

Tellus

The Centre of Earth Systems Science at the University of Gothenburg



**Tellus - BALTEX Workshop on
Biogeochemical Land and Baltic Sea
Interactions driven by Climate and Land Use
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Abstracts

Modelling terrestrial land cover and land use

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The Baltic Sea Basin covers an area five times larger than the Baltic Sea itself. Nutrients, organic carbon and weathering products in land runoff contribute greatly to the biogeochemical status and dynamics of the Baltic, while the discharges of individual rivers depend strongly on the vegetation and land cover of the source catchment (Mander et al. 2000; Humborg et al. 2004). Any projections of long-term changes in the Baltic Sea biogeochemistry and ecosystem, for example under global climate and atmospheric change, must therefore take account of changes in land cover and land use.

Modelling of natural vegetation patterns and dynamics has a long tradition, both at the 'global map' scale, where models relating the distributions of major world biomes (e.g. boreal conifer forest) to climate emerged in the early 1900s, and at the stand scale in forests, with models of the gap-phase dynamics established by the 1970s. Dynamic, process-based vegetation models targeted at the regional scale emerged first in the 1990s, but build on these earlier traditions. I present an overview of LPJ-GUESS (Smith et al. 2001), a regional vegetation and carbon biogeochemistry model that has been extensively validated and applied over northern Europe in a number of studies of ecosystem responses to climate forcing (e.g. Koca et al. 2006; Miller et al. 2008). Simulations suggest that 21st century climate and atmospheric [CO₂] change in the Baltic Sea area could lead to northerly shifts in the potential natural vegetation zones, upslope treeline shifts, and an increased broadleaved component in forests. Driven mainly by a sizeable proportional increase in growing season length, increased net primary production (NPP) in northerly areas could lead to enhanced leaf cover and tree density in forests. Southern Scandinavia and continental areas may, by contrast, experience small positive to negative trends in the same ecosystem parameters, as a response to deteriorating water balance (Smith et al. 2008). Whereas ecosystems appear to behave largely as carbon sinks over much of the Baltic Sea catchment area under the present climate, southerly ecosystems appear likely to turn into sources by the end of this century, a robust outcome, independent of the climate scenario assumed (Morales et al. 2007).

With the exception of a few upland and wetland areas, most of the land cover surrounding the Baltic is subject to more-or-less intensive human management. Factors such as global and regional economy, ecosystem services, energy demand and environmental policy are important for land use decisions and practices and may be expected to affect land use patterns over the coming decades. Models for describing plausible changes in land use under 'storylines' of global and regional change have been developed in recent EU projects (Schröter et al. 2005; Rounsevell et al. 2006). In combination with new agent-based modelling (ABM) techniques, such models offer an approach to this critical dimension in constraining land-sea biogeochemical coupling in future studies of the Baltic Sea system.

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The URL of the website is:

www.nateko.lu.se/lpj-guess

Baltic Sea catchment modelling

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We developed for the first time a catchment model simulating simultaneously the nutrient land-sea fluxes from all 105 major watersheds within the Baltic Sea drainage area. A consistent modelling approach to all these major watersheds, i.e., a consistent handling of water fluxes (hydrological simulations) and loading functions (emission data) will facilitate a comparison of riverine nutrient transport between Baltic Sea sub-basins that differ substantially. Hot spots of riverine emissions, such as from the rivers Vistula, Odra and Daugava or from the Danish coast, can be easily demonstrated and the comparison between these hot spots and the relatively unperturbed rivers in the northern catchments show decision makers where remedial actions are most effective to improve the environmental state of the Baltic Sea, and, secondly, what percentage reduction of riverine nutrient loads is possible. The model has been used within the formulation of the Baltic Sea action plan.

The second issue discussed are C fluxes in the Baltic Sea catchment. It has been argued that a change in climate and hydrology in high latitude regions could liberate large amounts of previously inactive OC during a prolonging thawing period, and new studies have shown that a great deal of this organic C is remineralized as CO₂ during its transport to the sea. However, it appears that the weathering regime of taiga and tundra watersheds is tightly linked to carbon-silicon interactions, in which carbon acts both as a weathering agent (soil CO₂ from degradation of OC) and as a weathering product (bicarbonate). Whereas respiration of OC can be regarded as a positive feedback to global warming, weathering can be regarded as a negative feedback to global warming since atmospheric CO₂ is converted to bicarbonate and thereby locked in the aquatic phase for geological time scales. Very likely, global warming will affect water flow through the soils in taiga and tundra ecosystems and, thus, will have an effect on watershed C budgets.

