THE EFFECT OF OCEANOGRAPHIC CONDITIONS ON DISTRIBUTION AND POPULATION
DYNAMICS OF COMMERCIAL FISH STOCKS IN THE BARENTS SEA
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CLIMATIC VARIATIONS IN THE BARENTS SEA

By

Lars Midttun and Harald Loeng
Institute of Marine Research
P.O. Box 1870 - Nordnes
5024 Bergen
Norway

ABSTRACT

The circulation system of the Barents Sea is described. Warm water flows into the sea from west and is gradually transformed into Artic waters flowing out from the sea, partly as surface currents, partly as dense bottom water. The climatic conditions of the Barents Sea are determined both by effects from variation in the inflow and by processes taking place in the sea itself. The large variations observed in temperature and salinity from standard sections through the inflowing watermasses are examined and possible explanations are discussed.

INTRODUCTION

Although the main purpose of this paper is a presentation and discussion of the rather large climatic variations observed in the Barents Sea, it is found worthwhile first to give a short description of the circulation system as far as this is known from the literature.

Based on early observations, KNIPOWICH (1905) gave a description of the water masses of the Barents Sea and NANSEN (1906) devized theories on the formation of bottom water in the northern seas including the Barents Sea. Nansen also believed that dense water formed in the eastern Barents Sea could supply the bottom water of the Arctic Ocean through the channel between Novaya Zemlya and Franz Josef Land as indicated by Admiral Makaroff's temperature observations in that area. Recently MIDTTUN (1985) has confirmed Nansens hypothesis. MOSBY (1938) studied the waters between Svalbard and Franz Josef Land. This area is mainly dominated by Atlantic water masses although some outflow from the Barents Sea may take place near Franz Jozef Land.

The majority of the contributions to the oceanography of the Barents Sea are presented by scientists from USSR. TANTSIURA (1959) made a comprehensive analyses of the currents in the Barents Sea. AGENEROV (1946) studied a large number of current observations. The detailed work by NOVITSKIY (1961) delt with the currents of the northern Barents Sea. SARYNINA (1969) was concerned with the bottom water of the Bear Island Channel, and

KISLYAKOV (1964) studied the conditions at the western inlet to the Barents Sea.

Naturally, the southern part of the Barents Sea has been the most intensively studied area, and where several standard sections have been established in order to investigate variations in the inflowing water masses. Measurements in the Kola section were started as early as 1900 by dr. N. Knipowich and have been regularly continued since 1920. BOCHKOV (1976) has studied the observed temperature variations in relation to the solar activity. Three sections observed by IMR have been analysed by BLINDHEIM and LOENG (1981) and later by LOENG and MIDTTUN (1984). The section Fugløya-Bjørnøya (Bear Island) has been studied by DICKSON and BLINDHEIM (1984). Varialbility in the fixed station Nordkapp was analysed by MIDTTUN (1969), while BLINDHEIM, LOENG and SÆTRE (1981) compared the climatic variations in Norwegian coastal water with the observations from the Kola sections. DICKSON, MIDTTUN and MUKHIN (1970) have presented results from the hydrographic work done during the joint O-groups fish surveys i Barents Sea 1965-69.

Mainly based on the above mentioned literature, LOENG (1987) gave a brief rewiew of the main circulation and water masses of the Barents Sea.

GENERAL DESCRIPTION OF THE PHYSICAL CONDITIONS

The current systems

Fig. 1, which shows a simplified picture of the surface current system, is based mainly on current maps made by TANTSIURA (1959) and NOVITSKIY (1961). Only minor corrections have been made on the basis of some recent observations. The map indicates two main current directions. In the southern part, the currents are towards the east, while the current direction in north is westwards and southwestwards.

The Norwegian Coastal Current flows along the western and northern coast of Norway. Outside, and parallel to the coastal current flows the Norwgian Atlantic Current along the Norwegian continental shelf. Off the coast of northern Norway the Atlantic current splits in two branches, one continuing northwards along the continental slope as the West-Spitsbergen Current, and the other entering the Barents Sea along the Bear Island Channel as the Nordkapp Current.

