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SHORT TIME VARIABILITY IN THE ATLANTIC INFLOW TO THE BARENTS SEA

by

Randi Ingvaldsen, Lars Asplin and Harald Loeng

Institute of Marine Research,
P.O. Box 1870 Nordnes
N-5817 Bergen, Norway

ABSTRACT

Current measurements along a section between Norway and Bear Island and results from a three-dimensional numerical model are presented. The results show that the water exchange between the Nordic Seas and the Barents Sea is highly variable on time scales of a few days. The general picture is dominated by frequent and large fluctuations in the current velocities, and an almost complete reversal of the current through parts the section may occur during 1-2 days.

The structure of the current shows substantial and complex variations. The flow may occur in distinct, relatively narrow (50-100 km) cores of inflow and outflow, or in wider (150-200 km) areas of inflow and outflow. Due to the vertical homogeneity of the currents, the variability are expected to be a result of the variability in the sea surface elevation. The variability in the sea-level is dominated by rapid changing (in both time and space) atmospheric conditions (wind and pressure).

Estimates of volume transports between 71°N and 73°45'N give daily mean fluxes between 16 Sv into and 13 Sv out of the Barents Sea. During two subsequent days the absolute volume flux may change by almost 10 Sv.

Introduction

The main inflow of Atlantic water (AW) to the Barents Sea takes place through the Barents Sea Opening (BSO) in the western part of the ocean (Figure 1). The current structure 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 presented by Blindheim (1989). However, more recent publications such as Haugan (1999), who analysed data from vessel mounted Acoustic Doppler Current Profiler (ADCP), found the inflow to take place in two cores with a return flow between. Ingvaldsen *et al.* (1999) analysed a 1-year time series from an array of moorings across the BSO with emphasis on describing the monthly to seasonal variability. Their results showed large fluctuations in the inflow, both in time and space, and suggested that the flow through the section may occur as a wide Atlantic inflow, as an outflow all the way south to 72°N, or as inflow and outflow in nearby cells.

The mean current across the BSO is dominated by density driven currents and the remotely forced North Atlantic Current (NAC). Superposed this mean field is barotropic currents forced by sea-level changes and currents forced by the local atmospheric wind field, as well as several other processes. The variability in the Atlantic inflow may be considerable (Loeng *et al.*, 1997; Haugan, 1999; Ingvaldsen *et al.*, 1999). On monthly basis the transport trough the BSO fluctuates over a range of almost 10 Sv (1 Sv=10^6 m^3s^{-1}) (Ingvaldsen *et al.*, 1999). The inflow is highly variable on daily time scales (Haugan, 1999), and the variability on time scales from day to year is clearly linked to the atmospheric field (Loeng *et al.*, 1997). Although the net effect of the atmospheric forcing on the transport is modest, fluctuations due to the local wind have shown to be of the same magnitude as the mean transport (Ådlandsvik and Loeng, 1991). Variability in the barotropic currents forced by sea-level are also expected to be important on short time scales. McClimans *et al.* (1999) found current fluctuations in the NAC on a 5 day time scale to be correlated to within 15% of the coastal sea-level fluctuations 300 km away. However, the relation failed at higher time resolutions due to (among other things) atmospheric variability.

This paper presents a 16-month time series from an array of moorings across the BSO and results from a three-dimensional numerical model. Parts of this material has been presented in

