Leibniz Institute For Baltic Sea Research Warnemünde

LEIBNIZ INSTITUTE FOR
BALTIC SEA RESEARCH
WARNEMÜNDE

Comparative studies of the Baltic Sea ecosystem variability by three-dimensional modelling experiments of Holocene periods with different climate conditions

Porsche, C. & Neumann, T

Department of Physical Oceanography and Instrumentation,
Leibniz Institute for Baltic Sea Research Warnemünde,
Seestraße 15, 18119 Rostock, Germany

BONUS
SCIENCE FOR A BETTER FUTURE OF THE BALTIC SEA REGION

BONUS INFLOW

Projektpartner:

- Geological Survey of Finland (GTK), Finland
- Leibniz-Institute for Baltic Sea Research (IOW), Germany
- Geological Survey of Denmark and Greenland (GEUS), Denmark
- Lund University, Sweden
- Swedish Meteorological and Hydrological Institute (SMHI), Sweden
- University of Szczecin, Poland
- Bjerknes Centre for Climate Research (BCCR), Norway
- Department of Geology, University of Helsinki, Finland
- Russian Geological Research Institute (VSEGEI), Russia

Introduction, Aim & Methods

Human society faces unprecedented challenges arising from environmental changes (e.g. desertification, Ozone Layer destruction, pollution (air, water, and soil), natural disasters, ...) through both natural and human induced processes [Peng *et al.*, 2002]. An important challenge thereby may be the impact on our environment and furthermore on human life. Therefore, it is necessary to be prepared for these threats for humankind and thus the first step is understanding the dynamics of the environment. An important issue to understand the effects of future climate change on complex ecosystems like the Baltic Sea is the understanding of the natural variability and the mechanisms behind it [q.v. Zillen & Conley, 2010]. Environmental modeling has become an essential tool for environmental studies, whereas instrumental measurements, thought indispensable, are limited to certain aspects. Ecosystem models and experimental model studies may provide us with new knowledge to face the future challenges. Understanding the climate change impact is an essential task before making predictions and providing solutions. [Peng *et al.*, 2002]

The aim of this work embedded in the Bonus INFLOW project is providing an approach of understanding mechanisms of climate change and natural variability of ecosystems by the example of the Baltic Sea. By modelling diverse time slices of the Baltic Sea under different climatic conditions (e.g. Little Ice Age (LIA), Medieval Climate Anomaly (MCA or MWP), and Modern Warming Period (MoWP), and combine the results with sedimentological data it should be possible to get some answers for the question of natural variability. Here, the emphasis is set to the modelling part of the projects work.

Modular Ocean Model (v.3.1) [Pacanowski & Griffies, 2000; Neumann, 2000; Neumann & Schernewski 2008]

- 3D circulation model with an integrated biogeochemical model based on "ERGOM"
- Grid with 222 longitudinal, 240 latitudinal, and 77 depth levels
- Resolution of ca. 3 nautical miles (0,1° Lon; 0,05° Lat) and 1,5 to 5 m in depth
- Baltic Sea area of 0.443E¹² m² and 0.244E¹⁴ m³
- Meteorological forcing: ERA-40 project
- 17 prognostic variables

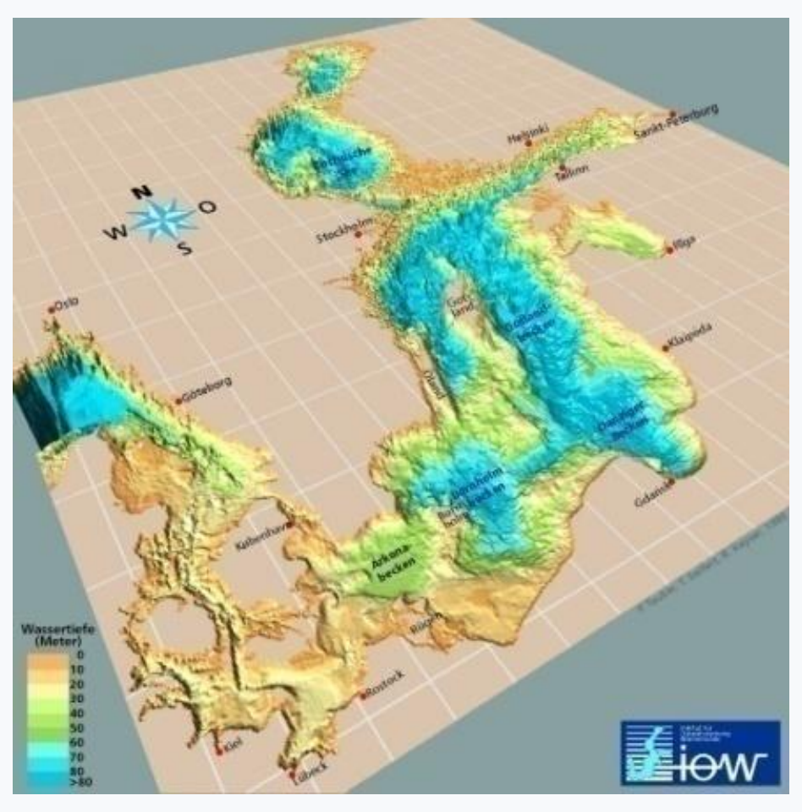


Figure 1: Bathymetric map of the Baltic Sea

Model Validation & 'delta change'