The southern part of this current continues eastwards together with the Norwegian Coastal Current and proceeds along the Murman coast as the Murman Current. The northern part of the Nordkapp Current divides along three major routes at about 30^{o}E. One arm turns northwards between Hopen Island and the Great Bank where it submerges under the lighter Arctic water. The second branch continues eastwards in the deeper area between the Great Bank and the Central Bank as an intermediate current. The third part turns southeastwards, south of the Central Bank, and flows parallel to the Murman Current, turning northeastwards along the axis of the eastern basins. A much less important inflow of Atlantic water to the Barents Sea takes place along the Storfjordrenna between Bjørnøya and Spitsbergen.

The influx of Artic water to the Barents Sea takes place along two main routes: firstly, between Spitsbergen and Franz Josef Land, and through the opening between Franz Josef Land and Novaya Zemlya (DICKSON et al. 1970).

The main part of the first mentioned current flows as the East Spitsbergen Current southwards along the coast of Spitsbergen. The current flowing southwestwards south of Franz Josef Land, called the Persey Current, splits north of the Central Bank. According to TANTSIURA (1959), one branch turns southwards to the Central Bank, but this part is probably small. The main part of the Persey Current goes southwestwards along the eastern slope of the Svalbard Bank as the Bear Island Current. The current turns around Bear Island and goes northeastwards around the Storfjordrenna.

