

WIND GENERATED FLUCTUATIONS IN WATER MASS STRUCTURE
IN THE NORDIC SEAS

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Abstract. Hydrographic sections in the Nordic Seas which have been repeated during the 1990s are compared with observations from 1958 (IGY) in the Norwegian Sea and from 1965 in the Greenland Sea. The comparison shows that the water mass structure has changed considerably since 1958/1965. In the Greenland Sea there has been a warming since the 1970s and the volume of water with salinity higher than 34.9 has increased while the volume of older Greenland Sea Deep Water has decreased and vanished after 1995. The product of the winter convection when no deep water is formed, is a less dense water mass which spreads isopycnally on top of the deep water. Depending on wind conditions, this water mass extends from the Greenland and Iceland Seas into the Norwegian and Lofoten basins and forms an intermediate layer between the inflowing Atlantic Water and the Deep water. Also the deep water formation seems to be wind generated since there seems to be close correlation between the upper layer salinity in the central Greenland Sea and the gradient of the mean sea level pressure across the East Greenland Current.

Introduction

During the past three - four decades there has been a gradual cooling and freshening in the western and central Norwegian Sea. This is driven by the prevailing wind conditions in the manner that increased westerlies result in an eastward shift of the Arctic front in the Norwegian Basin. Accordingly, there will also be a corresponding change in the water mass distribution with the increased eastward extent of the Arctic water masses (Blindheim et al. In press). Further north, in the Greenland Sea, there are contemporary changes in the water mass structure which seem to be closely associated with this variability in the Norwegian Sea.

Time series of hydrographic and transient tracer data have revealed variability of the Greenland Sea Deep Water (GSDW), probably associated with changes in the intensity of deep water formation. (For example, Aagaard, 1968; Meincke et al., 1992, Bönish and Schlosser, 1995) During the winters of the period since the early 1980s, there has been little or no formation of deep water in the Greenland Sea (Bönish et al. 1997). This has resulted in changes of properties and distribution of the water masses in the Nordic seas. The present paper presents some preliminary results from a time series of temperature/ salinity observations in the area since 1991 and compares these observations with observations from the 1950s and the 1960s.

Data

IGY data from the Norwegian and Iceland Seas are applied for comparison in the Svinøy Section while a section along 74,5° N from 1965 is used for comparison in the Greenland Sea. These data are obtained by use of reversing thermometers and water bottles and are of considerably lower accuracy than the CTD data from the 1990s. It is however felt that, after thorough screening, they are good enough to show the main features of the water mass structure for comparison with the more recent observations. The CTD data since 1993 have an accuracy of within ± 0.001 in both temperature and salinity, while those from 1991 and 1992 are slightly less accurate. During 1991-1996 the data in the Greenland Sea were collected in November or December, in 1997 during May, in 1998 during August and in 1999 during June-July.

Results and discussion

Fig. 1 shows time series of potential temperature since 1991 at 1000 dBar and selected greater pressures, averaged over stations between 3°W and 2°E, mainly between 1°W and 1°E, at 74.5°N or 75.0°N. It is shown that there has been a temperature increase at the depths of all selected pressures to the bottom. The largest temperature increase is observed at the depth of 1500 dBar where it exceeded 0.25°C. As a consequence, the temperatures at this depth has been higher than at the depths of 1000 and 1200 dBar since 1995. Even at 3000 dBar there has been an increase of 0.08°C since 1991.

The mean temperature below 2000 m depth in the central Greenland Basin has been presented by several authors (e.g. Clarke et al. 1990). The equivalent temperature in 1999 was -1.102°C. This represents an a warming of 0.1°C since 1991 and of 0,21°C since the latest observed minimum in 1972.

The curves for 1000 and 1200 m depth show a more noisy inter annual variability than those at greater depth. This may be an effect of convection during the previous winter. Also the weak temperature signal in 1997 which is visible to the depth of the curve for 3000 dBar may be due to convection and may possibly be associated with a chimney like feature which was observed around 30 n miles further north during the same cruise.

