Hydrographic Structure and Modification of Pacific Winter Water on the Chukchi Sea Shelf in Late Spring

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Introduction

The high nutrient content of Pacific-origin winter water spurs primary production in the Chukchi Sea (e.g. Hill et al., 2005). Notably, during the 2011 ICESCAPE cruise to the region, massive phytoplankton blooms were discovered underneath 1-m thick, fully consolidated sea ice. The Chlorophyll levels in the water column were some of the highest ever observed in the global ocean (Arrigo et al., 2014). Therefore, it is important to understand the physical drivers responsible for these blooms, including the circulation of winter water on the shelf . Here we analyze data from a May-June 2014 cruise that investigated the pre-, during, and post-bloom conditions.

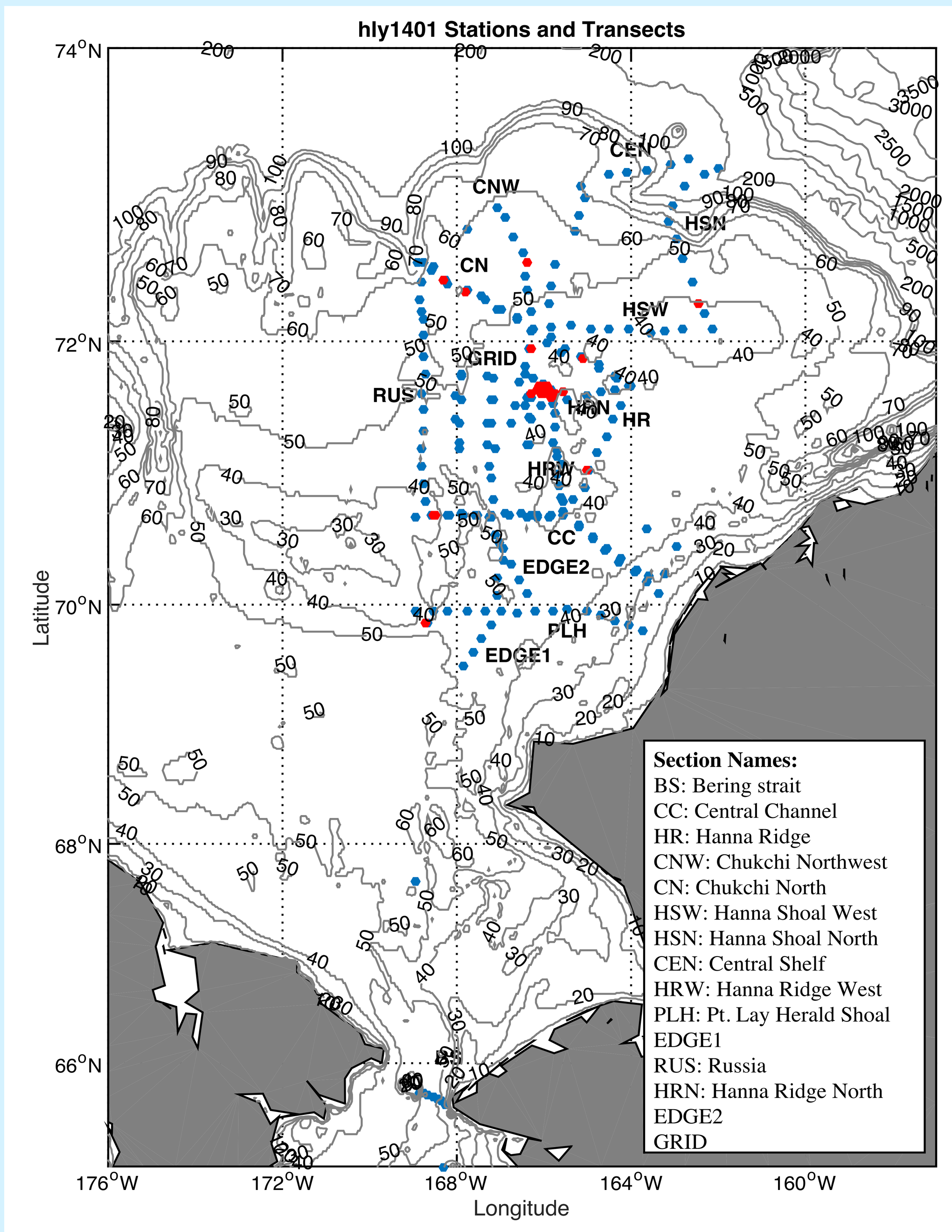

