater supply to the Baltic (Q_t) and the salinity (S_{2K}) of the Skagerrak water (upper graph) and the normalized mixing wind (W/W_N) and the normalized barotropic flow (Q_b/Q_{bN}) (lower graph). (From Stigebrandt, 1983).

Bornholm Channel, see Petrén and Walin (1976). The bottom current entrains ambient water by which it becomes fresher at the same time as the volume flow increases. The salinity distribution of inflows therefore changes with the distance from the entrance sills (cf. Fig. 3). By topographical reasons, however, there is no continuous bottom current carrying the inflowing, "new" deepwater all the way from the entrance sills to the central parts of the Baltic proper. Actually, most of the transport occurs while the deepwater is stored in dense bottom pools. Dense bottom currents only transport the new deepwater from one pool to the following, like a river transporting water between subsequent river-lakes. The first in the suite of pools encountered by new deepwater is situated in the Arkona Sea. Assuming a baroclinic-geostrophic force balance the flow of deepwater through a pool is self-controlled and may be computed from the vertical stratification.

Superimposed upon the basic filling-box circulation, driven by advective inflows and diapycnal mixing, is a circulation driven by the annual cycle of buoyancy fluxes through the sea surface that has very strong influence on the vertical stratification in the upper layers. In seasons with negative buoyancy fluxes through the sea surface and weak thermal stratification, wind-driven turbulence in the surface layer of the Baltic proper manages to homogenize an about 60 m thick layer. Below this, in the deepwater, the seasonal variations are much weaker and the water is strongly salt-stratified down to greatest depths, starting with very strong stratification (a halocline) in the uppermost about 10 m of the deepwater.

In the deepwater of the Baltic filling-box there is a long-term, approximate balance between advective salt supply by inflowing, new deepwater and upward salt loss by diapycnal mixing, implying that if one of these flows is known also the other is known. The rate of diapycnal mixing has been estimated from the observed inflow, using different kinds of one-dimensional advective-diffusive models, and is accordingly known to at least the same accuracy as the inflow of deepwater. However, from this approach it may be hard to separate the relative contribution to the total diapycnal mixing by mixing in dense bottom currents and by mixing in pools, respectively, although the observed maximal salinity in the different pools provide minimum constraints on mixing in dense bottom currents. From salinity changes during periods without advection, it is possible to obtain estimates of the mixing in pools that are independent of inflow estimates and mixing in dense bottom currents. The detailed mechanics of diapycnal mixing processes are not known very well. This is particularly true for mixing processes in the deepwater pools, that in some way or another should be forced by the wind since astronomical tides are exceedingly small in the Baltic Sea.

The residence time of water in the Baltic Sea, as determined by the ratio between the basin volume and the rate of total inflow, is tens of years which gives the hydrographical state of the Baltic large inertia to short-term variations in the external forcing. The physical state of the Baltic has been recorded during a century, which is about four times longer than the residence time for water and conservative substances, and the most important forcing functions are reasonably well known by measurements since about 1920 although the meteorological forcing is not yet available in useful format for the whole period. Thus, using historical data it should be possible to learn quite much about the response of the Baltic to variations in the forcing functions. Indeed, there are many papers trying to explain observed long-term variations in terms of changed forcing. However, almost all of these seem to be purely qualitative and focus on the variation of one single factor of the forcing that should explain the observed changes of the state. Since the system is quite complex with intricate non-linear interactions it is necessary for such an analysis to be based upon at least a good conceptual understanding or an appropriate model.

Though details may differ, the brief sketch of the dynamics of the Baltic proper given above also applies to the other major sub-basins in the Baltic Sea that all have positive freshwater balances and obtain their deepwaters from the seaward, neighbouring basin. As a result, the salinity in the sub-basins decreases in the direction away from the Baltic proper (Fig. 6).

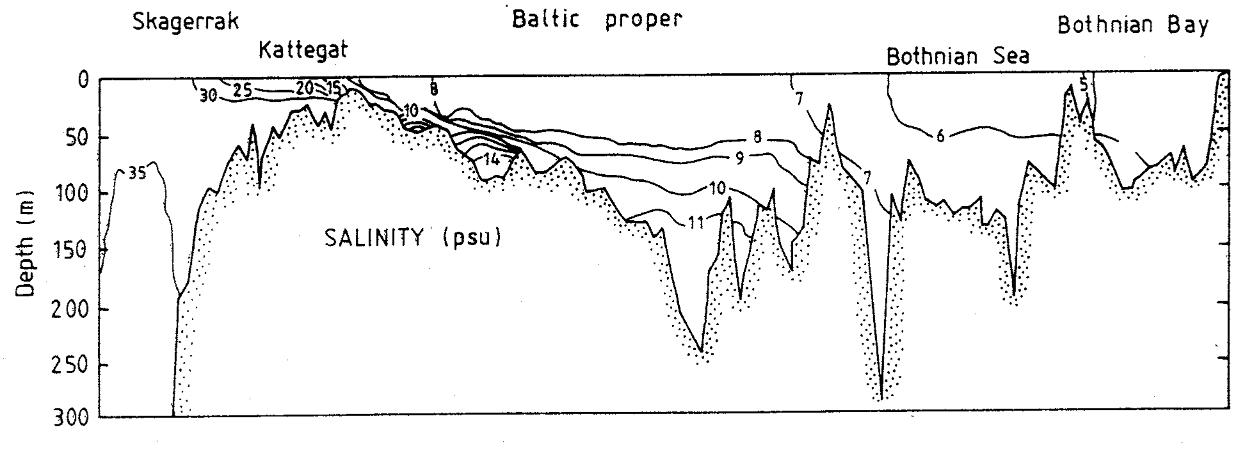

Fig. 6 The distribution of salinity in 1988 in a vertical cross section from Skagerrak to the Bothnian Bay (From Andersson et al., 1992).

The present paper is devoted to a description of the large-scale functioning of the Baltic Sea and the major processes of importance for this. It appears that the majority of oceanographic studies devoted to the Baltic Sea concern globally occurring oceanographic phenomena and processes, like different kinds of wave motions, coastal dynamics et cetera. These will not be mentioned here unless they are believed to be of importance to the understanding of the large-scale dynamics of the Baltic Sea. For rich reviews of earlier work on the Baltic Sea readers are referred to Kullenberg (1981) and, for work on the water balance including in- and outflows through the Belts and Öresund, Jacobsen (1980).

The water balance of the Baltic Sea

From the introductory section it should be clear that the distribution of sea salt in the Baltic Sea is determined in a rather complicated way by the water exchange with the ocean, the supply of freshwater, mixing processes and water exchange between the sub-basins. Knowledge of the different terms in the water balance is fundamental for an understanding of many aspects of both the physical oceanography and the biogeochemistry of the Baltic Sea. The water balance may be discussed starting from the continuity equation for volume which reads

$$\frac{dV}{dt} = Q_F + P - E + Q_2 - Q_1 + TEXP \tag{1}$$

Here t is time, V the volume of the Baltic Sea, Q_F the freshwater supply by runoff from the surrounding land, P the freshwater supply by precipitation on the sea surface, E evaporation from the sea surface, Q_1 (Q_2) outflow (inflow) across the entrance sills and, finally, TEXP the volume change due to thermal expansion. There are also small volume changes of the Baltic Sea due to the postglacial crustal uplift and sedimentation of particles of continental origin that may be neglected here ($<50\ m^3s^{-1}$), c.f. Winterhalter et al. (1981).

The terms on the right hand side of equation (1) span two orders of magnitude. The largest terms are the out- and inflows across the entrance sills, i.e. Q_1 and Q_2. These are typically either 0 or 100,000 m^3s^{-1}, indicating that the flow is momentarily unidirectional but with varying direction, but maximum values as large as 300,000 m^3s^{-1} may occur, see e.g. Jacobsen (1980). The long-term average of the run-off Q_F inside the entrance sills is about 14,150 m^3s^{-1} (1950-1990) but the mean monthly runoff may be in the interval 7,000 - 32,000 m^3s^{-1}, see Bergström and Carlsson (1993) and, for the period prior to 1950, Mikulski (1982). The amplitude of the annual cycle of TEXP is about 1400 m^3s^{-1}, based upon an amplitude of a sinusoidal annual steric sealevel cycle of 2 cm due to local heating/cooling. There are large interannual and annual variations in P and E. The long-term annual mean of P is ca. 7300 m^3s^{-1} (about 620 mm yr^{-1}, Dahlström, 1986) and of E ca. 5800 m^3s^{-1} (493 mm yr^{-1}, Henning, 1988). These values of P and E are, however, generally considered rather uncertain. If the figures for Q_F, P and E given above are correct the long-term net supply of freshwater is about 15,700 m^3s^{-1} to the Baltic Sea inside the entrance sills. As discussed below the rate of evaporation estimated by Henning seems to be overestimated and should probably be reduced by some 20-25%. If so, the long-term mean freshwater supply to the Baltic Sea inside the entrance sills may be as large as 17,000 m^3s^{-1}. It is the ambition of the BALTEX to develop methods allowing for making better estimates of P and E (BALTEX, 1995).

Jacobsen (1980) discussed in detail the different terms i equation (1), paying particular attention to both measurements and computations of the flow through Öresund and the Danish Belts. He concluded that because of the large fluctuating flow component it is almost impossible to determine the long term discharge (i.e. Q_F+P-E) of the Baltic Sea from measurements in the Belts and Öresund. Mattsson (1995) arrived at a similar conclusion from considerations of the precision of current measurements in these channels. Jacobsen (1980) also made a thorough review of earlier attempts to estimate the different elements of the water balance of the Baltic Sea, see also Ehlin (1981) and Mikulski and Falkenmark (1986), the latter appearing in a special volume from the Helsinki Commission on the water balance of the Baltic Sea.

Since P-E and TEXP are quite small compared to the other terms, equation (1) has been used successfully to compute volume changes of the Baltic Sea forced by changes of the sea level h_k in Kattegat and the freshwater supply to the Baltic Sea Q_F. For these computations the term dV/dt is replaced by Adh/dt, where A is the surface area and h the horizontally averaged sea level of the Baltic Sea, and Q_1 and Q_2 are taken proportional to $|h_k-h|$ (Wyrtki, 1954) or $|h_k-h|^{1/2}$ (Stigebrandt, 1980), see also Omstedt (1990). As already mentioned in the introductory section these computations, and early computations made by Bergsten (1933) and Hela (1944), demonstrate very clearly that the water exchange, in terms of volume flows, between Kattegat and the Baltic Sea is mainly driven by the instantaneous sealevel difference between these seas.

From a heat budget that included his evaporation estimates, Henning (1988) found that the Baltic Sea on an annual basis must import about $6.7 \cdot 10^{12}$ W. This should imply, however, that the temperature of inflowing water ($\sim 15{,}000\ m^3s^{-1}$) has to be lowered by about 100 K during the stay in the Baltic Sea! The inevitable conclusion is that Hennings heat budget is in serious error and his evaporation estimates should probably be reduced by some 20-25%.

The dynamics of the surface layer of the sea are intimately coupled to evaporation but also to precipitation by accompanying buoyancy fluxes and there is a mutual feedback between such fluxes and the temperature and salinity of the surface layer. Thus, computations of the rate of evaporation and the other terms in the heat budget should not be done as an isolated task, as in Henning (1988), but using a seasonal pycnocline model that gives the correct feedback on the surface temperature. From such a model, with negligible advective import of heat from the North Sea, the present author obtained a long-term mean evaporation of about 430 mm yr^{-1} for the Baltic proper, cf. Fig. 6 in Stigebrandt (1985) which is only about 78% of the 551 mm yr^{-1} obtained by Henning (1988) for the same area.

The inflow of saline water to the Baltic Sea

The flow rate and salinity of the dense water entering the Baltic proper through Fehmarn Belt and Öresund span wide ranges. From estimates based on different kinds of measurements in the southwestern Baltic proper we know reasonably well how contemporary inflows are distributed with respect to salinity and time. Petrén and Walin (1976) and Walin (1981) made direct, high-resolution transport measurements at about 30 occasions in the dense bottom current in the Bornholm Channel. The rationale for this measurement programme was to obtain the advective forcing needed by an one-dimensional advection-diffusion model with salinity as a space variable, developed by Walin (1977) for the description of estuaries.

A different approach to estimate the distribution of inflows with respect to flow rate and salinity was taken by Stigebrandt (1987b) who assumed that the inflowing water before reaching the Bornholm Channel should form a pool at the bottom of the Arkona Basin. He also assumed that the flow of dense bottom water from the pool and further into the

Bornholm Channel is hydraulically controlled by the pool itself, i.e. by the vertical stratification in the Arkona Sea. Using a tuned formula, derived from integration of the thermal wind equation, the inflow of dense water to the Baltic Sea may then be computed from standard observations from only one hydrographic station. This method should make expensive current measurements in a vertical cross-section superfluous. Statistics of flows into the Bornholm Channel, computed from almost 200 historical vertical density profiles from the western Arkona Sea were presented. A slightly smoothed version of this inflow statistics with respect to salinity is shown in Fig. 3. Quite similar statistics were also obtained by Kõuts and Omstedt (1993) using almost 300 profiles from the eastern part of the Arkona Sea.

At present, the estimates of the inflow statistics based upon historical vertical hydrographic profiles from the Arkona Sea are probably the most reliable. Inflow statistics were used for long-term simulations (20 years) with a one-dimensional advection-diffusion model for the vertical circulation of the Baltic proper (Stigebrandt, 1987a). The model reproduces the main observed large-scale properties of the time-dependent vertical stratification in the whole water column. This can be achieved only if the inflow is well described with respect to the flow distributions in the time and salinity domains respectively. In an experiment the model was run with stationary inflow of water of constant salinity ("Knudsen inflow"). In this experiment the deepwater became almost homogeneous below the halocline. Thus, the fact that the flow rate and salinity of the dense water entering the Baltic Sea span wide ranges is the ultimate reason why the Baltic Sea is strongly stratified also below the halocline.

The inflow statistics determined from the historical hydrographical data from the Arkona Sea show the additional interesting feature, namely that large flow rates are correlated with higher salinities. The explanation for this is as follows. About 37 km^3 of water have to flow into the Baltic to raise the sealevel by 0.1 m. However, most inflow events comprise less than 100 km^3 of water. From the sketch in Fig. 2, showing typical volumes and salinities of water masses in the entrance area, it follows that the water forced into the Baltic usually has rather low salinity. Inflowing waters attain high salinities only when inflow rates are large and persistent (so-called major inflows) and preceded or accompanied by strong wind-driven vertical mixing in Kattegat and the Belt Sea, raising the surface salinity in these seas. Due to the small volume of the surface layer in the Öresund, inflows taking this route may rather quickly attain the salinity of the Kattegat surface layer. Major inflows of water of high salinity occur irregularly and seldom, usually with intervals of several years, see Matthäus and Franck (1992) for a statistical analysis of inflows.

It is recalled that the distributions of inflows in the domains of time and salinity actually are determined by advective and diffusive processes in Kattegat and the Belt Sea. Thus, empirical inflow distributions, like those referred to above, may not be used to predict the response of the Baltic Sea to long-term changes in the external forcing, for instance to climate changes in the net freshwater supply to the Baltic Sea. This emphasizes what has already been discussed above, namely that the prediction of the long-term response of the Baltic Sea to changes of the external forcing requires a model for the stratification in the Belt Sea and Kattegat.

A major inflow of highly saline water occurred in January 1993 when the sealevel in the Baltic Sea rose by about 0.8 metres implying an inflow of about 300 km^3. The inflow through the Öresund is documented by Håkansson et al. (1993) and the flow through the

Great Belt is shown in Liljebladh and Stigebrandt (1995). The latter authors also investigated the Arkona dense water pool shortly after the inflow. Matthäus and Lass (1995) present measurements from the Darss Sill during the inflow and give a good overview of the inflow including effects of the inflow in the Baltic proper. This major inflow in 1993 was followed by additional major inflows in 1994 and the changes of the distributions of density and oxygen are really dramatic, cf. Fig. 4.

Dense bottom pools and bottom currents in the Baltic Sea

The dynamics of the dense water, intruding into the Baltic Sea through the Fehmarn Belt and Öresund, have been studied by several authors. The stratification and flow in the Arkona Basin was observed and discussed by Liljebladh & Stigebrandt (1995) who in particular focused on the question of possible self-control of the deepwater flow by the stratification in the basin. The existence of such a flow control makes possibly to monitor the flow using hydrographical observations from pools of dense water as already mentioned. Several expeditions showed that the predicted pool structure really exists, with a deepening of isohaline surfaces on the Swedish side and an accompanying strong eastward baroclinic current along the northern boundary of the pool. Barotropic currents were partially strong and modulated the baroclinic flow but did not destroy the structure of the pool.

Several authors have discussed and modelled the dynamics of the dense bottom currents in the Bornholm and Stolpe Channels, e.g. Pedersen (1977), and Lundberg (1983). Rydberg (1980) considered rotational critical flow and hydraulic control in the Stolpe Channel. Gidhagen and Håkansson (1992) suggested that there is upstream influence from the Bornholm Channel upon the Arkona deepwater pool. Stigebrandt (1987a) developed a simple model for an entraining dense bottom current that was tuned to give a reasonable dilution of the inflowing deepwater. Results by Krauss and Brügge (1991), using a 3-D numerical circulation model, suggest that windinduced barotropic flow modulates the deepwater flow in the Stolpe Channel.

It is well-known that the inflowing dense water entrains ambient water by which the volume flow increases and the distribution of flows among different salinities changes. Much of the diapycnal mixing in the Baltic proper is actually done before the dense water is incorporated into the deepwater pool of the Baltic proper, cf. Fig. 3 that shows how the distribution among salinities of the inflowing deepwater changes from the entrance sills to the Arkona Basin. Estimates of diapycnal mixing performed by dense bottom currents has been made by e.g. Pedersen (1977), Rydberg (1978), Stigebrandt (1987a,b) and Kõuts and Omstedt (1993).

Even if we during the last 20 years have learned a lot about the dynamics of the flow of dense water, both in dense pools and in the channels between pools, much more has to be learned before reliable models may be constructed. The study of the dynamics of through-flow of dense water in pools has just started. We have to learn how to parameterize diapycnal mixing, entrainment included, in dense bottom currents. If a dense bottom current is not thoroughly mixed but stratified in its upper parts, the top layer having the lowest density may be lost from the current when the ambient density, during the descent of the current, becomes equal to the density of the layer. This process, called detrainment by Carmack (1986), is probably an important feature of dense bottom currents in the Baltic Sea. A field program should be designed to study this. However, because of the unsteadiness of the flow of dense water, due to modulating barotropic flows as discussed above, it may be advantageous to use tracer studies as a complement to hydrographic measurements for studies of entrainment and mixing. The Bornholm and Stolpe Channels should be suitable places for studies of detrainment and mixing processes in dense bottom currents.

Interleaving of inflows into the Baltic proper - halocline ventilation

In the Arkona Sea some of the new deepwater is entrained into the surface layer, when the surface layer is deep and the wind is strong, as observed by e.g. Omstedt (1987) and Liljebladh and Stigebrandt (1995). However, interleaving into the Baltic deepwater pool seems to be the normal fate of the inflowing dense water. Most of the water is interleaved in the halocline region that thus is well ventilated, cf. Fig. 7. This is also clearly illustrated by the oxygen plot in Fig. 4 by the fact that anoxic conditions do not expand higher in the water column than about 120 m below the sea surface. Replenishment of the deeper parts of the deepwater occur more seldom and mostly in connection with so-called major inflows, cf. Fig. 4. The final incorporation of recently interleaved parcels of dense water into the Baltic proper deepwater has been studied by Kõuts and Omstedt (1994) using high resolution field observations.

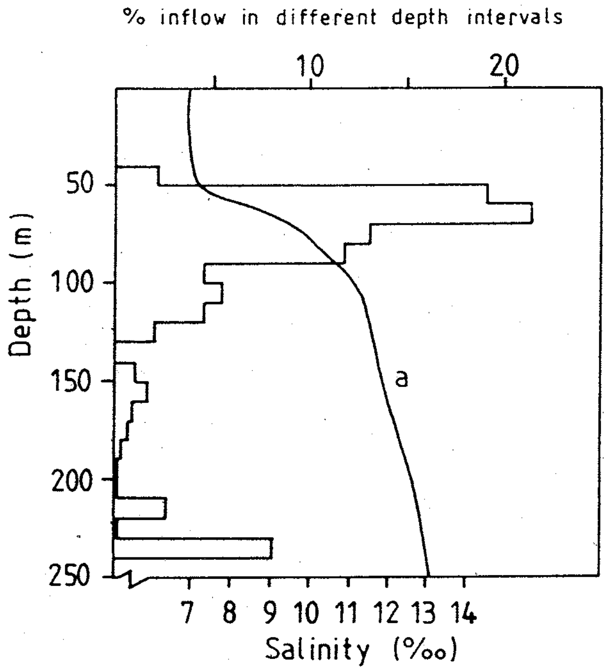

Fig. 7 Computed mean interleaving of new deepwater into different depths of the Baltic proper and "a" is a typical vertical salinity profile (from Stigebrandt, 1987a).

Diapycnal mixing beneath the seasonal pycnocline

Even if there is an approximate long-term advective-diffusive balance there are short term salinity variations in the deepwater because of temporary imbalances in the advective supply of deepwater, tending to increase the salinity, and diffusive flows that tend to decrease the salinity. There was an extremely rapid decrease of the salinity in the Baltic proper during the eighties and in the beginning of the nineties, in particular in and below the halocline. Samuelsson (1995) concludes that the reasons for this were both an increased mixing in the deepwater and a strongly decreased inflow of water of high salinities, the latter probably caused by the anomalously high freshwater runoff from land during this period (cf. Fig. 4). A comparison between the periods 1922-32 and 1977-90 suggests that the high freshwater supply by runoff was not the only external factor of importance for the great salinity decrease during the latter period.

The magnitude of the diapycnal mixing below the seasonal pycnocline in the Baltic proper is known reasonably well by estimates using budget methods. However, since the mechanics of diapycnal mixing are generally poorly known it has to be rudimentary parameterized in models. Assuming that the vertical diffusivity κ is proportional to the inverse of the buoyancy frequency N (i.e. $\kappa=\alpha N^{-1}$) Stigebrandt (1987a) determined α by tuning the modelled long-term development of salinity in the deepwater of the Baltic proper using a time-dependent one-dimensional (vertical) advection-diffusion numerical model that also includes a model for an entraining dense bottom current. The value of α was found to be about $2 \cdot 10^{-7}$ [m^2s^{-2}], a value also used by Omstedt (1990). Svansson (1980) used the observed salinity decrease during a period of stagnation (no advective inflow) in the Gotland Deep. The vertical diffusivity computed by him is in accordance with $\alpha=2$ which thus seems to be a representative α-value for mixing in the deepwater pool of the Baltic proper. Rahm (1985) used the one-dimensional advection-diffusion model with salinity as a space variable by Walin (1977). In the salinity interval 8-12 (psu) his κ-values are well described as proportional to N^{-1} with $\alpha \sim 3.5$-5. The difference between the results of Rahm and Stigebrandt may be explained by the circumstance that Rahm's model also includes mixing performed by dense bottom currents why this mixing is treated separately in the model by Stigebrandt.

It is most probable that the diapycnal mixing also beneath the seasonal pycnocline in the Baltic Sea ultimately is driven by the wind. Kullenberg (1981) found indications for this, see also Matthäus (1990) who gives a review of papers on mixing across the halocline in the Baltic proper. Thus, the α-value determined above may be regarded as a climatological mean value but one should expect at least a seasonal variation in response to the seasonal variation of wind speeds. A first step towards a better description of the vertical diffusivity in the deepwater would then be to investigate the seasonal variation of α. The ultimate goal, however, is of course to find the energy paths between large scale motions and the small scale processes that actually perform the mixing. One question is then whether or not it is necessary to describe the whole energy cascade or if one may use parameterizations of the small scale processes as functions of e.g. N and W (wind speed).

A basic problem with small-scale turbulence and diapycnal mixing in the stratified sea is that these are not directly coupled to the shear of the large-scale flow field. At the present level of understanding of diapycnal mixing below the seasonal pycnocline in the Baltic Sea, the main question is to find the sources and paths for the energy sustaining the turbulence. As discussed above it appears almost certain that the wind is the ultimate energy source for turbulence in the deepwater. It is also very likely that the energy transfer down into the deepwater is by internal waves. There are several mechanisms that may generate internal waves in the sea. Near-inertial internal gravity waves are excited by inertial currents in the surface layer, c.f. Krauss (1972) and Mälkki (1975). Since inertial currents were first observed in the thirties (Gustafsson and Kullenberg, 1936) it has become clear that they are prominent features of the surface layer in the Baltic Sea, see Kullenberg (1981). Internal waves may also be generated by resonant interaction with wind-waves on the sea surface, by interaction with long barotropic waves at sloping bottoms (topographical generation), by advection of windstress fluctuations along the sea surface and by extraction of mean current shear.

Because of convergence and divergence of wind-driven flows the coastal boundary is more active than the open sea with respect to generation of vertical motions. The coastal boundary is therefore expected to be more active than the open sea with respect to internal wave generation and diapycnic mixing in the deepwater, e.g. Shaffer (1979). However, the baroclinic coastal boundary layer is only 5-10 km wide in the Baltic proper (Walin, 1972) and only along a small fraction of the coasts of the Baltic proper is the deepwater, delimited upwards by the perennial halocline, that close to the shore (cf. Fig. 1). Thus, only in quite limited parts of the Baltic proper should wind-forced coastal dynamics be able to directly excite mixing in the deepwater. Most of the mixing in the deepwater of the Baltic proper should therefore be forced and performed in the open sea.

In the ocean, tides may be the dominating energy source to the turbulence, at least in the deepwater, and it may be hard to separate the contributions to diapycnal mixing from winds and tides. If we may understand and describe how the wind transfers energy to small-scale turbulence and diapycnal mixing below the seasonal pycnocline in the Baltic Sea this should be of very great value also for understanding diapycnal mixing in the ocean.

Dynamics of the surface layer

Fluxes of heat and freshwater through the sea surface create together with wind mixing a specific dynamical regime in the surface layer of the sea that is capable to establish and remove stratification close to the sea surface. The dynamical effects of heat and freshwater fluxes are best described in terms of local buoyancy fluxes B given by

$$B = g\left(\frac{\alpha}{\rho C_p} H + \beta F S\right) \qquad \textit{where} \quad \alpha = -\frac{1}{\rho}\frac{\partial \rho}{\partial T}, \quad \beta = \frac{1}{\rho}\frac{\partial \rho}{\partial S} \tag{2}$$

Here H is the local heat flux through the sea surface, F is the local freshwater flux and T, S and ρ are temperature, salinity and density respectively of the surface water. The freshwater flux F equals q_F+P-E where q_F is the contribution by runoff per unit surface area A ($q_F=Q_F/A$) and P and E are local values of precipitation and evaporation. The heat flux is computed from $H=H_s-H_b-H_c-L\cdot E$, where H_s is the absorbed solar radiation, H_b is the effective longwave back radiation, H_c is the sensible heat flux, L·E the heat loss due to evaporation E and L is the latent heat of vaporization of water. Monthly means of H_s for the Baltic at 54, 57 and 60°N are given by Dera (1983). The fluxes H_b, H_c and E may be computed from expressions given by e.g. Gill (1982) provided that air and sea temperatures, air humidity, cloudiness and wind speed are known. Evaporation E, for instance, is computed from $E=\rho_a C_e W(q_s-q_a)$ where ρ_a is the density of air, W the wind speed, C_e an empirical coefficient, q_a the specific humidity of air and q_s the specific humidity at the air-sea interface (assumed to be the saturation value at T). Exchange coefficients for heat and water vapour are given by Smith (1980) - the values used by Henning (1988) are appreciably greater than Smith's values and this may be the reason why Henning probably overestimated evaporation from the Baltic Sea as discussed earlier in this paper. The BALTEX field experiment on air-sea interaction will make possible validation of methods to estimate evaporation at sea.

There is a variety of globally applicable dynamic models for the well-mixed surface layer of the sea, usually called seasonal pycnocline models. These are forced by buoyancy fluxes through and windstress on the sea surface. The perhaps most commonly used model is the so-called K-ϵ model, see e.g. Mellor & Durbin (1975), Svensson (1979) and Omstedt et al. (1983). Simpler integrated model of the Kraus - Turner type are also in common use. The present author added to the development of this type of model by the inclusion of rotational constraints upon the vertical penetration of turbulence during neutral or positive buoyancy fluxes through the sea surface and applied the model to the Baltic proper (Stigebrandt, 1985). The two kinds of models compute almost identical seasonal development of the surface mixed layer. An observation of general interest of the erosion of a thermocline by strong shear of inertial waves in the Baltic Sea is described by Krauss (1981).

It is obvious that local evaporation and precipitation effects the sea surface instantaneously, but how is the freshwater Q_F from river runoff distributed over the sea surface? Eilola (1995) found that during the PEX (the Patchiness EXperiment in the open Baltic proper in the spring of 1986) when the local precipitation was negligible, the freshwater buoyancy came in pulses, probably connected to front passages. Thus, the freshwater buoyancy from runoff certainly spreads over the whole surface of the Baltic proper but the spreading pattern is complicated why it at present is not possible to formulate a simple connection between the supply of freshwater buoyancy to a certain point in the sea and the freshwater supply by runoff to the Baltic. However, horizontally integrated seasonal pycnocline models compute quite realistic evolutions of the salinity field in the Baltic proper using the freshwater flux by runoff from land without any time lag. The reasons for the good results may perhaps be found in the weak seasonality of Q_F and the large time constant of the Baltic proper surface layer.

Because of the relatively low salinity the surface water in the Baltic Sea has maximum density at about the temperature 2.5°C, implying that the heat expansion coefficient α changes sign at this temperature. Cooling below this temperature should thus produce lighter water and heating produces denser water. However, since the numerical value of α is quite small at temperatures in an interval around the temperature for maximum density, freshwater buoyancy fluxes are in this interval quite important for the evolution of the dynamics of the mixed layer at the sea surface, including the establishment of the spring thermocline, as discussed in detail by Eilola (1995).

A seasonal pycnocline model computes the different terms in the heat budget of the upper layers in the sea. This implies that this kind of model is a good tool to compute heat budgets since the resulting temperature and salinity stratification can be used as an extra check of the computations. The present author extracted and presented the seasonal (monthly means) heat budget for the Baltic proper (Stigebrandt, 1985). The estimated annual evaporation is only about 78% of that estimated by Henning (1988). As already pointed out in the section on the water balance, the heat balance by Henning requires an unrealistically large advective heat import from the North Sea while the budget in

Stigebrandt is balanced without advective heat import. It is strongly recommended that oceanographic circulation models are used to estimate heat budgets (and evaporation) for parts and the whole of the Baltic Sea. High resolution 3D-models may be especially interesting to use for studies of effects of horizontal inhomogeneities like e.g. those due to coastal upwelling. In a longer perspective coupled atmosphere-ocean models will of course be used.

When the sea surface becomes ice covered the sea becomes thermally insulated and evaporative and other buoyancy fluxes are radically changed. An ice-cover accumulates precipitation in the form of snow which affects the thermodynamics. Fluxes of momentum and mechanical energy from the wind are effectively stopped if the ice is land-fast. Correct descriptions of sea ice and possible snow cover are necessary for computations of the penetration of solar radiation and the heat flux through the sea surface. The dynamics and thermodynamics of sea ice are discussed in Omstedt et al. (1994, 1995). These reports also contain extensive lists of references.

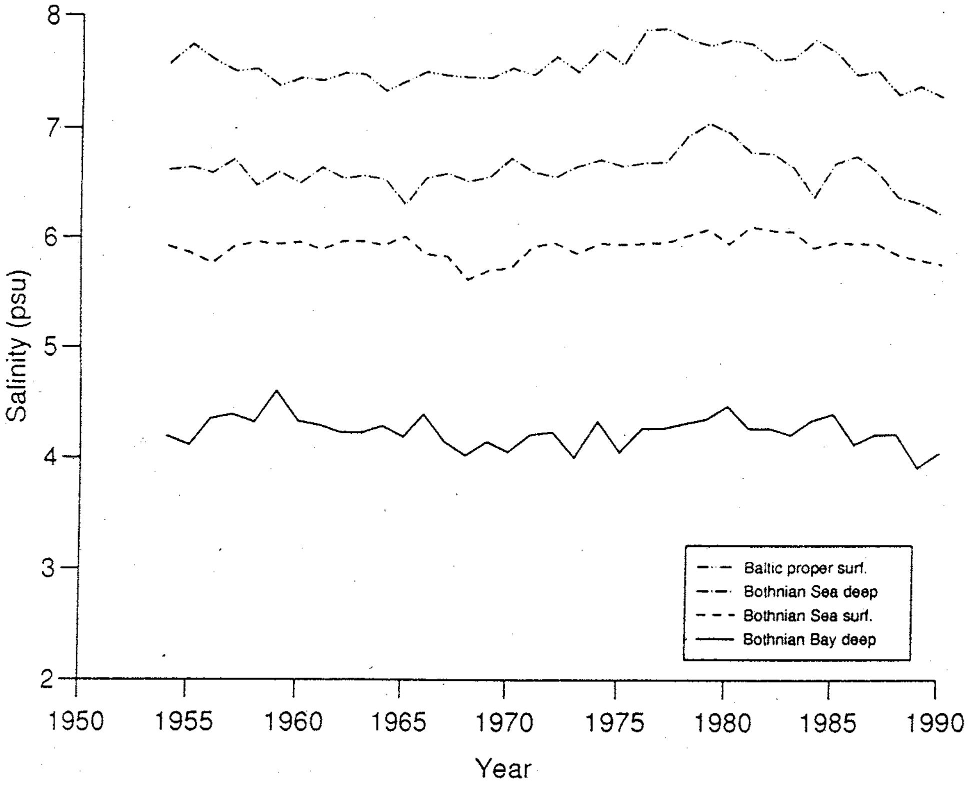

Fig. 8 The annual average of the salinity in the Baltic proper (surface water), the Bothnian Sea (surface- and deepwater) and the Bothnian Bay (deepwater). From Samuelsson (1995).

Water exchange between the different sub-basins

The Baltic Sea is built up by a number of major sub-basins connected by sea straits. All the major sub-basins obtain their deepwaters from the seaward, neighbouring basin. The close connection between the salinity of the deepwater in one basin and the surface salinity in its seaward neighbouring basin is clearly seen in Fig. 8. Since all the major sub-basins have positive freshwater balances the salinity in the sub-basins decreases in the direction away from the Baltic proper, with salinity jumps across the straits and only quite small horizontal salinity gradients within the sub-basins, cf. Wulff and Rahm (1989). The magnitudes of the exchange of water and salt across the different straits are reasonably well known from budget calculations using freshwater and salt, see e.g. Wulff and Stigebrandt (1989) and Yurkovskis et al. (1993).

The dynamics of the straits may differ depending on the magnitudes of the barotropic and baroclinic forcing and the influence of rotational effects. Ehlin and Ambjörn (1977) analyzed the water exchange through the Åland Sea and Marmefelt and Omstedt (1993) discussed the water exchange of the Gulf of Bothnia. In Omstedt (1990) the flow between the major sub-basins is modelled as barotropic. It appears that so far no attempts have been made to describe the inflows of new deepwater into the subbasins as functions of time and salinity.

Final remarks

Prediction of the response of the Baltic Sea to changes in the external hydrological and meteorological forcing requires that the relevant physical processes are identified, understood and well described in models constructed to compute the response. Apparently there is no single model that may be used to compute all kinds of response on all temporal and spatial scales.

In general it may be assumed that the correlation between the state of two points on the same vertical level in the open sea increases with time. In fact it was shown by Wulff and Rahm (1989) that the Baltic proper is fairly homogeneous in the horizontal on long time scales (from the seasonal and longer). Thus, to describe the state of the Baltic on long time scales requires time series of vertical profiles from only few places. This implies that models for the long-term response of the Baltic to changes in meteorological and hydrological forcing can be tested using available data. However, if one wants to test predicted response on small time and spatial scales there are no data available, perhaps with only one exception - the PEX data set (obtained in the central Baltic proper during the Patchiness EXperiment in 1986). Thus, the hydrographical data obtained so far from the Baltic Sea are good for a description of the long-term behaviour of the Baltic Sea but we lack almost completely data relevant for small spatial scales.

In these days when specialization on a variety of scientific methods in many cases has gone far, it is perhaps more important than ever that oceanographers working on the same complex system have a common understanding and description of the functioning of the system and the underlying processes. This is obviously fundamental for our ability to communicate but also for the efficiency of scientific research so that each new experiment, based on either modelling, field measurements or a combination of both, build on and add to, or possibly revise, existing knowledge.

This paper is focused on the large-scale vertical circulation of the Baltic Sea which of course is only a part of the physical oceanography of the Baltic Sea. However, the vertical circulation determines the large-scale distribution of salinity and is by that setting the rules of the game for all oceanographic processes and phenomena in the Baltic Sea.

Acknowledgement

Björn Sjöberg, SMHI kindly supplied the plots of the development of oxygen and density in the Baltic proper in Fig. 5.

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Sea surface temperature variability in the Northern Baltic Sea with reference to normal period 1961-1990

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Average annual course of sea temperature and salinity at different depths around the Finnish coasts for the normal period 1961-1990 were recently published by Haapala and Alenius (1994). The analysis was based on the coastal hydrographic station network of the Finnish Institute of Marine Research (FIMR). Although the network is no more very dense there are still stations that have operated for decades already before the last normal period. Here were refer to some results of the paper mentioned and give further discussion on the year to year variability of the surface temperature. The surface temperature is an important variable in the energy exchange between the sea and the atmosphere and its variability gives some idea of fluctuations in the climatic conditions as well.

The annual mean amplitude of the surface temperature varies from 16 C° in the Gulf of Bothnia to 18.5 C° in the Baltic Sea Proper. In winter, between mid January to late March, the temperature is near to the freezing point and coastal waters are mostly ice covered. The maximum temperature occurs in the beginning of August. The standard deviation in the open sea seasons is roughly 2 C°.

The thermal conditions in the northern parts of the Baltic Sea during the 20th century can be summarized as follows: the beginning of the century was cool, the 1930's warmer and the last decades in the middle. Comparison of the values for the normal periods 1901-1930, 1931-1960 and 1961-1990 show that then period 1931-1960 was clearly warmest. The difference is largest in summer. Periods 1901-1930 and 1961-1990 were quite similar specially in summer temperatures. The spring and autumn values of normal period 1961-1990 is nearly equal to period 1931-1960 and slightly warmer than in the beginning of the century.

Average annual course of temperature for a normal period is naturally an idealization. The annaul course varies considerably from year to year within the normal periods. Short durations processes, like upwelling, deviates the daily temperature values from the idealized smooth annual curve. The Baltx model year 1986/87 was not very far from typical conditions at the Finnish coasts. The autumn 1986 was first slightly cooler than on the average but continued longer than on the avegare. The summer 1987 was partly slightly cooler than on the average.

RECONSTRUCTION OF HYDROPHYSICAL FIELDS OF THE BALTIC SEA USING A FOUR-DIMENTIONAL DATA ANALYSIS

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The Baltic Sea is considered as one of the most intensively studied marine areas in the world. A large number of hydro -physical, -chemical and -biological observations are carried out in the Baltic within the frame of national and international monitoring programmes. A lot of data are also collected in different research centres. However if one is going to investigate some phenomena in the sea using information for a longer time period or a larger region there are usually only available data sets that are scattered unevenly over space and time. Averaged over some period (month, season, etc) hydrophysical fields are often used to initiate or validate models of large scale and long term sea processes. The question is then how to construct these fields? Interpolation of the data by some abstract functions and smoothing procedures might bring forth attractive pictures but they would not necessarily be in accordance with reality. Therefore we need an "intelligent" method that can take into account distribution patterns caused by hydrographic processes.

The aim of this work is to develop a procedure where observed data are used in a hydrodynamic model to yield distribution fields of salinity and temperature. A method for hydrodynamic interpolation of the data observed to construct such fields is proposed. It uses a 3-D "primitive" numerical model and four-dimensional data analysis. An iterative procedure used to realize the four-dimensional data analysis. It consists of direct integration of the temperature and salinity transport equations over some time interval and solving the inverse task, which implies the integration of equations adjoined with the transport ones back to the initial time level. For the data assimilation the transport equations include so-called source terms which are directly proportional to differences between measured and modelled values.

Using this method the August temperature and salinity fields of the Baltic Sea averaged over 21 years period were constructed. These results are described and discussed.

Hydrodynamic interpolation appears to give well-founded results and four-dimensional data analysis could form a basis of some routine procedure to construct hydrophysical fields. The method also should hopefully be applicable to assimilate currently observed information during the model run.

