High-resolution pCO_2 measurements on a cargo ship in the Baltic Sea: Patterns and trends derived from a synoptic look at 13 years of observations

Jens Müller & Bernd Schneider

Leibniz-Institute for Baltic Sea Research (IOW), Warnemünde, Germany

Motivation

- Characterize the production and mineralization of organic matter, which is inevitably coupled to CO_2 uptake and release:

$$106\, CO_2 + 16\, NO_3^- + HPO_4^{2-} + 122\, H_2O + 18\, H^+$$

Mineralization $\uparrow\downarrow$ Production

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138\, O_2$$

- Detect long-term trends, e.g., eutrophication status or rising pCO_2 levels due to anthropogenic emissions

Our tool box

Fig. 1: Voluntary observing ship *VOS Finnmaid* is equipped with an automated pCO_2 measurement system that enables measurement throughout the entire Baltic Proper with a high temporal (1-2 days) and spatial (1-2 nm) resolution, even in heavy weathers.

Surface water pCO_2 measurements:

- VOS Finnmaid
- ~1600 transects since 2003
- Mainly on Route „E“

Complemented by deep water total CO_2 measurements:

- Monthly observations at BY15
- Depth range: 100–233 m
- Vertical resolution: 25m

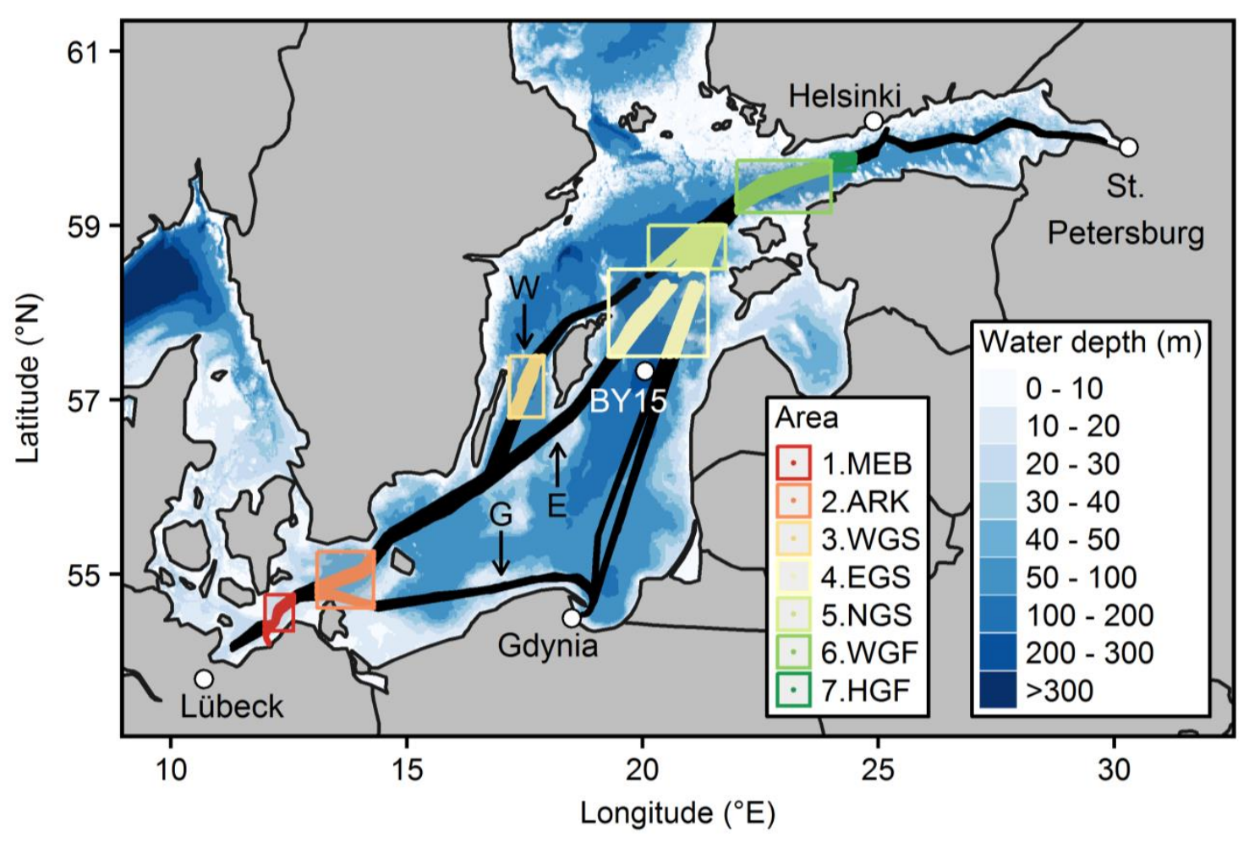