Figure 1: Map of the hydrographic stations carried out on hly1401. Blue dots represent CTD casts alone; red dots represent CTD casts performed at ice stations. The transects are listed in the legend.

Winter Water

As seen in the volumetric Temperature-Salinity plot in Figure 2, the Chukchi Sea consisted mostly of winter water during the late-spring cruise. Winter water is defined as water with temperatures colder than -1.6°C and salinity greater than 31.5. Winter water has a high nutrient content and is therefore conducive for phytoplankton growth.

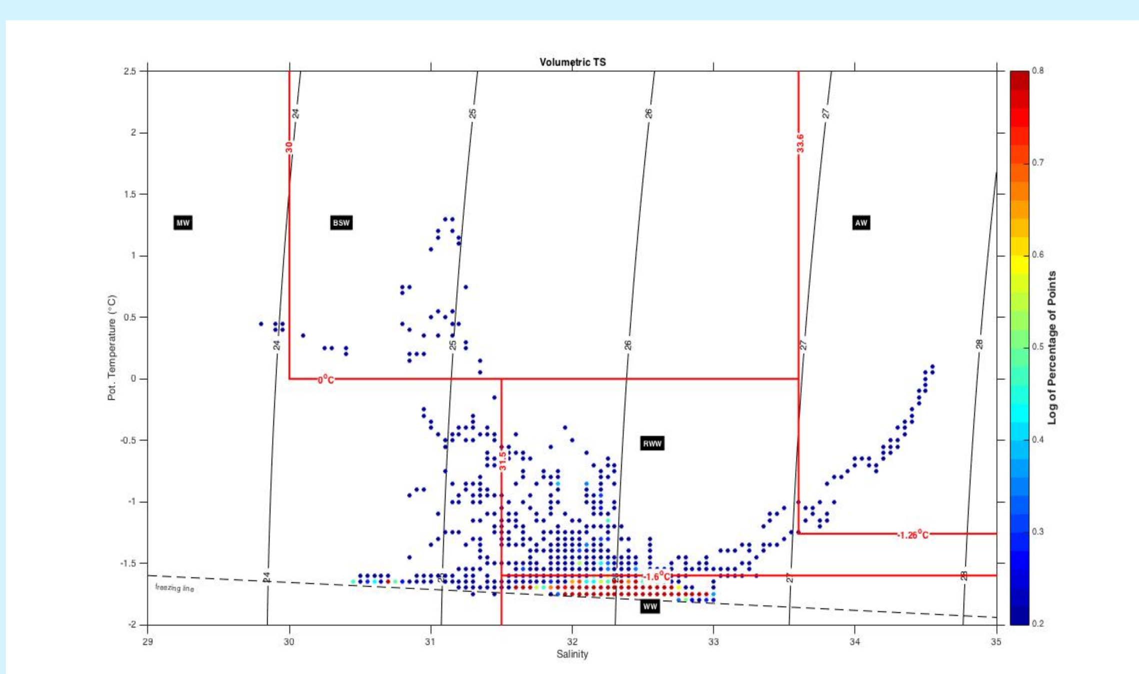

Figure 2: Water masses sampled on the 2014 cruise in temperature/salinity (T/S) space, with color indicating the amount of points that fall into the given T/S bin. The majority of samples fell into the winter water category, just above the freezing line.

