4. Gradual Extension to Air and Water Quality Studies

The fourth objective for Phase II is an entirely new extension to BALTEX. The aim is to gradually extend BALTEX research to eutrophication and pollution studies in the Baltic Sea catchment. Prior to defining related goals, this chapter will therefore start by briefly summarizing the background and rationale for the suggested extension.

Background

Anthropogenic eutrophication is caused by excess aquatic loads and atmospheric deposition of nutrients into the Baltic Sea and inland water bodies, associated with urbanisation and intensive industrial and agricultural production. Eutrophication increases phytoplankton and macro-algae production, leading to oxygen deficiency in deeper layers by microbial decomposition, which in turn may lead to fish kills, reduced biological diversity and death of bottom dwelling animals.

Nutrient concentrations in the Baltic Sea have increased considerably since the 1940s. In 1998, an overall 50% reduction target for nutrient inputs to the Baltic Sea was proclaimed by HELCOM (The Baltic Marine Environment Protection Commission). Since then, most countries around the Baltic Sea have reduced their point sources, but with smaller reductions for nitrogen than for phosphorus. The overall reduction of loads from diffuse sources has been less successful in most countries. For nitrogen, about 75% of the total load is waterborne, e.g. enters the Baltic Sea by rivers and point sources, and about 25% is airborne. For phosphorus, atmospheric input is only 1-5% of the total load, while the bigger share enters the Baltic Sea through waterborne sources (HELCOM, 2005). These gross values may vary substantially depending on the sub-basin, the compound and the season. Recent estimates indicate that the load from agriculture and managed forestry contributes to approximately 60 % of the waterborne nitrogen load, and nearly 50 % of the waterborne phosphorus load to the Baltic Sea (HELCOM, 2005). The largest reduction achieved for arable leaching is mainly related to the economic breakdown of the agricultural sector in the transition countries. So far it has been difficult to monitor these effects, which are mainly due to large storage of nutrients in the soil and water systems.

Results from the EU project MEAD (Marine Effects of Atmospheric Deposition) have shown that air-sea fluxes of ammonia close to source regions can be much higher than previously estimated, and that these inputs can be comparable in magnitude to wet deposited nitrogen. Model results from MEAD showed different patterns of turbulence intensity (and therefore different patterns of dry deposition) depending on model resolution. The results of the high resolution model showed that turbulence intensity is higher close to the coast than previously thought and that the pattern of intensity depends on the position of islands.

Combining model and experimental results showed that ammonia is deposited primarily as ammonia gas and therefore its deposition is fundamentally controlled by the turbulence intensity in the region. Gas phase nitric acid (HNO_3) in contrast reacts rapidly with aerosols such as sea salt, changing nitrogen into the particle phase as nitrate. Since HNO_3 has a higher deposition velocity than nitrate aerosols, this process actually decreases the deposition of oxidised nitrogen to surface waters 10 km offshore and beyond. These findings are still to be considered as preliminary results and therefore further research on air-sea fluxes and reactions in the marine atmosphere will be carried out based on new and improved measuring techniques. Accurate determination of the dry deposited flux of nitrogen from the atmosphere to the surface waters requires much higher resolution coupled meteorological and chemical modelling than is currently achieved. This will be a focal point in future research.