Fig. 2: Map showing Finnmaid routes east (E) and west (W) of Gotland, and via Gydnia (G). Seven sub-transects were defined: MEB – Mecklenburg Bight, ARK – Arkona Sea, WGS – Western Gotland Sea, EGS – Eastern Gotland Sea, NGS – Northern Gotland Sea, WGF – Western Gulf of Finland and HGF – Gulf of Finland, approach to Helsinki. BY15 is a standard monitoring station in the central Gotland Sea.

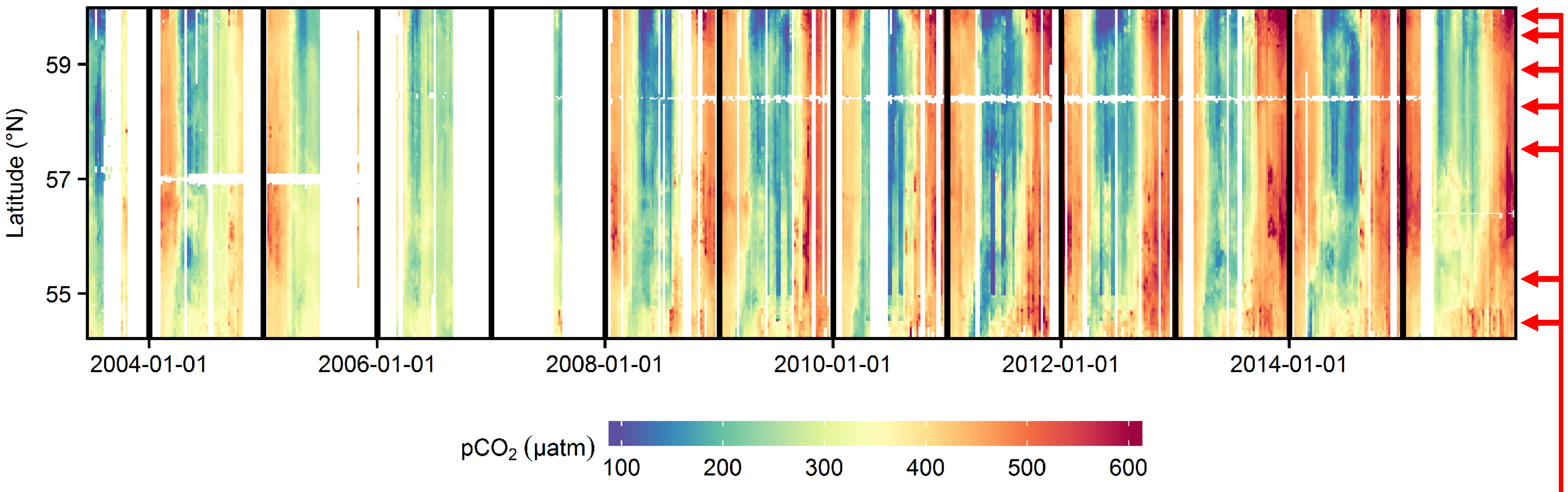


Fig. 3: Surface water pCO_2 in the Baltic Sea as a function of time and latitude. The range of the color scale was restricted to 100-600 µatm in order to obtain a reasonable resolution of the pCO_2 seasonality. The gridded data represent weekly mean values and are averaged over 0.02° in latitude.

Surface water pCO_2 patterns

- Highest pCO_2 levels in winter, lowest in summer clearly indicate biological control
- pCO_2 amplitudes are more pronounced towards the north-east, due to higher nutrient supply and a more pronounced thermal stratification seperating the processes of production and mineralization

Start of the spring bloom

The spring bloom started in:

- the end of march in the areas north of EGS; with low interannual variability (SD: 2-3 days)
- early and mid march for southern study areas MEB and ARK, respectively; with high interannual variability

