Lehmann, A. and Hinrichsen, H.-H. 2000. On the thermohaline variability of the Baltic Sea. J. Mar. Sys., 25, 333-357.

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

Lehmann, A., Ph. Lorenz, D. Jacob 2004. Exceptional Baltic Sea inflow events in 2002 - 2003. Geophysical Research Letters, Vol.31, L21308,doi:10.1029/2004GL 020830

BASEWECS - Influence of the Baltic Sea and its Annual Ice Coverage on the Water and Energy Budget of the Baltic Area

A. Lehmann (alehmann@ifm-geomar.de), W. Krauß, J. Karstensen, H. König, T. Müller, U. Send
Leibniz Institute of Marine Sciences at the University of Kiel, (IFM-GEOMAR), Germany
H.U. Lass
Institute for Baltic Sea Research Warnemünde at the University of Rostock, Germany
R. Dietrich, L. Eberlein, G. Liebsch, K. Novotny
Institute for Planetary Geodesy, Dresden University of Technology, Germany
H. Prandke
InSitu Wassermeßtechnik, Peterdorf, Germany

BASEWECS is a contribution to the German Climate Research Program DEKLIM. The project started in May 2001 and lasted until December 2004. BASEWECS aimed at the investigation of the influence of the Baltic Sea and its annual ice coverage on the water and energy budget of the BALTEX area.

Aim of the research in the framework of DEKLIM

The computation of the energy and water budget is a milestone in controlling the quality of numerical models, which later can be used for studies of extreme events and climate change in the Baltic area. Improved knowledge of the energy and water budgets can only be obtained from sophisticated numerical models, including data assimilation and model validation. The consortium used a 3 dimensional coupled sea ice-ocean model (BSIOM) driven by observed meteorological input fields and runoff data, in order to obtain the most accurate response of the Baltic Sea. The results have been compared to the results of an interactively coupled model of atmosphere, land surfaces, the Baltic Sea and sea ice (BALTIMOS).

Main conclusions

Three-dimensional ocean circulation models of the Baltic Sea (including ice) have reached a sufficient state of accuracy, so that a coherent picture of the circulation and the water mass exchange within the Baltic Sea can be described. The energy and water cycle can be determined for the Baltic Sea, but uncertainties remain mainly in the forcing functions, by unresolved processes such as turbulent mixing and the limited resolution of the hydrodynamic model. Improved atmospheric forcing data and river runoff are urgently needed. The flux parameterisation needs to be revised and further studies with respect to turbulent mixing and the effects of waves on mixing and fluxes need to be investigated. The improved understanding of the dynamics of the surface layer of the ocean is crucial for turbulent processes which control the exchange of momentum, heat, dissolved and particular matter. Subproject B contributed to this issue and improved the understanding of the energy transport within the mixed layer by complex measurements of dissipation and turbulence. The parameterization of turbulence in ocean circulation models should mirror the observed relations between the wind and surface turbulence regime with respect to both intensity and vertical scale. Subproject C has shown that the water transport through the Fehmarn Belt can be described with good accuracy by the combination of transport measurements at only one position and BSIOM. However, the accurate measurement of heat and salt fluxes need, because of the high variability, more measurement sites across the Fehmarn Belt. Subproject D has demonstrated that sea level variations are satisfactorily described by BSIOM with good accuracy for high frequency variations and some underestimation at seasonal and inter-annual time scales. An improvement can be achieved if observed sea level observations of the North Sea are applied as western boundary of BSIOM.

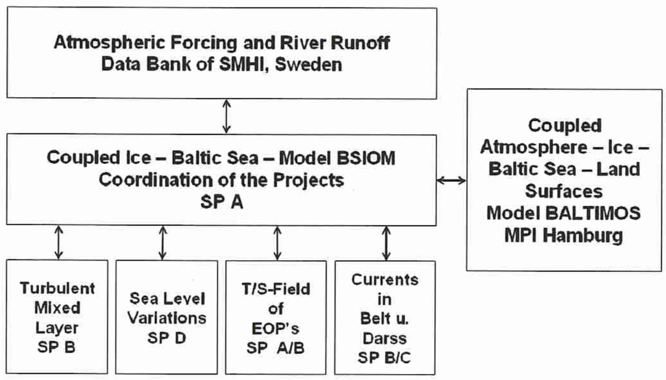

***Figure 1.** Cooperation within BASEWECS*

BSIOM has become the ocean model component of BALTIMOS, a regional climate model of the Baltic area. Simulations show that this model system is able to realistically describe extreme inflow events. A model system has been developed which proved to be suitable for regional climate change studies. Such sophisticated model systems are the basis for regional earth system models.