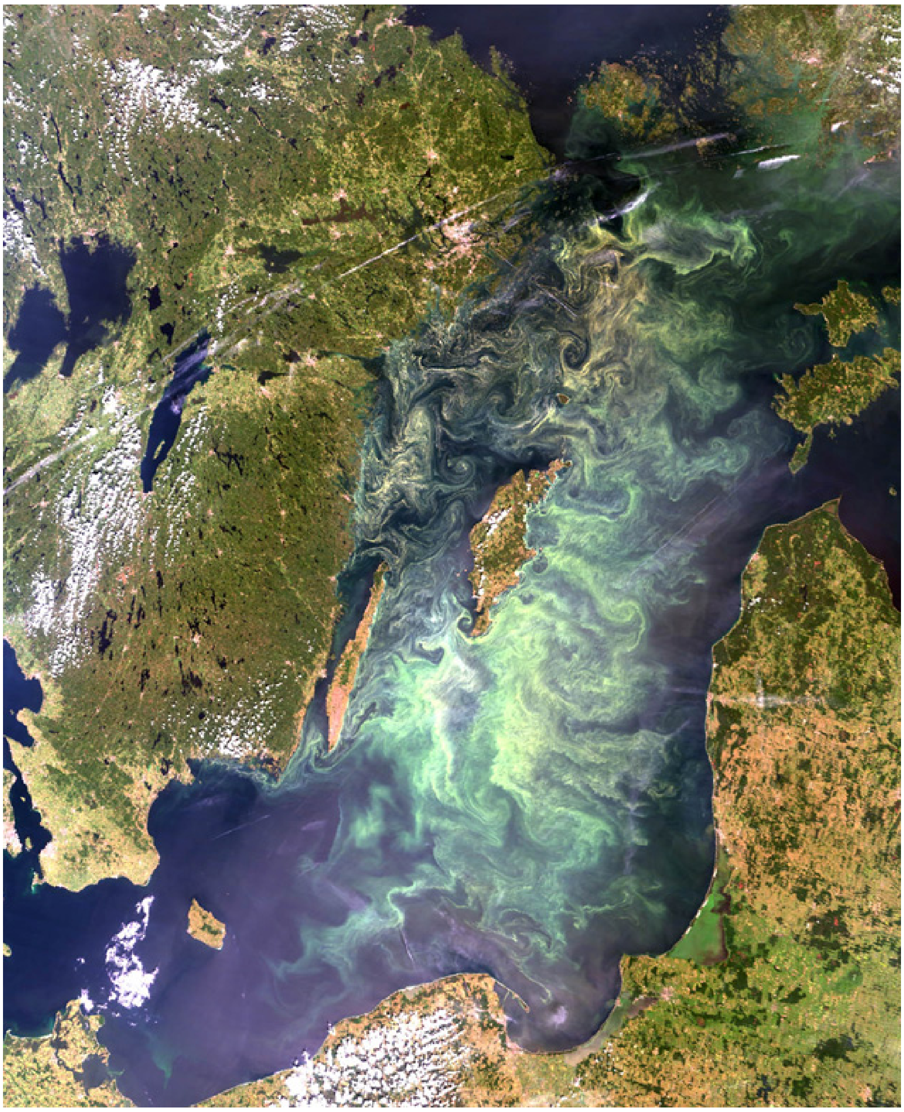

Fig. 4.1 A bloom of cyanobacteria in the Baltic Proper as seen from satellite on 11 July 2005. Algae blooms are a regularly occurring phenomenon in the central Baltic Sea and may have negative effects on the environment. The 2005 cyanobacteria bloom has been considered a strong event compared to earlier years. (Modis/Aqua data from NASA, processed by SMHI)

While eutrophication is caused by the increased input of natural components such as nitrogen and phosphorus, pollution defined as input of toxic substances and other material which threatens the Baltic Sea environment is completely man-made. It has been increasingly evident that the Baltic Sea region is a sink for many toxic pollutants, such as heavy metals and POPs (Persistent Organic Pollutants) which originate from industrial and agricultural activities both inside and outside the region. The transport includes wind-driven air masses, rivers and water currents, and ice-drift. Long-range airborne transport of pollutants, with subsequent releases in rain and snow over the Baltic Sea catchment deposits pollutants on land, in riverine melt water, and in the highly productive surface layers of the Baltic Sea. The carbon system is closely connected to the biogeochemical processes of the ecosystem. In particular, the surface water CO_2 partial pressure (pCO_2) reacts extremely sensitive upon changes in the CO_2 system caused by biological activity and thus a coupling between the eutrophication problem and climate issues (e.g. control of CO_2 uptake) exists. Increased nutrient inputs and phytoplankton concentrations are hypothesized to enhance CO_2 uptake. However, oxygen depletion as a result of too high nutrient input may lead to CO_2 emission.

The interaction between the atmosphere and the sea has substantial influence on the marine and atmospheric environment. Surface fluxes can be estimated with various techniques, such as eddy correlation, profile, inertial dissipation, bulk, and relaxed eddy accumulation methods. The most direct is the eddy correlation method but it is difficult to apply over the open sea due to movements of the platform (ship) and flow distortion caused by the structure of the platform. The bulk method, which provides the connection between the gradient and the fluxes, is commonly applied although the dependence of the transfer coefficient on atmospheric stability and the state of the sea is still not settled. The relaxed eddy accumulation is a promising novel technique to measure fluxes of constituents that are too low in concentration to be measured by the eddy correlation technique. Dependence between the height of the marine boundary layer and the wind and concentration profile in the marine atmosphere has recently been suggested, and recent measurements indicate a connection between the exchange processes and the marine boundary layer height.

