# Bipolar Atlantic Thermohaline Circulation – BIAC

*BIAC is IPY cluster #23, BIAC-Norway is one of the biggest IPY projects in Norway. BIAC is coordinated by Tor Gammelsrød and Svein Østerhus, Geophysical Institute and Bjerknes Centre for Climate Rresearch,*
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**Main objective:** To study the Arctic and Southern Ocean shelf ventilation processes and determine their impacts on the bipolar Atlantic thermohaline circulation.

**Project Summary**

Because they are ventilated in the Polar Regions, a striking feature of the world oceans is that most of the water masses are cold (80% below 5ºC). The main ventilation sites are in the high latitude Atlantic sector, where the densest water masses are formed in the Antarctic, and the slightly less dense water masses above are formed either north of the Greenland-Scotland Ridge (GSR) or in the Labrador-Irminger basins. The water mass transformations in the high latitude regions are among the key components in the Meridional Overturning Circulation (MOC). Currently the most fundamental aspects of MOC are under debate and call for thorough bipolar studies.

Cooling, ice formation and subsequent brine release determine the characteristics and volume of deep water formation over the continental shelf areas in both Polar Regions. However there are also significant differences. In the Antarctic, water at great pressures underneath vast floating glaciers is super-cooled with respect to the surface freezing point. Cold water is more compressible, so when this water descends towards great depths, this *thermobaric effect* will tend to increase the down-slope forcing. In the Antarctic the deep water formation sites are adjacent to the world ocean abyss, and the sills separating the Southern Ocean from the rest of the world oceans are more than 3 km deep. In the Arctic, path of the dense water from the shelves to the deep Atlantic is more complicated. The Atlantic inflow to the Nordic Seas is about 9 Sv with a heat transport of 300 TW. It is totally transformed as the heat is given up in the Arctic Mediterranean, and 6 Sv returns across the GSR as dense overflow water that directly links to the Atlantic deep water and overturning circulation. About a quarter of the Norwegian Atlantic Current enters the vast Arctic shelf region through the Barents Sea Opening, and the rest through the Fram Strait. The dense water formed in the north-eastern Barents Sea continues on a long journey (years to decades) around the Arctic perimeters where it mixes with the dense water formed on the shallow shelves. The dense water leaves the Arctic via the Fram Strait, follows the east Greenland coast and eventually enters the Norwegian Sea at about 2000 m depth.

In this project the mechanisms, manifestation and impact of intermediate and bottom water formation originating from the bipolar Atlantic Ocean shelves will be explored. The **overall goal** is to **evaluate the global ventilation** through circum Arctic and Antarctic shelves and **consequences for the climate** by up-scaling results and knowledge gained from two key sites: the **Barents Sea** and the **southern Weddell Sea**. Proposed dedicated **multidisciplinary** field surveys of hydrography, bathymetry, currents, turbulence, biogeochemistry, and sea ice with focus on the key investigation areas depend on the logistical opportunities provided by the IPY program. **International collaboration**, especially with **Russian researchers** in the Barents Sea, is crucial in achieving the overall goal. Observations will be used in concert with analysis from remote sensing and modelling tools to support the following Working Themes (WT):

WT1. Regional circulation and forcing - preconditioning and variability
WT2. Sea ice freezing and high-salinity shelf water (HSSW) formation
WT3. Downslope processes – pathways, cascading and mixing
WT4. Contribution to the thermohaline circulation (THC) and consequences for the climate

WT5. Sustainable monitoring system for dense water production on polar shelves

Integrated physical and biogeochemical studies will characterize the hydrography and carbon biogeochemistry of the source waters prior to dense water formation, the end products after cascading, and the anthropogenic carbon fluxes due to ventilation processes. The effects of unresolved processes such as mixing are parameterized in large scale conceptual models and in general circulation models (GCMs). Different parameterizations of the dense water formation on the polar shelves, including the violent entrainment as this water cascades into the deep ocean, will be evaluated. BIAC will thus investigate relationships between variability in deep-water formation, $CO_2$ uptake rates and large-scale natural or anthropogenic climate forcing.

**Scientific background and motivation**

Paleo records have revealed temperature variations on the order of 10ºC over only a few decades, possibly as a consequence of reduced ventilation and Gulf Stream transport due to enhanced melt water from inland seas or calving of icebergs. Although the ocean circulation and the north Atlantic climate have been relatively stable for more than 10 millennia, climate models have suggested that release of greenhouse gases and the associated global warming may perturb the balance. Warmer air, enhanced atmospheric moisture transport to the high latitudes, and melting of glaciers and ice sheets will lead to a more stable surface layer and a decreased production of deep water. A bipolar approach is needed to investigate the increasing view that the Southern Ocean dynamics affects the global THC and in particular the far northern Atlantic.