Structure of the Water Column

The water column was predominantly composed of high nutrient winter water (Figure 2). In addition, the shelf could be characterized predominantly as a two-layer system consisting of a surface mixed layer atop a bottom boundary layer, separated by a sharp interface (Figure 3 and 4). In most instances the density change across the interface was weak, and winter water was present in both the top and bottom mixed layers.

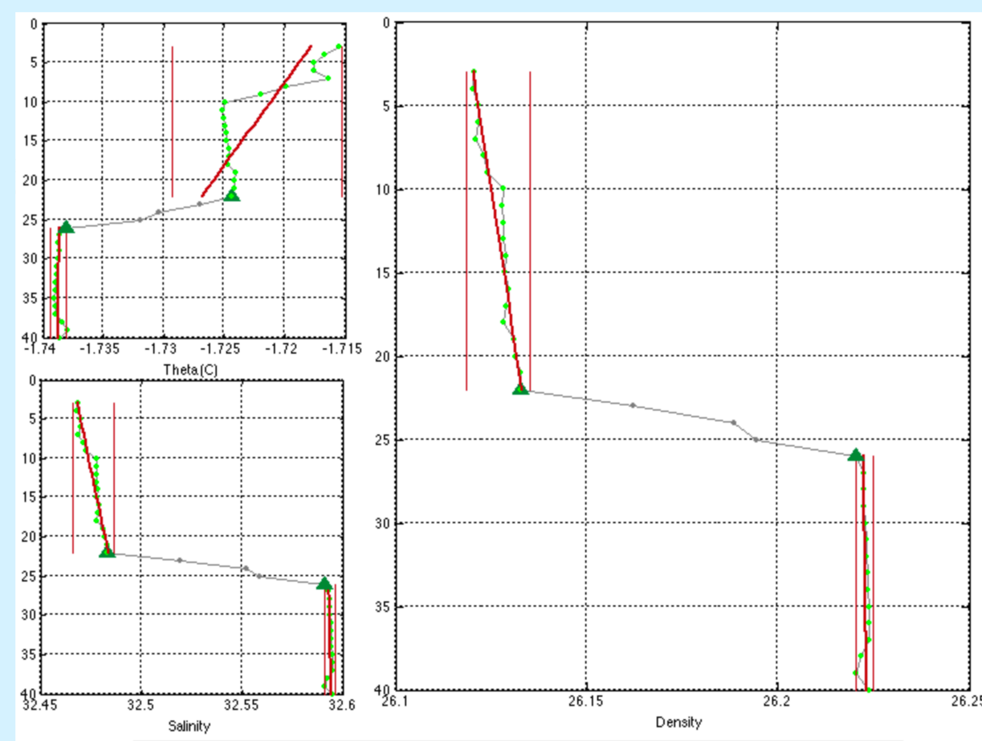

Figure 3: Representative CTD cast depicting the two-layer structure of the water column in density, salinity, and potential temperature.

