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Transport of Atlantic Water in the western Barents Sea

by

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Abstract

Measurements from an array of current meter moorings along a section between Norway and Bear Island indicate that the seasonal mean of inflowing Atlantic Water extends further to the north during the summer than during the winter. To further investigate this seasonal divergence and the transport routes of Atlantic Water in the western Barents Sea, numerical experiments of tracer advection have been performed. The numerical results agree with the observations by showing a more northerly transport route of tracer water masses in the western Barents Sea during summer. The tracer water masses originate in the core of the Atlantic Water inflow at the Norway-Bear Island section, thus represents an indication of the transport routes of the Atlantic Water. The main reason for this change from summer to winter is probably the seasonal changes in the atmospheric fields.

1. Introduction

The inflow and internal distribution of Atlantic Water (AW) is a key to the warm climate of the Barents Sea. The flow is also of vital importance for transport of fish eggs (cod and herring), zooplankton from the Norwegian Sea and algae and nutrients as these are being advected into the area bye the currents.

The Barents Sea is a relatively shallow continental shelf sea with an average depth of 230 m (Figure 1). AW is entering the Barents Sea in the western boundary of the Barents Sea (i.e. through the section between Norway and Bear Island). The current structures across the section as deduced from the hydrography indicate a rather stable inflow of AW in the southern part of the section and outflow further north. This circulation scheme was confirmed by time series from a 2-month current measurement programme (Blindheim, 1989). However, more recent publications such as Haugan (1999), analysing data from vessel mounted Acoustic Doppler Current Profiler (ADCP), found the inflow to take place in two cores with stagnant water or a weak return flow between. His results were supported by Furevik (2001) who analysed hydrographic data, and partly by Ingvaldsen et al. (2002) who based their conclusions on a 1-year time series from an array of moorings across the Norway-Bear Island section. A recapitulate of older drifter data made by Loeng and Sætre (2001) indicated the same results.

The continuation of the North Atlantic Current in the Barents Sea is named the North Cape Current. It divides into two main branches (Figure 1). One branch continues eastward parallel to the coastal current system and changes name to the Murmansk Current as it leaves the Norwegian area. The other main branch turns north along the Hopen trench. This branch further divides into at least two smaller branches where one continues northward while the other turn southwest going south of Central Bank. The bottom topography strongly influences the current conditions, especially in the shallowest areas.

The internal distribution of AW in the Barents Sea may change substantially from year to year. In some years the influence of AW in the Murmansk Current may be traced as far as the western shelf of Novaja Zemlja, while in other years AW can hardly be traced east of 40^{o}E. Recent publications indicate that different phases of local sea level pressure may cause an alternation between the amount of water carried in the two main branches (Murmansk Current and the Hopen trench branch), thereby have a significant effect of the internal distribution within the Barents Sea (Ingvaldsen et al., 2001).

The present paper will address some of the aspects considering the inflow and internal distribution of AW in the western Barents Sea by using currents simulated by a three-dimensional numerical model, and observations from moored current meters. The aspects addressed are the splitting of the current across the Norway-Bear Island section and the seasonal change of geographical distribution between summer and winter. We will show from the observations that the summer mean inflow of AW in the section extends further to the north than the winter mean inflow. This motivated a numerical tracer advection study, which supported the fact that AW has a more northerly transport route in the western Barents Sea when entering during the summer than during the winter. The reason for this has not been fully investigated, although seasonal differences of the rapidly changing atmospheric fields is pointed at as a candidate.

