BALTEX—an interdisciplinary research network for the Baltic Sea region

Marcus Reckermann1, Joakim Langner2, Anders Omstedt3, Hans von Storch4, Sirje Keevallik5, Bernd Schneider6, Berit Arheimer2, H E Markus Meier2 and Birgit Hünicke4

1 International BALTEX Secretariat, Helmholtz-Zentrum Geesthacht, D-21502 Geesthacht, Germany
2 Swedish Meteorological and Hydrological Institute, Folkborgvägen 1, S-60176 Norrköping, Sweden
3 Swedish Institute for the Marine Environment, University of Gothenburg, PO Box 260, S-405 30 Göteborg, Sweden
4 Institute of Coastal Research, Helmholtz-Zentrum Geesthacht, D-21502 Geesthacht, Germany
5 Marine Systems Institute, Tallinn University of Technology, Akadeemia tee 21, EE-12618 Tallinn, Estonia
6 Baltic Sea Research Institute Warnemünde, Seestrasse 15, D-18119 Rostock, Germany

E-mail: marcus.reckermann@hzg.de

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Abstract

BALTEX is an environmental research network dealing with the Earth system of the entire Baltic Sea drainage basin. Important elements include the water and energy cycle, climate variability and change, water management and extreme events, and related impacts on biogeochemical cycles. BALTEX was founded in 1993 as a GEWEX continental-scale experiment and is currently in its second 10 yr phase. Phase I (1993–2002) was primarily dedicated to hydrological, meteorological and oceanographic processes in the Baltic Sea drainage basin, hence mostly dealt with the physical aspects of the system. Scientific focus was on the hydrological cycle and the exchange of energy between the atmosphere, the Baltic Sea and the surface of its catchment. The BALTEX study area was hydrologically defined as the Baltic Sea drainage basin. The second 10 yr phase of BALTEX (Phase II: 2003–12) has strengthened regional climate research, water management issues, biogeochemical cycles and overarching efforts to reach out to stakeholders and decision makers, as well as to foster communication and education. Achievements of BALTEX Phase II have been the establishment of an assessment report of regional climate change and its impacts on the Baltic Sea basin (from hydrological to biological and socio-economic), the further development of regional physical climate models and the integration of biogeochemical and ecosystem models. BALTEX features a strong infrastructure, with an international secretariat and a publication series, and organizes various workshops and conferences. This article gives an overview of the BALTEX programme, with an emphasis on Phase II, with some examples from BALTEX-related research.

Keywords: BALTEX, Baltic Sea, regional climate modelling, water and energy cycles, hydrology, oceanography, biogeochemistry, climate research

1. Introduction

The need to better understand, quantify and model water and energy fluxes and budgets as accurately as possible has been a primary objective in meteorology and climate research in order to enhance the performance of weather forecasts and climate models. In the beginning of the 1990s, BALTEX was founded as one of the first Regional Hydro-climate Programmes
(RHPs, then called ‘Continental-Scale Experiments’, or CSEs) under the umbrella of GEWEX (Global Energy and Water Experiment), a global research programme under the auspices of WCRP (the World Climate Research Programme) and WMO, the World Meteorological Organization (BALTEX 1994). As for the other RHPs, establishing detailed regional knowledge of the processes governing the energy and water cycles at continental catchment scale has been a primary goal of BALTEX (e.g. Raschke et al 2001). Currently (as of June 2011), nine RHPs are active under the umbrella of GEWEX. Among these, the Northern Eurasia Earth Science Partnership (NEESPI, Groisman and Gutman 2011) has strong relations to BALTEX, as their geographical and scientific areas of interest overlap. In contrast to most of the other RHPs, the BALTEX region includes a marine component, the Baltic Sea.

The study region of BALTEX is defined by the hydrological drainage basin of the Baltic Sea which covers an area of 2.1 M km² or almost 20% of the European continent (figure 1). About 85 million inhabitants live in the region, which features pronounced differences between the northern and southern parts. The north features a boreal climate with sub-arctic conditions in winter, rocky coasts and is dominated by a rural landscape, extensive forests and a low population density. The southern areas have a mild and humid mid-latitude climate, are densely populated, heavily industrialized and feature intensive land use. The region experiences considerable seasonal, inter-annual, decadal and long-term variations in temperature, precipitation and other related variables. The basin’s net annual water discharge into the Baltic Sea is estimated to be about 480 km³ yr⁻¹, which is comparable to that of major river systems such as the Mississippi River (Jacob 2005). The basin represents a unique and challenging region for climate and environmental studies, and the Baltic Sea itself is among the most intensively studied seas in the world.

