Assessing Phytoplankton Activities in the Seasonal Ice Zone of the Greenland Sea over an Annual Cycle

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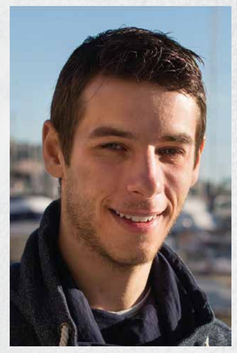

Introduction

The timing and the quantity of the phytoplankton production are already changing in the pan-Arctic area, with consequences for biogeochemical cycles and the production in higher trophic levels. The phytoplankton production occurring in the Seasonal Ice Zone (SIZ) of the Greenland Sea basin (Fig. 1), an area of the pan-Arctic system, is linked to the sea ice, which influence, for example, the light availability and the stratification of the water column. Characterizing the phytoplankton activity in the SIZ continuously over an annual cycle remains a challenge. Here, physical and biogeochemical data obtained at a five-day resolution from two BGC-Argo floats (Fig. 2), able to sample under sea ice, are analyzed. Our main objective was to quantify and understand the temporal variability of the annual cycles of phytoplankton biomass and Net Community Production (NCP) in the Greenland Sea SIZ.

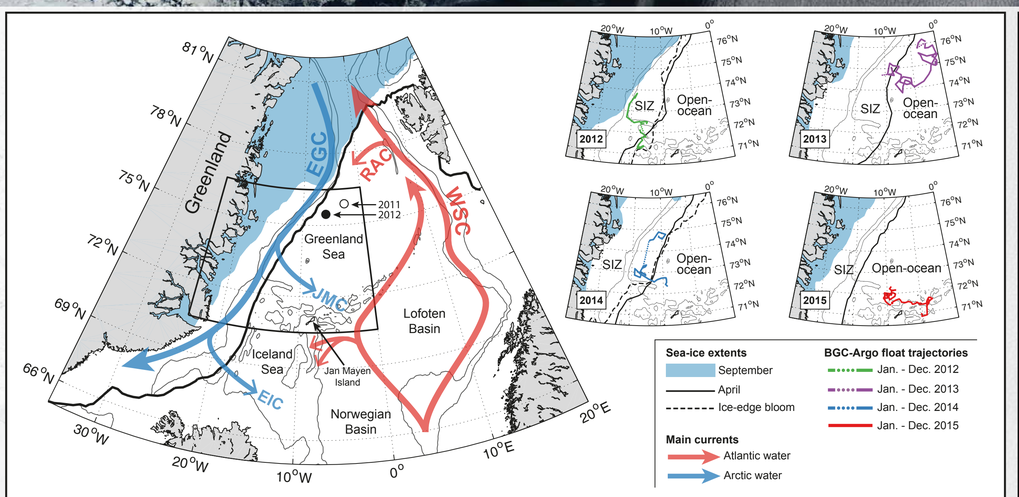

Figure 1 - Study area map with main currents, average location of sea ice cover during maximum and minimum annual extents, and BGC-Argo floats trajectories.

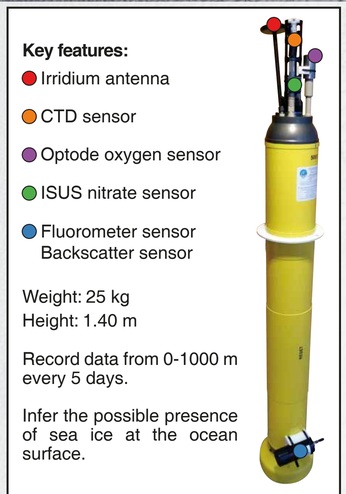

Figure 2 - A BGC-Argo float with its key features.

Pelagic Phytoplankton is Active Under-Ice

During the pre-bloom phase (see Fig. 4), the SIZ of the Greenland Sea was covered by sea ice (Fig. 3):

- Sea ice concentration averaged above 50%
- Ice avoidance algorithm of the floats was activated
- Surface water freshening likely from local sea ice melting

A clear phytoplankton biomass accumulation in the surface layer occurred (Fig. 4):

- Increases of the chlorophyll-a concentration ([Chl-a]) and of the particle backscattering (b_{bp}); 25-35% of the annually integrated phytoplankton biomass
- A decrease in nitrate concentration ([NO_3])

The onset in early-April of the phytoplankton biomass accumulation under-ice in this SIZ area is supposed related to the light availability.