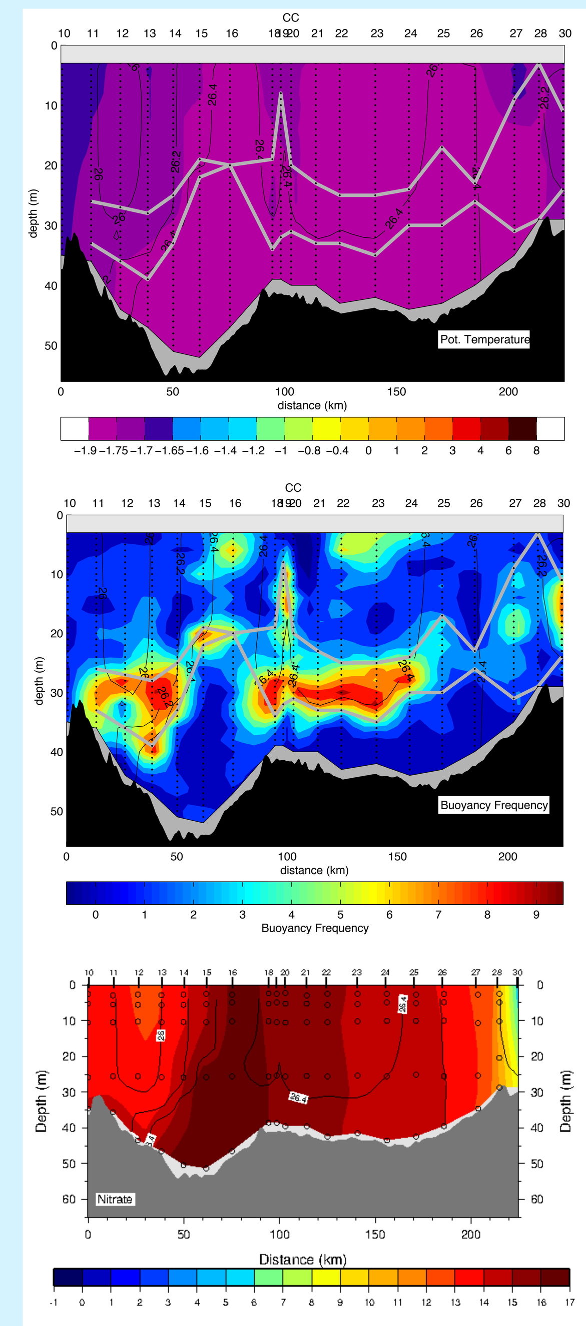

Figure 4: Vertical sections of the Central Channel transect in May 2014. (a) Potential temperature (°C, color) overlain by potential density (kg/m^3, contours). (b) Buoyancy frequency (s^{-1}) overlain by potential density. (c) Nitrate (umol/L) overlain by potential density. The thick grey lines denote the thickness of the interface between the surface and bottom mixed layers.

Bottom Boundary Layers

Previous theory (Trowbridge and Lentz, 1991; Lentz and Trowbridge, 1991) has demonstrated that the height of bottom mixed layers is sensitive to whether the interior flow is upwelling-favorable or downwelling-favorable. Consistent with this theory, we found that upwelling favorable conditions exhibited small bottom boundary layers with no dependence on bottom slope, while downwelling conditions exhibited large bottom boundary layers with a dependence on bottom slope—the steeper the topography, the larger the bottom boundary layer (Figure 5).

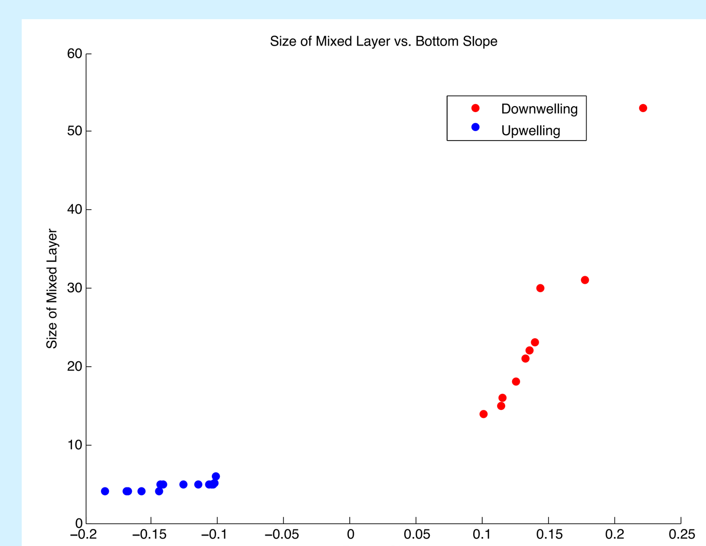

Figure 5: Bottom boundary layer height as a function of the local bottom slope at the station site for upwelling-favorable (blue symbols) and downwelling-favorable (red symbols) conditions.

