ICES C.M. 1995

CM 1995/Mini:6

EPISODIC FORMATION OF INTERMEDIATE WATER ALONG THE GREENLAND SEA ARCTIC FRONT

by

Johan Blindheim and Bjørn Ådlandsvik
Institute of Marine Research
Bergen, Norway

ABSTRACT. During CTD and plankton surveys in the Nordic Seas in November 1991 - 1994, a CTD section has been worked across the Arctic Front between the Lofoten and Greenland Basins. Along this front Isopycnic surfaces slope down from upper layers on its cold side in the Greenland Basin to intermediate depths of 800 to 1000 m in the warmer waters of the Lofoten Basin. While it earlier has been concluded that intermediate water masses are formed in the Greenland and Iceland Seas during winter, it has not been clear whether intermediate water sinks into the Norwegian Sea along the Arctic Front to the northeast of Jan Mayen. The present sections show that such formation may occur in November. This is indicated by narrow filaments of water which is less saline than the ambient water. This water seems to be brought to the front by mesoscale eddies on its cold side. The heaviest water is supplied at depths between about 100 and 500 m. It is therefore not affected by summer warming so that sinking plumes may in principle occur in all seasons. The occurrence of such plumes in two of the four sections suggest that such events may be rather frequent although they are episodic. In general, this may therefore be an important mechanism for formation of intermediate water.

INTRODUCTION

In the Nordic Seas the frontal zone between the region which is dominated by Atlantic water, mainly in the Norwegian Sea, and arctic water in the Greenland and Iceland Seas is here defined as the Arctic Front. This nomenclature is not consistent in the literature as many authors have applied the name "Polar Front". Here we will use the name "Arctic Front" as applied by for example Swift and Aagaard (1981). Fig. 1 shows a depiction of the front as represented by the temperature distribution at 200 m depth, based on data from August 1981. To the northeast of Jan Mayen the front is fixed to the bathymetry, following the mid-ocean ridge (Mohns Ridge).

The processes through which intermediate waters are formed, are rather vaguely described in the literature. For example Swift and Aagaard (1981) mentioned that what they define as upper Arctic Intermediate Water was observed at the surface of the central Iceland Sea during winter without any further discussion of how it was formed. Blindheim (1990) raised the question whether intermediate water would be advected into the Lofoten Basin after sinking to intermediate depths in the zone of the Arctic Front north of Jan Mayen, while Hopkins (1991) claimed that local winter production of this water along the Arctic Front appears unlikely. As an argument against he points out that the winter water types at the surface with the correct density ($\sigma_t \sim 28.0$) are too saline.

Since 1991 the Institute of Marine Research, Bergen, has repeated a section across the Arctic Front in November (see Fig. 1 for approximate position). Of these, the sections from 1991 and 1993 show a plume, or filament, in the frontal zone, extending from the upper layers to intermediate depths. Rather unexpected, this indicates that formation of intermediate water may occur along the Arctic Front northeast of Jan Mayen, and although episodic, it may occur as early as November. The possible driving mechanism behind this event is discussed in the following.

WATER MASSES

Descriptions of the water masses in the actual area are given by several authors. For example Swift and Aagaard (1981) described the water masses in the Iceland and Greenland Seas rather comprehensively while Hopkins (1991) presented a quite detailed description of water masses in the GIN Sea (Greenland, Iceland and Norwegian Seas). These authors share with several others the opinion that the many names and definitions may be confusing.

The naming of the intermediate water which flows into the Norwegian Sea makes no exception. Blindheim (1990) suggested to simply call it Arctic Intermediate Water when dealing with the Norwegian Sea, with the word "Arctic" pointing to its arctic source. Martin (1993) claimed that this name conflicts with the established use of this term for the warmer Arctic Intermediate water found at lesser depths between Northern Iceland and the Faroe Shetland Channel. Further, Hopkins (1991) used the name Norwegian Arctic Intermediate Water. This, or rather Norwegian Sea Arctic Intermediate Water, NSAIW, is possibly, in spite of its length, the best name as it indicates both its arctic source and where it is found. The Θ–S limits for this NSAI water is -0.5 - +0.5 °C and 34.87 - 34.90.