In the almost 20 years of its existence, BALTEX has undergone quite a remarkable development. Ten years after its establishment, the scope of BALTEX was extended to the topics climate variability and change, water management
and biogeochemistry, termed ‘air and water quality’ (BALTEX 2004). Next to these scientific objectives, two overarching issues were included, namely a strengthened interaction with decision makers with an emphasis on global change impact assessments, and education and outreach at the international level. Thus, the scope of BALTEX was broadened considerably, while the base remained the energy and water cycle, with a dedicated extension to matter fluxes. An outstanding aspect of BALTEX is the networking between scientists in different countries in the Baltic Sea basin and across different scientific disciplines. Today, BALTEX is a truly interdisciplinary programme encompassing meteorology, hydrology, oceanography, climatology, biogeochemistry, and related disciplines. In this respect, research towards an Earth System Modelling system on the regional scale is an ambitious challenge for the future.

2. A look back: BALTEX Phase I (1993–2002)

The main focus of BALTEX Phase I (1992–2003) was to explore and model the various mechanisms determining the space and time variability of energy and water budgets of the Baltic Sea drainage basin and the interactions with surrounding regions (Raschke et al 2001, BALTEX 1994, 1995). To achieve this, emphasis was on the collection of in situ and remote sensing data and the re-analysis of existing data sets. These data formed the basis for the development of model systems (BALTIMOS and RCAO, see below), and for comparing the model simulations with reality. The ‘BALTEX Box’ depicts the basic simulated processes in the atmosphere and the Baltic Sea, and the exchange of water and energy between the different compartments of the climate system (figure 2).

Figure 2. The ‘BALTEX box’ of BALTEX Phase I: the fluxes of energy (heat H and wind momentum W) and water (precipitation P, evaporation E and runoff R) between the three different compartments atmosphere, land surface and the Baltic Sea including sea ice. The Baltic Sea basin is connected to the outside world by the in- and outflow through the Danish straits (F), and the lateral atmospheric fluxes (L). From BALTEX (1995). For figure estimates of the different fluxes see Omstedt and Nohr (2004); BALTEX (2005) and references cited therein.

Special observing periods, such as the Pilot Study for Intensive Data Collection and Analysis of Precipitation (PIDCAP) in 1995 (Isemer 1996, Rutgersson et al 2001, www.baltex-research.eu/projects/pidcap1.html) and BRIDGE, the major enhanced observational period within BALTEX during 1999–2002 with dedicated additional observations, were conducted to improve water budget estimates (BALTEX 1997, 2000, 2003). The data have been used to improve the modelling of water and heat balances of the Baltic Sea (e.g. Omstedt and Nohr 2004). BALTEX has also coordinated activities at three observational in situ reference sites for CEOP, the Coordinated Energy and Water Cycle Observations Project: Sodaönkylä (Finland), Cabauw (The Netherlands) and Lindenberg (Germany). These reference sites represent different major climate and vegetation zones in the BALTEX area and provide a fixed and extensive set of meteorological data at a high temporal resolution to the CEOP data archive. This valuable database is crucial for validating models (Beyrich 2008, Beyrich et al 2010).

A main research goal of BALTEX Phase I was the establishment of coupled regional climate models to simulate processes in the atmosphere, the ocean, sea ice, the land surface with rivers, lakes and vegetation, as well as the fluxes in between (e.g. Raschke et al 2001, Bengtsson 2001, BALTEX 2005). This can be regarded as a regional contribution to the effort of ‘Earth System Modelling’, striving to integrate as many natural and anthropogenic processes as possible, shaping the environment of the Earth. Two coupled model systems were developed for the Baltic Sea drainage basin: BALTIMOS of the Max-Planck Institute for Meteorology (Germany) (Hagedorn et al 1999) and RCAO of the Swedish Meteorological and Hydrological Institute (SMHI) in Sweden (Dösher et al 2002). BALTIMOS stands for ‘BALTEX Integrated Model System’ and integrates the atmosphere, the sea (i.e. the Baltic Sea), and the land surface of the drainage basin. It has been used e.g. for a simulation of an exceptional Baltic Sea inflow event (Lehmann et al 2004). The Rossby Centre of the SMHI has developed the model system RCAO (Rossby Centre Atmosphere–Ocean Model) which couples the atmosphere and land sub-model Rossby Centre Atmospheric Model (RCA) (including a hydrological sub-model with river routing) with the ocean/sea ice model Rossby Centre Ocean Model (RCO). The RCO has been used in many regional climate simulations (see Rossby Centre at www.smhi.se). BALTEX Phase I contributions to Baltic Sea oceanography are summarized in Omstedt et al (2004) and a compilation of BALTEX Phase I achievements is available in BALTEX (2005).