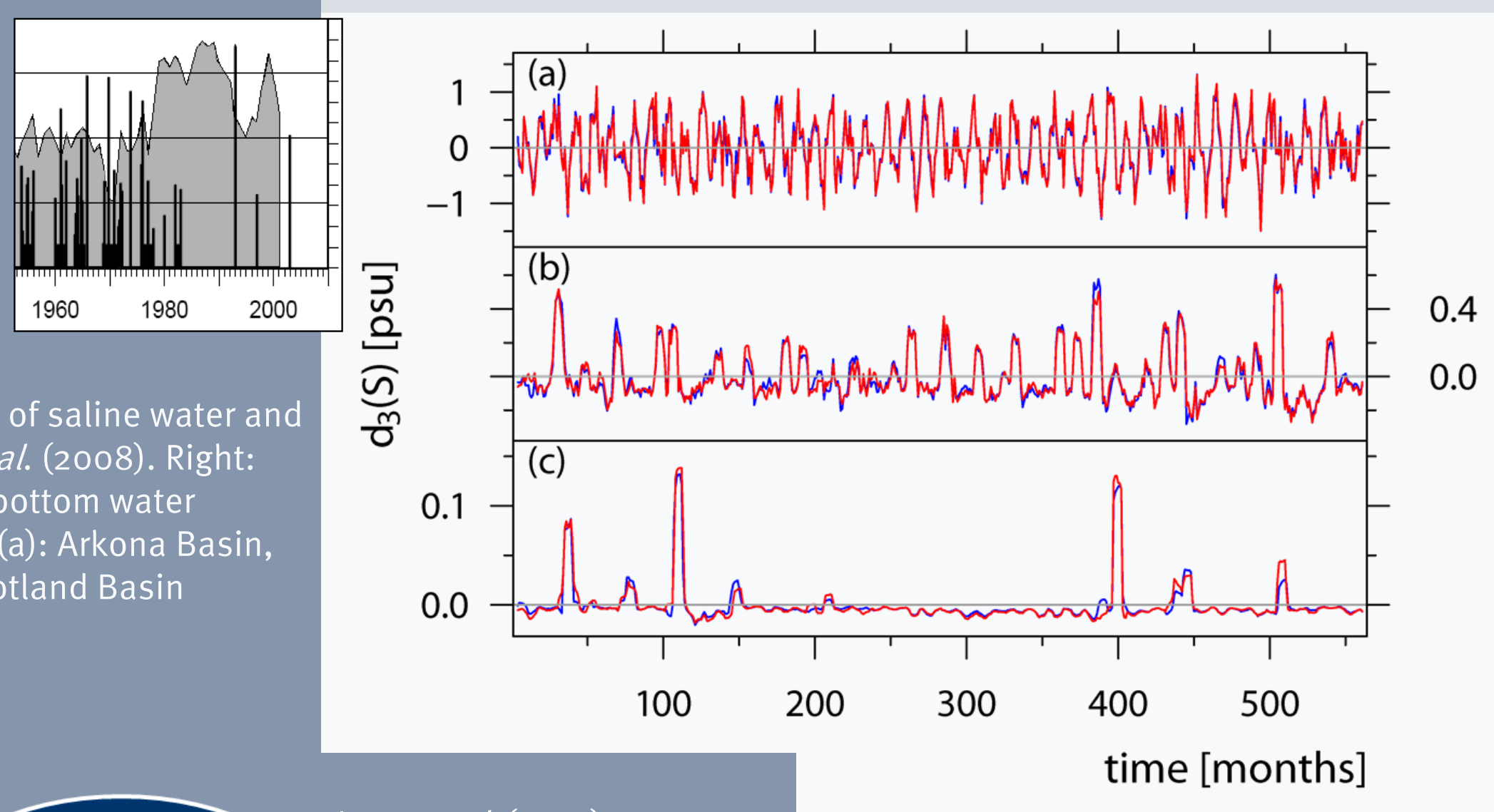


Figure 2: Top: Inflow events of saline water and river runoff by Matthäus *et al.* (2008). Right: Finite central difference of bottom water salinity from 1961 to 2007. (a): Arkona Basin, (b): Bornholm Basin, (c): Gotland Basin