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<http://www.balticnest.org/>

Modelling the coupling between biogeochemical and physical processes in terrestrial ecosystems

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Process oriented models with descriptions of biogeochemical processes in terrestrial ecosystem have always a focus on some components and on some time scale related to the use of the model. The CoupModel will have an emphasize on the interaction between the soil physical climate and the soil biology and the corresponding above ground dynamics of plants. In connection to this the role of water for the dynamics of ecosystem is illustrated. Typical time scale for the studies have been shifting from minutes to around 100 years and the normal vertical scale is some cm of soil layer thickness. The spatial scale have been from regional scales, represented by typical ecosystems extended to 1000 km² to small scales of some few m². The role of the interaction and the need for considering also more components of an ecosystems are common when the time scales are extended from part of year to some decades. The strong control of winter conditions on turnover of forest growth is and the nitrogen and carbon dynamics is demonstrated by the carbon dynamics of forest ecosystems. Recent examples shows the potential with using uncertainty methods when illustrating also connection between models and data.

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The role of the riparian zone for determining the carbon and solute export to surface water - Examples from the Krycklan catchment

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The linkage between the terrestrial component of the watershed, the riparian interface and stream water is fundamental for our understanding of surface water ecosystems. While hydrology is the key to explaining the physical linkage between different soil compartments and surface waters, the biogeochemistry of the hydrologically-connected soils provides the basis for understanding variability in the hydrochemical signature. By combining a hydrological and biogeochemical process-understanding we can better appreciate the natural variability in stream water quality. This understanding will also provide the basis for models that deal with predicting water quality effects from land-use changes and climatic warming on downstream lakes and oceans. This in turn, can help anticipate how aquatic ecosystems are likely to respond to changes in water quality across temporal and spatial scales.

One example of where a hydrological and biogeochemical process-understanding has been successfully related to stream ecology across scales is at the interdisciplinary, multi-scale Krycklan Catchment Study in northern Sweden. This study has combined detailed soil transect investigations, synoptic sampling of 100 stream sites and 18 intensively monitored sub-catchments ranging over three orders of magnitude in size, from 3 ha to 6780 ha, since 2002. The process-understanding comes from a cocktail of solutes (pH, DOC, inorganic monomeric Al, major anions and cations, Hg and other metals) and isotopic tracers (^{18}O , D, ^{14}C , ^{13}C , ^{15}N , ^{34}S , $^{206/207/208}\text{Pb}$, ^{226}Ra , ^{230}Th , $^{234/238}\text{U}$;) that have been measured in combination with hydrometric analyses, electro-fishing surveys, fish survival experiments, studies of macroinvertebrate taxa richness and species assemblages, diatom species composition and microbial utilization of DOM. In this presentation and in the references below (an others from Krycklan) I will provide a few examples of how this linkage functions.

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Phosphorus transport from terrestrial to limnic ecosystems

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Phosphorus (P) losses from the agricultural land may occur as point sources, diffuse pollution or in an intermediate form. Since large agricultural areas of the Nordic and Baltic region are artificially drained this pathway is mostly important being both a diffuse source from the entire field and a point source at the outlet of the drain system to the watercourse. The factors with the greatest impact on P transport from agricultural land are the hydrology of the site and intrinsic characteristics of the soil: soil physics and chemistry of the entire soil profile down to drainage depth. Transport of P from agricultural soil to the drain tile system may occur by channel (macropore) flow through the soil profile but local transport by more shallow water flows may also be intense.

Beside hydrology and soil chemical and physical processes a range of other processes are involved in P turnover and mobilisation. A characteristic of P losses from catchment areas is that 90% of losses can occur from 10% of the area and during 1% of the time, which have a strong impact on any prevention strategies introduced to mitigate the P loss. Manure, mineral fertilisers, soil, crop, crop residues and weeds are all potential sources for the water transport. The very mobilisation also occurs in several ways. Most P loss from agriculture is generally considered to be as particulate P but dissolved P can nonetheless make up 9-93%. Surface erosion can contribute to 10-88% and subsurface drainage to 12-90% of agricultural P losses. There is a complex and usually only indirect relationship between fertilization and P transport to water and consequently direct relationships may rarely be found and only in episodic events. At the present low or even negative P soil balance in Nordic and Baltic areas any relationship between balance and P transport may hardly be found at least in a short-time perspective.