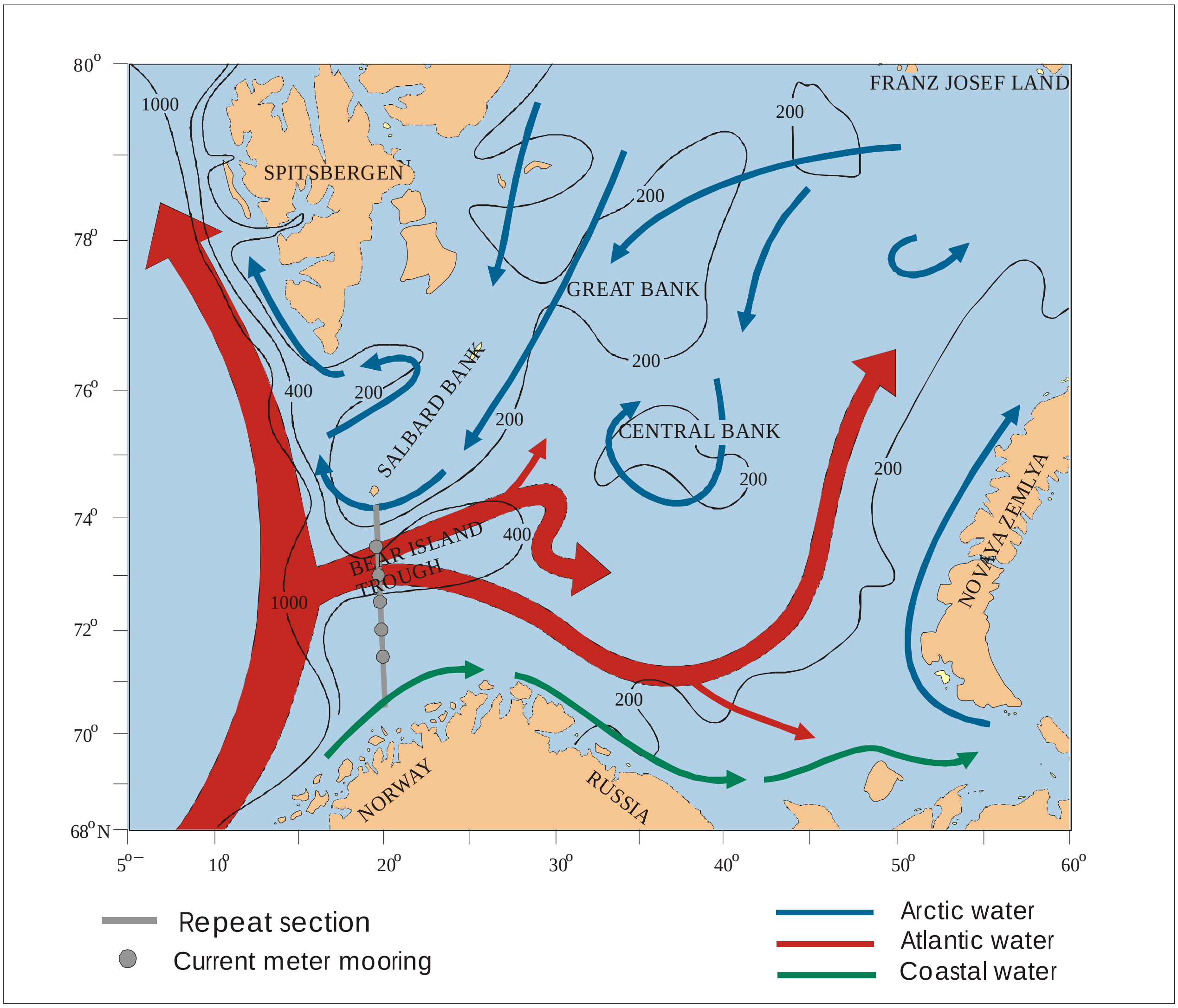

Figure 1. The current system of the Barents Sea. The positions of the current meter moorings at the Norway-Bear Island section are shown as gray circles.

2. Materials and methods

The current observations were made from 3-7 moorings with Aanderaa current meters RCM7 (Aanderaa Instrument, 1987) across the Norway-Bear Island section in the period August 1997 to August 2001 (Figure 1). The number of moorings has not been constant, and consequently the lateral resolution has changed somewhat during the period. However, only long-term means will be presented here. To fill in the gaps in the time series simple linear interpolation of the velocities from the instrument above and/or below was performed. This should be an adequate method since the velocity are predominantly barotropic but may have strong lateral velocity-gradients. When filtering was performed, an order 4 Butterworth lowpass filter (Roberts and Roberts, 1978) was applied.

A coupled ice-ocean model was used to calculate the three-dimensional current fields used for tracer advection. The Institute of Marine Research three-dimensional, primitive equation, free surface, sigma-coordinate ocean model NORWECOM (Skogen and Søiland, 1998; Asplin et al., 1998) based on the Princeton Ocean Model (Blumberg and Mellor, 1987) was coupled to a dynamic-thermodynamic sea ice model. This permitted the use of the model for a domain covering the whole Arctic Ocean and the Nordic, the North, the Kara, and the Barents Seas. The grid resolution is 20 km and the vertical has 23 sigma layers. The forcing of the model are realistic winds from the NCEP (National Center for Environmental Prediction) reanalysis fields at 6-hourly intervals, river runoff, tides, and climatological inflow at the open boundary in the North Atlantic.