Surface Mixed Layers

The weak interface between the surface and bottom mixed layers (Figures 3 and 4) implies that the water column was poised for overturning within a re-freezing lead or polynya. To investigate this we applied a simple polynya model coupled to the one-dimensional PWP mixed-layer model (Price et al., 1986). This analysis showed that overturning to the bottom would occur on the order of hours for realistic surface forcing. The overturn time is correlated both to the height of the surface mixed layer and the density jump between the two layers (Figure 6). A parameter defined as the product between the size of the surface mixed layer and the size of the density jump is highly correlated to the overturn time at each station (Figure 7).

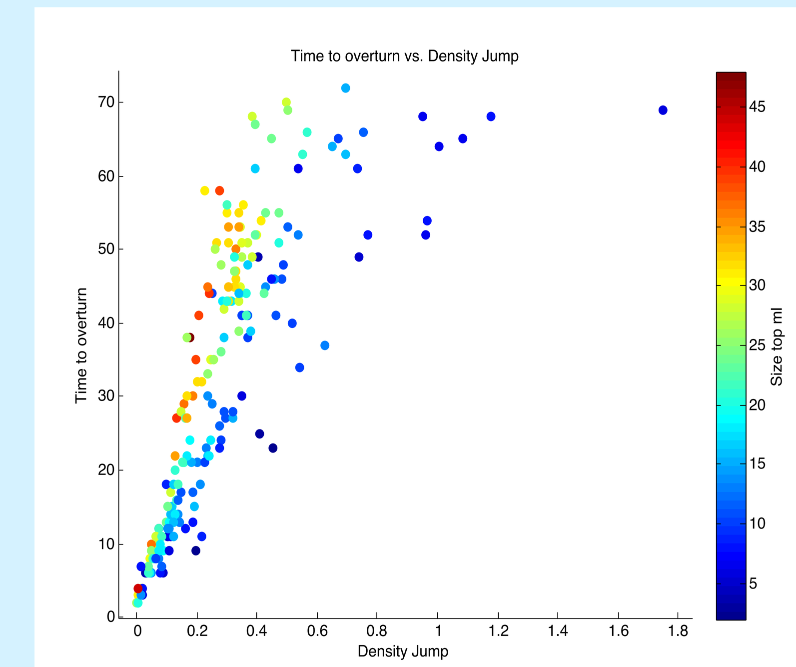

Figure 6: Overturn time for each station versus the density jump of the profile, where the color denotes the size of the top mixed layer.

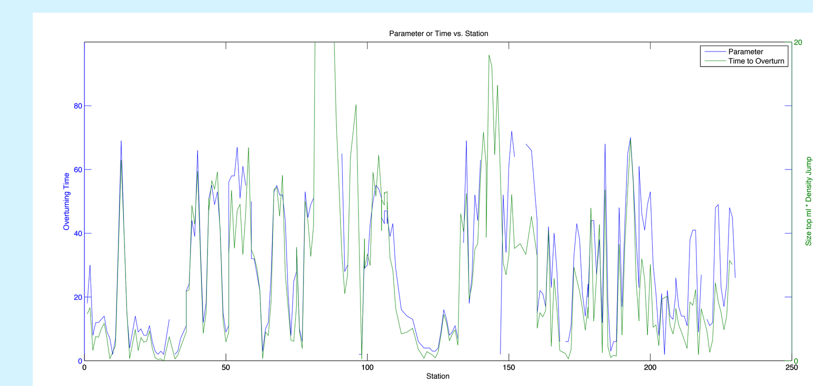

Figure 7: Comparison of the overturn time for each station (green curve) and the "area" parameter defined in the text (blue curve).

Conclusions

- During late spring, the Chukchi Sea is preconditioned for the development of under-ice phytoplankton blooms.
- The water column can be characterized as a two-layer system where the surface mixed-layer is separated from the bottom boundary layer by a density interface that is generally weak.
- Using a polynya model driven by realistic surface forcing, coupled to a one-dimensional mixed-layer model, it was demonstrated that the water column can overturn quickly when leads in the ice open up. The resulting convection would stir nutrients from the sediments into the water column, further increasing the nutrient content of the winter water and spurring productivity.

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