Fig. 2 shows salinity profiles for the years 1991-1999, based on the same stations as Fig. 1. All the profiles show a salinity maximum between 1500 m and 2000 m depth. This maximum was observed at greater depths during 1991-1994 than during the later years. In this depth interval also the largest change in salinity occurred, with an increase of 0.01 from 1991 to 1999. Over most of this period there was a gradual increase, although the profiles for 1992 – 1994 are overlapping and the differences between them are mainly less than the observational accuracy. The increase between consecutive years was largest after 1997 and between the depth of the salinity maximum and the bottom the increase from 1997 to 1999 was almost as great as during the period 1991 – 1997.

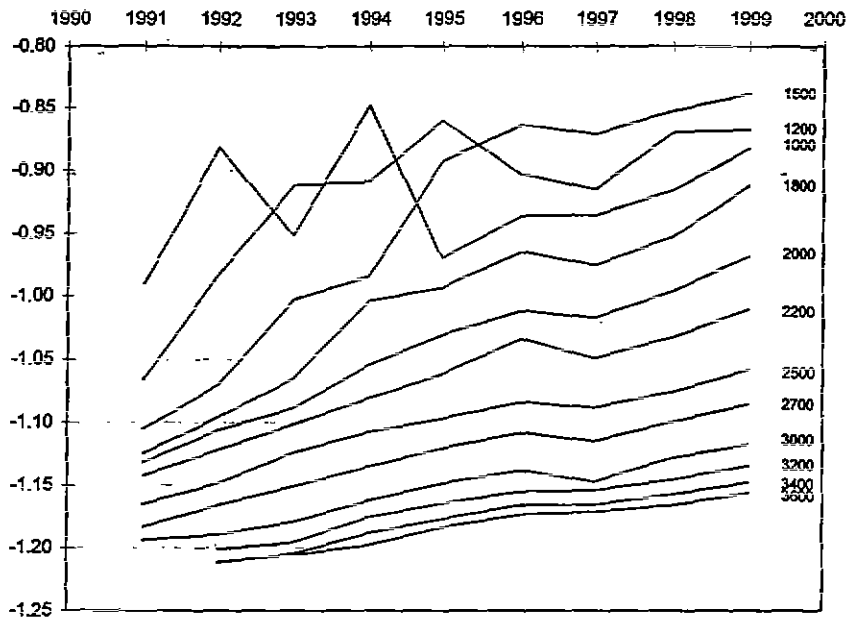


Fig. 1. Potential temperature in the central Greenland Sea at the pressure levels 1000, 1200, 1500, 1800, 2000, 2200, 2500, 2700, 3000, 3200, 3400 and 3600 dBar, 1991 through 1999.