Dense water masses form on the Arctic and Antarctic shelves through freezing of sea ice. The HSSW cascade off the continental shelves is crucial for the global ocean circulation and climate and is a major control on deep water biogeochemistry. As the direct link between the atmosphere and the intermediate and deep oceans, the rate of deep water formation controls the oxygenation of the deep ocean and regulates the response time of the ocean to changing concentrations of $CO_2$ and other gases in the atmosphere. Shelf processes are impossible to incorporate in GCMs, yet they exert significant control over the global circulation. Direct field measurements are urgently needed. The large-scale circulation, hydrography, forcing conditions and dominant mixing mechanisms preconditioning the shelf waters for dense water production must be well-understood to obtain accurate estimates of deep water formation. The mixing which occurs during the cascading process leads to irreversible modifications in the water mass properties further downstream from the production sites. These end products are fundamental in determining the carbon and nutrient fluxes to the deep ocean, and for shelf-deep water exchange in general.

The water masses formed on the polar continental shelves contribute to the deepest branches of the global THC and fill the abyss. The Antarctic Bottom Water (AABW) is denser than the northern component North Atlantic Deep Water (NADW), and the AABW resides below the NADW where the two water masses meet. The production rates of NADW and AABW are believed to be each about 8 Sv, but even such important quantities are still much disputed. Deep and bottom water formation has traditionally been associated with the Greenland Sea, but deep convection here appears to have ceased in the 1980s. Thus the densest source of NADW is now probably found within the Arctic Ocean, where the shelf processes described here are of fundamental importance and thus a key component in the climate system. The role of the last decades' large scale changes in the hydrographic properties of the North Atlantic-Arctic Mediterranean in the THC is not well understood. Although there are indications of a recent slow-down of the deep branch of the THC, this is not observed in the compensating northward flow of Atlantic Water via the North Atlantic Current. We have identified one region in each hemisphere where the densification of water masses is particularly important, namely the Barents Sea and the southern Weddell Sea.

The Barents Sea (Fig.1) is of particular interest. According to estimates based on atmospheric observations and oceanic heat budgets, about half of the heat loss in the entire Nordic Seas takes place here, and is known only with wide errorbars. This is one of the largest shallow shelves adjacent to the Arctic Ocean, and it is also the deepest (~230m). The ice extent shows large seasonal variations, so the conditions for ice formation and subsequent brine release are favorable here. HSSW is observed to form on the shallow shelves near Novaja Zemlja and Storfjorden and also in other shallow areas such as Storbanken.

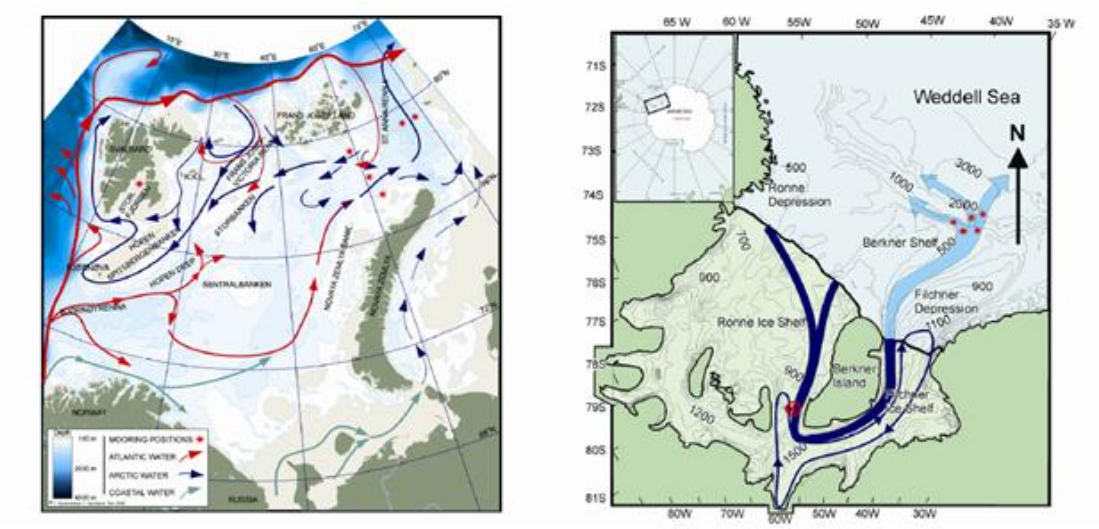
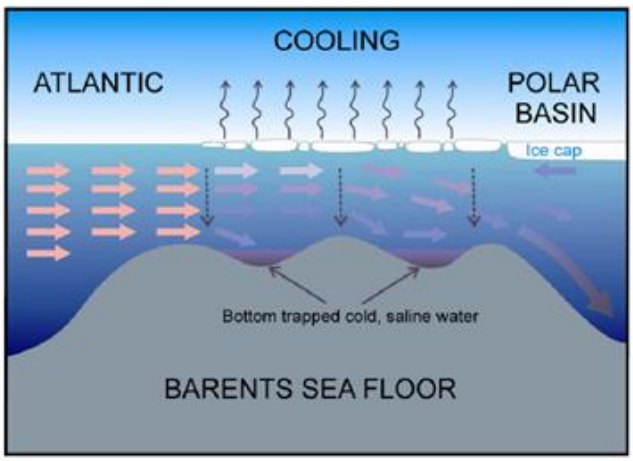



