An examination of Beaufort Shelf Winter Water in the Canadian Beaufort Sea

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1. Introduction:

- Pacific Winter Water (PWW) enters the Arctic through Bering Strait and cools to the freezing temperature over the Chukchi Sea in winter
- In the Canada Basin, PWW is associated with a maximum in dissolved nutrients and a minimum in temperature near 33.1 salinity
- Cold water formed on the Barents shelf appears from time-to-time in the southern Canada Basin, cooling the lower halocline near 34 salinity
- Winter water is also formed on the Mackenzie shelf of the Beaufort Sea (BSWW). It is distinguishable near its source by freezing temperature) and salinity above 32 (Melling and Lewis, 1982)
- Sometimes BSWW is dense enough to form a density plume that flows off the shelf & interleaves over the slope
    - The formation of BSWW encourages cross-shelf transport
- BSWW has lower nutrient concentration relative to PWW (Melling and Moore, 1995)
- Using year-round CT sensor, ice-profiling sonars, and ADCP data collected from moorings, we examine the properties of BSWW during the winters of 2009 – 2010 and 2010 – 2011 with sub-hourly sampling

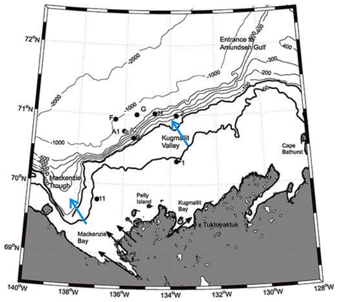

Figure 1: Bathymetric map of the study area. Mooring locations are marked by circles. The thick black lines mark the 50 m and 75 m isobaths. Blue arrows mark known areas of cross-shelf exchange – the Mackenzie Trough (Williams et al., 2006) and the Kugmallit Valley (Williams et al., 2008)

2. Data

- Two moorings (1 and 11) were on the continental shelf and six moorings (2, A1, A2, B, F, G, and H) were on the continental slope (Figure 1)
- The CT sensors at sites 11 and 1 on the continental shelf and at site 2 at the top of the slope were 3 m above the bottom
- The CT sensors at slope moorings A1, A2, B, F, G, and H were at depths 131 – 163 m

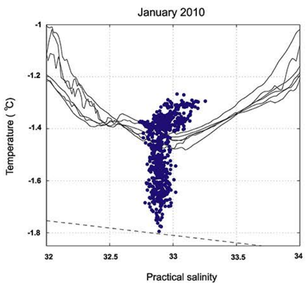

Figure 2: Temperature-salinity diagram from CTD profiles collected in the southern Canada Basin during the summer of 2009 (black lines) and from the CT sensor at 134 m at mooring F in January 2010

3. Definition of BSWW

- To be confident that BSWW differed from PWW, we established a tight constraint on temperature (Figure 2)
- We chose to identify BSWW as water over the slope that was colder than 0.1°C above the freezing temperature and saltier than 32.

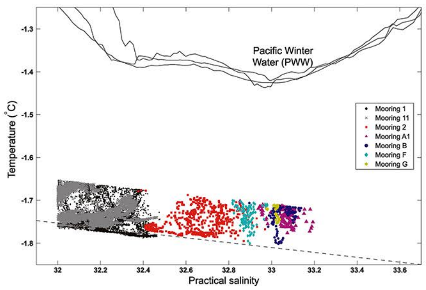

Figure 3: Observations of BSWW during the winter of 2009 – 2010. BSWW is plotted on a temperature-salinity diagram at all moorings. The solid black lines are nearby CTD profiles from the summer of 2009 and the dashed black line is the freezing temperature

4. 1 Observed BSWW in the winter of 2009 - 2010

- During the winter of 2009-2010, BSWW on the continental shelf was about 0.5 salinity units fresher than BSWW observed on the continental slope (Figure 3)
- These results suggest that the source of BSWW on the continental slope during the winter of 2009-2010 WAS NOT moorings 1 and 11

4.2. Observed BSWW in the winter of 2010 - 2011

- During the winter of 2010-2011, freezing-temperature shelf water at 50 m reached salinity characteristic of deeper halocline water over the continental slope
- Generally, winter water over the slope was appreciably above freezing, suggesting no recent interleaving of shelf water. (not shown)
- However the 2010-11 time series do contain events when winter water over the slope had the same properties as BSWW observed at mooring 1

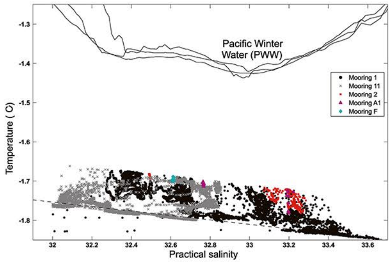

Figure 4: As in Figure 3 but for the winter of 2010 - 2011

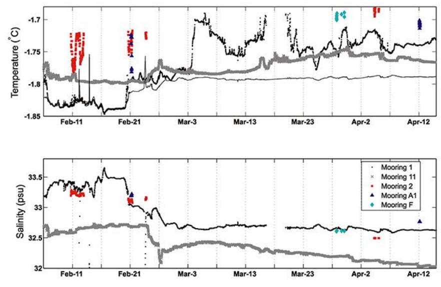

Figure 5: The (top) temperature and (bottom) salinity when BSWW was observed during the winter of 2010 - 2011

