Observations of physical and ecological processes at the sea-ice edge and the meltwater front

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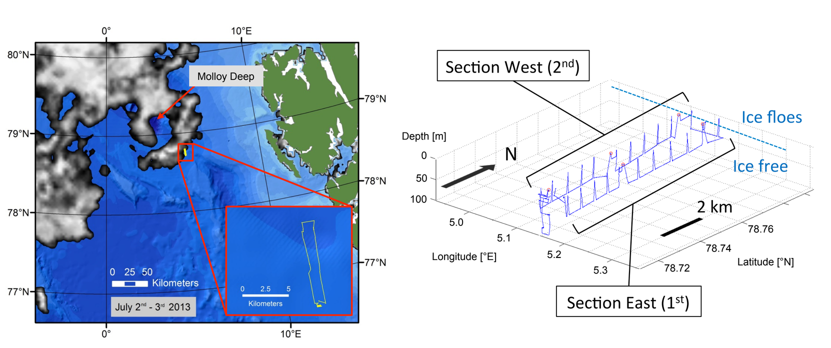
Introduction

In summer, after the spring bloom, the nutrient concentrations in the upper water column and euphotic layer in the Arctic have very low concentrations of macro nutrients, limiting phytoplankton growth. Here we investigate whether a meltwater front several kilometers away from the sea-ice edge can cause local upwelling of nutrient rich waters into the euphotic zone. Submesoscale resolving observations reveal a complex pattern including localized increases in phytoplankton stocks as measured by chlorophyll *a* concentrations.

AUV Observations

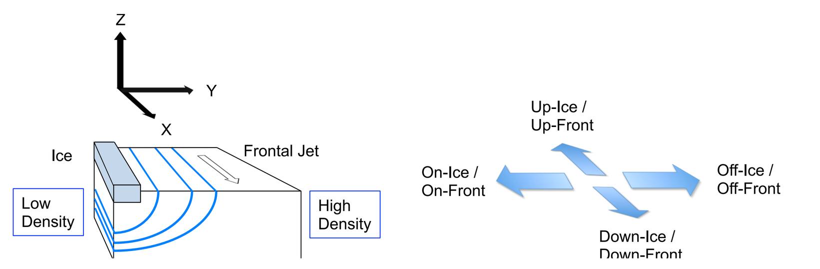


Study area and 3D rendering of the AUV track. Ice edge in Fram Strait at the entrance to the Arctic Ocean between Svalbard and Greenland.

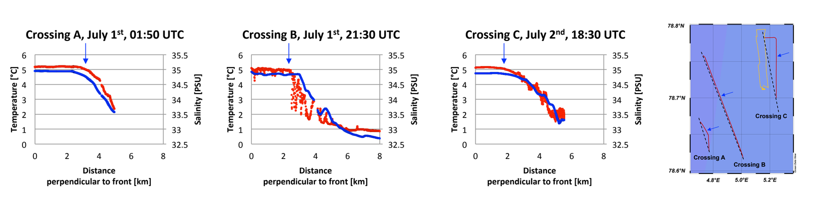
In summer 2013, an autonomous underwater vehicle (AUV) covered two cross-front sections of 9 km length each. During so-called "float maneuvers", it recorded high resolution vertical profiles of the physical and biogeochemical properties between 0 and 50 m water depth and at a horizontal station spacing of 800–1000 m (Wulff et al., 2016). The AUV was equipped with physical and biogeochemical sensors to study the complex interaction between physical processes and ecological responses along the ice edge.

The meltwater layer is so thin (≈5 m) that it is not observable from an ice capable research vessel.

Orientation of Front



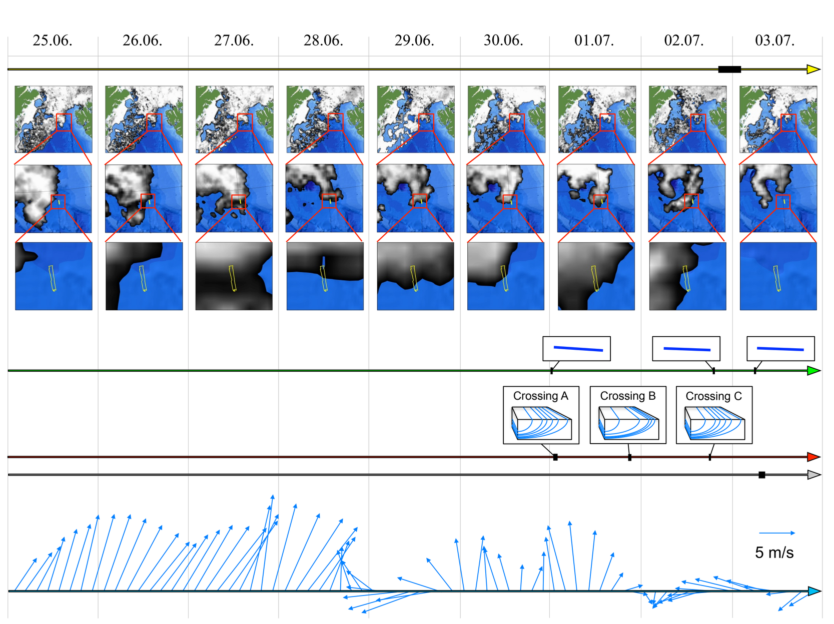
Definition of the frontal orientation and the wind directions.