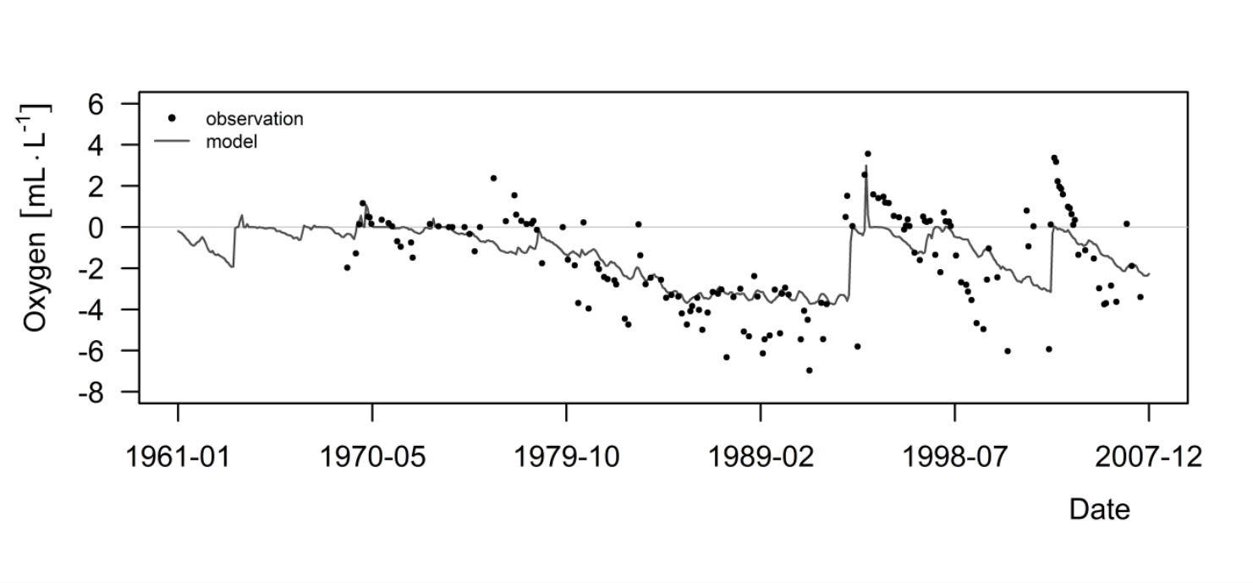


Figure 3: Oxygen concentration at Gotland station TF271. Grey line: modelled monthly mean; Points: measurements

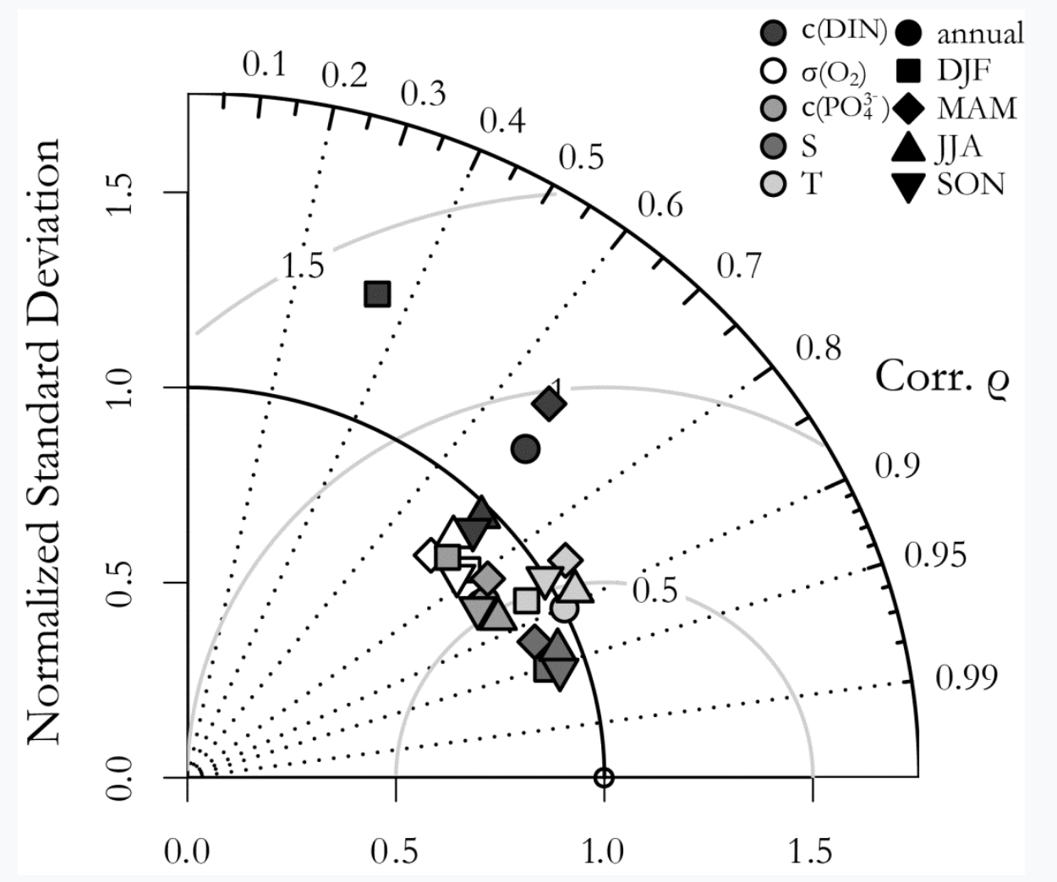
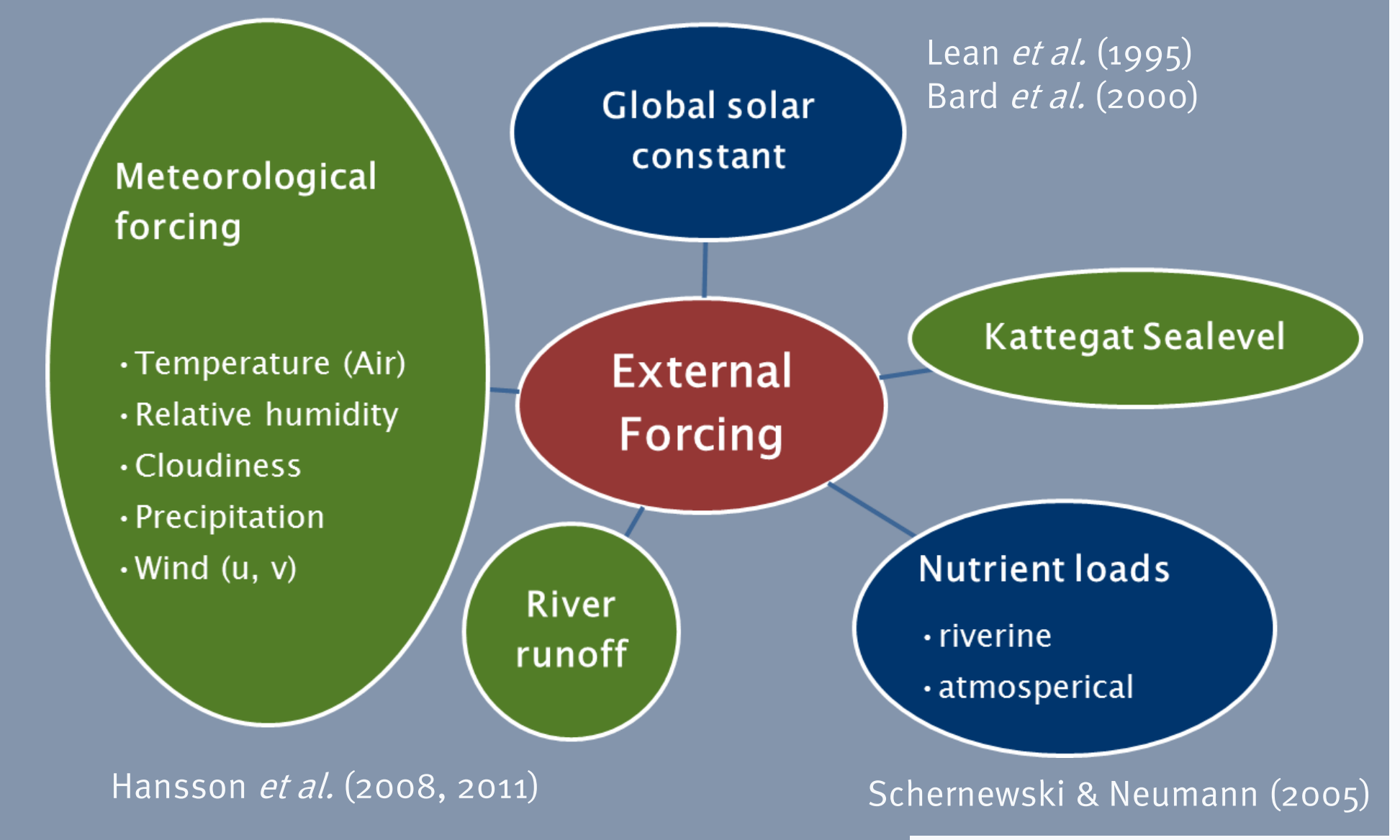