3. New objectives and challenges: BALTEX Phase II (2003–12)

The launch of BALTEX Phase II in 2003 marked a major re-orientation of BALTEX research within the scope of BALTEX as a GEWEX/WCRP-related programme (BALTEX 2004, 2006a). As such it was the first to explicitly include ‘air and water quality’ issues (now re-phrased as ‘biogeochemical cycles under anthropogenic influence’, (BALTEX 2009)) and their connections with the water cycle. Also, the inclusion of regional climate variability and change, water management issues and the outreach to policy makers and the general public were new aspects. The new objectives have evolved since 2003: some aspects have been shown to be outside of what a programme like BALTEX can achieve within its given lifetime; others have gained importance due to the availability of external funding. An important aspect of BALTEX Phase
II has been a more holistic approach towards observing, understanding and modelling major environmental and socio-economic aspects relevant for the Baltic Sea basin. The new BALTEX Box (figure 3) depicts the new matter fluxes investigated in Phase II.

In the following, we will briefly touch on selected results which were either presented at recent BALTEX Study Conferences, or are from BALTEX Phase II projects already completed, or still running at the time of writing (June 2011). It should be borne in mind that the research activities described below are mostly of interdisciplinary nature and may be assigned to another objective as well (e.g. salinity and oxygen in the Baltic Sea is also an issue for objective 4; the BACC project integrates research from all objectives, effectively).

3.1. Objective 1: improved understanding of energy and water cycles under changing conditions

This objective is largely a continuation of the BALTEX Phase I. The primary aim is the improvement of process understanding, related modelling capabilities, and the quantification of important energy and water cycle variables such as clouds, solar and terrestrial radiation, precipitation, river runoff, Baltic Sea water transports and sea ice dynamics.

Recent attempts to calculate the water budget of the Baltic Sea catchment were performed by Lind and Kjellström (2009) and Kjellström and Lind (2009). Using the regional climate model RCA3 and various re-analysis and observational data, they simulated the water cycle in the period 1979–2002. Although the water fluxes simulated by RCA3 were found to be broadly consistent with the available reference data (both observational and quasi-observational re-analysis data), the model systematically overestimated precipitation over the Baltic Sea drainage basin, when compared to the reference datasets. Moreover, there were also significant differences between the various observation and re-analysis datasets. This shows that despite the efforts and achievements of BALTEX Phase I, more high-resolution observational datasets of precipitation, evaporation and runoff are needed from the Baltic Sea drainage basin.

Long-term changes in meteorological parameters, sea level and sea ice have been documented for Estonia for a 50 year period. An increase in the intensity of zonal circulation during 1951–2000 is accompanied by an increase in late winter and spring air temperature (Keevallik 2003, Jaagus 2006a), decrease in the snow cover extent (Keevallik 2003, Jaagus 2006a), an increase in the amount of low cloud (Keevallik 2003), a decrease in sea ice duration (Jaagus 2006b) and an increase in winter storminess (Suursaar et al 2006, Jaagus et al 2008). Trends like these are usually analysed by standard statistical techniques which may not be able to detect abrupt changes in meteorological parameters, i.e. reveal regime shifts or breakpoints. Applying the regime detection technique of Rodionov (2004) to the time series of several meteorological parameters, Keevallik (2010) found that an intensification of the western flow in winter over North-East Europe might be due to an abrupt increase in the upper-air zonal wind component around 1987. An analysis of the average air flow in March revealed multiple regime shifts (Keevallik and Soomere 2008) which can be interpreted as transition changes from the winter to the summer circulation type. A close look at the frequency and trajectories of cyclones in the Baltic Sea region shows that the total number of cyclones did not change, but the percentage of deep cyclones increased (Sepp 2009). When the Arctic basin is included, the annual number of incoming cyclones increases significantly, as does the percentage of deep cyclones formed within the Arctic region, while the number and percentage of shallow cyclones decreases. These changes are most evident in winter (Sepp and Jaagus 2011).

The sensitivity of salinity and oxygen concentrations in the deep Baltic Sea to variations in physical forcing was investigated by Gustafsson and Omstedt (2009), using the PROBE-Baltic model. Their results indicate that an overall wetter climate than today (as projected for the next century by most regional climate models) may improve oxygen conditions in the upper deep layers, due to a weaker stratification and a more intense winter mixing. A drier climate on the other hand would have the opposite effect of increased stratification and stronger depletion of oxygen. Salinity and oxygen are crucial variables for the biogeochemical state of the Baltic Sea, and have also a strong effect on the reproduction success of cod. Cod eggs sink to a certain buoyancy level which must be above the oxycline in order for the eggs to survive, so that increased oxygen conditions could improve the situation for cod eggs. Still, further ecosystem processes may be important, and it is difficult to predict what effects changed salinity and oxygen conditions may have on cod reproduction and the ecosystem in general.