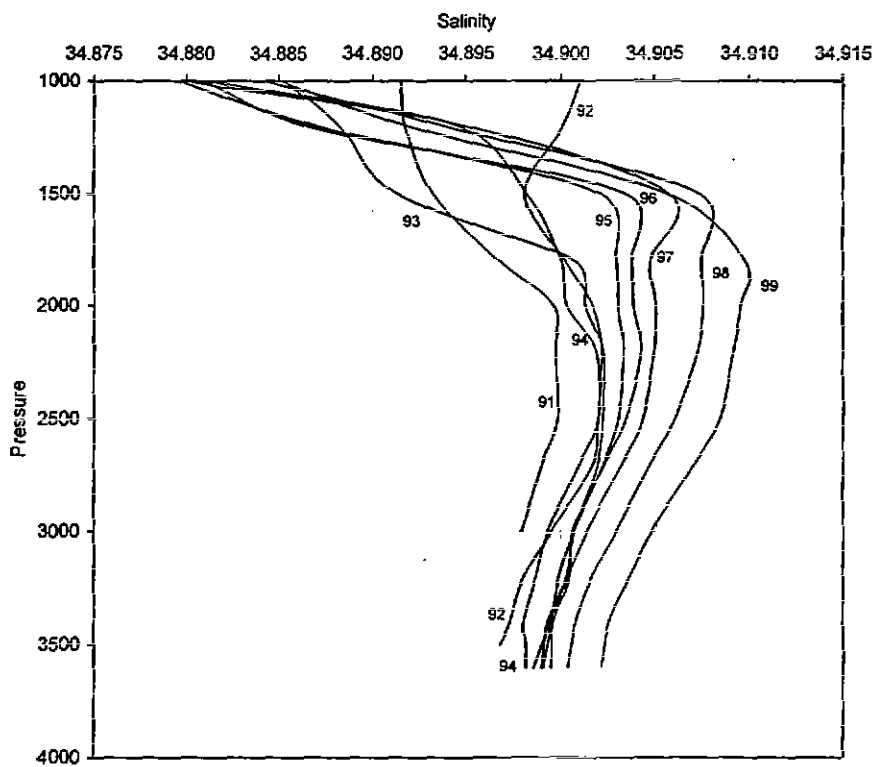


Fig. 2. Salinity profiles from the central Greenland Sea at pressures greater than 1000 dBar, 1991 through 1999.

The increase in temperature and salinity at depths greater than about 1500 m is most probably due to the combined effect of reduced deep water formation in the Greenland basin and inflow of warmer and saltier water from the Eurasian Basin in the Arctic Ocean. An indication of this inflow is shown in Fig. 3, which shows the vertical salinity distribution in a section from November 1994, stretching from the continental slope off the Lofoten Islands to the centre of the Greenland Basin. A core of relatively high salinities leaning to the western side of the mid-ocean ridge between about 1000 and 2400 dBar, indicates a core of Eurasian Basin Deep Water (EBDW) which has flowed south along the Greenland slope and diverted into the cyclonic circulation of the Greenland Basin. Considering only the section in Fig. 3, it might be argued that this maximum may be deep water from the Norwegian Sea which has entered the Greenland Basin through the gaps in the mid-ocean ridge. Although deep water from the Norwegian Sea also may flow into the Greenland Basin, sections running into the Greenland Basin west of Jan Mayen show this maximum more pronounced and support the assumption that this water derives from the flow of EBDW along the Greenland slope.