A second variety of Arctic intermediate water is also of importance in the Arctic Front. This is what Hopkins (1991) calls return Atlantic Intermediate Water, the same water type which Swift and Aagaard (1981) call lower Arctic Intermediate Water. The relatively high temperature and salinity (0 - 2°C, S = 34.9 - 35.0) of this water which flows southward under the polar waters in the East Greenland current, reflects its Atlantic origin through the Norwegian Atlantic and West Spitsbergen Currents. Some of this water flow into the Jan Mayen Curtrent and Hopkins (1991) even define it as a specific intermediate water mass when it is found in this there; Jan Mayen Intermediate Water with temperature 0 - 0.5°C and salinity 34.9 - 35.0. In the area of the sections which are dealt with here, its salinity is decreased to just below 34.9.

Atlantic Water in the Norwegian Sea is defined by $T > 2°C$ and $S > 35$ and the deep and Bottom waters has temperature below -0.5°C and salinity close to 34.91.

DATA

The observations were made with CTD systems equipped with a 12 position rosette sampler for collection of seawater samples. In 1991 and 1992 an NBIS Mark III CTD was used while a Sea-Bird 911 plus CTD with dual temperature and conductivity sensors was used in 1993 and 1994. Samples for field calibration of salinities were collected from all Niskin Bottles at pressures of 1000 db and greater. The accuracy of the data are in general within ± 0.003°C and also ± 0.003 units salinity.

RESULTS AND DISCUSSION

The sections which were worked across the front in 1991 and 1993 are shown in Figs 2 and 3. The salinity distribution in both of them show narrow tongues with relatively low salinity in the frontal zone, extending to about 800 m depth in 1993 while in 1991 its vertical extent was more uncertain.

In the section from 1993 (Fig. 3) the narrow tongue had salinities in the range 34.85 - 34.88. On Station 1121 salinities increased from about 34.85 to 34.88 between 50 and 400 dbar, with associated σ_θ values between 27.82 and 28.01 kg/m^3. Salinities between 34.87 and 34.88 were also observed at 825 to 855 dbar on the neighbouring Station 1120, indicating that the tongue may extend to this depth, or at least that the same water type was found at this depth. The σ_θ at 825 dbar was 27.97, showing instability in the tongue. This is better shown in Fig. 4 where σ_θ values in the tongue and in the intermediate water just east of the front are plotted against pressure. Values in the upper layer are from station 1121 which falls within the tongue to about 500 dbar while salinities less than 34.88 between 805 and 860 dbar on station 1120 also are interpreted as part of the tongue. The values from station 1119 show the densities between 850 and 1000 dbar in the intermediate water just east of the front. The figure shows that the water between 350 and 450 dbar on station 1121 is heavier than the tongue water at much greater depth on station 1120 and it is heavier than much of the intermediate water east of the front. This suggests that the tongue is rather new as it seems likely that if such a tongue had been produced during the previous winter mixing would have smoothed out such instabilities.

In the section from 1991 there was only one station which covered the low salinity tongue between 600 and 900 m depth. This station indicated an outstanding tongue, extending to more than 1200 dbar with salinities less than 34.86 (Fig. 5). If this tongue is real, it indicates a rather intense sinking of water in the frontal zone. It is however, quite uncertain whether the CTD data on this station are correct throughout the whole water column. The most important reason for this doubt is the difference between the downcast CTD profile and the upcast calibration at 1000 dbar. Hence, while the downcast salinity was 34.855, the bottle salinity at 1000 dbar was 34.902 and within the correction limit, it agreed with the upcast CTD reading. Further, the vertical salinity gradient at the bottom of the tongue was about .045 units over a 5 dbar interval, corresponding to ~ 0.04 in σ_θ.