Figure 4: Taylor diagram [Taylor, 2000], which shows differences in chosen variables of the model and observations. The circular arc around the point of origin prescribes the normalized standard deviation, whereas the observational data set are represented by a dot on the abscissa at normalized standard deviation of 1.0. The grey circles around this reference point shows the deviation of the centered root mean square (cRMS) and the dotted lines refer to the rank correlation coefficient by Spearman.



Meteorological forcing
- Temperature (Air)
- Relative humidity
- Cloudiness
- Precipitation
- Wind (u, v)

Global solar constant

Lean *et al.* (1995)
Bard *et al.* (2000)

External Forcing

Kattegat Sealevel

River runoff

Nutrient loads
- riverine
- atmosperical

Hansson *et al.* (2008, 2011)

Schernewski & Neumann (2005)

Figure 5: Schema of the 'delta change' approach

The most reliable modeled variables are temperature, salinity, oxygen concentration, and phosphate concentration. The model variations of salinity, oxygen, and phosphate are slightly smaller than the observed ones. The modeled variability of temperature is about the same magnitude as the observed variability. The DIN variability is slightly higher in the model than in the observations, but that may be caused by the smaller sample size, especially for the winter values. Furthermore, the analyzed variables of the model and the observations are strongly correlated with a Spearman's rank correlation coefficient. The deviation from the centered root mean square is for all variables but the DIN winter values smaller than one. Finally the model reflects the most important variables and therefore the general conditions of the Baltic Sea ecosystem in a very distinguish way.