RIVER DISCHARGE FROM THE TERRITORY OF THE RUSSIAN FEDERATION TO THE BALTIC SEA

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Numerous rivers from the territory of Russia (from the districts of Karelia, Vologda, Arkhangelsk, Leningrad, Novgorod, Pskov, Kalinin, Smolensk and Kaliningrad) discharge to the Baltic Sea. The area of runoff formation within the territory of Russia exceeds 375,000 sq.km, and the total amount of river runoff to the Baltic Sea from this region is 100 cu.km/year.

The Neva, Zapadnaya Dvina, Neman, Narva, Luga and Pregolia are the largest rivers in the region which make the major portion of water inflow to the Baltic Sea. This portion exceeds 98% of the total inflow to the Baltic Sea.

River runoff on the study territory is formed under various physiographic conditions. Precipitation here vary within narrow limits of 750-815 mm; evaporation changes from 470 to 600 mm, and runoff coefficients vary from 0.24 (Pregolia river) to 0.38 (Neva river).

River runoff on the Baltic Sea basin, if compared with river runoff of other seas on the European territory of Russia, is characterized by quite evident zonality and variability. Its variability is higher than that of rivers discharging to Barents and White Seas, and much lower than that of rivers discharging to the Black and Caspian Seas.

This evident variability and series interdependence of runoff reflect the cyclicity of time runoff variations as well as the availability of groups of years with different water availability and duration.

The problems of runoff variation analysis, discovery of periods of different water availability and duration in the largest rivers of Russian territory of the Baltic Sea basin are considered.

CLIMATE IMPACT STUDIES IN EASTERN BRANDENBURG USING THE SEMI-DISTRIBUTED HYDROLOGICAL MODEL EGMO AND PROPOSAL FOR NESTED DRAINAGE BASIN STUDIES (HYNEST)

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To get an understanding of the impacts of ongoing and expected changes in essential climate characteristics, in particular temperature and precipitation, on the hydrological conditions and the biosphere, a special modelling study has been carried out in the eastern part of Brandenburg, one of the driest regions in Germany (near to the Odra river).

For this study the 1937-1992 daily records of all relevant meteorological characteristics at the Potsdam meteorological station were selected as reference climate scenario. Based on a general analysis of simulation results of General Circulation Models (GCM), in particular the Hamburg GCM (ECHAM), this time series were modified to describe a less and a more intense increase in the frequency of dry and hot summers, and wet and warm winter seasons. Special attention was given here to ensure in the modified series (climate scenarios) the required consistency between the different meteorological characteristics at each time step, and thus to overcome the shortcoming of the widely applied approach of modifying observed temperature and/or precipitation records just by a certain percentage. The developed technique will be described elsewhere.

The reference and the two modified climate scenarios were then used as input in the semi-distributed hydrological model EGMO in a version earlier adapted to a river basin of 582 km^2 in East Brandenburg, being representative for large parts of that region in Germany. Four different types of land surfaces have been distinguished in modelling: water surfaces; areas with shallow groundwater (inluding wetlands); areas with deep groundwater; paved and other impervious areas. Further distinguishing, e.g. between forests, crop fields, pasture etc., is principally possible, but was not considered in this stage of the study.

Simulation results were time series of soil moisture, evapotranspiration, runoff formation and groundwater recharge for each of the investigated land surface types, as well as total basin discharge at the closing (gauged) river cross section. Selected results, in particular those for critical low flow and flood periods, will be presented and discussed. Special emphasis will be on summarising results, such as shifts in annual and long-term duration curves of basin discharge, changes in the long-term means of monthly evapotranspiration, groundwater recharge and basin discharge etc. A preliminary conclusion was that with the two modified climate scenarios groundwater recharges and basin discharges increased, while evapotranspiration during the vegetation season, and accordingly vegetation growth, decreased, especially on areas with deep groundwater.

Considering the results already achieved it is suggested to extend the modelling step by step to larger areas, in close collaboration with partner institutions in Germany and in other BALTEX countries, e.g. as follows:

a) to an area in East Brandenburg of about 70 x 70 km (around the radiosounding station Lindenberg), which covers the lower Spree river basin upstream of Berlin, and a few small German tributary river basins of the Odra river near Frankfurt;

b) to a larger area which includes in its southeastern part the area characterized before, and additionally large parts of the Havel river basin west and north of Berlin, and of the Uecker river basin, which drains directly into the Baltic Sea;

c) to the German part of the Elbe river basin (or the entire Elbe basin, in cooperation with Czech institutions), and eventually to the BALTEX region (or larger parts of it), as to be agreed with the BALTEX countries.

For the extended hydrological modelling a Nested Drainage Basin Approach HYNEST is suggested to be applied. HYNEST needs to be directly coordinated with the planned nested atmospheric modelling as far as time and space resolution, time domains and Soil-Vegetation-Atmosphere-Transfer models (SVATs) are concerned. Otherwise the focus of HYNEST will clearly be on gauged river basins of different size, and on research areas and watersheds, such as the NOPEX area, experimental watersheds in Eastern Brandenburg and in the Uecker basin, where measurements were made with very high space and time resolution, at least during selected periods, so that process understanding is best, high and lower resolution hydrological models can easily be applied, tested against the measurements and intercompared to understand their performance capabilities and limits in application. If such limits, or errors and shortcomings in the modelling will be observed appropriate steps can be initialized for model improvements.

Aspects in designing HYNEST for application in the BALTEX region across all relevant scales, and for the extrapolation of process understanding, models differing in resolution and detail, and research results, from detailed experimental and modelling studies at the microscale to larger scales, will be presented for general consideration and discussion.

RIVER RUNOFF TO THE BALTIC SEA - NATURAL VARIABILITY AND HUMAN IMPACT

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The total river runoff into the Baltic Sea system amounts to some 14 000 m³/s which is slightly less than the average runoff of the Mississippi river (Bergström and Carlsson, 1994). The annual variations are great. 1924 was the wettest year (average 19 500 m³/s) and 1976 the driest (average 11 100 m³/s) in a record covering 1921-1990 (Figure 1). 1981-1990 was the wettest decade (average 16 700 m³/s).

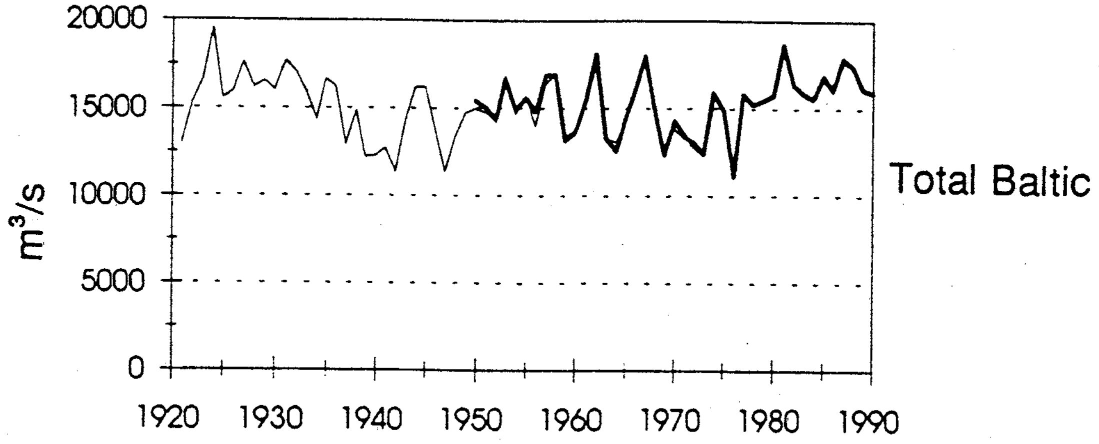

Figure 1. Total river runoff to the Baltic Sea (including the Danish Sounds and Kattegat) for the period 1921-1990 (from Bergström and Carlsson, 1994, the thin line is based on data from Mikulski, 1982).

The effects of snowmelt are clearly detected in runoff records to the Baltic Sea but the seasonality is less pronounced further south. A closer analysis of the seasonal patterns reveals that the increased inflows in the 1980-ies were particularily pronounced in winter (December to February, Figure 2). This has probably had a strong negative environmental effect as flows in winter are connected with high concentrations of nutrients in the rivers.

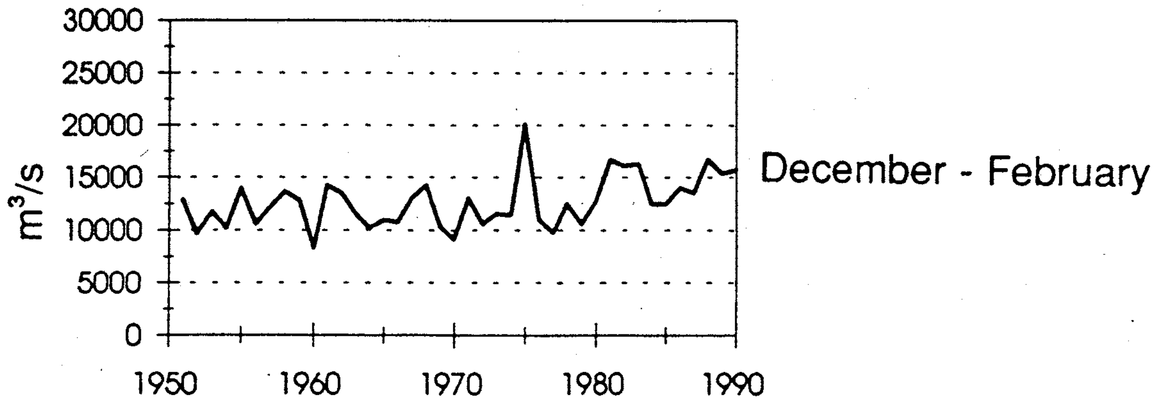

Figure 2. River flow to the total Baltic Sea system for the winter months during the period 1951 - 1990 (from Bergström and Carlsson, 1994).

The most clearly detectable human impact on water flows is the one caused by river regulation. It is most pronounced in the north where hydropower is developed to a high degree. Water is stored in the reservoirs during the flood season to be used for production in winter. The result is a runoff hydrograph which is greatly distorted. Figure 3 illustrates how the flow regime has gradually changed over time in river Luleälven in Sweden.

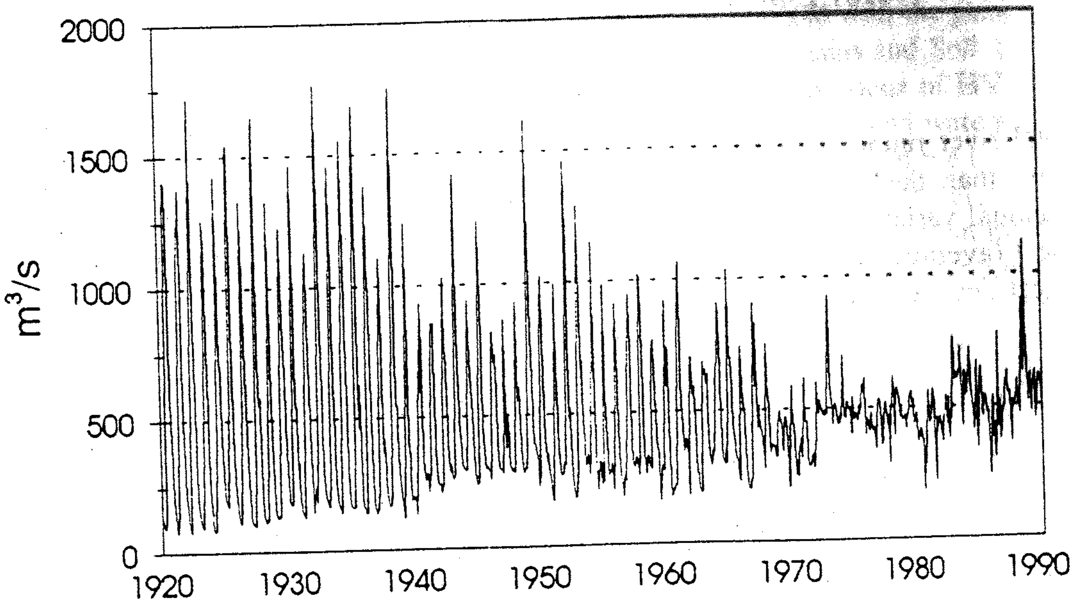

Figure 3. Illustration of the gradual change of the flow regime i river Luleälven in norhern Sweden for the period 1920 - 1990. The peak in 1989 is caused by a release of water when the reservoirs were full (monthly values).

In addition to the effects of hydropower on river flow, forest and agricultural practice and urbanization have been suggested as causes for changing runoff conditions. In the small scale the effects are obvious but they are not so easily detectible in large scale observations due to the great natural, climate induced, variabilities in runoff. The human impact is in this respect more important for the quality than for the quantity of water.

Climate change is another, although more speculative, possible cause of changes in the inflow regime of fresh-water to the Baltic Sea. The regional interpretations of GCM-simulations are still very uncertain but some perspective may be delivered by past experience. In Sweden the sequence of mild winters 1988 - 1993 were connected to westerly winds with high winter precipitation and runoff from the mountains. Thus there seems to be a correlation between annual temperatures and river runoff from the north to the Baltic Sea.

For the total Baltic Sea system the picture looks different and a bit confusing. The 15 warmest of the 30 years between 1961 and 1990 represent a total river inflow which is 1.5% lower than average if the analysis is based on Swedish temperature observations. If, on the other hand, a similar analysis is made based on global temperatures a 5.5% increase is observed. The conclusion is that it is very important to consider the difference between global and regional data in climate impact studies. Regional interpretations of GCM outputs is also a very important research task.

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Rainfall and cloud identification over oceans and coastal regions using a combination of infrared and microwave satellite data

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Although several global retrieval algorithms for cloud and rain parameters based on microwave data over ocean exist, the application of these algorithms to the BALTEX region is rather problematic. Two major reasons for that are: First, global algorithms may not represent special climatic regions very well. Second, the Baltic Sea is mainly comprised of coastal waters. In preliminary investigations it was shown that microwave classification algorithms (for SSM/I) developed for open ocean conditions fail to classify rain in coastal regions. This is due to the low resolution of the spaceborne radiometer and of the 'muddy' signal emitted from the nonhomogenous surface. To overcome these deficincies additional independant information has to be taken into account.

In our examination we made use of Meteosat infrared data and SSM/I or SSM/T2 data. In order to derive the channels with the most independant information, classical statistical methods (principal component analysis and correlation coefficients) where employed. The resulting datasets were analyzed and clustered using a neural network of the Kohonen type which can be placed in the class of unsupervised learning mechanisms. It allows to describe even non-linear data distributions by a small set of representative points. To classify the resulting clusters a set of radiative transport simulations for all SSM/I and SSM/T2 channels was carried out using a matrix operator model. The clustering algorithm was applied to the model results. This leads to a relation between physical properties and the statistical results of the network and even presents an opportunity to examine the accuracy of the clustering algorithm.

The results of our examination show that physically realistic classifications even in coastal regions are possible for the combination SSM/I and Meteosat as well as for the combination SSM/T2 and Meteosat. In further investigations semi-statistical retrieval algorithms will be derived using a combination of the three sensors.

RADIATION BUDGET COMPONENTS INFERRED FROM SATELLITE DATA FOR THE BALTIC SEA

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Radiation budget components at surface (SFC) and at top of atmosphere (TOA) were inferred using NOAA-AVHRR and Meteosat data for May and June 1993. The investigated area has a size of approx. 3100 x 1850 km^2 and covers the Baltic Sea, which is defined in the Baltic Sea Experiment (BALTEX). The spatial resolution of the satellite signal depends on the individual satellite sensor, where the maximal resolution was used.

To compute the radiation budget components, a two-stream model was applied to generate look-up tables for the downward shortwave and longwave fluxes and for the absorbed shortwave flux at surface. These look-up tables consider solar zenith angle, cloud optical depth, cloud base height and for the longwave standard temperature and humidity profiles. At top of atmosphere, the reflected shortwave and the outgoing longwave radiation could be approximated using the measured radiances with narrowband to broadband conversion techniques.

Concerning the determination of cloud optical properties, the optical depth were estimated using two-stream computations, too. To improve that estimate, a detailled cloud classification, based on the maximum likelihood method, was carried in advance to define individual cloud types. That allows the definition of microphysical cloud properties for each individual cloud, which are used in radiative transfer computations. Thus, for the two month period a detailled information on cloud cover variability and on radiation budget variability can be given. Using Meteosat inferred radiation budget, the daily mean of absorbed shortwave fluxes and net longwave fluxes at surface can be computed.

To estimate the influence of clouds on the radiation field, the concept of cloud forcing developed for radiation budget at top of atmosphere will also be applied to surface radiation budget data. That leads to an estimate of the cloud forcing of the atmosphere (ATM). The inferred radiation budget components (TOA, SFC), the derived cloud cover variability and the cloud forcing results (TOA, SFC as well as ATM), can further be used for regional studies on the energy cylce and for validations of model generated radiation fields.

ESTIMATES OF EVAPORATION AT THE BALTIC SEA FROM 1992/93

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The Baltic Sea Experiment is designed to get information about regional details of the energy and water cycles for the Baltic Sea basin. One of the major terms, affecting energy and water cycle, is the evaporation or water vapor flux at the Baltic Sea. Considering the widely used Bulk Parametrisation, water vapor flux E is a function of the mean wind speed U_{10} and air-sea difference of the specific humidity Δq_{10}

$$E = - \rho \, C_E \, U_{10} \, \Delta q_{10}$$

where C_E is the Bulk transfer coefficient for water vapor and ϱ is the air density (e.g. DeCosmo, 1991). Despite to a lot of efforts to find a predicted theoretical dependence of C_E on wind speed (e.g. DeCosmo, 1991), it seems still to be the best to use a constant value. In this study C_E given by Large and Pond (1982) has been used.

Interpolated fields with a spatial resolution of 1° latitude/longitude have been estimated from synoptic observations of coastal stations and voluntary observing ships. The 6 hourly synoptic observations from 1992 and 1993 have been made available by the Deutscher Wetterdienst. Since it is even difficult to get non biased estimations of surface wind speeds at open sea (Bumke, 1995) there should be a lot of problems to estimate surface wind fields for complex areas as the Baltic Sea. The main reason is the reduction of the surface wind speed due to changes of roughness in the coastal zone.

Interpolation of grid point fields has been done as follows. Pressure fields have been analysed by fitting a second order pressure surface simultaneously to both, pressure and wind observations, assuming geostrophic equilibrium (Bumke, 1995). Wind observations closer than 100 km to the coast, which might be influenced by orography, have been excluded. The relation between surface and geostrophic wind for open sea conditions is given by a stability dependent boundary layer parametrisation (Luthardt and Hasse, 1982). This parametrisation has been used for on shore wind conditions in the coastal zone, too. Off shore winds in coastal areas have been calculated from geostrophic winds by using ageostrophic coefficients adopted from Karger (personal communication). These ageostrophic coefficients have been derived from comparisons of direct observations of wind on voluntary observing ships to geostrophic winds as a function of the downwind distance to coast. For the estimation of the downwind distance to coast a map with a resolution of 0.1° latitude/longitude has been used.

Temperatures and humidities have been averaged linearely over areas of 2° x 2°. Since the number of water temperature observations has not been sufficient, 5 day running averages have been calculated.

The grid point fields have been used to derive fluxes of water vapor for a two year period 1992/93 with respect to the reduction of wind speed in coastal areas. Water vapor flux expressed in terms of latent heat is 55.8 Wm^{-2}, the average flux of latent heat for the Baltic in 1992 is given in figure 1. The reduction compared with fluxes without taken the wind speed reduction in coastal areas into consideration is only small and in order of 1%. Nevertheless the local reduction ranges up to about 15% in the area of Danish islands.

Using maps with higher spatial resolution will result in decreasing fluxes of water vapor. This is caused by the fact that only a small part of the Baltic islets and skerry are included in the map used for these calculations. Furthermore for on shore wind conditions a reduction of wind speeds due to changes in roughness has also to be taken into account. A first estimate shows that both will lead to an additional reduction of water vapor flux at a rate of some 2%. Thus the reduction of wind speed in the coastal zone would result in a systematic reduction of total flux of water vapor, averaged over the Baltic Sea basin, of at least about 3%.

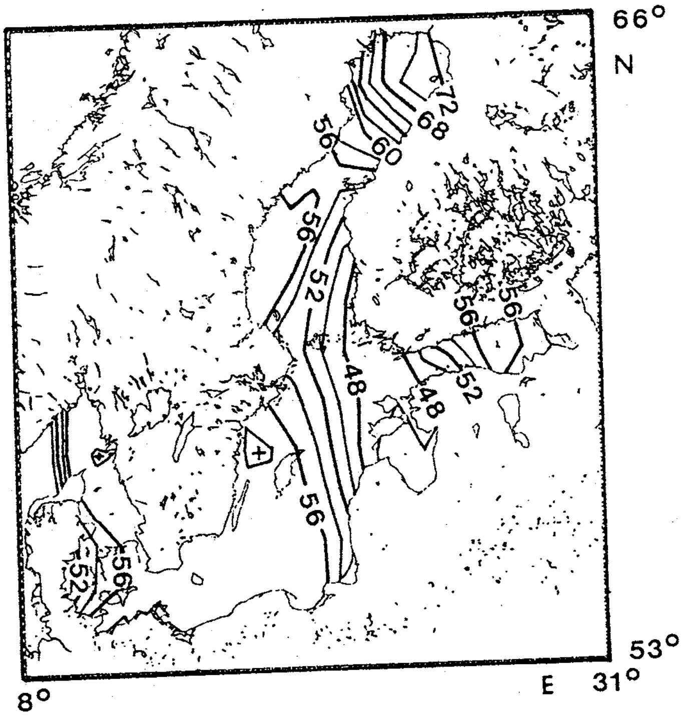

Figure 1: Averaged flux of latent heat in W m^{-2} for the Baltic Sea in 1992.

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ATMOSPHERIC DIAGNOSTICS FROM ASSIMILATION PRODUCTS OF A HIGH RESOLUTION LIMITED AREA MODEL

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Meteorological data assimilation systems were developed originally for the purpose of numerical weather forecasting. In practice, assimilation products represent consecutive descriptions of the atmospheric state that are potentially valuable for displaying the history of the atmosphere. These descriptions can be used to estimate quantities such as the diabatic heating and moistening, which may be hard to measure directly.

In deriving atmospheric diagnostics from assimilation products, two ways can be followed. The direct approach is to parameterize the relevant physical processes in terms of the available state fields - as a matter of fact, such parameterizations form already an essential part of the weather prediction models. Another possibility is to use the state variables to compute the quantities of interest as residuals in the appropriate budget equations.

The present study aims at identifying the most suitable database and computational procedure for monitoring routinely atmospheric diagnostics. The methodological investigations are based on products from the reassimilation experiment for the winter 1986/1987 carried out at the Swedish Meteorological and Hydrological Institute (SMHI) using a dedicated version of the HIRLAM forecast/analysis system. The limited area model covers the whole catchment basin of the Baltic Sea with a horizontal resolution of 22 km.

A number of fields that are usually not archived in the context of operational weather forecasting are available from the SMHI reanalysis. Diabatic heating and moistening are consequently evaluated for different stages of the assimilation cycle: as parameterized in the forecast model; from first-guess fields, analyses and initialized analyses in model coordinates; from analyses and initialized analyses in pressure coordinates; from circulation statistics in pressure coordinates. Advantages and weaknesses of each setup are discussed and a strategy for future studies over a much longer time period is outlined.

MODELLING THE BALTIC RIVER.

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The total river inflow to the Baltic Sea amounts to some 14 000 m^3/s of which some 6 000 m^3/s enters the Gulf of Bothnia (Bergström and Carlsson, 1994). There are many natural as well as human indused changes in the runoff. The most important man made influence on runoff is the development of hydropower. The effect of hydropower is most pronounced in The Gulf of Bothnia. The redistribution of runoff is of essential importance for the renewal of the water in the Gulf. In both Sweden and Finland most of the development of hydropower took place between about 1935 and 1980. The construction of regulation reservoirs implies a change to the landscape. Important for hydrological simulations is the creation of new or larger lakes. By reconstruction of the lake areas to the time before regulation and the runoff of recent time it has however been possible to calibrate and run an hydrological model (HBV-model, SMHI) and simulate the natural runoff of today. This is done for the Gulf of Bothnia. Results from this simulations, Figure 1 (Carlsson and Sanner, 1994) shows the characteristic differences between simulated natural and measured regulated discharge from Sweden and Finland to the Gulf of Bothnia, i.e. a higher flow in wintertime and a decreased flow in springtime. The regulated discharge in winter is about twice as large as the natural winter flow.

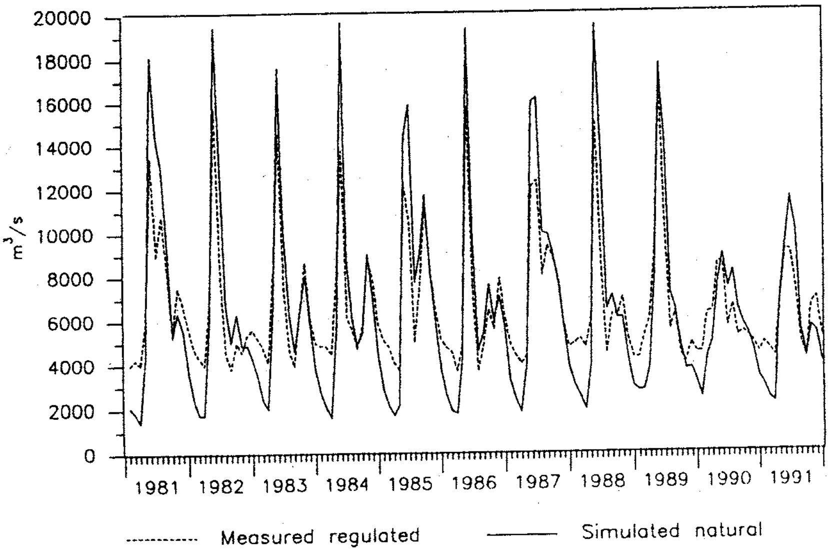

Figure 1. Simulated natural and measured regulated runoff from Sweden and Finland to the Gulf of Bothnia

So far hydrological modelling with the HBV-model has used more or less subjective weighted meteorological input from separate meteorological stations. In the Swedish project "Large-scale Environmental Effects and Ecological Processes in the Baltic Sea" synoptic meteorological data covering all the Baltic Sea discharge area have been put together into a database, Figure 2. This opens the possibility of using calculated means from regular grids instead of point observations. Further, for the Gulf of Bothnia, calibration can not be done with measured regulated discharge as these data does not reflect the runoff in a natural way. Instead the modelled natural runoff must be used.

Meteorological data from the synoptic stations shows considerably differences between the northern and southern parts of the area. The annual mean temperature for instance varies from around zero degrees in the north to around seven degrees in the south, figure 3. Of course this have a great influence on evaporation. Figure 4 shows the precipitation and runoff, both in mm/year, from the same three areas as show in Figure 3. Here we can see how the distance between the curves for precipitation and runoff increase from north to south.

This meteorological data-set now will be used in a hydrological model calculating the total runoff to the Baltic Sea.

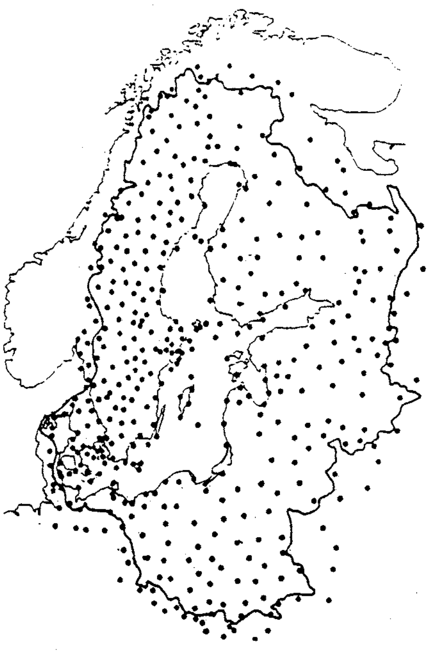

Figure 2. Synoptic meteorological stations.

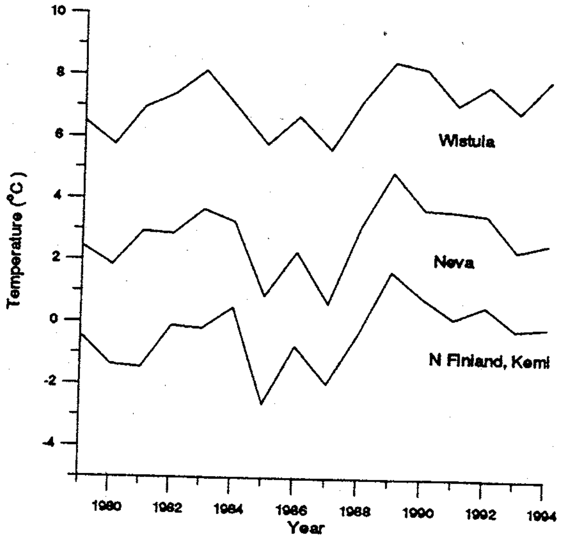

Figure 3. Annual mean temperature 1979-94. The data represent an area in which the river mentioned in dominating.

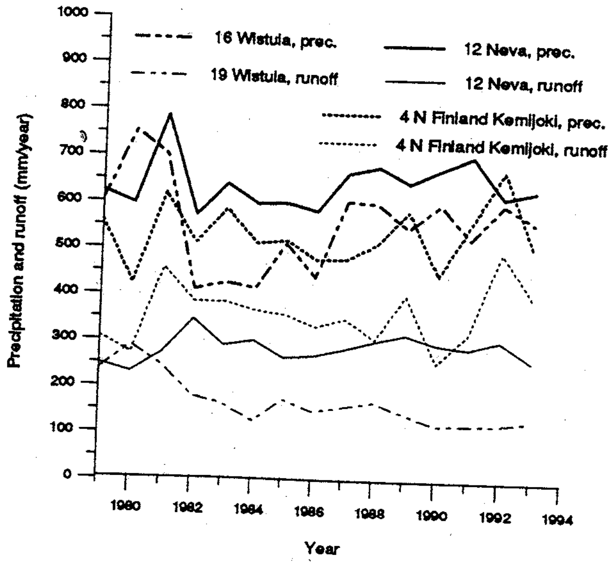

Figure 4. Annual mean precipitation 1979-94. The data represent an area in which the river mentioned in dominating.

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PRINCIPAL MODEL OF WATER EXCHANGE PROCESS BETWEEN VISTULA BAY AND BALTIC SEA AREA

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(1) The drainage region of South - Estern Baltic included basins of Vistula river , Vistula bay and Curonian bayis is near 318000 sq.km . The most part of it covers the area of Poland, Russia (Kaliningrad region) and Lithuania. The characteristic feature of this region is that near 48% of river inflow is turn to the Baltic Sea not directly, but through Vistula and Curonian bays, which are therefore the intermediate zone between rivers and sea waters.

(2) The river's waters sufficiently long time are in the aquatory of this bays and during this time take part in the various physical, chemical and biological processes. Then these transformed waters come to the coastal zone. The processes of intermediate water formation are more characteristic for the Vistula bay which has the intensive interraction with the Baltic Sea. This time and wind dependent water exchanging with sea area supply the irregular outflow of intermediate waters in the coastal zone.

(3) The principles of modelling of time variations of intermediate water inflow from Vistula bay to the Baltic coastal zone are discussed. The equations of time changing load on the coastal zone for various substances were deduce on the base of full mixed approach for Vistula bay.

(4) The model was tested on the task of time variation salinity simulation in Vistula bay in consequence with sea area - Vistula bay water exchange. The real data of 1994 monitoring in Vistula bay were used.

(5) The simple method of water exchange parameters determination on the base of harmonic analysis of water level variations was proposed. The certain characteristic (ventilation regime) was proposed for analysis of water exchange and bay's aquatory ventilation.

(6) On the base of monitoring data of 1994 for russian part of Vistula bay the load on coastal zone of South-Eastern Baltic were estimated for suspended solids material and some kinds of nutrients.

SOLAR RADIATION ENERGY ABSORBED BY BALTIC WATERS: THE EXAMPLE OF THE GDAŃSK BASIN

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The principal aim of this paper is to present a method of determining the influx and absorption of solar radiation energy by Baltic Sea waters on the basis of data from routine hydrometeorological and/or remote (e.g. satellite) 'sea-colour' observations. To estimate the influx of this energy as accurately as possible, the spectral distributions of the radiation reaching the sea surface under real weather conditions and in a given time must be determined, and the selective interaction of the light-wave spectral ranges taken into consideration. In accordance with these requirements, an algorithm has been developed to compute the solar energy flux distributions in the water from the spectral model of solar radiation flow (in the UV, VIS and IR to 2000 nm spectral ranges) through the atmosphere, a wave-roughened sea surface and seawater layers. This model comprises elements formulated earlier or available in the literature for the atmosphere, a wave-roughened sea surface and the water bulk separately. The numerous relationships and empirical constants in the model were determined for the southern Baltic Sea, and the Gdańsk Basin in particular, as a result of experimental studies and theoretical analyses by the team of hydro-optical scientists at the Institute of Oceanology, Sopot, in 1970–1993. Examples of solar energy flux distributions reaching and being absorbed by the water layers of the Gdańsk Basin, calculated using the model, are presented and compared with in situ measurements. The errors inherent in the model estimates and the measurements are of approximately the same order of magnitude. The model is expected to become a useful tool in the determination of solar radiation energy absorption in the various layers of Baltic waters from satellite data, e.g. from the planned SeaWiFS satellite.

MICROSPECTRAL ANALYSIS, SEASONAL AND GEOGRAPHIC VARIABILITY, IN THE BALTIC PROPER

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The presented work, has resulted from a series of campaigns for the period 1993-1994 carried out in the Southern Baltic region. These campaigns were the focus of a joint collaboration between the Joint Research Centre of the Commission European Communities and Institute for Oceanology of the Polish Academy of Science (project name ULISSE). The main objective of the collaboration was to provide a multiseasonal and geographically diverse bio-optical survey of the Southern Baltic region with the end of applying the obtained datasets to the development of a site specific bio-optical model. A wide variety of water quality and optical measurements were made. These included absorption spectra for CDOM (Coloured Dissolved Organic Matter or Gelbstoff), *in-vivo* phytoplankton and detritus. The absorption spectra were measured within one week of the end of the cruise, and the samples were preserved under appropriate conditions until that time. The CDOM spectra were measured using a cuvette and the absorbance values were converted into absorption coefficient. *In-vivo* phytoplankton and detritus absorption spectra were measured using a modified version of the filter technique.

In this investigation the above mentioned spectra types representing the three main absorbing parameters detectable by remote sensing are compared. Both in the air relationship at each station/sample to each other, as well as there geographic and seasonal variation compositely for the respective cruises.

The analysis was carried out using purely statistical methods (basic and multivariate) as well as a more heuristic approach. In particular certain specific wavelength ranges were considered corresponding to the forthcoming SeaWiFS sensors channels. These bands centred at 412, 443, 490, 555 and 670 (the two higher bands in near-infrared i.e. 765 and 865 being reserved for atmospheric correction) were compared statistically both individually and as ratios corresponding to those used in the subsequent geophysical algorithms, for all of the three absorption spectra.

This type of analysis offers an accurate fine scale investigation of the absorption characteristics of the optically active parameters present in the water bodies investigated. Additionally it allows the verification of the band ratios applied to remotely sensed imagery for the retrieval of geophysical parameters.

MICROWAVE SURFACE EMISSIVITY RETRIEVAL IN THE BALTEX AREA

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Modelling energy- and waterexchanges between the earth surface and the atmosphere requires a realistic surface hydrology. Therefore the knowledge about the large scale distribution of hydrological parameters is of high interest. Because of the lack of in situ measurements of soil water content we need satellite data to obtain a full area coverage.

The microwave surface emissivity ϵ is the key parameter for estimates of the surface wetness and the retrieval of atmospheric hydrological parameters like total water vapor content and cloud liquid water content. For a nonscattering, plane-parallel atmosphere with a non-blackbody surface the integrated radiative transfer equation can be written as:

$$\begin{aligned}\epsilon_r(\mu) = {} & \left(T^+_{B_r} - \int_0^{\delta_A} T(\delta) exp\left(-\frac{\delta}{\mu}\right)\frac{d\delta}{\mu} - exp\left(-\frac{\delta_A}{\mu}\right)\int_0^{\delta_A} T(\delta) exp\left(-\frac{(\delta_A-\delta)}{|\mu|}\right)\frac{d\delta}{|\mu|}\right. \\ & \left. - exp\left(-\frac{2\delta_A}{\mu}\right) T_{Sp}\right) / \\ & \left(T_S exp\left(-\frac{\delta_A}{\mu}\right) - exp\left(-\frac{2\delta_A}{\mu}\right) T_{Sp}\right. \\ & \left. - exp\left(-\frac{\delta_A}{\mu}\right)\int_0^{\delta_A} T(\delta) exp\left(-\frac{(\delta_A-\delta)}{|\mu|}\right)\frac{d\delta}{|\mu|}\right)\end{aligned}$$

with r=h,v (v=vertical polarization, h=horizontal polarization), $T^+_{B_r}$ the brightness temperature at the top of the atmosphere , δ_A the vertical integrated optical depth, T_{Sp} the space temperature, T_S the surface temperature, and $T(\delta)$ the atmospheric temperature.

In order to determine $\epsilon_r(\mu)$ we use SSM/I (Special Sensor Microwave / Imager) $T^+_{B_r}$ measurements at four frequencies (19 GHz, 22.3 GHz, 37 GHz and 85.5 GHz) and the numerical results of the Deutschland Model (DM), which provides surface temperature, atmospheric temperature and water vapor profiles with a horizontal resolution of 15 km.

For June 1993 mean surface emissivities range from 0.95 to 0.98 for vertically polarized radiance. For horizontally polarized radiances lower values from 0.97 to 0.95 are obtained due to the increased influence of water in soil and vegetation. Wet regions like the valleys of river Rhine or river Rhône, the Mecklenburger Seenplatte or the plain of river Po have lower emissivities from 0.91 to 0.93 (Fig 1). In general the emissivities show good qualitative agreement with emissivities derived for Colorado by Jones and Vonder Haar. Different structures of soil and vegetation are mainly responsible for the differences. Moreover the retrieval procedure is very sensitive to the surface temperature. Because of the difference in time between SSM/I measurements and DM results this effect can lead to errors in the range of 0.01 for surface emissivity. Errors due to variations in the water vapor content of the atmosphere are one order of magnitude smaller.

The computed emissivities will be related to soil water content obtained from measurements at 21 synoptic stations from the Deutscher Wetterdienst (DWD) and upper layer soil moisture content as predicted by the surface module of DM.