On the other hand, just below the tongue, as well as at all deeper levels of the 2900 m deep CTD profile, upcast calibration agreed with the downcast salinity. Above 1000 dbar no calibration samples were collected, but there are no signs of error on the profile like jumps in the density. It is therefore possible that the reason for the disagreement between down- and upcast at 1000 dbar is that the vessel during the time between has drifted out of the tongue. As the tongue may be rather narrow, there is a slight possibility that this might have happened. The fairly strong current in the frontal area together with the 18 knot westerly wind during the station time would be in favour of this. We are, however, inclined to the opinion that some suspended matter or a plankton organism has contaminated the CTD conductivity cell for some time. The version of salinity distribution entered in Fig. 2 is therefore believed to be the most correct one, although the vertical extent of the tongue is uncertain. Fig. 5 is, however, also shown since it can not be entirely ruled out that this may be the correct version of the salinity distribution.

The first mechanism which was looked into as possible driving force, was the wind field. The idea was that in November when cooling has just started, this will be more intense near Greenland than Near the Arctic Front. As a result the western part of the Greenland Sea Gyre will be more cooled than the eastern, but cooled surface water will be carried eastward by the Jan Mayen Current. The right wind conditions might increase this effect and bring heavy water to the front area and this water might sink in this zone. Fig. 6 shows the average air pressure distribution for November in 1991 and 1993. The map for 1991 shows an atmospheric low pressure area east of Iceland and a pressure field whic was in favour of northeasterly winds dominating over the Greenland and Iceland Seas during November. In 1993 the Iceland low was located over the Irminger Sea and according to the average pressure field, wind from south dominated over the Iceland and Greenland Seas. Although the wind pattern in 1993 might be in favour of the mechanism described above, the wind conditions in 1991 would have the opposite effect. In general therefore, the wind conditions are not convincing as a driving mechanism. Furthermore, the southerly winds in November 1993 did probably not bring about any massive cooling of the Greenland Sea. This is also supported by the temperature measurements at Jan Mayen which showed the highest November values for many years. In general most autumn temperatures at Jan Mayen since the mid 1980s were higher than the 1961 - 1990 standard. In conclusion it seems therefore likely that the wind has not played a major role as driving mechanism for the formation of the observed tongues.

A more effective mechanism seems to be created by mesoscale eddies with diameters in the order of 100 km in the frontal area. The sections from both 1991 and 1993 show such eddies which although they are different, may have the same effect. In 1991 the section cut through an eddy where the isopycnals domed at about Station 1354. In the depth interval between about 100 and 400 m this eddy had a salinity maximum with salinities between 34.88 and 34.90 with associated temperatures between about -0.25 and 2 °C. It is likely that this is water is carried by the Jan Mayen Current and that its main component is Jan mayen Intermediate water. Although the density distribution of this eddy is rather complex, a cyclonic eddy is indicated next to the front. Dynamic instabilities in this system may bring heavy water to the front whichin its turn may result in a gravity current in the frontal zone to form tongues like what is seen in the section.

The section from 1993 is different in the manner that here an eddy is of Atlantic Water has been torn loose from the front to form a warm, anticyclonic eddy on the cold side of the front. The chord which the section cut through this eddy was about 80 km long so that its diametre were at least this long. Although this in principle is a warm eddy, itmay have a similar effect as a cold eddy because cold water from the Greenland Basin may be entrained into the periphery of its circulation and sink down when it is brought to the front.

Eddies with tongues in the frontal area in two of the four sections from November, indicate that such events may be occurring rather frequently. It is not primarily a surface phenomenon as the water which is heavy enough to sink along the front comes from shallow intermediate depths in the deeper layers of, or just below the Arctic Surface Water in the Greenland Basin. The depth of this may possibly vary between about 100 and 500 m. Hence, it is not a surface process and therefore independent of the summer warming of the surface layer. The fact that it was observed in November, does therefore not need to be a signal of an early winter effect, but it is rather an event which may occur in all seasons. Although little seems to be known of this process, it appears therefore in general to be rather effective mechanism for formation of NSAI water.