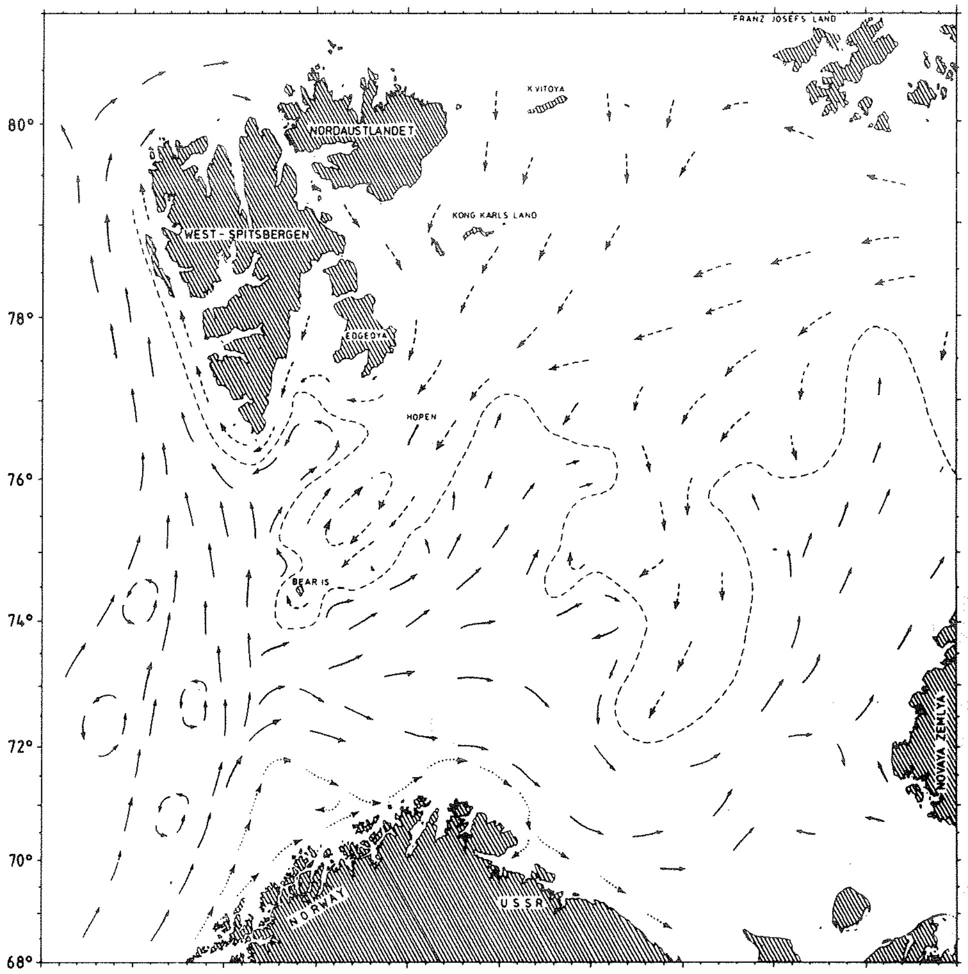

Fig.1. Surface currents in the Barents Sea. Arctic currents (– – ➔), Atlantic currents (——➔) and Coastal currents (·····➔). (Simplified after TANTSIURA 1959, NOVITSKIY 1961).

The details of the current system are poorly known. Hydrographic observations indicate an anticyclonic vortex above some of the bank areas, such as the Central Bank and probably also the Svalbard Bank. This implies a long resident time of the water masses and possibilities for vertical mixing during the winter season (NANSEN 1906). Current measurements indicate almost the same current direction from surface to bottom in areas with only one water mass (BLINDHEIM and LOENG 1978, HELLE 1979). However, in areas where the Atlantic water submerges the lighter Arctic water, as west and south of the Great Bank, one must expect different current direction with depth. Also in areas with outflowing dence bottom water, the current direction is probably different from surface to bottom. Therefore, Fig. 1, only to some extent represents the current systems in intermediate and bottom layers.

Water masses.

Following HELLAND-HANSEN and NANSEN (1909), Atlantic water is defined by salinity, higher than 35.0 o/oo. At the entrance to the Barents Sea, the mean salinity and temperature in the core in autumn during the period 1966-77 was 35,13 and 6.2°C, respectively (BLINDHEIM and LOENG 1981). Further east in the Barents Sea the characteristics change to lower salinity and temperature as shown in Fig. 2,and also clearly demonstrated by LOENG ans MIDTTUN (1984). As will be discussed later, there are also great long-term variations in the properties of the Atlantic inflow to the Barents Sea, which again may influence the properties of the locally formed water masses.

The coastal water is characterized by low salinity (S < 34.7 o/oo) and relatively high temperature (t > 3°C). This water mass is also most easily traced by the salinity (Fig. 2). The light coastal water spreads out in a wedge form above the heavier Atlantic water. The seaward extent of this wedge of Coastal water varies seasonally and has its minimum in the winter (SÆTRE and LJØEN 1971).

The Arctic water (or Barents Sea winter water) is during summer mainly found in the intermidiate layer, between 20-150 m, in the northern Barents Sea. The core is usually found between 30-60 m with temperature below -1.5°C and salinity between 34.4-34.6 o/oo. In the horizontal map (Fig. 2) most of the water with temperature below 0°C is Arctic water.

