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Variability of the surface circulation of the Nordic Seas during the 1990s

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The surface circulation of the Nordic Seas and its variability during the 1990s is investigated using current data obtained from satellite-tracked drifters. We find a seasonal intensification of the circulation during winter and during the first half of the 1990s, both due to the enhanced atmospheric momentum forcing.

Keywords: drifters, mean circulation, Nordic Seas, variability.

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Introduction

The near surface circulation of the Nordic Seas is cyclonic, with two meridional boundary currents on either side, the northward flowing Norwegian Current and the southward East Greenland Current. This general pattern has been known for a long time (Pettersson, 1900; Helland-Hansen and Nansen, 1909) and is based on ship drift observations and geostrophic estimates. As more data became available in the course of time, details were added to this picture. While Pettersson (1900) showed just one large-scale cyclonic circulation regime, Poulain *et al.* (1996) find four cyclonic gyres embedded between the boundary currents, tightly locked to the local bottom topography. In this article we study the near surface circulation of the Nordic Seas and the region south of the Greenland–Scotland Ridge using current data obtained with satellite tracked drifters during the 1990s. In addition to the mean flow we discuss the variability of the circulation on seasonal and interannual time scales.

Data and methods

Within the area between 58°N–80°N and 30°W –30°E more than 50 000 buoy days of position data were obtained from 266 surface drifters drogued at 15 m depth. These drifters were deployed within several international programmes during the 1990s, such as the World Ocean Circulation Experiment. The data distribution in time and space is not uniform. During the first half of the decade the majority of the data were obtained north of the Greenland–Scotland Ridge, while during the second half drifters were mainly released south of the ridge. This limits the quality of our results, in particular with respect to the discussion of interannual variability. Only drogued data are considered here. In a first step the position data were interpolated to 6-h time intervals and velocities calculated. Then tidal and inertial waves were removed from the calculated velocity time-series of the individual drifters using a low-pass filter with a cut-off period of 2 days. Finally we separated the meso-scale variability from the time-series by filtering with a cut-off of 18 days (Jakobsen, 2000).

Information about the circulation can be obtained directly from the Lagrangian data, as in Figure 1. However, for the discussion of variability we transformed the data into "pseudo-Eulerian" averages (vectors in Figure 2) – a technique discussed by Garraffo *et al.* (2001) for example. This enables the calculation of differences between seasons and years.

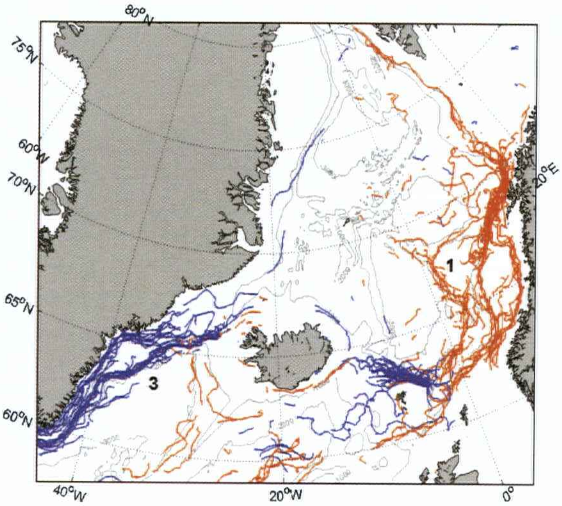

Figure 1. Trajectories of the satellite tracked drifters when the mean flow exceeded 25 cm s^{-1}. Red lines indicate northward and blue lines southward movement. Numbers refer to the circulation features discussed in the text. Black lines indicate the 1000, 2000, and 3000 isobaths.

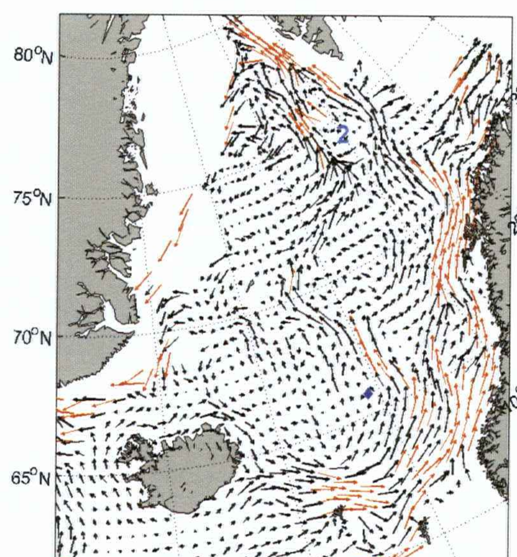

Figure 2. Pseudo-Eulerian description of the mean flow. The length of the vector scales with the velocity, but vectors in excess of 15 cm s^{-1} are held fixed and marked red. Numbers refer to the circulation features discussed in the text. The marking at 1°W, 65°45′N represents the minimal westward extend of Atlantic Water found by Blindheim *et al.* (2000).

