MODIFICATION OF NEAR-SURFACE AND ATLANTIC DERIVED INTERMEDIATE WATERS ALONG THE CONTINENTAL SLOPE OF THE EAST SIBERIAN, CHUKCHI AND BEAUFORT SHELVES

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During the 1990s, our knowledge of how the eastern Arctic continental shelves affect the formation of interior water masses in the Arctic Ocean increased dramatically through oceanographic observations from icebreaker cruises to the Barents, Kara, and Laptev seas and to the interior of the Nansen and Amundsen basins. Of particular importance was the inflow of surface and near surface Atlantic water and its modification by shelf processes. During the first decade of the new millennium an extensive study of western shelf processes in the Chukchi and Beaufort seas will be carried out and much will be learned about how processes on these shelves and the inflow of Pacific water through Bering Strait affect the interior water masses. To gain a pan-Arctic view of how shelf processes affect the interior water masses, understanding of interactions between interior water masses formed by processes on different shelves is also needed.

Processes occurring over the continental shelves form waters with a wide density range that spans the densities of interior water from the surface to the bottom. Thus, exchange between the shelf regions and the interior occurs at all depths. River water enters the surface layer at several locations around the periphery of the Arctic Ocean and is advected from the shelf regions into the interior at certain locations. Prior to the 1990s a significant point of entry for Eurasian river water was over the eastern end of the Lomonosov Ridge (Steele and Boyd, 1998). During the 1990s, the entry of river water has shifted eastward and the region between the Siberian and Chukchi shelves has become important (Jones et al., 1998; Ekwurzel et al., 2000; Maslowski et al., 2000). Beneath the surface mixed layer lies the halocline, which is formed by shelf processes. The upper halocline is colder and fresher than the lower halocline and is most prevalent in the Canadian Basin. It is thought to form from a mixture of Pacific water that enters the Arctic through the Bearing Strait and shelf waters from the Chukchi, East Siberian and Laptev seas (Jones and Anderson, 1986). The lower halocline is most prevalent in the Eurasian Basin and is thought to form from Atlantic water and shelf waters from the Barents and Kara seas (Jones et al, 1991). Prior to the 1990s the boundary between these two types of halocline water was along the Lomonosov Ridge, but in the early 1990s it shifted to the Alpha-Mendeleyev Ridge (McLaughlin et al., 1996; Morrison et al., 1998).

Beneath the halocline waters lie intermediate waters that form from inflowing water from the Atlantic. Surface and near surface water from the Atlantic Ocean enter the Arctic Ocean by two pathways, Fram Strait and the Barents Sea. Fram Strait Branch Water (FSBW) forms the extensive temperature maximum that is observed throughout the Eurasian Basin at a depth of about 300 m and to a lesser extent in the Canadian Basin. The branch that flows through Barents Sea is modified by mixing with river water and sea ice melt water and by air-sea interaction resulting in a cooler, less saline water mass with densities equal to and greater than FSBW. This branch, referred to as Barents Sea Branch Water (BSBW) enters the Eurasian Basin from the Kara Sea and displaces FSBW to the interior as well as under-riding it and mixing with it (Schauer et al., 1997). Both water masses flow cyclonically around the Eurasian Basin, cross the Lomonosov Ridge into the Canadian Basin (Rudels et al., 2000), and can be found along the slope of the Chukchi Sea (Swift et al., 1997, Carmack et al., 1997). Properties of BSBW are also present along the slope of the Beaufort Sea and in the interior of the Canada Basin (Smethie et al., 2000).

From the above discussion, it can be seen that intermediate waters entering the Arctic through Fram Strait and from the Eurasian shelves are transported in a cyclonic boundary current at least as far as the Beaufort slope. However, these waters are modified by mixing along their flow paths. A theta/salinity analysis indicates that FSBW is modified much more extensively than BSBW by mixing with other water masses after their entry into the Canadian Basin. Smethie et al. (2000) found FSBW in the central Canada Basin to be diluted by a factor of 5 compared to a factor of 2 for BSBW. They also found that the water diluting the FSBW contained high tritium and CFC concentrations indicating a shelf source, but the BSBW was diluted with water of low tracer content. The source of the shelf water that mixes with FSBW and the location of the mixing are not known, but the East Siberian shelf and slope appear to be likely regions.

Circulation and exchange time scales can be estimated from tracer derived ages. The tritium/^{3}He age of the surface mixed later ranges from about 2 to 10 years suggesting a residence time less than a decade for river water in the Arctic Ocean (Schlosser et al., 1999a). Halocline waters have a tritium/^{3}He age of 5-15 years (Schlosser et al., 1999a). Smith et al. (1999) have estimated the age of lower halocline water during the 1990s to be about 8 years in the central Makrov and Amundsen basins from 129I:137Cs concentrations, which come from European nuclear fuel reporcessing plants. For intermediate waters, at the eastern end of the Eurasian Basin along the Laptev slope, the tritium/^{3}He age of FSBW and BSBW are about 6 and 8 years respectively (Frank et al., 1998). Off the Chukchi slope the respective tritium/^{3}He ages are about 8 and 15 years (Schlosser et al., 1999b). The age of FSBW changed little between the Lomonosov Ridge and the Chukchi slope because of dilution with well-ventilated shelf water, but this is not the case for BSBW whose age increased by about 7 years. The age of BSBW over the Beaufort slope is about 18 years indicating a 10 year transit time from the Eurasian Basin (Smethie et al., 2000). The age of BSBW in the center of the Canada Basin is also about 18 years and its relatively high CFC and tritium concentrations suggest that exchange of water between the boundary and the interior occurs in the vicinity of the Chukchi Plateau.

To fully understand how shelf/basin interactions impact the formation and variability in the interior waters of the Arctic Ocean, observations are needed around its entire periphery. From oceanographic sections extending across the continental shelf and slope in the Eurasian Basin, transport of shelf derived water masses in cyclonic boundary currents has been firmly established. Sparser observations from the Canadian Basin indicate these water masses are also transported into and around the Canadian Basin in cyclonic boundary currents where they are transformed by mixing with additional shelf derived waters. An extensive set of measurements will be made in the Chukchi and Beaufort shelf and slope regions during the next few years as part of the SBI program. The results from this program will increase our understanding of shelf/basin exchange in this region, but to understand the link between the Eurasian Basin shelf waters and the Canadian Basin shelf waters, observations are also needed along from the East Siberian shelf and slope. Another important program that is planned to run concurrently with the SBI program is SEARCH. One objective of the SEARCH program is to document temporal variability in the Arctic Ocean and its link to climate change that became so dramatically evident with the shift in the boundary between Atlantic and Pacific halocline waters that occurred in the early 1990s (Morrison et al., 1998). The logical time for observations along the Siberian shelf and slope is during the time frame of these two experiments. These observations, when combined with previous work, would allow a complete description of the cyclonic boundary flow and shelf/basin exchange along a flow path extending from Fram Strait to the Beaufort Sea.

The observations will require sections extending from the East Siberian shelf into the Makarov and Canada Basins. Parameters that should be measured are temperature and salinity with a CTD, oxygen, nutrients, anthropogenic tracers (CFCs, tritium, He isotopes, ^{129}I and ^{137}Cs), river water tracers (oxygen isotopes and barium) and current velocity. This will require work in both Russian and international waters and would best be accomplished by an international collaborative effort.

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