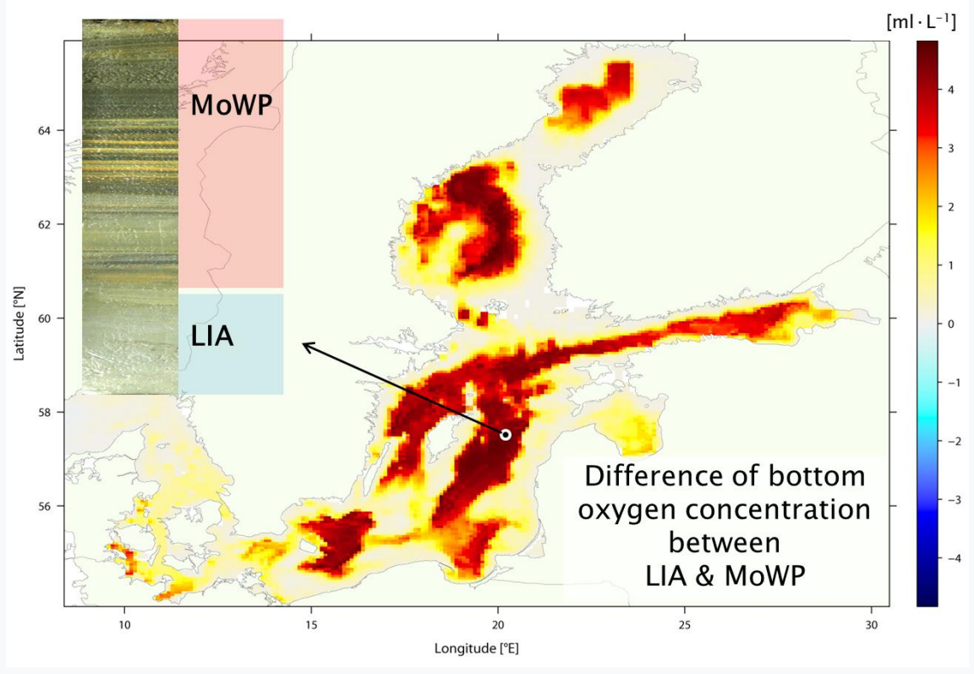


Figure 6: Possibility for the validation of model scenarios of past periods (e.g. LIA) by comparison to sediment proxy data