Mean circulation

Since about half of our data are identical to those used in Poulain *et al.* (1996) we describe the mean circulation only briefly. The numbers refer to those indicated in Figures 1 and 2.

(1) There are three branches of the eastern boundary current system. The coastal current and the two branches of the Norwegian Current, one on continental slope and one spreading further offshore towards the Greenland Basin. (2) These two outer branches continue into the West Spitsbergen Current, following the shelf edge and the Arctic Front Jet east of the Greenland Sea Basin. (3) Two branches of the East Greenland Current system are seen in the Denmark Strait, a near coastal one over the shelf and one on the slope originating from the eastern side of the Denmark Strait. Further south at 65°N the two branches diverge, indicating topographic steering.

Blindheim *et al.* (2000) found that the westward extent of water with salinity above 35, measured on a 65°45'N transect, shifted between 0° and 7°W with changing NAO conditions. This led Blindheim *et al.* (2001) to state that a strong western branch of the Norwegian Atlantic Current is absent during high North Atlantic Oscillation Index conditions. We cannot confirm this finding, as our drifter data do show such a branch, even though the 1990s are characterized by the highest NAO Index conditions of the century. To show that our western branch is most likely carrying water of Atlantic origin rather than recirculated water, we show the minimal westward extent of the 35 isohaline measured in the study of Blindheim *et al.* (2000) in Figure 2.

Seasonal variability

To examine the seasonal variability we subtracted the mean Eulerian summer flow (May to October) from the mean winter flow (November to April) (Figure 3). Over most of the Nordic Seas and the North Atlantic the difference is positive, indicating a winter intensification of the circulation. This holds in particular for the strong eastern boundary currents and jets associated with topographic features. The winter increase of the flow is in the order 5 cm s^{-1}, which corresponds to about 20% of the mean flow, but in some areas, such as close to the Norwegian continental slope, it may be up to 15 cm s^{-1} stronger. Such seasonal variability has also been observed in long-term measurements with moored instruments, for example in the Norwegian Current near 63°N (Orvik *et al.*, 1999) and in the east Greenland Current near 75°N (Woodgate *et al.*, 1999). It can be related to the strengthening of the wind forcing during winter (not shown), although its amplitude is much weaker than a direct Sverdrup response to the forcing would suggest. This is likely

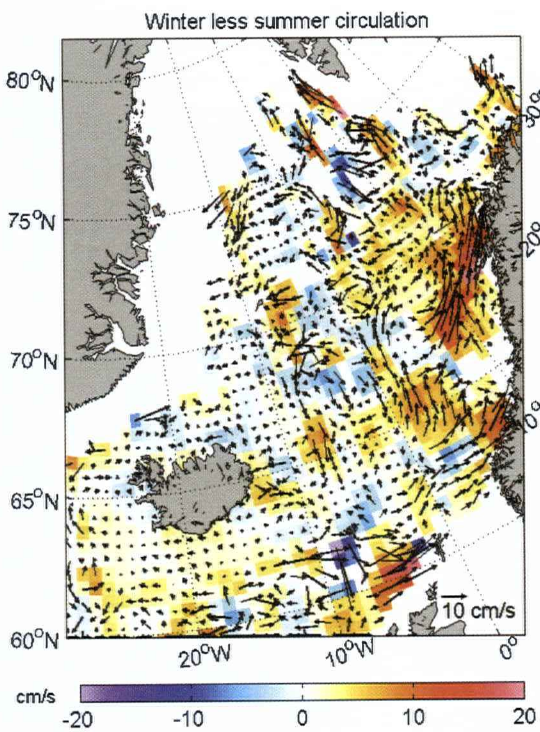

Figure 3. Seasonal variability of the surface circulation, depicted as difference vectors between the winter mean (Nov–Apr) and the summer mean (May–Oct) circulation. Colours indicate the difference in rms values.