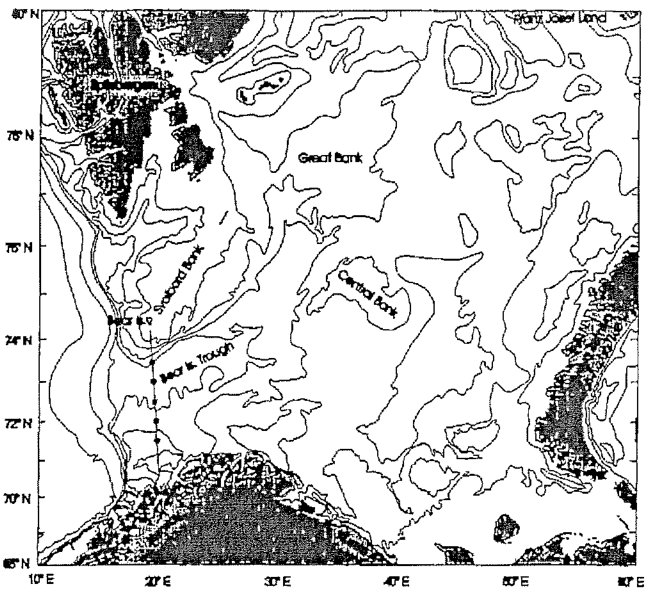

Figure 1. Map of the Barents Sea, indicating the positions of the current meter moorings

Ingvaldsen *et al.* (1999), but then with focus towards describing the monthly to seasonal variability. This study aims at giving a brief description of the short time variability, that is variability on daily to fortnightly time scales, and to present a hypothesis considering the physical phenomena which controls the variability.

Material and methods

The data material consists of current measurements from 5 moorings with all together 19 Aanderaa current meters RCM7 (Aanderaa Instrument, 1987) across the BSO in the period August 97 to December 1998 (Table 1). Data were recorded every 20 minutes, but were decimated to 1-hour sampled series. To fill in the gaps in the time series (se Table 1) 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. The data were lowpass filtered using an order 4 Butterworth filter (Roberts and Roberts, 1978).

The volume flux was estimated by dividing the section between 71°15'N and 73°45'N into rectangles, each current meter assigned a rectangle surrounding it. The transport within each rectangle was estimated from the east-west current component (i.e. the current component normal to the section). The inflowing Coastal Current along the Norwegian coast and the currents on the slope of the Svalbard Bank are not included in the transport calculations, as no current measurements exists from these areas.

Numerical simulations of currents to be compared with the observations were performed with NORWECOM (Skogen and Søiland, 1998). NORWECOM is a 3D, primitive equation, sigma-coordinate coastal ocean model based on the Princeton Ocean Model (Blumberg and Mellor, 1987). The model domain covers the Nordic Seas, the Barents Sea and parts of the Arctic Ocean, and is discretized on a 20 km horizontal polar stereographic grid. In the vertical, 23 sigma layers are used, with high resolution in the Ekman layer to avoid aliasing (Asplin, 1999). The model forcing includes initial and boundary conditions from The Norwegian Meteorological Institute (DNMI)-Institute of Marine Research (IMR) diagnostic climatology (Engedahl, *et al.*, 1998), realistic meteorological forcing from the hindcast archive of DNMI (Eide *et al.*, 1985), monthly mean river runoff and tidal forcing. The model has been validated for the Nordic and Barents Sea (Asplin *et al.*, 1998).

Mooring	Location	Depth of instrument	Bottom depth	Observation period
1	71°31.0'N, 19°46.2'E	50 m	227 m	28/09/97-31/12/98
		125 m		28/09/97-05/03/98 and 28/08/98-31/12/98
		212 m		28/09/97-31/12/98
2	71°58.9'N, 19°37.5'E	50 m	309 m	22/08/97-31/12/98
		125 m		——"——
		225 m		22/08/97-04/03/98 and 28/08/98-31/12/98
		294 m		——"——
3	72°30.7'N, 19°33.2'E	50 m	388 m	22/08/97-28/08/98
		125 m		——"——
		225 m		22/08/97-31/12/98
		373 m		——"——
4	72°59.7'N, 19°33.0'E	50 m	419 m	22/08/97-31/12/98
		125 m		——"——
		225 m		22/08/97-28/08/98
		400 m		22/08/97-11/09/97 and 05/03/98-28/08/98
5	73°29.9'N, 19°19.4'E	50 m	480 m	22/08/97-16/10/97and 05/03/98-31/12/98
		125 m		22/08/97-31/12/98
		225 m		——"——
		465 m		——"——

Table 1. Details of the current meter moorings.