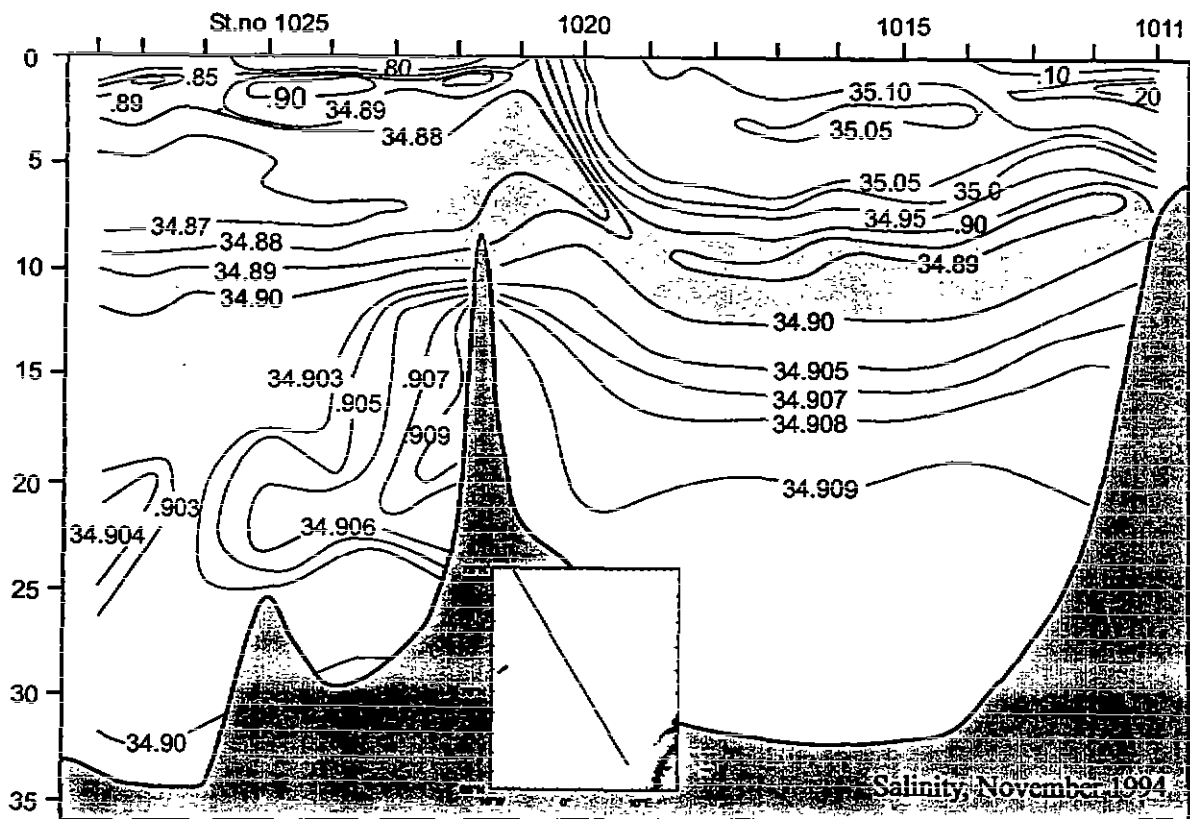


Fig. 3. Salinity in a section across the Norwegian Sea and into the central Greenland Sea, The intermediate layer of salinity less than 34.9 is shaded. For position, see inset map.

The resulting change in water mass structure in the Greenland Basin and the neighbouring Lofoten Basin is further demonstrated in Figs 4, 5 and 6 which show the salinity distribution in sections along 74,5°N in 1965, 1991 and 1996.

Fig. 4 shows a section from May 1965. Then there was a well developed dome of GSDW between about 5°E and the western end of the section at 3°W. In its centre near the prime meridian, the surface layer with fresher water was only 100 m deep. The salinity of this dome was homogeneous within the accuracy of the observations, between 34.88 and 34.89. In the upper approximate 1000 m the Arctic front between the GSDW and the Atlantic domain was observed in the vicinity of the mid-ocean ridge and at greater depths there was also a clear border zone over the ridge between the GSDW and the Norwegian Sea Deep Water (NSDW) off the Barents slope.