BASEWECS - Subproject A : Energy, Water, Salt and Sea Ice Cycle of the Baltic Sea *(IFM-GEOMAR)*

The main goal of the project was the accurate determination of the energy, water, salt and sea ice budget of the Baltic Sea by utilizing a high resolution coupled sea-ice ocean model (BSIOM, Lehmann and Hinrichsen, 2000). Beside this, the focus of the research was directed to the general circulation, extreme inflow events and up- and downwelling. Results of the subprojects B, C and D have been directly incorporated for model improvement, validation and assimilation. The period from January 1979 to December 2004 has been simulated and analyzed with respect to the energy and water cycle of the Baltic Sea. The water heat and salt exchange between the deep basins of the Baltic Sea has been determined (Lehmann and Hinrichsen, 2002). Extreme inflow events to the Baltic Sea have been modeled and validated with corresponding observations (Lehmann et al., 2004). BSIOM has become the ocean- sea ice- component of the regional climate model BALTIMOS, a coupled atmosphere-land-ocean model system for the Baltic region.

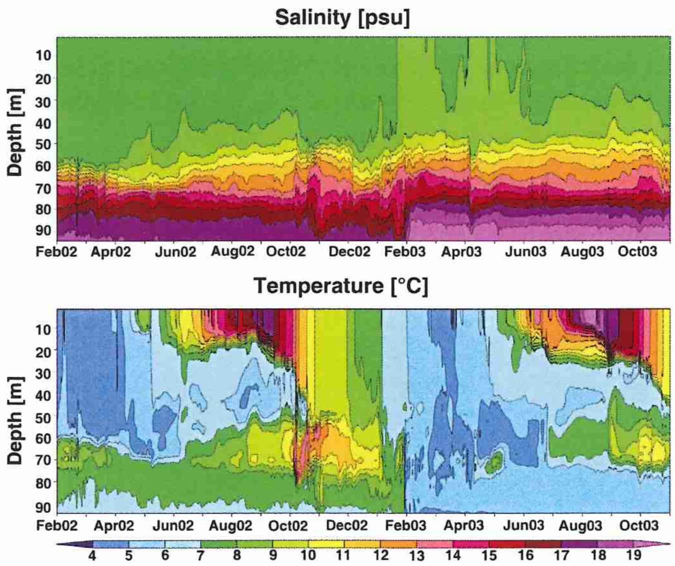

Figure 2. *Time series of vertical profiles of salinity [PSU] (upper panel) and temperature [°C] at Bornholm Deep vs. Time from February 2002 until October 2003.*

Main conclusions

BSIOM has become an accurate and sophisticated tool to model the Baltic Sea. A coherent picture of the circulation and the water mass exchange with the North Sea could be achieved. Thus, the energy and water cycle of the Baltic Sea can be described with high level of accuracy. Furthermore, BALTIMOS has demonstrated that extreme inflow events can be simulated realistically (Figure 2). Thus, not only the causal conditions for extreme inflow events could be described with the regional climate model, but also the complicated in- and outflow regime and the corresponding salt and heat fluxes have been simulated in high agreement with the observations. A model system has been developed suitable for regional climate change studies.

BASEWECS - Subproject B: On the Vertical Structure of the Turbulent Mixed Layer in the Baltic Sea *(Institute for Baltic Sea Research Warnemünde)*

The understanding of turbulence in the dynamic surface layer of the ocean is a key goal since turbulent processes are crucial in controlling the exchange of momentum, heat, dissolved and particulate matter between atmosphere and ocean. Until recently our knowledge of turbulence in the surface mixed layer has been severely limited by the difficulties to make measurements of the fluctuating velocity components near the sea surface remote from a disturbing platform (ship), carrying the necessary equipment. There are different conceptual models of the ocean mixed layer which differ even in the causal relation between turbulence and mean current. However, proving a conceptual model by field observations remains a challenging task because both the superposition of wave motion and turbulence as well as the highly intermittent nature of the turbulence impede the access to statistically reliable results. In this project, we attempted to study the relations of the dissipation of turbulent kinetic energy and the surface wind-waves in the upper surface mixed layer of the sea by means of a rising dissipation profiler (MSS). Emphasis was given on the evaluation of the relation between the thickness of the transition layer and the wavelength of the peak of the wind-wave spectrum, as well as on the depth dependence of the dissipation from the sea surface down to the shear production layer.