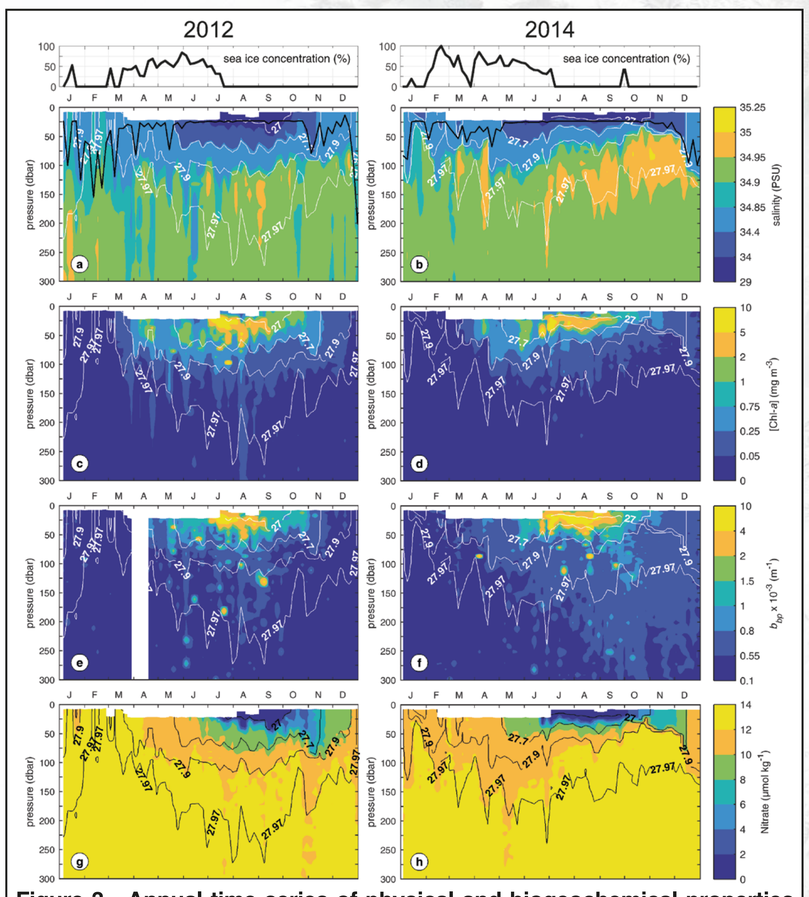

Figure 3 - Annual time series of physical and biogeochemical properties measured by BGC-Argo floats. Top panels represent the sea ice concentration from satellite passive microwave data (NSIDC/NOAA). (a-b) Salinity, (c-d) [Chl-a], (e-f) b_{bp} and (g-h) [NO_3] measured in 2012 (left panels) and 2014 (right panels); white or black isolines correspond to the potential density. (c-d) Black lines represent the Mixed Layer Depth. Missing data between the surface and 20 m were the consequence of the ice avoidance algorithm being activated.

From a Phytoplankton Ice-Edge Bloom to a Post-Bloom Subsurface Chlorophyll Maximum

In the SIZ, one of the main events during the winter-to-summer transition is the development of a phytoplankton ice-edge bloom following the ice-edge retreat. Phytoplankton blooms in 2012 and 2014 (Fig. 3-4), coincided with:

- Important sea ice concentration decreases
- Vertical profiles of [Chl-a] that displayed a Subsurface Chlorophyll Maximum (SCM) feature below 10 m (Fig. 3)

Later, after the bloom, the stable and ice-free water column prevented a vertical resupply of nitrate, that likely maintained the SCM feature throughout the post-bloom phase.

Our observations suggest that the Net Primary Production based on satellite observations might be underestimated, because in the SIZ of the Greenland Sea:

- Under-ice phytoplankton activity can occur
- Ice-edge bloom may start under more than 10 % of sea ice concentration and at a SCM
- A post-bloom SCM can be a recurring feature

