ICOS Station Utö, photo: I Willström, FMI

Status of technology and measurements in the Baltic Sea

The measurable variable most directly linked to acidification is definitely the pH. Our efforts to develop a respective indicator for the Baltic Sea therefore focuses on this variable. Efforts are currently underway within HELCOM´s intersessional network on eutrophication (IN-Eutrophication) to establish such an indicator. Until now, pH measurements were not suitable to monitor long-term trends. Recently, a highly precise measurement procedure and instrument has been developed within the project BONUS PINBAL, and its use for monitoring purposes was demonstrated within BONUS INTEGRAL. Thus, the technology is now in place.

Alkalinity measurements with very high precision have been regularly performed by SMHI for 30 years, ever since the introduction of the reference materials that form the basis to depict long-term trends (Fig. 1). Continuing this in a multinational effort is a key to understand and predict trends of important Baltic Sea ecosystem functioning, such as resilience against acidification or uptake of atmospheric CO_2.

Key messages

The results of BONUS Integral demonstrate that carbon variables are of highly valuable information and have the potential to strongly improve the HELCOM environmental monitoring with respect to eutrophication indicators. Carbon variables are mandatory

- to trace acidification,
- to recognize trends in productivity,
- to get a better linkage to oxygen demand.

Besides, there are advantages in terms of practicality and cost-efficiency:

- the technology is ready for operation,
- it can easily be incorporated into regular monitoring cruises without additional ship time,
- the sampling and measuring guidelines are already concluded and available,
- surface pCO_2 measurements are maintained within the ICOS RI with added values but without additional costs for ecosystem monitoring.

We therefore recommend

- to include these variables into the HELCOM sampling scheme,
- to make use of ICOS pCO_2 data in the regular HELCOM assessments,
- to acknowledge the importance of ferry box systems and SOOPs,
- to strengthen the Baltic ocean branch of ICOS,
- to support the development of an operational carbon net production assessment.

BONUS Integral: Integrated carbon and trace gas monitoring for the Baltic Sea

Duration: 01.07.2017 – 30.09.2020
Coordinator: Leibniz Institute for Baltic Sea Resarch Warnemünde (IOW)
Consortium: Finnish Meteorological Institute, Helmholtz Centre for Ocean Research Kiel, Institute of Oceanology of the Polish Academy of Sciences, Leibniz Institute for Baltic Sea Research Warnemünde, Swedish Meteorological and Hydrological Institute, Tallinn University of Technology, University of Exeter, University of Uppsala
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ICOS Integrated Carbon Observation System — *https://www.icos-cp.eu*

BONUS INTEGRAL — *https://www.io-warnemuende.de/integral-home.html*

BONUS Science for a better future of the Baltic Sea region — *https://www.bonusportal.org*

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From the BONUS project INTEGRAL:
Integrated Carbon and Trace Gas Monitoring for the Baltic Sea

POLICY BRIEF

Towards an improved Baltic Sea monitoring of acidification and eutrophication by focussing on the carbon system

The message in brief

The temporal development of environmental issues like acidification, but also eutrophication, can be efficiently monitored by focusing on the inorganic carbon system. Smart innovative technologies facilitating a routine application and infrastructures like 'Ships of Opportunity' (SOOP) or moorings carrying these devices are already in place and operating. As part of the European Integrated Carbon Observation System Research Infrastructure (ICOS RI), they are regularly collecting respective data, which are freely available. Demonstrating the added value and promoting the state-of-the-art measurement of carbon parameters in the Baltic Sea was the core objective of BONUS INTEGRAL. It could be shown that the assessment of the ecological status of the Baltic Sea would clearly benefit from these data.

The marine carbon system

In marine and brackish water the inorganic carbon system, i.e. the different species of carbonic acid in seawater, determines the acidity (pH) of the water as well as the water's ability to buffer external pressures on the acid-base equilibrium. It can be described via four measurable parameters: seawater acidity (pH), alkalinity, total inorganic carbon content, and the partial pressure of CO_2 (the latter usually measured at the surface and determining the exchange of CO_2 between sea surface and atmosphere). Usually, it is sufficient to know two out of four of these parameters to describe the inorganic carbon system.