3.2. Objective 2: analysis of climate variability and change and provision of regional climate projections over the Baltic Sea basin for the 21st century

The primary aim of this objective is the detection and attribution (i.e. to discern between natural and anthropogenic causes) of current regional climate change, and the development of projections for future climate change throughout the 21st century in the Baltic Sea drainage basin. The focus is on variables closely related to water, energy and biogeochemical fluxes.
The BALTEX Assessment of Climate Change for the Baltic Sea Basin (BACC) represents a major achievement of BALTEX Phase II. It was compiled by a consortium of 84 scientists from 13 countries around the Baltic Sea (BACC Author Team 2008) and covers various disciplines related to climate research and related impacts. The BACC report aims to bring together consolidated knowledge on climate change and its effects on the Baltic Sea basin which has broad consensus in the scientific community. At times this consensus takes on the form of ‘consensus on dissensus’, as for certain issues, contrary opinions could not be resolved. The work was organized in four chapters (past and current climate change, projections of future anthropogenic climate change, climate-related change in terrestrial and freshwater ecosystems, and climate-related marine ecosystem change); a number of annexes which provide relevant background information; and an introductory chapter, which places the initiative in context, clarifies key analytical and modelling concepts, and provides a summary of the assessment.

The intergovernmental Baltic Marine Environment Protection Commission (Helsinki Commission, HELCOM; www.helcom.fi) used the BACC report as the basis for the HELCOM Thematic Assessment 2007 on ‘Climate change in the Baltic Sea area’ (HELCOM 2007a) which was officially adopted by representatives of Baltic Sea riparian states in March 2007. The BACC assessment report has led to the launch of other, similar initiatives, including, for example, a climate report for the greater Hamburg area in Germany (Klimabericht für die Metropolregion Hamburg, Doerffer 2011), a similar report for the North Sea area (NOSCCA) is currently in preparation (Quante and Colijn 2011). An update to this report (BACC II) is currently in preparation and will provide the latest findings, a good 5 years after the publication of the first BACC report (Reckermann 2011). Some aspects will be emphasized in BACC II, e.g. sea level change, socio-economic impacts, impacts on urban regions, and an attempt to attribute regional impacts to anthropogenic climate change. For a summary of BACC see BALTEX (2006b) and Reckermann et al (2008), recent information on BACC II is available at www.baltex-research.eu/BACC2/.

Investigations of sea level change in the Baltic Sea have shown that other factors influence the water level in addition to the global rising in a complicated manner (land uplift, atmospheric forcings). Thus, an estimation of regional sea level change is needed for the development of regional climate change adaptation strategies. Statistical downscaling techniques were used to investigate the influence of different regional climate drivers on past and present Baltic Sea level variability on multi-year to decadal scales in the observational time period 1800–2000 (Hünicke and Zorita 2006, 2008, Hünicke et al 2008). The results indicate that the influence of the analysed atmospheric forcing factors on sea level vary geographically within the Baltic Sea region: decadal sea level variations at selected northern and eastern Baltic tide gauges are strongly influenced by atmospheric circulation (air-pressure, wind) patterns, including the North Atlantic Oscillation. The decadal variability of Southern Baltic tide gauges could be statistically better explained by the Baltic Sea catchment area averaged precipitation and its relation to water salinity changes. The statistical relationship between sea level and large-scale climate fields (air-pressure, wind, precipitation) in the observational record allow us to estimate the contribution of future regional climate change to future Baltic Sea level changes.

Furthermore, selected long-term sea level changes at selected tide gauges in the southern, central and eastern Baltic Sea were simulated for the 21st century (Hünicke 2010a). Regional climate factors such as wind and precipitation caused a clear upward trend in sea level. For the selected central and eastern Baltic Sea tide gauges, the estimated contribution of atmospheric forcing changes is in the range of 10–20 cm until 2100. For selected south-western Baltic Sea level stations, this contribution was smaller, but statistically more stable values around 4 cm until 2100. All values were found to be statistically significant and larger than the past variability. Thus, a heterogeneous behaviour of future sea level trends within the Baltic Sea is possible, but depends on future trends of the regional climate drivers.

3.3. Objective 3: provision of improved tools for water management, with an emphasis on extreme hydrological events and long-term changes

The objective is to develop and apply numerical models able to simulate effects of extreme weather (heavy precipitation, droughts, storm surges) and climate conditions on, for example, river runoff and coastal regions, helping to improve precautionary measures and to efficiently manage water resources in the Baltic Sea drainage basin.

