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THE CIRCULATION IN THE NORTERN PART OF THE DENMARK STRAIT AND ITS VARIABILITY

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ABSTRACT

A well established feature of the Denmark Strait Overflow Water (DSOW) plume is its apparent stability. It shows very little variability on time scales longer than a few days. In particular no seasonal signal has been detected in the plume and there also seems to be little interannual variability. This raises questions on the source for this steady plume upstream from the sill and indicates that the source probably does not show significant seasonal or interannual signal. Current meter records from a section in the northern part of the strait indicate that the flow is towards the southwest over the whole deeper part of the section. Over the Greenland slope the current shows a very pronounced seasonal signal with the current even reversing during the summer. On the other hand the current over the Iceland slope shows similar behaviour to the one observed in the plume. It shows no significant seasonal nor interannual variability. This would indicate that there is very little, if any, water recirculating back into the Iceland Sea from the East Greenland Current after it crosses this section. Furthermore this suggests that the DSOW has its source at the eastern edge of the EGC and thus a large part of it could be originating directly from the Iceland Sea.

Keywords: circulation, climate, Denmark Strait, overflow, variability.

INTRODUCTION

One way in which the ocean redistributes heat and salt is through the thermohaline circulation, which is of primary importance in the global climate system. The thermohaline circulation is mainly driven by heat loss from the ocean to the atmosphere whereby water at high latitude sinks and flows towards lower latitudes at deep levels and is replaced at the surface by warmer water from lower latitudes. In the northern hemisphere the main inputs to the thermohaline circulation are from the Iceland Sea, the Greenland Sea, the Labrador Sea and the Arctic Ocean. In the southern hemisphere various sources are located on the continental shelf of Antarctica. One of the most important of the northern sources is the Denmark Strait overflow water (DSOW) that comprises 30% of the total overflow-generated tongue, including the Labrador Sea Water, flowing southwards around the Grand Banks, Swift (1984). To be able to assess the possible impacts of different conditions on the strength of the thermohaline circulation one must at least know where and how the different water masses contributing to the circulation are formed and by which way they enter the deep ocean. Since 1955 when Cooper (1955) suggested that the overflow through the Denmark Strait was a significant contributor to the deep water of the North Atlantic, there have been different views on the origin of this water and how it reaches the Denmark Strait.

Swift (1980) concluded from water mass analysis in the Iceland Sea that the water constituting the overflow was mainly upper Arctic Intermediate Water (uAIW) formed in the Iceland Sea during winter. He assumed that the water reached the Denmark Strait within the EGC since his view of the circulation was such that it did not allow a direct flow of water from the Iceland Sea through the Denmark Strait. More recently his conclusions have been questioned, and it has been suggested that the formation of the DSOW occurs further north in the Greenland Sea, Strass et al. (1993) or even partly in the Arctic Ocean, Mauritzen (1996 a,b). The main reason for those alternative ideas, is that it has not been shown that there exists a direct flow of DSOW from the Iceland Sea towards the Denmark Strait and the mixing of uAIW towards the EGC has been thought to be a too slow process to account for the persistence and stability of the Denmark Strait overflow. Strass et al. (1993) show the presence of water within the Greenland Sea with properties similar to those of the overflow water as defined by Swift et al (1980) and they suggest that this water is formed by mixing induced by baroclinic instability within the EGC. They suggest that this water then flows with the EGC towards the Denmark Strait and eventually overflows. Mauritzen (1996 a,b) goes a step further and assumes that the main source of the DSOW is the Arctic Atlantic Water that exits the Arctic Ocean underneath the Polar Water of the EGC. These views will be disputed in this paper and it will be shown, using direct current meter measurements from the northern part of the Denmark Strait, that there is a direct path for the DSOW from the Iceland Sea to the Denmark Strait contrary to what has been suggested by some authors recently. Also the circulation is different from that indicated by Swift (1980).

DATA

Aanderaa current meters have been deployed annually since 1988 at several positions at 2-4 depth levels on a section about 200 km north of the Denmark Strait sill (Figure 1). Also CTD stations have been taken on this section annually in early September since 1987. The usual vertical distribution of current meters is shown in Figure 2 superimposed on a potential temperature on the section in September 1997. It reveals the water mass distribution with warm Atlantic Water along Iceland on the right. The Polar Water dominates in the upper layer along the rest of the section seen as a temperature minimum at ca. 100 m depth. The Intermediate Waters are seen as a maximum in the temperature at about 400 m depth. The deeper parts are covered by cold deep waters.

