NUMBER 5, OCTOBER 2011

BONUS briefing

SCIENCE FOR A BETTER FUTURE OF THE BALTIC SEA REGION

BALTIC-C
Building predicative capability regarding the Baltic Sea carbon and oxygen system

Carbon forms the basis of life on Earth. The carbon cycle – the movement of carbon between the atmosphere, land and oceans – is crucial for the health and stability of Earth's ecosystems. Carbon is carried in rivers from the continents to coastal seas (such as the Baltic Sea), and finally to the oceans (Figure 1). It connects ecosystems and human activities across an entire drainage basin. Human activities directly influence the carbon cycle, and may cause severe damage to ecosystems. Scientific knowledge, improved monitoring programmes and models to predict the behaviour of the carbon cycle are therefore strongly needed. BALTIC-C project addresses this need through extensive field expeditions, data-mining and computer modelling.

OVERVIEW

BALTIC-C aims to develop and apply a new integrated ecosystem model system to the cycling of carbon in the Baltic Sea and drainage basin. Project relies on strong interdisciplinary work of scientists from seven institutes and four countries.

OUTLINE OF KEY RESULTS

NEW OBSERVATIONS ON THE BALTIC SEA CO_2 SYSTEM

A fully automated system that measures pCO_2 – the amount of carbon dioxide in the surface water – was deployed on a cargo ship that commutes regularly between Lübeck and Helsinki. Using this high-resolution data set, the seasonal pCO_2 cycle was described in detail, allowing the biogeochemical and physical processes controlling the cycle to be identified. The data were also used to calculate the net biomass production in different regions of the Baltic Sea. Different production periods were identified and related to the availability of nutrients. The results from the BALTIC-C scientists at the Leibniz Institute for Baltic Sea Research, Warnemünde, Germany, responsible for the project's studies of the Baltic Sea CO_2 system, showed that net production continued when nitrate was exhausted after the spring bloom. This implies a source of nitrogen that has not yet been identified. The early ("cold") nitrogen fixation hypothesis has not been confirmed by biological investigations. Biological production and nitrogen fixation rates were also determined for the well-known mid-summer nitrogen fixation period. The data showed that the production was strongly enhanced at high temperatures and was not limited by availability of phosphate.

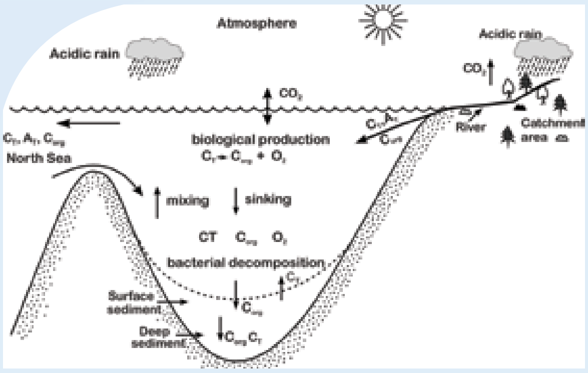

Figure 1. The Baltic Sea carbon cycle. The symbols denote: Organic carbon (C_{org}), total inorganic carbon (CT), total alkalinity (AT) and carbon dioxide (CO_2).

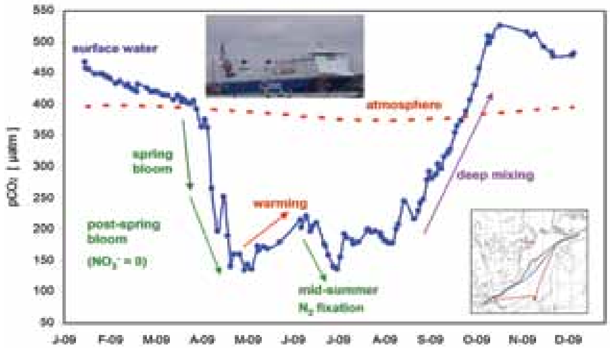

Figure 2. Seasonality of the surface water and atmospheric carbon dioxide partial pressure measured on cargo ship FinnMaid. The insets show the FinnMaid and its course between Helsinki and Lübeck.

Long-term measurements of the total carbon dioxide in the Gotland Sea performed in conjunction with the monitoring programme were complemented by two BALTIC-C research cruises. Almost complete two-year water stagnation was observed between 2004 and 2006 at depths below 150 m. This facilitated the description of processes that are linked to the microbial decomposition of organic matter. In addition to the determination of mineralization rates, mass balance calculations yielded denitrification and phosphate transformation rates during the transition from oxic to anoxic conditions. These processes are of highest importance since they affect the nutrient budgets of the Baltic Sea and thus the consequences of eutrophication and the carbon cycle.