Graham et al (2009) used a climate model coupled to a hydrological model to reconstruct river flow to the Baltic Sea during the past 1000 years. Their general conclusion is that although climate has varied considerably during the past millennium, annual values and variability were not significantly different in the 20th century than during the past millennium. Variability in extreme precipitation events over more recent timescales (1961–2008) was investigated for Lithuania (Rimkus et al 2011) and for Estonia (Päadam and Post 2011). For Lithuania, a slight positive trend was detected for heavy precipitation events over Lithuania, which is expected to increase even more (up to 22%), following regional climate model projections for the 21st century. Also for Estonia, the number of extreme precipitation events has increased over the last half century.

The southern coasts of the Baltic Sea are especially vulnerable to storm surges, due to the low-lying lagoon type coastlines. In contrast to the northern parts of the Baltic Sea, there is no land uplift counteracting global sea level rise. A 10 yr study of storm surges in the Odra estuary revealed three distinct types of storm surges, caused by different atmospheric configurations and having different effects on the coast and upstream of the river (Kowalewska-Kalkowska and Wisniewski 2009, Kowalewska-Kalkowska 2010, Wisniewski and Wołski 2011). The results of this project contribute to the development of tools for forecasting and better managing extreme surge events in the southern Baltic Sea area.
A new hydrological model was designed by the Swedish Meteorological and Hydrological Institute (SMHI) to simulate water and nutrient transport from land to the sea on a daily time-step for the entire Baltic Sea catchment basin. BaltHYPE is based on the HYPE model (HYdrological Predictions for the Environment; Lindström et al 2010), which can be characterized as a dynamic, semi-distributed, process-based and integrated catchment model. It uses well-known hydrological and nutrient transport concepts and can be applied for both small and large-scale assessments of water resources and status. In this model, the landscape is divided into classes according to soil type, vegetation and altitude. The soil representation is stratified and can be divided in up to three layers. Water and substances are routed through the same flow paths and storages (snow, soil, groundwater, streams, rivers, lakes) considering turn-over and transformation on the way towards the sea. So far, the model has been used to assess a variety of environmental issues, e.g. net contribution of land-based sources to the sea, a reconstruction of discharge and nutrients at daily time-steps for the period 1971–2008 (Arheimer et al 2011), and an analysis of the combined effect of the Baltic Sea Action Plan7 (BSAP) implementation and climate change on nutrient load (Donnelly et al 2011). During 2012, the model will deliver operational forecasts of water and nutrient concentrations on a daily basis to oceanographic models. New model versions will be released regularly and results are available for free downloading of time series for rivers and coast segments at www.smhi.se/balt-hype.

3.4. Objective 4: biogeochemical cycles in the Baltic Sea basin and transport processes within the regional Earth system under anthropogenic influence

Biogeochemical cycles are closely interwoven with the hydrological cycle. These fluxes and reservoirs are expected to vary under climate change conditions with possible impacts on both marine and terrestrial ecosystems, as well as the socio-economy in the Baltic Sea drainage basin. This objective contributes to further develop Earth system models, capable of realistically integrating impacts on ecosystems.

The projects briefly outlined below are all concerned with the impact of the changing conditions in the future on the marine environment of the Baltic Sea. On the one hand, they contribute to the vision of a regional Earth System Model System; on the other hand, they have a very practical relevance for working out managing options for the Baltic Sea by developing software tools and models. These international and interdisciplinary projects are funded by the EU funding scheme BONUS8 for a 3 year (2009–11) period. Partners from institutions and countries all over the Baltic Sea region are involved in the BALTEX-related BONUS-funded projects ECOSUPPORT, Baltic-C and AMBER.

ECOSUPPORT (advanced modelling tool for scenarios of the Baltic Sea Ecosystem to support decision making) attempts to assess the combined future impacts of climate change and industrial and agricultural practices in the Baltic Sea catchment on the Baltic Sea ecosystem. The main aim of ECOSUPPORT is to provide a multi-model system tool to support decision makers. The tool is based on scenarios from an existing state-of-the-art coupled atmosphere–ice–ocean–land surface model for the Baltic Sea catchment area, marine physical–biogeochemical models of differing complexity, a food web model, statistical fish population models, and new data on climate effects on marine biota. It is a challenging new approach to integrate different model ‘worlds’ in order to generate benefits for Baltic Sea management.