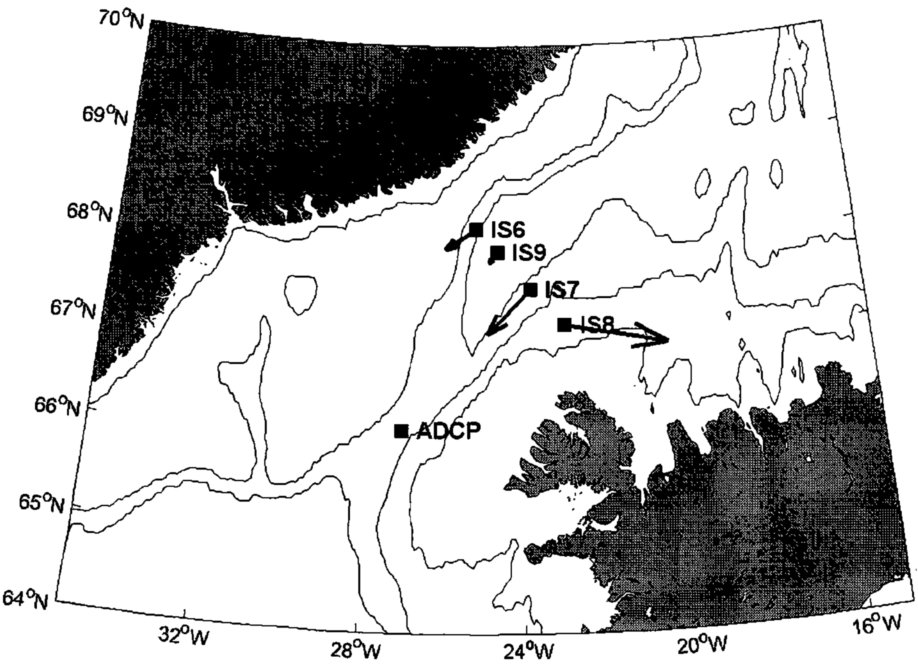

Figure 1. The current meter mooring positions. The annually averaged mean velocity at 500 m depth is shown over the deeper part and at 200 m depth at IS8.

The vertical distribution of the current meters was chosen to cover the water masses present in the area, the upper (cold Polar Water) the intermediate (relatively warm Intermediate Waters) and the bottom meters (cold Deep Waters). The IS8 mooring was designed to measure the flow of Atlantic Water to the North Icelandic shelf.

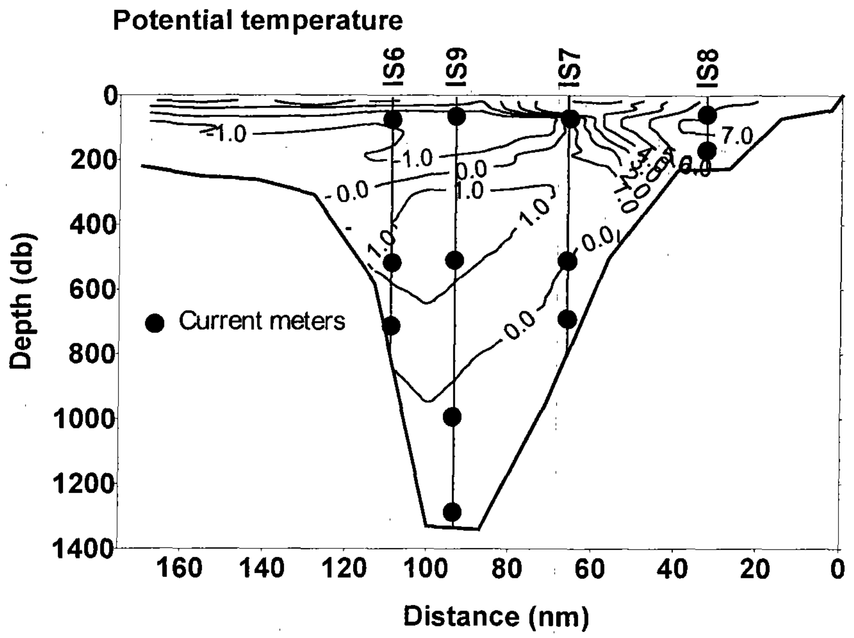

Figure 2. The potential temperature on the mooring section and the vertical position of the current meters.