In recent years, significant progress has been made in developing and coupling circulation and biogeochemical models on the one hand and atmospheric-hydrological and transport-chemistry models on the other hand. BALTEX Phase II will take advantage of this development and will include pollution and dispersion processes into regional circulation models, in particular the coupled regional models developed in Phase I of the programme, and will further promote the improvement of existing biogeochemical models and their coupling with climate models within the BALTEX modelling platform. One goal will be the simulation of ecosystem responses to changes in atmospheric forcing.

Transports and fluxes of matter connected to the water cycle finally end up in the Baltic Sea, which acts as the “collector” of nutrients and pollutants. The Baltic Sea and its marine ecosystem is therefore a key indicator for the environmental status of the entire Baltic Sea region. Research aspects related to this objective of BALTEX Phase II will therefore to some extent focus on the Baltic Sea and its marine ecosystem.

4.1. Major Goals

- To foster the coupling of climate and biogeochemical models and enhance the modelling capability for dispersion processes of nutrients and pollutants by implementing these into regional coupled atmosphere-land-ocean models including sea ice, rivers and lakes.
- To promote the integration of the carbon cycle into biogeochemical models and to initiate first steps towards including these into the BALTEX modelling platforms
- To continue establishing and exploring more comprehensive observations into data sets for development and evaluation of modules and models, and to stimulate field experiments to study exchange processes of pollutants, nutrients, and carbon over sea and land including ice and snow.

4.2. How to achieve these Goals

4.2.1. Including Pollution and Dispersion Processes into Regional Circulation Models

- *To foster the coupling of climate and biogeochemical models and enhance the modelling capability for dispersion processes of nutrients and pollutants by implementing these into regional coupled atmosphere-land-ocean models including sea ice, rivers and lakes.*

Existing biogeochemical models should be gradually integrated and coupled with hydrological and atmospheric models to comprehensively describe the dispersion processes of nutrients and pollutants. Within BALTEX Phase I, coupled atmosphere-land-ocean models of the Baltic Sea catchment have been developed and applied. In Phase II, inputs, dispersion and transport, as well as transformation and the fate of nutrients and pollutants shall be investigated by coupling biogeochemical sub-modules for aerosols and substances into regional coupled atmosphere-land-ocean models of the Baltic Sea. For this purpose, relevant existing models and necessary extensions or modifications should be identified.

As a first step, nutrients and pollutants (heavy or trace metals and POPs) should be identified and selected for which sufficient data exist so that they can be successfully implemented into coupled models. Nitrogen and phosphorus compounds are generally the limiting nutrients for primary production in the Baltic Sea. Especially the extensive cyanobacterial blooms which may cover large parts of the Baltic Sea every summer are strongly dependent on phosphorus availability. Large data sets are available for these compounds. Their complex cycles including the redox transformations in the anoxic deep waters have been simulated in biogeochemical models, and efforts should be made to link these with meteorological, hydrological and atmospheric models to extend their scope to distribution and transport processes in air, sea and on land. Emphasis should be put on the atmospheric transport of gases, aerosols and particles.

For trace metals, the following different biogeochemical transformations and pathways must be considered:

1. ***Riverine input**:* Data are available about the riverine input of trace metals into the Baltic Sea and the direct input from point sources. Due to the incomplete regional coverage of the measurements, extrapolation procedures were applied which involve considerable uncertainties. Nevertheless, the data provide an acceptable basis for first attempts to model the distribution of trace metals in the Baltic Sea.

2. ***Atmospheric transport and deposition:*** Data on emissions from anthropogenic land-based sources, concentrations in ambient air and precipitation as well as dry and wet deposition fluxes to the water body and the drainage basin of the Baltic Sea for the priority metals lead, cadmium and mercury have been reported. Those data have been derived both from measurements and model simulations. However, the available observational data are still scarce with a limited spatial coverage. They mainly refer to monitoring stations at coastal sites and, in some cases, do not allow an overall assessment of the atmospheric input of heavy metals to the Baltic Sea.