Pressures on the marine carbon system

The constantly rising concentration of atmospheric CO_2 is the main trigger of global warming. Oceans play a crucial role in buffering the effect as they are the most important CO_2 sink, globally. However, this precious service is directly connected with the so-called 'other CO_2 issue' – ocean acidification. In the open ocean, with its nearly constant salinity conditions, precise measurements of the pH value are already implemented since many years and confirm a tendency towards lower values, thus reflecting the expected acidification trend. In the brackish water of the Baltic Sea, however, a high variability in salinity and in the chemical composition of river runoff hampered the tracing of long-term acidification trends. Most recently, it was shown that over the last three decades, the buffer capacity of the Baltic has risen, and thus, partly compensated the potential effect of ocean acidification (Fig. 1). On the other hand, the current and expected future warming of the Baltic Sea forces the sea towards more acidic conditions, and an ongoing eutrophication increases the seasonal range of pH and biological uptake and mineralization.

SOOP Finnmaid, photo: Finnlines

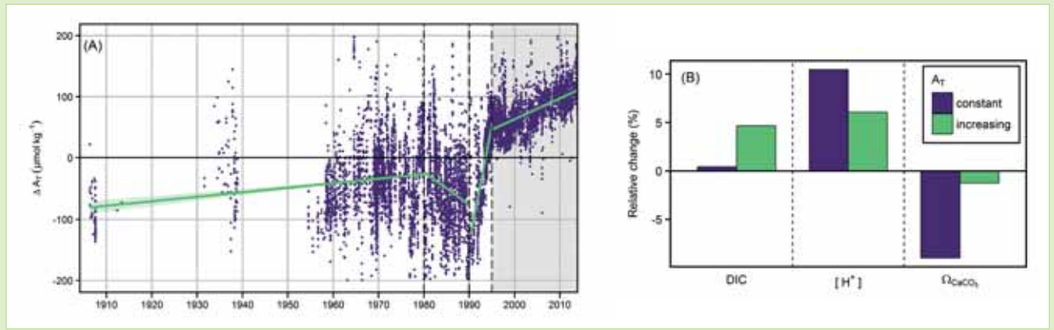

Fig. 1: (A) Data base and trend analysis for (salinity normalized) alkalinity in the Central Baltic Sea. (B) Trends of seawater properties (1995 – 2015) expected in the Central Baltic Sea from the atmospheric CO_2 rise with (green) and without (violet) taking into account the increased buffer capacity (alkalinity); effect of acidification is reduced (H+), effect on calcite saturation almost compensated (Ω), and storage potential for atmospheric CO_2 (DIC) increased (Source: J. D. Müller, IOW, modified after Müller et al., 2016, https://doi.org/10.1002/lno.10349)

The Integrated Carbon Observation System (ICOS)

Due to their decisive role for the global climate, greenhouse gases are the subject of worldwide observation. In Europe alone, 130 measurement stations exist in 12 countries, where scientists collect data on greenhouse gas concentrations in the atmosphere as well as carbon fluxes between the atmosphere, the land surface and the oceans. They gather under the umbrella of the so called 'Integrated Carbon Observation System – ICOS', one of the European Research Infrastructures (RI). Among the Baltic Sea countries, Finland, Sweden, and Germany are already partners of the ICOS European Research Infrastructure Consortium with established infrastructure in the Baltic Sea.

Surface partial pressure of CO_2 (pCO_2)

Following the concept of 'Ships-of-Opportunity' (SOOP), the Finnish ferry Finnmaid was equipped in 2003 to continuously measure the surface pCO_2 on its regular connection between Lübeck and Helsinki. The valuable and still growing data set gained this way is a key to quantify carbon and nitrogen fixation and export during the productive period, a prerequisite to link nutrient inventory, primary production, and deep water oxygen demand. The data are also suitable to handle interannual variability and trends in productivity in a quantitative way at a spatiotemporal resolution not achievable by any other method. With SOOP Finnmaid and SOOP Tavastland being part of ICOS and the measurements on MS Silja Serenade up to ICOS standards, the major basins of the Baltic Sea are already covered year-round, without additional costs for monitoring.