A numerical simulation from March 15, 1997 to the end of June 1999 produced daily mean current fields on the 20 km resolution grid and with full vertical resolution. Together with a separate tidal currents model, currents with hourly time resolution were used to advect tracer water masses (passively flowing along with the currents) in the western Barents Sea. Several simulations of one year duration of tracer advection were performed, each starting the first day of the month and with the initial distribution at positions in the core of the AW. Thus, results from altogether 15 different one year long simulations make up a statistical material of water mass transport. The geographical spreading of the tracer fields will of course increase throughout the simulation. To summarize the large picture, the centre of gravity (P_x , P_y) for the tracer water masses (i.e. the two-dimensional field $F(x,y)$) at a given time and depth is performed by the expressions:

$$P_x = \frac{1}{T}\int_A xF(x,y)dxdy, \quad \textbf{(1)}$$

$$P_y = \frac{1}{T}\int_A yF(x,y)dxdy, \quad \textbf{(2)}$$

where A is the area of the model domain and $T = \int_A F(x,y)dxdy$.

3. Results and discussion

The mean cross-section flow at the Norway-Bear Island was estimated from the current observations for both the summer season and the winter season (Figure 2). An obvious feature from these current structures is that the inflowing AW extends further to the north during the summer than the winter.

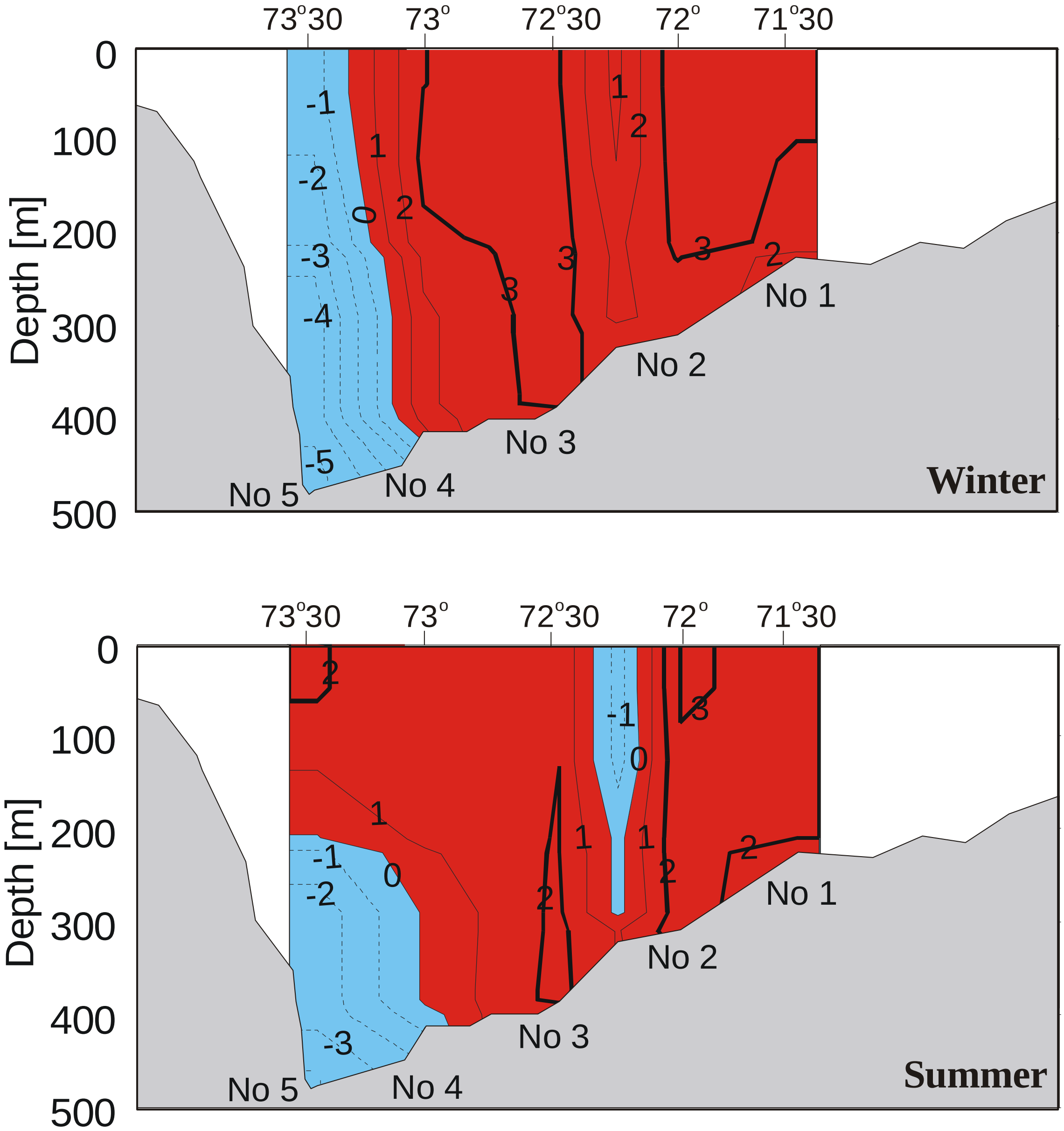

Figure 2. Seasonal mean currents at the Norway - Bear Island section as estimated from the current measurements. The inflowing water has red color and the outflowing water blue.

To further investigate this feature, the numerical tracer experiment was performed. Two tracer water masses with initial positions in the AW cores were advected in the simulated flow field for one year (Figure 3). Totally 15 simulations were executed, and the centre of gravity trajectories for the tracer fields at 100 m depth were grouped into the simulations staring during one of the summer months and those starting during the winter months, and mean “summer” and “winter” trajectories were constructed. These results clearly indicate that the water masses in the mean follow more northerly routes in the western Barents Sea when entering during the summer season than during the winter season.