3. ***Internal transformations and sedimentation:*** According to the mode of interaction of dissolved trace metals with particles, two different types of trace metals are distinguished: “nutrient-like” and “scavenged” trace metals. The cycling of nutrient-like trace metals (e.g. cadmium, Cd) widely resembles that of phosphorus and nitrogen compounds. Many studies concerning the distribution coefficient of Cd have been published and the data may be used to make a first step to model the distribution of Cd representing the nutrient-like trace metals. In a second step, scavenged trace metals should be included in the model. Scavenged trace metals (e.g. lead, Pb) interact preferentially with mineral particles such as iron and manganese oxides. Finally, in a third step the formation and changes of anoxic conditions in the Baltic Sea deep water should be taken into account. A special case is the chemical behaviour of mercury (Hg) in seawater. Mercury is transported into the Baltic Sea mainly as oxidized Hg, but may be reduced photochemically or biochemically to elemental Hg. Since elemental mercury is volatile, it may escape into the atmosphere by gas exchange.

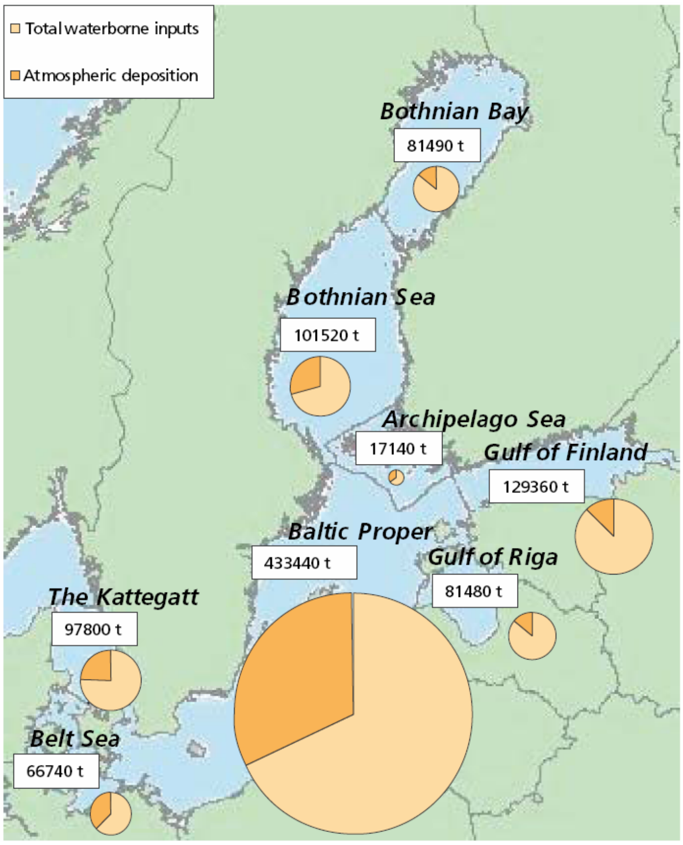

Fig. 4.2 Proportion of airborne and waterborne nitrogen inputs into the Baltic Sea sub-regions in 2000. From *HELCOM, 2005.*

4.2.2. Towards extending Biogeochemical Models by integrating the Complete Carbon Cycle

- *To promote the integration of the carbon cycle into biogeochemical models and to initiate first steps towards including these into the BALTEX modelling platforms*

Any modelling approach to describe the carbon cycle must include an ecosystem module. Since nutrients limit biological production, ecosystem models in general focus on the cycling of nutrients in order to simulate the production and decomposition of biomass. Most of them consider only the organic carbon and ignore the interaction with the marine CO_2 system. BALTEX will promote research involving the CO_2 system in order

- to balance the CO_2 gas exchange between the Baltic Sea and the atmosphere. In contrast to the atmospheric pCO_2, the surface water equilibrium pCO_2 shows a marked spatial and seasonal variability and thus controls the air/sea CO_2 exchange. Since the surface pCO_2 is mainly controlled by biological activity, any approach to model the air/sea CO_2 balance must be based on an ecosystem model that includes the CO_2 system;
- to introduce additional variables for the validation of ecosystem models,
- to simulate potential changes of the Baltic Sea CO_2 system using different scenarios for climate changes and anthropogenic nutrient loads, and to estimate the implications for the ecosystem functioning and for the role of the Baltic Sea as a source/sink for atmospheric CO_2.