REFERENCES

Blindheim, J. 1990. Arctic intermediate water in the Norwegian Sea. Deep-Sea Research, Vol. 37, No. 9:1475 - 1489.

Hopkins, T.S. 1991. The GIN Sea — A synthesis of its physical oceanography and literature review 1972 - 1985. Earth-Science Reviews, 30: 175 - 318.

Martin, J.H.A. 1993. Norwegian Sea intermediate water in the Faroe-Shetland Channel. ICES J. mar. Sci., 50: 195-201.

Swift, J.H. and K. Aagaard. 1981. Seasonal transitions and water mass formation in the Iceland and Greenland Seas. Deep-Sea Research, Vol. 28A, No. 10: 1107 - 1129.

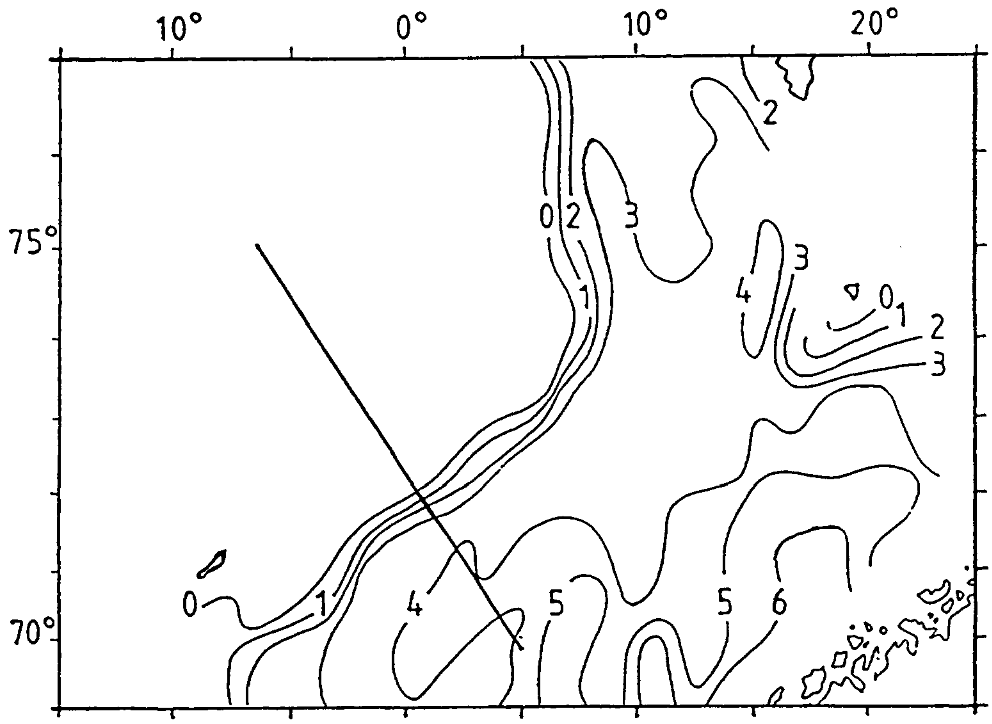


Fig. 1. The Arctic Front as represented by the temperature distribution at 200 m depth, August 1981. The approximate position of the section CTD section across the front which has been repeated in November 1991 - 1994 is shown .