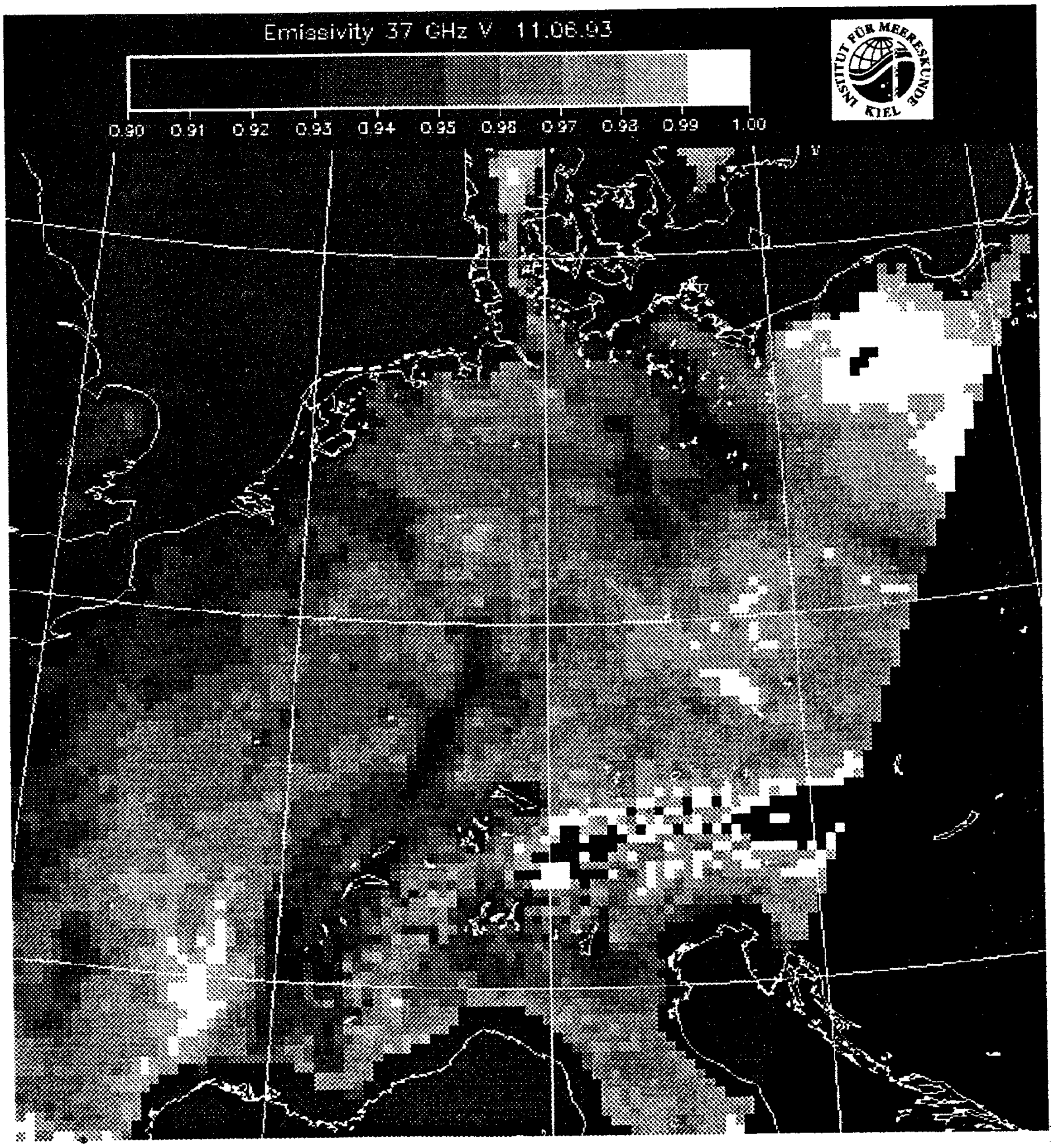

Figure 1: *Microwave surface emissivity at 37 GHz (vertical polarization, descending overpath) for 11.06.93*

PATTERN OF LONG-TERM CHANGES IN PRECIPITATION AMOUNT IN THE AREA OF POLAND AS AN EFFECT OF ANTHROPOGENIC FACTORS

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1. Introduction

Recent observations have revealed a continuing decrease in the amounts of river discharge within the entire area of Poland. In this context, the Wrocław Branch of the Institute decided to investigate the long-term pattern of precipitation received in Poland concentrating on the following items:
-tendency of changes in the intensity of peak precipitation producing summer floods;
-tendency of changes of the precipitation amount in the warm season (May-October),and
-pattern of long-term changes in the precipitation amount of the warm season (May-October) in the time span of 1951 to 1990 (forty years).

2. Methods

The methods used for the purpose of the study were those dealt with in statistical analysis; i.e.,the consecutive curve of five-year steps, the linear regression coefficient and the double mass curve.

3. Results

We prepared maps illustrating the pattern of long-term changes in the precipitation amount received by the area of Poland. Thus:

1. The sets of summer precipitation sums (May-October) collected at 124 stations in the 40-year period (1951-1990) have shown that one half of Poland's territory experienced negative tendencies, which were observed primarily in West Poland (westward of the Gdańsk-Wrocław line), in a broad belt in South Poland (including the Kraków-Czestochowa Upland and the foot of the Carpathian Mts.) as well us in the central part of the river Bug basin.
2. The highest negative coefficients of the linear regression line slopes (ranging from -2.0 to -5.3 mm day^{-1} year^{-1}) concentrated in the vicinity of the most hazardous emitters of industrial pollutants. The same holds for area windward of the prevailing air mass inflow from the direction of the emission sources.

Positive tendencies were observed in the precipitation pattern of the central and downstream parts of the Vistula basin, of the central part of the Oder basin, as well as in the precipitation pattern of South-East Poland. The positive coefficients of linear regression took smaller values, ranging from +1.32 mm day^{-1} year^{-1} in central part of Silesia Lowland and in South-East of Poland, respectively, to +0.10 mm day^{-1} year^{-1} in the central part of the Vistula basin.

In the last 35-40 years, decrease of precipitation amounts in the warm season within the area of West Poland averaged 20 to 60 mm, The highest decrease (amounting up to 130 mm) was observed in the vicinity of particularly nuisant emitters - a number of power plants fired with high-sulphur-content brown coals. The area is often referred to as the "Black Triangle", because it is influenced by three contributing sources - German, Czech and polish power-generating plants.

3. A similar decrease of the precipitation amount was observed in the area influenced by the heavy industry of the Ostrava-Karvina Basin (Czech Republic). An only slightly lower decrease was measured in the vicinity of the Legnica-Głogów Basin (with copper mines and copper smelters), in the city of Kraków (with ironworks and some chemical plants), as well as in the vicinity of Tarnobrzeg (sulphur mining). In some parts of Poland with no industrial activity and no emission of toxic pollutants there was either a noticeable, continuing increase of the precipitation amount, or only negligible variations.

The spatial distribution of long-term changes in the precipitation amount is shown in Fig. 1.

Recent studies, including the sums of precipitation from the last four years (1991-1994), have led to the following findings:

the negative tendencies observed in the warm season continue to persist, and the zone influenced by those negative tendencies continues to move eastward to the center of Poland's territory.

It should be noted that the pattern of long-term changes in the precipitation tendencies and amount depends strongly on the atmospheric emission of SO_2, whereas the spatial distribution of precipitation changes is influenced by the concentration of airborne SO_2 aerosol.

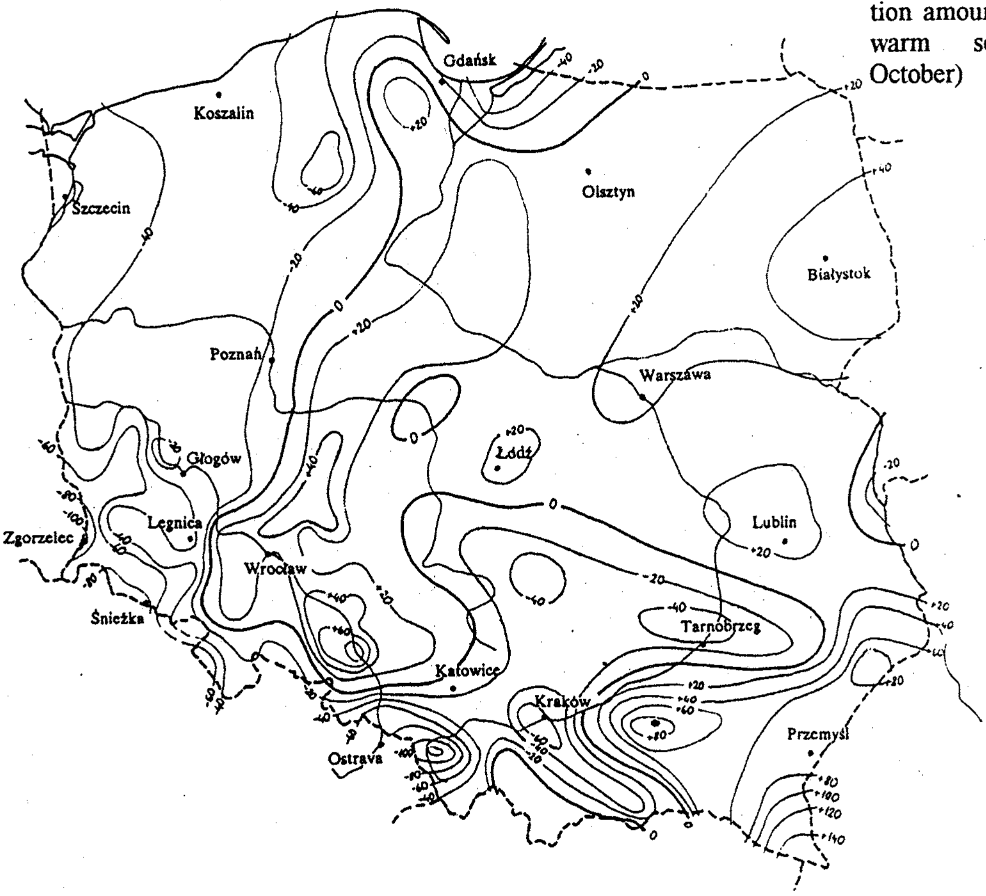

Fig. 1. Spatial distribution of long-term (1951-1990) changes in the precipitation amount (mm) in the warm season (May-October)

LONG-TERM TRENDS OF OUTFLOW OF THE COASTAL WATERS FROM THE LAGOON KURSCHIU MARIOS

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A shallow lagoon Kurschiu Marios gathers water from 100458 km^2 or about 6% of the drainage area of the Baltic Sea. These waters mostly flow to the side of the Gotland Deep area. Systematic routine investigations of the river water run-off were started in the post Smalininkai (112 km from the mouth of the river Nemunas) since 1811. It helped to calculate the outflow of the coastal waters from the Kurschiu Marios to the Baltic Sea for 184 years.

Integrated parameters derived from the hydrologic measurements show large variations during a long time period. Precipitation and evaporation form run-off which according to investigations covering slightly different periods falls in the range of 14-34 km^3 per year or about 5% of the total outflow to the Baltic Sea. The most interesting is the last 20-30 year period when an increase of the water run-off and a big number of warm winters were observed.

A long time investigation in this century show an increase of processes of eutrophication in the deep waters of the Baltic Sea. Especially it is seen in the Gotland and Fårö Deeps where a high hydrogen sulphide form concentration lasts for a very long period. The stagnation of deep waters corresponds to the fact of the increase of the river inflow to the Baltic Sea. Stagnation leading to the formation of the hydrogen sulphide was first observed in 1931 when during 1922-1936 there was the largest increase of the coastal outflow from the Kurschiu Marios since 1811. The next period with hydrogen sulphide occurred in 1957 and with little gaps it extended to 1978 when it held on for a long time. The short time increase of the river run-off in 1955-1958 and for a longer period in 1978-1990 was noticed.

Another significant phenomena is a gradually increasing of the pollution of the coastal waters with the maximum in 1986-1988. It formed possibility of the increase of high eutrophication in the deep waters during unfavorable hydrological conditions.

ON THE DEVELOPMENT OF A THERMOCLINE IN SPRING AT TEMPERATURES BELOW THE TEMPERATURE OF MAXIMUM DENSITY WITH APPLICATION TO THE BALTIC SEA

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The development of a thermocline in spring from a deep wellmixed surface layer of temperature well below the temperature of maximum density, Tmax, is discussed. The Baltic Sea is used to exemplify the situation in low saline estuaries where the freshwater runoff causes the buoyancy flux to shift from negative to positive before the temperature reaches Tmax. Thus, the pycnocline retreats before the water column reaches Tmax. Historical data show that the temperature of the water left below the thermocline often stays below Tmax till summer.

The development of the thermocline, as recorded during the Baltic Sea Patchiness Experiment, PEX, in the spring of 1986 in the central parts of the Baltic proper, is studied with the aid of a horizontally integrated numerical model. The observed retreat of the pycnocline is reproduced by the model only if freshwater is added at the sea surface. The supply of the freshwater to the PEX area was caused by advection of surface water of lower salinity.

THE HEAT BALANCE COMPONENTS CALCULATED WITH THE PROBE TEMPERATURE MODEL FOR TWO LAKES

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The FCE1 (First Concentrated Field Effort) phase of NOPEX (a *NO*rthern hemisphere climate *P*rocesses land-surface *EX*periment) in summer 1994 included measurements at the lakes Råksjö and Tämnare. Measurements from two projects are being used to predict and compare the components of the heat balance with the one-dimensional PROBE temperature model of a lake. These projects are studying the energy budget of a lake (Dr. Martti Heikinheimo) and primary production with the underwater light conditions (Dr. Kurt Petterson). Lake Tämnare is rather large and very shallow. The surface area is about 27 km^2 and the depth is about 2 m. Lake Råksjö has more typical morphology, but it is small. The surface area is 1.15 km^2 and the maximum depth is 10.5 m.

As input data the PROBE model uses measured global radiation, temperature and relative humidity of air and wind velocity. Also reflected radiation from the water surface was measured and reduced from the short wave radiation entering the water body. The needed long wave radiation from the sky was calculated with a method, which uses global radiation with temperature and relative humidity of air. The profiles of wind, temperature and humidity were measured above both the lakes at four heights (about 1m, 2 m, 4 m and 8 m). Measurements were made at fixed places, but also from movable floats. The measurement interval was 10 minutes.

Net radiation was also measured and used in comparisons. Surface skin temperature was obtained with an infrared sensor. Temperatures from some depths were also recorded. In lake Råksjö there was also a temperature chain recording temperatures from the whole depth with a 20 minute interval.

Attenuation of light in the water was also measured at both of the lakes. At lake Råksjö the attenuation was studied with an intensive series of measurements followed with some other physical and biological measurements. Attenuation was measured more than once a day. Examples are going to be presented to describe, how the temperature model can describe the diurnal changes. Also effects of calibrating the model and introducing the iteration routine for surface fluxes, also the momentum flux, are going to be studied.

The preliminary simulations with the model have included calculation of daily values of the components of the heat balance and time series of temperatures from different depths. Also measured and calculated temperature profiles from Råksjö have been compared through the simulated 11 days. For comparision corresponding daily values of latent and sensible heat fluxes are calculated with measured surface skin temperatures using an iteration routine. This method describes open water area and doesn't consider possible effects by limited lake surface area.

Usually the series (simulated with the PROBE lake model) of the daily values of fluxes of latent and sensible heat and net radiation show similar changes as the comparision values. The values of the fluxes are larger than the compared values. The net radiation deviated usually less than 10% from measured values. Also the simulated time series of temperatures resemble the measured temperature series, but usually too much energy goes into lakes. The skin temperature is lower than the temperatures of the uppermost layers of water that may often be used in the model. Measurements from the photic layers are also perhaps easily affected by radiation errors. The predicted skin surface temperatures of Tämnare were usually too high. At the beginning of the simulation the skin surface temperatures of Råksjö were closer to the measured values. The most severe error was, that the simulated lake Råksjö was mixed all the way to the bottom on the third day, which was sunny and windy. The measurements showed that it stayed stratified.

According to preliminary simulations it seems that the model doesn't directly predict the components of the heat balance and the temperatures perfectly for these lakes. It still seems, that it could predict these values, if it was tuned and calibrated to simulate the particular lakes.

VARIABILITY OF SEA SURFACE CHARACTERISTICS IN ESTUARIES UNDER THE CONDITIONS OF NATURAL CLIMATE VARIATIONS,RIVER RUNOFF AND ICE EFFECTS.

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Introduction.

The new view for discription of the formation regime in the coastal zone near Estonia is introduced. The classification of hydrophysical fields variability in the separate regions coastal water of Estonia is presented based on undulate nature of fundamental variability types for which space-time scales are given.

The report presents some results obtained with the methods of analyses oceanological processes based on the theory of probability functions. Using the unifying methods of processing the information basis of oceanographical data the variation of the processes and fields of different spatialtemporal scales was revealed.The regime sea definition is given and estimating of probability characteristics of hydrometeorological processes in annual, seasonal, synoptical and daily variability ranges are formulated. The necessity of exposing the main external factors forming the variability of regime in the separate regions coastal water of Estonia has been revealed. The importrance of influxes of waters from rivers has been better understood, their effects on the hydrological regime of the estuaries have been studied. Much studies are devoted to the sea level variations in estuaries under the conditions of natural climate variations and river runoff .

Data.

The regular sea level measurements in the coastal part of Baltic sea near Estonia started in 1805 year in Tallinn. The regular sea surface temperature measurements in the coastal part of sea began in 1825 year. The regular salinity measurements started in 1906 year. A hydrografic station network along Estonia coastal began work in 1885 year. The network was based on coastal stations and lihtships. At present net of coastal stations on Estonian shore contains 16 stations. The measurement programme of the coastal stations has included sea surface temperature measurements every six hour and salinity measurements every day (7 stations),sea level measurements every hour, pressure and wind every six hour.

Method.

Spectral analysis is the name given to methods of estimating the spectral density function, or spectrum, of a given time series. The research works were essentially concerned with looking for 'hidden periodicities' in data, but spectral analysis as we know is mainly concerned with estimating the spectrum over the whole range of frequencies.
We are mainly concerned with purely indeterministic prosesses, which have a continuous spectrum, but the techniques can also be used for deterministic processes to pick out periodic components in the presence of noise.

Spectral analysis is essentially a modification of Fourier analysis so as to make it suitable for stochastic rather than deterministic functions of time.The time series of the sea level, air pressure , temperature, salinity ,wind and river runoff are considered like upon a periodically correlated stochastic processes. Variations as a stochastic processes are treated in the framework of both the spectral and values statistics is widely used.

The main characteristic of such processes is a spectral density, which is the natural tool for considering the frequency properties of a time series.The physical meaning of the spectrum is that represents the contribution to variance of components with frequencies in the range. A peak in the spectrum indicates an important contribution to variance at frequencies in the appropriate interval It is important to realize that the autocovariance function and the power spectral density function are equivalent ways of discribing a stochastic process.From a practical point of view, they are complementery to each other. Both functions contain the same informarion but express it in different ways. In some situations a time-domain approach based on the autocovariance function in more useful, while in other situations a frequency-domain approach is preferable. So that the spectrum is the Fourier transform of the autocovariance function.

We have so far been concerned with the spectral analysis of discrete time series.For series which contain components at very high frequencies, it may be possible to analyse them mechanically using tuned filters, but the more usual procedure is to digitize the series by reading off the value of the trace at discrete intervals.

Finally, we make a comment about the lowest frequency we can fit to a set of data.Thus if we are interested in variation at the low frequency of 1 cycle per year, then we must have at least one year's data. Thus the lower the frequency we are interested in, the longer the time period over which we need to take measurements, where as the higher the frequency we are interested in, the more frequently must we take observations.

Four basic ranges influence to the hydrometeorological process rhythmics:

annual ($\omega<\omega_1=2\pi/T_1$, $T_1 \leq 1$ year);

seasonal ($\omega_1< \omega<\omega_2 =2\pi/T_2$, $T_2 \leq 1$ month);

synoptical ($\omega_2< \omega<\omega_3 =2\pi/T_3$, $T_3 \leq 1$ day);

daily ($\omega_3< \omega<\omega_4 =2\pi/T_4$, $T_4 \leq 1$ hour) .

Long term averages of temperature, salinity and sea level were calculated over all available yearly mean data.

Seasonal variability were calculated on basis of monthly mean values.

Synoptical variability were calculated on daily values.

Daily variability were calculated on 6-hour value.

Rezults.

The method is applied to data from 13 stations for differend periods.The rezults of the annual, seasonal, sinoptical and daily rhytmics analysis of the hydrological processes are given and examples of using spectral analysis for the processes with an unknown rhythmics period are also shown.

Spectral analysis can be a useful exploratory diagnostic tool in the analysis of many types of time series.

Spectral analysis is at its most useful for series of the type , with no obvious trend or 'seasonal' variation.

Spectral analysis allows to consider characteristic features of the hydrological process rhythmics - an approximative recurrence of values and its stochasticity.

Errors of the spectral estimates and some principled limitations of analysis are discussed.

HYDROLOGICAL AND HYDROCHEMICAL CHANGES IN THE BALTIC SEA BASIN RIVERS AND LAKES IN BELARUS

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The hydrological regimes of the Baltic Sea riversand lakes have been disturbed by wide-spread drainage amelioration including creation of reservoirs, straightening and diking of channels, drainage density increase and so on. Besides amelioration accompanied by intensification of agricultural product ion and quick industrial expansion in the river catchment. In Table 1 are given Characteristics of maximum, minimum and average annual discharges with coefficients changing are given in Tabie 1 before the beginning of large- scale human activity (from 1965 to 1975) and after (up to 1993) that.

Table 1

Characteristics of river water regime before large-scale human activity and after that

River - Section	Maximum of spring discharge			Minimum of winter discharge			Average annual discharge		
	before m3/s	after m3/s	K*	before m3/s	after m3/s	K*	before m3/s	after m3/s	K*
Neman - Grodno	926	644	0.69	72.2	62.3	0.86	197	194	0.98
Neman - Stolbtsy	228	99.4	0.43	6.47	6.43	0.99	18.7	15.7	0.84
Viliya - Vileika	290	70.3	0.24	11.3	8.2	0.72	30.0	21.3	0.71
Viliya - Zalesye	385	125	0.32	19.1	18.4	0.96	47.6	39.4	0.83
Viliya - Mihalishky	522	212	0.41	29.5	29.0	0.98	73.4	65.5	0.89
Lesnaya - Zamosty	77.1	41.5	0.54	2.62	4.38	1.67	8.0	9.0	1.12
W.Dwina - Vitebsk	1664	1344	0.81	46.7	54.1	1.16	224	216	0.96

* $K = \frac{\text{after}}{\text{before}}$

As it is seen from Table 1 the results of changes are different. Deep analysis ot these changes shows that approximately 50% reduction of maximum spring discharges are conditioned by climate changes but not by amelioration. The reduction of annual discharges are challenged basically by increase of the irrevocable water-use (in agriculture, industry and so on).

Comparative analysis of changes of hydrochemical regime of the rivers Neman and West Dvina has beeh carried out. As it is it is seen from Table 2 amount of chlorine, sulphate, nitrite and general mineralization are increase especially in spring. Concetrations of iron, ammonia, nitrate are reduced essentially.

Table 2

Coefficients of hydrochemical regime changes

River - Section	Seasons	Fe	NH_4	NO_3	NO_2	Cl	SO_4	Total mineral
West Dvina - Polotsk	spring	0.88	0.33	0.52	2.5	1.35	1.52	1.32
	autumn	0.68	0.87	0.60	1.0	1.41	2.16	0.99
	winter	0.45	0.73	0.32	5.0	1.11	1.33	0.96
Neman-Grodno	spring	0.41	1.8	0.49	1.0	2.76	1.85	1.41
	autumn	0.34	0.62	0.74	0.67	2.08	2.0	1.13
	winter	0.53	0.71	0.40	1.0	1.83	1.84	1.08

The analysis shows that high concentrations of oil products, phenols, surfactants, BOD and COD are marked in the sections of transboundary rivers and often exceeds maximum admissible concentrations (MAC).

In the report as well is considered changes hydrological and hydrochemical regimes of lakes: Drisvyaty, Osveiskoe and Lukomlskoe.

MULTI-SEASONAL ANALYSIS OF CDOM CHARACTERISTICS IN THE SOUTHERN BALTIC PROPER

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Absorption and fuorescence emission measurements of Coloured Dissolved Organic Matter (CDOM) were made during a series of oceanographical campaigns in the Southern Baltic sea in 1994. The stations were chosen in areas displaying differing water qualities to allow an initial assessment of the relative contributions in different zones of various sources of CDOM. The different *zones* identified were i) the open sea. ii) the coastal zone and iii) the Gulf of Gdansk. Relationships between absorption and fluorescence were considered for the above mentioned *zones*. Good correlations were obtained both for the whole dataset and for the coastal zone and Gulf of Gdansk independently over a wide variety of seasons .These results imply that fluorescence can be used as an effective tool to easily retrieve CDOM absorption data for the application of Remote Sensing to Baltic Sea investigations (which is characterised by high concentrations of CDOM). Furthermore an initial evaluation of the use of CDOM absorption to retrieve Dissolved Organic Carbon (DOC) is presented. The results have shown a positive correlation between CDOM absorption at 355 nm and DOC measurerement using the High Temperature Combustion method.

RESOLUTION ENHANCEMENT OF MICROWAVE OBSERVATIONS OVER THE BALTIC SEA

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One of the main scientific aim of BALTEX is the investigation of the hydrological cycle. For this purpose numerical models will be applied. Such models need, however, a careful validation. The goal of our work is to use satellite observations, in particularly those in the microwave spectral range, for a validation of the numerical results. In this paper a problem will be discussed which appears if microwave observations are applied to retrieve geophysical parameters over a relative small area as the Baltic Sea.

The retrieval of geophysical parameters by microwave radiometry (i.e. from the Special Sensor Microwave Imager (SSM/I)) involves the problem of different resolution of the used frequencies. The SSM/I observations at the four frequencies 19 GHz, 22.3 GHz, 37 GHz and 85.5 GHz have different effective fields of view (EFOV's) namely 69 km x 43 km, 60 km x 40 km, 37 km x 29 km and 15 km x 13 km, respectively.

One problem of the resolution differences occurs primarily by the retrieval of horizontally inhomogenous parameters like cloud water and precipitation. Another problem appears over the sea near the coast due to the high emissivity of land (~ 0.8 - 0.9) compared to water (~ 0.4 - 0.6). Because of the different EFOV's coastal effects which give rise to an increase of the brightness temperatures occur already 60 km off the coast for the two lower frequency observations and only 30 km off the coast for the 37 GHz data. This temperature increase may falsify the evaluation of geophysical quantities near the coast. SSM/I algorithms using the lower frequencies should therefore be limited to the free sea. This will dramatically limit the possible area of evaluation of small water regions like this of the Baltic Sea. If SSM/I data are applied only to that area which is not influenced by land, the part of the Baltic Sea which can be evaluated without a bias is reduced to ~ 20 % for the 19 GHz resolution, ~ 40 % for the 37 GHz resolution and ~ 65 % for the 85 GHz resolution.

An enhancement technique developed by Robinson el al.(1992) is used to match the resolution of the lower SSM / I-frequencies to the resolution of the 37 GHz-frequency. For a selected pixel this method uses the brightness temperatures of the surrounding and therefore overlapping SSM / I-footprints to correct the pixel to a brightness temperature which would be at 37 GHz-resolution.

This method has been further developed and applied to the Baltic Sea. For the monthly mean of June 1993 the difference between uncorrected and corrected water vapour content is about 1 kg / m^2 near the coast. For certain situations these differences can be even greater. The results prove that the enhancement technique is useful to correct geophysical quantities over the open sea up to 30 km distance to coast.

In order to extent this part of the area of the Baltic Sea which can be evaluated, a further method is developed on the basis of multiple regression to increase the resolution of all SSM / I frequency channels to that of the 85 GHz channel. With that method it is possible to use the SSM / I data unaffected by the land 15 km off the coast. Results will be shown in comparison with that derived from the method of Robinson et al. (1992).

To check the coastal effect and the possibility to correct it, observations during the planned field experiments will be used.

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ATMOSPHERIC LARGE-SCALE FORCING OF THE WATER EXCHANGE IN THE DANISH STRAITS BETWEEN THE NORTH SEA AND THE BALTIC

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The balance of water volume and salt in the Baltic sea is mainly governed by water exchange through the Danish Straits. The inflowing water with high salinity and reach in oxygen is of fundamental importance for the environmental conditions and the natural resources.

The water exchange through the connecting sounds is mainly driven by water level difference between the two sub-basins at the ends of the sounds. During major inflows, the barotropic component dominates, whereas during minor inflows the baroclinic component may also be of importance. Large variations in the water exchange take place both on a diurnal time scale caused by the main seiche in the Baltic proper as well as in meteorological forcing and on a seasonal scale due to variations in the hydrological cycle i.e. precipitation, evaporation and river runoff.

To estimate the influence of the large scale meteorological and hydrological forcing on the barotropic part of the water exchange, a shallow water model covering the North Sea and the Baltic Sea region has been run for the whole year 1993. This year is particularly suited as it contains the largest single inflow event since 1976. The model results are evaluated against sea level data and water volume transports through the Öresund, one of the connecting channels of the Danish Straits. The atmospheric conditions during 1993 will then be compared to other years in order to look for a coorelation between major inflow events and meteorological variations in the North Sea - Baltic Sea region.

THE RESPONSE OF THERMALLY FORCED MESOSCALE COASTAL CIRCULATIONS ON THE SYNOPTIC WIND DIRECTION

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The influence of the main large-scale wind directions on the thermally driven mesoscale circulations on the Baltic coast, southeast of Sweden, is examined. A numerical three-dimensional mesoscale model is used. The study is particularly concerned about sea-breeze and coastal jet development; their occurrence, intensity, shape, inter-connections and travelling are analyzed. It continues on previous analyses which regarded measurements, case-study modeling and perturbation sensitivity tests.

It is found that even such a moderate terrain, together with the synoptic conditions, governs the coastal mesoscale dynamics triggered by the land-sea temperature difference. The area of most complex dynamics is around the intersection of the two coasts (Blekinge and Kalmar coast). Subtle nature of the coastal low-level jets and sea-breezes is revealed; their patterns are largely governed by the interplay between the synoptic wind and the coastline orientation. Additional structures in the atmospheric boundary layer are identified, e.g., low-level eddies, shear-driven gravity waves behind the sea-breeze front, nocturnal downslope flow, etc.

Coastal jets typically occur during nighttime and varying in their height, intensity and position with respect to the coast; they may branch and interact with downslope and land-breeze flow. Depending on the regarded coast and the prevailing ambient wind, the sea-breeze can be suppressed or enhanced, standing at the coast or rapidly penetrating inland, locked up in phase with another dynamic system or almost independently self-evolving. The "classical" compensating return flow rarely occurs in three-dimensional flows over the real topography.

PRECIPITATION MEASUREMENTS ON MOVING SHIPS

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L. HASSE, Institut f. Meereskunde an der Universität Kiel
K. UHLIG, Institut f. Meereskunde an der Universität Kiel

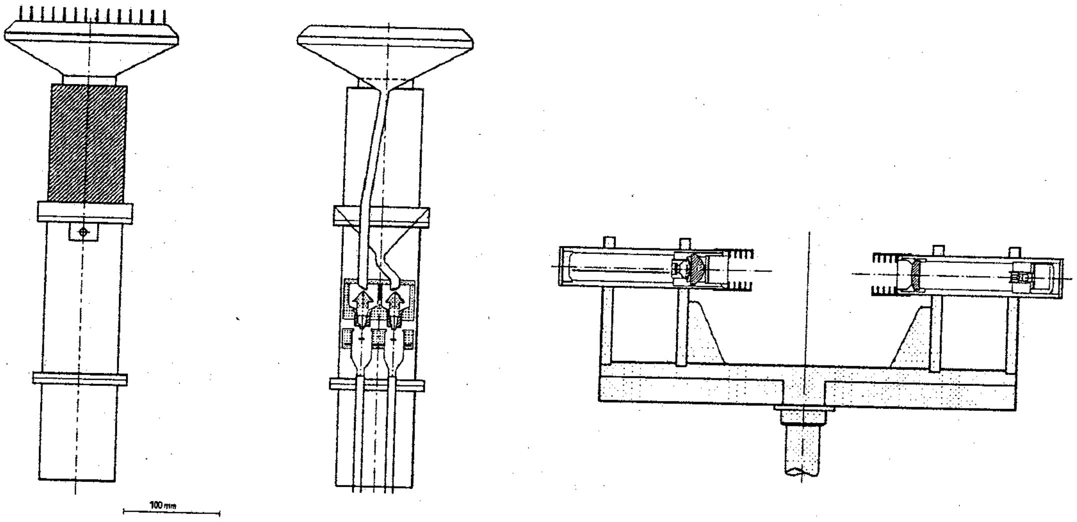

Figure 1: *Sketch of the mechanical ship–raingauge (left hand) and the IfM optical Disdrometer (right hand)*

Introduction

Precipitation at sea forms an important branch of the hydrological cycle. Yet, undisturbed precipitation measurements at sea, except from a few stations at small islands, are practically not existent. Therefore, new specialized ship rain gauges have been developed and tested over many years on board of several research vessels. The mechanical gauge (Figure 1a) is provided with a horizontal collector of improved aerodynamic design and an additional lateral collector (shaded area). Both collectors have been calibrated separately using simultaneous measurements of the IfM–optical Disdrometer (Figure 1b). This intercomparison showed a rms error of the mechanical rain gauge of 1.8 % considering a 24 hours sampling period.

Data collection

As a contribution to the BALTEX experiment two Baltic Sea ferries have been equipped with a mechanical ship rain gauge in 1994. Each ship is also provided with an anemometer and a Global Positioning System (GPS). Two more ferries will be instrumented in spring of 1995. These ferries shuttle between Lübeck and Helsinki with 80% of time at sea. Figure 2 gives a map of the ships route. It is evident that the ferries cross the main body of the Baltic Sea. A rough test for the installed rain gauges is possible every second day, when the ferries meet in the central Baltic Sea.

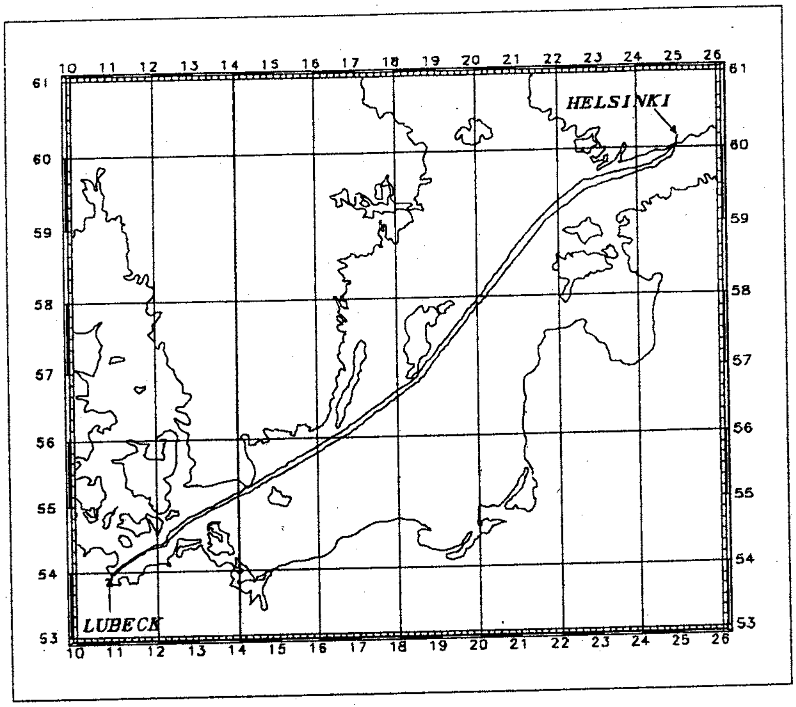

Figure 2: *Sailing route of the ferries that are equipped with a mechanical ship rain gauge*

First results

Figure 2 illustrates that the distance between a ship and the shore varies strongly along the ships route. Analysis of a first six months dataset showed a decrease of rainfall probability with increasing distance to shore. Also monthly sums of liquid precipitation along the route were determined. Maximum totals occur in the Fehmarn Belt, in the Hanö Bay and in the Gulf of Finland, while minimum rain amounts are observed in the central Baltic Sea. Doubling the number of observing ships in 1995 will enhance accuracy.

Outlook

Areal coverage of precipitation at the Baltic Sea can be obtained from weather forecast models, seaward looking radars and microwave satellite remote sensing. These methods need ground truth at sea. The precipitation data collected by the Baltic Sea ferries can be used for intercomparison with other estimates. Thus, in situ measurements of precipitation will help to verify or improve the determination of the fresh water flux into the Baltic Sea.

Acknowledgement

We thank the POSEIDON SCHIFFAHRTS OHG who made their ferries available to our measurements. We are also grateful to the ships officers for their help with our measurements.

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A TIME-DEPENDENT MODEL FOR CALCULATION OF HIGH SALINE INFLOWS TO THE BALTIC SEA

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A new time-dependent numerical model of the Öresund, Belt Sea and Arkona Basin is presented. When connected with the earlier presented model for the Kattegat (Gustafsson, 1995), it provides a tool for the calculation of the complete water exchange between the Baltic and the North Sea. Of special interest for e.g. modeling the vertical circulation in the Baltic is the capability to calculate the intensity and properties of high saline deep-water inflows.

The model is geographically divided into the three sub-basins Öresund, Belt Sea and Arkona. Each basin is described with a new one-dimensional general multi-layered model, which enable very high vertical resolution. The Öresund and the Belt Sea are interactively coupled with the Kattegat model through the narrow mouth in northern Öresund and the Great Belt, respectively. Water entering the Arkona basin from the Belt Sea and the Öresund may form a deep-water pool if denser than the surface water. The inflow to the Baltic from the pool is described by assuming a baroclinic control, as proposed several authors (e.g. Stigebrandt, 1987 and Liljebladh & Stigebrandt, 1995).

The model is verified against daily observations of salinity and temperature conducted at light vessels in the Belt Sea and the Öresund for a four year simulation period between 1950 and 1954. For a fourteen years long simulation period (1980-1994), the Arkona part of the model was verified against the inflow distributions calculated by Stigebrandt (1987) and the statistics of available salinity and temperature profiles in the area.

The model is able not only to hindcast both the very large inflow in 1951 as well as the inflow in 1993 but the results also shows quite clearly the lack of extreme inflows in the eighties. This gives confidence in the models ability to simulate the important mechanisms governing the dynamics of large inflows. Thus, the model will be an important tool in order to provide us with information on the sensitivity of these mechanisms to e.g. changes in the environment such as sea level rise or increased winds over the area.

MESOSCALE RE-ANALYSIS FOR BALTEX - A PILOT STUDY

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The basic aim of the BALTEX project is to get an improved understanding of the energy and water cycles in the Baltic Sea area. For the atmospheric contribution to these energy and water cycles, it is necessary to utilize a combination of observational and modelling simulation techniques, i.e. to apply meteorological data assimilation within the framework of a Numerical Weather Prediction (NWP) system. In order to get a proper description of certain important atmospheric circulation systems, for example the convective snowbands associated with wintertime cold air outbrake over the warm water surfaces of the Baltic Sea (Andersson and Gustafsson, 1994), it is necessary to apply the meteorological data assimilation at mesoscale resolutions with model grid resolutions in the range 10-25 km.

A mesoscale re-analysis of atmospheric data for a period of 10-25 years has been discussed within the framework of the BALTEX project. This is certainly a huge project, that would require the joint efforts of several institutions involved in operational mesoscale NWP.

The Swedish Meteorological and Hydrological Institute has volunteered to carry out a Pilot study in Mesoscale re-analysis for BALTEX for the period 15 December 1986 - 15 February 1987. The geographical area for this re-analysis consists of 162 x 142 horizontal gridpoints with 22 km grid resolution in a rotated latitude/longitude geometry (approximately 10W - 45E, 48N - 75N) and with 24 vertical model levels. The assimilating model is the HIRLAM Level 2 (Gustafsson, 1991) with Eulerian advection and 4th order horizontal diffusion, including the Sundqvist condensation/precipitation scheme and the Savijärvi/Sass radiation scheme.

In order to reduce the spinup of physical processes during the HIRLAM data assimilation for the BALTEX purposes, the data assimilation is carried out with a two-step "telescoping" technique. As a first step, data assimilation is carried out in 55 km horizontal resolution over an extended area with ECMWF initialized analysis fields on the lateral boundaries. The initialized analysis fields from this 55 km HIRLAM data assimilation are then used as lateral boundary conditions for the mesoscale BALTEX Pilot study data assimilation. Other details of mesoscale data assimilation include:

(1) The SMHI sea ice and sea water model as well as a model for lake ice and water thermodynamics (Ljungemyr, 1994) have been two-ways coupled to the HIRLAM meteorological data assimilation.

(2) An improved HIRLAM physiography data set, including national data bases from Sweden and Finland, is utilized.

(3) The HIRLAM (ECMWF) 3-dimensional multivariate Optimum Interpolation (OI) analysis scheme is used for the analysis of atmospheric mass-, wind- and humidity fields.

(4) A surface analysis scheme is used for snow depths, ice coverage and sea surface temperatures.

(5) The output data include a complete set of model level fields such as cloud variables, surface fields, surface fluxes and tendencies from parameterized physical processes averaged over 6 hours periods in addition to post-processed fields at standard pressure levels.

It is expected that the production phase of the Pilot study for the BALTEX re-analysis will be finished by the summer 1995. A cooperation with the Helsinki University for the evaluation of the usefulness of the assimilated data for atmospheric diagnostic purposes has been established. In addition, the output data from the re-analysis project will be utilized at SMHI for various purposes, e.g. to test the sensitivity of numerical weather predictions to two-ways coupled sea/lake ice and water models. Results from the BALTEX re-analysis Pilot study and, hopefully, also from some applications of these two-ways coupled models will be presented.

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A DATA BANK FOR THE BALTIC SEA ICE CLIMATE STUDIES

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A data programme has been constructed for Baltic Sea ice climate studies. Three particular ice seasons and the climatological normal period 1961-1990 statistics have been chosen for the reference cases. Ice winters 1983/1984, 1986/1987 and 1991/1992 have been selected to represent a normal, severe and mild ice seasons. A databank of meteorological and hydrological forcing data and ice and oceanographic verification data have been constructed. A total number of 22 meteorological stations, monthly mean runoff data, water exchange data in the Danish Straits, eighth water level stations, two hydrographic stations, eighth ice monitoring stations and forms the basis of the databank. A short analysis of the selected ice winter is given.