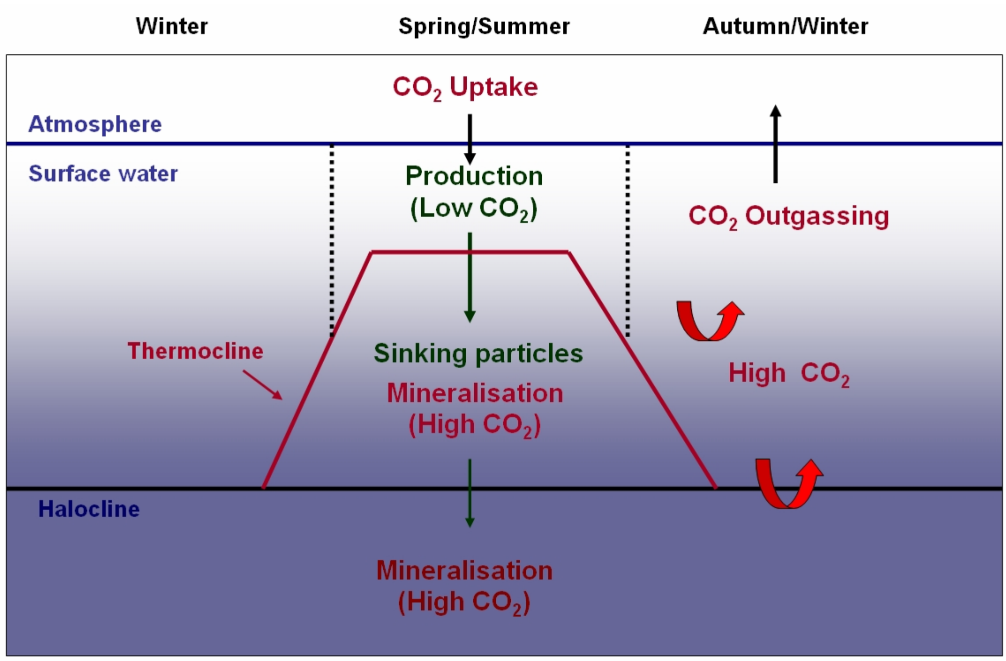

Fig. 4.3 Relationship between mixing/stratification and CO_2 seasonality in the Baltic Proper. CO_2 is taken up by surface waters in the productive spring and summer while respiration in winter results in a net outgassing to the atmosphere. Particle sedimentation export organic carbon to the deep waters, where it is remineralized to CO_2 which may be mixed up to the surface layer by convection (by courtesy of Bernd Schneider, IOW).

4.2.3 Inclusion of new Data Sources and Measurement Methods for the Improvement of Parameterisation and Model Validation

- *To continue establishing and exploring more comprehensive observations into data sets for development and evaluation of modules and models, and to stimulate field experiments to study exchange processes of pollutants, nutrients, and carbon over sea and land including ice and snow.*

Remote sensing from satellites increases the potential of high resolution monitoring of the terrestrial and marine environment by providing high resolution information on temperature, soil moisture, sea ice extent, sea surface roughness, swell and ocean colour (see also Chapter 8.3). Monitoring and short term field experiments should be carried out on moving and stationary platforms to investigate the processes which control exchanges of energy, water, and biogeochemical components such as nutrients and carbon, between air and sea, land, snow and sea ice. Newly developed technologies for flux measurements of gases and particles (i.e. relaxed eddy accumulation and inertial dissipation) will be applied. These data will form a basis for the development and validation of satellite retrieval algorithms, and for flux parameterisations of environmental substances for model development as well as model validation. Furthermore, meteorological measurements over land should be complemented with nutrient flux measurements.

4.3. Involvement of Stakeholders

It is necessary to involve stakeholders at an early stage in the environmental modelling process to obtain reliance in model results, and to ascertain that stakeholder questions are answered in a comprehensive way. Stakeholder contacts are also necessary for researchers to obtain detailed information on several environmental variables, which serve as input to the models. The most important stakeholders are:

- HELCOM (Helsinki Commission)
- EEA (European Environment Agency)
- ICES (International Council for the Exploration of the Seas)

- Research institutions
- Authorities (including governments) at national, regional and local level
- Industry
- Farmers
- Fisheries and aquaculture
- Tourism
- General public and media

4.4. Research Needs and Potential Activities

The model systems and related experience elaborated during BALTEX Phase I should be exploited by environmental impact models in BALTEX Phase II (*e.g.* meso-scale air pollution models, riverine-nutrient transport models, biogeochemical models). Such models are of vital importance to serve decision makers in environmental policy. Chemical sub-modules for aerosols and substances such as carbon, nitrogen and ozone should be linked to the coupled ocean-atmosphere-land surface models developed in BALTEX Phase I.