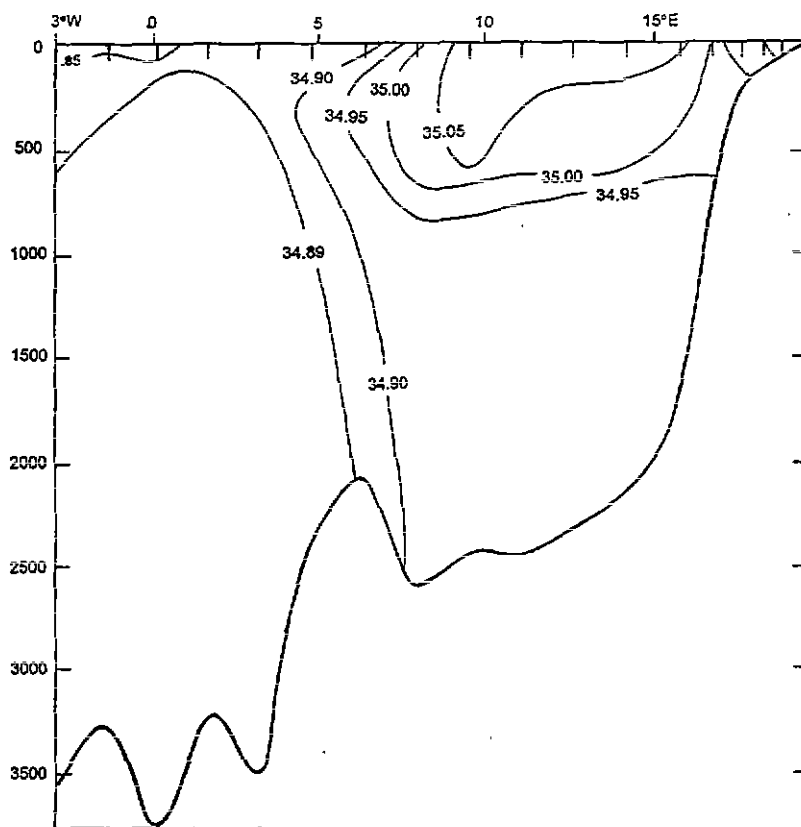


Fig. 4. Salinity in a section along 74.5°N, May 1965.

The salinity distribution in November 1991 is shown in Fig. 5. Then there was no dome of GSDW as in 1965. The salinities in the upper layers were below 34.7 in central areas of the

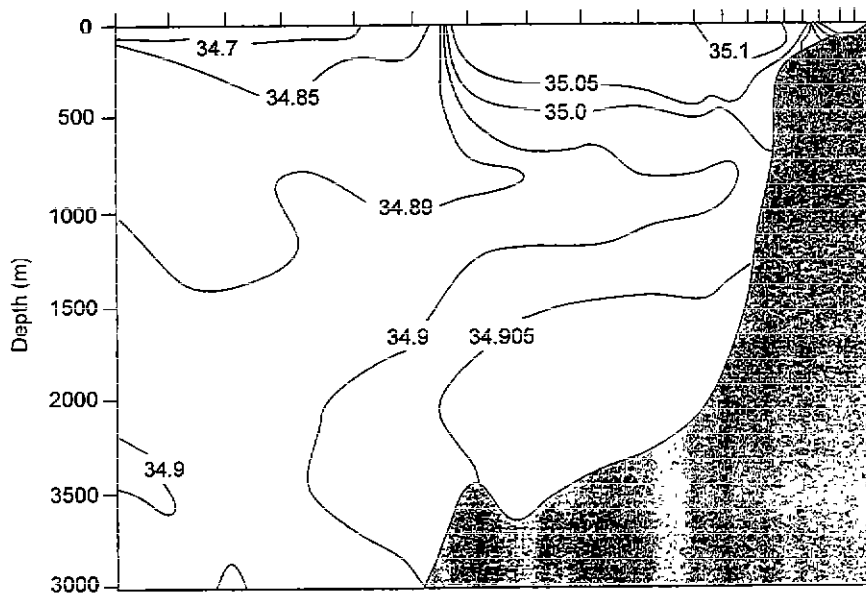


Fig. 5. Salinity in a section along 74.5°N from the Barents shelf to 5°W, November 1991.