Results

The current components normal to the section between Bear Island and Norway reveal large short time fluctuations in both current speed and lateral structure (e.g. in January 1998 as shown in Figs. 2 and 3). A complete current reversal may take place, at least in parts of the section, within a few days (e.g. Figs. 2 and 3 at the deepest part of the channel in January 25-27). The flow may occur as two distinct, narrow (50-70 km), cores of inflow and outflow, or in a medium wide (~100 km) inflow core and with outflow to the north. There may also be a wider outflow or inflow covering and area of width 150-200 km. The flow seems to adopt certain different structures, and there may be a shift between these structures within days. The consistence between the observations and the numerical model is mostly good. As already shown in Asplin *et al.* (1998) the model inclines to underestimate the outflow.

To further illustrate current fluctuations, the normal component at 225 m depth are plotted against time in Figs. 4 and 5. As the currents in the BSO by several authors (e.g. Blindheim, 1989; Haugan, 1999; Ingvaldsen *et al.*, 1999) have been shown to be predominantly barotropic, the currents at this depth are representative for the water column. A thorough examination show that both the observations and the model indicate shifts of the flow between a structure with two or more relatively narrow inflow cores with return flow between them (cell-structure), a structure with one broader inflow core, or a structure with inflow or outflow over a wider area. The cores of inflow and outflow seem to be in relatively fixed positions (although with some discrepancy between the observations and the model). When the structure of two inflow cores are present, the time series generally imply one core located between 71°N and 72°N and the other at approximately 73°N. The model results imply that the southern cores are wider than the northern core, although this is not confirmed by the current measurements. In the situation with one broader inflow core, this is typically located between 72°30'N and 73°N. Both the observations and the model show that strong inflow may take place as far north as 73°30'N.

The sea surface elevation from the numerical simulations (Fig.6) reveal high variability on the same time scales as the currents. Moreover, a thorough comparison with the current (Figs. 4 and 5) indicates a relation between high net inflow across the section and high sea surface elevation in the southern parts of the section.