4.4.1. Input, Dispersion, Transport and Fate of Nutrients and Pollutants

BALTEX has developed tools to model the distribution of conservative seawater constituents which are transported by advection and mixing. However, nutrients and most heavy metals, and especially those which have toxic effects, behave non-conservatively and undergo physical and biogeochemical transformations. The quantification and integration of these processes into models requires extensive research efforts and should be a primary activity. A precondition for modelling the distribution of nutrients and pollutants is the availability of data for atmospheric and riverine inputs. With respect to atmospheric transport and deposition, the overall research needs should focus on the adaptation of the most advanced atmospheric chemistry and transport models suited for the simulation of transport, transformations and deposition of air constituents on adequate spatial and temporal scales. Such models will have to be extended and/or restructured fundamentally to address the current understanding of atmospheric nitrogen and phosphorus, as well as heavy metal and POP distribution, including the complex physical and chemical transformations and air-sea exchange processes of mercury species.

This will require research with respect to the:

- Coupling of biogeochemical sub-modules to atmosphere-land-ocean models of the Baltic Sea
- Characterization and quantification of air-water and air-soil exchange processes, which may significantly influence the atmospheric deposition level over the Baltic Sea and its drainage basin, respectively. This will include field campaigns including the atmospheric boundary layer parameters and flux measurements to close existing gaps in knowledge of nutrient, pollutant and biogeochemical transformation processes in air, sea and inland waters as well as soils for model validation and database construction.
- Investigation of physical and chemical transformations of non-conservative tracers and its implementation into coupled models
- Establishment of links to hemispheric or global models to improve initial and boundary concentration fields of regional models. Recently performed model simulations for mercury show that global background concentrations contribute by about 40 % of the total atmospheric input to the Baltic Sea. This indicates that emission reductions in Europe would only have a limited effect on the reduction of the total mercury load of the Baltic Sea.
- Integration of atmospheric deposition and other environmental modelling techniques to encompass the entire Baltic Sea ecosystem and to address the total cycle of heavy metals.

4.4.2 The Carbon Cycle

BALTEX Phase II will provide the framework for research aiming at the description of the Baltic Sea carbon cycle. It will thus extend its modelling activities, beyond the hydrographical and hydrological processes, to biogeochemical models. BALTEX will not deal with the further development of the biological model components since this is pursued at many institutions dealing with ecosystem research. Instead, BALTEX will focus on the description of processes that are specifically related to the carbon/CO_2 cycling, and will aim at integrating these into biogeochemical models. This will require research concerning the:

- Parameterization of the gas exchange transfer velocity. Currently used parameterizations of the transfer velocity are only wind speed dependend. They show large discrepancies both with regard to the type of the function and the magnitude of the predicted transfer velocities.
- Input of alkalinity by river water derived from geologically different regions in the watershed area. Dissolution of calcium carbonate in rain and river water constitutes the main contribution to the Baltic Sea alkalinity and controls the storage capacity of seawater for CO_2. Changes in environmental factors such as temperature, precipitation amount/chemistry and atmospheric CO_2 concentrations may modify the alkalinity input and thus affect the total CO_2 in the Baltic Sea.
- Input of dissolved organic carbon. Organic carbon may be released from soils in the watershed area and transported by river water into the Baltic Sea. The labile fraction may be decomposed by bacteria thus adding CO_2 to the Baltic Sea and modifying the air/sea CO_2 balance.
- Decrease of the Baltic Sea alkalinity by acidic precipitation. Acidic atmospheric trace constituents are deposited to the Baltic Sea mainly by precipitation. The consequence is a decrease in alkalinity and a lower storage capacity for CO_2.

