High-resolution pCO₂ measurements on a cargo ship in the Baltic Sea: Patterns and trends derived from a synoptic look at 13 years of observations

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Motivation
• Characterize the production and mineralization of organic matter, which is inevitably coupled to CO₂ uptake and release: 106 CO₂ + 16 H₂O + 4NO₃⁻ + 122 HPO₄²⁻ + 18 H⁺
• Detect long-term trends, e.g., euphotic status or rising pCO₂ levels due to anthropogenic emissions

Our tool box
Surface water pCO₂ measurements:
• VOS Finnmaid
• ~1600 transects since 2003
• Mainly on Route „E“

Surface water pCO₂ patterns
• Highest pCO₂ levels in winter, lowest in summer clearly indicate biological control
• pCO₂ amplitudes are more pronounced towards the north-east, due to higher nutrient supply and a more pronounced thermal stratification separating the processes of production and mineralization

Surface water pCO₂ trends
• pCO₂ increased (2008-2016) consistently at a rate of 4.6-6.4 µatm yr⁻¹ in all subareas
• This rate is higher than the global atm. trend ~2 µatm yr⁻¹, which is also reflected in open ocean surface waters [1,2]
• Possible reasons: natural variability, temperature increase, mixing of CO₂ accumulated in deep waters (Fig. 6) into the surface

Deep water CO₂ accumulation
• Mineralization of organic matter in the Golland deep causes accumulation of CO₂ during stagnation periods (2003-2014, and Major Baltic Inflow 2014)
• Mineralization takes place at the sediment interface
• Accumulation of CO₂, and mixing across halocline might impact surface water pCO₂ trends

Conclusion & Outlook
• Observations of the CO₂ system are an ideal tool to determine biogeochemical processes
• Processes in surface and deep waters occur on different time scales (seasonal vs. Inflow-related), but are clearly linked
• Simulations of the CO₂ system with biogeochemical models can be validated by our observations and help to extrapolate our findings to basin-wide estimates, as envisaged in the proposed BONUS project INTEGRAL

Acknowledgements:
Regarding the work on the cargo ship, we are much obliged to the Finnish Environmental Institute (SYKE) for their generous cooperation.

References:
[1] Feely et al. (2009)

This work was supported by the BONUS PINAL project.

https://www.leibniz-institut.de/jens-mueller-publications.html

Fig. 1: Surface water pCO₂ in the Baltic Sea as a function of time and latitude. The range of the color scale was restricted to 100-600 µatm in order to obtain a reasonable resolution of the pCO₂, seasonality. The gridlines represent yearly mean values and are averaged over 1°C in latitude.

Fig. 2: VOS Finnmaid is equipped with an automated pCO₂ measurement system that enables measurement throughout the entire Baltic Sea with a high temporal (1 day) and spatial (0.003 rad) resolution, even in heavy weather.

Fig. 3: Temperature at the starting date is indicated by the color scale. The vertical lines represent the mean starting dates for 2004-2015 and grey areas indicate the standard deviations of the starting dates.

Fig. 4: Starting date of the spring bloom for the individual years and subareas (Fig. 5). The sea surface temperatures at the starting date is indicated by the color scale. The vertical lines represent the mean starting dates for 2004-2015 and grey areas indicate the standard deviations of the starting dates.

Fig. 5: Time series for the seven sub-areas defined in Fig. 2. The solid black line represents a linear regression analysis for the period post-2003 (based on daily interpolated data). Values below 50 µatm and above 650 µatm are not shown but interpolated data. Values below 50 µatm and above 650 µatm are not shown but included in the regression analysis.

Fig. 6: Time series of the depth distribution of total CO₂, C, during a stagnation period in the eastern Gotland Basin. White and black dots indicate occurrence of oxygen and hydrogen sulfide, respectively.

Fig. 7: Map showing Finnmaid routes east (E) and west (W) of Gotland, and via Gydnia (G). Seven sub-transects were defined: VOS – Vashinglund-Bottger, ARB – Altona-See, BGS – Western Gotland Sea, EGS – Eastern Gotland Sea, NGS – Northern Gotland Sea, WGS – Western Gulf of Finland and HG2 – Gulf of Finland, approach to Helsinki. By15 is a standard monitoring station in the central Gotland Sea.