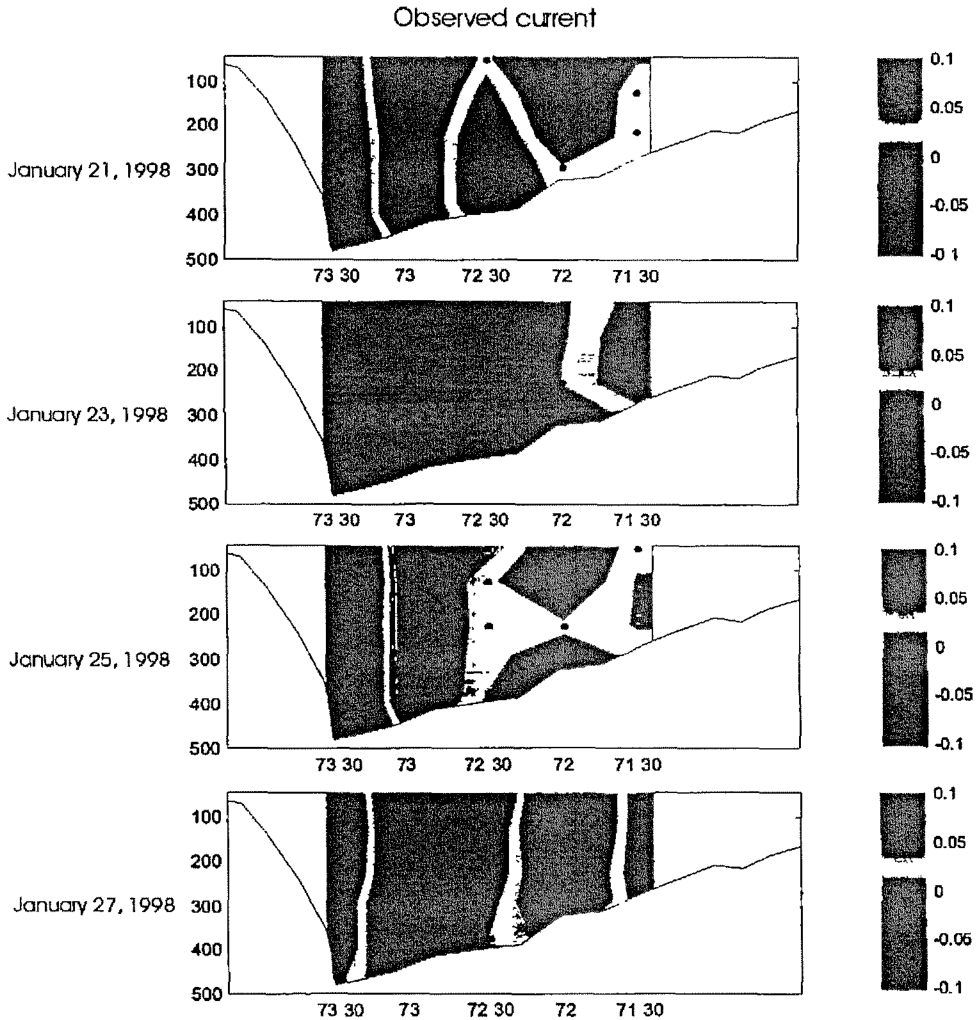

Figure 2. Vertical sections of daily mean currents (m/s) across the BSO as observed with the current meters. The positions of the instruments are indicated by•.

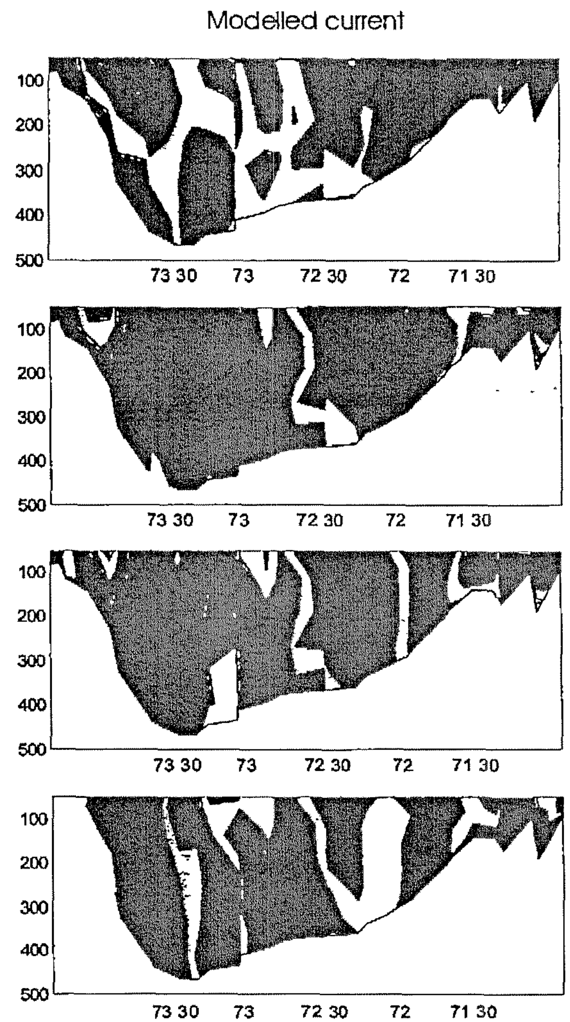

Figure 3. Vertical sections of daily mean currents (m/s) across the BSO as obtained from the numerical model.