CIRCULATION IN THE NORTHERN PART OF THE DENMARK STRAIT

Until recently the ideas of the circulation in the northern part of the Denmark Strait have mainly been based on the assumption of geostrophic flow. A typical example of the dynamic height in the Iceland Sea is shown in Figure 3 from Swift (1980). It indicates the southward flowing East Greenland Current (EGC) along the East Greenland continental slope. A part of this current is shown recirculating northwards along the Icelandic continental slope and Swift and Aagaard (1981) suggested that this recirculation constituted a part of the East Icelandic Current. On the Icelandic shelf and partly over the slope, the North Icelandic Irminger current carries Atlantic Water towards the North Icelandic shelf area.

Within this circulation scheme there is no current flowing directly from the Iceland Sea to the Denmark Strait and this was why Swift and Aagaard (1981) had to propose isopycnal mixing of their uAIW towards the EGC that would subsequently carry the water through the Denmark Strait as overflow water. This was thought by Mauritzen (1996 a,b) to be a too slow and unstable process to provide a realistic source for the Denmark Strait Overflow Water (DSOW). This has led to investigations of other possibilities for the source of the DSOW.

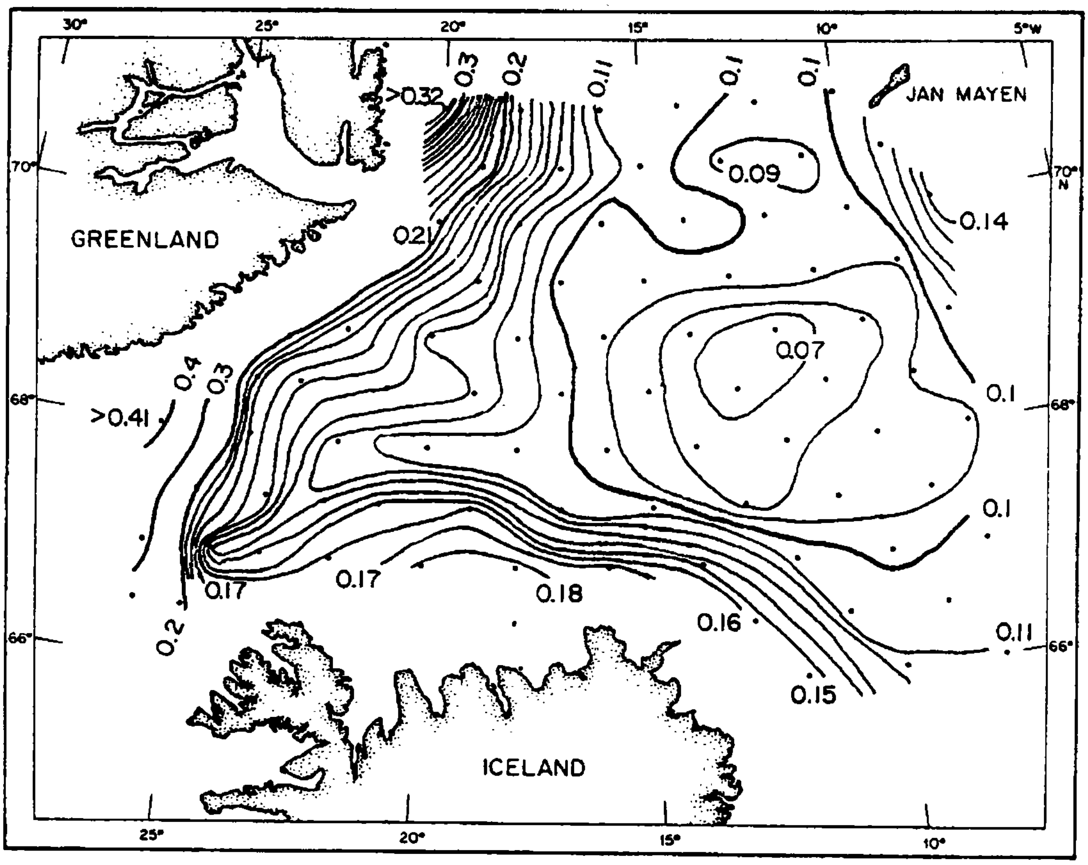

Figure 3. The dynamic topography relative to 800 m depth in dyn m. From Swift (1980).