5. Transport of BSWW from shelf to slope

- During the winter of 2010 – 2011, BSWW on the slope was most similar to BSWW at mooring 1 (Figure 5)
    - this correlation suggests that a cross-shelf flow of BSWW followed Kugmallit Valley (cf. Williams et al. 2008),
- While salinity of BSWW on the shelf (mooring 1) was almost identical to salinity of slope moorings at the same time, the temperature was 0.01 to 0.09°C warmer on the slope
    - As illustrated by Melling & Lewis (1982) this warming reflects entrainment of warmer overlying water into the cold dense bottom current via shear instability
- BSWW drained sporadically from the shelf to some of the slope moorings from February to April 2011

6. Currents Associated with BSWW

- At mooring 1 in Kugmallit Valley, bottom flow was generally southward (on-shelf) indicative of upwelling. However, in February 2011, the densest BSWW was associated with a northward current that was directed down the valley (Figure 6)
- On the slope there was no indication that BSWW was associated with a particular current direction
    - On the slope, the BSWW was presumably moving with the flow once it had interleaved at its level of neutral buoyancy.

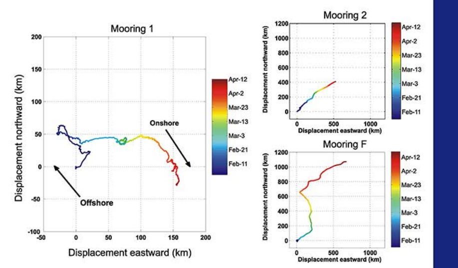

Figure 6: Progressive vector diagrams from moorings a) 1, b) 2, and c) F from February 1 – April 15, 2011. Note that the scales are different in some plots. The ADCP for mooring A1 did not work for the winter of 2010 – 2011.

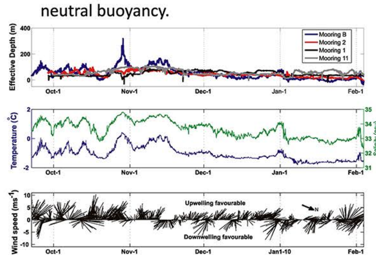

Figure 7: An estimate of upwelling based on a) effective depth (ED), b) temperature and salinity, and c) winds during the winter of 2009 – 2010. ED is an estimate of how much each salinity measurement from the CT sensor has moved vertically in the water column compared to a nearby reference CTD profile – positive values suggest upwelling. The wind speed and direction data from the NCEP/NARR reanalysis at grid point 71.1°N, 136.2°W.

7. Can upwelling explain why BSWW was saltier in 2010-2011?

- To estimate upwelling, the salinity at the CT sensor at moorings 1, 11, 2, and B were compared to a reference CTD profile for 2009 – 2010 (Figure 7) and 2010 – 2011 (Figure 8)
- Easterly winds cause upwelling along the edge of the Canadian Beaufort Sea shelf (Williams et al., 2008)
- During the fall of 2009, there were 4 easterly wind events from the end of September to the beginning of November that appeared to cause upwelling at moorings B and 2
- During the fall of 2010, there were three prolonged easterly wind events from the end of September to the beginning of December
    - The salinity of bottom water on the shelf increased at the same time of the upwelling events
    - We suggest that the later, more prolonged upwelling events in the fall of 2010 preconditioned the shelf for saltier BSWW

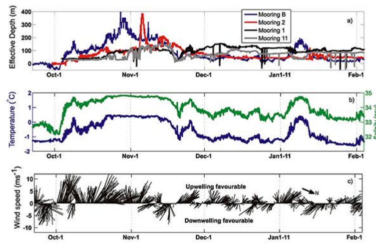

Figure 8: As in Figure 6 but for the winter of 2010 - 2011

8. Summary and future research

- T-S data recorded on moorings reveal that BSWW was present on the continental slope during the winters of 2009-10 and 2010-2011 show
- BSWW on the shelf was saltier during the winter of 2010 – 2011
- We suggest that prolonged easterly winds that lasted until December 2010 drove pre-existing surface water off to the west, and substituted more saline water via upwelling, thereby pre-conditioning shelf waters for dense BSWW formation later during winter.
- The cold BSWW intrusions on the continental slope during the winter of 2009 – 2010 were too saline to have originated via Kugmallit Valley or the Mackenzie Trough
    - Future research will focus on finding other nearby regions where winter water forms
- Because low temperature is not a unique identifier of BSSW, other tracers are needed for a more definitive analysis, perhaps accessible via autonomous dissolved nutrient recorders on moorings

Acknowledgements

We gratefully acknowledge Imperial Oil Resources Venture Ltd., BP Exploration Co., the Canadian program for energy R& D, and ArcticNet for funding and conducting the data collection.