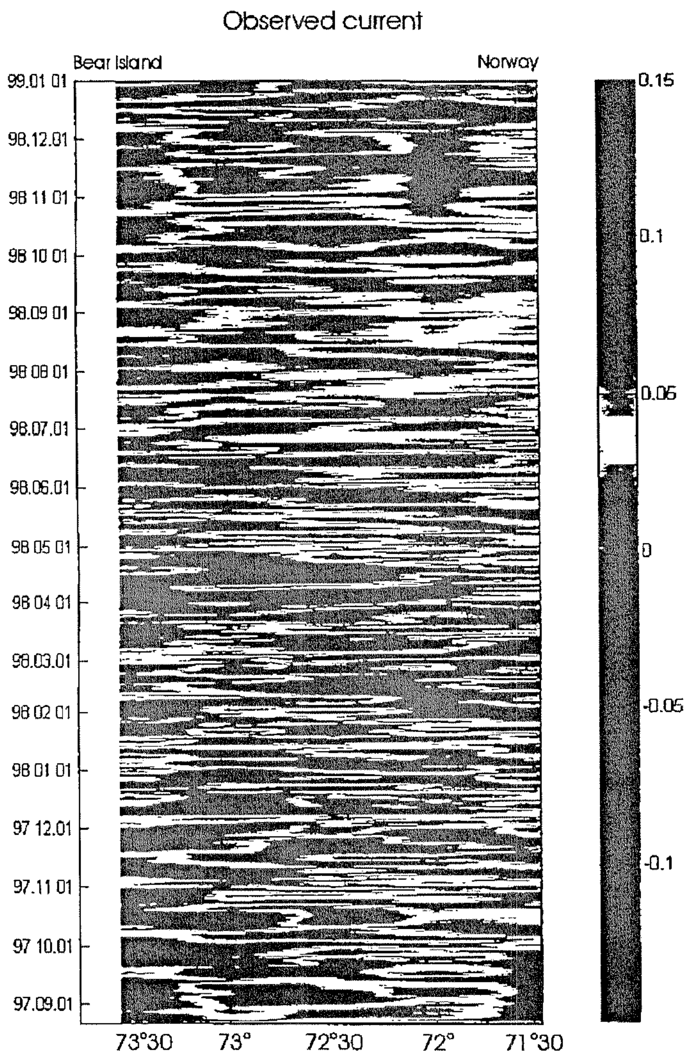

Figure 4. Time series of daily mean currents (m/s) at 225 m depth across the BSO as observed with the current meters.

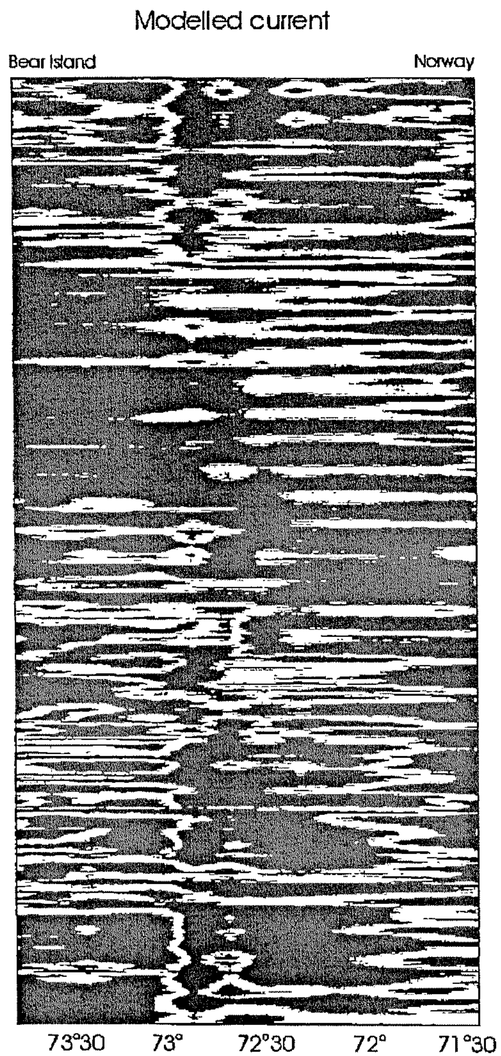

Figure 5. Time series of daily mean currents (m/s) at 225 m depth across the BSO as obtained by the numerical model.