Global warming may cause increased water temperatures, reduced sea ice cover and locally increased river runoff in the Baltic Sea catchment (e.g. BACC Author Team 2008). These changes might cause significant impacts on the marine ecosystem and have been studied within ECOSUPPORT by performing an ensemble of model simulations for the 21st century (Meier et al 2011a). Four climate change scenarios using regionalized data from two General Circulation Models (GCMs) and two greenhouse gas emission scenarios (A2, A1B) have been used to force three state-of-the-art coupled physical–biogeochemical models. These models are the ‘Baltic Sea Long-Term Large-Scale Eutrophication Model’ (BALTSEM) (Gustafsson 2003, Savchuk 2002), the ‘Ecological Regional Ocean Model’ (ERGOM) (Neumann et al 2002, Neumann and Schernweski 2008) and the ‘Swedish Coastal and Ocean Biogeochemical Model’ coupled to the Rossby Centre Ocean circulation model (RCO-SCOBI) (Meier et al 2003, Eilola et al 2009). Different nutrient load scenarios, ranging from a pessimistic business-as-usual to the more optimistic case following the BSAP have been investigated, following recommendations by the Helsinki Commission (HELCOM 2007b).

The results suggest that the impact of changing climate on Baltic Sea biogeochemistry might indeed be significant (figure 4). The projected warming is an important driver in relation to eutrophication and it will reduce the water quality of the Baltic Sea in terms of the chosen ecological quality indicators. According to preliminary results, the efficiency of nutrient load reductions will be smaller in a future climate compared to the present climate, emphasizing the need for political actions to reduce nutrient flows into the Baltic Sea (Meier et al 2011b). ECOSUPPORT is coordinated by Markus Meier, Swedish Meteorological and Hydrological Institute, Sweden (www.baltex-research.eu/ecosupport/).

Another large BONUS-funded project from within the BALTEX community with strong relevance for objective 4 is Baltic-C (Building predictive capability regarding the Baltic Sea organic/inorganic carbon and oxygen systems). The overall objective of this project is to improve our understanding of the Baltic Sea carbon system, including the acid–base (pH) balance. This is done by developing and applying a new integrated ecosystem model framework based on the cycling
Figure 4. Annual mean changes of bottom oxygen concentration (in ml l$^{-1}$, left column), phytoplankton concentration (in mg Chl/m$^3$, middle column) and Secchi depth (water transparency, in m, right column) between the periods 2070–99 and 1969–98. The depicted results from transient regional scenario simulations were calculated with the coupled physical–biogeochemical model RCO-SCOBI (Meier et al. 2003, Eilola et al. 2009), driven by atmospheric fields regionalized from the global climate model HadCM3, and assuming the A1B greenhouse gas emission scenario (see Kjellström et al. 2011). Three nutrient load scenarios were calculated assuming (1) current nutrient concentrations in rivers and current atmospheric deposition (REF, upper row), (2) reduced nutrient concentrations in rivers following the BSAP and 50% reduced atmospheric nitrogen deposition (BSAP, middle row) and (3) business-as-usual for loads from rivers assuming an exponential growth of agriculture in all Baltic Sea countries and current atmospheric deposition (BAU, lower row). The depicted results are part of a larger ensemble consisting of four regional climate scenarios and four nutrient load scenarios, calculated with three different Baltic Sea models. For details see Meier et al. (2011b).
reaches a first minimum as a consequence of CO2 consumption of the and in the atmosphere in the central Baltic Sea in 2009. In March, the air/sea CO2 gas exchange and the production of dissolved organic which considerably exceeds the atmospheric pCO2 in the winter. To quantify the biomass production, the pCO2 data were used to calculate the total CO2 (CT) concentrations. Taking into account the inorganic carbon (Corg) and carbon dioxide (CO2) in the Baltic Sea and its drainage basin, taking into account fluxes across the atmosphere and sediment interfaces. Seawater pH is among the most important factors controlling life in marine systems, and acidification could severely alter and threaten marine ecosystems. Understanding pH changes in coastal regions characterized by high biological production and various anthropogenic mechanisms, such as climate change, land use change, eutrophication and overfishing, is therefore crucial. The overall aim of the Baltic-C is to provide a tool which can be used to support the management of the Baltic Sea.

Carbon and oxygen data collected on research cruises can be used to identify and quantify biogeochemical processes (Schneider et al 2006, 2007, 2009), e.g. the seasonality of biomass production in surface waters (figure 5). Together with river input data of river flow, alkalinity, total inorganic carbon, total organic carbon, pH, temperature and biologically relevant elements, these data will form the basis for model development and validation. The Baltic-C model system involves two land surface models (LPJ-GUESS and CSIM) and one Baltic Sea model (PROBE-Baltic). Climate scenario data were extracted for the Baltic Sea drainage basin and for the various Baltic Sea sub-basins for a period representing the climate change between 1960 and 2100. Data from several emission scenarios (A1B, A2, and B1) and from several global climate models (ECHAM 5, HadCM3, and CCSM3) were derived for forcing the various model components. These models and scenarios are now used in an extensive study on the interaction between climate change, eutrophication and marine acidification. Baltic-C is coordinated by Anders Omstedt, University of Gothenburg, Sweden (www.baltex-research.eu/baltic-c/).