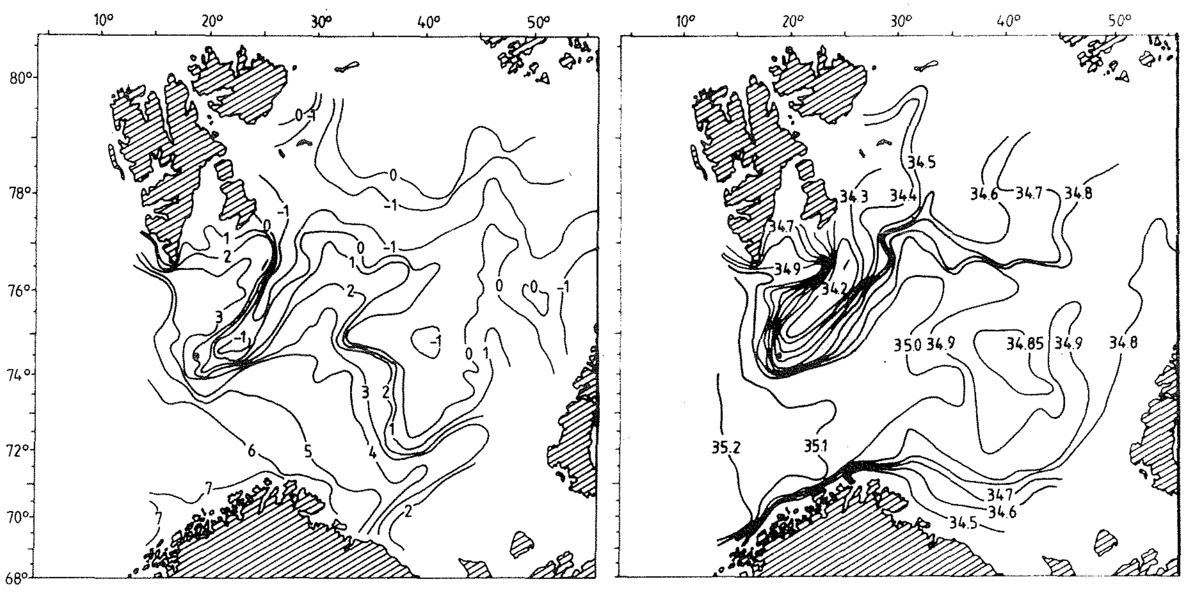

Fig. 2. Distribution of temperature (left) and salinity (right) at 100 m depth, autumn 1984.

The area between the Atlantic and the Arctic water masses is called the Polar front. In this area Arctic and Atlantic water mix. In the area west of the Central Bank, the Polar front is sharp and follows typical features of the bottom topography. In the eastern Barents Sea the front area is less distinct, and a mixed water mass cover great areas.

Bottom water of different kinds may be formed at various places in the Barents Sea. Dense bottom water is formed through rejections of brine during ice freezing and is a more or less regular phenomenon, particularly on the shelf of Novaya Zemlya, but sometimes also on the Svalbard Bank (MIDTTUN 1985).

Bottom water with a somewhat lower salinity is formed on the Central Bank during the winter season. The bottom water of the Bear Island Channel, however, is formed in the frontal zone (Polar front area) during the period of vertical winter circulation on the southeastern slope of the Svalbard Bank (SARYNINA 1969). This bottom water may have temperatures higher than 1^{o}C.

The winter and summer situations differ most clearly in the vertical structure of the water masses. During winter, vertical mixing takes place all over the Barents Sea. Over shallow bank areas, convection may reach down to bottom and contribute to bottom water fomation as already mentioned. In the deeper areas, the water masses may be homogeneous down to more than 200 m. In the ice-covered areas, the temperature will be homogeneous, while a salinity gradient will maintain a weak vertical stability. Ice-freezing with rejection of brine will break down the salinity gradient.

Sea ice conditions.

The variation in the position of the ice edge, based on satellite images from a period of 10 years,(1971-1980), is shown in Fig. 3 for the months February, April, June, August, October and December. The figure shows considerable variations in ice extension, which may take place from year to year. Some months, especially in summer and autumn, these variations may exceed 500 km. In spite of this, the seasonal variations of the sea ice extension is, in its broad features, similar from one year to another with maximum and minimum extension in March-May and August-September, respectively (LOENG 1979, LOENG and VINJE 1979). The formation of ice usually starts in late September or in October, and the ice border moves rapidly southwards to the Polar front during November and December. The melting of ice starts in May-June, but in the beginning the melting is very slow. The retreat of the ice border is usually most rapid in July and in early August.

Fig. 4 shows the variations of maximum ice coverage in the years 1979-1985. In the vicinity of Bear Island, there is almost no variations from one year to an other. In the eastern Barents Sea, however, the variations are considerable.

As seen in Figs 3 and 4, the year-to-year variations may be considerable. Some authors have proposed cyclic variations in the sea ice conditions of 3-5 years (KISSLER 1934, LUNDE 1965). Long-term variations, not necessarily of cyclic nature, are also well known from other marginal areas of the Arctic, e.g., on the west coast of Greenland (DUNBAR 1972).