A layer of extreme high turbulence dissipation was observed with a thickness of one significant wave height Hs right beneath the sea surface. Below this, another layer of enhanced turbulence dissipation was found whose thickness Hp was related to the wave length of the peak of the surface wave spectrum. Turbulent dissipation in the interior of the water column was independent of the surface waves and related to the mean current shear.

Main conclusions

The results of the non-linear regression of the decay of dissipation with depth imply that the turbulence regime in the surface layer is closely correlated with surface wave regime. It consists of an injection layer with a thickness of the significant wave height. Nearly one third of the turbulent energy flow from the atmosphere to the ocean is dissipated within this injection layer. Below the injection layer, a transport layer is located which has a variable thickness determined by the wave length associated with the peak frequency of the wind wave spectrum. Dissipation decays with depth according to an exponential law within this layer. A smooth transition exists from the transport layer to the underneath laying classical law of the wall layer (Figure 3). The parameterisation of turbulence in ocean circulation models should mirror the observed relations between the wind and the surface turbulence regime with respect to both intensity and vertical scale.

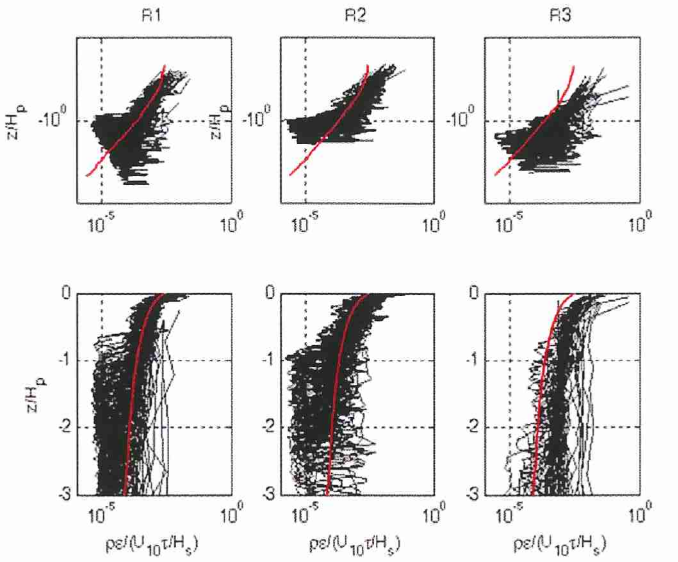

Figure 3. *Normalised dissipation versus normalised depth in log-log and semi-log coordinates. The red line indicates the wall-layer dissipation profile.*

BASEWECS - Subproject C: Water Mass Exchange through the Fehmarn Belt *(IFM-GEOMAR)*

The key question to answer within the project was to which accuracy it is possible to estimate the total transport through the Fehmarn Belt and thus one of the two major components of the total water mass exchange, from vertical profiles of moored current measurements at a single position. From May 2002, an Acoustic Current Doppler Profiler (ADCP) has been moored at the southeastern entry of the Baltic Sea to the Fehmarn Belt, providing time series of vertical current profiles at a resolution of better than 1 day in time and 2 m in the vertical. As part of a detailed correlation analysis, König (2004) has used low pass filtered daily averages of in-situ currents from the year 2003 for comparison with current data output from the model of Lehmann and Hinrichsen (2002). The major result is that the vertically integrated in-situ current component, which is parallel to the main axis of the belt, correlates highly (r=0.92) with the amplitude of first Empirical Orthogonal Function (EOF) from the model transport, normalized to the section area. This shows that the vertically integrated current at that position indeed is a measure for the total transport, and thus can be taken as such.

Main conclusions

Measurements of vertical current profiles at the southeastern entry of the Fehmarn Belt can be used to estimate the total transport through the Fehmarn Belt, and model simulations performed well to describe the net flow through the Fehmarn Belt, which gives confidence also to its outputs where comparisons with direct measurements are not possible.