A very complex database is needed for P modeling. Important parameters are i.e. fertilizer/manure addition, cattle management, crop, soil tillage, drain tiles (including their function) and soil management.

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SITE AND CATCHMENT MODELLING OF PHOSPHORUS TRANSPORT IN TERRESTRIAL ECOSYSTEMS

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Generally, phosphorus (P) load models work on a singular field plot scale or alternatively at catchment scale. In Finland, the observed plot scale erosion and P data is scarce and traditionally it has been used to compare different cultivation practices. Due to the lack of data, the plot scale modelling (e.g. ICECREAM) is highly needed and it is a useful approach in order to develop the field plot modelling concept to better correspond the prevailing natural processes.

Tools are also needed to assess loading from agricultural sources to water bodies as well as the effect of alternative management options in varying environmental conditions at catchment scale. For this, mathematical models like SWAT offer an attractive option. In addition to loading estimates, SWAT also offers a possibility to include various agricultural management practices like fertilization, tillage practices, choice of cultivated plants, buffer strips, sedimentation ponds and constructed wetlands in the modeling set-up.

In Finland, the VIHMA assessment tool has been developed to estimate P load from agricultural land and to target mitigation measures. The VIHMA tool is based on field-scale data, but it can be scaled up to account for entire catchments. The risk of the P load is determined as a function of slope, soil type cultivation practice and P status. Using the VIHMA it is possible to estimate the present load and to assess the effect of different water protection measures.

The parameterization of the model to achieve satisfactory results in terms of flow and phosphorus dynamics is a laborious task. Achieving satisfactory fit on daily basis is quite challenging for a long calibration period with varying flow patterns. The automatic, continuous turbidity data has additionally shown that the models calibrated with manual water samples are not necessarily able to catch all relevant phosphorus processes.

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SWAT-model, www-pages: <http://www.brc.tamus.edu/swat/doc.html>

Biogeochemical C and P transformations in marine sediments

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An overview of important biogeochemical and early diagenetic processes responsible in marine sediments for the transformations and alterations particulate organic carbon and phosphorus are undergoing after deposition on the seafloor will be given. These processes result in recycling of some of this material to the overlying water, and in retention or burial of another fraction of it. Marine sediment thus acts both as a source of dissolved inorganic mineralization products, and as a sink through burial of incompletely degraded organic carbon and phosphorus. Adsorption of phosphate on metal oxides during oxic conditions will also contribute to retention of P in sediment. Factors influencing the efficiency with which marine sediments recycle and bury organic carbon and phosphorus will be discussed and pertinent examples given. Results from recent investigations in the deep NE Atlantic, Aegean Sea, Skagerrak, White Sea, Gulf of Finland, and previous ones in the Gullmar Fjord will be presented. Phosphate fluxes from sediments in the Gulf of Finland (GoF) were measured in-situ with the autonomous Gothenburg benthic lander during 2002, 2003, 2004 and 2005: Fluxes were low (on average $< 0.07 \text{ mmol P m}^{-2} \text{ d}^{-1}$) from oxic transport bottoms and high (on average about $0.7 \text{ mmol P m}^{-2} \text{ d}^{-1}$) from suboxic-anoxic accumulation bottoms. By integrating over the entire area of the GoF, the internal load of phosphate was preliminary estimated to be about 100 kton P per year. The internal P load to GoF waters is thus clearly higher than the external load from land and atmosphere.

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Recycling and removal of fixed N in marine sediments and at the oxic-anoxic interface in the Baltic Sea water column

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An overview of important biogeochemical and early diagenetic processes responsible in marine sediments for the transformations and alterations particulate organic nitrogen is undergoing after deposition on the seafloor will be given. These processes result in recycling of some of this material to the overlying water, in retention or burial of another fraction of it in sediment, and in removal of remineralised nitrogen through denitrification and anammox producing dinitrogen gas. Marine sediment thus acts both as a source of dissolved inorganic nitrogen, and as a sink of fixed nitrogen through burial and dinitrogen gas production. Factors influencing the efficiency with which marine sediments recycle and remove fixed nitrogen will be discussed and pertinent examples given. Denitrification and anammox activity at the oxic-anoxic interface in the Baltic proper water column will be presented, and a preliminary estimate of the significance of water column denitrification on a Baltic basin wide scale will be shown. Results from recent investigations in the deep NE Atlantic, Aegean Sea, Skagerrak, White Sea, Gulf of Finland, and Baltic proper will be presented.