DATABASE OF OBSERVATIONS OF CARBON AND NUTRIENT INPUTS FROM RIVERS

Scientists at the Finnish Meteorological Institute have produced a reliable dataset describing carbon and nutrient inputs to the Baltic Sea via rivers. This data is essential for assessing the relative importance of river flows in the carbon cycle, and for validating computer models. The dataset describes such characteristics of the water running into the Baltic Sea, as water flow, alkalinity, inorganic carbon, organic carbon, pH, temperature, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}. Data were collected every month during the years 1990 – 2008. The only major river for which data could not be obtained was the Neva, despite several approaches to Russian authorities.

OBSERVATIONS ON ORGANIC CARBON REFLUX AND BURIAL IN SEDIMENTS

At the Institute of Oceanology, Polish Academy of Science, Sopot, Poland, scientists have been working on interaction between water and marine sediment. The rivers entering the Baltic Sea transport organic matter at concentrations greatly exceeding that of seawater. Even more importantly, the nutrients carried in rivers fuel an intensive production of organic matter. Due to the low water depth of the Baltic Sea, most the organic matter sinks and is deposited on the sediment surface. Although most of the deposited matter mineralizes, a fraction is also transformed into dissolved compounds via lyolysis (formation of an acid and a base from the interaction of a salt with a solvent). These dissolved compounds accumulate in pore water in the sediments, and diffuse back into the overlying sea water. This reflux of dissolved organic carbon, from sediments back into the Baltic Sea, has been quantified for the first time.

Burial of organic carbon in sediments is another import term in the carbon budget. To estimate burial rates, sediment cores were collected at representative locations of the Baltic Sea during research cruises with R/V Oceania, R/V Alkor and R/V Aranda. The vertical distribution of the organic carbon content was determined with a resolution of 10 mm, which, combined with radio-isotopic dating, allowed carbon burial rates to be estimated with high precision. By extrapolating these data to the entire Baltic Sea, an overall carbon mass balance for the entire Baltic Sea was established that accounted for both the carbon burial and the reflux of dissolved organic carbon.

NEW UNDERSTANDING OF THE AIR-SEA INTERACTION AND SCENARIOS

Acid rain data, new climate scenarios for the Baltic Sea, and steps towards understanding how the air and sea exchange carbon dioxide has been studied by the scientists at the Uppsala University. They have analysed and provided to other members of the project team acid deposition data and climate scenario data that allow biogeochemical modelling of the Baltic Sea and its drainage basin. A large number of samples have been collected and analysed to understand atmospheric deposition of acidifying compounds (i.e. acid rain). Acidifying compounds increased between 1960 and 1990, and decreased after 1990. Deposition of neutralizing compounds has shown a similar decreasing trend after 1990.

A new climate database for the Baltic Sea and its drainage basin was created by combining outputs from climate model simulations and observations. Model outputs from downscaled regional climate models showed reasonably good agreement with data derived from measurements (both for mean values and variability). Even so, the model outputs were corrected to more closely match the observations, so they could be confidently used as inputs to our land- and sea-ecosystem models. Also research on air-sea interaction with improved parameterizations of the air–sea exchange of carbon dioxide is developing.

MODELLING AND SCENARIOS FOR TERRESTRIAL ORGANIC MATTER INPUT TO THE BALTIC SEA

The research group at Lund University have developed a model for production and adsorption of dissolved organic carbon (C_{org}) in wetland organic soils. Incorporating the new model within LPJ-GUESS (a process-based, dynamic vegetation-ecosystem biogeochemistry model) allowed dissolved organic carbon production rates and trends to be estimated for the entire Baltic Sea drainage basin. For forest and arable land ecosystems, a simplified model was used. The simulated production rate of C_{org} in drainage water closely follows the geographic distribution of wetlands. The model also successfully simulated the increases in C_{org} production that are inferred from increases in river concentrations in Southern Sweden over the last 30 years (Figure 3).