**Fig.1.** (left) Study areas in the Arctic are focused on Storfjorden and the eastern Barents Sea between Novaja Zemlja and Franz Josef Land including the St. Anna Trough (right). The main study area in the Weddell Sea is concentrated along the path of the Ice Shelf Water. Approximate mooring positions are indicated by (*). The long term monitoring position on the ice shelf south of Berkner Island is marked by a circle.

The main inflow of water to the Barents Sea in the west between Norway and Bjørnøya is called the Barents Sea Opening (BSO). This inflow is about 2 Sv and consists mainly of Atlantic Water (AW) with an average temperature above 6°C. Most of the water leaves the Barents Sea between Novaja Zemlja and Franz Josef Land, the Barents Sea Exit (BSX), but here the average temperature is below 0°C, thus the water has been subjected to strong cooling. The salinity of the inflowing AW is high (S>35), and although this water mixes with fresher waters from melting and the Norwegian Coastal Current, the brine release helps to maintain the high salinity in the BSX, and the BSX water is sufficiently dense to contribute to intermediate and bottom water formation within the Arctic, see schematic sketch in Fig.2.

HSSW formed on Antarctic continental shelves, depending on initial density excess, will cascade to form AABW or intermediate waters. We have chosen the southern Weddell Sea (Fig. 1) as our study area, because the coldest bottom water in the Antarctic is observed here (Fig.2). About 4 Sv of Weddell Sea Bottom Water (WSBW) is estimated to form here. WSBW is one of the precursors to AABW. Ice formation and subsequent brine release is believed to be important on the shallow shelf north of the floating Filchner and Ronne ice sheets (Fig. 1), and particularly in the polynya adjacent to the ice shelves kept open by favorable winds and tides. Some of the HSSW formed here penetrates southwards underneath the ice shelves, where it becomes super-cooled with respect to the surface freezing point (T~ -1.9°C) when it contributes to the melting of the meteoric ice at high pressures. The corresponding melt product is called Ice Shelf Water (ISW), easily identified by its temperature (T< -1.9°C). Sub ice shelf measurements obtained by hot water drilling through the ice sheets have revealed the circulation patterns and formation sites of ISW, and model experiments have been useful to interpret the sub ice circulation. Some of the ISW leaves the sub-ice cavity in the Filchner Depression and overflows the sill at about 74°40'S where it penetrates down the steep continental slope deflected to the left by the Coriolis force and controlled by the bottom topography (Fig.1). ISW also contributes to WSBW and is believed to be particularly important for the deepest branches of the overflow because of the thermobaric effect.



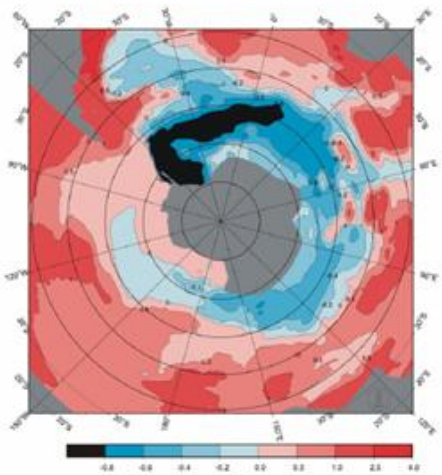



**Fig.2.** Schematics of dense water production in the Barents Sea (left). Bottom temperatures in the Antarctic (right)