BALTIC SEA ICE WINTER SIMULATIONS WITH COUPLED ICE-OCEAN MODEL

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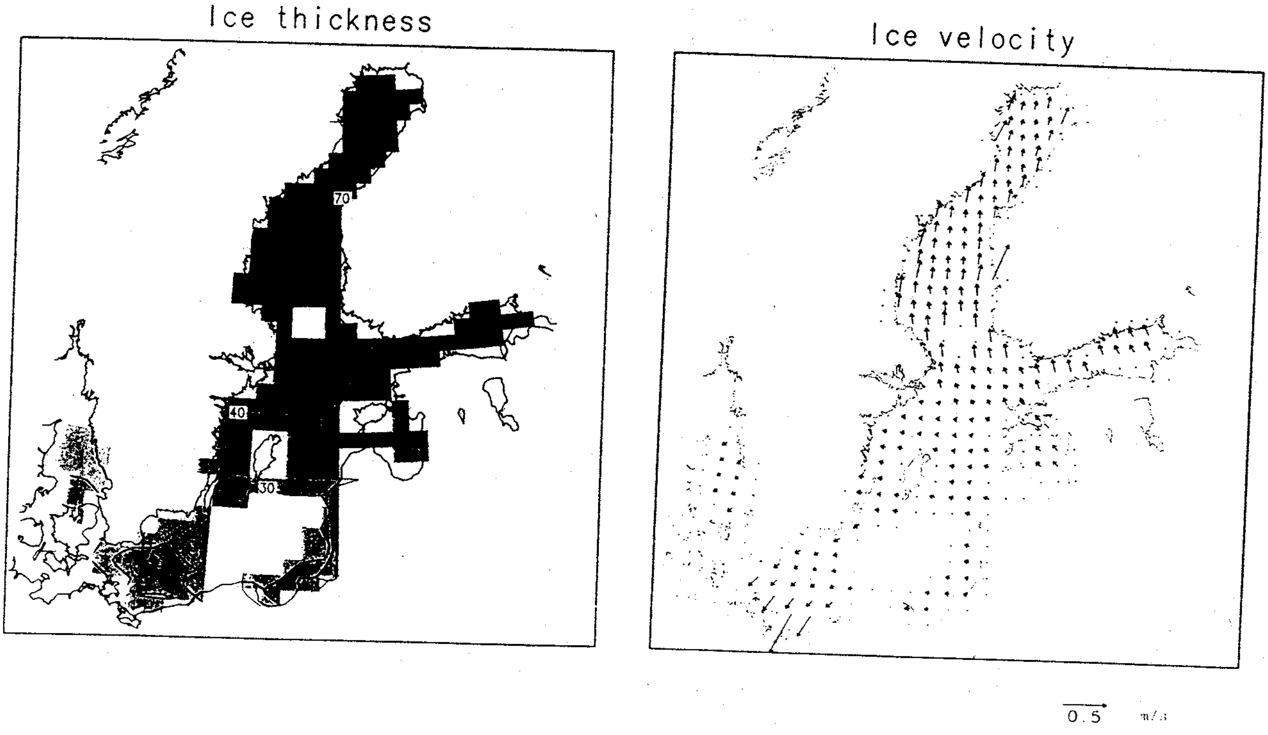
Baltic Sea ice winter climatology is studied with a coupled ice-ocean model. The evolution of SST, ice thickness, drift and deformation have been simulated during three particular ice winters, normal (1983/84), severe (1986/87) and mild (1991/92), with prescribed atmosperic data.

Ice model is a plastic Hibler model with three level ice thickness description (open water, level ice and ridged ice) and full thermodynamics. Ocean part is under development; test runs has been done with mixed layer model and a barotropic ocean model. Model is forced by momentum, heat and radiation fluxes, which are calculated from the observed meteorological data.



Examples of the simulated ice thickness and drift in March 1987.

NOAA CORE PROJECT SUPPORT FOR GCIP

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The GEWEX Continental-Scale International Project (GCIP) is a multifaceted group of activities primarily designed to improve scientific understanding and the ability to model, for climate prediction purposes, the coupling between the atmosphere and the land surface on a continental scale. The operational or enhanced observing period (EOP) of GCIP will run for five years commencing in October 1995. The GCIP activities are focussed on the Mississippi River basin to take advantage of existing meteorological and hydrological networks that are being upgraded with new Doppler radars, wind profilers and automatic weather stations. Data from these networks together with those of other operational agencies and satellite data are key to the success of GCIP. Most of these data will be provided by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) and National Environmental Satellite and Data Information Service (NESDIS).

The NOAA GCIP Core Project has been designed to meet specific objectives which are critical for GCIP and to provide essential support for other inter-related NOAA objectives which will in turn benefit GCIP. The Core Project has the following four Project themes:

- **Data:** collection, preparation and transfer to the GCIP Data Management and Service System high quality hydrological and meteorological data sets that are not obtainable from other sources.
- **Data Enhancement:** development of new high quality derived data products that are based on data assimilation and analysis, and statistical and numerical modeling techniques.
- **Model Enhancement:** development of enhancements to operational numerical weather prediction models that improve the land surface parametization and couple atmospheric processes with surface hydrological processes.
- **Management Support:** support the management and operation of GCIP itself.

The NOAA Hydrologic Data System is currently being developed for GCIP and NWS requirements and will handle the large volumes of data to be archived from the five NWS River Forecast Centers (RFCs) in the Mississippi River basin. An archiving system is needed to handle the gridded radar precipitation products and the hydrological model outputs of the RFCs. All these data will require the development of near real-time quality control techniques and procedures. A modern data system, consistent with NOAA's evolving data management architectures and approaches, and incorporating largely-automated data quality control and analysis procedures, must be developed for the efficient handling of these data.

Operational model output fields are needed for continental scale water and energy budget studies and for improving and validating climate models, the latter being an ultimate goal of GCIP. Within its five year time frame GCIP is to observe the hydrological cycle on a continental scale and then validate and improve the degree to which today's numerical models can reproduce the observed hydrological cycle, water balance and water component and spatial distribution. Model outputs will be provided from the National Meteorological Center's (NMC) operational models and from hydrologic models operated at RFCs. Runoff will be a key output product in the validation of continental evaporation fields. Runoff volumes from the operational RFC streamflow outputs and the United States Geological Survey (USGS) streamflow stations will be used to estimate parameters of the improved Eta model surface parameterization.

Precipitation and evaporation are important fluxes in the water and energy budgets of both the atmosphere and the land surface. Precipitation is an essential data item for hydrological and atmospheric models of surface processes and for assimilation into operational atmospheric models which will provide the key source of continental scale evaporation fields. The multi-sensor products to be produced in this Core Project will include data from gages, the radar network and satellites.

Snow is the major input to the water budget in mountainous areas in the US. Thus, daily continental-scale snow cover and snow water equivalent products are needed to meet GCIP data requirements and for assimilation into RFC and NMC models. These products will be developed using GOES/VISSR, NOAA/AVHRR and DMSP/SSM-I satellite data from existing operational programs and products.

Improved modelling of the land surface component of numerical weather prediction (NWP) models requires a measure of the surface insolation, surface temperature and vegetation which can be observed from operational satellites. These observations are needed for assimilation into these models, for validation of model and land surface fluxes and for calibration of model physical parameters. These same parameters can also be important to hydrological modeling. NESDIS will use GOES and AVHRR data to estimate solar insolation, surface temperature, evaporation and a vegetation index. The USGS will use the same data to provide vegetation classes, soil parameters and terrain data. Satellite-derive retrievals of atmospheric water vapor and cloud water will be important new data sources of moisture in the 4-D assimilation systems of NMC's mesoscale Eta model and global MRF model, especially over oceans.

High quality retrospective data bases of surface observations (primarily precipitation, synoptic and streamflow data) are needed for model development and calibration. Typical parameter values are needed to support enhancements to operational models both by NMC, the RFC and by the scientific community in general. Another need is for development and validation of improved macroscale hydrological models within the NWS. These data are also needed to develop techniques to estimate parameter values in surface process representations over continental areas that are appropriate for application globally.

Major components of the surface and atmospheric water and energy budgets over large space and time domains (such as surface evaporation and soil moisture) can most efficiently be provided by operational models and their corresponding data assimilation and analysis systems. The OSU model and the SSiB model of COLA are now being tested in the Eta model. Improvements in the land surface physics are needed in the NMC models to include explicit vegetation effects, multi-layer soil representations, improved snowpack physics and advanced treatments of surface infiltration of rainfall and runoff. Studies of the retrospective data sets will guide the specification of spatially varying land surface parameters. Improvements in other closely related areas such as atmospheric radiation and cloud and precipitation physics are also needed. The development and testing of an off-line assimilation system is needed to produce soil moisture initial conditions. The off-line assimilation system will process data products from RFCs in part of the Eta model domain. It will also process a multi-sensor precipitation product, a multi-sensor snow product and satellite cloud cover and vegetation information.

AN INVESTIGATION OF ENERGY AND WATER BUDGETS FOR THE BALTEX AREA BASED ON SHORT-RANGE NUMERICAL WEATHER PREDICTIONS

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The present study aims at determining water and energy budgets of the BALTEX area from short-range numerical weather predictions of the Europa-Modell of the Deutscher Wetterdienst (MAJEWSKI, 1991). Area mean values for the BALTEX area of budget components of enthalpy and latent energy are computed, averaged over 6h to 30h forecast time. The vertical integrals of enthalpy and latent energy are determined at the beginning and the end of the averaging period. Thus the predicted time tendencies can be determined too. Neglecting the transfer between enthalpy and kinetic energy, a 'reversed aerological method' can be used to compute the net flux divergence of enthalpy and vapour transports, which at present are not computed directly from the model results. The computations started on March 1, 1992 (for some variables on February 1, 1992). January (and February) monthly mean values of the years 1993 and 1994 are used as surrogates for missed values in 1992 in order to obtain annual mean values for three years.

The enthalpy budget (Table 1) shows the area to be a sink region for enthalpy. On average one third of the energy loss by radiation is supplied by convergence of horizontal enthalpy transports. In the latent energy budget (Table 2) again one third of the energy loss by condensation is supplied by convergence. Here the interannual variation of the storage term seems to be rather large. But it is impossible to distinguish between true interannual variability and changes due to the model development.

	1992	1993	1994	mean
Radiation	-93.9	-111.6	-113.4	-106.3
Condensation	56.1	57.1	56.8	56.7
Sensible heatflux	12.8	4.7	8.6	8.7
Storage	1.8	-10.2	-4.2	-4.2
Convergence	26.8	39.6	43.8	36.7

Table 1: Simulated atmospheric enthalpy budget of the BALTEX area (W/m^2).

	1992	1993	1994	mean
Condensation	-56.1	-57.1	-56.8	-56.7
Latent heatflux	30.4	57.0	32.7	40.0
Storage	-9.8	22.8	-6.2	2.2
Convergence	15.9	22.9	17.9	18.9

Table 2: Simulated atmospheric budget of latent energy for the BALTEX area (W/m^2)

The water budget of the Baltic Sea (Table 3) can be compared to some climatological estimates. Definitely the model production of runoff was much too low in 1992 and 1993. A reformulation of the runoff generation process, which became operational in March 1994, obviously alleviated this problem. The two climatological estimates of precipitation differ considerably, the model results being roughly in agreement with the values given by LEGATES and WILLMOTT (1987).

	1992	1993	1994	mean	Legates	HEL-COM	Berg-ström
Precipitation	354	341	362	352	329	255	
Evaporation	356	346	270	324		208	
River runoff	201	164	335	233		473	484
Outflow	199	159	427	261		520	

Table 3: Simulated water budget of the Baltic Sea (km^3/year). The outflow through the Danish Straits is computed as a residuum, assuming a vanishing change of the water level of the sea.

These results give an indication of the ability of short-range numerical weather prediction models to produce reliable estimates of the energy and water budget of the BALTEX area. Existing climatological budget components were used to verify the model simulations. One challenging task of BALTEX is to provide measurements of more of these budget components in order to better verify the numerical weather and climate prediction models. This in turn will give more confidence in those simulated components which can hardly be measured as, e. g., areal evaporation.

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Underwater LIght Satellite Seatruth Experiment (ULISSE)

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Unlike most marine areas, the radiative transfer in Baltic waters and, hence, its productivity largely depend on the optical properties inherent to material covarying and not covarying with chlorophyll concentration. These properties play a key role in determining the reflectance signal from seawater, whose spectral variations are used in remote sensing to estimate over synoptic scales the concentrations of various optically-active components, as well as primary production. The success of future space-borne sensors (OSC/SeaWIFs, NASDA/OCTS, ESA/MERIS, NASA/MODIS) in the Baltic will rely on our knowledge to parameterize, spectrally, the regional and multi-temporal variability of the optical properties of each component in the upper layer and their relative contribution to the total attenuation of light.

The programme ULISSE is a joint study regrouping scientists from the Institute for Remote Sensing Applications of the European Commission (Ispra, Italy) and the Institute of Oceanology of the Polish Academy of Sciences (Sopot, Poland), aiming at obtaining a suitable datasets to support the development of site-specific algorithms to determine fluxes of matter in the Baltic. In this work, we present the outline of this project and introduce in a general way the results showing the spatial and multi-temporal heterogeneities of the bio-optical properties as measured during three R/V "Oceania" cruises conducted in the Southern Baltic during 1994. On average 30 stations were sampled on each cruise, covering a large area from the Bay of Gdansk to Borholm Basin and Pomeranian Bay and including various water types: open waters, coastal zone, and river plumes. In addition, the cruise time periods encompassed typical situations of spring bloom strongly influenced by river runoff, summer stratified conditions dominated by cyanobacterial bloom, and a September period affected by atmospheric forcing. For each period, beam attenuation coefficient, absorption spectra and particle size spectrum are discussed in terms of vertical stability of the water column and particle structure. We then examine the variability of these quantities and discuss the implications for remote sensing and bio-optical models of primary production.

A REVIEW OF DIAGNOSTIC STUDIES ON ATMOSPHERIC BUDGETS OF ENERGY AND WATER

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The latent heat of water vapour is part of atmospheric total energy. The budgets of water vapour and energy must therefore in general be considered together.

The difference between evaporation and precipitation, E-P, links the atmospheric branch of the water cycle to that of the land/oceans. The traditional hydrological/oceanographic methods infer this difference from surface observations. By contrast, the aerological method derives it from the conservation equation for atmospheric water vapour by using atmospheric circulation data, as demontrated for the Baltic Sea area by Palmén (1963). The aerological data can in principle also be used to infer the diabatic heating or the net source of dry energy in the atmosphere. The diabatic heating is the "prime mover" of the atmospheric circulation but cannot be directly measured.

In this lecture recent studies employing the aerological method are reviewed. It appears that the large-scale aspects of (E-P) and of the diabatic heating can nowadays be deduced from the threedimensional fields of meteorological variables much more accurately than in the 1960´s. How useful the aerological method is for BALTEX scales remains to be investigated.

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THE ÖSTERGARNSHOLM AIR/SEA INTERACTION PROJECT

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The small island Östergarnsholm, situated east of Gotland, is the site of an instrumented tower which forms the nucleus of an air/sea interaction experiment in the Baltic Sea. The aims of the project can be stated in the following points:

* To establish relations between sea surface drag on one hand and sea surface state on the other hand, as well as relations between sea surface state and non-dimensional fetch and non-dimensional duration of wind .

* To establish corresponding relations related to sensible and latent heat exchange.

* To investigate crucial factors related to the turbulence regime in the marine surface layer (to perform 'a Kansas experiment at sea').

* To investigate effects on the marine boundary layer of advection of air from surrounding land masses out over the Baltic Sea.

* To study properties and role of organized turbulence structures in the marine boundary layer.

Figure 1 shows that the island Östergarnsholm is situated about 4 km east of the Östergarn peninsula. The island is very low and flat, its surface being covered by grass and herbs mainly. The 30 m high instrumented tower is situated at Havdudden, the southernmost

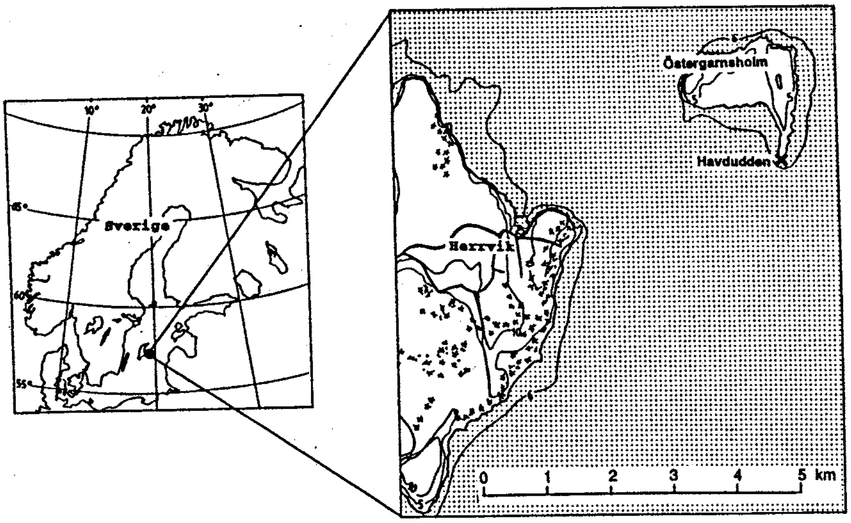

Figure 1a. Map of Scandinavia, showing the geographical location of the site. 1b. Close up of the Östergarnsholm area, with the tower site at Havdudden.

tip of the island. The sea floor at the site has a slope of about 1:7, descending gradually to 100 m at about 10 km east of Östergarnsholm. The fetch is between 100 and 300 km in a sector from NE to SW. The wind is disturbed by the island Östergarnsholm itself for the 90°-sector from NW to NE and between 4 and 100 km for the remaining sector.

The experimental project has two components: 1) Continuous measurements according to the plan outlined below, will be carried out with the purpose to cover as wide a variety as possible of occurring meteorological and sea state conditions at this site. 2) Intensive measurements will be performed, in order to give more complete information on the conditions of the atmospheric boundary layer as a whole.

The basic instrumentation on the tower is accordingly.

* Sonic anemometers of the Solent Ultra Sonic Anemometer 1012R2 type at three levels plus additional thin Pt-wires for recording of rapid temperature fluctuations; sampling rate 20 Hertz.

* Cup anemometers and slow response temperature sensors at 5 levels.

* Humidity and radiation measurements at one level.

* Recording rain gauge (Hellman).

Outside the island a directional waverider buoy is installed, which also records water temperature. Data from the tower installations and the wave rider buoy are recorded on a continuous basis locally, but direct telephone connection to our Institute in Uppsala enables instant checking of all data.

The tower measurements will be run continuously for at least one and a half year. Wave measurements will be done during at least two half-year periods (excluding periods when there is a possibility for ice). On request from our group in Uppsala there will also be carried out pilot balloon measurements from a site on the Östergarnsholm peninsula at selected times during this period of continuous measurements.

A first intensive measurement campaign was launched in June this year, immediately after the tower instrumentation and the wave rider buoy had been installed. During the course of three weeks, 12 missions were flown with an instrumented aircraft. At the same time numerous radiosondes and pilot balloons were launched.

If future EU funding is obtained, the measuring period will be extended to cover a longer time period and additional instrumentation provided by several research groups will be installed either on the tower or nearby. In that case the Östergarnsholm project will be able to play a central role in the BALTEX project.

WINDSPEED AND EVAPORATION AT THE SURFACE OF THE BALTIC SEA

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The Baltic Sea covers about 20 % of the BALTEX region. Without detailed knowledge on the water and energy balance at the surface of the Baltic Sea the key objectives of BALTEX will hardly be met. The implementation of BALTEX foresees the analysis of existing historical data sets in order to e.g. establish climatological statistics as background information for studies of actual events. The present study is a contribution in this field. The only existing information from the open Baltic Sea, covering time periods on time scales of years to decades, are the meteorological reports made onboard of Voluntary Observing Ships (VOS). These reports consist of standard meteorological observations and measurements at or near the surface which allow to estimate shortwave and net longwave radiation as well as the turbulent fluxes of latent and sensible heat, using bulk parameterizations.

The most comprehensive VOS data set is probably the COADS (Comprehensive Ocean Atmosphere Data Set). This global data set consists of millions of meteorological ship reports from the period 1854 to 1992 and is stored at the National Center for Atmospheric Research in Boulder, USA. For this and future BALTEX-related studies all individual marine observations from the region 50° to 70°N and 1° to 30°E have been extracted from the COADS archives. The Baltic Sea portion is investigated here. The data coverage is not homogeneous in both time and space. Time periods with good coverage include the periods 1905 to 1915 (more than 1500 observations per month in the Baltic Sea in general), 1925-39 (> 500 observations per month), 1963-70 and 1980-92 (> 1500 and 2000 observations per month, respectively).

Most of the reports include windspeed, air- and sea surface temperature, as well as air pressure. Observations of total cloud cover are included in nearly all reports, however, low-cloud cover and further information on cloud type are available only after about 1950. A crucial parameter is surface air humidity required for the parameterization of latent heat flux and, hence, evaporation. Unfortunately, only very few observations from the period before World War II include measurements of either dewpoint or wetbulb temperature. The data coverage is remarkable good in the period 1980 to 1992, in particular for the Baltic Proper. Here, 60 % of all individual observations include wetbulb temperature, and therefore evaporation can be calculated by means of bulk parameterizations using the *individual* method based on approximately 600 observations per month, or more. For the *individual* method fluxes are computed for each ship observation and are averaged afterwards in order to avoid biases due to the cross-correlations of the meteorological parameters involved.

The present study focuses on the wind speed and the latent heat flux at the surface of the Baltic Proper. For three sub-areas of the latter, based on data from the period 1980 to 1992, the annual cycle as well as intramonthly and intermonthly variances and other statistics are presented and discussed in the context of earlier studies.

Spectra of monthly values of windspeed for the Baltic Proper of the last 40 years are investigated and compared to wind speed spectra from other ocean areas, especially the North Atlantic Ocean.

MESOSCALE PRECIPITATION PATTERN IN ESTONIA

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Precipitation is anas a leading role in water cycling. Water balance calculations and hydrological modelling require exact precipitation data.

Spatial distribution of precipitation is extremely complicated, especially in summer. Diurnal pattern of rainfall seems rather random and it is not possible to derive any regularities. But summing diurnal data up to monthly and still more annual values, general peculiarities appear.

The aim of the present study is to determine statistical structure of precipitation fields in Estonia during different time intervals. Another task is to compose a cartographical model of mesoscale precipitation pattern taking into account the influence of landscape factors (relief, sea) on spatial distribution of precipitation. In this study the term mesoscale corresponds to horizontal dimension of 10-100 kilometres.

In spite of comparatively small area there is a remarkable variety of different landscape units in Estonia. Local climate has formed under the influence of the Baltic Sea, large inland lakes, uplands with hilly moraine relief, big forested areas, wetlands etc.

Usual observations at synoptical stations present macroscale distribution of meteorological values. At the same time, precipitation fields are very variable and measurements at single stations are representative only for a small area. To determine the influence of local mesoscale factors on precipitation pattern a dense observation network is needed.

There is a great number of precipitation data in Estonia measured during a long period. First, the dense network of rainfall gauges was established in 1885. It was organized by the Livländische Gemeinnützige und Ökonomische Sozietät. The precipitation stations were mostly located at former manorial estates. The Meteorological Observatory of the University of Tartu and first of all its directors - prof. A. v. Oettingen, prof. K. Weihrauch and prof. B. Sresnewsky - served as scientific advisors for the network. More than three hundred precipitation stations functioning at different time intervals before the World War I was a quite unique action in the world at that time.

The two world wars caused interruptions in the most time series of precipitation in Estonia. But during the rest of years rainfall data measured at more than a hundred stations every year are available. It allows to generate mesoscale precipitation fields with satisfactory exactness.

Quality of the precipitation measurements is not equal during the 110-year period (1885-1994) used in current study. Improved gauges and methods have enabled to register an increasingly bigger part of precipitation. Therefore, it was reasonable to use four periods of homogenuous data (1885-1910, 1920-1944, 1945-1965, 1966-1994) for investigation of mesoscale precipitation pattern in Estonia. Besides, there was assumed that spatial variability remained stable.

Monthly, annual and seasonal totals of precipitation were used for statistical analysis. Winter includes period of December - February, spring correspondingly March - May etc. Usual statistical characteristics such as mean values, standard deviations, coefficients of variation, asymmetry and excess were calculated for the four periods. Also spatial autocorrelation function as an important indicator of territorial variability of meteorological fields was found.

Statistical analysis of precipitation fields in Estonia indicated a certain stability of characteristics during the 110-year period. A remarkable increasing trend is evident. The mean level of annual precipitation has rised approximately 150 mm. It is mostly caused by higher quality of measurements. Annual courses of autocorrelation functions calculated for monthly precipitation have some significant differences between the four periods.

Geographical information system IDRISI was applied for territorial data processing. It allows to create raster images. A digitized vectorial map of Estonia was converted into IDRISI raster map that consists of 410 columns and 280 rows. Every cell would correspond to one square kilometre. There are 43440 cells for the terrestrial part of Estonia. Some series of precipitation raster maps were computed using spatial interpolation in IDRISI.

A very valuable IDRISI's possibility is to do arithmetical calculations with images. One can compare raster maps, determine relations between them and also analyze time series of images. IDRISI has also a module to realize standardized principal component analysis for time series of up to 84 images. In this study, principal components calculated for the four time series of precipitation maps are analyzed.

A simple spatial model is composed that calculates mean annual precipitation in every cell as a product of mean minimum value and coefficients of four landscape factors. The mean minimum value is found with assumption that landscape factors do not influence on precipitation at all. For the period 1966-1994, 580 mm measured in the most western coastal station in Estonia is taken as the mean minimum value. The landscape factors were the following - absolute height, windward slope and shade of uplands, 3 km coastal zone and distance from the sea in windward (SW) sector.

Every 10 metres of height adds 1 per cent of annual precipitation. Windward slopes get 5 per cent more and shade area 5 per cent less. Within the 3 km coastal zone precipitation totals are 6 per cent lower than in inland. Depending on the distance from the sea, the coefficient rises up to 1.12 on the distance of 30-60 km, and further decreases to 1.00 at the 120 km.

Maps of the four factors were composed using IDRISI modules. Hypothetic precipitation maps were calculated for the four time intervals within the 110-year period multiplying the maps of the four factors with the mean minimum value. Good correlations (0.6-0.8) were obtained between the hypothetic and real maps of annual precipitation.

In conclusion, the mean regularities of mesoscale precipitation pattern in Estonia can be stated.

1. Precipitation in coastal area of the Baltic Sea as well as of the great lakes Peipus and Vôrtsjärv is substantially lower than in inland.

2. There is a zone of maximum precipitation in the Western Estonia parallel to the coastal line on the distance of 30-60 km from the sea.

3. Rainfall at higher regions (uplands) is heavier than in lowlands.

4. Precipitation totals on the windward side of uplands are ca 10 per cent bigger than at the shade side.

5. During the first half of warm period in the South-Eastern Estonia it rains much more than in the Western Estonia. In the second half the precipitation pattern is opposite. West Estonia tends to be more wet and East Estonia - drier.

REMO - A MODEL FOR CLIMATE RESEARCH AND WEATHER FORECAST

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Numerical experimentation as well as validation of numerical models are essential components of BALTEX. On the one hand, it is intended to guide and to interpret field measurements of energy and water fluxes within the area of the Baltic Sea. On the other hand, parameterizations of physical processes that describe components of the hydrological cycle in a numerical model need to be validated. This concerns time-scales of a few days (using weather forecast models) to seasons and years (using climate models).

Therefore, a new regional model was set up in a joint effort by DKRZ (Deutsches Klimarechenzentrum), DWD (Deutscher Wetterdienst), GKSS (GKSS-Forschungszentrum Geesthacht) and MPI (Max-Planck-Institut für Meteorologie). This model, called REMO (Regional Model) can be used in the weather forecast mode as well as in the climate mode, it has the possibility of using different packages of physical parameterizations. Thus, the performance of different physical parameterizations can be tested within the same dynamical framework. Moreover, the regional model has the possibility of using the same physics as the global model into which it is nested to assess the problem of scale dependence of physical parameterizations.

REMO has been applied to the Baltic Sea area to assess the annual cycle of precipitation and evaporation. Therefore, time varying meteorological fields (surface pressure, horizontal velocities, temperature, and moisture) of the MPI climate model ECHAM3-T42 were used as lateral boundary fields.The comparison of the annual cycle of precipitation and evaporation of one climatological year simulated by ECHAM3-T42 and REMO shows that the regional model basically follows the annual cycle of the driving global model. But monthly means of precipitation and evaporation differ mainly during the summer. Also, the spatial patterns differ due to more realistic orography in the regional model.

Furthermore, the flow domain covered by the regional model was varied. Striking differences are seen in precipitation patterns over the Baltic owing to small scale cyclones whose development is suppressed if the flow domain of the regional model is too small and, hence, the forcing by the driving large scale model dominates. Slightly different initial conditions used for 3 July simulations on a large simulation domain result in similar climate for the Baltic Sea, but differ in precipitation pattern and amount for the Baltic drainage basin.

This result reflects the instability of limited area simulations which has to be qualified when assessing regional climate simulations.

TEMPORAL AND SPATIAL VARIABILITY OF RUNOFF COEFFICIENT IN ESTONIA

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The paper examines the variabilities of the spatial and temporal characteristics of runoff coefficient of some rivers basins of Estonia with a view to assessing the consequences of the recent climatic variations and establishing some relationships between these variations and the river flow regimes. The rainfall-runoff relation for each catchment was computed in a standardised manner using annual values of both component. Analysis of variability of runoff coefficient could be used for connection of climate models and hydrological models.

The Estonian territory, which has an area 45,200 sq.km, has been devided into 27 river basins each with area of 105-7840 sq.km. Most of the basins have an area of less than 1000 sq.km. These catchments were chosen according to a number of criteria, as well as well-defined area, good quality rainfall and flow data and the absence of artificial influences (human impact) to runoff regime. Monthly and annual sums of precipitation and rivers runoff were used for statistical analysis. The grid network for precipitation spatial distribution calculation was 6-7 km.

There is a great number of precipitation and runoff data in Estonia measured during a long period. Basic data for the runoff coefficient calculations (precipitation and runoff areal series) consist of:

1. Precipitation data (65 years long on the average) for the whole Estonian territory (about 200 observation stations).
2. Hydrological data (52 years long on the average, 73 years maximum) for the actual catchments (127 gauging stations).
3. Digital data files for the boundaries of the catchments.

Runoff coefficient calculations follow two steps: first long term means are calculated and then values for individual years.

Despite the small size, there is a remarkable variability of hydrological parameters in Estonia both in space and in time. In this study, an attempt is made to identify and describe quantitatively the spatial and temporal variation of the runoff coefficient. Spatial distribution of runoff coefficient is extremely complicated, especially in summer and winter - during minimum runoff regime.

To investigate the influence of the changes in the precipitation on the intensity and magnitude of runoff coefficient, the analysis have been made also for the different landscape regions: forested river basin with swamps and bogs in West-Estonian Lowland, hillocky relief of moraine landscape in South-Estonia and highly cultivated basin owing to karst in North-Estonia. More detailed investigated the spatial distribution of the runoff coefficient within Lake Vôrtsjärv watershed. Six subcatchments have been selected based on differences in soil properties, vegetation and gradient.

The problem of generalizing for relatively large area using data from a relatively small area is illustrated by the fact that the characteristics of runoff coefficient extremes can be different by catchments located close to one another in the same climatic region.

Using information from a runoff coefficient, can also be illustrated of the recent climatic variations on the characteristics of other hydrological components. An example of these components is evaporation, which is the most important outflow component of the water balance. In basins, located in the Estonia, in the zone of surplus and adequate humidification, dependence of evaporation on precipitation is significant. Thus, for such conditions a close relation of precipitation with total river runoff and almost completely uncorrelated precipitation and evaporation are characteristic.

THE VARIABILITY, AND ITS CHANGES IN TIME, OF SUNSHINE DURATION AND PRECIPITATIONS IN ESTONIA

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In addition to the changes in mean values of energy and water conditions, changes in their variability are considered to be very significant. To characterize the solar energy balance, an analysis of sunshine duration s has been carried out. This choice has been made because of the availability of a long-time series of sunshine duration data and their high correlation with the sums of total radiation. The amount of precipitations r is used for characterising the water conditions. The sequence of daily data for s and r from the beginning of this century are taken into account for Tartu ($\varphi = 58°23'$ N, $\lambda = 26°43'$ E).

To study the degree of diversity, the Shannon entropy of daily sums of sunshine duration (H_s) and precipitations (H_r) within the monthly periods were introduced by means of the following expression:

$$H = -\sum_{i=1}^{n} p_i \log_2 p_i,$$

where p_i is the probability of a certain i-th realization interval. Entropy reaches its maximum ($\log_2 n$) in the case of the uniform distribution in all n classes. The quantity

$$\kappa = 1 - \frac{H}{\log_2 n}$$

has been calculated to express the level of homogeneity of sunshine duration (κ_s) and precipitations (κ_r).

The time series of entropies and their changes has been compared with the time series of monthly sums. To bring out the common traits, the annual mean values were calculated and the time-series were smoothed by the means of the technique of harmonic weights. The mean annual curves of entropies and homogeneities averaged over a 92-year period are studied. The width of the intervals used in entropy calculations was 2 h for sunshine duration and 1 mm for precipitations.

A certain periodicity with oscillations lasting approximately 30 years has been noticed in the series of mean annual values of sunshine duration, which is supported by the data for the most months (Fig. 1). The absolute peak was reached at the beginning of the 1940-ties. From these years onward a decreasing general trend can be observed, while the absolute minimum noticed in 1920-ties has no longer repeated. The smoothed curve of annual precipitations has had two maxima. The first rise occurred in the 1920-1930-ties, the second growth began at the end of the 1970-ties and probably has peaked already.

The 92-year series of annual and monthly sums of s and r do not reveal the existence of reliable linear trends, except the sums of sunshine duration in December, where the monthly increase is 8.6 h per 100 years (the correlation coefficient is 0.206), and precipitations in September.

The run of entropies is positively correlated with the run of monthly sums. In the case of higher monthly sums the entropy is higher too (Fig. 1). The correlation is very high for the precipitations on the annual scale and is high for the sunshine duration during the winter half-year. Better accordance is achieved for the smoothed curves than for the yearly oscillations. There is a negative correlation between H_s and H_r.

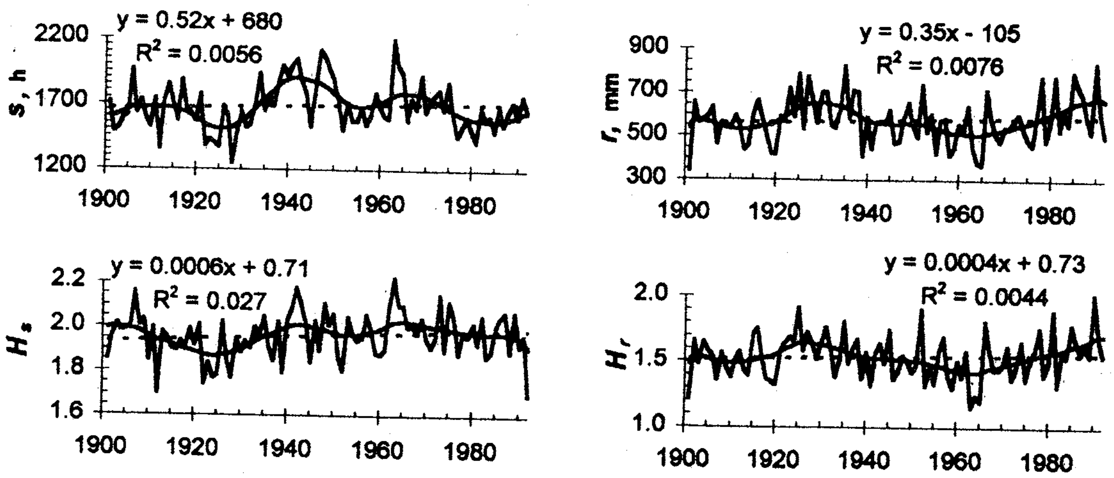

Fig. 1. Time series of annual sunshine duration (*s*), annual precipitations (*r*) and the annually averaged entropies H_S and H_D respectively, in conjunction with their smoothed curves, linear trendlines and trendline parameters

The only reliable increasing linear trend for H_s exists in December, for H_r in August and September. For these months respectively we can declare the increase of changeability of the everyday sunshine duration and precipitations during this century.

The annual mean homogeneity of *s* shows a declining linear trend throughout the period because of decrease in κ_s in the winter months. Particularly strong is the decrease in December - 0,26 per century which is about 43% of the homogeneities' mean value in December. The decline in κ_r falls into the autumn period, being most marked in October.

The annual curves of the long-time mean values of *s* and *r* have their maxima in summer months (Fig. 2). The run of *s* and H_S curves is very similar. It is otherwise in the case for precipitations, where the entropy curve shows no significant annual oscillations (Fig. 2). It must be noted that entropy depends on the choice of the width of the intervals. Therefore entropies of different items are comparable only qualitatively, not quantitatively. The homogeneity of sunshine duration is low (about 0.1) from April to September and is higher (0.5-0.6) from November to January. The homogeneity of precipitations has its values in this interval throughout the year (Fig. 2).

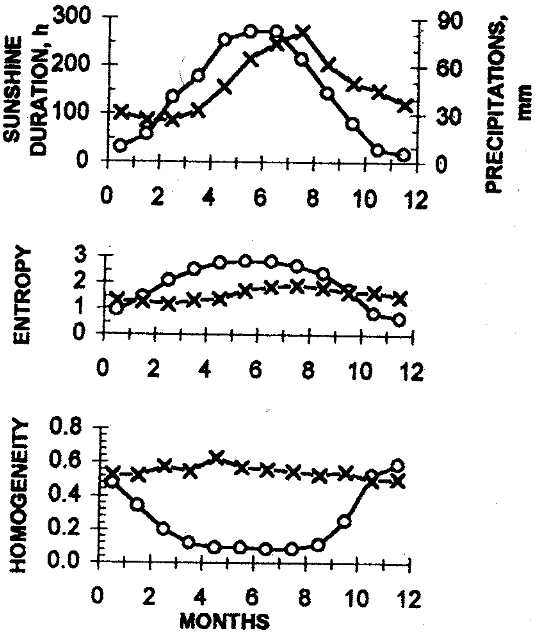

Fig. 2. The mean annual runs of monthly sums, entropies and homogeneities of the daily sunshine duration (o) and the precipitations (×).

As the result of the above analysis covering the 92-year period in Tartu, it can be resumed that the sunshine duration and precipitations show linear trends neither in their sums nor in their entropies, except for the months December (sunshine duration) and September-October (precipitations). A certain periodicity is observed. The mean annual runs of entropies are rather different for the sunshine duration and for the precipitations, their long-time series are negatively correlated.

MICROCLIMATE SYSTEM STUDY

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Microclimatological variability of energy and water exchange processes are closely dependent on the characteristics of the meteorological regime of the air layer near the ground. As a result of the interaction of the ground structure and the weather regime there are formed the climate differences on close areas located between observation stations of meteorological network.

Microclimate affective systems are composed of natural factors and human activity components. Considering with the total effect of these on forming microclimate differences underlines the necessity of application of complexity principle on defining and scientific treatment of the microclimate system. Solving a several applicate tasks and clearing a regional characteristics of climate change the complex microclimate research is essential.

At present the most rational is to realize the complex approach on studying microclimate system using a microclimate cartographical modelling method.

In order to solve the defined tasks the method of cartographical estimate of microclimate and the method of areal estimate of territorial distribution of different microclimate types have been worked out. The application of both methods is based on the concept of microclimate elementary area which means the parts of subsoil which induce changes even in a single climate element in comparison with the indexes of general climatological background.

According to these methods the temporal and spatial changeability of climate elements could be presented in several ways:

- in single climate elements
- as microclimate complexes
- as applicational climatological indexes (the sum of air temperature for agriculture; the dates of the start of heating period - for the purpose of rational use of energy resources)
- as a map of microclimate district.

We are using the data of Estonian Meteorological stations, special observational microclimatological data between 1968-1989 and soil maps in order to study the microclimatological changeability of water and energy change on different geographic areas on agricultural lands of Estonian territory, characterizing a general climatological background by an above mentioned methods.

In order to characterize the energy and water cycle in areas with different microclimate have been compiled the microclimatological maps on radiation balance and its components and water resources. The analysis of those maps shows that the leading factor in forming microclimatological differences is the relief at Upper-Estonia with a variable relief (the absolute difference between heights is about 50-200 m). At Lower-Estonia (the absolute difference between heights is 0-50 m) the leading factors are the differences of soil and the human activity. The range of microclimatological changeability of energy and water resources may exceed the limits of change of those indexes which are determined on the basis of observations in standard meteorological stations.