CLIMATIC VARIATIONS

General description

Climatic variations can be recorded in sections crossing the inflowing water masses. At the entrance, between Fugløya and Bjørnøya (along 19^{o}30'E), temperature and salinity have been observed each autumn since 1964, while the Kola-section (along 33^{o}30'E), with exceptions of two periods, 1906-1920 and 1941-1944, has been observed by the Russians back to 1900.

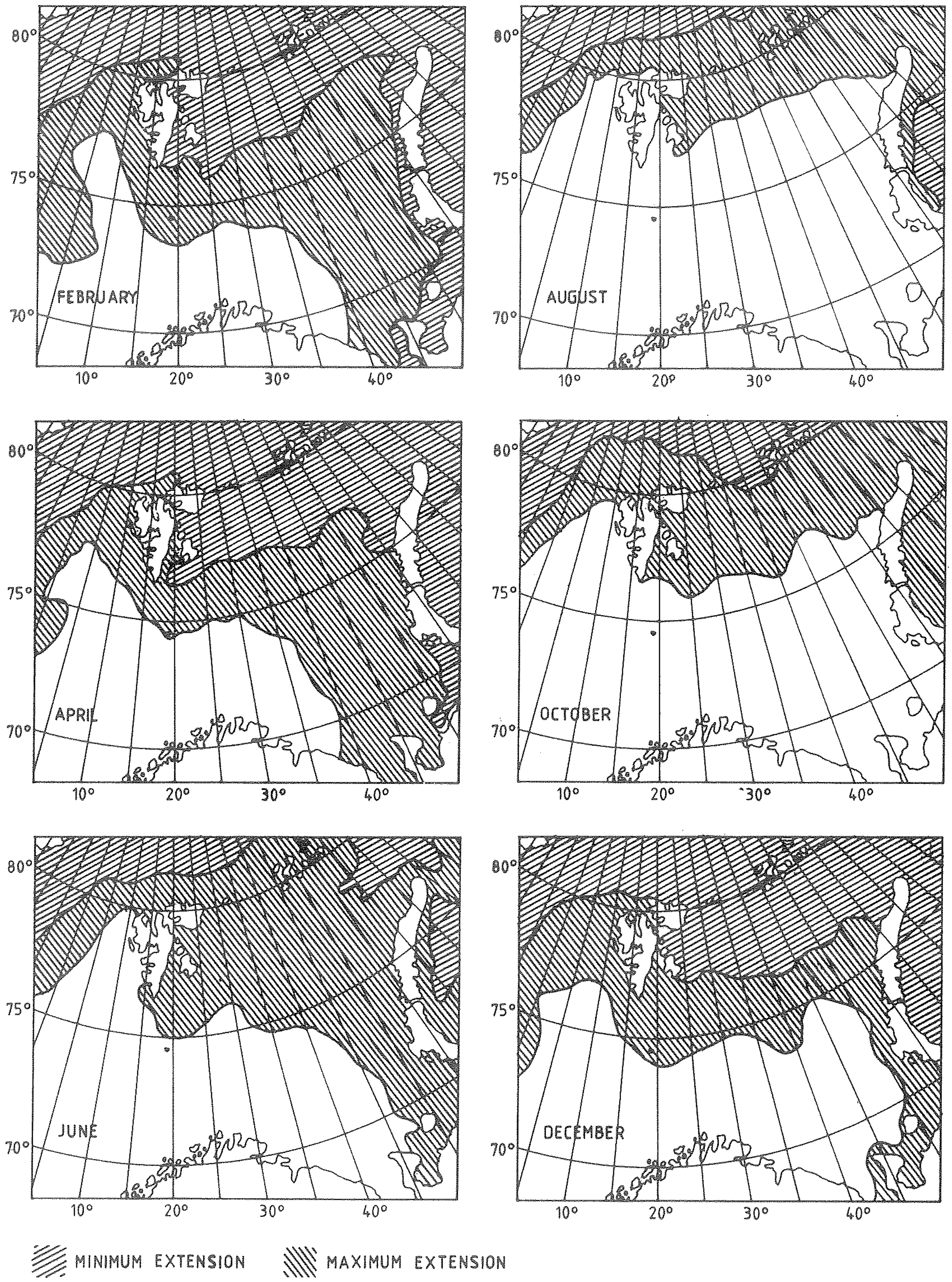

Fig. 3. Southern limit of sea ice at the end of the months February, April, June, August, October and December during the period 1971-1980 (after VINJE 1983).