The goal of AMBER (Assessment and Modelling of Baltic Ecosystem Response) is to provide a ‘toolbox’ for a sustainable management of the Baltic Sea ecosystem with a focus on the coastal ecosystem, following the concept of the Ecosystem Approach to Management (EAM). Elements of this toolbox are Ecological Quality Objectives (EcoQOs) which form the basis for the development of indicators, limits and targets. To fulfill these goals, three parallel approaches are followed: a retrospective analysis of long-term data sets with the aim of improving the predictive capacity of model systems, extensive modelling with combined regional climate models and land use and watershed models to estimate the future impacts of human activities on the Baltic Sea and finally measuring selected biogeochemical processes in coastal waters including groundwater seeping (Dippner 2011).

An outcome of AMBER is the development of a new index for the environmental state of the Baltic Sea, the ‘Baltic Sea Environmental Index’ (BSE), which helps to interpret the environmental status of the Baltic Sea in the past. Preliminary results suggest that dissolved organic substances may play a more important role for nutrient budgets than previously thought and that nitrogen removal capacity in coastal waters is effective but may be constrained by extending oxygen free zones. Combined regional climate and land use models show that an intensification of agriculture may seriously affect Baltic Sea coastal water quality. As for the other BONUS projects, results are currently being drafted as documents and synthesis papers. AMBER is coordinated by Joachim Dippner, Baltic Sea Research Institute Warnemünde, Germany (www.io-warnemuende.de/amber.html).

3.5. Objective 5: strengthened interaction with decision makers, with emphasis on global change impact assessments

The involvement of governmental agencies and intergovernmental organizations such as HELCOM helps to improve communication and knowledge transfer between scientists and decision makers. A successful example of stakeholder involvement in BALTEX Phase II is the collaboration with HELCOM, the Baltic Marine Environment Protection Agency, in sharing the BACC material for a dedicated HELCOM Report (HELCOM 2007a). This collaboration will be further strengthened in the scope of BACC II. A currently ongoing collaboration with BSSSC, the Baltic Sea States Sub-regional

The Ecosystem Approach to Management (EAM) emphasizes that humans are integral components of ecosystems whereby human social and economic systems constantly interact with the physical, chemical and biological parts of the ecosystem. Thus, the EAM is concerned with managing human impacts on ecosystems rather than implying an attempt to manage ecosystems by humans, in order to seek an appropriate balance between conservation and use of biological diversity.
Co-operation, represents an interface between the scientific community and a network of politicians on the local (sub-regional) scale, broaching the issue of local impacts of regional climate change. Recently, a joint conference on ‘Adapting to Climate Change—Case Studies from the Baltic Sea Region’ was held in Hamburg, Germany. The key objective of the conference was to give practitioners and decision makers at the regional political level in the Baltic Sea Region a platform to present and discuss concrete examples of regional or local adaptation to climate change.

3.6. Objective 6: education and outreach at the international level

Scientific exchange through conferences, academic training through summer schools and courses, and the involvement of the general public through dedicated publications are goals of this overarching objective. The rationale for BALTEX Phase II clearly demonstrates the relevance of the programme for various sectors of society. Dedicated scientific conferences on BALTEX-related research, followed by proceedings in international scientific journals, have been an important component from the very beginning of the programme (Study Conferences on BALTEX, see below). Examples for specific educational activities are the organization of summer schools, e.g. on ‘Climate impacts on the Baltic Sea: from science to policy’, which took place on the Danish island of Bornholm in 2009. A text book based on the content of this summer school is due to be published in late 2011. Another example for outreach activities is the publication of a booklet on ‘The Baltic Sea coast under climate change’, based on the results of the North German Climate Office, a regional climate service provider for Northern Germany, and the BACC book (see above). The booklet focuses on the southern coasts of the Baltic Sea, and is written in German in a non-scientific style to facilitate access by the general (German, in this case) public. Similar booklets are planned in other languages.

4. Infrastructure and activities

BALTEX has a strong infrastructure, which is a prerequisite for a successful and sustainable networking. A dedicated secretariat, various panels, regular meetings and publications form the backbone of the programme which has no central funding but nevertheless profits from a common infrastructure.