Medieval Climate Anomaly & Little Ice Age

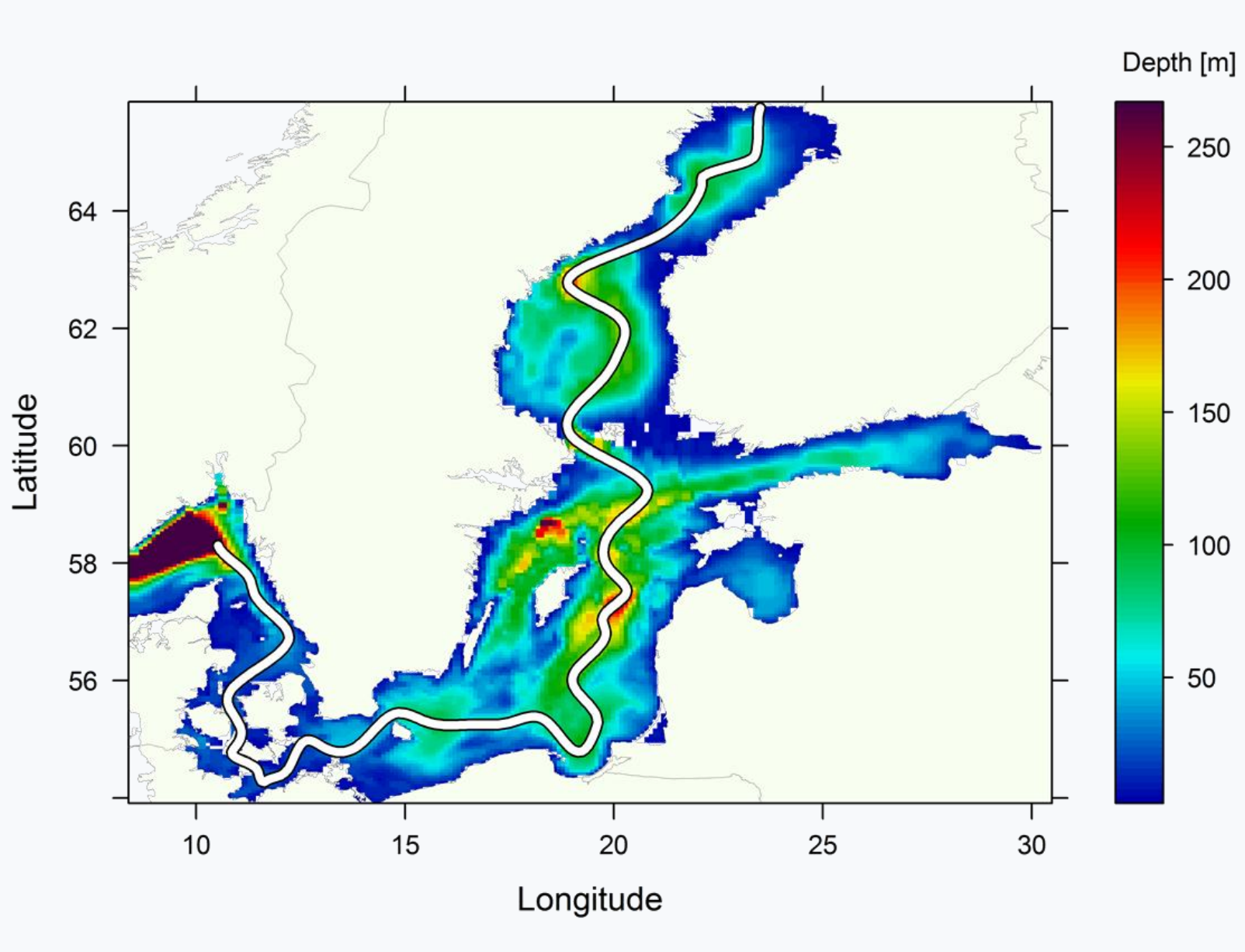
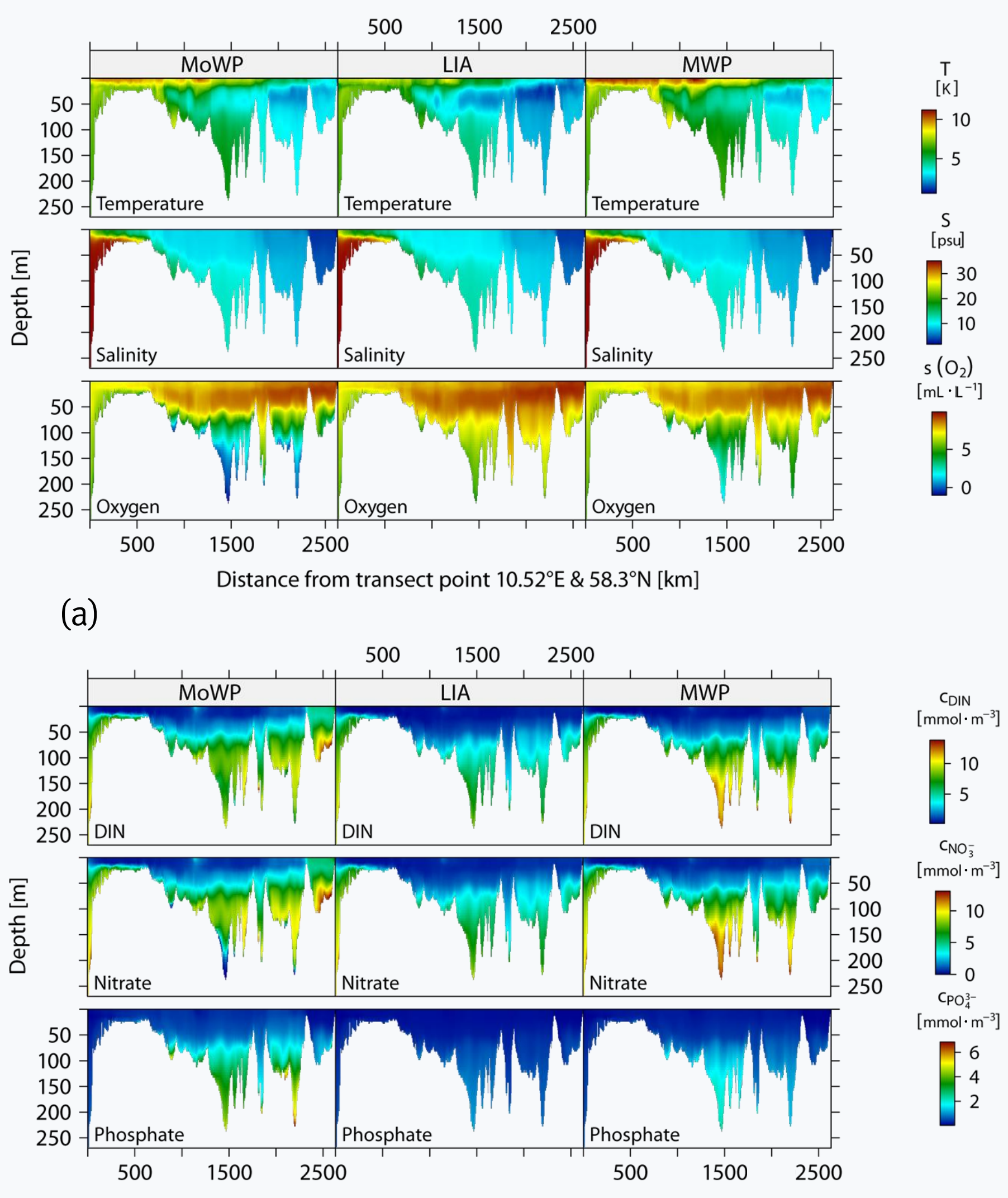


Figure 7: Model bathymetric map and transect (white line)