Fifteen scenarios – describing plausible changes in climate, emissions, anthropogenic land cover change, anthropogenic nutrient loads and other factors affecting the ecosystems in the Baltic Sea drainage basin – were explored using separate simulations with the LPJ-GUESS model. Scenarios included one or a combination of several driving factors. The analysis of the results from this suite of simulations is on-going, but the pattern emerging is of moderate (0-25%) increases in C_{org} concentrations in drainage water, mainly associated with warming, and carbon dioxide driven increase in terrestrial vegetation production, and increased precipitation-driven flushing of organic soils.

NEW MODEL AND SCENARIOS FOR RIVER INPUTS OF CO_2 AND NUTRIENTS

Scientists at Stockholm University have created the first consistent, Baltic-catchment-wide hydrological model for total carbon (CT= mineral carbon + C_{org}) and alkalinity (AT) inputs to the Baltic Sea, covering all major rivers. The model successfully simulated the magnitude and seasonal patterns of CT, AT and C_{org} fluxes to all major Baltic Sea basins. We used the model to assess the effects of i) changes in hydrology and vegetation cover related to future climate change and ii) changes in life-style, i.e. intensified agricultural practices in the transitional countries as an effect of increased protein consumption. The results indicated that hydrological changes caused by climate change (increased river flows in the northern boreal part of the catchment and decreases in the south eastern agricultural region, together with an increase in wetland and forest cover in the boreal region) could increase C_{org} transport to the Baltic Sea by some 20% (Figure 4). However, the warmer temperatures and increases in vegetation in the boreal regions could also increase weathering rates, and thus increase total carbon and alkalinity inputs by about 10%. The results for the lifestyle scenarios showed an increase in nitrogen and phosphorus river loads by 20-30%, increasing eutrophication of the Baltic Sea.

NEW MODEL FOR THE BALTIC SEA PHYSICAL–BIOGEOCHEMICAL SYSTEM AND CLIMATE CHANGE

Bringing together the results from the other BALTIC-C work packages, the scientists from the Gothenburg University have developed and validated a new physical–biogeochemical model system (based on CO_2/O_2 dynamics) for the Baltic Sea. We have used the model to explore how the acidy (pH) of the Baltic Sea might change as atmospheric carbon dioxide levels increase and river load change. Seawater pH is among the most important factors controlling life in marine systems, and acidification could severely alter and threaten marine ecosystems. The results show that, as atmospheric carbon dioxide levels increase, they will equilibrate with surface waters and pH will decrease (i.e. the sea water becomes more acidic). However, if more dissolved-limestone is delivered in river runoff (i.e. alkalinity increases), the pH may actually increase. The pH sensitivity to change in alkalinity varies throughout the Baltic Sea, having greatest impact in the north where alkalinity is the lowest . In the future, changes in the river runoff, nutrient load and river transport of carbon may counteract or amplify the acidification. A large number of possible scenarios are now under analysis, and the results will soon be available to public (Figure 5).

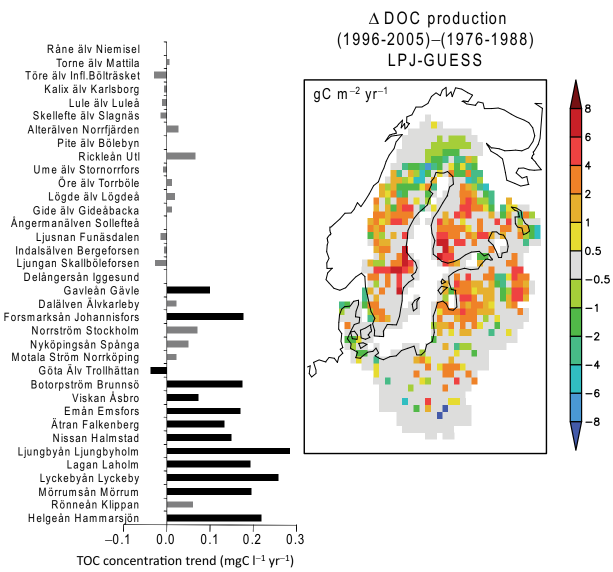

Figure 3. Observed total organic carbon concentration trends 1976-2005 for Swedish rivers, shown in order from north to south; and simulated C_{org} production trend from the LPJ-GUESS ecosystem model.