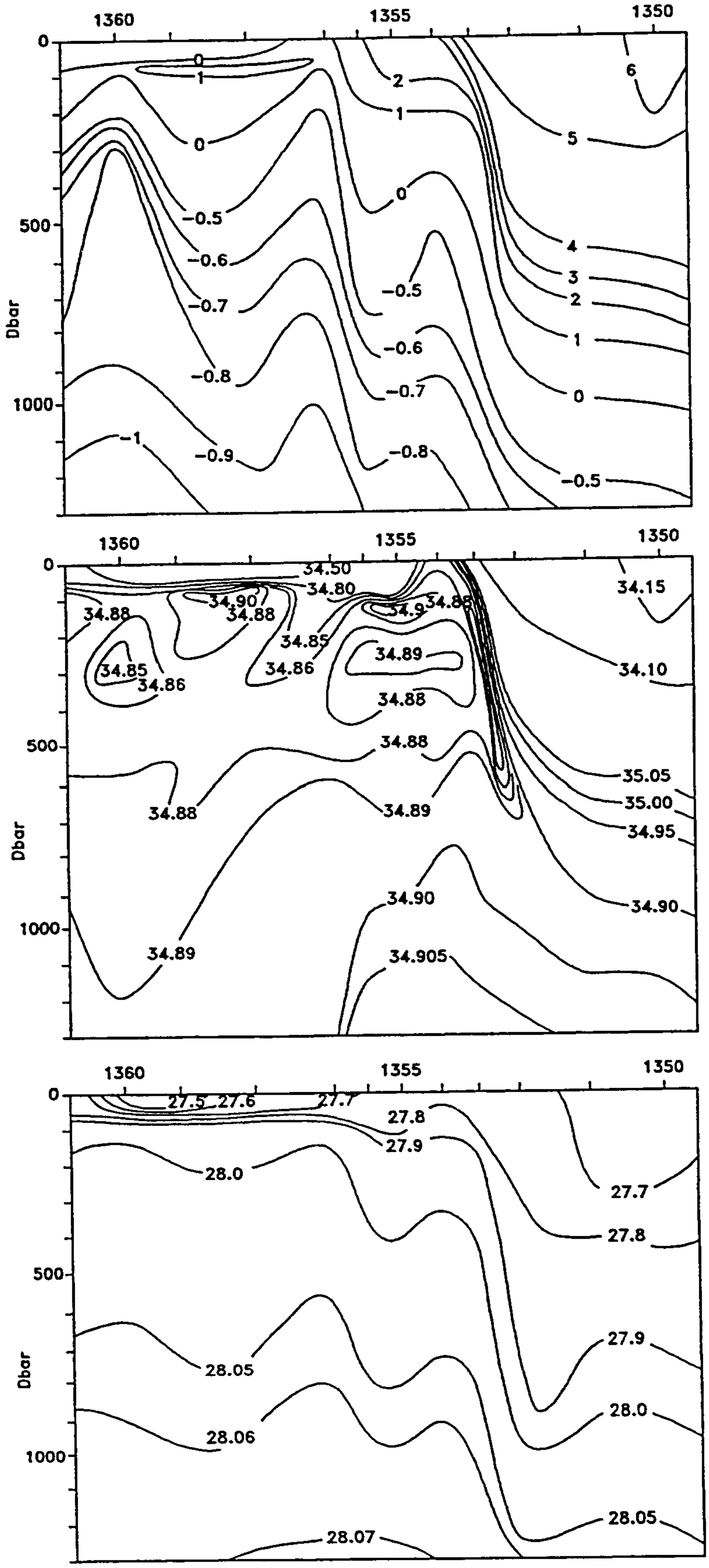