On fig. 1 is shown the annually averaged current from September 1990 to September 1991 at nominally 500 m depth at IS6,7 and 9 and at 200 m at IS8. It shows that the current is at all the positions except at IS8 to the southwest, towards the Denmark Strait. This holds true at all depth levels so there is no evidence of a recirculation of water from the EGC towards the north over the Icelandic continental slope. Over the Icelandic slope at IS7 there is a strong current (>8 cm/s) flowing towards the Denmark Strait. In the central part of the strait at IS9 the current is somewhat smaller than on either side. This might indicate that the outflowing current is split into two branches, one of which is the EGC and another one that has a more direct connection to the Iceland Sea. There is therefore a possibility for a direct route for water from the Iceland Sea to overflow through the Denmark Strait.

The mooring at IS8 over the shelf measures the flow of Atlantic water towards the North Icelandic shelf area and its velocity at 200 m depth is shown on the map in Figure 1.

There have been several studies of the current structure in the overflow downstream of the Denmark Strait sill, Aagaard and Malmberg (1978), Dickson and Brown (1994). The most prominent feature of the flow is high variability at periods of a few days but an absence of variability at longer timescales. In particular this is true for the seasonal variability and none of the 4 one year long current meter records studied by Aagaard and Malmberg (1978) nor any of the several tens of records studied by Dickson and Brown (1994) show any sign of seasonal variability.

Recently an ADCP has been placed just south of the sill in the Denmark Strait, about 200 km downstream from the Aanderaa current meter section. These measureurements also show high variability at short timescales (days), but little variability at longer timescales. The monthly mean values of the along channel velocity is shown in Figure 4. As seen there is no incation of seasonal variability.

When looking for a source for the DSOW upstream of the sill it is therefore an important constraint that the flow does not have a marked seasonal variability.

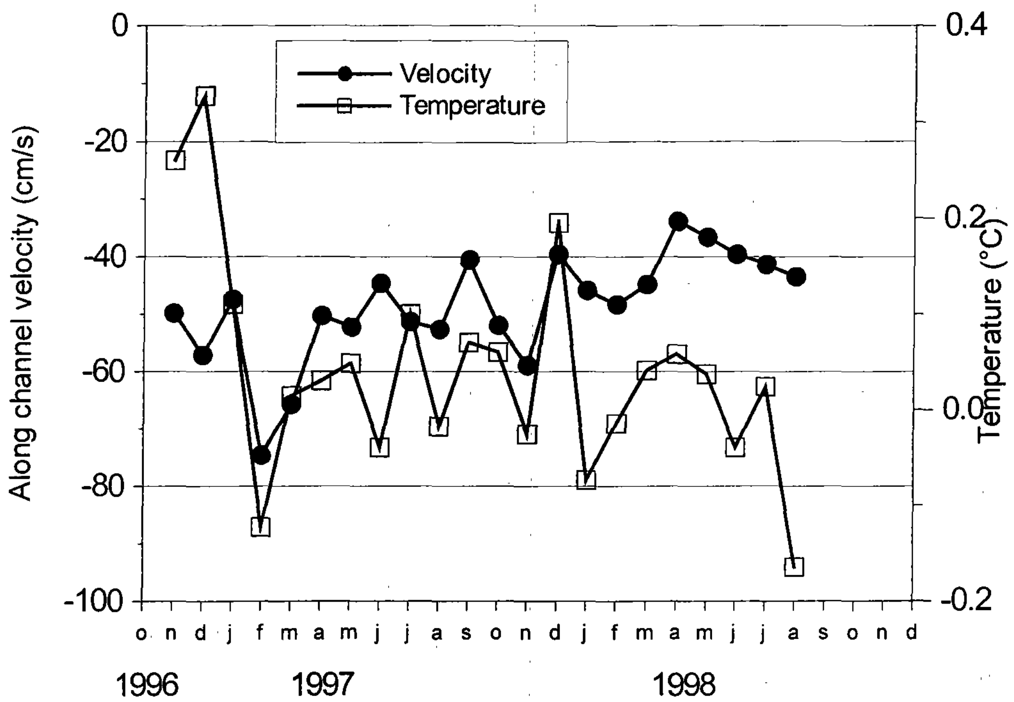

Figure 4. Monthly averages of the along channel velocity and temperature from an ADCP situated just south of the sill. Negative valus indicate flow to the southwest.