Temperature (red) and salinity (blue) from the ship's thermosalinograph along three cross-front tracks.

The frontal location was mapped with these three tracks that were taken shortly before and after the AUV dive. However, they are not sufficient to establish the length scale of variability in the along front direction; specifically whether it is true that the along-front gradients are much weaker than the cross-front gradients.

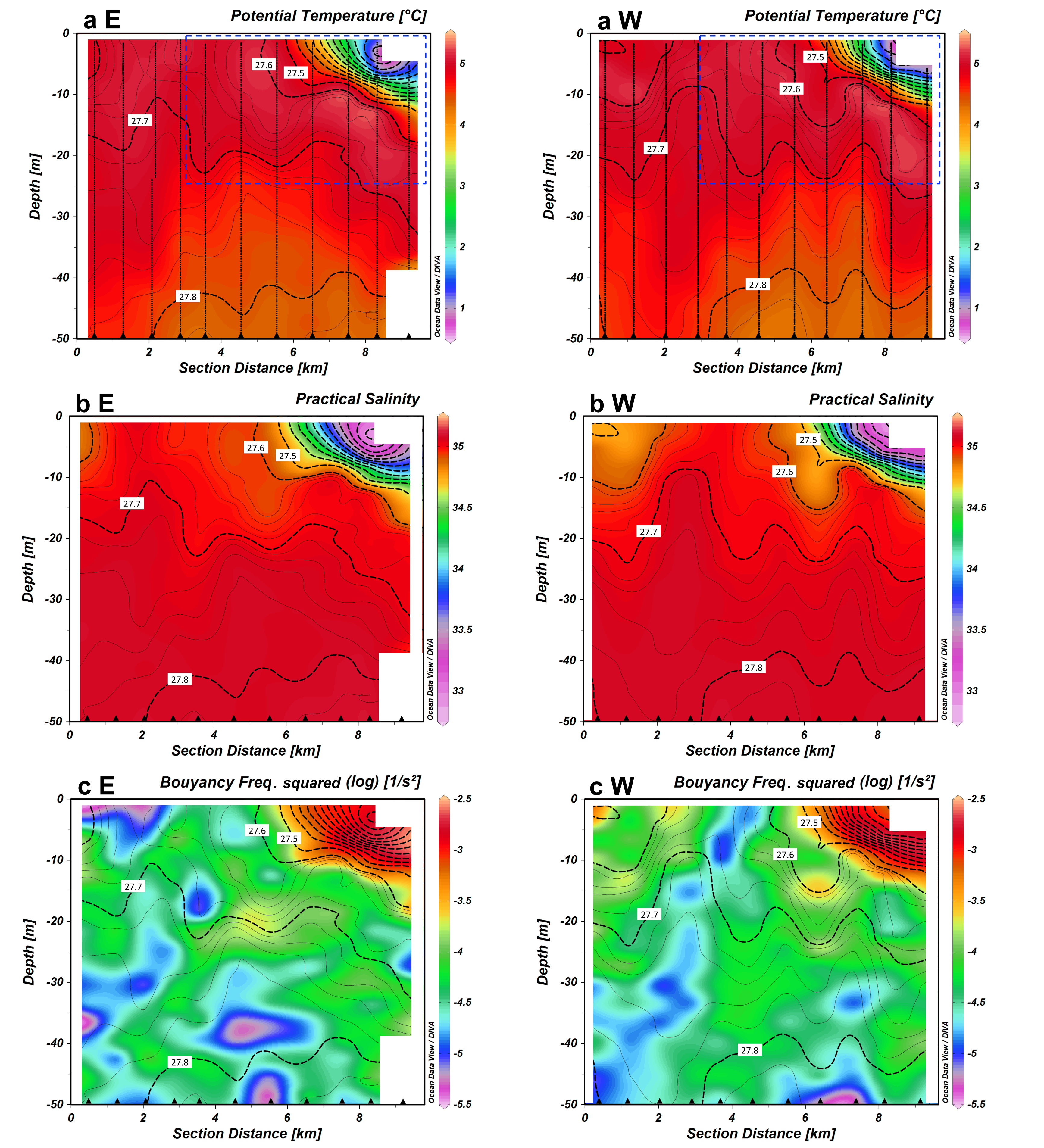
Sea-ice and Wind Forcing



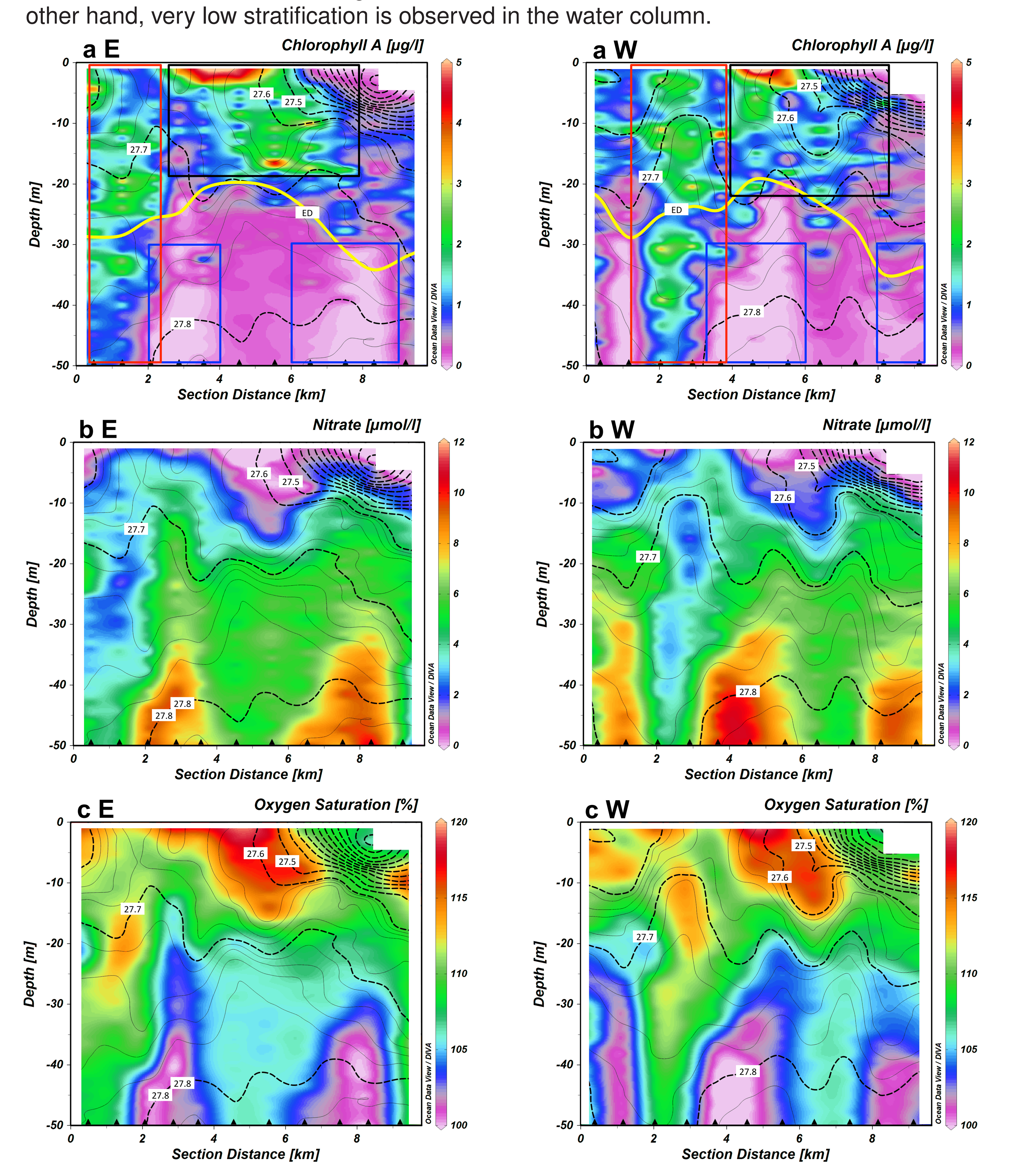
Sea-ice concentrations at successive zoom levels with dive track on July 2nd/3rd shown in yellow; frontal orientation and steepness from the ship crossings; wind speed and direction.

The atmospheric forcing and the evolution of the ice cover contributed to the complexity of the water column. Down front winds only persisted for about a day on June 29th and then in the 12 hours preceding the dives.

Physical and Biogeochemical Sections



Temperature, salinity, and stratification along the eastern (left) and western (right) AUV sections. The individual profiles are shown by the black lines in (a). The meltwater layer in the top right of the figures (northern end of the sections) is associated with lower temperatures and lower salinities as well as strong stratification. Near section distances 1 km and 5 km, on the other hand, very low stratification is observed in the water column.



Chlorophyll *a*, nitrate, and oxygen saturation along the eastern (left) and western (right) AUV sections.