IMPLEMENTATION OF UNESCO"BALTIC FLOATING UNIVERSITY" PROGRAMME IN THE GULF OF FINLAND

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The objective of the UNESCO "Floating University" Project is to implement marine research programmes around the world with the participation of undergraduate and post-graduate students and researchers from different universities and institutes. The guiding principle of the UNESCO "Floating University" is "Training-through Research". The "Floating University" Programme was proposed to UNESCO in 1987. The proposal was supported by the UNESCO General Conference and the programme was begun in 1991. One of the main purposes of the "Floating University" Project is to prepare highly-skilled specialists in the marine sciences by involving students in practical research within the framework of the major international programmes. The "Floating University" Project envisages the development of practical teaching courses for students, the organisation of scientific conferences to discuss work results, grants for the best students, teacher exchanges and the publication of results in UNESCO's and other scientific journals.

In 1993 the Russian State Hydrometeorological Institute organised a UNESCO "Floating University expedition in the eastern Gulf of Finland. Following decisions of the UNESCO General Conference (1993) and consultations with the National Commission for UNESCO of the Russian Federation, the RSHI was selected by UNESCO as the organisation responsible for extending the "Floating University" into the Baltic Sea region. "Baltic Floating University" activity will follow the general recommendations in "Year 2000 - Challenges for Marine Science Education and Training Worldwide" (UNESCO, 1988).

The "Training-through-Research" cruises of the "Floating University" in the Baltic Sea took place in 1993-94 in the eastern Gulf of Finland, with the R/Vs "Persey", "Professor S. Dorofeev" and the sailing catamaran "Orients" (RSHI, Ministry of Higher Education,Russia). Physical, chemical, biological and geochemical works in the deeper waters were carried out from the "Persey" and "Dorofeev", while shallow-water, coastal work and work within the St.Petersburg flood-barrier were made from the"Orients".

Combining research and training these cruises were sponsored by the RSHI and UNESCO's TREDMAR Programme (Training and Education in Marine Sciences). 26 students from Colombia, Mexico, Morocco, Russia, Cameroon and Ukraine participated in 1993 expedition. 21 students from Finland, Russia, Angola, Cameroon and Zaire took part in 1994 cruise.

On May 25-27th 1994 the RSHI convened a meeting in St. Petersburg to discuss the UNESCO "Floating University" Programme for the Baltic Sea Region. According to the programme of Seminar in Helsinki on 23-24 August there were 24 presentations on the results of BFU expeditions. 73 people participated and 17 institutions from Estonia, Finland and Russia were represented on the Helsinki Seminar.

The hydrophysical, chemical, biological and geochemical data obtained from the research vessels are being used for the analisys of ecological conditions of the Eastern part of the Gulf of Finland.

THE CLOUD CLIMATE IN THE BALTIC SEA REGION ESTIMATED FROM NOAA AVHRR IMAGERY

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1. Introduction

Mean cloud conditions over land areas in the vicinity of the Baltic Sea are quitewell known as long time series of cloud observations from surface stations (SYNOP stations) are available for almost 100 years. Naturally, cloud conditions over the Baltic Sea are less familiar due to the lack of available surface stations. For example, it is well known that the cold sea water suppresses cloud formation near coasts in spring and in early summer but knowledge of the exact minimum in mean cloudiness over open sea far from coasts is still not established from any observations. Some conclusions can be made by interpolating cloud observations from coastal SYNOP stations but introduced uncertainties may then be substantial. This concerns especially the central portions of the Bothnian Sea and the southern part of the Baltic Proper.

2. Satellite-derived mean cloud conditions

Satellite measurements are not restricted by land and sea boundaries and may therefore be used to get a more objective and detailed survey of cloud conditions. This paper describes a method to estimate mean cloud conditions (mean cloud cover) for the Baltic Sea region by use of multispectral satellite imagery from the polar orbiting NOAA satellites. A multispectral cloud classification scheme has been applied to all available NOAA AVHRR (Advanced Very High Resolution Radiometer) imagery since 1988. Monthly means of cloud cover have so far been estimated from a subset of high quality cloud classifications for the years of 1993 and 1994.

3. Comparisons with forecasted cloudiness

Satellite-based analyses of mean cloudiness have also recently been compared to forecasted cloudiness from two presently used numerical weather prediction (NWP) models at SMHI: the HIRLAM model and the ECMWF model. A reformulation of the SCANDIA model was here necessary to adapt the model to be run on a much larger area covering a large part of northern Europe. Cloud forecasts with forecast lead times ranging from six to 36 hours were studied in order to estimate the model spin up of cloudiness. Also, the vertical distribution of cloudiness was studied by comparing cloudiness at selected model levels with the cloud type information from the cloud classifications.

4. Summary

The following items and results are discussed in the paper:

(1) Structure of the cloud classification model SCANDIA (the SMHI Cloud ANalysis model using DIgital AVHRR data).

(2) Creation of monthly cloud climatologies from SCANDIA cloud classifications with four km horizontal resolution.

(3) Satellite-derived monthly cloud climatologies for 1993 and 1994 compared to surface observations (SYNOP).

(4) Annual mean of cloud conditions for 1993.

(5) Seasonal variations in cloudiness related to varying land characteristics (land and sea boundaries, mountain areas, coastal and open sea conditions, etc.).

(6) Diurnal variation in cloudiness for a summer month and a winter month.

(7) The revised SCANDIA model for comparisons with NWP models.

(8) Validation of cloud forecasts from the HIRLAM and ECMWF models.

WATER AND ENERGY BALANCES OVER THE BALTEX AREA FOR JUNE 1993

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Atmospheric water and energy budgets are studied using simulations of a regional-scale model.

The regional model (REMO) is based on the operational limited-area weather forecast model (Deutschland Modell) of the German Weather Service. It covers the catchment area of the Baltic Sea including a boundary zone. The horizontal resolution is about 18 km. Lateral boundary conditions are provided by the Europa Modell (approx. 50 km horizontal resolution) and the Global Modell (approx. 200 km) of the German Weather Service.

The water and energy balance is determined from short-range predictions that are carried out for selected time periods, starting with may and june 1993. All budget components are available on an hourly basis for 6h to 30h forecast time.

The validation of individual components of the simulated water and energy cycle is necessary to assure reliable estimations of the balance. It will also indicate possible deficiency in the parameterizations of the physical processes and their feedbacks in the model. At the moment routinely observed data from the national meteorological and hydrological services in the countries surrounding the Baltic Sea as well as satellite data will be used for the validation. Lateron during BALTEX specially designed experiments will provide more detailed datasets. One of the main points is the validation of the precipitation field because this is a critical input parameter for hydrological models. The model precipitation is compared to measurements from the operational rain gauge network of the meteorological services as far as they are available. First results for selected regions indicate that the model underestimates the total amount of precipitation. The reason is not only an underestimation of rain rates but also a mismatch between the predicted position of the precipitation regions and reality. Clouds which are related to both, water and energy cycle, are another parameter which has to be validated. The location and especially the motion of cloud systems will be examined using satellite images.

RELATIONSHIPS BETWEEN SNOW COVER AND TEMPERATURE IN SNOW TRANSIENT REGIONS

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The BALTEX area belongs to the regions that are characterized by large interannual fluctuations of the frequency and extent of the snow cover. Such regions are referred to as snow transient regions.

The snow-cover extent and frequency are mainly forced by temperature change, but have a strong feedback to the radiation budget and affect indirectly temperature. During autumn and early winter this feedback is positive - the Earth's radiation budget increases with the increase of the snow-cover extent. Starting from February, the net feedback of the snow-cover extent on the Earth's radiative budget is negative and the cooling effect of snow cover due to albedo dominates over the warming influence due to the reduction of outgoing longwave radiation (Groisman et al. 1994).

In this paper, attention has been paid to the relationships between snow cover and temperature in the second half of the hydrological year, i.e., during the period of intensive spring heat accumulation in conditions of negative snow feedback when radiative and hydrological processes depend on the existence or absence of snow cover. Data on the snow-cover fraction (or surface albedo) and the near-surface temperature have been taken from the International Satellite Cloud Climatology Project C2-level sets. The analysis has been carried out for latitude zones of seven longitudinal sectors of the Northern Hemisphere where strong interannual variability has been detected.

High correlation between the surface albedo or snow-cover fraction and the simultaneous temperature in Europe and in the eastern part of North America is described. In these regions also significant correlation between the spring heat accumulation and late winter snow-cover fraction is found. This fact can contribute to the prediction of summer temperature and humidity regime by using the late winter snow data in these regions.

P. Ya. Groisman, T.R. Karl, R.W. Knight, and G.L. Stenchikov, 1994: Changes of snow cover, temperature, and radiative heat balance over the Northern Hemisphere, J. Climate, 7, 1633-1655.

ON HIBLER'S MODEL OF LARGE-SCALE SEA-ICE DYNAMICS INCLUDING ITS APPLICATION TO THE BALTIC SEA

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Hibler's well established model of large-scale sea-ice dynamics is considered. Although sea-ice is a granular material made up of floes it has become usual to view and treat its large-scale features as in the framework of continuum mechanics. It is modelled as a fluid rather than a solid body. In addition, the complete model of sea-ice dynamics comprises momentum budget equations for the ice drift velocity and conservation laws for continuity of its mass and compactness.

The ice cover is assumed to be a two-dimensional isotropic compressible fluid. In particular the constitutive hypothesis is of viscous-plastic type. Usually it is stated in terms of viscosities not only for the viscous state but also for the plastic one. In contrast, the constitutive equations are reformulated here in terms of projection to the convex yield body in stress space. In this way, Hibler's physically dubious relationship between yield stress and hydrostatic pressure becomes superfluous and is dropped. The point of view of projection also gives a suitable approach to mathematical investigation and numerical treatment.

Hereby the central problem is posed by the sensitive crucial adjustment of the quasistatic equilibrium of forces as the most rapid respond to the forcing. Together with the utterly stiff constitutive law the balance of forces gives a strongly nonlinear system of partial differential equations. Its mathematical features (existence and uniqueness of a solution) may be clarified making use of variational inequalities and general theorems on equations including nonlinear monotone operators in Hilbert spaces.

As a result, the solution to Hibler's problem is unique if there is any. However, because of the ideally plastic restriction to stress the problem is not coercive. Thus, the existence of a solution is not guaranteed. Therefore, to ensure a solution, the constitutive equations should be modified from ideally plastic to slightly strain-rate-hardening.

Based on this an appropriate fully implicit numerical procedure is presented. The nonlinear problem is iterated by a sequence of linearisations. However, the linear problems turn out to be badly conditioned whence iterative treatment by common solvers is not satisfying. Therefore exact elimination is employed.

Such an algorithm was incorporated into the BSH's operational model of the North Sea and the Baltic Sea. This model is driven by a set of dynamic thermodynamic parameters of the atmosphere daily delivered by the German Weather Service. It simulates large-scale patterns of water level, circulation, salinity, temperature and ice cover. The ice component of this model comprises both dynamics (drift) and thermodynamics (growth, melting) which are interacting. The latter is essentially due to Maykut & Untersteiner. Although highly nonlinear too, it is conceptually relatively simple because it consists of ordinary differential equations only, i.e. lacks any horizontal coupling.

The complete ice model has been working uninterruptedly since late autumn 1993 at BSH. So far the model is without any manipulation (assimilation, reinitialization etc.). Because of its numerical effectiveness it is suited not only for operational use but also for the simulation of long-term features of sea ice and related effects.

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RETRIEVING OPTO - METEOROLOGICAL CHARACTERISTICS AND ITS APPLICATION FOR CALIBRATION OF SMMR SEA ICE CONCENTRATION DATA.

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Retrieving opto-meteorological characteristics of cloudy atmosphere and hydrological parameters of the ocean is developed on base of satellite multispectral remote sensing data. The original complex technique along with the known threshold and statistical methods incorporates a special procedure of data assimilation with simulation of indirect satellite measurements and solution of ill posed inversed problem. The technique is used for processing of AVHRR data to retrieve opto-meteorological parameters of clouds and for verification of cloud parametrisation scheme in numerical models of athmosphere.

Some results of this method are used in the processing of computing sea ice concentration from AVHRR brightness temperature. It allows to calibrate ice concentration values more accurately.

The algorithm and applied software are developed for analysis and interpretation of remote sensing data. Some examples of using of this information are done for climatological researches based on atmosphere and numerical modelling of processes in the Baltic Sea, which could be connected with researches within the GEWEX.

ON WATER RENEWAL OF INTERMEDIATE LAYERS OF THE BALTIC SEA

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The renewal of the Baltic Sea watermasses below the halocline takes place through inflow of more saline waters from the Kattegat. Due to the higher density, the water flowing in moves as dense bottom current mainly trough the Great Belts, but also through the Öresund. The sill depth in the Great Belts is 18 m at the Drass Sill, while the sill depth in the Öresund at the Drogden Sill is only 8 m. In the Arkona Basin, the inflowing water forms a dense bottom layer, about 5-15 m thick, and with salinities up to 24 PSU. The maximum depth in the Arkona Basin is about 55 m. Due to meteorological forcing the water exchange between the Baltic Sea and Skagerrak is higly variable. Salinity of the inflowing water in the Arkona Basin is decreased remarcably by wind driven mixing with less saline surface water. Finally water masses with quite different salinity interleave into layers beneath the halocline.

Historical data show intensification of thermohaline anomalies during late autumn and winter seasons in the halocline layer of the central deep area of the Baltic Sea- in the Gotland Deep. This is mainly caused by processes as intensive currents, tonques and vortex lenses of anomalous water. Intrahalocline lenses with a diameters of 11-13 km in the depth range of 90-130 m are more treated in the present work. CTD data collected at several cruises of R/V Arnold Veimer are used. An anomalous by temperature ($T = 0.5 - 1.2$ °C) water mass forms isolated horisontally symmetric waterbody with a lenselike shape on the vertical section of the density field. Maximal displacement of isopycnals from their reference state, 15-20 m in the centre of the lense gives an geostrophic orbital speed of 0.1-0.15 m/s of anticyclonic rotation, which was confirmed by direct current velocity measurements. Drifting speed of the lenses was in the order of background velocities, 0.01 m/s, and showed circlelike trajectories with contraclockwise direction in the Gotland Deep. TS analysis and biological-chemical measurements showed that the water inside the lenses has its origin from the surface layer. A halocline ventilation mechanism is presented: when the thermocline is pushed down to the halocline due to late autumn wind and thermal conditions, the winddriven movements and vertical mixing will reach the isopycnal layers, 7-8 kg/m^3 in the Southern Baltic. Since the topography of the isopycnal surfaces prove to be deepening towards the Central Baltic, intensive density-driven currents will carry anomalous surface water into the halocline layer in the Gotland Deep. Due to current instabilities lenses are formed, which are capable to carry anomalous water all over the area of halocline in the Gotland Deep.

The conclusions to outline the study are:

- The horisontal advection of water masses with intermediate salinity, play the major importance ventilating the upper deep layers of the Baltic Sea.
- If water masses of deepest deep layers in the Baltic Proper are renewed only by major inflows, then parallel process can be drawn out, the ventilation of intermediate or

upper deep layers (just below the halocline 70-80m), when salinity/density of intruding into subbasin water mass is not high enough to interleave into near bottom layer.

- Thermohaline anomalies in the halocline layer of the Baltic Proper showed remarcable increase during the late autumn and winter seasons, from which one concludes the occuring the ventilation of intermediate layers during these seasons.
- Watermasses ventilating seasonally the halocline layer in the Central Baltic Proper, are originating from the surface layer of the Southern Baltic - the Arkona and Bornholm Basins. Wind forcing in relatively shallow Southern Baltic is initial driving mechanism for strong alongchannel currents and jets, which then continiue further along the isopycnal surfaces into the Gotland Basin.

ESTIMATION OF SURFACE ALBEDO AT HIGH LATITUDE CONDITIONS FROM NOAA AVHRR DATA.

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In climatological terms surface albedo, or reflectance of the surface element of interest, is defined as the ratio of the reflected radiant flux density to the solar irradiance taking their components perpendicular to earths surface. Best possibility for long term monitoring of land surface albedo globally, is the use of remote sensing from polar orbiting satellites.

This paper represents surface albedo values of 9-day compositing AVHRR images in Finland over the period April to October in the year 1994. In middle summer the albedo was 15 to 18 % for fields, 11 to 13 % for forestry land, 15 to 16 % for open mires, 14 to 18 % for high moreland and about 5 % for open sea. In snow-melting period the changes in surface albedo were mainly caused by the retreating of the snow towards the north. The albedo limit between snow-covered and snow-free land was assumed albedo value as 20 %. According to the maps of snow depth the same kind of changes in the 20 % albedo limit and in the snow cover was observed.

The annual variation on different surface types was also investigated. In the beginning of April the highest albedo (66 %) occurred in the ice-covered northern part of the Gulf of Bothnia. The albedo of snow-covered forestry land in the Northern Finland was about 50 % but in the Eastern Finland only about 30 %. We assumed that the albedo difference between these regions was caused by the properties of snow. In the snow-free field regions in April the albedo was about 13 %. At the end of May the snow and ice have melted in the Finnish region and the surface albedo was everywhere under 20 %.

During the snow-free period 26. April to 26. September the effect of ground humidity on the surface albedo was investigated. The chosen regions were two northern forestry regions and two southern field regions. In the field regions an inverse correlation between the ground humidity (amount of precipitation) and albedo was seen. In the forestry regions this correlation was ambiguous.

The albedo pixel distributions inside the 24 x 24 pixel squares of different surface types were analyzed in the cases of spring and middle summer. For all above mentioned surface types the deviation of pixel distributions was notable greater in spring than in middle summer. The deviation difference between spring and summer came probably mainly from the partial snow cover in spring. In the open sea region the deviation difference came from the mix of melting ice, ice floats, brash ice and clear water.

ON WIND PATTERNS FORCING MAJOR INFLOWS INTO THE BALTIC SEA

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Salt water inflows into the Baltic Sea are important processes for both maintaining the general stratification and the ventilation of the bottom water in the deep basins of the central Baltic. These events occur preferably during the winter season in a random sequence of one to several years. This sequence changed since the mid-seventies when only weak or no major inflows were observed. During that period a steady loss of salt together with a steady increase in hydrogen sulfide concentrations was observed in the central Baltic deep water.

It is generally assumed that strong westerly winds force a salt water inflow. Long time series of daily wind records at the meteorological station Arkona and sea level observations at Landsort tide gauge station between 1951 and 1990 has been analyzed in order to find characteristic sequences beeing associated with inflow events. A necessary condition for the wind to force a salt water inflow is to blow for several ten days effectively from west.

The weighted mean of the yearly cycle of the wind components for years without and with salt water inflows revealed that this condition happens usually in November and December of each year. But in years with inflows a long lasting easterly wind occurs between October and November before the strengthening of westerly winds. A similar sequence is observed in the yearly cycle of the mean sea level of the Baltic Sea, i.e. in years with inflows a lowering of the mean sea level precedes the increase of the sea level in November to December.

Hence, major salt water inflows are obviously 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.

A COUPLED ICE-OCEAN MODEL OF THE BALTIC SEA

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A three-dimensional eddy-resolving baroclinic model of the Baltic Sea is coupled with a Hibler-type ice model. The model comprises the whole Baltic Sea including Gulf of Bothnia, Gulf of Finland, Gulf of Riga as well as Belt Sea, Kattegat and Skagerrak. The horizontal resolution is 5 km and in the vertical 21 levels are specified. The two-dimensional ice model has the same horizontal resolution as the ocean model. The ice-ocean model is forced by meteorological fields from the Europa Model of the Deutscher Wetterdienst in Offenbach. The coupled system is used to investigate the influence of ice-coverage on the circulation of the Baltic Sea and the water exchange with the North Sea. The system is only dynamically coupled, neglecting ice thermodynamics. This is no restriction for the generality of the model solutions because the ocean model has been proved to simulate in- and outflow through the Danish Straits in a reasonable way. The impact of sea ice on the water mass exchange can thus be studied by prescribing different ice-coverages retaining the wind forcing. Due to the sea ice the amplitudes of the sea level variations are reduced. The influence of ice-coverage on the water exchange with the North Sea is a function of the ice-extent and compactness.

OBSERVATIONS OF THE DEEP WATER FLOW INTO THE BALTIC SEA

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It has been hypothesized that the deepwater flowing in to the Baltic Sea forms a bottom pool in the Arkona Sea. The flow from the pool further into the Baltic Sea was assumed to be baroclinic geostrophic and controlled by the stratification in the pool.

To reveal the dynamics of the Arkona Basin a hydrographic survey was undertaken shortly after a major inflow event in the beginning of 1993. Several CTD sections reveal a thick pool of dense water with a complicated current field recorded by a ship mounted ADCP. Subtraction of an assumed barotropic part gives a current field similar to that computed from the density distribution. Thus, a dense bottom pool including a baroclinic geostrophic boundary current along the northern flank is quite evident from our measurements.

BASIC PHYSIOGRAPHIC INFORMATION ON THE BALTIC DRAINAGE BASIN

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Basic physiographic information on the Baltic drainage basin is in great demand from many sectors. Specific needs as well as general needs of basic data have been studied. Current work in the field as well as known available datasets are also presented.

Parameterization of lake thermodynamics in a high resolution weather forecasting model

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The particular effects of inland lakes have so far been neglected in weather forecasting models. Therefore a model for the parameterization of lake temperature and ice thickness in the High Resolution Limited Area Model (HIRLAM) surface parameterization scheme has been developed at SMHI. The model calculates the surface temperature and ice thickness of the lakes and uses a new data base including the positions, the areas and the mean depths of the Swedish lakes. Sweden has about 92,000 lakes, larger than 100x100 m spread over the whole country. These lakes cover together about 9 % of the land area. When the lake model is used in HIRLAM, all the smaller lakes and the fractions of larger lakes within each horizontal grid square of the meteorological model are parameterized by four "efficient" lakes with four different lake depths.

The lake model is based on thermodynamics and it is forced by the meteorological model via short wave radiation, total cloudiness, air temperature, air humidity and low level winds. The lake depth is an important parameter of the lake model. In the mathematical formulation, each lake is treated as one well mixed box with the depth D(the mean depth of the lake) which follows a heat conservation equation. The model time step is one hour and every third hour new meteological data are read.

The ice growth is best described a a combination of frazil ice and columnar ice. The frazil ice consists of ice crystals that are formed during turbulent water conditions. When the first centimetres are formed, the ice grows linearly to time (frazil ice) and later, when there is 5 - 10 cm of ice, the growth is slower and proportional to the square root of the time (columnar ice). The short-wave radiation, that goes down through the ice surface minus the short wave radiation that goes through the ice and down into the water, melts the ice. For the calculation of the heat fluxes there is a program called PROBEFLX at SMHI that with date, latitude and standard meteorological data (SYNOP-data) determines the sensible heat flux, the latent heat flux, the short-wave radiation and the net long-wave radiation.

The lake model has been tested against both a more advanced model and observed data. The model works well with temperature compared with the more advanced model. The prediction of ice formation and ice break-up dates also works satisfactory compared with the same model. A test against surface water maps of lake Vänern shows a mean error of 1.7 °C (see Figure 1). A test of the ice formation and break up dates against observed dates during 9 years gives a mean error of about 7 days which is regarded as a good result. The lakes in the north are easier to simulate than the ones in the south where the temperature oscillates around 0 °C during the winter. The deeper lakes are generally more difficult to simulate.

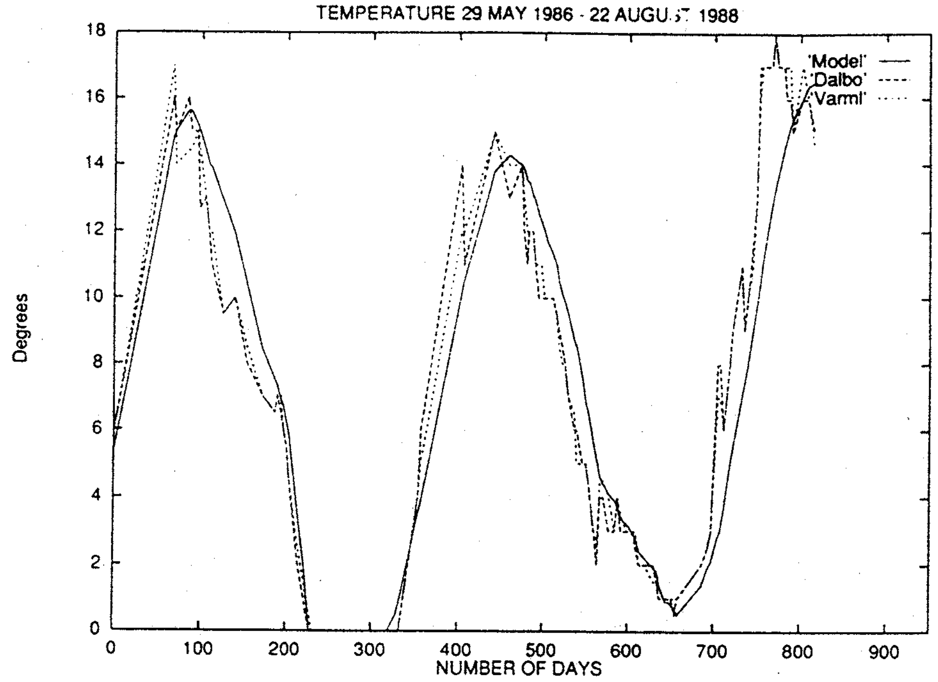

Figure 1. *Lake Vänern and its two parts Lake Dalbo and Lake Värmland (Varml.). 29 May 1986 - 22 August 1988.*

A parallel run with the Lake model coupled to the HIRLAM data assimilation system has been carried out for the period 2 - 16 May 1994. Before the lake model was inserted into HIRLAM it was spinned up with SYNOP data during about one year. Compared to standard HIRLAM this test shows a decrease of the 2 meter air temperature mainly in the ice-covered areas. The decrease is maximum 2 °C. The study illustrates the importance of introducing a model for the temperature and ice on the lakes as the climate data badly simulates the actual situation.

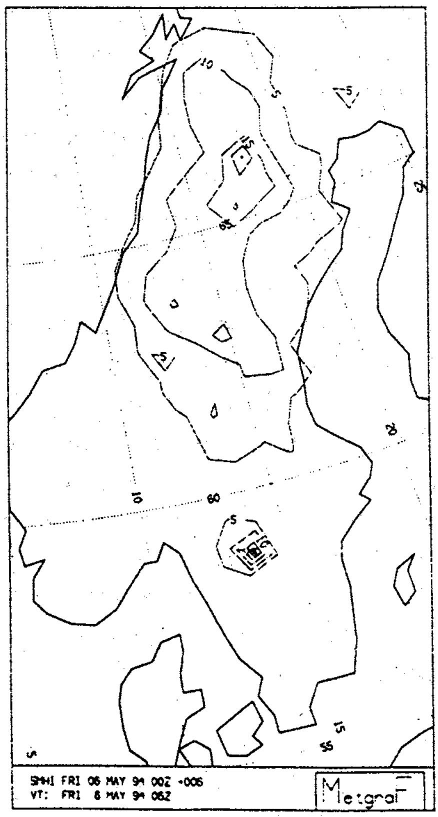

Figure 2. *2-meter temperature decrease when using the lake model in HIRLAM*(tenths of °C)

SIMULATION OF THE WATER CYCLE OVER THE ELBE REGION - A GRID - RELATED MODEL FOR RIVER ROUTING AND OVERLAND FLOW.

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It is aimed at creating a hydrological model to asses the main characteristics of the land surface water regime in the BALTEX region which determines the water boundary conditions for exchange processes between land surface, soil and atmosphere. An application of a grid related conceptual hydrological model within a main part of the Elbe river basin has been done and the results are discussed.

The processes of the the land phase of the hydrological cycle can be divided into processes describing the vertical water movement and processes describing the horizontal water movement. The vertical processes describe such exchange processes between the atmosphere and the land surface as evaporation, interception,infiltration, soil moisture recharge, rainfall and overland flow formation. Runoff comprises stormflow ,with the components instantaneous runoff or quickflow, delayed runoff and baseflow. The time scales of the parts of runoff are different. The contribution of each runoff must be treated separately to build in the total runoff. The horizontal water movement is divided into overland and channel flow phases.

The water movement in the river channels is computed by flood routing based on the instationary diffusion wave approximation for the momentum equation. The friction accelaration term can be expressed using the Manning equation for steady uniform flow. Conservation of mass takes into account all tributaries and the overland flow. For the computational procedure we have to set up a link-node network, which allows the computation of complex branching flow pattern. This network solves the equation of motion and continuity at alternating grid points. At each time step, the equation of motion is solved at the links and the equation of continuity is solved at the nodes or junctions. Lateral inflow and overland flow takes place at the junctions.

The regime of the overland flow is controlled by the roughness coefficient and by the landslope. The assumption of constant velocity leads to the theoretical concept for linear reservoirs. The storage coefficient K is defined for each grid . The direction of overland flow is determided by the steepest gradient of height. It forms a network which at least is an influx to a junction point of the channel river system.

A grid of about 18 x 18 km has been overlayed the Elbe river basin which network correspond to the BALTEX Regional Model (REMO), a numerical weather forecast model.

This study includes the Elbe - Saale - Mulde catchment area of about 40.000 skm, which is part of the German Elbe catchment . The Saale, Mulde basins are of mountain regions. The upper boundary condition of this basin is well defined by the water discharges at the gauge of Schoena which is situated at the River Elbe near the border between Chech Republic and FRG. The outlet of the whole catchment is also well defined by the gauge of Magdeburg.

The river network has been defined by digital mapping. Input data for each junction is the water initial surface and bottom elevation above the mean local sea level. For each link we have determined the flow direction, the roughness coefficient, river length and width. The whole area has been divided into sub - catchments. The prescription of the grid points to a defined watershed is sometimes ambigious, but we have tried to find a real areal description. Computing overland flow a mean height of a grid above the mean local sea level and a roughness coefficient is used.

Long times series of gauges measuring discharge and water level were used to perform a data assimilation procedure finding the best fit for the parameter set needed in the evaluation of overland flow and river routing. The roughness coefficient was the primary calibration parameter. Measured time series of daily precipitation, air temperature, air moisture and cloud cover were taken to evaluate the runoff generation with the help of a one dimensional SVAT model. Using the effective parameter set, a one year long model output was compared with measured discharge series. There were also available two month long runoff model data from the REMO, which were used as input in the hydrological model. For these two months a comparison of measured and modelled runoff was done and the results are discusssed.

HYDROLOGICAL MODELLING ON THE REGIONAL SCALE

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Using measured data and output from the regional numerical weather predicition model (REMO) [RO95] over the BALTEX area, hydrological calculations are done in the catchment of the German river Weser and in a catchment which drains into the Baltic Sea. The hydrological model consists out of three different components to allow for the different demands of hydrological and atmospherical models. It takes into account that detailed data for physical hydrological modelling (like MIKE-SHE) are not available over large areas in BALTEX.

The overall concept is to identify some large scale hydrological parameters by doing invers modelling with measered river discharge and rainfall data. The idea will be followed to use a nonlinear model for runoff production [XU94], which also fulfils atmospheric demands and a linear model for overland flow, base flow and river routing [MES86] [DU93].

River routing is done with the linearized St. Venant equation. It can be shown that this is not a strong limitation, because of fast overland flow and base flow having longer time scales. The main advantage of the linearized St. Venant equation is, that it only has two free parameters, which can be determined out of streamflow or topographic data.

The fast overland flow component (0-6 days) is calculated with a modified FDTF-ERUHDIT (First Differenced Transfer Function - Excess Rainfall and Unit Hydrograph by Deconvolution Iterative Identification Technique) method [DU93]. Invers modelling allows to determine the effective rainfall which goes into the fast runoff component and an estimation of some parameters in the vertical soil moisture model.

The vertical model is similar to the model presented by [XU94]. It is used for the calculation of the sensible and latent heat fluxes, soil water content, soil temperatur and runoff. It accounts for horizontal heterogenity.

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TRANSFORMATION OF MEASURED FLOW DATA TO GRID POINTS

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The development of grid related estimates derived from point measurements of stream discharges are described. Estimates of gridded runoff data have been developed on a monthly basis for the period 1971 to 1980 for a 0.5° x 0.5° grid net. The results are areal weighted runoff values based on the catchment boundaries together with their physiographic properties (elevation, landuse, soils etc.). The study area covers the Weser river basin (AE 46.472 km^2) and Elbe river basin (AE 144.055 km^2). Computations for the period 1961-1990 are in preparation.

The method used in the study is following the agreements within the WCP-Water Project B.3 "Development of Grid-related Estimates of Hydrological Variables" utilizing the subsequent applications:

(i) Application of discharge values using areal weights only.
(ii) Application of empirical-statistical relationships between physiographic properties and runoff in the catchment.
(iii) Application of (ii) in contribution with hydrometeorological parameters.

A Geographic Information System (GIS) is being used as an adventageous tool for overlaying and analyzing the spatial data sets (DEM, soils, landuse etc.) to allow the interactive estimation of the runoff values.

For water resource management requirements the grid size can be altered for different applications on a regional and global scale. The adaptation to the grid size 0.125° x 0.125°, e.g. used by the German weather service is intended. It is also proposed in future applications of this study to validate the results with a varying number of gauging stations.

CHARACTERISTIC ATMOSPHERIC CIRCULATION PATTERNS NECESSARY FOR THE OCCURRENCE OF MAJOR BALTIC INFLOWS

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The water exchange between the North Sea and the Baltic is one of the key processes for the water and salt balance of the Baltic Sea. Inflows of highly saline and oxygenated water into the Baltic Sea, termed major Baltic inflows, are among the extreme exchange processes between the two seas. They contribute to a large extent to variations in the salt budget of the Baltic. However, major inflows are very intermittent and rare events. The forcing mechanism behind these events and its long-term changes is not understood in detail.

A characteristic atmospheric circulation pattern is obviously necessary for triggering major Baltic inflows. In order to identify that pattern we analyzed the mean sea level pressure field and the mean geostrophic wind conditions before, during and after the 87 major inflows between 1899 and 1976. The analysis is based on a daily 5° x 5° grid point data set covering the North Atlantic and Europe.

The results show that major inflows are substantially caused by strong developed zonal wind and pressure fields over the North Atlantic and Europe with relatively small variations in direction. About a decade before the start of the main inflow period, the Azores High shifts in north-eastern direction connected with increasing pressure. At the same time the centre of the lowest pressure moves eastward from the Greenland-Icelandic area to northern Norway while strengthening. Due to these movements very strong pressure gradients occur over the North Sea and the entrance area to the Baltic. The maximum gradient could be found two days before and on the first day of the main inflow event, respectively. Strong inflows are characterized by higher pressure gradients than weak events.

The eastward component of the geostrophic wind over the transition area between North Sea and Baltic increases during the 15 day pre-inflow period from about 3 m/s to 14 m/s on the day before the start of the main inflow and decreases during the main period. The northward component changes not until 2 days before the beginning of the event from speeds of 1 m/s from south to values of 3 - 4 m/s from north. The stronger the inflow, the higher both the mean wind speeds and the duration of the strong wind period.

A REGIONAL HIGH-RESOLUTION MODEL OF THE WESTERN BALTIC IN CONNECTION WITH DATA ASSIMILATION USING THE ADJOINT METHOD

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One of the projects of BALTEX is the modelling of the water and salt budget of the Baltic catchment area. The calculation of the net outflow from the Baltic will be an important component of the water budget of the whole BALTEX region. To achieve this objective, an accurate monitoring of the highly variable in- and outflow through the narrow Danish straits over longer time periods is required. A first test period was chosen from October 1992 until December 1993 including the latest major inflow of saline water into the Baltic in January 1993. Our present calculations are based on data assimilation into a numerical model of the Baltic Sea using the adjoint method and are aimed at a precise description of the water and salt exchange through the Danish straits.

In this context we use a three-dimensional baroclinic model, a special version of the so-called GFDL model with a free surface (Bryan-Cox-Killworth). To resolve the topography of the Danish straits we developed a regional model of the western Baltic with a resolution of one nautical mile in horizontal and 3 m in vertical direction. The model domain comprises the Kattegat, Belt Sea, Arkona and Bornholm Basin. For regional models it is very important to implement time and space dependent active open boundary conditions for temperature, salinity and surface elevation because the dynamics in the model area depend strongly on the along-strait gradient of sea level and of the hydrographical situation in the Kattegat. Temperature and salinity values at the boundaries in case of inflow can be provided by observed profils. In case of outflow an Orlanski radiation condition is implemented. The wind forcing is calculated from surface pressure fields from the German weather forecast model for Europe (Deutscher Wetterdienst, Offenbach). A realistic temperature and salinity distribution for starting the model is constructed by using objective analysis of measurements from October 1992. In the same manner SST charts for the whole test period are calculated to force the model to realistic surface conditions. More than 2000 temperature and salinity profils and sea level data obtained from tide gauges are collected and will be used for the calculation of the boundary and surface conditions as well as for the assimilation procedure described in the next paragraphs.

With this regional high-resolution model we can simulate the inflow of saline water over Drogden and Darss Sill in January 1993, the subsequent sinking down to the bottom of the Arkona Basin and its flow through Bornholm Gatt to Bornholm Basin in February, where it sank down to the bottom, thereby lifting up the old bottom water which partly left the Bornholm Basin through Stolpe Channel, in good correspondence with the observed data. A detailed analysis of the spreading of the saline water after the inflow is presented. Of course, there are model-data differences manly due to the inaccurate wind fields, which show a tendency to be too smooth causing differences between observed and modelled sea level. To overcome these deficiencies the complete adjoint code of the free surface version of the GFDL model for the purpose of data assimilation was developed at our institut. This allows simultaneous assimilation of all different kinds of data.

In a first step the assimilation of sea level data into a barotropic model for the whole Baltic with low resolution (six nautical miles) and prescribed monthly means of river run off is used to improve the meteorological forcing. The cost function consists of the squared model-data-differences of wind velocities and sea levels. Control variables are wind stress and air pressure on time scales of one day up to one year. It is shown, that the assimilation projects high frequency fluctuations from sea level data onto the smooth model wind. This procedure provides forcing and boundary surface elevation for the regional high-resolution model.

In a second step the results will be further improved through the assimilation of temperature and salinity data directly into the regional model.

SWEDISH WEATHER RADAR DATA IN BALTEX

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Sweden has an operational network of nine Ericsson C-band doppler weather radars. Within the next few years this number will increase to 11 or 12. The radars are interconnected through the NORDRAD cooperative project among the countries of Sweden, Finland and Norway. Composite radar images are generated every 15 minutes around the clock through this network, covering most of the Baltic Sea, Sweden, large areas of Finland and part of Norway. The range of each radar in non-doppler mode is 240 km and geometric resolution is 2 km. The main tasks of the network are *precipitation monitoring* and *wind measurements.* This paper will present and discuss SMHI's uses of Swedish weather radars with special emphasis on BALTEX.

1 Preprocessing of imagery

Weather radar images are often distorted by undesired effects. Examples of such effects are: clear air echoes, anomalous propagation echoes (anaprop) and jamming by military activities. Anaprop is a particularly difficult form of noise that must be removed; it is caused by superrefraction of radar waves which result in echoes being generated from the earth's surface. Such echoes can reach strengths above 60 dBz which is comparable to severe thunderstorms. The Ericsson doppler weather radars are designed as operational sensors, as opposed to experimental instruments, and thus do not presently allow an operator to analyse the raw radar signals on their way to forming an image. A comprehensive preprocessing of image data using image analysis methods is therefore an essential step as the result will affect all consequent analysis of the radar data. We propose to evaluate an operational routine that makes use of two methods for identification and removal of undesired effects in radar data. The two methods are applied to the data from the individual radars before the composite image is generated.

Time filter: A time series of five radar images is defined. Echoes which move in any direction during the time series are isolated. Echoes which are static in space and time are removed. Premiminary results show an effective removal of anaprop, no matter how strong, as long as it is static in space and time for the given image series; precipitation information is retained unchanged. Problems arise when strong anaprop varies considerably in space during the time series.

Wind filter: The doppler mode of the radars is exploited to estimate radial wind speeds. The range in doppler mode is 120 km with a geometric resolution of 1 km. A logical routine is implemented where the corresponding wind image for each precipitation image is cross-checked. Precipitation echoes having no corresponding wind echoes are removed. This routine is effective in removing anaprop and clear air echoes but a certain proportion of precipitation echoes is also removed. A natural drawback is that the routine only works in the radar's doppler area.