The current at 500 m depth should correspond to the overflowing water masses since the sill depth is 630 m. Over the Greenland slope at IS6 Figure 5 the current shows a very pronounced seasonal signal with the current reversing during the summer. This makes it very unlikely that this part of the circulation contributes much to the DSOW.

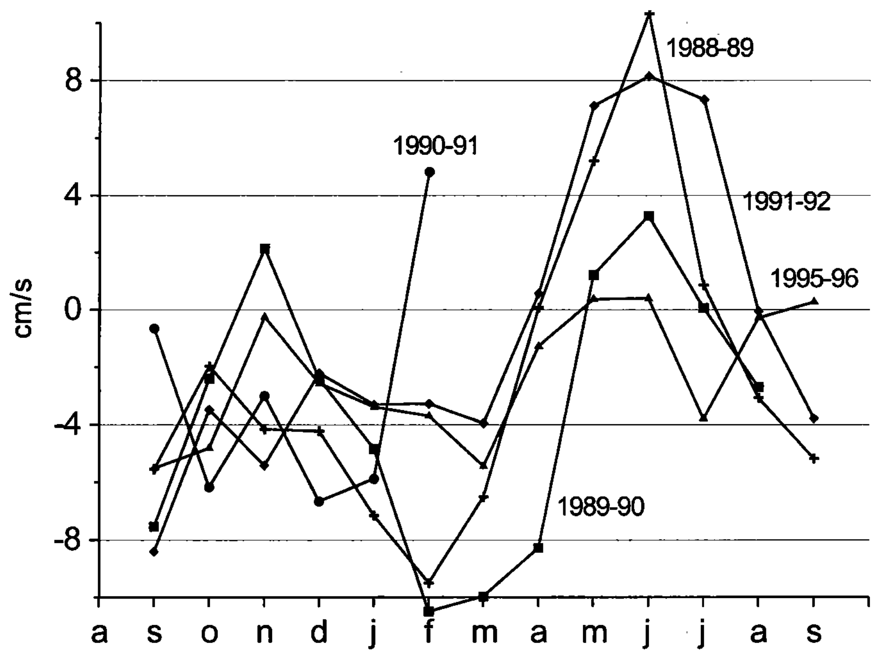

Figure 5. Monthly averages of the N-S component of the velocity at IS6.

Also at IS9 over the deepest part of the section and in the core of the warm intermediate water (Figure 6) the current indicates a similar seasonal signal.