Chlorophyll *a* concentrations of 5 μg l^{-1} were detected at the frontal interface in a small corridor just 2–4 km wide and only 5 m deep. The chlorophyll concentrations reached offshore of the outcropping of the front are higher than what could just have resulted from growth based on the maximum ambient nutrient concentrations. Hence, accumulation through non-tracer like behavior of the phytoplankton must have occurred. Nutrients at the surface were depleted, but still present in the euphotic zone. Below the euphotic zone, nitrate concentrations of 8 μmol l^{-1} and oxygen saturation values of 100% resulted in a "dome-like" pattern—suggestive of vertical transport processes bringing nutrients into the euphotic zone.

Interpretation

What could lead to these small scale structures in the upper water column?

The mixed layer radius estimated from the stratification in the upper 50 m is approximately 3 km, which is roughly the scale of the variability seen in the sections.

Mixed layer eddies with a full 3D structure (in which case the along-front and cross-front scale of variability would be similar) could be an explanation, but this is not resolved observationally and the two parallel sections are similar to each other. Hence, we assume that the system is uniform in the along-front direction. Then:

Hypothesis 1: Frontal intensification mechanisms from the down front winds result in ageostrophic secondary circulations, similar to the setting of Thomas and Lee (2005) and Thomas et al. (2013). The difference here is that the front is pre-existing from the meltwater and does not have to be formed in the first place from frontogenesis. But the resulting cross-front wave length of variability agrees well.

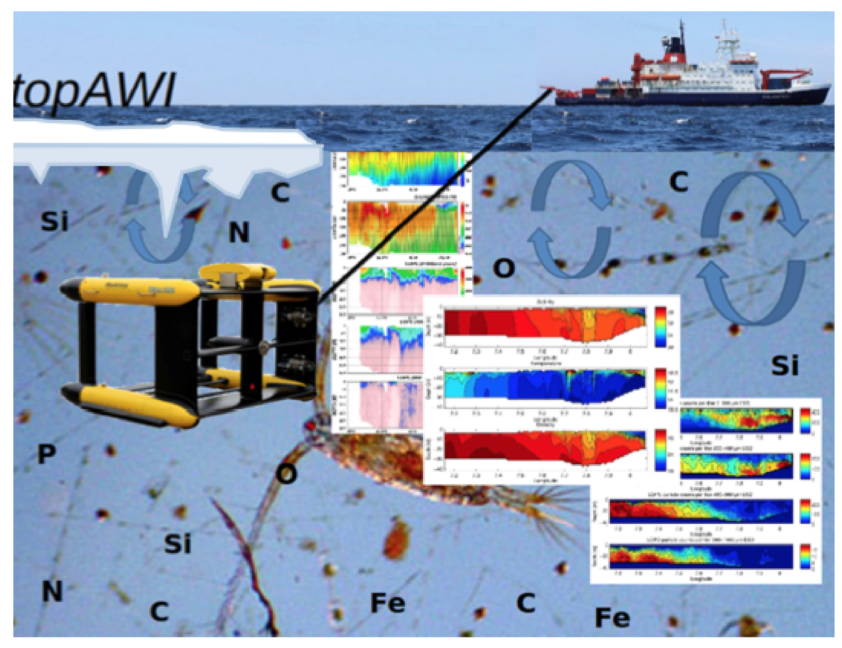
Hypothesis 2: The difference of the drag coefficient between sea-ice and open water results in Ekman convergence or divergence (e.g. Fennel and Johannessen, 1998). However, this does not explain the features away from the meltwater front (near section distance 2 km).

The most likely scenario then is:

- Along-front uniformity.
- Down front wind component.
- No frontogenesis as front is already there. But the front is intensified due to wind forcing.
- Here, the horizontal buoyancy gradient is much larger (by an order of magnitude) than what is typically observed in open ocean scenarios.

The major limitations of this study are that the 2D horizontal view is missing and that direct velocity measurements are missing which means that potential vorticity cannot be determined.

Outlook



"topAWI" is a new towed undulating system which is equipped with sensors to measure most relevant physical and biogeochemical properties in the water column, similar to the AUV. The system is towed horizontally offset outside of the ship's wake and can be used in open water as well as in light and medium sea-ice. It can profile from the surface down to 400 m.

Based on the insights from the AUV results, measurement campaigns are planned in the Arctic and Antarctic to resolve the physical and ecological processes on the submesoscale at the sea-ice edge and meltwater fronts. The surveys will be 2D in the horizontal in order to determine the relevant gradients both in the cross-front and the along-front directions. ADCP velocity measurements on the topAWI will allow the mapping of potential vorticity. The mixed layer radius is so small at high latitudes that surveys covering several mixed layer radii in both horizontal directions can be accomplished in significantly less than a day, i.e. on a synoptic time scale. Those areas will then be revisited a day to days later in order to study the submesoscale evolution.

References

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