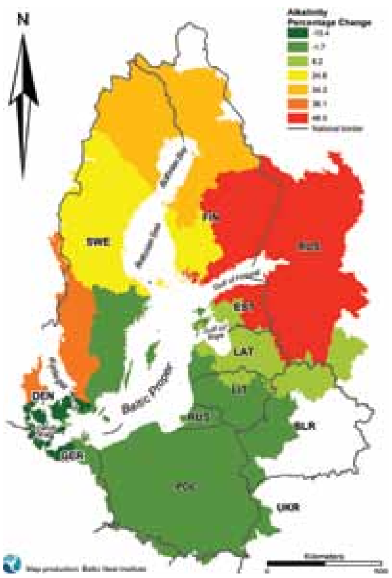

Figure 4. The map illustrates one scenario run (ECHAM1 A1B GRAS delta change). Two data periods are compared, 1995-2000 and 2090-2095, using average values for both periods. The runoff is expected to increase (about 20% overall) except in Danish Sounds and Baltic Proper, where a slight decrease is expected.

NEXT STEPS AND FUTURE PLANS

The BALTIC-C work is now in a synthesising phase, with major results coming out soon. The future changes in the river runoff, nutrient load and river transport of carbon may counteract or amplify Baltic Sea acidification. It is therefore important to improve monitoring programmes for detecting changes, and improve the methods for attributing the causes of changes in the carbon cycle. From this knowledge we need to develop new Baltic Sea strategies that include climate change. Future management's ambitions need to support reduction both in nutrient loads and carbon dioxide emissions.

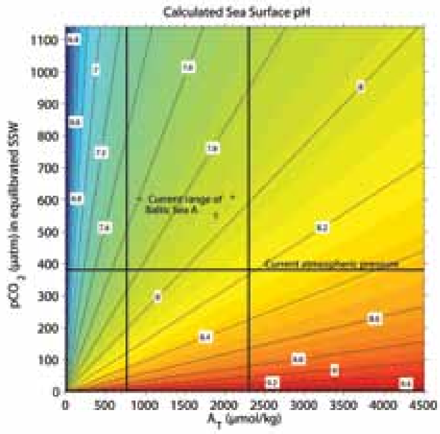

Figure 5. Change of pH with variation in water carbon dioxide pressure and AT. Salinity is kept at 8 and temperature at 0°C throughout the calculations. Indicator lines show the current status of the area with regard to AT and atmospheric carbon dioxide pressure.

IN BRIEF

BALTIC-C
Building predicative capability regarding the baltic sea carbon and oxygen system

Carbon forms the basis of life on Earth. The carbon cycle – the movement of carbon between the atmosphere, land and oceans – is crucial for the health and stability of Earth's ecosystems. The Baltic Sea carbon cycle connects ecosystems and human activities across the entire drainage basin. Scientific knowledge, improved monitoring programmes and models to predict the behaviour of the carbon cycle are in the focus of BALTIC-C project.

KEY RESULTS

BALTIC-C has developed the first integrated Baltic Basin (the sea and its catchment) model framework, addressing all major river inflows of inorganic and organic carbon, alkalinity and nutrients, atmospheric load and interaction with the North Sea.

Extensive field measurements have also been taken for example a fully automated system for the measurement of the surface water pCO_2 was deployed on a cargo ship that commutes regularly between Lübeck and Helsinki. The high temporal and spatial resolution of the data facilitated the identification of different production periods in the Baltic. Neither the post-spring bloom nor the mid-summer nitrogen fixation production were consistent with the availability of nutrients and conflicted with our present conception of the surface water productivity. Results that have strong implications on the Baltic Sea modelling.

WHO NEEDS THE INFORMATION

Eutrophication, climate change and water acidification threaten the Baltic Sea ecosystem which calls for improved management. BALTIC-C's new modeling system can support managers in addressing these threats. The information gained by Baltic-C will be communicated to HELCOM and other water authorities in the Baltic Sea region.

PROJECT PARTNERS AND COORDINATOR

Sweden
University of Gothenburg (coordinating partner)
Lund University
Uppsala University
Stockholm University

Germany
Leibniz Institute for Baltic Sea Research

Finland
Finnish Meteorological Institute

Poland
Institute of Oceanology, Polish Academy of Sciences

Project coordinator
Professor Anders Omstedt, email: anders.omstedt@gvc.gu.se

www.baltex-research.eu/baltic-c
www.bonusportal.org/baltic-c

Photos: iStock.com; Baltic-C

BONUS is supported by the national research funding institutions in the eight EU member states around the Baltic Sea and the EU Commission's Research Framework Programme

More information about BONUS:
bonus@bonuseeig.fi
www.bonusportal.org

BONUS
SCIENCE FOR A BETTER FUTURE OF THE BALTIC SEA REGION