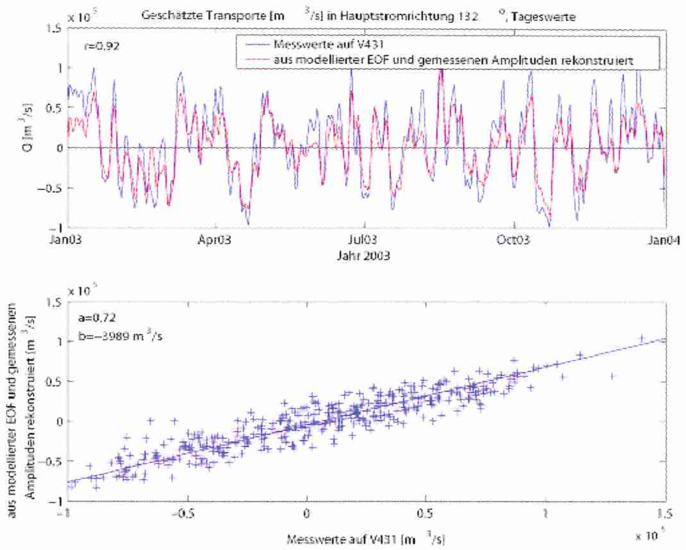

Figure 4. *Upper panel: Comparison of observed and modelled transport through the Fehmarn Belt. The simulated transport was constructed out of the 1st EOF of the modelled transport and observed amplitudes. Lower panel: correlation between observed and modelled transports.*

BASEWECS - Subproject D: Validation of Modelled Sea-Surface Elevations by Comparison with Observed Sea-Levels *(Dresden University of Technology)*

The main task of the project was the validation of the Baltic Sea sea-ice-ocean model (BSIOM; Lehmann und Hinrichsen 2000) in terms of its sea-surface elevations by comparing them with observed sea-level heights obtained from tide gauges, satellite altimetry and GPS. An off-shore, multi-sensor sea level monitoring system was developed at the Dresden University of Technology, that provides precise sea-surface heights with short temporal lags (Eberlein et al. 2004). The system, which is composed of a GPS receiver, a tide gauge, an inclinometer and a data logger, was installed on two MARNET stations (Figure 5) in co-operation with the Bundesamt für Seeschifffahrt und Hydrografie and the Institut für Ostseeforschung Warnemünde, and became operational in 2003.

Main conclusions

The comparison of modelled and observed sea-level heights show the high quality of BSIOM. The model reproduces all main sea-level variations within the Baltic Sea (Novotny et al. 2002). High frequency variations and Baltic Sea internal effects are well reflected by the model, and the differences of observed and modelled sea-level heights are on average 10 to 15 cm. Low frequency variations, which are mainly caused by external effects, are somewhat underestimated. However, it was shown that the model can be improved when observed sea-level observations in the North Sea are applied as western boundary (Novotny et al. 2004).