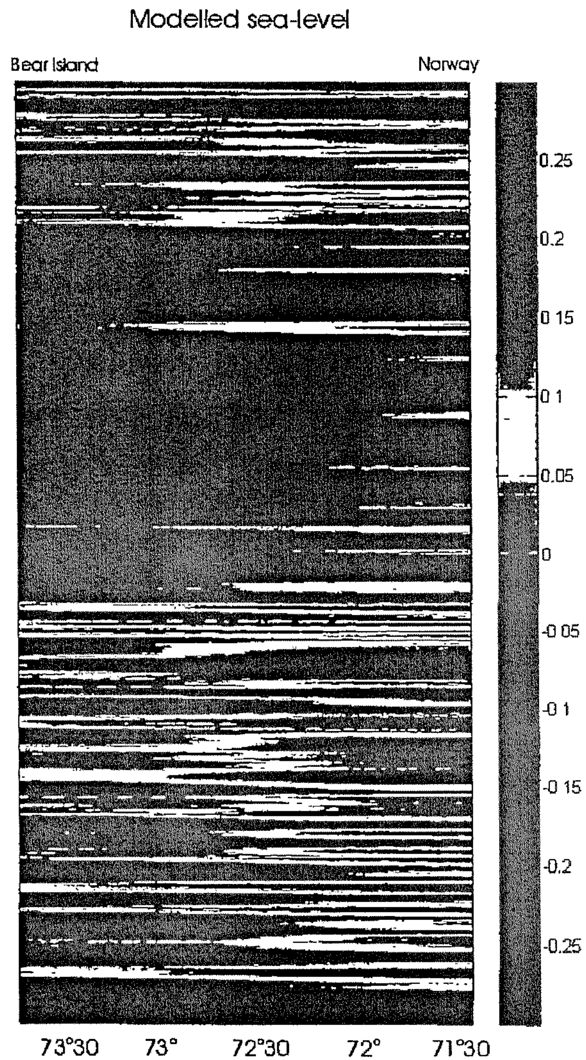

Figure 6. Time series of daily mean sea-level (m) across the BSO as obtained by the numerical model.

The daily mean volume transport is fluctuating between 16 Sv into and 13 Sv out of the Barents Sea (Fig.7). During two subsequent days the absolute volume flux may change by almost 10 Sv. Although this is not shown, a preliminary time series analysis of the transports reveal short time fluctuations on time scales of 55, 64 and 83 hours, 7 and 14 days.

High variability in time and space are also evident in the atmospheric wind field (Fig. 8). A preliminary time series analysis of the east-west wind component reveals short time fluctuations on the same time scales as the currents (55, 64 and 83 hours, 7 and 14 days). Fig. 8 also illustrate the spatial variations in sea surface elevation, and that strong westerly winds give an accumulation of water in the southeastern parts of the BSO.

Discussion

The exchange across the BSO seems to fluctuate between different structures. Both current measurements and model results show that the exchange trough the section may take place in a wide core located in the area 72°30'-73°N with outflow further north. This is consistent with the picture deduced from the hydrographic characteristics in the area, and also by current measurement from a 2-month time series presented by Blindheim (1989).

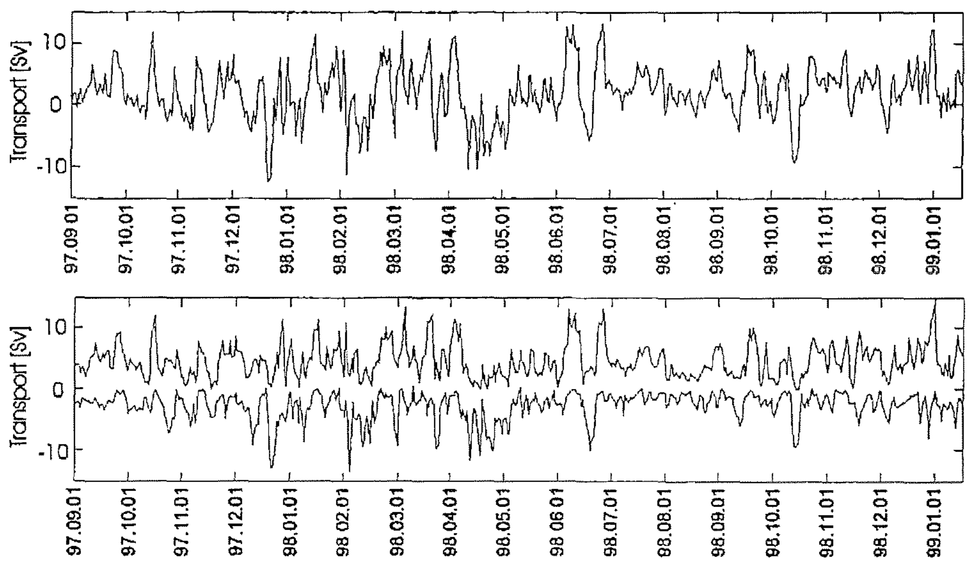

Figure 7. Daily mean volume flux through the BSO as estimated from the current measurements. Upper panel shows total flux, lower panel shows volume flux separated into inflow (positive values) and outflow (negative values).