2 Applications of weather radar

Quantitative precipitation analysis: Analysis of accumulated precipitation is pursued in the Mesoscale Analysis Project. The analysis scheme utilizes radar reflectivity, synoptic observations and HIRLAM precipitation forecasts. A fixed Z-R (reflectivity-rainrate) relationship is used and corrections for the vertical reflectivity profile and anaprop are applied.

Quantitative precipitation forecasts: The radar precipitation forecast scheme produces quantitative precipitation forecasts for up to three hours. Input data is presently a simple radar image and a steering wind from HIRLAM. The scheme is now developed to use the composite radar image, and to include HIRLAM precipitation forecasts as well as corrections for the vertical reflectivity profile and anaprop.

Vertical wind profiles: A Velocity Azimuth Display (VAD) routine to retrieve the vertical profile of horizontal winds above the radar antenna will become implemented at all the Swedish doppler weather radars during the spring of 1995. Besides horizontal wind, the routine estimates horizontal divergence, the vertical velocity of the air and the targets. Winds are obtained from precipitation echoes as well as clear air echoes. Precipitation echoes usually give winds up to 6-8 km height, while clear air echo winds are confined to the warmer seasons and the planitary boundary layer (up to 1-2 km).

Vertical reflectivity profiles: A routine similar to the VAD, but which retrieves reflectivity instead of winds, may be implemented.

GENERALIZATION OF MESOMETEOROLOGICAL MODELING RESULTS FOR THE LARGE-SCALE ESTIMATES OF LAND-ATMOSPHERE ENERGY EXCHANGE ON THE RUSSIAN PLAIN

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The vertical fluxes of some substances in the surface air layer mean for a diverse territory (integrated vertical fluxes - IVF) were obtained by two methods: 1) as a result of weighting the fluxes (calculated by Monin-Obukhov equations) typical for the given landscape and weather type; 2) after horizontal averaging the fluxes calculated by the mesoscale meteorological model. The main task of the study was to describe the behaviour of the IVF obtained by the model and to investigate the reason(s) of the contrasts between 2 sets of IVFs.

The model is full hydrodynamic non-hydrostatic, based on the right-angled coordinate system, with the L-b closure for the turbulence coefficient calculation. The experiments were done for the horizontal resolution of 2 km and more, for the lower troposphere layer (up to 2 km by height), with the vertical levels amount from 9 to 20. The values of albedo, roughness length and relative surface wetness were prescribed for every given landscape type. The geostrophic wind velocity at the upper model boundary, cloud cover fraction, season and hour were taken as external parameters (the latter 2 give air temperature and humidity as well as the solar radiation income). Two different landscape types with some properties were taken for every experiment, each occupying 50% of the territory like on the chess-board.

The following conclusions can be made from the obtained results.

(1) Maximum differencies between 2 series of IVF (up to 100%) were obtained for very low wind velocity (0.5 m/s) and strongest surface temperature contrasts between landscapes (10 degrees like melting snow and bare soil). For the wind speed 20 m/s the IVF differencies were 10% only.

(2)The modeled IVF values don't depend on the absolute size of the landscape cells if the latter is the constant fraction of the territory size: cells with the size of 2x2 km inside the modeling territory 50x50 km give the same IVFs as the 100x100 km cells inside the 2500x2500 km territory. If the ratio of the landscape cells size to the total territory size changes from 0.08 to 0.4, the absolute values of the modeled IVF grow nearly 1.5 times linearly.

(3)The convective processes practically don't influence the IVF values obtained by the model. They result mainly from the advection in the lowest 100 meters of the boundary layer. The replacement of hydrostatic condition by non-hydrostatic one practically does not change the IVFs.

(4)The main reason in the appearance of the IVF differencies is the local circulation of the breeze type around the landscape spots, especially for the weak geostrophic winds (0.5 - 2 m/s). Its direction isn't the same as the main wind direction.

So, for the parameterization of IVFs for large territories (for example, for the GCM grid cells with the resolution of 250-1000 km) is possible according to the results of many runs of mesometeorological model for different external conditions considering the relative size of the landscapes. Such parameterization was developed for the typical landscapes sets at the Russian plain territory. The scheme allows one to obtain the IVF values for large territory for different external parameters and the landscapes' condition as well as their spatial disposition.

REFLECTION OF CLIMATE VARIABILITY WITHIN THE MONTHLY MEAN TIME SERIES OF TEMPERATURE AND DISCHARGE IN THE BALTIC SEA DRAINAGE BASIN: A STATISTICAL APPROACH

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The paper contains some results of long-time series analysis with respect to climate variability and change. Data are 33 and 16 time series of monthly (of each month) and of annual mean values of air temperature and discharge with an average length of ca. 103 and 86 years, respectively. The data have been collected for points of the Baltic Sea drainage basin or its vicinity.

We have adopted the hypothesis that the considered processes of mean monthly values are the periodical random processes with one year cycle, that is, the 12-dimensional random variables which for the months of the same name have identical two moments, i.e., mean value and variance. We have adopted the same assumption for the mean annual values, that is, for the one-dimensional random variable.

In every case, the above assumptions refer to the identity of the appropriate mean values and variances.

The adopted hypothesis has been then subject to falsification procedure of nonparametric tests: the runs test, Mann-Kendall test of trend in the mean or in the variance, Lombard's test of number of change-point, and Pettitt's change-point test. The procedure consists of the consecutive use of the following tests:

(a). The runs test allows one to consider the hypothesis concerning the origin of the time series from the process with consecutively independent elements.

(b). The Mann-Kendall test enables us to assess the overall tendency in the mean value run of the time series. It is performed in a sequential onward and backward manner.

(c). In case when there is not a ground for rejection of the hypothesis about the homogeneity in the mean value one goes to consider possible changes in the variance by the Mann-Kendall test. This ends the test analysis of the time series.

(d). If the Mann-Kendall test reveals the overall tendency in the mean value one should ask about the existence of abrupt changes in the series. The Lombard test allows to assess a number of the change-point.

(e). At the end, the Pettitt test enables us estimates the change-point.

Frequently, one cannot ascribe to the statistically significant number of the change-point the same number of the statistically significant change-points.

The tests (a) - (e) should be used in the above-mentioned succession.

The test studies have been carried out for the standard significance level of 5%.

After appropriate statistical analysis, we found that the climate characterized by processes of monthly and annual mean air temperature and discharge has definitely to be considered as unstable.

'LITFASS' - A NUCLEUS FOR A BALTEX FIELD EXPERIMENT

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The meteorological observatory Lindenberg, located close to the southwestern boundary of the BALTEX area, will host a long-term investigation of atmospheric processes. In order to further the development of this investigation, project LITFASS (**L**indenberg **I**nhomogeneous **T**errain - **F**luxes between **A**tmosphere and **S**urface - a long-term **S**tudy) is being initiated. The main focus of LITFASS is a combination of observation and model simulation. Both will concentrate on one 14 x 14 km^2 grid element of the Deutschland-Modell of the Deutscher Wetterdienst. The grid element of the Lindenberg area (52.241° N, 13.966° E; 52.234° N, 14.169° E; 52.116° N, 13.954° E; 52.109° N, 14.157° E) is covered with about 30 % forest, 45 % agricultural fields, 5 % lakes and wet land and 20 % others. The height above sea leavel is 40 m to 120 m. The place is typical for the northeastern part of Central Europe. The Lindenberg observatory with its synoptic station, radiosonde and windprofiler/RASS as well as extensive radiation and aerosol measurements and the Radar at Berlin-Schönefeld airport (some 50 km westwards) provide a concentration of observation technics. Presently a joined measuring field of the meteorological observatories Lindenberg and Potsdam is in a build up phase. Intensive studies of the fluxes between atmosphere and surface over a flat grassland with good fetch conditions of more than 1000 m in the main wind direction and studies of the lower boundary layer using a 100-m-tower and active remote sensing techniques are to be conducted here. It is planned to put this main measuring field in full operation in 1998.

A successful modelling in the local scale as well as a good description of the surface atmosphere interactions in regional scale models mainly depend on the determination of averaged fluxes of momentum, sensible and latent heat in the model grid elements. Currently regional scale models normally use rather simple considerations. For example, maps of the roughness parameter z_o are calculated from land-use maps (e. g., the mean height of plants) and, therefore, effects of plant area density on z_o and the zero-plane displacement height are neglected. This causes significant systematic deviations in the friction velocity u_* of about 20 - 50 %. The stability and the turbulent and molecular resistances, which are functions of the transfer characteristics for momentum and the specific quantity under consideration, are influenced too.

A better concept uses different averaging procedures to calculate at first mean surface and surface layer properties for each single area and from this area-averaged fluxes for the grid element. Such a concept was used, e. g., for the HAPEX experimental area. This method is used also for the determination of small scale area averaged plant physiological parameters (e. g., stomatal resistance and canopy resistance) especially for tall vegetation in terms of a modified 'big leaf' approach. A more sophisticated concept considers each small section a_j, being influenced both by the atmospheric boundary layer (ABL) at place a_j and by advection from sections a_i in the neighbourhood. Under these conditions the exchange at the surface of a_j is not in equilibrium with the ABL at a_j. Local advection influences the flux distribution in a_j (and a_i) and internal boundary layers develop. They are different for momentum, sensible and latent heat and for trace substances. Different concepts and methods to calculate the resulting fluxes under such conditions are described, for example the combination with the concepts of 'footprint' and 'blending height'. It was experimentally shown that local advection influences the measured fluxes by up to 10 - 30 % or more.

To determine area averaged fluxes for the Lindenberg grid element within project LITFASS measuring points (in addition to the main measuring field) will be build up in a forest site, an agricultural site and on a lake. These stations with reduced equipment will measure all parameters (including visual observations) to determine the fluxes over these surfaces using resistance models. It is planned to calculate nearly real-time fluxes for each homogeneous area of scale 100 m^2 by combining these measurements with agrometeorological and hydrological transformation methods.

There are two streams of modelling efforts: i) The measurements at the Lindenberg area will be used for a long-term validation of parameterizations routinely applied in the forecast models of the Deutscher Wetterdienst. In addition, alternative parameterizations will be tested and compared with the routine versions in order to find the best versions available. This validation stream will mainly apply to boundary layer and soil processes. It will be based on computations with one-dimensional versions of the parameterizations as well as on monitoring the results for the grid element Lindenberg of the routine numerical weather predictions. ii) At present a non-hydrostatic meso-γ-model is developed at the Deutscher Wetterdienst in a joint effort with other research institutes and universities. This model will be used for both downscaling the results of the Deutschland-Modell for the Lindenberg area and upscaling the measured turbulent fluxes. This last most challenging part of the modelling effort strives for an area integration of the turbulent fluxes at the surface. This is definitely a key element for a lot of the BALTEX activities.

Project LITFASS will be managed by the Lindenberg Observatory. Different departments of the Deutscher Wetterdienst take part in this work as well as research institutes and universities in Germany. In the context of BALTEX atmospheric processes over an inhomogeneous terrain can be observed and modelled by different groups of the BALTEX community for the Lindenberg area and surrounding regions. The experimental and logistical facilities in Lindenberg and the modelling facilities of the Deutscher Wetterdienst make LITFASS likely to become a promising nucleus for a BALTEX field experiment.

Two-and three-dimensional hydrodynamic models for the Baltic Sea - a comparison of different meteorological forcings

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Both 2D and 3D baroclinic prognostic multi-layer flow models based on fully non-linear equations has been developed for the Baltic Sea and verified by using experimental data during 1990´s. The model results are now available both as figures and as an animation of the Baltic Sea hydrodynamics. The observations and model simulations show that there are several quasi-permanent salinity fronts in the sea. These fronts, which are highly non-linear from their origin, basically form due to the effects of saline water intrusion through the Danish Straits and fresh water input from the rivers. The structure of these fronts is modified by wind, bottom topography and coriolis-effect. In conncetion of these fronts a number of small-scale flow vortices (diameter ca. 5-20 km) become visible. The vortices rapidly change their size and intensity in time. These vortices seem to be produced by non-linear interactions. The results of the comparisons of the 2D and 3D model versions will be shown in the conference.

How sensitive the hydrodynamic models are for the inaccuraties of the atmospheric forcing has not yet been studied widely in the Baltic Sea area. The output from atmospheric model HIRLAM has been used as meteorological forcing for our hydrodynamic models. However, in the Gulf of Finland the present resolution of the HIRLAM model (55*55 km) is too coarse to describe the open-sea wind-field. The wind field from the HIRLAM-model has been interpolated to the grid of the hydrodynamic model (4.7*4.7 km). The interpolated HIRLAM-winds have been compared with the observations of the open sea-station Kallbådagrund in the Gulf of Finland. The comparisons show that the wind stress calculated from the HIRLAM-winds are often only 30-50 % of the wind stress calculated from the measured winds of Kallbådagrund. The HIRLAM-winds speeds have been corrected by using the amplitude of the winds in Kallbådagrund. The spatial variability of the wind field is that produced by the HIRLAM-model. To include the spatial variability of the wind field is important, because without it the poincare waves etc. cannot be described. Several different methods have been used in order to correct the HIRLAM-wind speeds. The resulting different meteorological forcing fields have been used as a input for the simulations carried out by the hydrodynamic models. The model results have been compared with observations. The results of the hydrodynamic models show their sensitivity to the atmospheric forcing.

MEASUREMENT OF CIRCULATION AND HORIZONTAL TURBULENCE CHARACTERISTICS USING LAGRANGIAN TECHNIQUES IN LARGE LAKES

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Observations of satellite-tracked Lagrangian drifters were made in the coastal zone and open waters to measure the circulation and horizontal turbulence characteristics in the surface mixed layer of Lake Ontario. Single drifters as well as clusters of drifters were used in four different regions of the lake in the epilimnion during the stratified season and tracked for time periods ranging from seven days to two months. The examination of individual drifter trajectories indicate that a diversity of flow fields ranging from large-scale current regimes, coastal boundary currents, inertial oscillations, trapping regions characterized large scale eddies and the effect of small-scale turbulent motions. Observed large-scale circulation features include the identification of a belt of strong eastward currents along the south shore, compensating return westward current in the centre of the lake, and the trajectory of the buoyant Niagara River plume in the open lake for considerable distances. The computation of dispersion of single particles about the mean drift shows that the theory of diffusion by homogeneous random motion describes these dispersive motions reasonably well despite the non-uniform nature of the observations. The cluster analysis of trajectories of groups of drifters show that the kinetic energy of motion relative to the cluster centroid is about 0.6 times smaller than the single particle energy indicating that a significant portion of the single particle energy is due to turbulent motions that have spatial scales larger than the cluster dimension. The zonal and meridional component of the eddy diffusivities for the single particle analysis are 16.5×10^6 cm^2 s^{-1} and 2.2×10^6 cm^2 s^{-1}, respectively. For cluster analysis, these are 9.9×10^6 cm^2 s^{-1} and 1.7×10^6 cm^2 s^{-1}. Joint space-time correlations of the relative velocities show that the longitudinal and transverse velocities are coherent over a wider range of space and time lags.

ON THE INFLUENCE OF SURFACE HETEROGENEITY ON THE WATER CYCLE

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Weather prediction as well as modeling of present and future climate scenarios requires an accurate description of the water and energy cycle. Within this framework hydrological models and meteorological models have to be coupled to describe the whole water cycle from evapotranspiration, over cloud and precipitation to evapotranspiration and runoff. Unfortunately, the horizontal grid resolution of meteorological models is much coarser than that required by hydrological models and a grid element may even include a whole catchment area of a small brook with all related surface processes. Obviously, the parameterization of the Earth's surface processes (e.g., evapotranspiration, soil moisture dynamics) may be particularly relevant in determining the runoff relevant precipitation, which can be regarded as the difference between the rain above the canopy minus the evapotranspiration and infiltration. The land surface strongly interacts with the atmosphere at all scales by exchange of momentum, heat, water vapor and water. Usually in meteorological models a dominant landuse type is used as representative for the entire grid cell. A grid cell typically encloses a region of several square kilometers, wherein, in nature large inhomogeneities of surface temperature, vegetation types, soil type, soil wetness, water availability, slopes, urbanization etc. may occur which may lead to different cloud and precipitation formation, precipitation, infiltration as well as runoff. Since natural surfaces are usually heterogeneous over the resolvable scales considered in meteorological models the approach mentioned above may fail to represent the surface forcing. Unfortunately, the possibility to increase the grid resolution of meteorological models in order to better represent the surface characteristics is limited due to computer performance and model parameterization limitations as well as due to the availability of land use data to initialize the model. In order to represent heterogeneous land surfaces a mosaic approach was implemented in the model. Numerical experiments were carried out to investigate the influence of subgrid heterogeneity on evapotranspiration, cloud and precipitation formation as well as on runoff relevant precipitation.

The non-hydrostatic meteorological model used in our study is GESIMA. The model domain encompasses the troposphere over the mouth of the river Elbe (which drains the south of the hinterland of the Baltic Sea) and parts of the western Baltic Sea from the surface to about 11.5 km height with a horizontal extension of 130 km in the North-South and 200 km in the West-East direction. The vertical resolution varies from 20 m to 1 km with 8 levels below 2 km and 7 above that height. The horizontal grid resolution is 4 km x 4 km. All simulations were carried out using an average height within a grid box and a time step of 10 s. The 3-D-simulations have been initialized with profiles of wind, temperature and moisture of 26 April 1986 obtained from a 1-D-simulation which adjusts the vertical profiles of temperature and wind speed to homogeneous terrain (This day was chosen due to the availability of satellite and precipitation data.). The dynamical part of GESIMA is based on the anelastic equations (Kapitza and Eppel, 1992). The representation of the soil /vegetation/atmosphere interaction follows Claussen et al. (1992). The surface parameterization incorporated in GESIMA assumes homogeneous land characteristics within a grid element. Twelve land use categories can be distinguished for which different plant and soil parameters are used. In the mosaic approach each grid area is divided into homogeneous patches according to the different land use types within that grid cell. Assuming that horizontal fluxes/advection between the different patches within a grid element are small as compared to the vertical fluxes, patches of the same type located at different places within the grid element can be regrouped together. Then fluxes are calculated for each land use type separately using the same surface parameterization. The grid element averaged fluxes are given by the sum of the area weighted fluxes (Avissar and Pielke, 1989). Note that this mosaic approach neglects the occasionally observed effects from internal boundary layers (IBL; Raabe, 1983). In the simulations using the mosaic approach the contribution of each landuse type was considered on the basis of a 1 km x 1 km data set according to its area weight within the grid cell. An improved version of the cloud parameterization developed by Jacob (1991) is applied to describe cloud and precipitation formation.

The results assuming a dominant landuse type for the entire grid cell are compared with those obtained by the mosaic approach to investigate the sensitivity of predicted water components to subgrid surface heterogeneity. It is substantiated by these simulations that the microclimate close to the ground is strongly influenced by the surface characteristics. These results reflect the need to consider subgrid variability of soil moisture, precipitation and vegetation when modeling hydrological quantities. Heat and mass fluxes associated with landscape discontinuities are typically larger than turbulent fluxes and may contribute significantly to subgrid scale fluxes. Thus, the consideration of heterogeneity introduces locally large changes to latent heat flux over land surfaces which plays an important role in determining surface temperature and lower tropospheric moisture. A positive feedback ensues because more solar radiation reaches the Earth's surface.

The major deficiency of the assumption of a dominant land use type occurs when the grid area is very heterogeneous and the sizes of the different patches are small. The use of a dominant landuse type may lead to unrealistic precipitation due to too large evapotranspiration. As a consequence, this may affect runoff, especially in small basins. Therefore, for investigations of the hydrological cycle the contribution of the landscape heterogeneity should be considered in the determination of the runoff relevant precipitation. The large differences between the results of the domain average evaporation demand experiments for evaluation.

An important point to investigate in the future will be how to regionalize the heterogeneity of precipitation. Improved parameterization of spatially heterogeneous rainfall in each grid box should improve the simulation of spatial and temporal variations in evapotranspiration as well as in runoff.

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EPISODES OF ENERGY AND WATER TRANSPORTS INSIDE THE BALTEX AREA DURING MAY AND JUNE 1993

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Using a regional numerical weather predicition model (REMO) over the BALTEX area, the atmospheric branches of the energy and water cycles over different subregions are computed. The model is essentially the Europamodell (EM) of the German Weather Service DWD, but with enhanced horizontal resolution of $1/6^{\circ}$ ($\approx$ 18 km). Boundary conditions are provided at every hour by the EM. (See the presentation abstract of B. Rockel et al. for more details.) All relevant budget components are directly computed within the framework of the model.

To allow for detailed regional investigations, the following quantities are computed diagnostically for every grid box during model runs: cloud water and water vapour contents and their respective fluxes, latent and sensible heat fluxes, potential and kinetic energy fluxes as well as radiation fluxes. Moisture and energy fluxes determined from the soil model are also used to close the atmospheric balances.

Results are shown for May and June 1993, a relatively dry and a relatively wet month, respectively. The aim is to analyze the spatiotemporal variability of the budget components in the course of these two months, and to relate it to the characteristica of the actual weather situations. Thus episodes rather than climatological properties are investigated.

In a first step, budgets for the commonly considered seven subregions of the Baltic Sea drainage basin are computed. The deviations from the corresponding climatological data are briefly discussed. However, this can provide only a plausibility check of the model results.

As a second step, the fluxes into and out of some regions suggested by the actually existing meso-scale structures are investigated. This approach may help to illuminate typical processes of energy and water transports under the specific geographical and meteorological conditions of the BALTEX area. It may also be of interest in model validation. If possible, a comparison with measured data will be shown.

FORECASTING ICE IN THE BALTIC SEA

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The atmosphere, the ice and the ocean constitute a physical system with strong coupling; therefore, coupled models are needed for proper simulation. At SMHI, coupled models have now been introduced in operational use for the Baltic Sea.

This work began in 1992, starting from a coupled ice-ocean model developed in a joint Chinese- Finnish effort (1). This model was modified to cover the whole Baltic Sea inside the Belts and Öresund, and was run pre-operationally during the winter 1992/93 (a very mild winter). 24- and 48-hour forecasts were made daily, and the necessary forcing was obtained from routine forecasts from the HIRLAM system. The extent and the thickness of the ice were updated manually, mainly during periods of ice formation and melting in the early and late stages of the winter. The simulations of ice ridging, opening of leads etc. were very promising (3).

During 1993, the model was further developed, and thermodynamics were included, based upon earlier work of Omstedt (2). This made manual updating of the ice fields almost redundant during the next winter 1993/94 (of about normal severity), when the model was run operationally by the authors. The results were again very promising (4). Some tests were made on coupling the model to the HIRLAM system. Information on the ice concentration and ice thickness was updated daily and transmitted to HIRLAM, which earlier had relied upon a rather crude climatological description of the ice. In the oral presentation, some results from this winter will be shown, together with verification data.

During the last winter 1994/95 (a mild winter) the coupling to HIRLAM was in fully operational use; apart from the ice forecasts for navigational purposes, data on ice concentration were transmitted daily for use by HIRLAM. Also, the responsibility for the daily runs was transferred from the researchers to the routine system.

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A BALTIC SEA ICE CLIMATE MODEL

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The water temperatures in the Baltic Sea is subject to large seasonal and interannual variations. Small variations in forcing conditions, particularly during wintertime can drastically change the system from for example subpolar to maritime conditions. A model for studing the sensitivity of sea ice to seasonal and interannual variations and to different forcing conditions is now under development. The model extend the earlier models developed by Omstedt(1990 a,b) and treats the Baltic Sea as thirteen sub-basins with vertical resolution including horizontal exchange, thermodynamics and sea ice.

Forcing data were taken from weather and wind information from seven synoptic weather stations, sea level data from the Baltic Sea entrance area, and river runoff data to each sub-basin. At present we have considered the period 1980-1993, which includes both mild, normal and severe winter conditions.

The model has first been verified with data for three winters representing a mild winter (1991/1992), a normal winter (1983/1984) and a severe winter (1986/87). These years have been identified as particular test ice seasons in a joint Baltic Sea Ice Climate Program (Haapala et al,1993). The results were most promising. Then data on maximum seasonal ice extent for the period 1980-1993 were examined, based upon simulated and modelled data. In general the model predictions were very good, giving confidence in the modelling approach.

The sensitivity of sea ice to climate change was then examined by forcing the model with data from the period 1980-1993 and considering the climate change scenarios for the Nordic countries, discussed by Johannesson et al 1995 ,with an increased winter and summer temperature over the Baltic Sea of +0.55 (°C) and +0.25 (°C) per decade respectively. The sensitivity to a corresponding colder alternative (a decrease of -0.4 (°C) per decade) was also considered. In general the study illustrates that sea ice is a most sensitive component to climate change and that small changes in the air mean temperature can drastically decrease or increase the ice extent.

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Emission of sea spray droplets and their contribution to air-sea exchange

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The paper presents the role of sea spray droplets emission in the mass and heat exchange between the sea and the atmosphere. Particular attention has been given to the mass exchange in coastal zone. Method of estimation emission flux of sea spray droplets basic on aerosol gradient concentration over a coastal zone was given.

The data were collected in the coastal zone of the southern Baltic Sea on the board r/v "Oceania" and from land at the Lubiatowo station during the BAEX One Experiment in October 1993. The aerosol formation was measured with six-stage impactors working simultaneously and located at different highest. At the land station in Lubiatowo, the bottom impactor was 2m above the sea level, then 3m, 4m, the top one at 5m above the sea. The impactors on the ship were situated 0.5 m, 2m, 3m and 10m above the sea level. The number concentration and size distribution of sea salt aerosol particles were obtained beside on microscopy analysis.

In the paper has been used data from measurement of turbulent fluxes of heat, momentum and humidity. During the experiment BAEX -I the measurement of turbulent fluxes were taken by group Institute of Water Problems R A S from Moscow.

The fluxes of aerosol particles emission from sea surface has been determined. The sea spray emission fluxes are compered with turbulent vapour fluxes. Same examples of comparison of aerosol and turbulent parts of mass transfer has been given.

Basic on the volume of emission fluxes from experiment has been estimated total annual flux of aerosol particles from the Baltic coastal zone.

REGIONAL DISTRIBUTION OF DAILY RAINFALL OVER THE TERRITORY OF ESTONIA AND LATVIA

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The spatial and temporal variation of precipitation field is brought about by differences in the type and scale of precipitation-producing processes. It is also strongly influenced by local or regional factors, such as topography and wind direction at the time of precipitation. Several mathemathical methods are available to interpolate between surface meteorological data points. Mostly methods imply that observations that are close together are highly correlated and with the distance correlation decreases. Unfortunately rainfall fields are neither homogeneous no isotropic in space. And they do not meet the most important precondition in order to use statistical methods correctly and validly, they are not normally distributed. Daily data are strongly positively skewed, with a large number of totally dry days, and generally far more days on which small amounts occur and very few extremely wet days.

From the preciding may be concluded that better results for precipitation interpolation may be achieved if at first find regression between rainfall and topography, rainfall and windfield. Once such study has been carried out, it remains in principle to analyze "mathematically" the regression residuals whose variance is hoped to be much lower than that of the basic field. The mathematical portion of interpolation is then greatly completed with a "physical" portion by making allowance for topography and windfield parameters.

The aim of the work is to get an interpolation method for point measurements of daily precipitation using additionally windfield and orography data. For that purpose data from the gauge measurements in Estonia and Latvia over the timeperiod June - August 1993 are used. The investigation region includes the whole territory of Estonia and Latvia plus some eastern parts of Russia. The area covers approximately 300 000 km^2, what is divided to 59 × 59 grid areas with the horizontal step of about 9 km. During June, July and August 1993 12-hour sums of precipitation are available from 193 stations. Wind speed and direction has been registrated in 46 synoptical stations after every 3 hours and vertical soundings were made in 3 stations twice a day.

Considered three month period is sufficiently long to include different weather situations what are needed for interpolation study. In June airmasses have come dominateley from North-West or West, therefore the islands and western part of Estonia have the highest values of monthly precipitation. The sums are close to longterm means except the islands. In July the highest sums of rainfall are situated over the hilly regions of South-East Estonia and Central Latvia. About half of the monthly sums over these areas has rained during one day, 24th of July, then the measured daily sums reach up to 89 mm (Oandu) and 88 mm (Vilami). This event explains the monthly distribution of rainfall, as the cyclone has come from South-East, what is unusual direction for considered

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[1] The work was performed while on leave at the BALTEX Secretariat, GKSS Research Centre, Institute of Atmospheric Physics, Geestacht, Germany

area. Maximal sums of precipitation in August sit over the Northern and Western coastal regions, what is caused by the governing direction of cyclones from West or North-West.

The three-dimensional windfield in boundary layer is calculated by a mass consistent flow model using orography, surface roughness and surface windfield data as input. The local topography is coded in vector form by means of principal component analysis. The covariations of precipitation and windfield, precipitation and topography are studied. Over northern and western regions of the area more attention should be directed to coastal effects and over southern and eastern parts to topography. The obtained precipitation distribution is valuable for BALTEX regional model validation.

PHYTOPLANKTON COMMUNITIES IN THE LAKE LADOGA-NEVA RIVER-EASTERN PART OF THE GULF OF FINLAND WATER SYSTEM: IMPLICATIONS FOR THE REMOTE MONITORING OF HYDRODYNAMIC PATTERNS

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Insolubly related to energy and water cycles, thermohydrodynamic processes in inland and marine waters are characterized by high spatial and temporal variability. This warrants the imployement of remote sensing means to study the above phenomena on an operational basis. The water system comprising Lake Ladoga-the Neva River-eastern part of the Gulf of Finland is a natural site perfectly suited for a case study of energy and water exchanges in the coastal zone.

The chlorophyllous pigments of phytoplankton proved to be a fairly efficient quasi-passive tracer of surficial thermohydrodynamic processes in inland, marine and oceanic waters.

Both spectroradiometric and lidar techniques operating in the visible are liable to imployement to this end provided the phytoplankton communities are studied and their absorptive/emissive characteristic are known.

The phytoplankton community in Lake Ladoga is under a very heavy anthropogenic pressure. In early hydrological spring in shallow areas *Aulacosira* species (*Bacillariophyta*) are first to grow in number. One or one and a half month later the same species become residents of surficial waters of deep areas. In late spring *Aulacossira* is complemented by *Asterionella, Cyclotella, Stephanodiscus* and *Synedra* (*Bacillariophyta*). At the beginning of the summer, a new structure of the phytoplankton community sets up with *Asterionella, Tabellaris* and *Flagilaria* (*Bacillariophyta*) as dominants. These are accompanied by *Chysophyta, Chlorophyta* and *Cyanophyta* species. Midsummer phytoplankton is particularly rich floristically and is most heterogeneously distributed over the lake. Alongside with *Bacillariophyta, Chysophyta* (first of all *Microcystis* and *Oscillatoria*) become abundent. *Chysophyta* and to a somewhat lesser extent *Xanthophyta*, start being also salient in the phytoplankton total count number. In late autum *Bacillariophyta* regains the leading role.

The planktonic community structure in the Neva River is almost a total replica of the Lake Ladoga`s one, since the specific influence of tributaries is only marginal.

The phytoplankton community structure in the Gulf of Finland is regionalized: within the Gulf eastern margins (diluted with fresh water) it is practically identicall to the Neva River`s one. In deeper eastern areas (with higher salinity levels) *marine* taxonomic groups are dominant. The above data shows that seasonal optical models and emission characteristics once established for the hytoplankton communities in Lake Ladoga, could be equally representative of the whole Lake Ladoga-Neva River- eastern part of the Gulf of Finland water system, whereas for the Gulf pelagic areas *marine* models and emission characteristics typical of temperate latitudes are relevant.

The required lake models and emission characteristics for midsummer have been established from our anticipatory studies. These were successfully used to remotely retrieve surficial concentrations in phytoplankton chlorophyll and to eventually map temporal variations of surficial phytoplankton distributions over the lake. Applying this information, water circulation patterns in the lake have been identified, and the understanding of water mass exchange and merging was furthered.

Basing on these and other accomplishements, a large scale comprehensive experiment is under preparation being focused on energy and water exchange in the coastal zone between inland (Lake Ladoga-the Nava River) and marine environments.

3-D-SIMULATION OF RAINING CLOUDS AND THEIR MICROWAVE RADIATION

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For the investigation of energy and water cycle processes precipitation is one of most important parameters of interest. The spaceborne measurement of microwave radiation is a very promising method for the detection of precipitation parameters, bacause the measured signal comes from all parts of the cloud and not only from the upper level. However, the application of present publicated microwave algorithms for the detection of rain intensity over sea, lead to the conclusion that the highly non-linear and frequence-dependent correlation of brightness temperature and 3-dimensional distribution of hydrometeors must be further investigated. As there are only very few direct measurements of cloud structures, 3-dimensional simulations are the only possibility for a systematic investigation.

The 3-dimensional, non-hydrostatic, and anelastic mesoscale model GESIMA ("GEesthacht SImulation Model of the Atmosphere") was developed at the GKSS Research Laboratory (Geesthacht, Germany) to examine the circulation in coastal areas of mid-latitudes. For the last few years the model was mainly used at GKSS to simulate cirrus clouds and vapour trails. As the parameterisations for the generation of rain have not been tested in detail, several improvements of the cloud routine were necessary in order to generate raining clouds with realistic amounts of water vapour and hydrometeors.

The the first tests, the volume of the simulated area is $20 \times 20 \times 10$ km^3. The horizontal grid-spacing is 2 km and the thickness of the 25 vertical layers increases with height from 100 to 1000 metres. After about 20 minutes of simulation time a maximum cloud water content of 0.5 g/kg is reached in a height of 2.1 km. Ten minutes later the first precipitation reaches the ground. The maximum amount of precipitation is 9 mm/h after 40 minutes of simulation time.

The vertical profile of each grid point was used, in order to compute the corresponding microwave brightness temperatures with the 1-dimensional microwave radiation transfer model (MWMOD) from C. Simmer. As for lower frequencies the emission effects of the rain drops are dominating, there is a good spatial and temporal correlation of the maxima in 10.6, 19.4, and 22.2 GHz brightness temperatures with the maximum of rain intensity. For 37 and 85.5 GHz the location of the temperature maximum corresponds with the cloud water maximum. On the other hand, the scattering effects of the raindrops cause a local minimum in the brightness temperatures of the higher frequences. The correlation of polarisation difference and hydrometeor content is frequence dependent as well and gives additional information about the cloud structure.

For further investigations simulation of clouds from different synoptic situations occurring over the Baltic area are planned.

METHODOLOGY FOR MODELLING OF HYDROLOGICAL PROCESSES AND SUB-GRID VARIABILITY IN THE HYDROLOGICAL-ATMOSPHERIC COUPLING

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A key objective of BALTEX is to develop a fully coupled oceanographic-atmospheric-land surface model for the entire BALTEX area. Development and testing of a coupled hydrological-atmospheric model is an important step in this context. Key issues in this regard are improved process descriptions for soil-vegetation-atmosphere-transport (SVAT) and snow accumulation and melt as well as improved descriptions of variability of hydrological processes and variables at different scales. The present paper outlines the BALTEX research plans which have been prepared to address these issues.

Hydrological models are traditionally classified in lumped conceptual and distributed physically-based. Typical representatives of the first group are NAM and HBV which both are extensively used, while MIKE SHE is a prototype of the much more detailed and complex distributed physically-based models. A third, intermediate, group consist of semi-distributed models such as EGMO and WATBAL and recent versions of HBV.

In a climate modelling context, the primary strength of the distributed physically-based models is their ability in a physical realistic way to simulate the spatial variability of the hydrological processes at the land surface. This forms a good basis for a realistic land surface-atmosphere coupling and enables direct utilization of distributed data such as radar and satellite data. The primary strength of the lumped conceptual models is that they on the basis of small amounts of data and using small computer resources are well proven for simulation of catchment runoff as well as indexes for catchment water storages such as soil moisture and snow storage.

In BALTEX an integrated hydrological modelling system comprising a combination of semi-distributed conceptual and distributed physically-based models will be developed. In order to use them at different scales ranging from experimental catchments such as NOPEX to the entire BALTEX area scaling relationships will be developed.

The strategy for developing and testing the integrated hydrological modelling system will be outlined. This includes development of a new soil-vegetation-atmosphere-transfer module and an energy balance snow module.

A coupling between the hydrological modelling system and an atmospheric model (HIRLAM) will be developed and initially tested on NOPEX data.

Data assimilation routines will be developed and tested for integration of remote sensing data and distributed hydrological models.

During the first three years it is planned to test the models on local scale and meso scale. The primary data base for the local scale will be NOPEX near Uppsala. For meso scale modelling catchments in Sweden, Germany and Poland will be utilized. During a subsequent project phase the modelling will be extended to cover the entire BALTEX area.

VELOCITIES IN VERTICAL CROSS-SECTION - PROBLEMS IN 3D MODELS

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oral

Description of hydrodynamic conditions becomes more often represented by 3D models, using different numerical schemes.
This approach is of major importance in areas where water motion can not be represented by depth averaged approximation eg. wind driven or density driven currents. These problems occur in case of the Gdańsk Bay where currents are not only wind driven but additionally influence of stratification (salinity and temperature) and river discharge (Vistula river) play an important role.

It is a common practice to analyze the influence of horizontal grid on results of hydrodynamic conditions. Unfortunately this is not the case in 3D models.In this paper the influence of vertical discretization and turbulence model on the vertical velocity profile will be presented in case of simplified test area and the Gdańsk Bay model.

The numerical tests are based on three - dimensional hydrodynamic package TRISULA (license Delft Hydraulics), where vertical discretization is introduced by σ - coordinates.

As an example (Fig.1) the results obtained for the test area, with uniform depth of 10 m over which wind 10 m/s has been introduced, are presented. From the calculations we can conclude that the results obtained with of k - ϵ turbulence model approximate better conditions observed in nature than those obtained with the algebraic model (Fig.1 - lines 1&2). Moreover usage of non-uniform discretization enables better velocity representation in the upper part of the water column (Fig.1 - lines 2&3) in case a limited number of layers in use.

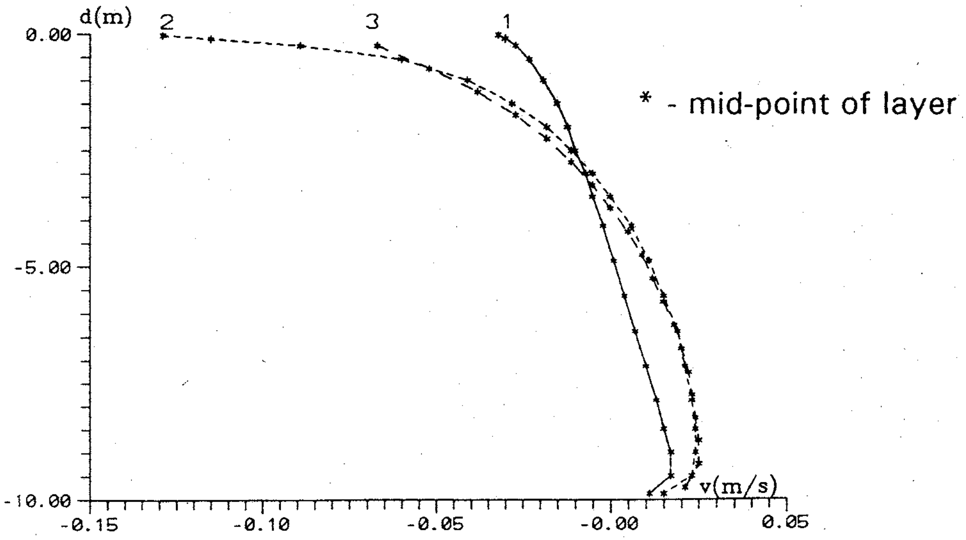

Fig.1. Vertical velocity profiles induced by wind 10 m/s.
Non - uniform layer distribution: 1 - algebraic turbulence model, 2 - k-ϵ turbulence model; *uniform* layer distribution: 3 - k-ϵ turbulence model.

COMPARISON OF COMPONENTS OF THE ENERGY AND WATER CYCLE FOR REMO, EM, AND ECMWF T213 WEATHER FORECAST MODELS FOR MAY/JUNE 1993

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Within the frame of BALTEX a joined initiative of the GKSS Research Centre, the German Weather Service (DWD), and the Max-Planck-Institute for Meteorology (MPIfM) started to develop a regional atmospheric forecast model. The basis is the Europamodell (EM) of the DWD. Optionally the physical package of the climate model ECHAM may be chosen.

For our comparison studies we used a version of REMO that is equivalent to the EM in terms of dynamical and physical aspects. The difference between the models is the horizontal resolution (1/2° for the EM, i.e., ≈ 55 km; 1/6° for the REMO, i.e., ≈ 18 km). Comparison of results of these two model versions gives us information about the effect of grid resolution (e.g., orographical effects on precipitation). The third model is the European Centre T213 medium range weather forecast model.

For a first intercomparison a dry month (May 1993) and a wet month (June 1993) were chosen.