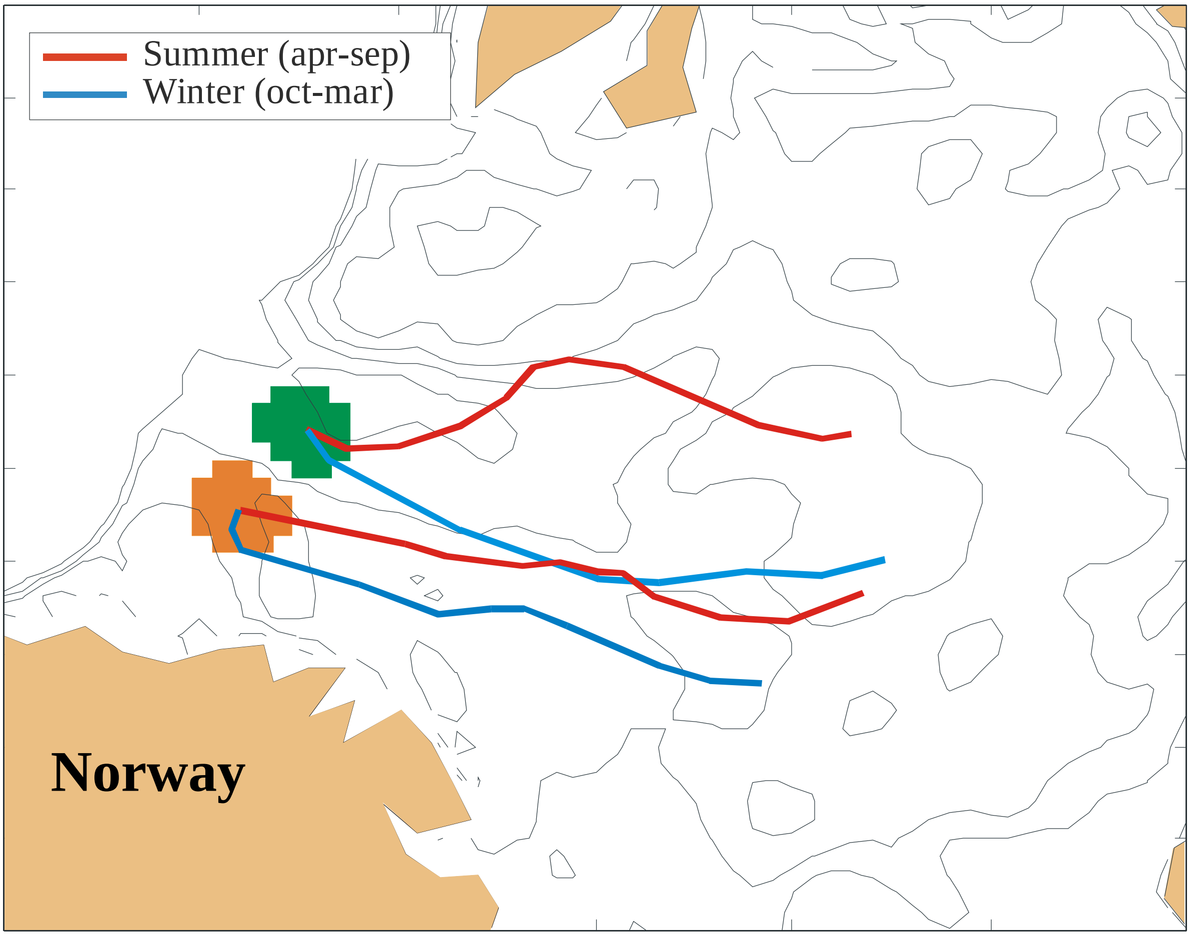

Figure 3. Trajectories for the centre of gravity of tracer water masses at 100 m depth from repeated simulations of one-year tracer advection between March 1997 and June 1999. Red trajectories represent the mean of the simulations starting one of the summer months (April to September) and the blue trajectories represents the mean of simulations starting one of the winter months (October to March).

The reasons for this are most likely manifold, although the atmospheric fields are an obvious candidate. The atmospheric conditions in the Barents Sea are rapidly changing and energetic, making the currents in the Norway-Bear Island section change significantly from day to day (Ingvaldsen et al., 1999). These atmospheric changes are included in the numerical simulations since it uses realistic wind fields and atmospheric pressure with a high time resolution (6-hourly). From the hindcast archive of the Norwegian Meteorological Institute (DNMI) mean wind fields from October 1997 to