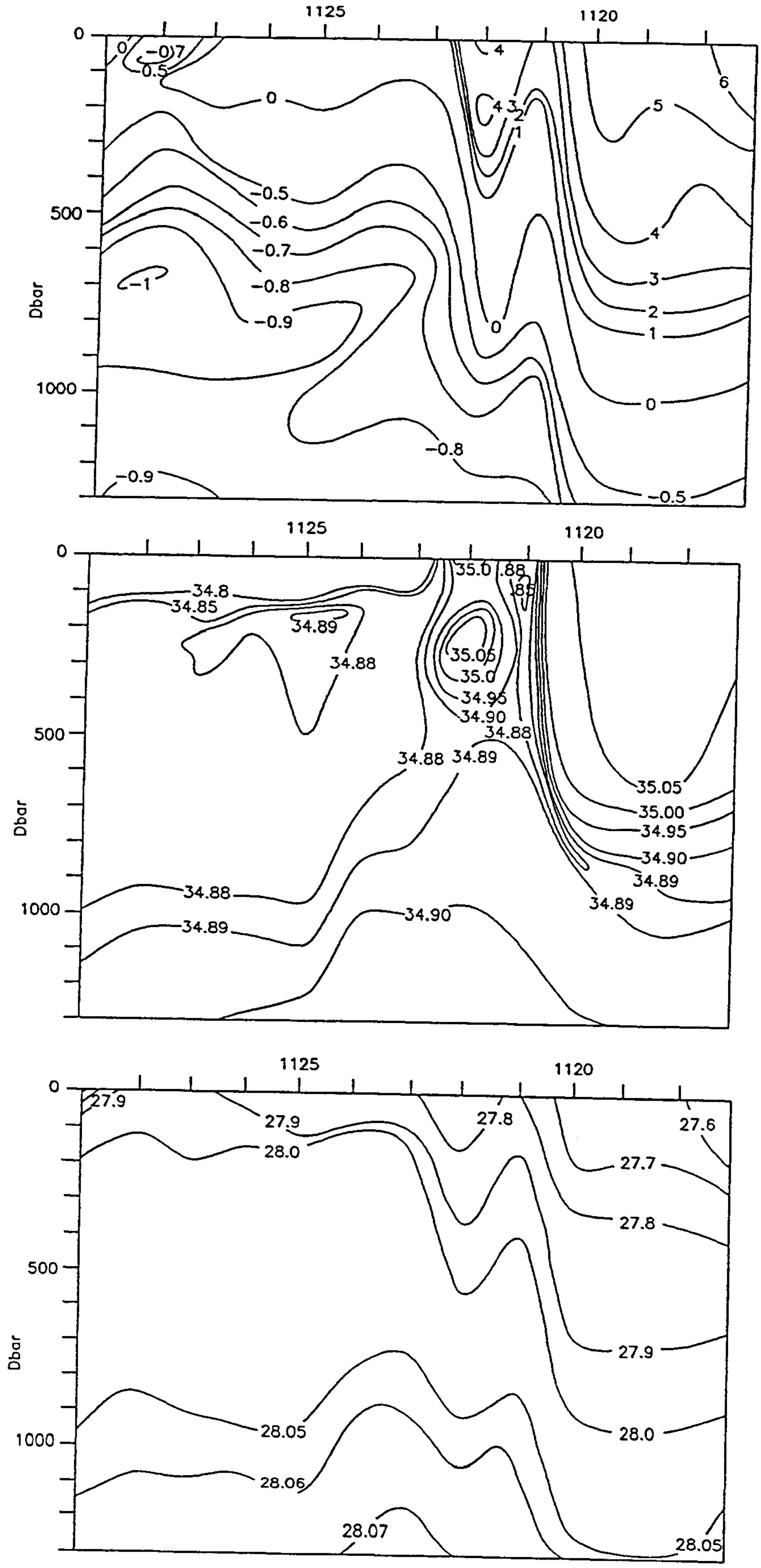