The following atmospheric variables were examined:

- Radiation (solar and thermal fluxes at the top of the atmosphere and at the surface)
- Cloud Cover (high, medium, low)
- Precipitation (at the surface)
- sensible and latent heat fluxes (at the surface)

For each day of the two month 30h weather forecasts were performed with REMO/EM. To avoid spin up problems only the hours 6-30 were compared between the different model versions. Initial fields for EM forecasts were taken from the 6 hourly EM3AN Analysis data base of the DWD. Boundary conditions for the REMO were obtained hourly from the EM forecast.

The ECMWF T213 (31 vertical levels) forecast results were taken from the European Centre's MARS archive.

The EM/REMO and the ECMWF T213 use different physical packages:

Radiation:

The EM/REMO radiation scheme was developed by Bodo Ritter and J.-F. Geleyn (1992). It is an improved version of the old ECMWF radiation scheme. The new ECMWF radiation scheme was written by J.-J. Morcrette (1990).

Clouds:

The parametrization of stratiform clouds in the EM/REMO is written by Ulrike Wacker. The ECMWF scheme is based on the work by Julia Slingo (1987). Tiedtke's (1989) cumulus convection scheme is used in all three models.

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ATMOSPHERIC AEROSOL VARIABILITY IN ESTONIA

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A decreasing tendency of solar radiation incident on the ground surface has become evident in several regions of the Earth during recent decades, among these, also, in the countries situated close to the Baltic Sea. Due to the essential role of solar radiation in the energy budget of atmosphere and, thus, in the formation of weather processes the investigation of possible reasons of observed changes in radiation regime should be considered very important. In the Baltic Sea region the radiation conditions are mainly determined by cloudiness. Besides this the possible changes in the aerosol generated both by natural processes and human industrial activities must be treated as another reason of observed trends in radiation transfer.

As a suitable data basis for the study of changes in solar radiation actinometric measurements data obtained at Tõravere Actinometric Station of the Estonian Meteorological and Hydrological Institute (Estonia, $58^{0}16'$N, $26^{0}28'$E) have been used. This station is situated in a rural area, where the local atmospheric pollution sources are lacking.

The analysis of solar radiation in cloudless hours allowed us to assess the atmospheric aerosol optical thickness and its variability in different months during the period 1955-94. In these time series a significant increasing tendency has become obvious. The averaged over April - August aerosol optical thickness has increased by 73% in these years (significance level p>99%). For the same period the reduction of direct solar radiation in cloudless hours was 10% (p>99%).

We suppose that at Tõravere we have mostly to do with the aerosol transported here from more distant sources. This can be confirmed by the dependence of the observed optical thickness on wind directions. The maximum amount of aerosol is coming to Tõravere from the S-direction, also the SE winds have an essential role. The smallest amount of aerosol is usually transported to Tõravere by NW-winds (then the mean value of optical thickness is 1.7 times smaller than in case of S-winds).Thus, we can conclude that the most essential for Estonia sources of anthropogenic aerosol in the period under study have been situated on the territory of the former Soviet Union.

A CLIMATOLOGICAL STUDY OF THE WIND RESOURCES IN THE BALTIC AREA USING A MESO SCALE MODEL

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The distance between climatological stations with measurements of wind speed and wind direction is generally large. These stations are concentrated to the coastal areas and measurements are made at a height of only 10 m, while for many practical applications such as wind energy the main interest is in the height interval 30 to around 100 m. Consequently, as the number of wind observing stations are limited, models are essential to get more detailed information regarding the horizontal and vertical variation of the wind field.

A three-dimensional mesoscale model, the MIUU model (Enger, 1990), has been used to analyse the climatological wind distribution in the Baltic area. The model is hydrostatic, with a terrain following coordinate system and uses a second order closure, level 2,5 following the nomenclature of Mellor and Yamada (1974). A parameterisation for the sea waves is under development.

Special considerations have to be taken when using this type of model to map the climatological wind field, since it is rather computer time consuming to run. To cover all types of synoptic and boundary layer conditions of importance many model runs have to be

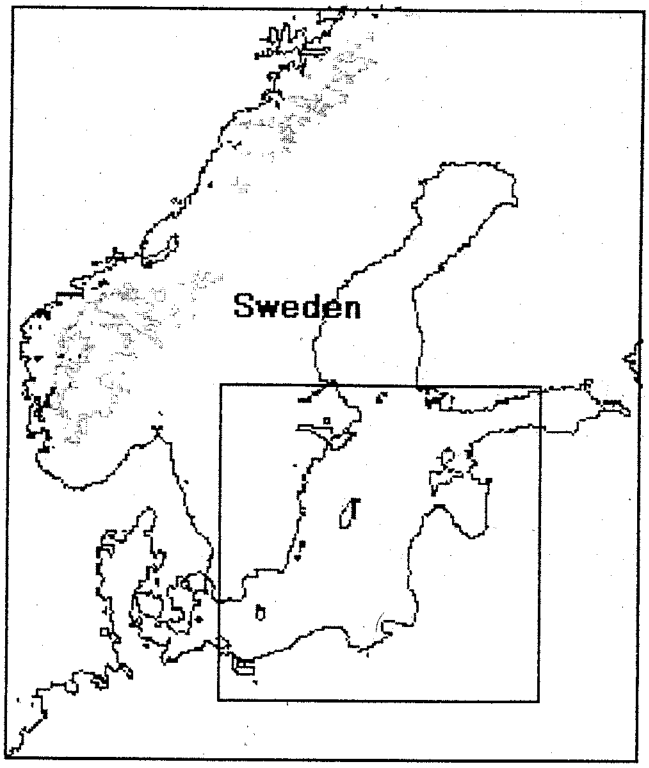

Figure 1. The area used in the simulations. The model resolution in the centre (around Gotland) is about 5 km.

made. Therefore, limitations in number of simulations have to be made, and consequently the parameters of greatest importance have to be identified. These parameters must then be allowed to vary to cover a wide range of atmospheric conditions. The most relevant parameters to the atmospheric wind field are:

1. the geostrophic wind
2. thermal stratification
3. surface roughness
4. topography
5. land and sea surface temperature and differences
6. thermal wind

The simplest way to proceed would be to make simulations using just the mean values of the geostrophic wind and the temperature with a daily mean variation, and making these runs for a number of wind directions and months. This approach would however diminish the effects of thermal stratification and land-sea temperature differences. Therefore the following division of the variation of the parameters were made:

1. 8 wind directions sectors (45°,90°......315°)
2. 3 geostrophic wind speeds (5, 10 and 15 m/s)
3. 4 months (January, April, July, and October)
4. 3 mean temperatures over land with a diurnal variation,
5. sea surface temperature was kept constant at the monthly average.

The model simulations were then made during these different conditions with the monthly mean of the daily temperature variation to include the effect of thermal stratification. A total of 24 hours where simulated with each set of parameters. The simulated wind fields were then weighted together using climatological data on the geostrophic wind. A comparison between the modelled climatological data and measurements made at Näsudden at the southern part of Gotland was also made.

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LONG-TERM HORIZONTAL SEA LEVEL VARIATIONS IN THE BALTIC SEA

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The mean sea level difference between seven areas in the Baltic Sea has been calculated for three different periods, two five-years and one 26-year-period. The model calculates both the steric effect (the effect of density) and the effect of a varying air pressure. A level of no motion, i.e. no horizontal pressure gradient at a specific depth, is assumed for the steric effect, while the effect of air pressure is calculated with the "inverse barometric law". The two shorter periods are used to investigate the seasonal variations of the horizontal sea level difference, and the longer period is used for comparison with two other models.

The short periods had both the same seasonal sea level difference, about 10 cm during summer and about 15 cm during winter, the air pressure contributed with between 1 - 5 cm (for summer and winter respectively). The effect of winds and currents are mostly costal phenomena of comparable short duration, and therefore these effects are only discussed theoretically and not included in the model.

The results from the 26-year-period have been compared with both another oceanographic model and a geodetic model. The oceanographic model, constructed by E. Lisitzin during the fifties and sixties, considered the effects of density, air pressure and winds. The calculation of the wind effect assumes a shallow, homogenous and non-rotating basin (but this is not applicable to the Baltic Sea). In the geodetic model, made by M. Ekman and J. Mäkinen, the mean sea level above the mean geoid was calculated.

The model of Lisitzin gave a sea level difference between the south and north of the Baltic Sea of 25 cm, while both the geodetic and the present model gave a difference of 12 cm. The deviation between the two oceanographic models was mostly due to the wind effect which Lisitzin has included in her model, but also to some extent to slightly different methods for calculating the steric effect. (Lisitzin did not consider the effect of the sills which is significant in the Baltic.) The good agreement between the geodetic model and the present model shows that the determining factor for the long-term horizontal sea level difference in the Baltic Sea is not the wind forcing but the variation in density which, in the Baltic, is mostly dependent of the salinity.

SEA LEVEL VARIABILITY IN THE BALTIC SEA

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Sea level variability on times scales from two days and longer have been analysed using up to 21 years sea-level-records. These are from six locations along the Swedish coast, from the Kattegat up to the Bay of Bothnia. The analysis showed that the annual variance varies considerably from year to year with the largest variations in the Bay of Bothnia and the smallest in the Kattegat. The five stations in the Baltic Sea have the same variation, i.e. a high variance during the same years. The monthly and weekly variances both have an evident seasonal variation with a maximum in the winter and a minimum in the summer, but the monthly variances were 1.5-2 times larger than the weekly variances. The annual variance was divided into two parts, one containing fluctuations with periods between two days and two months, and the other containing fluctuations with periods longer than two months. In the Kattegat, 57% of the annual variance consist of the first part (high frequencies) while the same part only contributed with about 30% in the Baltic Sea.

Fourier analyses showed that much of the energy is concentrated in the lower frequencies (<0.03 cycles per day) for all stations, but the noise level were higher in the Kattegat than in the Baltic. Cross spectrum analyses showed a high coherency for low frequencies (~0.1cpd) in the sea level variations in the Kattegat and the Baltic. Within the Baltic Sea, the coherency was high for low frequencies, but it was also high for frequencies around 0.2 and 0.3 cpd. Both gain functions show a misleading picture of an energy transmission of more than 100% for low frequencies (< 0.11 cpd ~ 3 month). This occurred both between the Kattegat and the Baltic Sea as well as between the north and the south of the Baltic. Preliminary studies show that the air pressure might be responsible for the high energy content of the low frequencies. The phase functions showed that the variations in the Kattegat precedes the ones in the Baltic Sea while the northern parts of the Baltic precedes the southern parts.

A model for the sea level variations in the Baltic Sea is under construction. With the model, the effects of different forcing variables will be distinguishable. Today, the model includes inflow from the Kattegat, air pressure and density. The spatial resolution is moderate, the Baltic is only divided into five areas: the Bay of Bothnia, the Sea of Bothnia, Baltic proper, The Gulf of Finland and the Bornholm basin. Pilot studies show that the air pressure might be responsible for the high energy transfer for low frequencies. The model will be expanded with larger spatial resolution and the wind effect will be included.

MAJOR ACTIVITIES PLAN FOR GCIP (1995-1997)

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The GEWEX Continental-Scale International Project (GCIP) Major Activities Plan for 1995, 1996 and Outlook for 1997 presents research goals and objectives together with supporting activities for the next three years. The principle research areas include: coupled modelling, data assimilation, diagnostic studies, water resources research, precipitation (including snow), streamflow/runoff, soil moisture, land surface characteristics, and clouds and radiation. The geographic focus starts in the Large-Scale Area - Southwest, the Arkansas-Red River basin, and includes the Large-Scale Area - North Central, the Upper Mississippi River basin, toward the end of the period. Supporting activities include developing model assimilated and derived data sets, providing access to GCIP data through a Data Management and Service System (DMSS), compiling sub-sets of the total data set on CD-ROMs and developing enhanced observations to augment operational data. The National Meteorological Centers mesoscale Eta model is being used as one source of model assimilated fields and improvements are being made to its land surface parameterization. This paper will highlight key elements of the GCIP research strategy and the supporting activities.

PROFILING OF WATER VAPOR CONCENTRATION AND CLOUD PARAMETERS BY RAMAN LIDAR

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Introduction

Vertical profiles of the atmospheric water vapor content are essential for our understanding of the atmospheric energy and water budget. Thus, remote measurements of water vapor concentrations by Raman lidar will be of particular interest for BALTEX, with its main scientific objective in modelling and measuring the energy and water budget in the Baltic sea area [1]. These measurements provide also important data on cloud optical properties, such as absorption coefficients, optical depths and backscattering coefficients.

GKSS will participate in a BALTEX field experiment at the DWD station (Deutscher Wetterdienst) at Lindenberg (Germany, 52°N, 14°E). During this intensive experimental field phase, GKSS will operate two lidars for the measurement of horizontal and vertical profiles of moisture and cloud properties in different scales. Both systems are described below.

Experimental Setup

One system is a modified version of the GKSS combined Raman lidar [2]. The system emits laserlight with 200 mJ at 308 nm wavelength and 200 Hz pulse repetion frequency (PRF), and 300 mJ of 355-nm radiation with a PRF of 50 Hz. A 0.8-m telescope collects the backscattered radiation and it is registered in 8 single photon counting channels. In addition to the elastical backscattered light at 308 and 355 nm, inelastic vibrational-rotational Raman scattering is observed from N_2 at 332 and 387 nm, and from H_2O at 408 nm. The elastically backscattered radiation at both wavelengths is split in a near- and a far-field channel. Moreover the 355-nm near-field intensity is separated into light with polarization parallel and perpendicular to the polarization of the laser emitted light and is registered in different channels.

The other system, sometimes referred to as ATLAS (Advanced Temperature and Humidity Lidar for Atmospheric Sounding), is based on an excimer laser (KrF, 248 nm, 300 mJ, 250 Hz). Its output is shifted by stimulated Raman scattering in hydrogen to 277 nm with an pulse energy of 80 mJ. After collection of the backscattered light with a 0.6-m telescope, the light is spectrally separated into 8 channels and registered in the photon counting mode [3]. In addition to the elastic (277 nm) and the vibrational-rotational Raman channels at 289 nm (O_2), 296 nm (N), and 308 nm (H O), four channels (between 276 and 278 nm) register the purely rotational Raman spectra from N_2 and O_2, which is spectrally very close ($\Delta\lambda < 1$ nm) to the elastic backscatter peak. These channels allow to determine the temperature profile from the ratio of high to low rotational quantum number line intensities.

Purpose

The former system is designed to measure from the planetary boundary layer (PBL) height up into the upper stratosphere, whereas ATLAS is better suited for PBL measurements. Both systems can determine moisture, ozone, and cloud geometric, radiometric and microphysical parameters and temperatures.

In addition to the determination of vertical profiles, ATLAS will be upgraded to operate also in a horizontal profile mode. ATLAS is mounted in a van and is thus fully mobile.

The larger Raman system is presently being modified to fit into a standard 20' container for easy transportation.

Accuracy

The long range system measures water vapor profiles from 2 to 10 km with a time resolution of 15 minutes and a variable height resolution from 120 m between 2 to 4 km, and 900 m above 4 km, depending on atmospheric conditions [4]. Absolute accuracy is 5 to 10 %.

ATLAS measures moisture profiles from 400 to 3000 m with a time resolution of 15 minutes and a spatial resolution of 60 m. Absolute accuracy is 5 %.

These specifications are for the normal operation mode and can be changed for special purposes, e.g., lower time resolution results in better spatial resolution at constant absolute accuracy.

Outlook and Conclusions

Optimization of the lidar hardware and operation modes will be carried out in the months to come. After that, two powerful lidar systems will be operated by GKSS during the field measurement phase at Lindenberg station. They will provide significant information on the time development of water vapor in connection with the BALTEX experiments.

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ON THE PROBLEM OF EVALUATION OF REGIONAL MOISTURE CYCLE BY MEANS OF THE ATMOSPHERIC GENERAL CIRCULATION MODELS

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The Caspian sea received an increased attention from geophysical science owing to its unique natural characteristics. Being a closed basin with no surface outlets, the Caspian sea shows high sensitivity to climatic variations. Its level depends on the balance between precipitation and evaporation over large area including the sea and its watersheds. It effectively filters high frequency variation of net water balance and serves as a good indicator of long-term climatic trends through observed change of its water level.

In study of the causes of long-term Caspian sea level variations and connections between trends of sea level and large scale moisture cycle over the sea surface area and watersheds of mouthing into the sea rivers it occurs important to evaluate skills of atmospheric general circulation modeling to correctly represent the cycle of moisture in the atmosphere over separate regions. With this aim, the analisys of the water and heat balance components for Volga and Ural watersheds and Caspian sea aquatorium is conducted using results of numerical modeling of atmospheric circulation covering ten years (from 1979 through 1988) of computation when the temperature of oceans is prescribed (AMIP program). The analisys is realized for most models participating in AMIP with different spatial resolution and various parametrizations of physical processes. The results are compared to each other and against observational data on precipitation, snow mass in winter time, runoff, cloudiness, radiation balance, etc. The models representing the water balance components close to observational data are chosen to further analize the Caspian sea level changes for the period 1979-1988. The applicability of the atmospheric general circulation models in evaluation of regional moisture cycle in the atmosphere is discussed.

WATER VAPOUR AND CLOUD LIQUID WATER OVER THE BALTIC SEA DERIVED FROM SSM/I OBSERVATIONS

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The vertically integrated water vapour content (or Precipitable Water) PW and the vertically integrated cloud liquid water content (or Liquid Water Path) LWP is retrieved from passive microwave measurements of the Special Sensor Microwace/Imager (SSM/I) operating on the satellites of the Defence Meteorological Satellite Program (DMSP) series. The retrieval method (Liu et al. 1994), which is based on an extensive library of simulated brightness temperatures (MRL) and a simple interpolation technique gives results comparable to or better than the usual regression methods with errors of $0.84\,kg/m^2$ for PW and $13\,g/m^2$ for LWP. Because the high frequency channels of SSM/I (85 GHz, H- and V-polarized) were unstable on the DMSP-F8 satellite only the lower frequency channels (19 GHz and 37 GHz, horizontally (H) and vertically (V) polarized, 22 GHz only vertically polarized) are used for the retrieval.

Before computing PW and LWP three modifications have to be applied to the measured SSM/I brightness temperatures:

- The method by Robinson et al. (1992) is used to enhance the resolution of the 19 GHz (69 km x 43 km) and 22 GHz (60 km x 40 km) channel data of SSM/I to the resolution of 37 GHz channel data (37 km x 29 km). This modification ensures that the same part of the earth surface and atmosphere is measured at all frequencies used for the parameter retrieval. Due to the resolution enhancement SSM/I measurements up to about 30 km off the coast can be retrieved. Without this modification low-frequency measurements that close to the coast would suffer substantial land contamination due to the coarser resolution of these channels.

- Due to the elliptical form of the satellite orbit and due to changes of the orientation of the satellite relative to the direction of flight the incidence angle under which the earth surface is measured by the radiometer changes slightly. If uncorrected these variations lead systematic errors in the retrieved geophysical parameters. We correct incidence angle variations using a procedure developed by Fuhrhop and Simmer (1995).

- The brightness temperatures are finally corrected for an off-set between SSM/I measurements and the radiative transfer model used (Simmer 1994, Karstens et al. 1994) to simulate the microwave radiation library. These off-sets were determined during the International Cirrus Experiment (ICE'89) over the North Sea by comparing model simulations with radiosonde measurements as input with collocated SSM/I measurements.

We computed monthly mean values of PW and LWP from SSM/I measurements on the DMSP-F8 satellite for the whole year 1989, and for January, April, July, and October of several years between 1987 and 1993. The horizontal resolution of the retrieved fields is 0.5° x 0.5°. Preliminary results indicate:

- For 1989 average values of PW are $10\,kg/m^2$ in January decreasing to $8\,kg/m^2$ during February and March. In spring PW increases slowly to $11\,kg/m^2$ in April and $13\,kg/m^2$ in May followed by a larger increase to $17\,kg/m^2$ in June. In summer the increase slows down to $20\,kg/m^2$ in July and levels off at a maximum of $21\,kg/m^2$ in August. An interesting feature of PW is an almost missing zonal gradient throughout the Baltic Sea while at the same time North Sea and Norwegian Sea show a decrease from South to North over the same latitudinal range. The year to year variability is low.
- The LWP does not exhibit a seasonal variation as regular as PW. Basin-wide averages range from $20\,g/m^2$ to over $100\,g/m^2$ for individual months. For most of the months investigated there is also a marked difference between the Northern and Southern part of the Baltic Sea with LWP different by a factor of three with no preference for higher or lower values in either part.

We will extend the evaluation od SSM/I data to additional months and also look at the day-to-day variability of PW and LWP. For May and June 1993 we have data from both DMSP-F10 and DMSP-F11 satellites available. Satellite overpasses at about 6, 9, 18, 21 UTC will be available allowing us to investigate the diurnal variation of the retrieved parameters.

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THE DISTRIBUTION OF SUSPENDED MATTER IN THE GOTLAND DEEP

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Nepheloid layers (accumulations of suspended matter) were studied during last 10 years in the Gotland Deep using sinking nephelometer, Coulter counter, water filtration and sediment traps. Chemical composition of suspended matter was determined in samples. Sedimentation environments was characterized judging by water temperature and salinity, dissolved oxygen and hydrogen sulphide concentration.

Nepheloid layers (NL) in the Gotland Deep can be subdivided into 3 types according to their origin. The bottom NL (type 1) appear as a result of sedimentary-diffusive balance in the marine dispersion system. In this case the NL is defined as that portion of the lower, deep-sea water column in which the concentration of suspended matter generally increases with depth to bottom. They acquire distinct features with bottom currents intensification and consequencly, turbulence of the near-bottom layer. The concentration of suspended matter upon the bottom may be two orders increased as compared to the background values. Data from sediment traps consistently show increasing apparent vertical fluxes with increasing proximity to the sediments.

The deep-sea (above but not touching the bottom) NL are formed first, as a result of complex interaction involving near-bottom currents, relief, sediments and water density stratification (type 2), and, second, as a result of the transition of dissolved Fe, Mn and other chemical elements into their suspended forms on the geochemical barrier "oxygen-hydrogen sulphide" (type 3). Haloclyne plays a decisive role in the first case and, besides, it acts as a kind of horizontal "suspension supplier", through which sedimentary matter from slopes is delivered into the deeps. In the second case geochemical process leads to accumulation of fine suspension, looking like milke "clouds" with sharp horizontal boundaries and laminated structure as has been observed from submersible "Mir".

Variability and complexity of suspended matter formation and it existence require determination of nepheloid layer origin in each particular case.

THE STRUCTURE OF THE STABLE MARINE BOUNDARY LAYER OVER THE BALTIC SEA

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For more than half of the year the land surfaces surrounding the Baltic Sea is warmer than the sea surface, and the marine boundary layer over the Baltic is stable. Observations, at various sites in the Baltic Sea area during the last decade, also indicate frequent occurrence of low-level jets at the top of the stable boundary layer. In many cases the marine jet can be considered as an analogy in space to the evolution of the nocturnal jet with time. The frictional decoupling occurs when warm air over the land is flowing out over the could sea.

Data from two areas (see Figure 1) together with model simulations are used in this study to characterise turbulence structure in the marine boundary layer. The measurements include profiles of wind and temperature on towers situated at two isolated islands, together with turbulence recordings and aircraft measurements. Also wave height and water surface temperature have been measured. The model simulations are performed with the MIUU mesoscale model (Enger, 1990), which is a hydrostatic three dimensional model with terrain following coordinates. The turbulence closure scheme is of the second-order type.

The development of the stable internal boundary layer over the sea at the two sites was quite different. At Nässkär (site A) the SBL was characterised by stable stratification of the entire boundary layer, whereas at Utlängan (site B) a well mixed layer showed up below the jet with a temperature inversion higher up. This can be interpreted in terms of Csanady's (1974) model for the development of an internal boundary layer over a cold water surface: when the difference in temperature between the air and the water is larger than a certain threshold value, frictional decoupling at the water surface occurs and the inversion remains intact (Site A) whereas if the temperature is smaller a well mixed boundary layer develops (Site B). Measurements together with model simulations have been used to further develop Csanady's theory. The overall structure of the stable internal boundary over the sea can be expressed as a function of:

* a bouancy parameter $g\Delta\theta/\Theta$, where $\Delta\theta$ is the temperature difference between land and sea
* the geostrophic wind speed
* the distance from the shore land

As stated above a low level jet is frequently occurring at the top of the marine boundary layer over the Baltic Sea and the analysis showed that the turbulence produced within the low-level jet will affect also the turbulence structure close to the ground. The height to the low-level jet centre (h_o) appear to be an important parameter. Figure 2 shows a schematic picture of the impact of the low-level jet on the turbulence structure in the marine boundary layer. When the jet height > 500 m turbulence is produced in the shear layer and brought down to the surface by the pressure transport term. This additional turbulence has been identified as 'inactive turbulence' (Högström, 1990). During one situation of weak pressure forcing and swell condition over the sea no momentum flux was produced in the surface layer but still there was considerable amount of turbulent energy close to the surface. In this case all turbulent energy was 'inactive' and produced aloft (Smedman et al., 1994).

On the other hand if the jet height < 300 m the whole boundary layer can be looked upon as an 'atmospheric wall jet'. In this case similarity theory breaks down and the jet scale becomes the relevant length scale. When the marine boundary layer is part of a wall jet low frequency fluctuations such as 'inactive turbulence' and waves will be suppressed and a very marked spectral gap will appear in the energy spectrum.

The results discussed here show that the structure of the atmospheric boundary layer over the Baltic Sea is often quite complicated. The findings have obvious implications for climatological modelling within the framework of BALTEX:

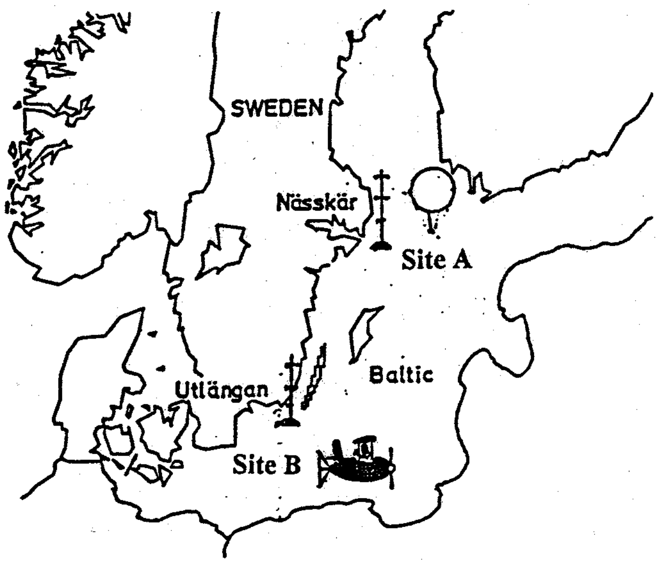

Figure 1.

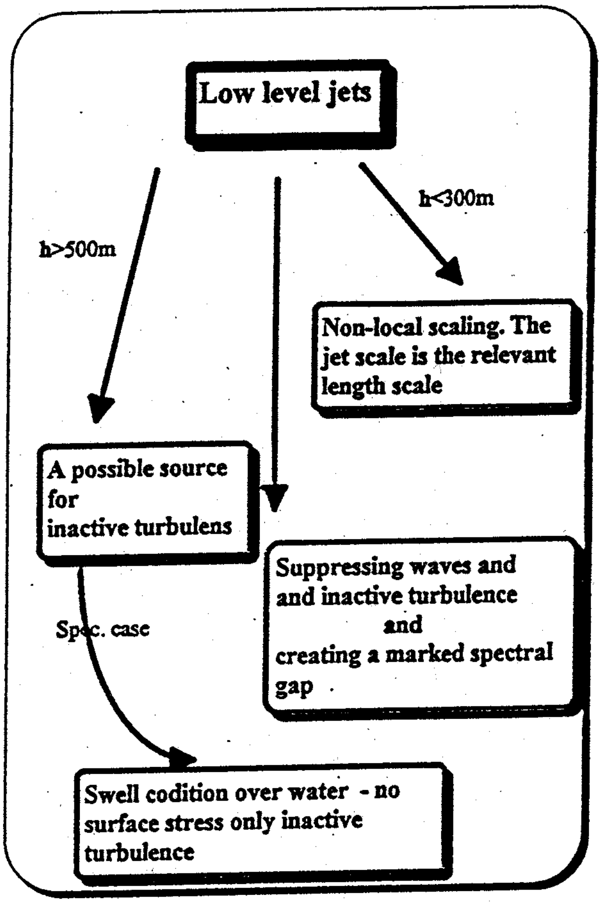

Figure 2

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VARIABILITY REGULARITIES OF WATER EXCHANGE THROUGH THE DANISH STRAITS AND ITS INFLUENCE ONTO FORMING THE REGIME OF THE BALTIC SEA

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The Baltic Sea hydrological regime is greatly determined by the water exchange through the Danish straits. Different scale variations of water exchange components on the one side form background changes off sea ecosystem elements but from the other side occasional but great inflows off salt North-sea waters promote the renewal of sea conditions of the Baltic Sea.

The information about estimation of atmospheric circulation influence onto large scale variability off the Baltic regime elements, in particular onto salinity, has confirmed that the water exchange with the North sea is the principal mechanism of that influence. Firstly this conclusion concerns salinity long-period changes in 10 years and more.

The changes of meridional atmospheric transfers over Atlantic-European sector of the Northern hemisphere are the main reason for large scale changes of bottom and vertically averaged salinity of the Baltic sea. Revealed maximum estimations of interconnection between atmospheric transfers and water exchange components allowed to obtain approximations of long-period variations of transfers through the Danish straits on the basis of multi-regression models. For water inflow into the Baltic sea its background changes have been calculated up to 1997. After long period of inflow intensity decrease (since fifties) in 1993-94 the tendency of its increase began, it lasted up to the end of calculated period (1997). It is coordinated well with outstripping trends in probability of atmospheric circulation different forms.

Sharp episodic changes of hydrological and hydrochemical conditions of the sea are connected with great inflows from the North sea and are characterized with other combination of external factors. A number of scientists consider that some large inputs of salt North-sea water are caused by a combination of a series of consecutive phenomena namely, western atmospheric transfers off long time, previous eastern transfers and low level of the Baltic, high salt content in deep layers of the Kattegat which is determined by previous atmospher processes.

To show this mechanism off interaction the combined analysis of daily water exchange and probability of atmospherie circulation forms for 3 months period including the great inflow of 1951 has been made.

When restoring the water exchange picture the results of elctroanalogue modelling of wind and baroclinic circulation in strait area and southern Baltic have been used. Obtained estimation of inflow volume (225 km) is well coordinated with indirect estimations of some researchers.

The results of combined analysis confirm the necessity of synchronous registration of probability and duration of atmospheric transfers when modelling different natural situations, especially as the results of background forecasts say about increase of large inflows probability during next years. Observations made in the frameworks off international projects "The Baltic", "The study of great inflows into the Baltic sea", "The study of deep-water areas of the Gotland basin" confirm the correctness of this forecast. In January 1993 the large inflow off salt water from the North sea came into the sea. It was a beginning of the process of water renewal off the Baltic deep basins. However because off long stagnation the main body of that inflow delaid in Bornholm basin which is a sort of buffer zone on the way off high salt waters to the proper Baltic. Late and not so great inflows in December 1993 and March 1994 had greater influence onto sanitation of bottom waters off the Baltic sea as "buffer zone" was filled.

So we can conclude that the period of Baltic water freshening has been over and salinity period begins.

SEVERITY OF WINTERS AT THE POLISH COAST

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oral presentation

Several methods used in estimation of the severity of winters at the Polish coast were compared in order to gain a uniform definition. The results of these methods were the values of the coefficients (one for each method) severity and their range determined the type of winter.

Winters of the centenary 1896 - 1994 were classified as severe, moderate or mild, as recomended by different autors.

To each of these winters refer measerable values of ice-conditions indicators (for 10 coastal area), as the number of days with ice, ice durablility, length of ice season, dates of beginning and end of ice season, and so on. They were analysed and the range of variability of these indicators could be found for particular types of winters. In this way a better tool for estimating winter type has been gained.

Further frequency of particular winter types in the years 1896-1994 was calculated.

Also relation of winter-season type and atmospheric circulation (pressure pattern) in preceding months was investigated (August, September, October and November). The latter can be used in longterm (seasonal) forecasting winter conditions at the Polish coast.

CHARACTERISTICS OF THE WATER VAPOUR FLUX FIELD OF BALTIC SEA.

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Due to international meteorological information we have opportunity of deep analysis of humidity of drainage basin of Baltic See. In our work we concentrate on analysis of basic characteristics of the water vapour flux field for suitably chosen month. Data are collected from 25 aerological stations from Poland, Germany, Sweden, Finland, Estonia, Latvia, Lithuania, Russia. The area of investigation includes drainage basin of Baltic Sea (49°N-70°N,10°E-35°E). Data are obtained from GRIB message. Observations are made every twelve hours at midnight and noon on the earth level and isobaric surfaces : 1000,925,700,500,400,300,250,150,100 hpa. The following meteorological elements are measured :

- surface pressure and geopotential heighter [hpa]
- temperature [°C]
- temperature dewpoint depression [°C]
- direction of the wind [0 - 360°]
- speed of the wind [m/s]

We calculate for the above specified data daily specific humidity(q), zonal wind component (u) and meridional wind component(v).
Then we make a monthly analysis of the following characteristics :

- mean precipitable water given by

$$\overline{W} = \frac{1}{g}\int_{p_u}^{p_s} q \, dp \qquad [\ g/cm^2\ ]$$

- verticaly integrated mean total zonal water vapour flux

$$\overline{Q_\lambda} = \frac{1}{g}\int_{p_u}^{p_s} \overline{qu} \, dp \qquad [\ g(cm/s)^{-1}]$$

- verticaly integrated mean **total meridional water vapour flux**

$$\overline{Q}_{\phi} = \frac{1}{g}\int_{p_u}^{p_s} \overline{qv}\, dp \qquad [\ g(cm/s)^{-1}\ ]$$

- verticaly integrated mean total water vapour flux

$$\overline{Q} = i_{\lambda}\overline{Q}_{\lambda} + i_{\varphi}\overline{Q}_{\varphi} \qquad [\ g(cm/s)^{-1}\ ]$$

g - acceleration of gravity
p_s - pressure at the ground
p_u - pressure above which the vapour flux divergence becomes negligibly small
i_{λ} , i_{φ} - eastward- and northward-pointing unit vectors respectively

This analisys need be to continued. It will allow us to make comparisons with other drainage basins (e.g. Mississippi River Basin).

APPLICATIONS OF REMOTE SENSING DATA (NIMBUS-7, F8) FOR MODELLING OF ICE PROCESSES IN THE BALTIC SEA.

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Application of numerical models of different scale variations of hydrological and ice characteristics requires the input of averaged meteorological data, initial and boundary conditions for hydrological parameters. The computer modelling of large scale processes have also engaged by joining the data of sea ice thickness and concentration. The fields of ice concentration are used as initial fields and especially or the comparison with the results of modelling. These data could be received from remote sensing data.

Numerous data on CD-ROM were received from National Snow and Ice Data Center (NSIDC) and contained brightness temperature and sea ice concentration grids for North hemisphere regions. These data were taken from the observations made by F8,and Nimbus-7 satellites during 1978-1991. Sea ice concentration values were computed from the brightness temperature values and were analyzed for region of Baltic Sea. The algorithms developed in Russia for computing sea ice concentrations from brightness temperature values were also utilized, and then one can find out which method and in what cases is better for analyzing the position and dynamics of the ice cover of Baltic region.

Some exemples of applications of sea ice concentration values from F8 and Nimbus-7 for numerical modelling in Baltic Sea are discussed.

TYPES OF STORM SURGES AT THE POLISH COAST

Marzenna Sztobryn

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.oral presentation

At the Polish Coast a storm surge is - by definition - when the water level rises above the mean sea level at least by 0.7 m, even when locally.

From among more then 100 storm surges in the years 1951-1990 more than 80 % could be classified in 3 main types :

A - of long duration (more than 1 day and the water levels keeping all time close to the maximum value (e.g. 5-8 Feb. 1964),

B - of medium duration and of the variation curve resembling a normal distribution curve,(e.g. 13-15 Dec. 1957),

C - a shortlasting and rapid rise of sea level with the big difference between the maximum and minimum values, the most dangerous type (e.g. Kołobrzeg 16-18 Jan. 1955).

The remaining 20% of cases could be classified to 3 intermadiate types. Hydrological indicators characteristic to storm surge were calculated, as : the time of duration of a surge, maximum sea level reached during a surge with time of the duration of the maximum, the difference between minimal value preceding the rise and reached maximum, rate of rise and decay (extreme and average value for 1 hour) and so on. Meteorological indicators were calculated as the differences between air pressure over the Baltic Sea.

The ranges of variability of these indicators were estimated for each type of the storm surge.

Also the frequency of storm surges in particular years and months was computed and longterm changes in storm surges occurence were investigated.

NUMERICAL SIMULATIONS OF THERMALLY DRIVEN MESOSCALE CIRCULATIONS ON THE BALTIC COAST

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A three-dimensional mesoscale numerical model is employed to investigate an observed and documented sea-breeze event on the Baltic coast, southeast of Sweden. The model, thoroughly documented in the literature, is initialized using generalized and simplified input extracted from the experimental and synoptic data with the aim to generate the main properties of the observed case. A comprehensive set of three-dimensional, time-dependent data is generated in order to obtain a more complete description of the case characteristics. Based on the control simulation, exhibiting all the main observed aspects of the observed case, several perturbation runs are performed to study the influence of several forcing parameters emanating from the surface (e.g., terrain and surface temperature effects).

Among the conclusions are that the sea-breeze stage is preceded by a coastal jet stage featuring significant influence on the flow by the quite moderate terrain ($h_0 \leq 206$m, h_0 is the maximum terrain height). This is due to the ratio of the depth of the marine boundary layer to the terrain height - the terrain is blocking the airflow. A sea-breeze evolves at one coastline but does not penetrate inland until another sea-breeze on a perpendicular coastline moves inland and removes the off-shore flow balancing the first sea-breeze at the first coastline. After this balancing is removed, the first sea-breeze rapidly propagates inland too. The development of the two sea-breezes is strongly influenced by the terrain. Removing the terrain completely alters the time-history of the flow. Removing the major offshore island, Öland, had a notable effect but did not change the main flow structure. This is also the case for various perturbations on the specified inland temperature that vary the intensity and shape of sea-breezes and coastal jets. Additionally imposed sea surface temperature gradients had minor to moderate (at most) influence on the considered case.

TRENDS IN SNOW COVER, SURFACE ALBEDO AND TEMPERATURE IN ESTONIA

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Underlying the present paper are mainly the data provided by the Tartu-Tõravere Actinometry Station between 1953 and 1994. The mean monthly surface albedo $\bar{A}$ averaged over this period was highest for February (0.69) and lowest for May (0.20). The absolute maximum 0.89 of monthly mean albedo was reached in February 1960. The variations in albedo are most expressed in March, April and January due to the critical state of surface (snow or old grass). The respective standard deviations of albedo in March, April and January are 0.20 and 0.18. The values of the variation coefficients peak in March (0.37) and in April (0.38).

Table 1. Regression and correlation coefficients for the trend - equation of the duration of snow cover ($\tau = a_1 t + b_1$) and for the mean monthly surface albedo ($A = a_2 t + b_2$) in Tartu between 1953 and 1994: t denotes time in years from the beginning of the observation period, **r** are the correlation coefficients and **p** are their significance level.

		Duration of snow cover τ (in days)			
Period	a_1	b_1	r	p	The trend during the 42 years
March-April	-0.42	32.4	0.30	<0.05	-18
		Surface albedo			
	a_2	b_2	r	p	The trend during the 42 years
January	-0.005	0.745	0.343	<0.01	-0.17
February	-0.003	0.763	0.269	>0.05	-0.13
March	-0.005	0.649	0.321	<0.05	-0.21
April	-0.002	0.297	0.334	<0.05	-0.08
May	0.000	0.195	0.158	>0.05	0.00
November	-0.000	0.330	0.040	>0.05	0.00
December	-0.003	0.605	0.308	<0.05	-0.13
March-April	-0.004	0.459	0.420	<0.01	-0.17

Snow cover and surface albedo are interpreted as integrators of weather and indicators of climatic changes. It is found that the decreasing trend in the albedo of snow cover in Tartu Actinometry Station during the last 42 years between 1953 and 1994 is obvious (Table 1).

During the last 42 years the duration of snow cover has decreased by about 18 days. The respective decrease in the measured surface albedo in

Tartu is 0.17 (January), 0.13 (February, December) and 0.21 (March). The changes in the duration of snow cover and albedo are caused by a positive trend in winter and spring temperature (Table 2).