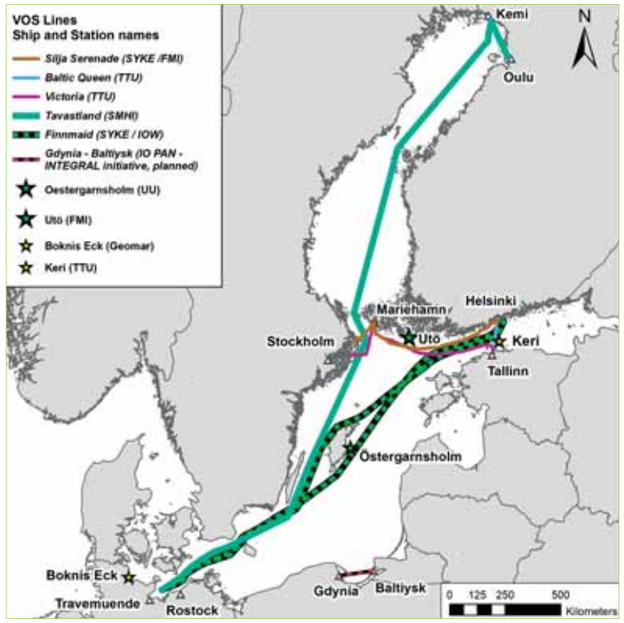

Fig. 2: The BONUS INTEGRAL 'Network', including the ICOS SOOP lines Finnmaid and Tavastland, as well as the ICOS stations Östergarnsholm and Utö. (Source: M. Glockzin, IOW)

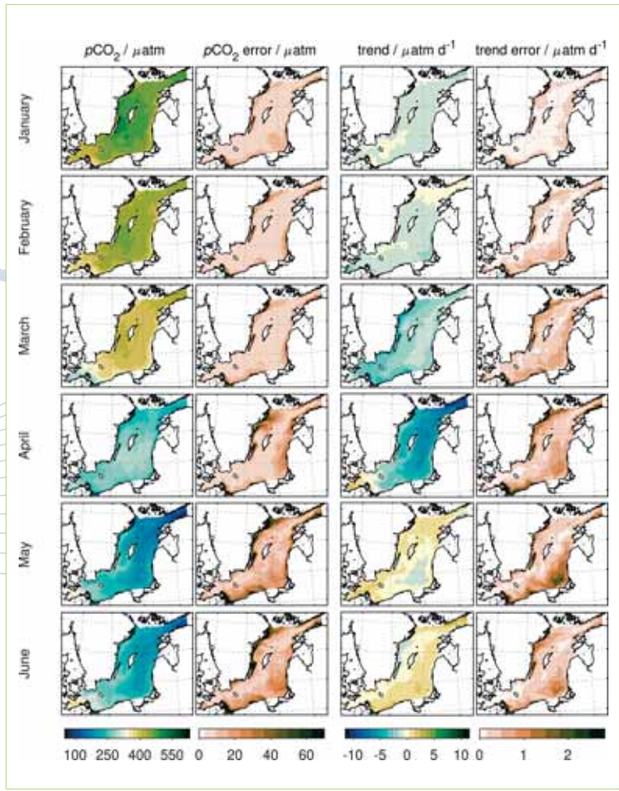

Fig. 3: Monthly climatology of surface pCO_2 (left) and surface pCO_2 trend (right), both with value and estimated error, for the months January – June. (Source: H. Bittig, IOW)

BONUS INTEGRAL

This European project integrated the different data streams of ICOS and related infrastructures in the pan-Baltic area. A main result are charts of the seasonal carbon dioxide flux over the Baltic Sea including advanced remote sensing approaches and modelling for data extrapolation. A high resolution 3D-model with the carbon system integrated was further developed allowing for a better description of the biogeochemical coupling of eutrophication and deoxygenation. Finally, we demonstrated the added value for a better description of the Baltic Sea´s biogeochemical ecosystem status. Besides, BONUS INTEGRAL supported the implementation of ICOS in the south-eastern countries of the Baltic.

Carbon – the missing link in the suite of eutrophication indicators

The current list of HELCOM eutrophication indicators include total nitrogen (N) and phosphorus (P) as well as winter inorganic N and P inventories, chlorophyll *a* and water clarity, the cyanobacterial bloom index, deep-water oxygen debt and the state of the soft-bottom macrofauna. For the assessment of the 'pressure' to the system, only the N- and P-loads are considered. This implies that N- and P-availability governs the intensity of primary production (CO_2 fixation) and carbon export, the latter leading to oxygen consumption in the deep waters, which ultimately impacts the benthic habitats. Recent studies indicate that in the Baltic Sea the assumed close link between the amount of carbon transported downwards and the nutrients N and P is by far not as robust as in the open ocean (varying C/N/P ratios). Thus, linking primary production based indicators to indicators addressing the state of deoxygenation in deep and coastal Baltic waters requires the monitoring and modelling of the amount of carbon incorporated into biomass. This is what carbon system parameters can provide.