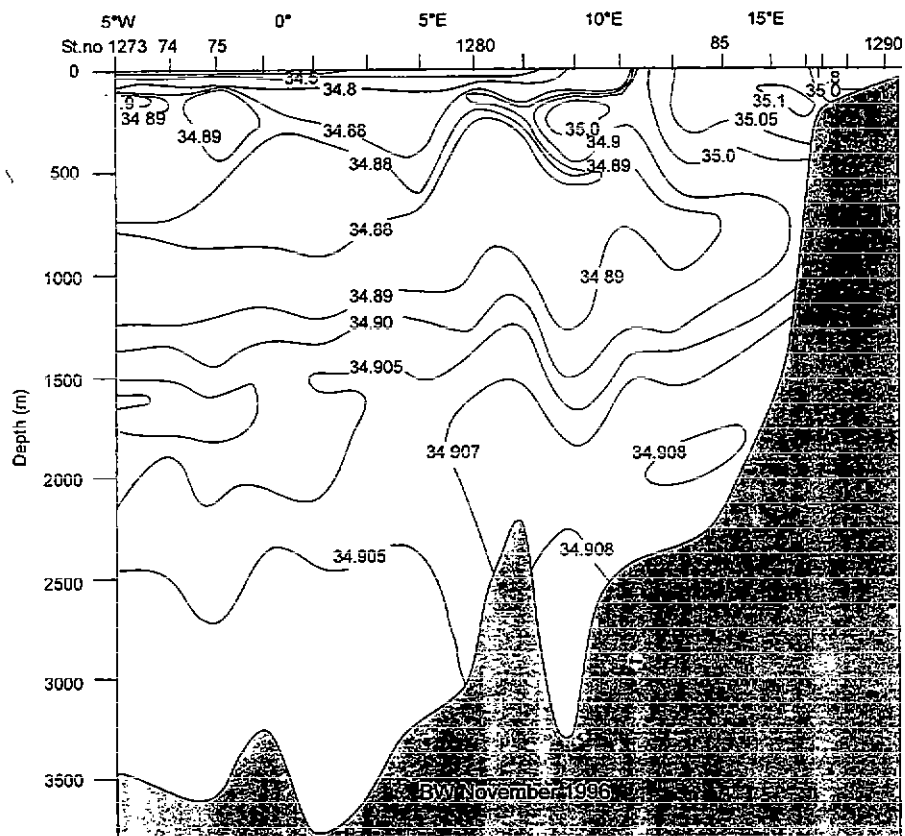


Fig. 6. Salinity in a section along 74.5°N, November 1996.

Greenland Basin. At depths between about 1500 and 3000 m a wedge of water with salinity above 34.9 extended into the basin. In the central basin, between about 1°E and 3°W, there were, however, still waters with GSDW characteristics below about 1500 m depth. In a similar section from November 1992 (not shown), water of salinities above 34.9 was extending across the whole section to 3°W between about 2000 and 3000 m depth. Also in this section there was water with GSDW characteristics at depths greater than 3000 m.

In similar sections from the years 1993-1995 the volume of water with salinities in excess of 34.9 increased gradually with time and the core salinities increase slightly as shown in Fig. 1. In the section from November 1996, which is shown in Fig. 5, the salinities were above 34.9 at all depths greater than 1400 - 1500 m. There were no rests of water with GSDW even near the bottom at 3600 m depth and the deeper parts of the whole basin to 5°W were filled with water originating from the Arctic Ocean and/or the Norwegian Sea.

While the volume of GSDW gradually decreased, another water mass appeared and increased in volume. This is known as Norwegian Sea Arctic Intermediate Water (NSAIW) because its expansion was first observed in the Norwegian Sea (Blindheim, 1990). In the section from 1991 (Fig. 5), this is observed as a tongue like structure which extends toward the Barents Shelf at around 1000 m depth and the section from 1996 (Fig.6) shows that the vertical extent and volume of NSAIW had increased considerably since 1991.

The distribution of NSAIW in the Norwegian Sea is further shown in Fig. 3. This section, from November 1994, shows a 300 to 400 m thick layer of NSAIW extending from the Greenland Basin, across the entire Lofoten Basin to the Norwegian shelf. Further south in the Norwegian Sea, its dominance has increased even more. This is demonstrated in Fig. 7 which shows the distribution of potential temperature and salinity in a Svinøy Section from May 1958 (IGY) which extended to the Iceland Plateau, and in a repetition of this section from May 1997. In 1958 salinities below 34.9 were observed only over the Iceland Plateau while the waters of the upper 300 - 500 m layer across the whole Norwegian Basin were saltier than 34.9. In 1997 on the other hand, Arctic water of salinities below 34.9 occupied the upper 900 - 1000 m of the water column in the north western half of the section, approximately west of 1°W. In the south eastern part of the section, the Arctic water formed an intermediate layer which extended to the slope off the Norwegian coast at 62,3°N between the inflowing Atlantic