The start of the spring bloom is independend on the sea surface temperature

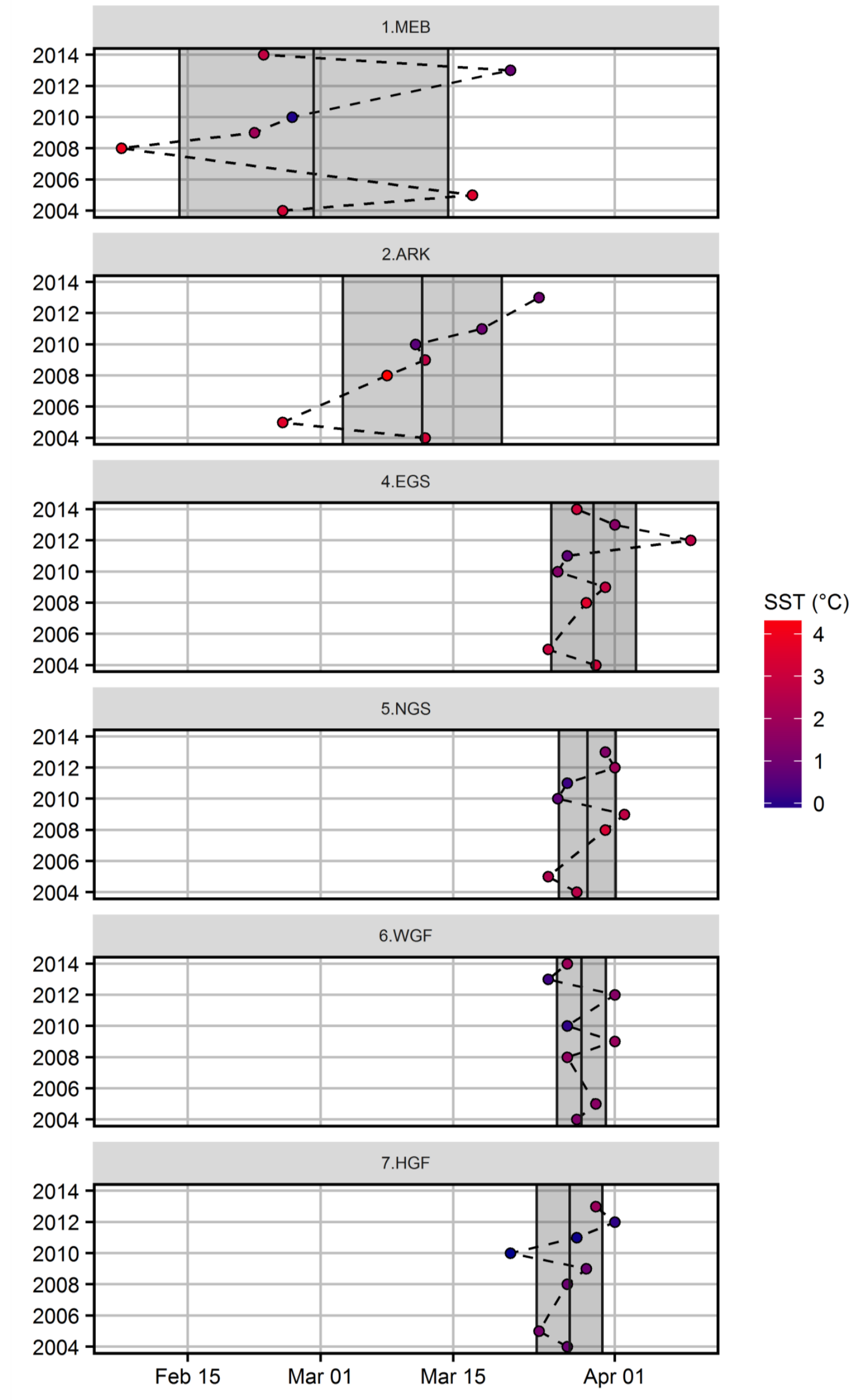
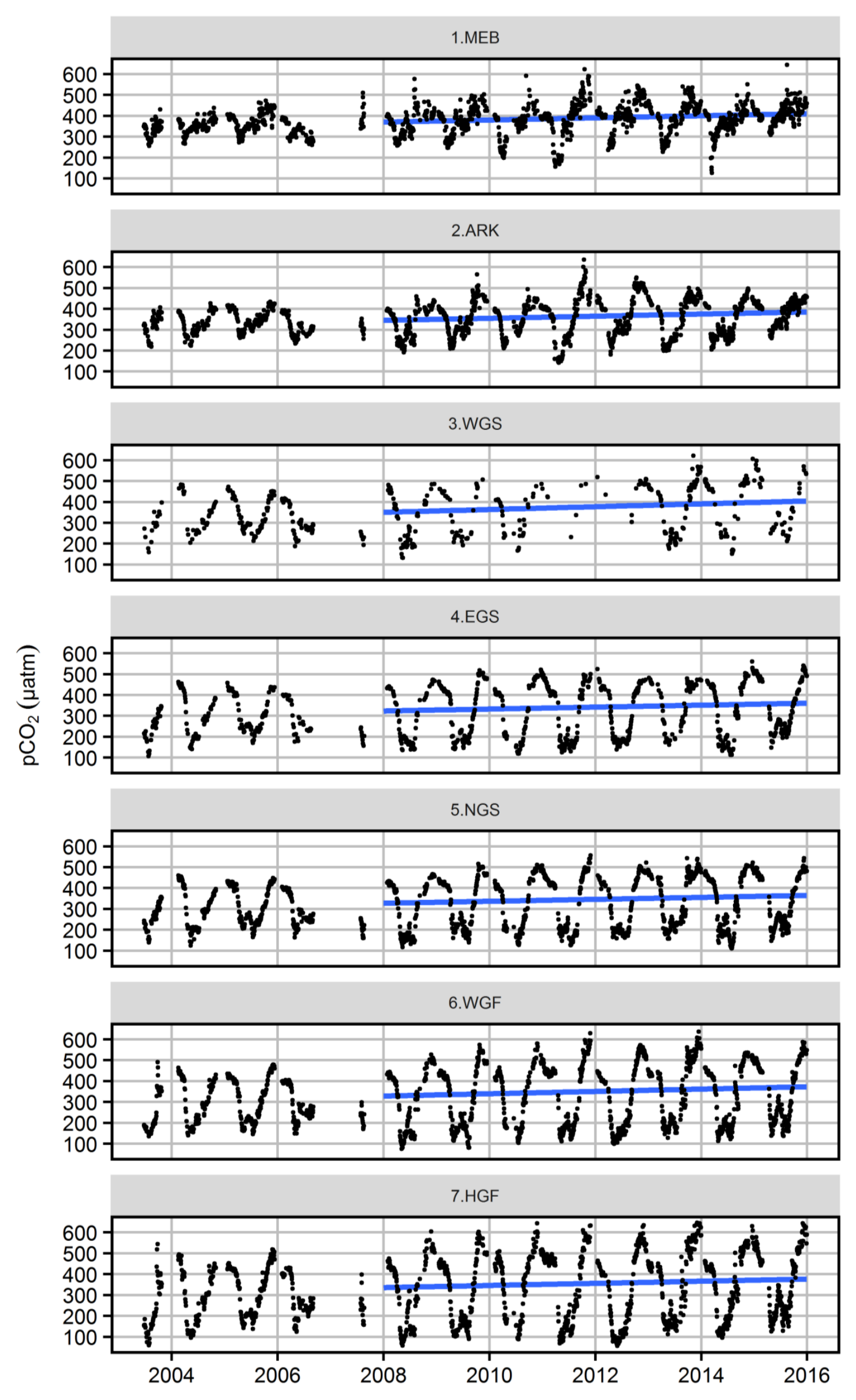