Fig. 2.

Potential temperature, salinity and σ_θ in the section across the Arctic Front in November 1991.

Fig. 3.

Potential temperature, salinity and σ_θ in the section across the Arctic Front in November 1993.



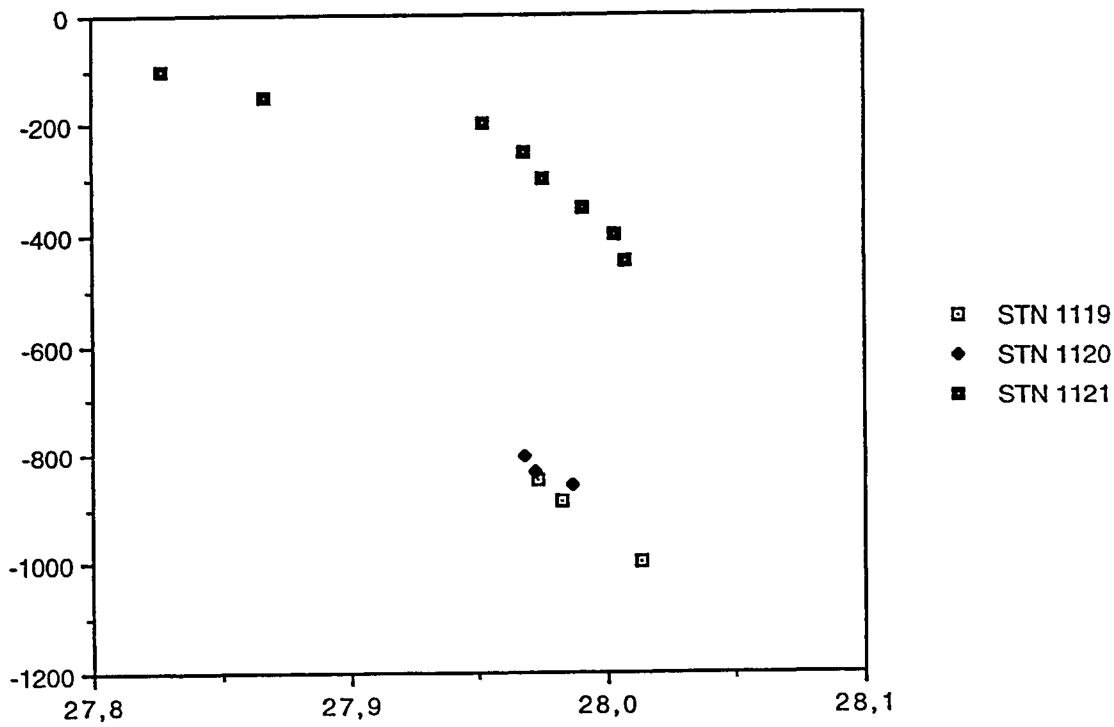


Fig. 4. Potential densities, σ_θ, from the frontal tongue with salinities less than 34.88 in Fig. 3, plotted against pressure.

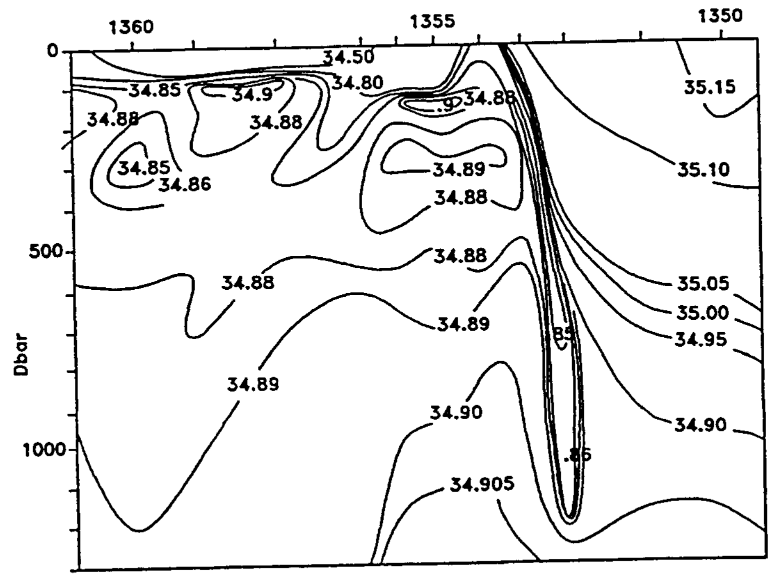


Fig. 5. Salinity distribution in the section from November 1993 where the tongue with water of salinities less than 34.88 based on the uncertain CTD salinities on Station 1352.