Table 2. Regression and correlation coefficients for the trend-equation for the monthly mean temperature ($T=a_3t+b_3$) in Tartu.

Period	a_3	b_3	r	p	The trend during the 42 years
January	0.079	-7.9	0.226	>0.05	3.3
February	0.079	-8.3	0.230	>0.05	3.3
March	0.094	-4.3	0.395	<0.01	3.9
April	0.053	2.8	0.378	<0.05	2.2
May	0.041	10.2	0.283	>0.05	1.7
November	0.006	-0.1	0.030	>0.05	0.3
December	0.051	-5.0	0.209	>0.05	2.0
March-April	0.078	-0.7	0.490	<0.01	3.3

The trend in temperature during the last 42 years is high in January and February (3.3°C) but its significance level is low. This trend reaches the maximum in March (3.9°C) with the high significance level..Significant is the trend in temperature also in April (2.2°C). In other months the trend is smaller and it is absent in summer. For the other spots in Estonia the albedo run and trends were reconstructed. For this purpose data for the duration of snow cover in early spring (March-April) were used. For the reconstruction the values of the albedo, a correlation between the surface albedo and the duration of snow cover has been established from the observations made in the Tartu-Tõravere Actinometry Station between 1953 and 1992. In this a way an approximate time series for the surface albedo has been found for other spots where no direct measurements of radiation had been made. The changes in the duration of snow cover and the decrease in surface albedo during the last 42 years were analyzed as indicators of the change in climate. The shortening of the duration of snow cover and the decrease in albedo are more pronounced along a belt crossing Central and South Estonia. The changes in the duration of snow cover and the decrease in albedo are less pronounced on the islands and in some coastal regions.

The above results show that the climatic changes during the last 42 years expressed by the trends in temperature, the duration of snow cover and surface albedo in Estonia are most obvious in winter and early spring. Changes in the surface albedo are energetically most effective in early spring when the flux of total radiation is fairly high and snow cover varies from year to year considerably. Changes in temperature and albedo exert a positive feedback. Indeed, a rise in temperature immediately leads to the shrinking of snow cover while the respective decrease in albedo, in its turn, causes a further rise in temperature and accelerates the melting of snow cover.

SIMULATION OF A DENSE WATER INTRUSION INTO THE BALTIC

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To investigate the main features of the dense water intrusion from the Kattegat into the Baltic a two-dimensional (depth and axial directions) model is used. A set of gorverning equations includes equations of vorticity and stream function which are obtained from equations of momentum and mass conservation. It also includes equation of salinity conservation and equation of state.The model was applied to simulate the dense water intrusion into the Baltic with two types of initial vertical salinity distribution. At the first case the initial salinity was accepted to be 0 pml for depthes less 50 m, and 10 pml for more depthes.At the second case in the down layer initial salinity gradually increases from 10 pml at the depth 50 m to 18 pml at the 200 m.At the first case penetrating dense water reaches the most depthes after 10 days and its salinity decreases from 15 pml to 12 pml. At the second case the intruding dense water reaches only the depthes with salinity equal to its salinity. After that penetrating water begins to spread horizontally. The obtained results makes it clear that the presented model can be successfully used for simulating such procecces as the dense water spreading in the Baltic, the bottom water forming and the Baltic water exchange. The model used can be a base for the development of a three-dimentional the Baltic sea model.

AMOUNT OF WATER, ENERGY AND HEATING IS BROUGHT BY ESTONIAN RIVERS TO THE BALTIC SEA.

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To create the approximate carrying-out model for water, energy and heating as a basis for future obtaining of suspend, hydrochemical and/or biological component of input to the Baltic Sea from Estonia.

Method

1. The coastal line of Estonia with the three main islands (Saaremaa, Hiiumaa and Muhu) has been devided by pieses so that each one is not more than 10-20 km (97 cutted for Estonia and islands). Through each subline the long-term month run-of f, energy and water heating are obtained by following equations:

average month run-of f - Q1, m^3/s or volume W1, m^3/month - as the sum of all stream discharges which cross this subline:

$Q1 = Qi$; $W1 = t*Q1$, where t - amount of seconds on the month;

month water energy (work, J):

$$E = t*y*g* \ (Qi*I*L),$$

where I - water surface slope on the river mouth,
y - speciphic water gravity (=1)
g - speciphic gravitation factor (=9.8 m/sek2),
L - length of the river plot with Qi;

month heating (H1, J):

$$H1 = t* \ (Qi*Ti),$$

where Ti - monthly water temperature of calculated stream.

2. Ungauged and unknowen revers discharges were obtained by analogy, regression and/or proportion method.

3. The slope size was defined by map for river plot which has a constant discharge in it^{1}s borders. Was used the same slope for each day undepending on sea level.

4. The water temperature for ungauged rivers was taken by analogy.

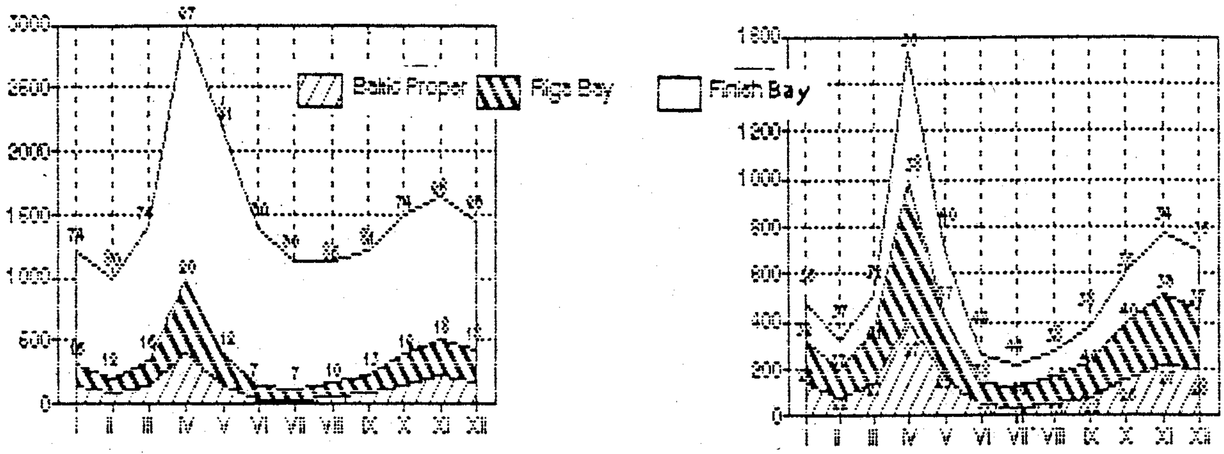
Results

A flow from 79 819 km^2 flows over the Estonian coastal line (Estonian area is equal 45 000 km^2) and overage discharge of this flow is equal 625 m^3/s (320 m^3 is discharge of the river Narva). To Finish Bay the 78% of water, 78% of energy and 76% of heating are carrying out by Estonian rivers (with the Narva r.) or 37%, 39% and 40% without it; to Riga Bay - 13%, 14% and 14% or 39%, 38% and 36% corresponding.

Month distribution of these parameters are shown on the fig. 1 abc.

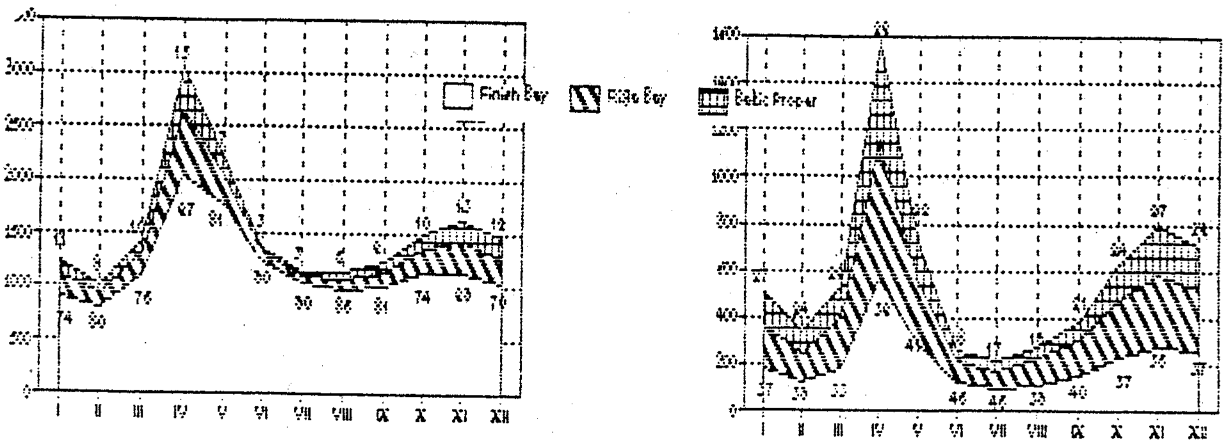
a) distribution of water volume, Mln. M^3
with Narva r.

without Narva r.



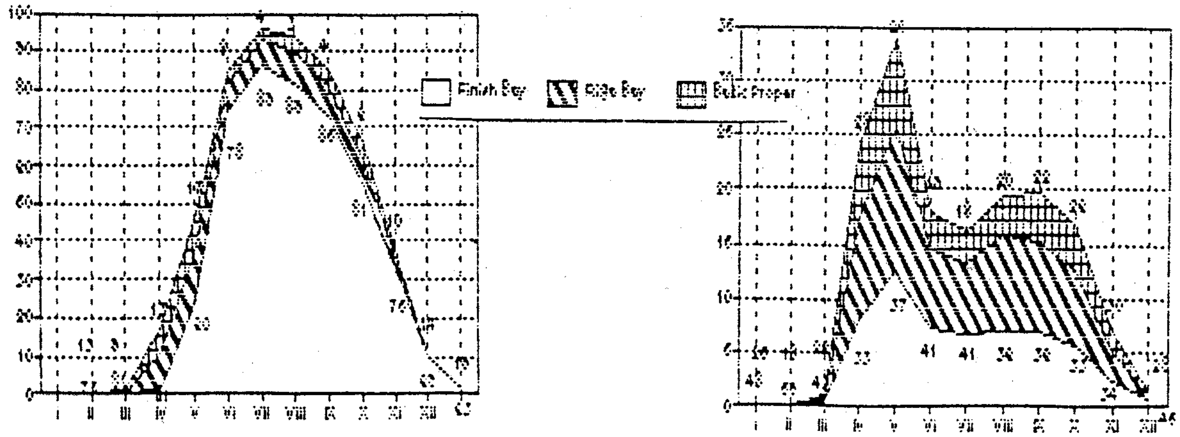
b) distribution of energy, Mln. J
with Narva r.

without Narva r.



d) distribution of water heating, Mlrd J
with Narva r.

without Narva r.



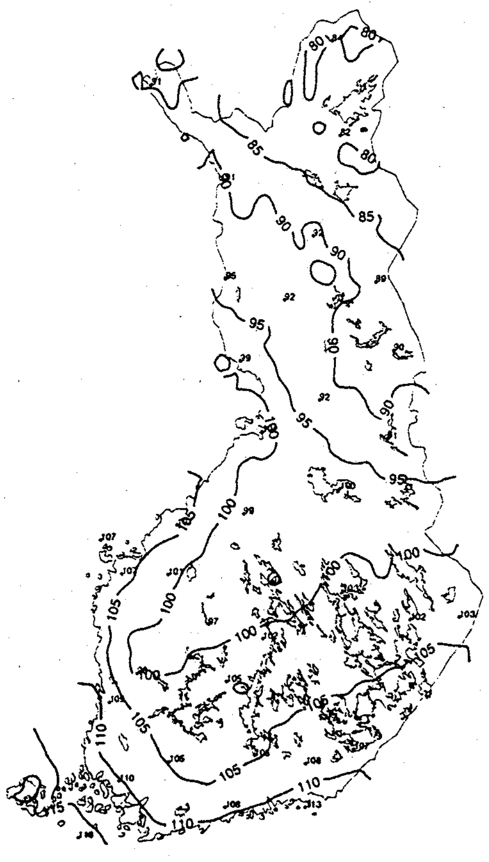
The spatial variation of mean monthly global radiation in Finland

Ari Venäläinen and Martti Heikinheimo, Finnish Meteorological Institute

In this study detailed spatial analyses of global radiation in Finland were made using both directly measured and indirectly estimated radiation values. The use of indirect methods was found meaningful, and the spatial distribution of the long-term mean monthly global radiation was analysed onto a 10km*10km grid. The analyses were based on (a) measured radiation values (5 stations) with the help of estimated radiation values from (b) cloud observations (15 stations) and (c) sunshine duration observations (17 stations). The time period used was 1961-1990.

The interpolation onto the grid was done using the kriging interpolation method, which can take external forcing, such as the altitude, into account in the interpolation. When inaccuracies due to indirect estimation methods and due to the interpolation method are taken into account the error of the interpolated radiation value at any randomly-selected grid point was found to be less than five percent for most months.

During winter months the spatial distribution of global radiation is very clearly dependent on latitude, the northern parts of the country getting less radiation than the southern parts. During summer the spatial distribution of global radiation is determined by the variation of cloudiness.



The mean annual global radiation in Finland (W.m^2).

MEASURED AND ESTIMATED PRECIPITATION IN THE MOUNTAIN AREAS

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1. Introduction

The objective of this presentation is to show how to solve the problem of implementing precipitation data (obtained from field investigations) to the BALTEX Project according to relevant requirements. To achieve this, it is necessary to prepare maps of the precipitation field on the basis of data sets as close as possible to the 'real' ones. It is commonly known that precipitation measurements are plagued by a number of systematic errors induced by evaporation, wetting and, primarily, by the wind.

The latter originates in wind-field deformation above precipitation gauge. The aim of our experiments was to eliminate the effects of sparse and inaccurate precipitation measurements in the mountain areas.

2. Methods

The best set of methods with respect to the actual amounts of precipitation was given by Sevruk. In Poland, an original (although similar) approach was proposed by Kwiatkowski, as well as by Woźniak and Stopka. The general idea of the Kwiatkowski method consists in comparing the precipitation data for the same range of elevations collected at stations with different (bad, good or very good) measuring conditions. For example, by comparing data obtained from wind-protected sites (like forest clearings or orchards) with those collected in open areas with no wind protection.

Kwiatkowski made a simple assumption: The well protected sites have higher sums of measured precipitation, so they can be adopted as the reference stations for correcting the sums of other stations, located mostly in open or partly protected sites. In our study, a new empirical relationship was determined on the basis of the data sets from recent and more accurate measurements. With this relationship it is easier to estimate the measured (P) and corrected (P_c) sums of precipitation at each point of the same area under study.

3. Study area

The precipitation patterns were monitored on the area of northern slopes of Karkonosze Mts. and in the adjacent part of the Jelenia Góra Valley, (that is in the central part of the West Sudety Region). The elevations vary from 1200 to 1602 m asl. Above 500 m asl. almost half of the overall precipitation falls as snow. The upper parts of the area (over 800 m asl) have a sub-alpine climate characterized by a short vegetation period, and strong winds (at 1000 m asl wind speed averages between 5 and 7 m/s).

The first investigations of this area were carried out by Kwiatkowski in the span of 1968-1980. The investigations have been furthered since 1981, but detailed monitoring of errors covered only the period of 1983 to 1986.

4. Results

At the first stage of the study regional precipitation data were found to be quite homogeneous in time and space, but divided into two slightly different subregions (West and East Karkonosze Mts). Fitting was carried out to determine the empirical relation between the measured sums of the precipitation (P mm) and the heights of the measuring stations (H_s m asl). Several statistical relations were fitted and the logarithmic regression curve was found to be the best possible. In first step we estimated the degree of gauge site protection from the wind (in 7 classes). Next, we computed the local wind-induced error of the precipitation measurement (X_w) and the errors induced by evaporation + wetting. When added to the measured sums (P), the values of precipitation measurement errors (X_w mm) gave a new set of point data-the corrected average sums of precipitation (P_c mm). The monthly, seasonal and yearly sums of corrected precipitation amounts were computed. The equations of mean yearly sums P and P_c, correlation coefficient R and error of the precipitation evaluation V_x (%) were as follows:

<u>West Karkonosze Mts</u>

measured values:	$P=559 \times \ln(H_s)-2570$	$R=0.88$	$V_x=7.8$
corrected values:	$P_c=735 \times \ln(H_s)-3570$	$R=0.91$	$V_x=7.2$

<u>East Karkonosze Mts</u>

measured values:	$P=471 \times \ln(H_s)-2040$	$R=0.89$	$V_x=8.4$
corrected values:	$P_c=732 \times \ln(H_s)-3580$	$R=0.97$	$V_x=4.7$

A comparative analysis of the results obtained by Kwiatkowski (1968-1980) and those obtained later (1981-1994) has positively verified our method. The average sums from different periods were well fitted to the general curve which relates the precipitation amount to elevation. The elevation/precipitation relationship may be a useful tool in preparing the corrected precipitation sums for each BALTEX grid point. However, the lack of current observation data the errors of precipitation measurements makes the correction of the precipitation values a difficult task. But analogy seems to be one of the most convenient ways to solve this problem.

Our presentation also concentrates on the methods that should be applied to the computation and implementation of corrections, as well as to the estimation of their usability.

The method proposed has two major drawbacks:

1. The differences induced by windward and lee zone conditions are neglected.
2. The problem of the differences induced by the real inclination and exposure of the slopes is not solved.

PRINCIPAL FORCING FACTORS OF THE SEASONAL BALTIC MEAN SEA LEVEL OSCILLATIONS

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The work mainly presents an influence of the atmospheric pressure and wind fields on the seasonal oscillations of the Baltic basin mean sea level. Other factors causing the phenomenon are briefly mentioned and their influence is not computed.

The period of the analyzed Baltic mean sea levels expands from the last decade of the nineteenth century to the second half of the twentieth century. An exact formula connecting empirical orthogonal functions of the several representative tide gauge stations and the Baltic mean sea level is presented. The formula enables to extend the sea levels under consideration for a period of the representative tide gauge station measurements.

The influence of the atmospheric pressure field and the wind field is analyzed on the basis of the historical atmospheric pressure data. Empirical orthogonal functions constitute the main method of representing the fields. A stochastic dynamic system of stable parameters for correlated inputs allows to separate the influence of particular forcing elements on the mean sea level and to show their characteristics.

A stochastic analysis of the Baltic mean sea level seasonal changes and its statistical characteristics are also presented.

BASIC TRENDS IN THE CONTRIBUTION OF RUSSIAN SCIENTISTS TO THE IMPLEMENTATION OF BALTEX PROJECT

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The BALTEX Project is of a great interest for Russia because it is aimed at a more profound study of heat and water exchange processes in the Baltic Sea basin, and the major portion of this basin is within the territory of Russia. By the present time, a great number of studies made by SHI, MGO and SPBOI are available on air and moisture fluxes within the Russian part of the basin and within the adajcent areas. These studies are based on long-term data of observations from the standard hydrometeorological network, as well as on the data of special field teams collected during different years on land and sea.

The outlined studies of Russian institutions on BALTEX Project should be regarded as a logical continuation of the studies implemented on the research of the climate system of the Baltic Region. During the first stage of the project implementation (1995-1996) the major emphasis is to be made on the collection, analysis and processing of data on the hydrometeorological regime components and on energy balance characteristics of the underlying surface of the Russian territory of the Baltic Region relatively to several typical periods selected for modelling and specified in the Implementation Plan for BALTEX. It is planned to create a special bank of hydrometeorological data, including historical data massives. Studies on the assessment of the laws of surface and subsurface water inflow to the Sea will be also developed, as well as on the computation of energy and water exchange components for the Russian territory of the Baltic Sea basin.

The work will be done on the creation of the regional climate model with horizontal grid step of 50 km, 14 vertical design layers and time integration step of 120 s. It is expected to make a series of tests for modelling the seasonal water exchange in the atmosphere above the Baltic Region (including computation of precipitation, evaporation, snow pack storage and melting, as well as river runoff) and to compared the computed and observed data. This would require the use of appropriate basic information over the entire region, collected during the first stage of the BALTEX Project implementation.

It is supposed to apply the modified three-dimensional hydrodynamic model to compute fields of currents, temperature and salinity in the Baltic Sea. This work will be done in cooperation with Swedish and Danish scientists.

TRENDS IN HYDROLOGICAL REGIME CHANGES IN THE BALTIC SEA BASIN ON THE TERRITORY OF RUSSIA

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Assessment of trends in the hydrological regime changes under the effect of climate variations is one of the most important problems of the modem hydrology. According to the results of the analysed data from mass hydrometeorological network on the Russian territory of the Baltic Sea basin (more than 300,000 sq.km), the climate characteristics changes during the last 40 years are rather uniform, i.e. annual air temperatures have raised by 0.4 - 0.6 °C on average, moreover the temperature rise is observed during the cold season, meanwhile summer has become cooler; annual precipitation increased by 40-60 mm on average, during autumn-winter period in particular.

This uniform climate variations led to overall increase in annual river runoff by 10-30 % on average during the last 10 years, if compared with the norm. Moreover, low flow, winter and summer-autumn flow increase is maximum (up to 40-80 % of the norm), but spring snowmelt flood runoff is unchanged or is reduced by 5-10 %, on average, if compared with the norm. In the rivers flowing in the southern part of the Region, a trend to recharge changes is observed, i.e. "mainly snow" river recharge is replaced by "mixed recharge with snow predominance". Some deviations from the general trend are observed in the rivers with large lake areas and karst availability in the basins.

Observation data on water balance from the Valdai Laboratory of the State Hydrological Institute, located at the southern boundary of the Neva River basin, show that river runoff increase in the Region was mainly caused by evaporation decrease during the warm season (up to 60 mm), higher precipitation and snow melting during winter thaws. Some increase in the ground water storage was probably insignificant because of shallow aquifers, though it also contributed to the increase of the low flow. A certain dry of the top soil layer 1 m deep (about 10 mm) during the last years observed from January to July is probably connected with lower amount of moisture motion to the front of soil freeze-up in winter.

Assessments of possible changes in the hydrological regime over the territory from different scenarios of climate changes and paleoclimate reconstructions demonstrate a probable intensification of the observed trends.

BALTEX - A REGIONAL COMPONENT OF GEWEX

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Oral, invited

1. Introduction

The concept for the Baltic Sea Experiment (BALTEX) has been developed to improve observations and the modeling of energy and water transports within our climate system but with very high spatial and temporal detail over the water drainage basin of the Baltic Sea with the primary goal in mind to improve the global modeling and monitoring of such transports. Here atmospheric models must be coupled with others for oceans (the Baltic Sea) and hydrological processes at land surfaces.

The plans for BALTEX began to evolve as early as in 1991. At present an organisational structure has been established and an Initial Implementation Plan (1995) has been worked out for coordinated research activities during a built-up phase (1994-1996) and an intensive research phase (1997-2001), where during the latter several field experiments will be carried through to study primarily exchange processes over different terrain and in different time zones. Interfaces will be defined for the applications of this more basic research by environmental and impact studies.

At present, research groups and agencies from 10 countries, from whose territory water is drained into the Baltic Sea, participate in BALTEX. The BALTEX research will provide many interfaces to other relevant environmental research and applications. An International BALTEX Secretariat has been established as a focal point for all individual and coordinated actions.

2. The problem

Cascades of energy transfer processes occur in our climate system which essentially is driven by solar electromagnetic radiation. Water in the atmosphere, in the oceans and within the ground plays in those processes a dominant role; it further is of basic importance for life on earth. Thus any model computing the present, past or future climate patterns must take these roles into account to reproduce at least the present realities. However, despite of the recent dramatic advances in direct and indirect (spaceborne) measurement techniques, our knowledge of such exchange processes and the involved amounts of energy and water is still rather inaccurate as the intercomparisons of model results (Gates, 1993) and of climatologies (WMO, 1990) show.

Therefore, several coordinated research efforts are now installed within the framework of the World Climate Research Programme (WCRP) to obtain better modeling and observing techniques which include also advanced data analysis procedures.

One particular programme, the Global Energy and Water Cycle Experiment (GEWEX), has been established in the earlier 1980' ties for these purposes (WMO, 1990; Chahine, 1992). Its various subprojects consider in particular the still open questions on "cloud-radiation interactions", the spatial distribution and temporal variability of atmospheric water vapor, precipitations in form of water and snow and the areal evaporation and evapotranspiration. GEWEX contains further a strong hydrological component to measure and model in proper detail the runoff in all river systems, and also the possible storage in the ground. The latter then provides on various time scales the water sources for life on earth.

An accurate knowledge of these processes and their sensitivity to changes in the climate is also essential for estimates of the impact of climate changes on the availability of water resources and the comlex interplay with the surface vegetation system.

3. Regional Programmes of GEWEX

Within GEWEX, now five regional programmes have been established whose primary goals are related to the GEWEX objectives but are limited to particular geographical regions. Their purpose in particular is to improve our knowledge on hydrological processes over continents with very high spatial and temporal detail. They, therefore, will primarily contribute to improve the modeling of the fast climate processes - i.e. in particular the weather forecast and its consequences for various applications. Their major characteristics are summarized in Table 1. Representatives of these five experiments and of the ISLSCP form now a working group within GEWEX, the GEWEX Hydrometeorological Panel (GHP), which will also meet during the meetings in Visby. The BALTEX area is shown in Fig. 1.

4. The Baltic Sea Experiment

The BALTEX has in principle been defined in 1992 (see time table in Table 2) with the major scientific objectives to

- to explore and model the various mechanisms determining the space and time variability of energy and water budgets of the BALTEX regions 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.

Details are written down in the Science 94 and Initial Implementation Plans (BALTEX 1994, 1995).

Its organisational structure (Fig. 2) is related to that of the GEWEX. An International BALTEX Secretariat, at present located at the GKSS Research Center, is the focal point for all coordinating activities between the different BALTEX - Working Groups on one side and the BALTEX - Science Steering Group on the other. In the latter, membership from each participating country (at present 10) and representation of all 3 involved scientific disciplines (meteorology, hydrology and oceanography) is ensured. These members are also the connections to their home countries. BALTEX does not yet possess a special budget, rather its success will depend on individual commitments.

The German Weather Service in Offenbach is serving now as a data center, responsible for all operational meteorological observations which are available through the Global Telecommunication System (GTS) and which also will be made available through other connections (e.g. additional precipitation and radiation data). The Swedish Meteorological and Hydrological Institute in Norköpping and the Finnish Institute for Marine Research in

Table 1 Regional Programmes of GEWEX

Programme	**Drainage Area** km^2	**Discharge** km^3 / year	**Location**
GEWEX Continental International Project (GCIP)	$3.22 \cdot 10^6$	570	Drainage Basins of the rivers Mississi and Missouri (Central United States)
Mackenzie-River GEWEX Study (MAGS)	$1.75 \cdot 10^6$	330	Northwestern Territories of Canada
GEWEX Asian Monsoon Experiment (GAME)	-	-	Japan, South-East Asia and the Lena - Basin in Siberia
Large Scale Atmospheric Moisture Balance of Amazonia using Data Assimilation (Lambada)	$4.7 \cdot 10^6$	~ 6000	Drainage basin of the Amazone River Brasil
Baltic Sea Experiment (BALTEX)	$2.1 \cdot 10^6$	470	Drainage basin of the Baltic Sea of about 14 European countries

Helsinki will primarily act as remote centers for all hydrological and oceanographic data, which are collected at different centers in the BALTEX states.

5. The BALTEX - Implementation

The BALTEX working groups shown in Fig.2 have provided essential input to implement BALTEX in its present initial built-up phase, which may last until the end of 1996. An overview on all planned activities and of their time periods is given in Table 2 (from BALTEX Initial Implementation Plan). The organization forsees three major projects which are linked together within seven networks to assure interdisciplinary and international work. These are listed below on consider

- full-scale studies of the energy and water cycles
- high-resolution process studies with emphasis on hydrological modeling
- coupled modeling of the Baltic Sea and the atmosphere
- a cloud / precipitation / air-sea interaction experiment
- a cloud / precipitation / air-land interaction field experiment
- an atmosphere-ice-ocean field experiment
- a Baltic Sea vertical advection and mixing experiment

The key strategy of BALTEX is related to the scientific objectives making simultaneous use of numerical modeling techniques, of ground-based and satellite-based observations and of process studies with intensive measurements in the field. All numerical models shall couple the atmosphere with the land surface hydrology and also atmosphere-ocean (Baltic Sea and North Sea) interactions, where in principle such investigations will be made within three major scales (large, meso and small) as shown in Tables 3 and 4 (from BALTEX Initial Implementation Plan).

Several specific modeling projects and process studies have been defined for which a particular scientific group will be responsible to carry major coordinating work load for it. A special pilot study (PIDCAP) arose from recent consideration to improve in particular the observations of precipitation. The PIDCAP-area covers the western portions of the Baltic Sea and adjacent continental surfaces and is well covered by ground-based radar and other stations, while only a few rain sensors will be carried on board of ferry boats. PIDCAP has the purpose to combine all available informations on precipitation in Aug. to Dec. 1995 for improving model results but also data collection and handling techniques over the active area.

6. References

(1) BALTEX, 1994: BALTEX - Scientific Plan for the Baltic Sea Experiment - Sec. Edition, available through the International BALTEX Secretariat in Geesthacht.

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(3) Chahine, M. T., 1992: The hydrological cycle and its influence on climate. Nature, **359**, 373-380.

(4) Gates, W. L. et al., 1992: An intercomparison of selected features of the control climates simulated by coupled ocean-atmosphere general circulation models. Report WCRP-82, WMO/TD-No. 574, 102pp.

(5) WMO, 1990: Scientific Plan for the Global Energy and Water Cycle Experiment. WMO/TD-No. 376, WCRP-40, 83pp.

Figure 1 The BALTEX - Model area. In the upper right curve are shown grids of the Europe - Model (54 km) and of the BALTEX - Model (18 km), where the latter is nested into the other.

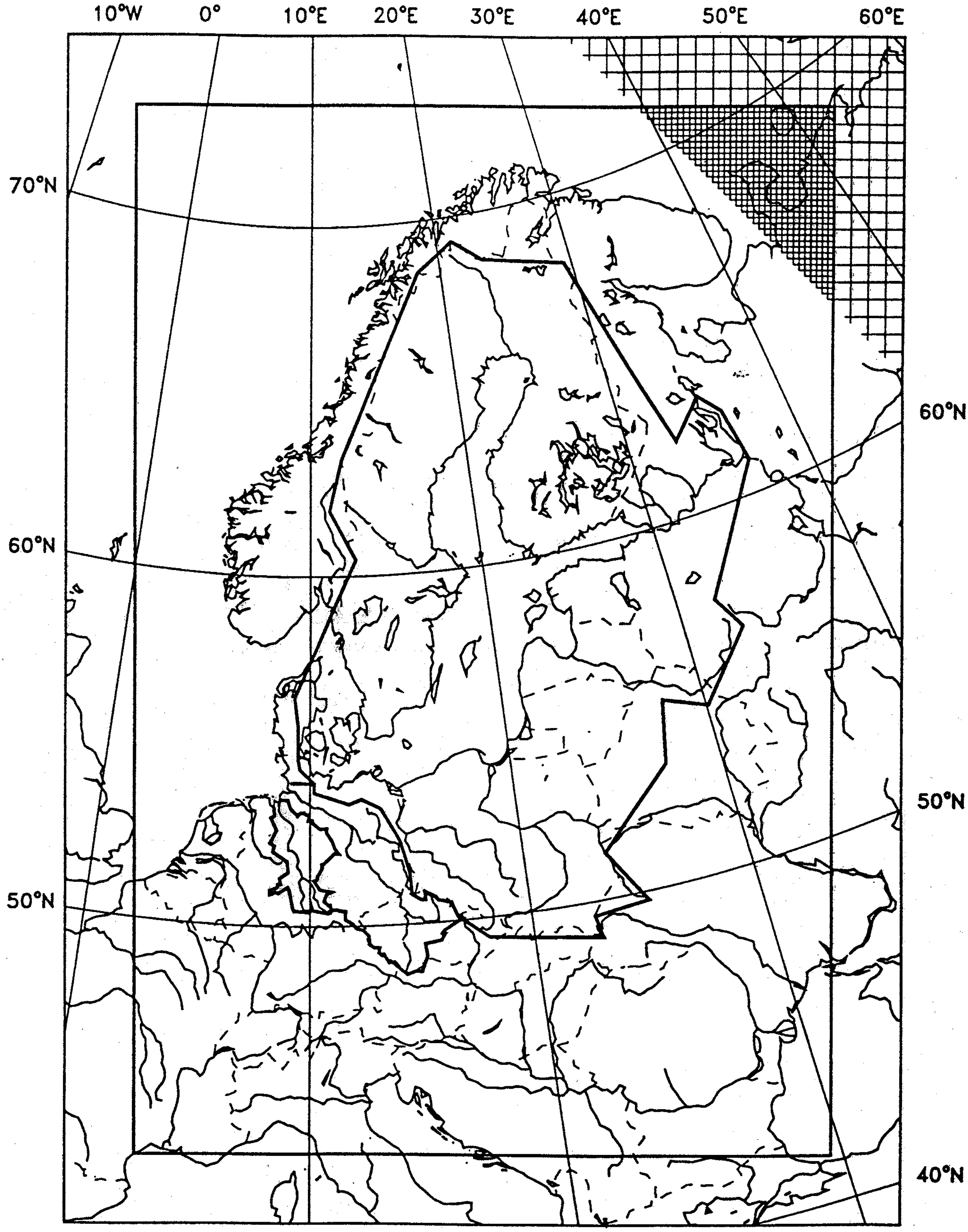

Figure 2 Organisational Structure of BALTEX

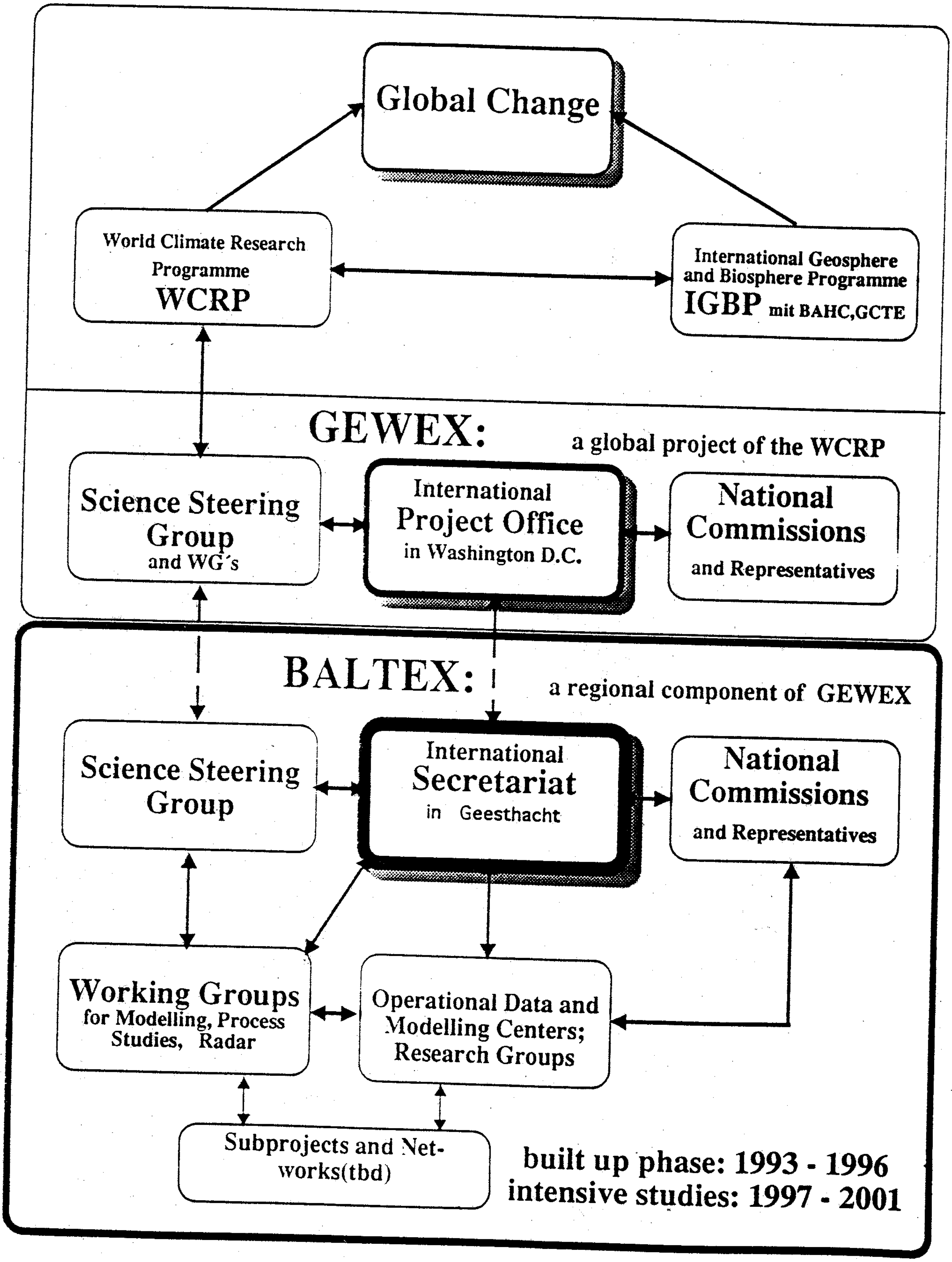

Table 2 Time schedule for BALTEX Research Projects

Project	Year							
	94	95	96	97	98	99	00	01
1. Data Assimilation Projects								
1.1 Meso-scale Meteorological Re-analysis		****	****	****				
1.2 Oceanographic Data Assimilation	**	****	****	****	****	****		
1.3 Hydrological Data Assimilation			****	****	****	****	****	
1.4 Transports through the Danish Straits	**	****	****	****	****			
2. Modelling Projects								
2.1 Water and Energy Budgets over the BALTEX Region		****	****	****	****	****	****	
2.2 Baltic Sea Response to Atmospheric and Hydrological Forcing	****	****	****	****	****	****	****	
2.3 Development of a Sea Ice Model for the Baltic Sea Model		****	****	****	****	****	****	
2.4 Thermohaline Circulation and Long-term Variability of the Baltic Sea			****	****	****	****	****	
2.5 Intercomparison of Atmospheric Models			****	****	****			
2.6 Full Hydrological Model for the BALTEX Region	****	****	****					
2.7 Validation of the Hydrological Components of the Meteorological Models			****	****	****	****	****	
2.8 Development and Intercomparison of Hydrological Models for selected River Basins			****	****	****	****	****	
2.9 Coupled Atmosphere/Ocean/Land Surface Model					****	****	****	****
3. Field Experiments - Process Studies								
3.1 Cloud/Precipitation/Air-Sea Interaction			**	****	****	**		
3.2 Cloud/Precipitation/Air-Land Surface Interaction				**	****	****	**	
3.3 Atmosphere - Ice - Ocean				**	****	****	**	
3.4 Baltic Sea Vertical Advection and Mixing			**	****	****	**		
3.5 Front Modification					**	****	****	
	94	95	96	97	98	99	00	01

Table 3 Scales and science strategy for atmosphere - land surface coupling

Scale	Size (km)	Spatial resolution in modelling (km)	Data base	Research focus
Large scale	Atmosphere: 10^3 - 10^4 Hydrology: 10^3	Atmosphere: 10 - 30 Hydrology: 1 - 5	Standard observational network	• Coupled atmospherie - land surface models • Prediction of regional climate impacts
Meso-scale	10^1 - 10^3	Atmosphere: 2 - 10 Hydrology: 0.1 - 0.5	All available data for at least the following study areas: • Torneälven catchment • Daugava catchment • Vistula catchment	• Data assimilation of remote sensing data • Scaling of model process descriptions and parameters • Validation of coupled models
Small scale	≤ 10	Atmosphere: 2 - 5 Hydrology: 0.01 - 0.05	Small hydrological research catchments with special field measurement programmes, at e.g.: • NOPEX • Lindenberg	• Process submodels • Atmosphere - land surface interaction • Process studies

Table 4 Scales and science strategy for atmosphere - ocean surface coupling

Scale	Size (km)	Spatial resolution in modelling (km)	Data base	Research focus
Large scale	10^3 - 10^4	Atmosphere: 10 - 30 Ocean: 5 - 30	Standard atmospheric and hydrographic data, runoff data and data from process studies, data from monitoring activities	• Data assimilation • Coupled atmosphere - ocean models • Ocean modelling including sea ice
Meso-scale	10^1 - 10^3	Atmosphere: 10 - 30 Ocean: 1 - 10	Data from process studies and runoff data	• Data assimilation • Process submodels
Small scale	≤10	Atmosphere: 2 - 10 Ocean: 0.1 - 1	Data from process studies and inflow data	• Inflow dynamics and - mixing • Model nesting • Process submodels