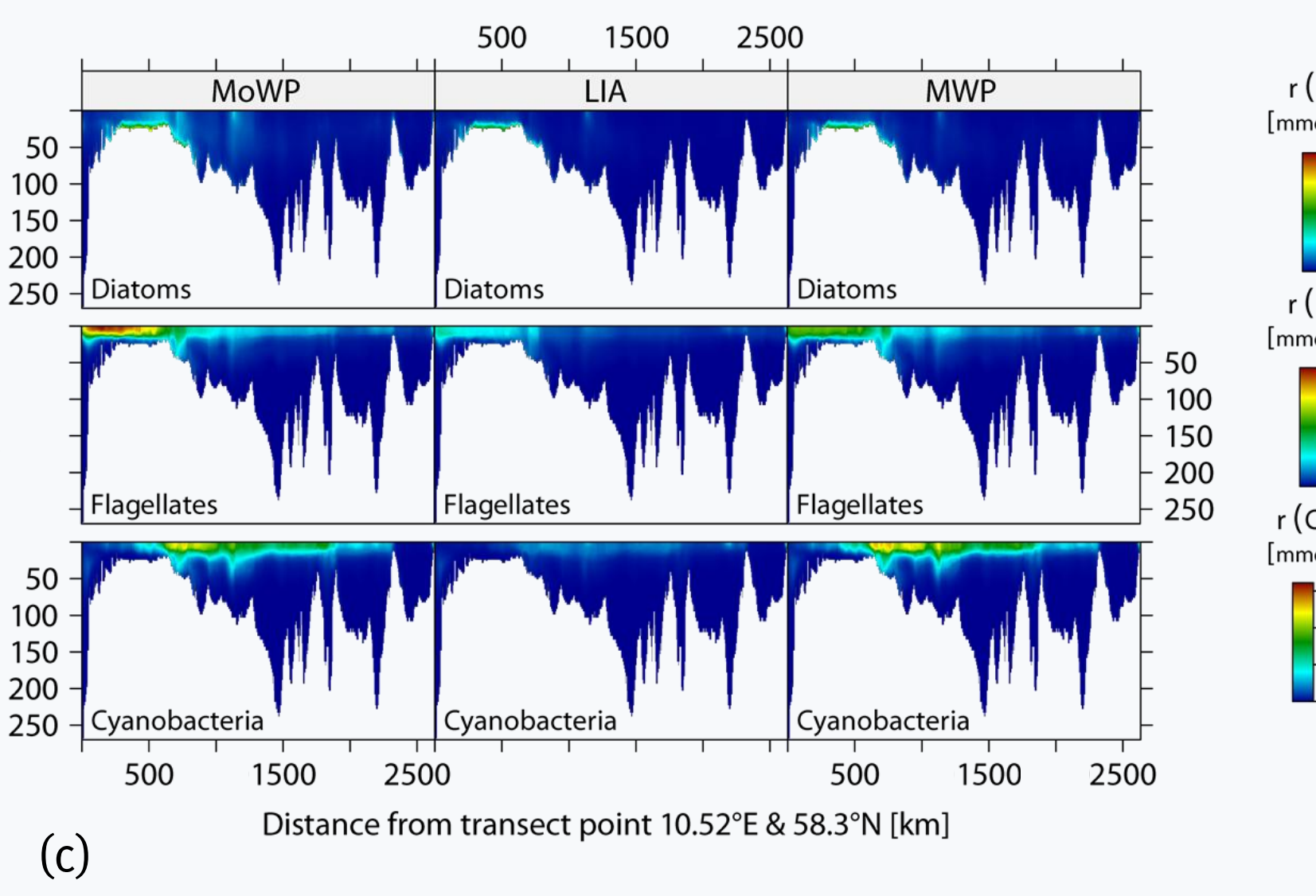


Figure 8: Median plot of (a) temperature, salinity, and oxygen, (b) Dissolved Inorganic Nitrogen, nitrate, and phosphate, (c) diatoms, flagellates, and cyanobacteria along a transect through the Baltic Sea (Fig. 7) and over a period of 47 years.

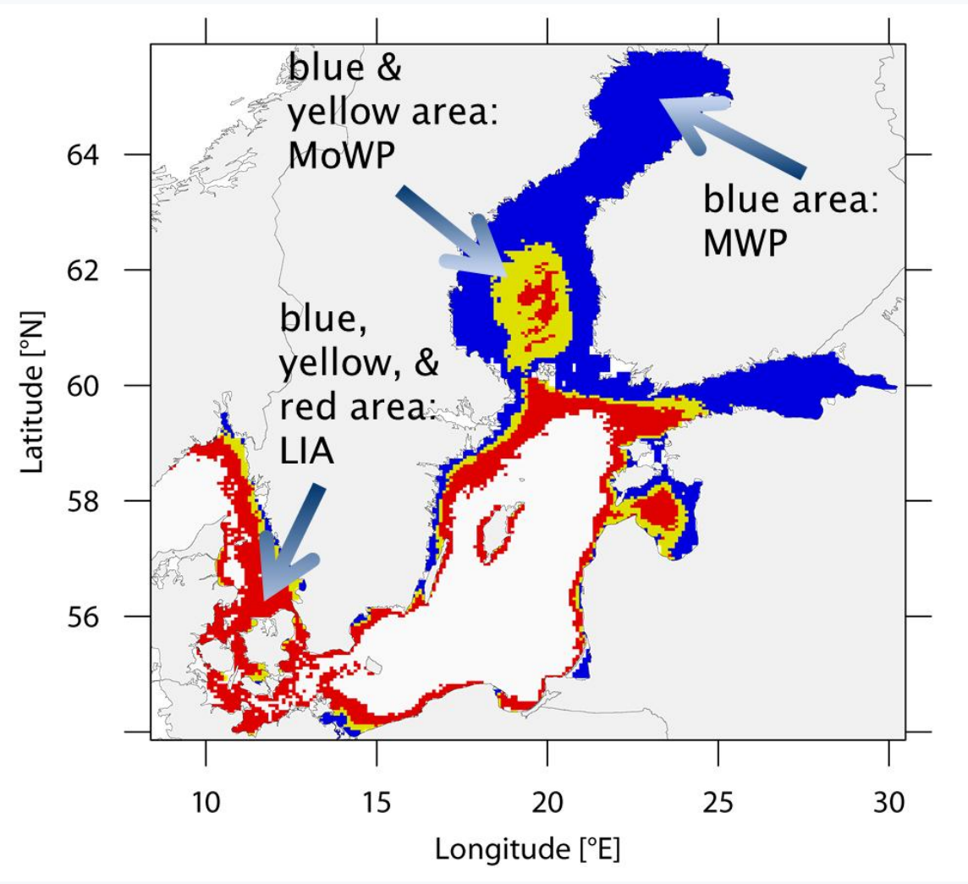


Figure 9: Median maximum ice extent of the studied three periods: Modern Warm Period (MoWP), Little Ice Age (LIA), and Medieval Climate Anomaly (MWP)