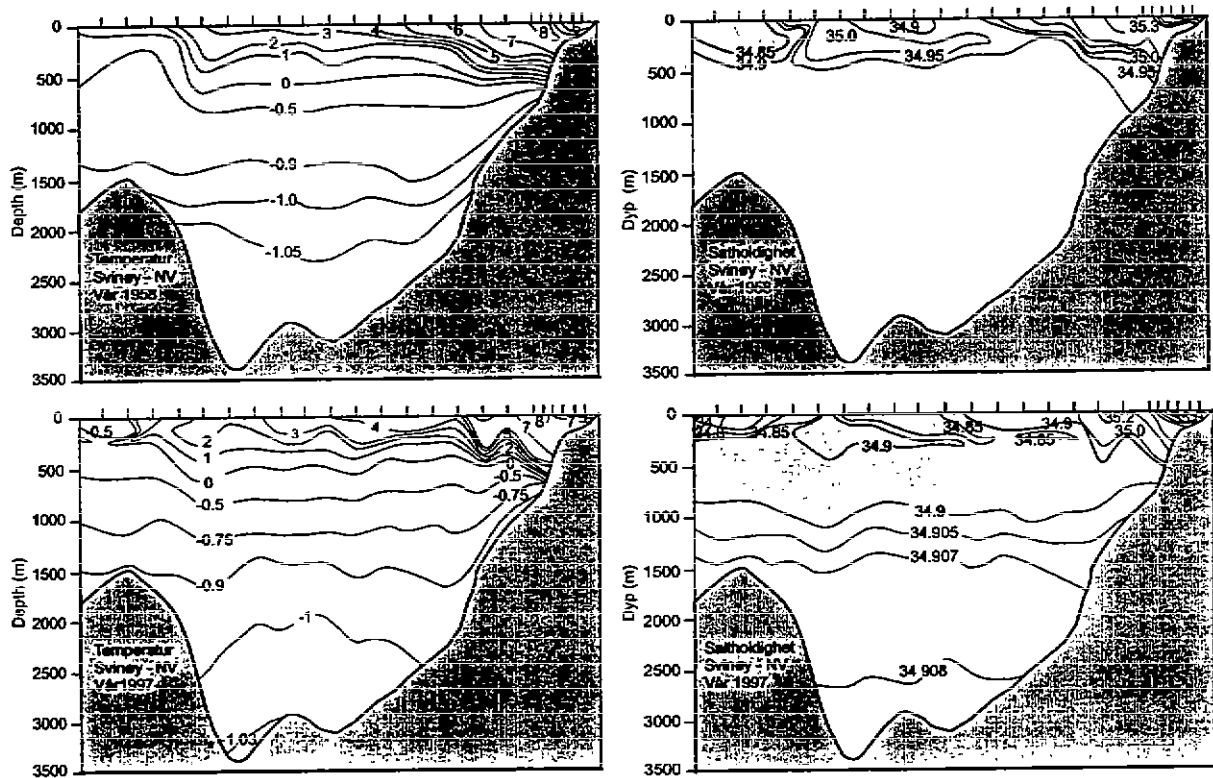


Fig. 7. Potential temperature and salinity from 62.3°N on the Norwegian coast, upper panel from May 1958, lower panel from May 1997. Water of salinity less than 34.9 is shaded.

Water and the NSDW. This large volume of intermediate water in the southern Norwegian Sea indicates that it is not formed only in the Greenland Sea, but probably also in the Iceland Sea.

The temperature sections in Fig. 7 show that also the NSDW has become warmer since 1958 and at depths greater than 2000 m this warming amounted to about 0.05°C. This warming which is studied in more detail at Ocean Weather Station “M” (Østerhus and Gammelsrød, 1999), affects the water column at depths greater than about 1200 m.