MIDTTUN et al. (1981) using the Kola-section, calculated monthly mean temperatures on the basis of the period 1921-1980 and anomalies from those means have been calculated for the whole period up to 1985 (Fig.5).

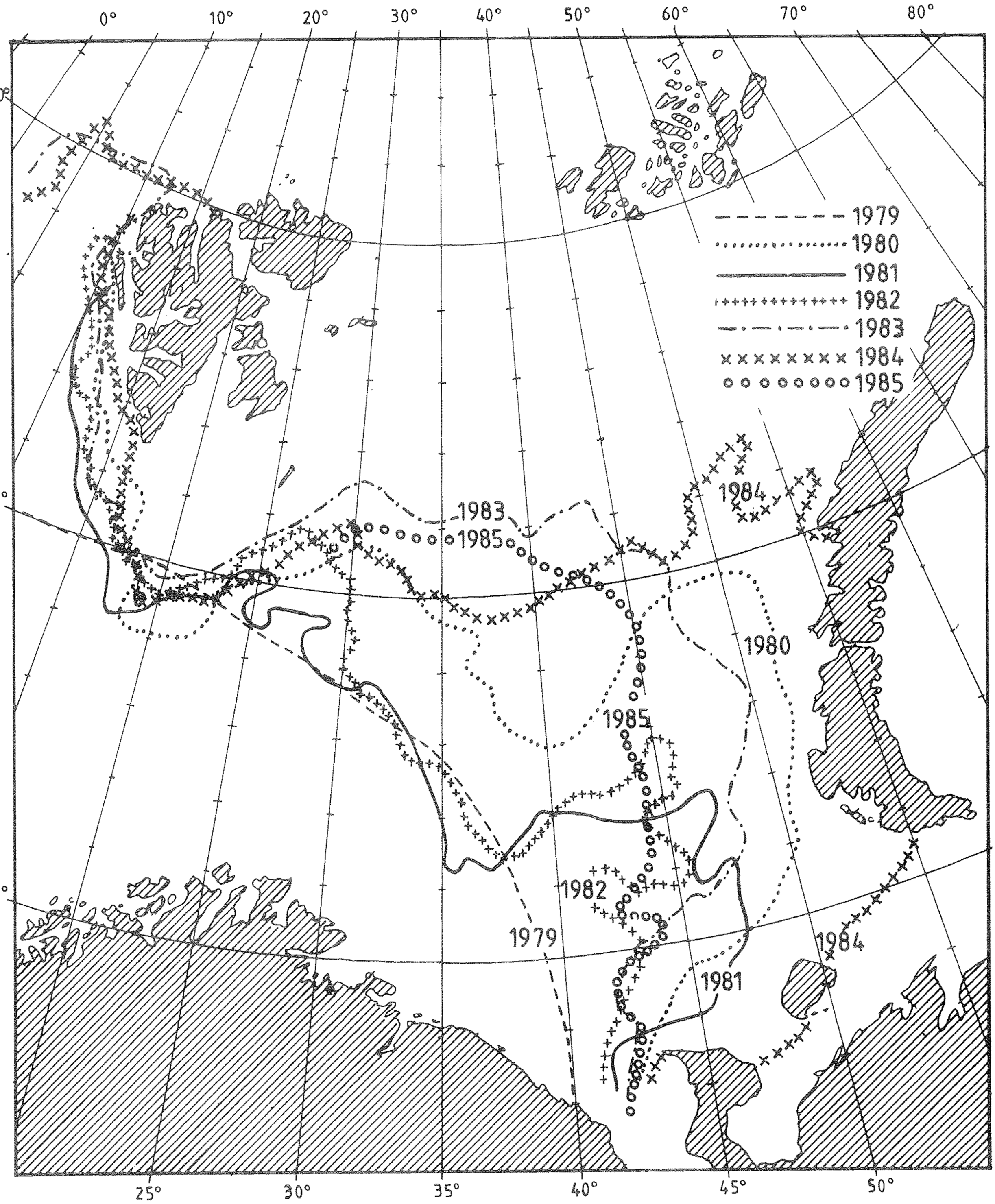

Fig. 4. Maximum ice coverage in the Barents Sea during winter in the period 1979-1985.