BALTEX is led by a Scientific Steering Group (BSSG), which currently has 20 members from across the entire Baltic Sea drainage basin, and from various research institutions and national hydro-meteorological agencies. As mentioned above, the national agencies have played a crucial role in the first phase of BALTEX, but have remained important scientific stakeholders for BALTEX. The steering group has the responsibility to organize and maintain the programme efficiently and in accordance with the general structures of GEWEX and other projects within WCRP.

The International BALTEX Secretariat (IBS), located and funded from the very beginning at the Helmholtz-Zentrum Geesthacht (formerly GKSS Research Centre), is the coordinating centre of the programme. The IBS prepares meetings, workshops, seminars and conferences and issues reports and conference proceedings, e.g. the International BALTEX Secretariat Publication Series and the BALTEX Newsletter (see below).

Working Groups are established to cover either a dedicated topic or element within one BALTEX Phase II objective, or a topic or element cross-cutting through several or all objectives. Currently, three working groups are active: the Working Group on Radar (weather radar as wind and precipitation observation systems in the Baltic Sea basin), the Working Group on Data Management and the Working Group on the Utility of Regional Climate Models. For more information on the organisation of BALTEX, see www.baltex-research/organisation/.

Data Centres and Data Management. Data relevant to BALTEX cover a wide range of disciplines, data types, periods, geographical extent, frequency and spatial resolution. Four BALTEX data centres for meteorology, hydrology, oceanography and for radar data were installed during BALTEX Phase I by the Science Steering Group, with the main objective to concentrate specific types of data or information (metadata) at these centres, and thus to facilitate the data exchange between the different data suppliers on the one side and individual scientists or research groups within BALTEX on the other side. Currently, the data delivery to the BALTEX Data Centres has ceased, but historical data are available anytime (Reckermann and Lautenschlager 2011). For more information, see www.baltex-research/data/.

Publications. BALTEX publishes a range of documents. The International BALTEX Secretariat edits and issues the BALTEX Newsletter, which is published roughly on a yearly basis. The Newsletter is sent to about 900 scientists across the complete Baltic Sea area, and features scientific articles spanning the complete range of the scientific scope of BALTEX, but also project reports, news and announcements. The International BALTEX Secretariat Publication Series (ISSN 1681-6471) has published 49 issues to date. Examples include project reports, science and implementation plans, meeting minutes and conference proceedings. Following large BALTEX conferences, selected papers are published in a special issue of an international scientific journal. Apart from that, a large number of books, reports and peer-reviewed journal articles (roughly 630) have been published with reference to BALTEX. These are regularly included in a freely accessible online publication database (mostly with abstracts included), and a comprehensive listing as PDF. Recently, a special literature research on publications dealing with sea level change in the Baltic Sea, containing 167 citations was published (see also Hünicke 2010b). For a complete overview over BALTEX publications, see www.baltex-research.eu/publications/.

Events. The glue of a programme like BALTEX is the personal communication between the involved individuals, be it scientists, stakeholders, politicians, students or just interested laymen. Therefore, BALTEX regularly organizes meetings, workshops, conferences and summer schools. The main regular BALTEX event takes place every three years on a Baltic Sea island: the ‘Study Conferences on BALTEX’. To date, the
six study conferences have taken place on Gotland, Sweden (1995); Rügen, Germany (1998); Åland, Finland (2001); Bornholm, Denmark (2004); Saaremaa, Estonia (2007); and Wolin, Poland (2010). The 7th Study Conference on BALTEX is envisaged to take place on the Swedish island of Öland in 2013. Between 100 and 150 participants from across the BALTEX area meet for these 5 day events, with presentations and discussions spanning the whole range of BALTEX-related research. Selected results are published in a special journal issue. Apart from these regular large events and the BALTEX seminars associated to regular BSSG meetings, many other scientific conferences and workshops have been organized by BALTEX. For information on BALTEX events, see www.baltesh-research.eu/events/.

5. Outlook

The second 10 year period of BALTEX is coming to an end in 2012. Currently, various publications are in preparation which will document the achievements of BALTEX Phase II. The 7th Study Conference on BALTEX will provide an opportunity for an overview and wrap-up of the programme. Vivid discussions on the scope for a follow-up programme to BALTEX have been going on over the past two years, and the drafting of a new science plan for a new programme is currently in preparation. While concrete objectives and goals cannot be presented in this early stage, it is nevertheless possible to anticipate the direction of the new programme towards further promoting an interdisciplinary regional Earth System approach for the Baltic Sea basin, encompassing the physical, chemical, biological and socio-economic spheres as far as appropriate. Developments can be followed on the BALTEX web site (www.baltesh-research.eu).

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