Seasonal Evolution of a Near-Surface Temperature Maximum (NSTM) in the Marginal Ice Zone (MIZ) of the Beaufort Sea from 2012-2013

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Abstract:

A changing Arctic climate has been linked to significant changes in sea ice conditions in the Arctic Basin. The seasonal melt-growth cycle of sea ice in the Marginal Ice Zone (MIZ) of the Arctic Ocean is largely a function of both top-down radiative forcing from the atmosphere and bottom-up heat flux from the surface ocean. A variety of intersecting feedback mechanisms complicates the melt-growth cycle in the MIZ. The density structure and stability of the upper ocean water column, in particular, influences bottom-up heat flux. In this study, data on upper water column properties collected from two Ice-Tethered Profiler (ITP) buoys deployed in the MIZ of the Beaufort Sea from 2012 -2013 was examined to trace the seasonal evolution of a near-surface temperature maximum (NSTM). Results will be used to show that the degree of stratification of the surface ocean in the MIZ influenced by freshwater inputs has the potential to influence heat exchange between surface waters and the warmer waters of the NSTM, constituting a potentially important feedback in the seasonal melt-growth cycle of Arctic sea ice.

Study Area and Methods:

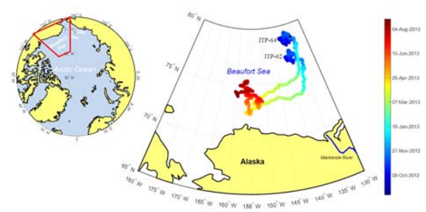

Figure 1. Map of Arctic Ocean with expanded view of the Beaufort Sea MIZ showing the drift paths of Ice-Tethered Profiler (ITP) buoys 62 & 64 from August 2012 – September 2013 (dates shown as increasing from blue to red). Also shown is the location of the Mackenzie River on the U.S.-Canada border.

Table 1. Start-to-end dates and positions for ITP 62 & 64.

ITP	Start Date	End Date	Start Location	End Location
ITP-62	SEP 2012	AUG 2013	76.950°N 139.540°W	74.827°N 158.807°W
ITP-64	AUG 2012	AUG 2013	78.775°N 136.663°W	73.726°N 169.627°W

Figure 1 shows the tracks of ITPs in the Beaufort Sea MIZ from August 2012 – September 2013. The ITP was developed by Woods Hole Oceanographic Institute (WHOI) and is designed to repeatedly sample ocean water column conditions under and around sea ice over time-periods of 1-3 years (**Fig. 2**). Water column property data (temperature and salinity) collected by ITP-62 & 64 were downloaded from the WHOI ITP site (http://www.whoi.edu/itp) and used to assess stratification of the water column and the seasonal development and characterization of a near-surface temperature maximum (NSTM) following the methods of *Jackson et al.* (2010).

Ice-Tethered Profiler data were collected and made available by the Ice-Tethered Profiler Program (Toole et al., 2011; Krishfield et al., 2008) based at the Woods Hole Oceanographic Institution (http://www.whoi.edu/itp).

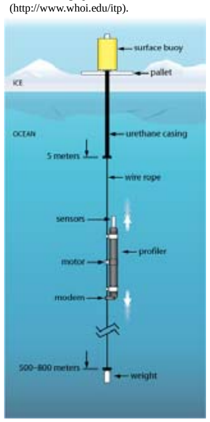

Figure 2. Engineering schematic of an Ice-Tethered Profiler Buoy (http://www.whoi.edu/itp).

Results and Discussion:

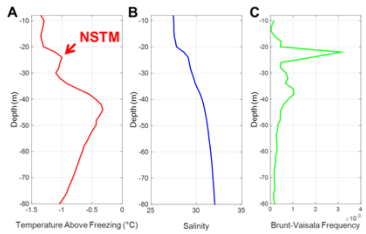

Figure 3. Properties of the upper 80 m of the Beaufort Sea water column on 01 September 2012 from data collected by ITP-64 showing (**A**) Temperature above freezing (ºC), (**B**) Salinity, and (**C**) Brunt-Väisälä Frequency (s^{-1}). The NSTM is highlighted by a red arrow.

The NSTM is a seasonal feature of elevated water column temperatures (above freezing) that lies below the relatively fresh surface mix layer and above warmer, saltier Pacific Summer Water (PSW). *Jackson et al.* (2010) identified and characterized the NSTM in the upper water column (10-80 m) of the Canada Basin from 1993-2008 and observed that it lies within the summer halocline, a seasonal feature that is the most stratified part of the water column. It also lies above a temperature minimum that is likely a remnant of the previous winter's mixed layer. The NSTM was identified as meeting the following three criteria: 1) a temperature maximum nearest to the surface of the water column that was greater than a temperature minimum at least 0.1 ºC cooler than the NSTM; 2) salinity < 31; and, 3) temperature of at least 0.2 ºC above freezing. An example of an NSTM can be seen in the temperature (**Fig. 3A**) and salinity (**Fig. 3B**) structure of the upper 80 m of the Beaufort Sea water column on 01 September 2012 from data collected by ITP-64. A localized peak of higher temperatures (above freezing) can be noted at ~ 22 m near the base of the summertime halocline yet above the deeper peak in temperature of the higher salinity waters ~ 45m indicative of PSW. The Brunt-Väisälä frequency (BVF) in the water column (**Fig. 3C**) can be calculated as:

$$N^2 = \frac{-g}{\rho} \times \left(\frac{d\rho}{dz}\right)$$

Where: N = Brunt-Väisälä frequency (s^{-1}); g = gravitational acceleration constant ($\frac{m}{s^2}$); ρ = observed density ($\frac{kg}{m^3}$); and z = depth (m). The BVF can be used to estimate the strength of stratification of the water column and relate it to the depth of the NSTM (**Fig. 3C**). The depth of the maximum BFV represents the most stratified region of the water column.

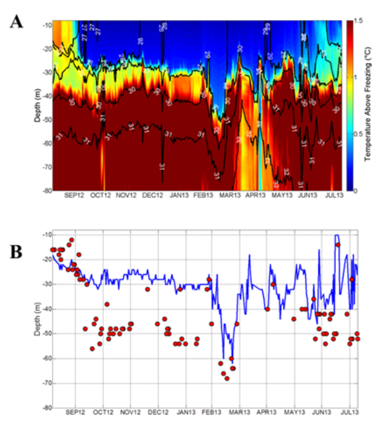

Figure 4. Results from ITP-62 showing: (**A**) A contour plot of observed temperature above the freezing point (ºC) from 10 to 80 m. Salinity contours are indicated by black lines and labeled in white; and (**B**) A comparison of the depth of the maximum Brunt-Väisälä frequency (blue line) and the depth of the NSTM (red dots).

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Results and Discussion (continued):

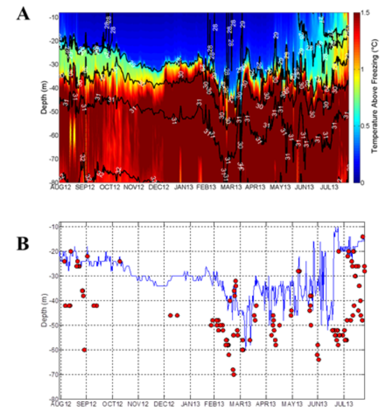

Figure 5. Results from ITP-64 showing: (**A**) A contour plot of observed temperature above the freezing point (ºC) from 10 to 80 m. Salinity contours are indicated by black lines and labeled in white; and (**B**) A comparison of the depth of the maximum Brunt-Väisälä frequency (blue line) and the depth of the NSTM (red dots).

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Figures 4A & 5A show temperatures above freezing and salinity contours in the Beaufort Sea from August 2012 to August 2013 as observed by ITP-62 & 64, respectively. There is a pattern of summer-to-fall heating along with a freshening of surface waters from sea ice melt or other freshwater sources (**Fig. 6A-C**). Data from both ITP's indicate the presence of a shallow NSTM (~20-40 m) in the late summer-to-fall of 2012 that deepens through Spring 2013. The NSTM shallows in the summer of 2013 but not to the degree that was observed in the summer of 2012. There are differences in the depth of the NSTM between the two ITP tracks that may be a function of their distance from land (**Fig. 1**). For both ITP tracks, the NSTM (when present) generally occurs below the depth of the maximum BVF. Separation between the two depths is sometimes as great as 20+ m (**Fig. 4B & 5B**). The lack of a consistent correlation between the two depths could be from noise in the data or indicative of other dynamic processes such as advection, mixing with other water masses, surface mixing, and/or Ekman pumping that could affect the behavior of the NSTM (**Fig. 6D**; *Jackson et al*., 2010).

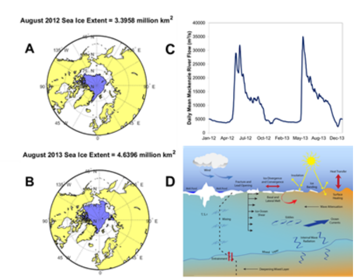

Figure 6. Sea ice extent for **(A)** August 2012 and **(B)** August 2013 (www.nsidc.org/data/masie/index.html); **(C)** 2012-13 daily mean Mackenzie River flow (www.wateroffice.ec.gc.ca); and **(D)** Diagram of air-ice-ocean interactions in the MIZ (www.apl.washington.edu/project/project.php?id=miz).

Conclusions:

ITP data clearly shows the seasonal evolution of a NSTM in the MIZ of the Beaufort Sea from August 2012 to August 2013. Results suggest that inputs of freshwater from the Mackenzie River and sea ice melt influence water column stratification and the development and persistence of the NSTM. Additional factors potentially influencing the NSTM include advection, mixing with other water masses, surface mixing, and Ekman pumping. Stratification influences heat exchange between surface waters and the warmer waters of the NSTM, constituting a potentially important feedback in the melt-growth cycle of Arctic sea ice.