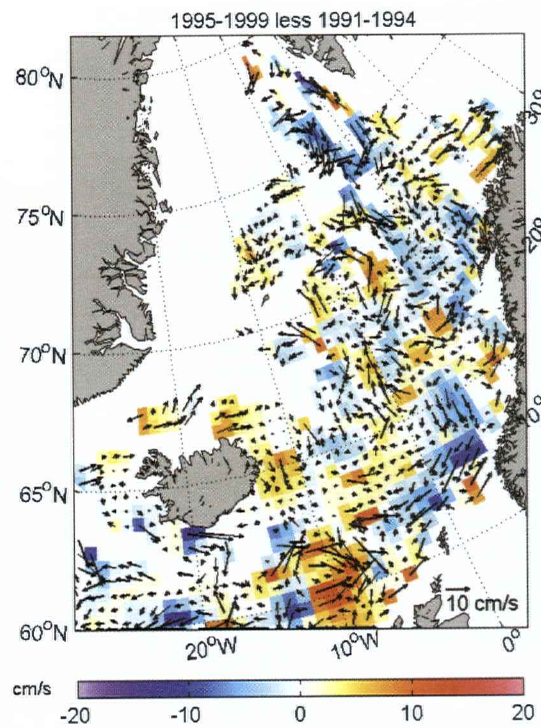

Figure 4. Interannual variability of the surface circulation, depicted as difference vectors between the 1995–1999 mean and the 1991–1994 mean circulation. Colours indicate the difference in rms values.

due to the influence of the bottom topography, which upsets a simple Sverdrup balance. In addition, the relatively stronger baroclinic forcing during summer keeps up the circulation during this period of weak wind forcing.

Interannual variability

The distribution of the drifter data in time allows a comparison of the mean circulation during the two periods 1991–1994 and 1995–1999 (Figure 4). The distribution of the differences is rather scattered in the regions of weak mean currents, but is clearer in the Atlantic inflow regime. The west Norwegian and West Spitsbergen currents are about 5 cm s^{-1} stronger during the first period, which is comparable to the seasonal variability.

For the eastern boundary currents, the weakening towards the second half of the decade can be related to the wind forcing. The windstress curl over the eastern Nordic seas during 1996–1997 was less than half of the mean during the rest of the 1990s (Figure 5). Our drifter data do not allow separation of these 2 years, but the low values could explain the weaker Atlantic flow during 1995–1999.

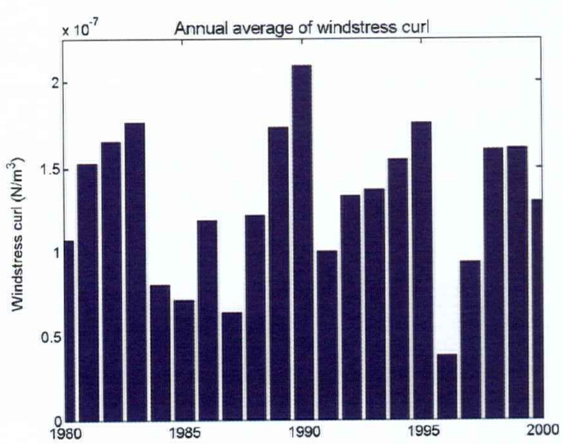

Figure 5. Interannual variability of the windstress curl over the area 10°W–10°E, 60°N–75°N. Shown are yearly averages in N m^{-3} derived from the NCEP/NCAR data set (Kalnay *et al.*, 1996) during the period 1980–2000.

Conclusions

The analysis of 9 years of drifter data from the Nordic seas shows substantial variability of the circulation, in particular within the Atlantic regime. The variability on seasonal and interannual time scales is related to, and at least partly driven by, the wind forcing in the region. The wind-driven circulation in the Nordic Seas is generally thought to redistribute water masses, while the exchanges with the North Atlantic are thermohaline driven (Hansen and Østerhus, 2000). However, the latter is dependent on the redistribution of water (Dickson *et al.*, 1996). Since the Atlantic Water provides the heat for a mild northern Europe, and the salt for maintaining deep convection and the thermohaline overturning circulation, this aspect should also be considered in climate studies in addition to the usual buoyancy forcing.

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