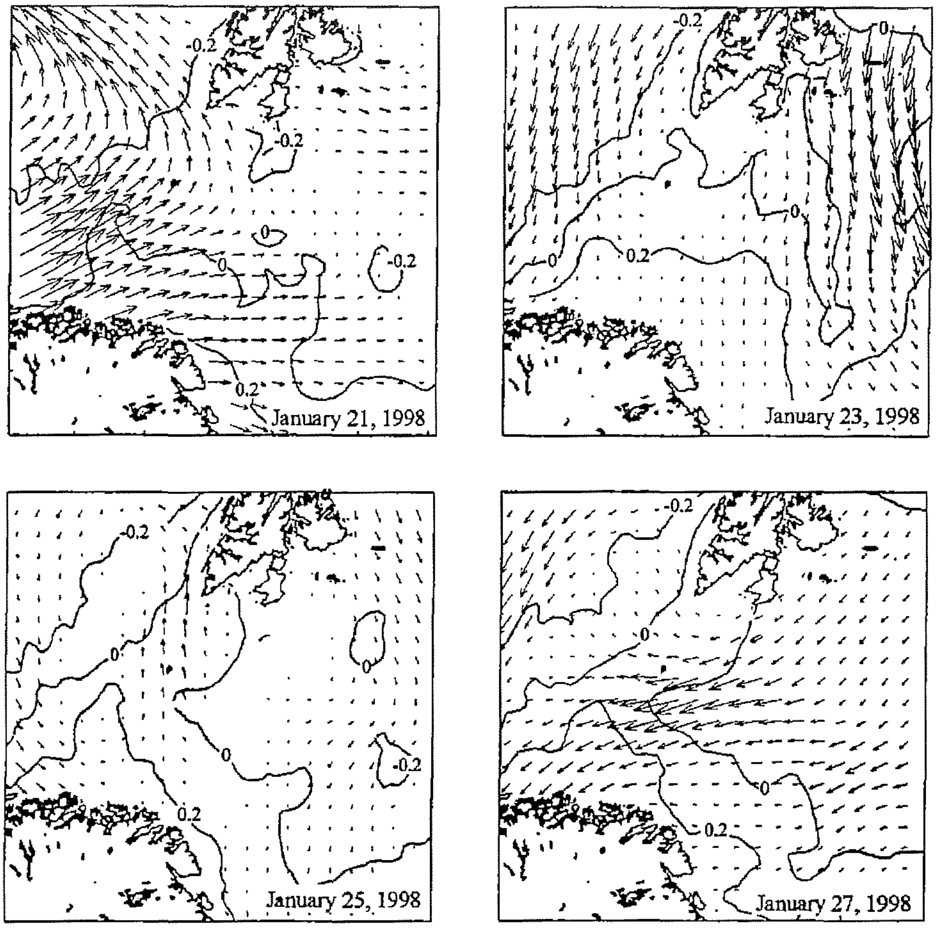

Figure 8. Daily mean wind from DNMI hindcast archive (arrows) and sea-level as obtained from the numerical model (isolines).

The results also showed convincing evidence that the exchange through the section at times takes place in two cores of Atlantic inflow with a return flow in between (Fig.2 and 3, January 21). One core seems to be centred in the area between 72°45'N and 73°N, the other somewhere between 71°N and 72°N. These results are in close agreement with Haugan (1999) who found two cores of Atlantic inflow sited close to the mentioned positions, and a return flow between them. Moreover, as pointed out by Blindheim (1989), the presence of such a semi-permanent countercurrent are suggested in the many hydrographic mappings across the section. The lateral location of the cores are subject to uncertainties due to possible insufficient lateral resolution in both current measurements and numerical grid. As these cores seems to be 50-70 km wide, the array of moorings with a mutual distance of 50 km are not able to resolve these features with high accuracy. The numerical model has a horizontal grid size of 20 km, which makes it more suitable for studying the cell-structure, although a finer grid resolution would make it more reliable. Future plans include decreasing the grid size to 4 km for the BSO. The separation of inflow in two cores with return flow between are likely to be related to bottom topography. This relation may then be investigated by sensitivity tests due to small changes in model topography.