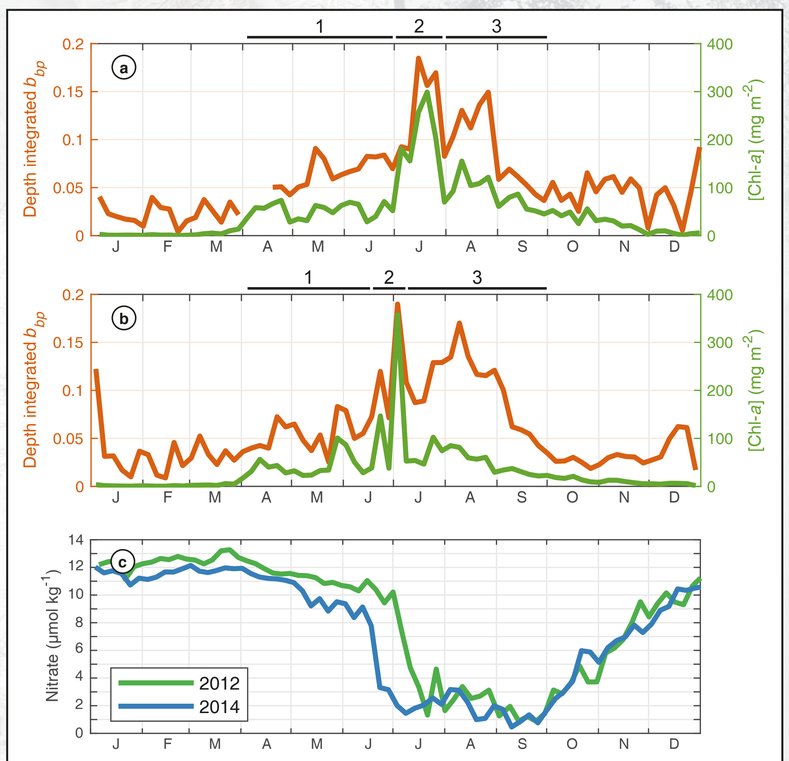

Figure 4 - Annual time series in 2012 and 2014 of surface integrated [Chl-a] and b_{bp} (a-b), and surface averaged [NO_3] (c). The surface layer is defined between 0 m and the depth where the maximal negative gradient in the vertical profile of [Chl-a] was observed. Three phases in phytoplankton activity are defined: pre-bloom (1), bloom (2) and post-bloom (3).

NCP Interannual Variability in the SIZ of the Greenland Sea

Integrated differences between mean winter and summer nitrate profiles were used to estimate annual NCP. Next, each single available summer vertical profile of [NO_3] is used to get time series of time-integrated NCP (Fig. 5),

- Annual NCP estimates are 3.2 ± 0.8 mol C m^{-2} in 2012 and 2.6 ± 0.2 mol C m^{-2} in 2013
- A deepening of the nitracline ([NO_3] = 9 µmol kg^{-1}) in August 2012 results in a 0.6 mol C m^{-2} difference in annual NCP estimated between 2012 and 2014
- The annual NCP occurred equally during the pre-bloom under-ice (52%) and ice-edge bloom (40%) phases

During the post-bloom phase, b_{bp} increased in the SIZ, but decreased in the open-ocean region. Therefore, annual estimates of phytoplankton production based on ocean color information may be biased, even when the SIZ becomes ice-free. The spatial variability of the NCP should be considered for subsequent studies on the biological carbon pump, and the ecosystem functioning in this basin.

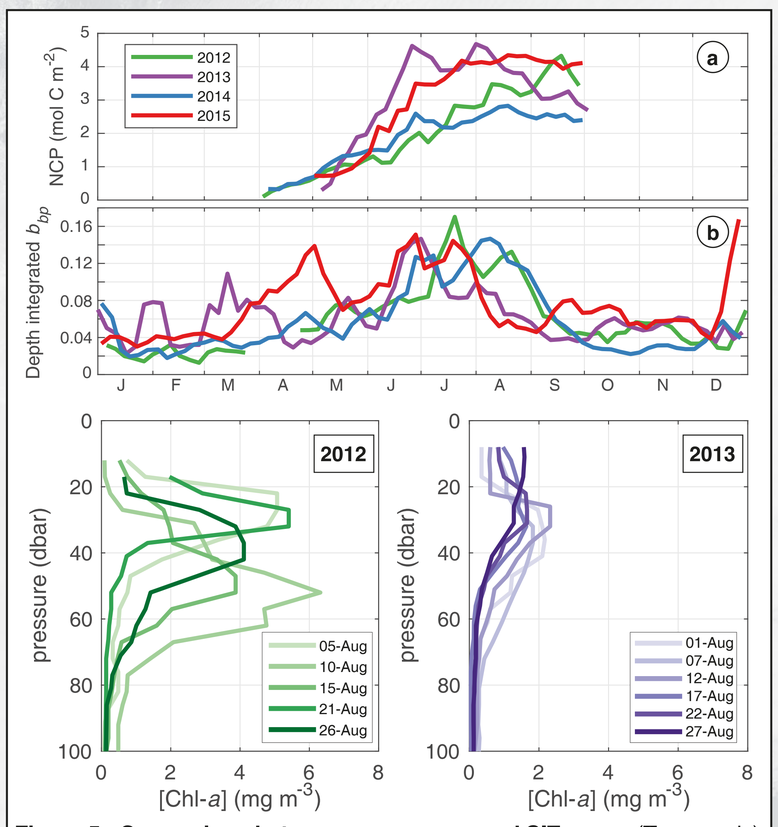

Figure 5 - Comparison between open-ocean and SIZ areas. (Top panels) Annual time series of cumulative (time-integrated) NCP (a) and surface-integrated b_{bp} (b), from 2012 to 2015. (Bottom panels) Vertical profiles of [Chl-a] measured in August 2012 (SIZ) and 2013 (open-ocean).

Acknowledgments

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