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Modelling the Baltic Sea acid–base (pH) balance

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Introduction

Water and heat balances are at the heart of climate research and have been the main focus of BALTEX phase I. In BALTEX phase II, we are now promoting the integration of the carbon cycle into climate models, as it lies at the heart of biogeochemical modelling. Our research group (www.oceanclimate.se) is now working on fully coupled physical–biogeochemical climate models of the Baltic Sea, using these as tools with which to study the Baltic Sea CO_2 – O_2 system. This modelling includes the interaction between physical (i.e., stratification, temperature, salinity, sun penetration, and ice), chemical (i.e., alkalinity, pH, dissolved inorganic carbon, oxygen, and nutrients), and biological processes (i.e., plankton and dissolved organic carbon).

Rising atmospheric carbon dioxide levels due to human activity have been shown to reduce the ocean pH by 0.1 units and are believed likely to reduce it even more in the future – according to some recent estimates, by up to 0.4 pH units during coming 100 years (IPCC 2007). There are also suggestions that acid precipitation may increase the acidification of coastal seas, which then may lead to more severe conditions in these areas (Doney et al. 2007) in the absence of other processes damping coastal acidification.

Modelling

Biogeochemical processes are built into our Baltic Sea numerical model (PROBE-Baltic), which has been extensively explored and validated. The model is an advanced process-oriented coupled ocean-basin model, allowing the effective modelling of fully coupled physical–biogeochemical processes. The modelling system is fully described in a number of papers and coarse material, see references below.

Great effort has been put into the development of forcing functions, and we have now generated realistic forcing under both pre-industrial (AD 1500–1750) and industrial era (AD 1750–present) climatic conditions. These forcing data, together with nutrient load data, are used for multi-century model runs in which we assume that eutrophication starts at 1950.

Outlook

From a modelling viewpoint, it is interesting that the partial pressure of CO_2 in water is dependent on several physical, chemical, and biological processes, often in a strongly non-linear way. The modelling thus creates many challenges and will be central to the development of Earth System Models in BALTEX phase II.

The present model system captures major physical–chemical and biological response patterns, evaluated based on observations from the central Baltic Sea, with interesting implications for the coupling between climate change, eutrophication, and the acid–base (pH) balance. In our work, however, we have not yet considered acid precipitation, changes in land use, or future possible projections, nor have we considered the carbon chemistry of anoxic waters. These matters will be addressed in the upcoming BONUS Baltic-C research, which will also examine air–sea exchange processes as well as river and ocean inputs of organic and inorganic carbon, total alkalinity, and nutrients.

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Processes determining Air–Sea exchange of CO₂ in the Baltic Sea

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The exchange of CO₂ between the atmosphere and the ocean is driven by the product of the difference in partial pressure over the air-sea interface and the transfer velocity. The atmosphere pCO₂ is relatively constant, while the surface ocean pCO₂ varies significantly through a number of processes. The solubility of all gases is strongly temperature dependent with increasing solubility with decreasing temperature. Hence winter waters in equilibrium with the atmosphere have much higher concentration of CO₂ than summer waters. One affect of this is that when a winter water warms up in the spring its pCO₂ increases an it starts to outgas. However, once the water warms up stratification builds up an primary production starts, which consumes CO₂ and compensate (at least to some degree) for the increase in pCO₂ caused by the warming. When the produced organic matter decays CO₂ is released and thus pCO₂ increases. Some organic matter decays in the water column, but in the shallow Baltic Sea most end up at the sediment surface where a large fraction is decayed. The decay products are added to the bottom waters which with time are mixed back into the surface layer. When the electron acceptor is oxygen during organic matter decay the original chemical composition is re-established. Hence, when such a water is mixed up to the surface both nutrients and CO₂ are added in the same ratio as was consumed during primary production. In the Baltic Sea with a lot of low oxygen environments other electron acceptors than oxygen is used. In extreme conditions sulphate is used and hydrogen sulphide is produced. During this process protons are consumed, increasing pH. When the sulphide containing water is mixed up it gets oxidized, but not necessary all the way to sulphate. If the end product is elementary sulphur (which has been shown to happen in high sulphide environments) more protons are consumed, further increasing pH. As a result when such a water is mixed back to contact with the atmosphere it has a higher pH and thus also a lower pCO₂ than otherwise would have been expected. Such a chain of reactions makes this system being an efficient sink of atmospheric CO₂. What we learn from this is that there is a need to consider the full system, both in space and time, in order to make correct conclusions.