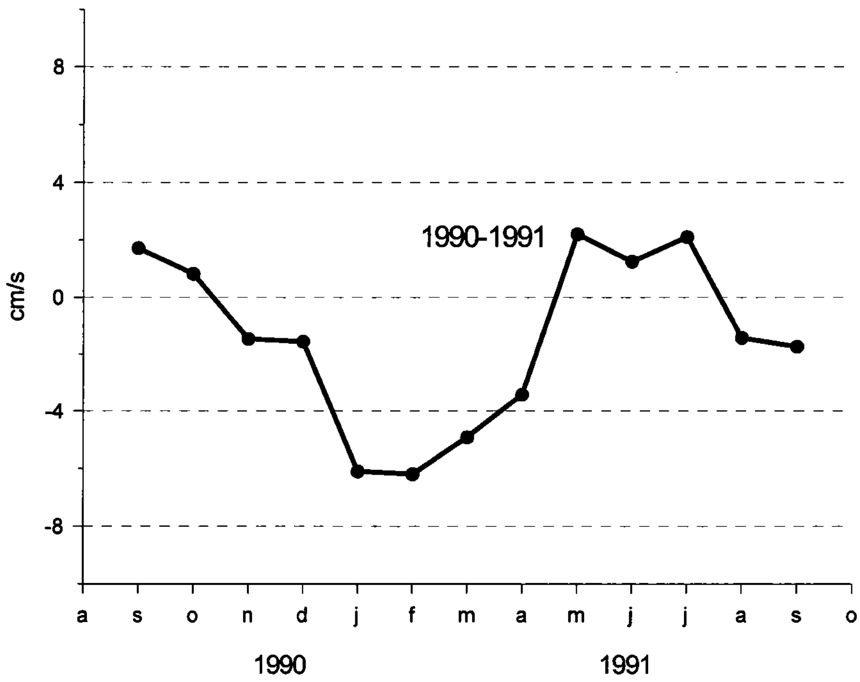

Figure 6. Monthly averages of the N-S component of the velocity at IS9.

On the other hand the current meter over the Iceland slope at IS7 (Figure 7) shows a behaviour similar to the one observed in the plume. It shows no clear sign of seasonal or interannual variability.

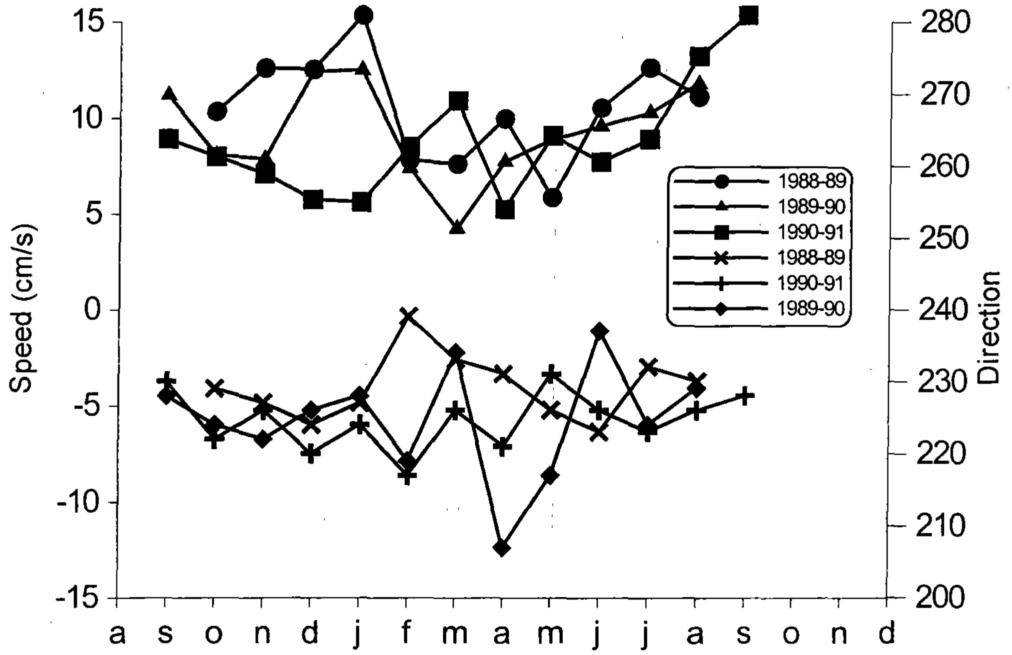

Figure 7. Monthly averages of the velocity, shown as speed and direction IS7. The upper curves are speed and the lower ones are directions.

This suggests that the DSOW has its source at the eastern edge of the southwards flow towards the Denmark Strait and thus a large part of it could be originating from the Iceland Sea and transported directly towards the Denmark Strait.

CONCLUSIONS

It has been shown here that there is no sign of a recirculation in the Denmark Strait of a part of the EGC into the Iceland Sea contrary to what has been thought to be case earlier. Thus the East Icelandic Current must have its origin north of the current meter section discussed here. The current over the Icelandic slope in the Denmark Strait shows no seasonal nor interannual variation and it is therefore likely that it is contributing most of the DSOW rather than the flow over the Greenland slope that shows large seasonal signal contrary to what has been observed for the overflow plume. This indicates that there is a possibility that a large part of the DSOW is provided directly from the Iceland Sea which was the most likely source for this water according to the water mass analysis of Swift and Aagaard (1981).

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