Fig. 4: Starting date of the spring bloom for the individual years and subareas (Fig. 2). The sea surface temperature at the starting date is indicated by the color scale. The vertical lines represent the mean starting dates for 2004-2014 and grey areas indicate the standard deviations of the starting dates.



Surface water pCO_2 trends

- pCO_2 increased (2008-2016) consistently at a rate of 4.6-6.1 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 variablity, temperature increase, mixing of CO_2 accumulated in deep waters (Fig. 6) into the surface

Fig. 5: pCO_2 time series for the seven sub-transects defined in Fig. 2. The blue line represents a linear regression analysis for the period 2008-2015 based on daily interpolated data. Values below 50 µatm and beyond 650 µatm are not shown but included in the regression analysis.

Deep water CO_2 accumulation

- Mineralization of organic matter in the Gotland deep causes accumulation of CO_2 during stagnation periods (2003-2014, last Major Baltic Inflow 2014)
- Mineralization takes place at the sediment interface
- Accumulation of CO_2 and mixing across halocline might impact surface water pCO_2 trends

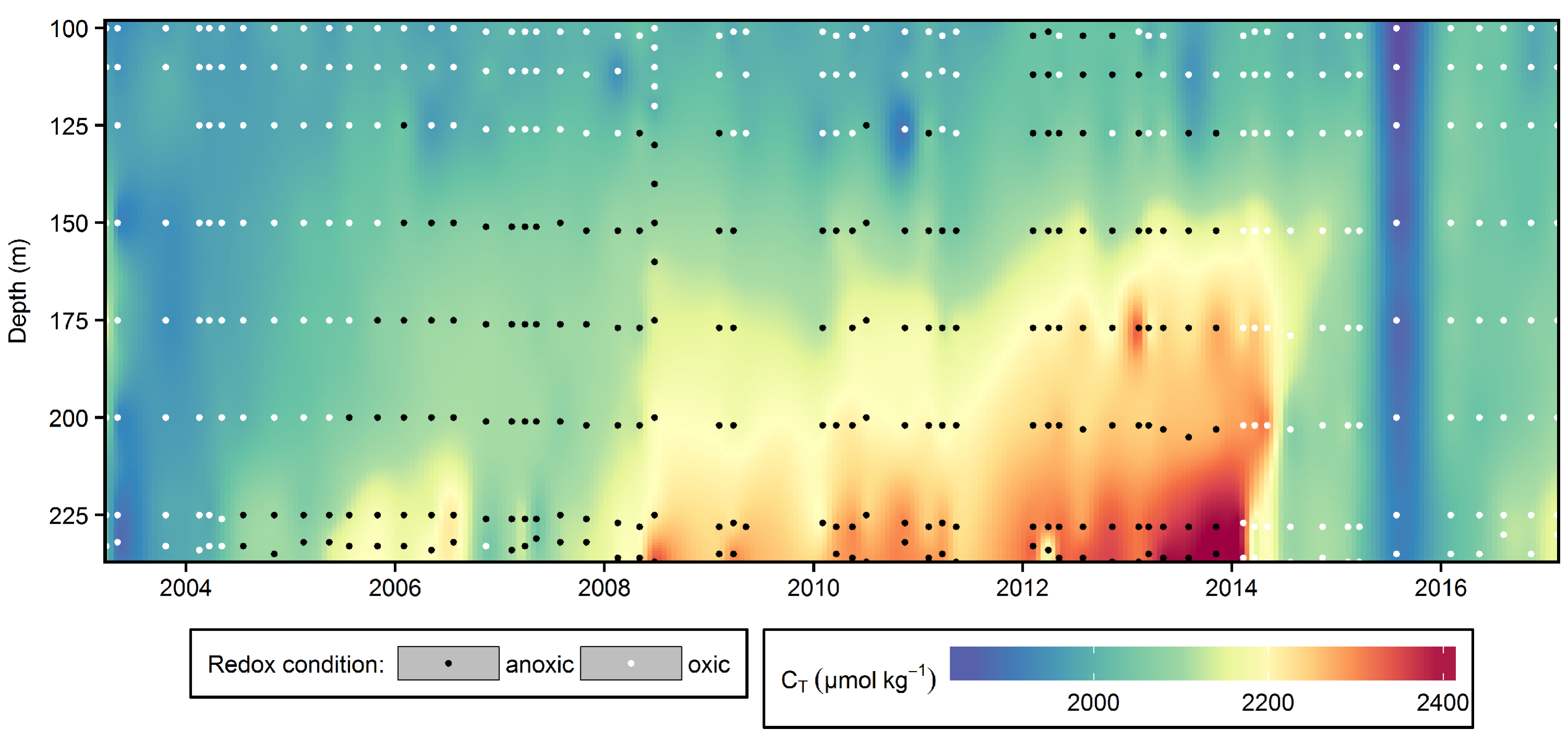


Fig. 6: Timeseries of the depth distribution of total CO_2, C_T, during a stagnation period in the eastern Gotland Basin. White and black dots indicate occurrence of oxygen and hydrogen sulfide, respectively.

Conclusion & Outlook

- Observations of the CO_2 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 CO_2 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

This work is submitted to Springer for publication as a book with the title ***“Biogeochemical transformations in the Baltic Sea: Observations through carbon dioxide glasses“***

Link to the book:

Find the poster online:

https://www.io-warnemuende.de/jens-mueller-publications.html

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References:
[1] Feely et al. (2009)
[2] Bates et al. (2012)

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