At times both current measurements and model results show inflow over an area of width 150-200 km, a situation also observed by Haugan (1999). This phenomena is not only a short time feature; it might be present for a whole month (Ingvaldsen *et al.*, 1999).

The variability in the local atmospheric fields in the BSO is large (Fig.8), and fluctuations in transport due to the local wind have shown to be of the same magnitude as the mean transport (Ådlandsvik, 1989; Loeng *et al.*, 1997). This is confirmed by the preliminary time series analysis which revealed short time fluctuations on the same time scales for volume transport and wind-field (55, 64 and 83 hours, 7 and 14 days, unpublished results). For the cycles on the tidal periods (14 and 7 days), the fluctuations in the current field are obviously partly forced by the tides. Also the sea-level reveal strong variability both in time and space (Fig.6 and 8). Using a simple geostrophic model, McClimans *et al.* (1999) showed that fluctuations in coastal sea-level may be traced in the NAC 300 km away, even on a 5 day time scale. Based on this it seems reasonable to expect the short time variability in the currents across the BSO to be forced by a combination or interaction of fluctuations in the local wind field and fluctuations in sea surface elevation. The results from January 21-27 are used to illustrate this (Fig.2, 3 and 8). During periods with strong westerly or easterly winds (Fig. 8, January 21 and 27) the flow is cell-structured with two cores of inflow and a return flow between (Fig. 2 and 3). During periods with calm winds there might be a structure with wide outflow if the sea-level east in the area is raised prior to the wind-cease (January 23), or there might be a wider inflow core and outflow in the northern parts if the sea-level is not raised (January 25). Note that due to the remote forcing of the NAC a higher water level in southern parts of the section is likely to be present even with no wind forcing. The effect of the wind on the current structure is also important on seasonal time scales (Ingvaldsen *et al.*, 1999). During winter the strong, highly fluctuating winds produce a mean current structure with distinct cores and strong lateral velocity gradients. During summer the winds are weaker and the mean current structure is dominated by inflow over a wider area and lower horizontal shear (Ingvaldsen *et al.*, 1999). This feature is also evident from the daily mean currents as presented in Fig. 4 and 5.

The results may be summarised as follow:

- The short time variability in the Atlantic inflow to the Barents Sea is controlled by an interaction between the local atmospheric fields and the sea surface elevation. Wave motions or other processes might also be important.
- The flow in central parts of the section may occur in two distinct, relatively narrow (50-70 km) inflow cores located between 71°30'N and 72°N and near 72°45'N-73°N. Between the inflow cores it is a return flow. This structure seems to be initiated by strong, highly fluctuating winds typically for late autumn and winter.
- The flow in central parts of the section may occur in a wider (~100 km) inflow core somewhere near 72°30'N-73°N. This might be the situation when the inflow is dominated by the remote forcing of the NAC without local wind and sea-level interference.
- The flow in central parts of the section may occur as an outflow or inflow covering an area of width 150-200 km. These patterns are most likely caused by horizontal pressure gradients caused by a change in sea-level either by accumulation of water or by an atmospheric low or high.

Based on these results we construct the following hypothesis for further investigation:

The short time variability in the Atlantic inflow to the Barents Sea is controlled by an interaction between the local atmospheric fields and the sea surface elevation. Dominated by the remote forcing of the NAC, the inflow occur as a medium wide core. During strong, highly fluctuating winds the flow occur in distinct cores of inflow and return flow between. In periods with strong gradients in sea-level between the Norwegian Sea and the Barents Sea, the flow occur as an inflow or outflow covering a wide area.

Acknowledgements

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