The generating mechanism behind this large structural change seems to be the rate of deep water formation in the Greenland Sea. While NSAIW was an insignificant feature before about 1980, as shown for example in Fig. 7, it has become increasingly dominant during the 1980s and 1990s. It seems to be a product of winter convection in both the Greenland and Iceland Seas. In the Greenland Sea it seems to be formed in large quantities when the winter convection produces a water mass which is less dense than the older deep water. Then convection will stop at an isopycnic surface above or in the upper layers of the older deep

water. This is just what has happened since the early 1980s as the NSAIW has spread isopycnally over almost the entire Nordic Seas to form intermediate layers as shown in Figs 3, 5, 6 and 7. The upper layers of the deep waters are also modified by admixture of the intermediate water.

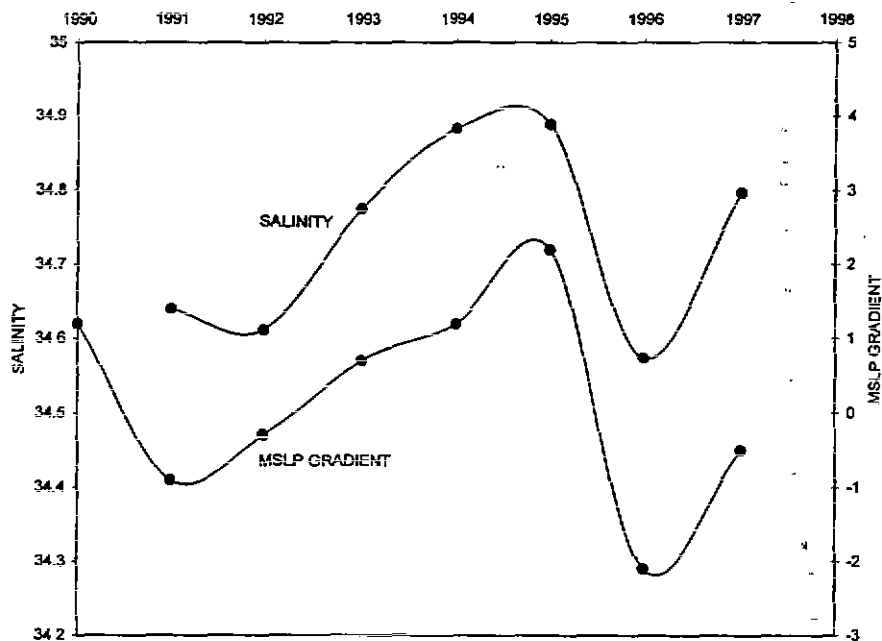


Fig. 8. Upper curve: Salinity in the upper 100 m of the central Greenland Sea. Lower curve: Normalised gradient of mean sea level pressure between Danmarkshavn, NE Greenland, and Svalbard, West Spitsbergen. (MSLP data from the Danish and Norwegian meteorological institutes.)

The rate of deep water formation in the Greenland Sea seems to depend on the wind forcing in the manner that steady northerly winds along the East Greenland coast will bring about a narrow East Greenland Current and as a result, relatively high surface salinities in the central Greenland Sea, and vice versa. An indication in support of this is presented in Fig. 8 which shows mean salinities in the upper 100 m of the central Greenland Sea during the years 1991 – 1997. These salinity means are based on the same stations which were applied in Figs 1 and 2. The figure also shows normalised values for the gradient of winter (December through March) mean sea level pressure (MSLP) between Danmarkshavn, (NE Greenland) and Svalbard (West Spitsbergen), the salinity values falling within the same year as January in the MSLP values. This gradient will give an index of the wind component along the East

Greenland Current and high positive values indicate strong northerly winds. The figure shows that the upper layer salinity in the central Greenland Sea vary closely in phase with this index. Further, it is also worth noting that there close correlation between this index and the North Atlantic Oscillation (NAO) winter index (Hurrell, 1995). However, although the figure gives an encouraging indication of the role of the wind forcing in GSDW formation, it must be born in mind that the series of observations is still short and the validity on longer time scales of the obtained correlation is accordingly uncertain.

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