March 1998 (winter 1998) and April to September 1998 (summer) are constructed (Figure 4). These mean wind fields show that at the Norway-Bear Island section, the winds are more along the section during summer, indeed supporting a more northerly extension of the AW than the winds during the winter.

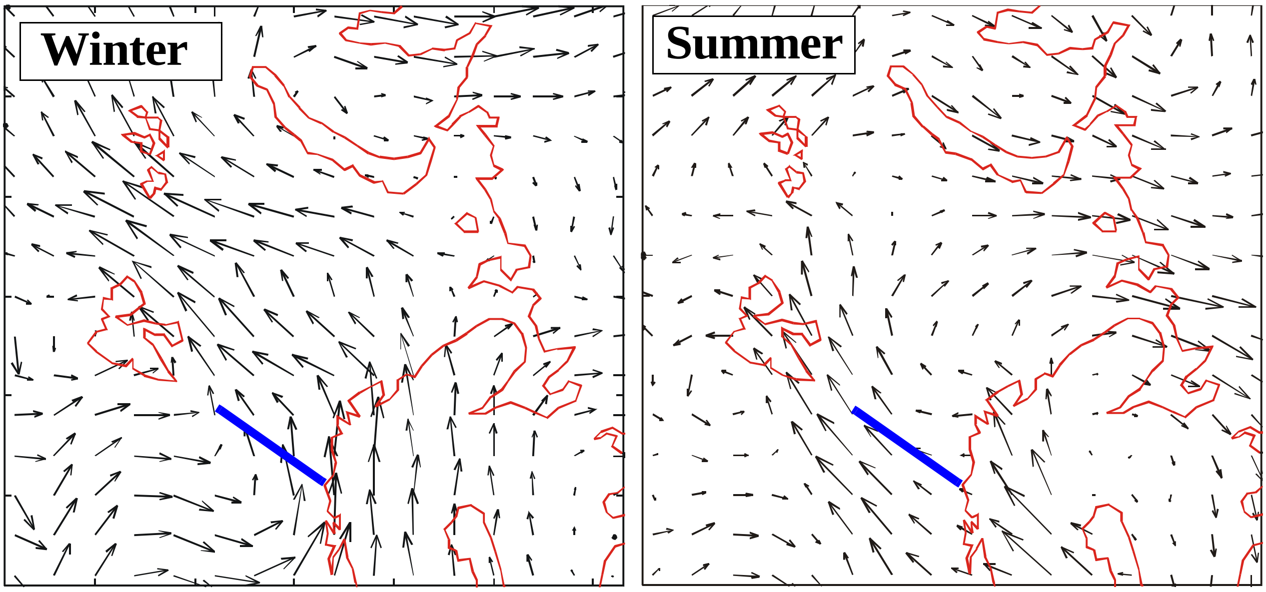

Figure 4. Mean wind fields from the DNMI Hindcast archive for the winter season of 1998 (left panel) and the summer season of 1998 (right panel). The section Norway-Bear Island is marked by the blue line.

Other mechanisms could be the ice-extension or the larger scale interactions (atmospheric pressure over a larger region and/or water mass distribution in the Norwegian, the Barents, and the Kara Seas, and the Arctic Ocean).

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