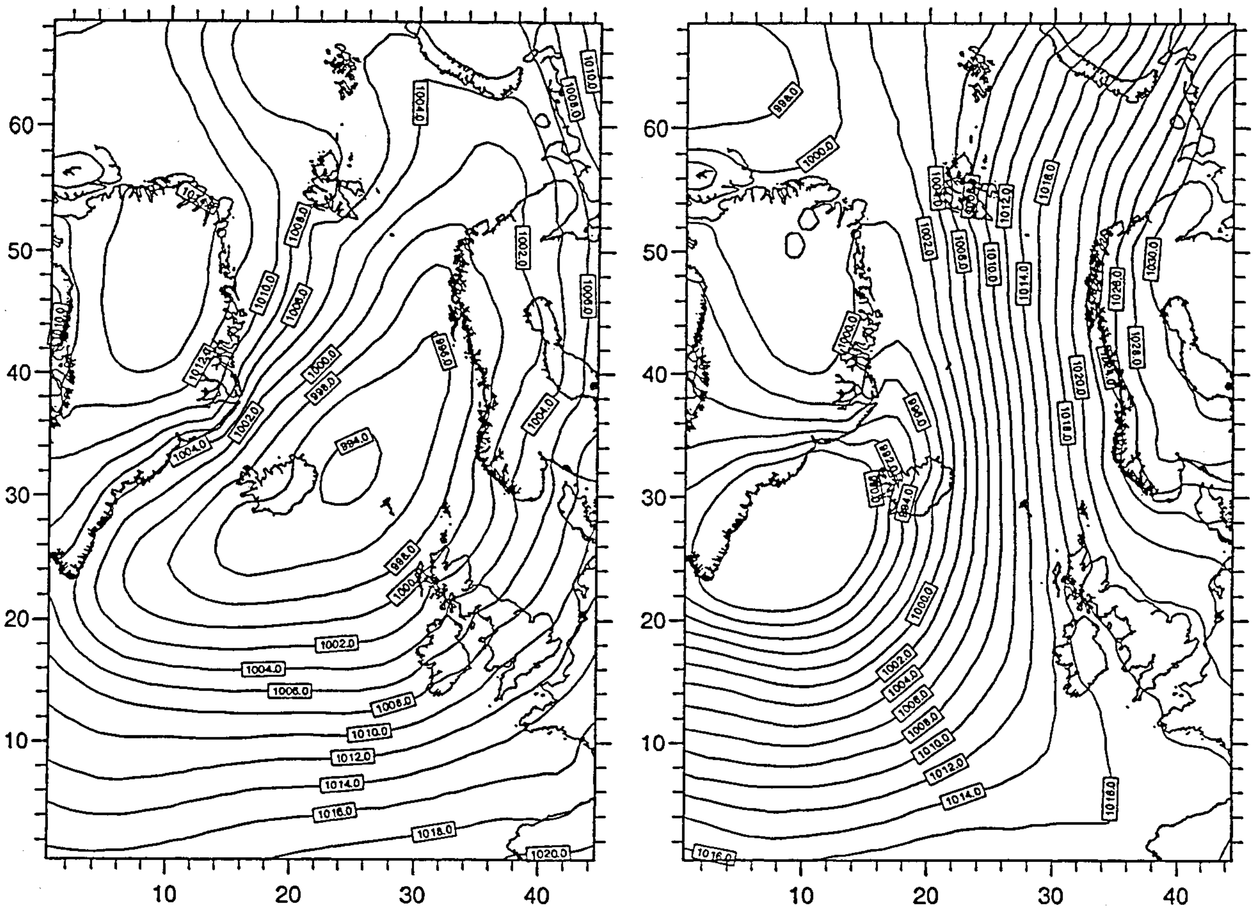


Fig. 6. Monthly mean atmospheric pressure over the Nordic Seas in November 1991 (left) and November 1993, based on hindcast data.