Fig. 5 shows that the years up to 1906 were cold. According to SÆTERSDAL and LOENG (1984), almost the whole missing period, 1907-1920, also was cold. After some years with higher temperatures in the beginning of the 1920's, the years up to 1930 had lower temperatures than normal. The longest period of a warm regime was between 1930-1939, with maximum in 1938. The years after 1945 are characterized by fluctuations of duration 3-5 years. These periods

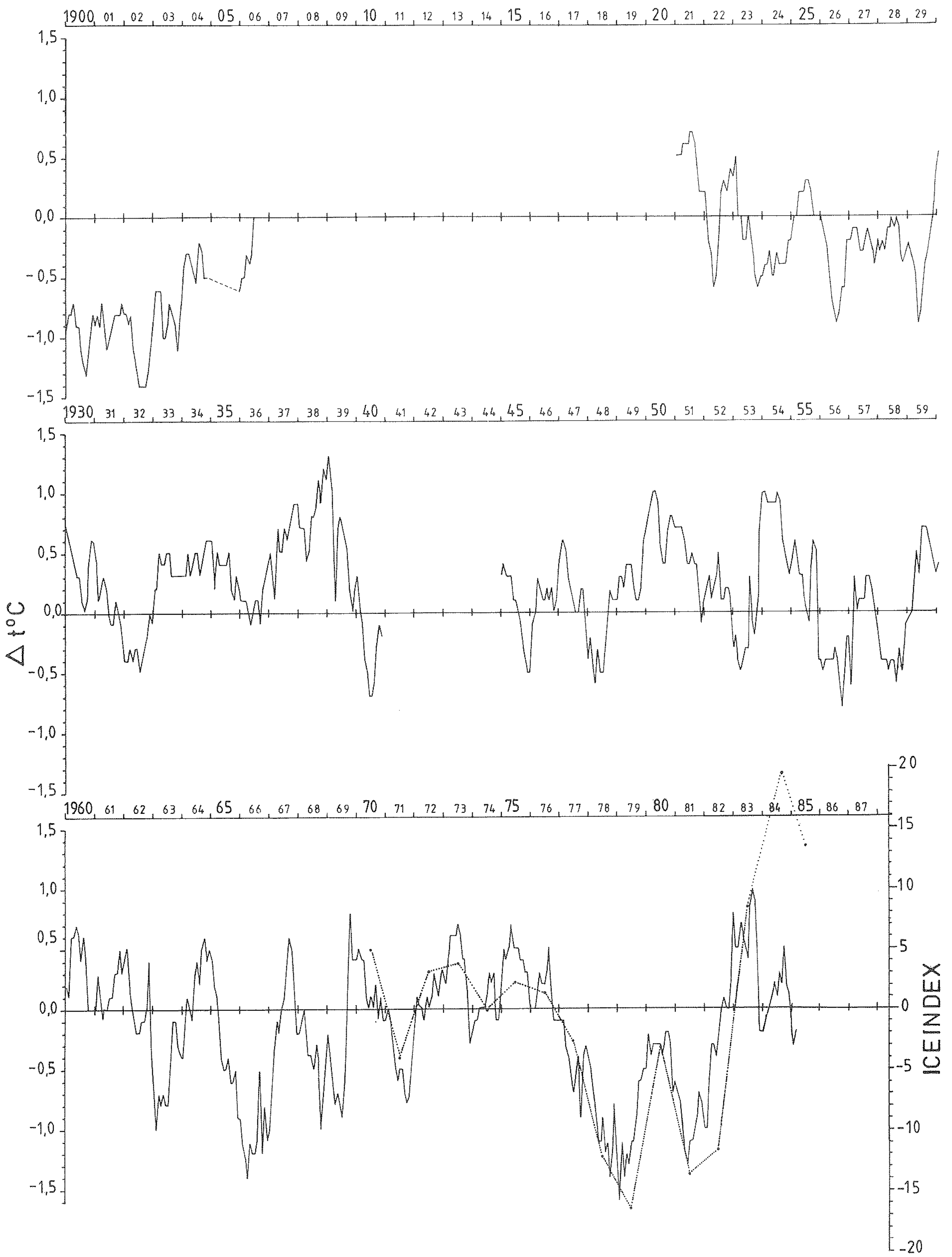

Fig. 5. Temperature anomalies in the Kola section for the period 1900-1985 (continuous line) and ice index for the Barents Sea (dotted line).

coincide with cyclic variations in sea ice condtions, as proposed by KISSLER (1934) and LUNDE (1965). A period of 11 years, which coincides with the solar activity cycle, has also been suggested both for temperature and ice conditions (BOCHKOV 1976).

During the 1970's, large variations have been observed in climatic conditions in the Barents Sea. The period 1970-1976 was warm, while the second half of the decade was charcterized by low temperatures (Fig. 5). Through the beginnings of the 1980's, temperatures were increasing. An ice index for the period after 1970 shows similar trends, indicating a close relationship between variations in sea temperature and ice conditions (Fig. 5).

The salinity also shows great variations after 1970. Fig. 6 shows temperature and salinity variations between 50 and 200 m at a section between Fugløya and Bjørnøya (BLINDHEIM and LOENG 1981, LOENG and MIDTTUN 1984). The temperature variations are equal to those in the Kola-section. The most striking feature in the salinity curve is the decrease, which started in 1969 and lasted until 1979. The minimum in 1978-1979 is characterized by the lowest salinity values ever observed in this section, and the salinity of the Atlantic inflow was below 35.0 $^{0}/oo$. Since then the salinity has been increasing towards the mean values for the period 1966-77, given by BLINDHEIM and LOENG (1981).

Fig. 6. Mean temperature (continuous line) and mean salinity (broken line) of the Atlantic inflow to the Barents Sea in autumn during the period 1964-1985.