The external forcing affects the complex physical, biological, and geochemical processes as well as the resulting conditions of the Baltic Sea in a significant way [Zillen *et al.* 2008, 2010]. These facts are well reflected by the realized model simulations. Though the models are limited to reflect the reality due to technically and theoretically reduced complexity, the results of the model simulations especially the physical variables are noteworthy reliable.

Conclusions

The adaptations of the external forcing variables affect nearly all processes and conditions of the ecosystem. Maybe the only possibility to validate the model output for past scenarios is the comparison with proxy data.

The bottom oxygen condition of the Baltic Sea during the LIA & MCA scenario is well reflected by the model compared to proxy studies of [Virtasalo *et al.*, 2011].

During the LIA the Baltic Sea was colder, more oxygenic, and more saline than today, and during the MCA the Baltic Sea was warmer, more oxygenic, and less saline than today

Acknowledgements

We acknowledge the HLRN (Norddeutscher Verbund für Hoch- und Höchstleistungsrechnen) for providing the supercomputing power. Further, we thank the modelling group of the Baltic Sea Research Institute for providing support for the circulation model. This work was supported by the BONUS project INFLOW, which was funded by the EU.

Bard, E.; Raisbeck, G.; Yiou, F. & Jouzel, J. (2000), 'Solar irradiance during the last 1200 years based on cosmogenic nuclides', Tellus 52(3), 985-992. | Hansson, D.; Eriksson, C.; Omstedt, A. & Chen, D. (2011), 'Reconstruction of river runoff to the Baltic Sea, AD 1500–1995', International Journal of Climatology 31(5), 696-703. | Hansson, D. & Omstedt, A. (2008), 'Modelling the Baltic Sea ocean climate on centennial time scale: temperature and sea ice', Climate Dynamics 30(7-8), 763-778. | Lean, J.; Beer, J. & Bradley, R. (1995), 'Reconstruction of solar irradiance since 1610: Implications for climate change', Geophysical Research Letters 22(23), 3195-3198. | Matthäus, W.; Nehring, D.; Feistel, R.; Nausch, G.; Mohrholz, V. & Lass, H.-U.Feistel, R.; Nausch, G. & Wasmund, N., ed., (2008), The Inflow of Highly Saline Water into the Baltic Sea, John Wiley & Sons, Inc., chapter 10, pp. 265-309. | Neumann, T. (2000), 'Towards a 3D-ecosystem model of the Baltic Sea', Journal of Marine Systems 25, 405-419. | Neumann, T.; Fennel, W. & Kremp, C. (2002), 'Experimental simulations with an ecosystem model of the Baltic Sea: A nutrient load reduction experiment', Global Biogeochemical Cycles 16(3), 7.1-7.19. | Neumann, T. & Schernewski, G. (2008), 'Eutrophication in the Baltic Sea and shifts in nitrogen fixation analyzed with a 3D ecosystem model', Journal of Marine Systems 74(1-2), 592-602. | Pacanowski, R. C. & Griffies, S. M. (2000), 'MOM 3.0 manual', Technical report, Geophysical Fluid Dynamics Laboratory. | Peng, G.; Shao, Y. & Leslie, L. M. (2002), Environmental Science, in Gongbing Peng; Lance M. Leslie & Yaping Shao, ed., 'Environmental Modelling and Prediction', Springer-Verlag Berlin Heidelber New York, , pp. 1-20. | R Development Core Team (2011), 'R: A Language and Environment for Statistical Computing', R Foundation for Statistical Computing, Vienna, Austria. | Schernewski, G. & Neumann, T. (2005), 'The trophic state of the Baltic Sea a century ago: a model simulation study', Journal of Marine Systems 53(1-4), 109-124. | Taylor, K. E. (2000), 'PCMDI Report No. 55 - Summarizing multiple aspects of model performance in a single diagram', Technical report, University of California, Lawrence Livermore National Laboratory, Livermore, CA 94550. | Virtasalo, J. J.; Leipe, T.; Moros, M. & Kotilainen, A. T. (2011), 'Physicochemical and biological influences on sedimentary-fabric formation in a salinity and oxygen-restricted semi-enclosed sea: Gotland Deep, Baltic Sea', Sedimentology 58(2), 352-375. | Zillén, L. & Conley, D. J. (2010), 'Hypoxia and cyanobacteria blooms - are they really natural features of the late Holocene history of the Baltic Sea?', Biogeosciences 7(8), 2567-2580. | Zillén, L.; Conley, D. J.; Andrén, T.; Andrén, E. & Bjцrck, S. (2008), 'Past occurrences of hypoxia in the Baltic Sea and the role of climate variability, environmental change and human impact', Earth-Science Reviews 91(1-4), 77-92.