Moreover, BALTEX will support and extend current CO_2 measurement programmes in the Baltic Sea which provide data for the validation of model simulations, and which can be used for process parameterizations. It is intended to deploy autonomous measurement systems on platforms or commercial ships in order to obtain high resolution long-term time series. Measurements of the pCO_2 which are presently performed continuously on a cargo ship may be used for model validation.

4.5. Specific Data Needs

Environmental data are needed to describe and quantify the distribution of pollutants, components of the carbon and nutrient cycles, and selected components of the ecosystem. Although these data are partly available from the continuous monitoring programmes around the Baltic Sea, it has to be identified which data are required in which spatial and temporal resolution in order to suffice modelling requirements for validation. Remote sensing from satellites has demonstrated its potential for high resolution monitoring of the terrestrial and marine environment and provides crucial data such as sea surface temperature and ocean colour to estimate algal occurrence and concentration, as well as other parameters. Dedicated field measurements and experiments (ground truth data) must be performed to calibrate the satellite data wherever there are gaps in existing monitoring programmes.

Parameters to be investigated include sea surface temperature, roughness and colour; the production of bubbles, sea spray and white caps, water surface enlargement due to waves, the occurrence of swell, PAR (Photosynthetically Active Radiation) at the surface, PAR attenuation by phytoplankton, suspended particulate matter and Yellow Substance ("Gelbstoff"), phytoplankton concentrations (Chlorophyll *a* and the occurrence of filamentous cyanobacteria, nutrient and pollutant (trace metals and POP) concentrations, and the depth of the upper mixed layer.

Monitoring and short-term field experiments should be carried out on moving and stationary platforms to investigate the processes controlling the air-sea/land/snow exchanges of energy, nutrients, carbon and pollutants. These data sets will form the basis for flux parameterisation of other environmental substances and for model validations. Novel technologies for flux measurements of gases and particles (i.e. Relaxed Eddy Accumulation) shall be applied. Fluxes of momentum, latent and sensible heat, and quantities describing the sea state shall be measured in the marine boundary layer, together with air-sea exchanges of CO_2, gaseous and particulate nitrogen.

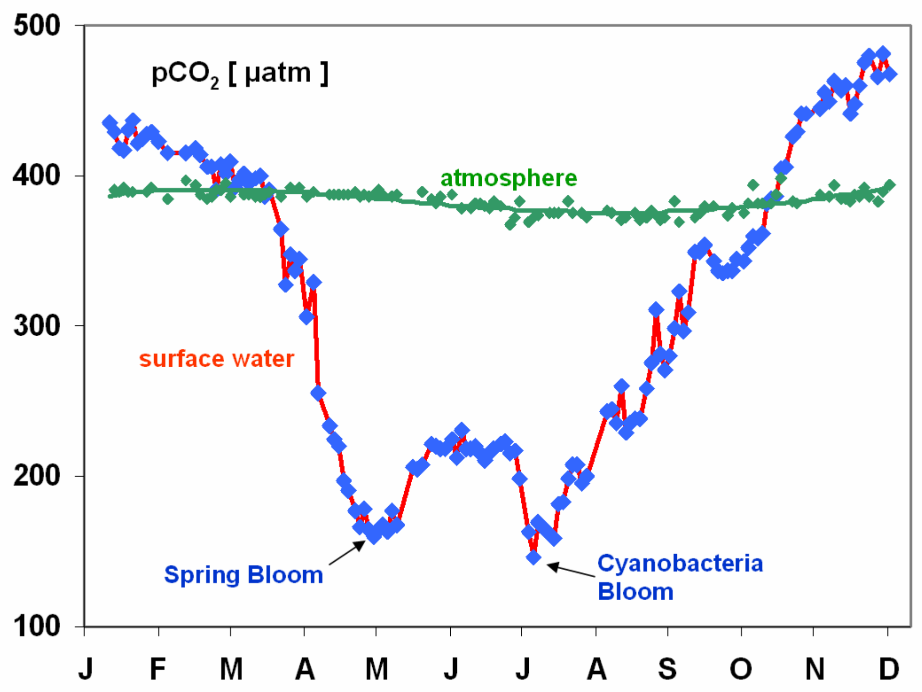

Fig. 4.4 Annual cycle of the CO_2 partial pressure (surface water and atmosphere) in the northern Gotland Sea as measured automatically on the cargo ship FINN-PARTNER in 2005 (by courtesy of Bernd Schneider, IOW).