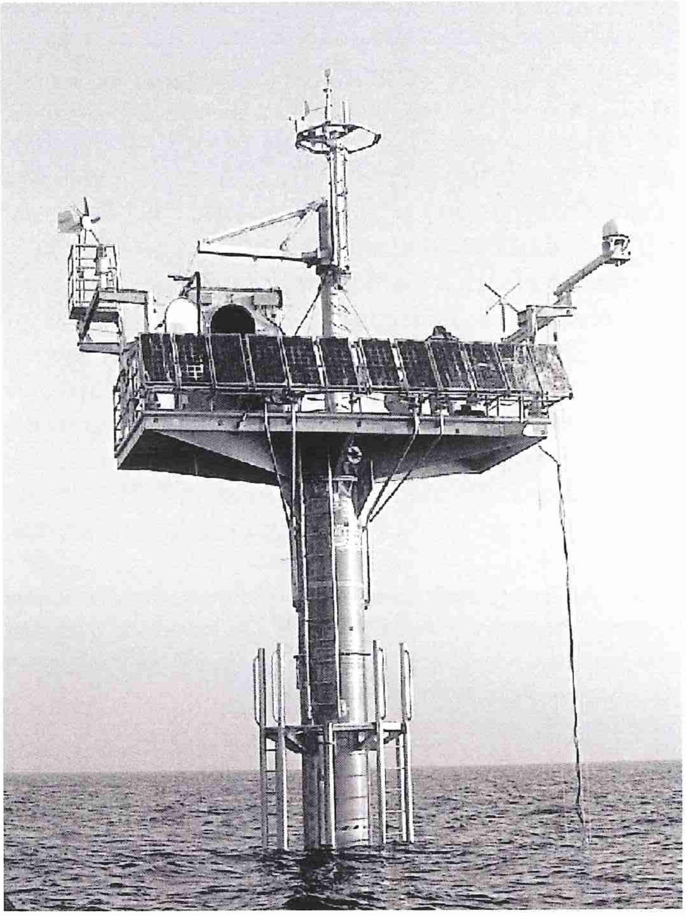

Figure 5. *MARNET station Arkona Sea. At the right hand side of the platform, the GPS antenna and the radar gauge can be seen.*

References

Eberlein, L., R. Dietrich, M. Neukamm, and G. Liebsch, 2004, Sea-level monitoring at MARNET stations in the southern Baltic Sea, IVth Study Conference on BALTEX, Gudhjem, Denmark, 24-28 May 2004.

König, J., 2004, Wassermassenaustausch durch den Fehmarnbelt, Diploma Thesis, Univ. Kiel.

Lehmann, A. and Hinrichsen, H-H., 2000, On the thermohaline variability of the Baltic Sea, J. Mar. Sys., 25, 333-357.

Lehmann, A. and H.-H. Hinrichsen, 2002, Water, heat and salt exchange between the deep basins of the Baltic Sea, Boreal Environment Research, 7, 405-415.

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

Novotny, K., G. Liebsch, R. Dietrich, and A. Lehmann, 2002, Sea-level variations in the Baltic Sea: Consistency of geodetic observations and oceanographic models, In J.Ádám and K.-P. Schwarz (Eds.), Vistas for Geodesy in the New Millennium, Vol.125 of Springer Series of IAG Symposia, pp. 493-498, Springer.

Novotny, K., G. Liebsch, R. Dietrich, and A. Lehmann, 2004, Comparison of observed and modelled sea-level heigths in order to validate and improve the oceanographic model. IVth Study Conference on BALTEX, Gudhjem, Denmark, 24-28 May 2004.

DEKLIM

BOBA - A 4D-Var Data Assimilation System for the Hydro-Thermodynamic Soil-Vegetation Scheme (HTSVS)

Hendrik Elbern (he@eurad.uni-koeln.de),
Anna Klyuchnikova
Rhenish Institute für Environmental Research at the University of Cologne, Germany
Nicole Mölders
University of Alaska Fairbanks, Geophysical Institute, USA

Introduction

In the Baltic region, frozen ground and snow are frequent conditions that affect the exchange of heat, water, and trace gases at the land surface-atmosphere interface. To simulate these fluxes without prior-calibration - an important goal within GEWEX – frozen ground and snow metamorphism processes have to be treated in detail and the distributions of soil and snow temperature, snow height, volumetric water and ice content have to be reasonably well predicted. Herein a major difficulty is to consistently initialize the soil and snow state with the ceaseless interaction between soil, snow and atmosphere. As shown by Douville et al. (2000) for soil moisture, forecasts can be significantly improved by assimilating soil moisture data in a physically consistent way. Advanced spatio-temporal data assimilation algorithms that have the theoretical potential to provide a Best Linear Unbiased Estimator, like the four dimensional variational (4D-var) method are able to exploit consistently sequences of observations and the physical laws inherent in the model. Therefore, tangent-linear and adjoint components were developed for the Hydro-Thermodynamic Soil-Vegetation Scheme (HTSVS) coupled to the Penn/State NCAR mesoscale model generation 5 (MM5), i.e. the HTSVS was completed by a soil and snow assimilation system.

Brief description of the method

HTSVS consists of a one layer canopy model, a multi-layer soil model (Kramm et al., 1996) with inclusion of freezing and thawing, the related release and consumption of latent heat energy, effects of frozen soil layers on vertical fluxes of heat and moisture, water uptake by vertically variable root distributions (Mölders et al., 2003), a temporal variation of soil and snow albedo and snow emissivity, and a multi-layer snow metamorphism model (Mölders and Walsh, 2004).