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Changes in temperature and salinity in the eastern Eurasian Basin and its implication for the Arctic Ocean heat and freshwater balance

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The Arctic Ocean is the northernmost part of the North Atlantic. It is an almost enclosed bay dominated by Atlantic water masses. Only the narrow and shallow Bering Strait allows the less saline water of the North Pacific to enter the Arctic Ocean. The Pacific water together with runoff and net precipitation comprises a large part of the low salinity upper layer of the Arctic Ocean. The Atlantic water enters through Fram Strait and over the Barents Sea. The deep (>2500m) Fram Strait allows for a two-way flow and it is the only passage, where intermediate and deep waters can be exchanged between the Arctic Ocean and the Nordic Seas, while the shallow Barents Sea essentially only permits inflows to the Arctic Ocean.

The Atlantic water entering through Fram Strait experiences strong cooling in the Norwegian Sea, but when it encounters sea ice north of Svalbard the upper part loses heat to ice melt, which decreases, not increases the density of the surface layer and a low salinity, colder layer is created from the upper part of the Atlantic water. This insulates the main part of the inflow, which becomes subsurface temperature and salinity maxima in the Arctic Ocean water column.

The Barents Sea inflow, by contrast, does not meet sea ice until it reaches the eastern part of the Barents Sea and the Atlantic water continues to lose heat to the atmosphere before its upper part becomes transformed into a low salinity surface layer by melting sea ice. This implies that the Atlantic water core that enters the Arctic Ocean via the Barents Sea is colder and less saline than that of the Fram Strait branch. In addition ice formation and brine rejection over the shallow banks, especially west of Novaya Zemlya, transform Atlantic water of the Barents Sea branch into denser waters that flow to the Arctic Ocean in the St. Anna Trough.

The meeting of the two branches north of the Kara Sea shelf causes the Fram Strait branch to leave the continental slope and the upwelling of warm Atlantic water close to the shelf break, which occurs north of the Barents Sea, ceases since the colder Barents Sea branch now occupies the upper part of the continental slope, The mixing between the two branches increases in the eastern Kara Sea and north of Severnaya Zemlya, where the bathymetry of the slope becomes steeper and the two branches are forced closer together. This results in strong interleaving between the two water columns and intrusions of water with different properties dominate the intermediate layers of the water column. Furthermore, the temperature of the temperature maximum and the salinity of the salinity maximum are reduced between the Kara Sea and the Laptev Sea slopes by about 1^{o}C and 0.05 respectively.

Although the lower temperature, in principle, could be caused by heat loss to the mixed layer and to ice melt and the atmosphere the salinity reduction occurs at depth >200m, which hardly can be explained by ice melt, which would remain in the surface layer. The alternative is mixing between the two inflow branches. This mixing then mainly occurs as thermohaline intrusions, at least partly driven by double-diffusive fluxes, which forces the waters across the front between the branches.

Similar, but more developed, or rundown, intrusions are observed on the basin side of the Fram Srait branch. These intrusions also require a colder, less saline end member and the only one available is the Barents Sea branch. The simplest explanation for the presence of the intrusions in the interior of the Nansen Basin and over the Gakkel Ridge is that part of the boundary current leaves the slope north of the Laptev Sea and returns towards Fram Strait. This implies that the main part of the Fram Strait branch would return towards Fram Strait in the Nansen Basin and only seldom contribute to the Atlantic layer beyond the Gakkel Ridge and even more rarely penetrate across the Lomonosov Ridge into the Amerasian Basin. An examination of the Atlantic layer found in the different basins shows that the Barents Sea branch Atlantic water is warm and saline enough to supply the temperature maxima found in the different basins of the Arctic Ocean except the Nansen Basin.

The properties of the boundary current north of the Laptev Sea vary strongly with time. In the 1990s the waters were comparatively warm and saline almost to the Lomonosov Ridge, while e.g. in

2007 and 2011 the maximum temperature and salinity of the Atlantic layer were considerably lower, especially in 2011. Since the Atlantic water temperature and salinity observed in Fram Strait have been high since 2000 with a maximum in 2006, the reduction observed north of the Laptev Sea is most likely caused by less saline and colder Barents Sea inflow, or with an even smaller contribution of Fram Strait branch Atlantic water north of the Laptev Sea.

The Barents Sea inflow does not only consist of Atlantic water. A large part of the inflow is supplied by the Norwegian Coastal Current, which brings low salinity water from the Baltic Sea as well as runoff from the Norwegian coast to the Barents Sea and eventually to the Arctic Ocean. Recent estimates (Skagseth et al., 2011) have shown that the inflow of low salinity water in the Norwegian Coastal Current is more than twice the earlier estimate by Blindheim (1989). This, together with recent estimates of the outflow through the Canadian Arctic Archipelago (see e.g. Rudels, 2011 and references therein), allows for an almost closed volume and freshwater budget for the Arctic Ocean.

The 1.5 Sv (1 SV = 1×10^6 m^3s^{-1}) with salinity 35.05 of Atlantic water entering through the Barents Sea Opening (Ingvaldsen et al., 2004) should be combined with the 1.8 Sv with salinity 34.4 from the Norwegian Coastal Current (Skagseth et al., 2011) and the 0.8 Sv with salinity 32.5 entering through Bering Strait (Woodgate et al., 2005). To this 0.1 Sv of runoff and a net precipitation of 0.04 Sv should be added. The outflow through the Canadian Arctic Archipelago is around 1.6 Sv of surface water with salinity 33.1 and 0.6 Sv of denser water with salinity 34.45 (Rudels, 2011). The ice export is about 0.08 Sv. This gives a net outflow through Fram Strait of 1.9 Sv. This is close to the recent net outflow estimate, ~2 Sv, obtained from direct current measurements in Fram Strait (Beszczynska-Möller, pers. comm.)

The average salinity of the Fram Strait inflow has been estimated to 34.93 (Rudels et al., 2008). The freshwater input to the Arctic Ocean through the Barents Sea by the Atlantic and Coastal water relative to this salinity is about 0.01 Sv, while the Pacific inflow adds 0.05565 Sv of freshwater. The outflow of freshwater through the Archipelago is in the upper layer 0.8382 Sv and 0.00852 Sv in the lower layer. Adding the runoff and the net precipitation and subtracting the ice export this give a net outflow of 0.0333 Sv of freshwater through Fram Strait.

This freshwater can be accomplished by a net outflow of 1.9 Sv with a salinity of 34.32. The excess water leaving through Fram Strait is likely to a large extent supplied by the Barents Sea inflow and by runoff. Assuming that all the Atlantic water entering through the Barents Sea opening leaves the Arctic Ocean through Fram Strait a volume and freshwater balance can be found, if in addition to the 1.5 Sv of Atlantic water also 0.367 Sv of Coastal water and 0.0328 Sv of runoff is exported through Fram Strait. This is but one of an infinity of possible combinations but it might give some indications of how volume and freshwater and eventually also heat balances might be formulated.

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