Already in 1909 HELLAND-HANSEN and NANSEN (1909) suggested that climatic variations in the Barents Sea probably are of advective nature. They observed a time lag of one year between Lofoten and the Kola-section. LOENG, NAKKEN and RAKNES (1983) showed that temperature changes in the eastern part will most often occur about one year later than in the western part. Also in the Norwegian Sea, climated variations seem to be due to advective processes in the Atlantic inflow (BLINDHEIM 1987).

Discussion of possible causes

As shown by the majority of the other contributiones to this Symposium, the rather large variations observed in the physical environment of the Barents Sea exercise great effects on biological conditions in the large fish stocks of the sea. It is therefore felt important to discuss possible explainations and try to understand the physical causes behind the climatic variations observed in the inflowing watermasses. The variations are described by the long series of temperature observations in the Kola section crossing the main branch of the Murman Current (Fig 1). The temperature is alternating with warm and cold periods in succession with lenghts of 3-5 years (Fig. 5). Similar variations are observed in other sections further west in the Barents Sea, and are also reflected in the ice coverage. It can be seen from Figs. 3 and 4 that the ice coverage in winter has the greatest variations over the Central Bank and in the eastern part of the Barents Sea.

The variations may be hypothetically explained as caused by similar variations in the property of the inflowing water, that is, the current system of constant velocity and volume is bringing in a watermass with changing temperature and salinity. But the variations may as well be a result of variations in the current system itself. Since both temperature and salinity increase in countercurrent directions, high velocity should result in high temperature and salinity, low velocity in low temperature and salinity. In the last case the variation of the current system has to be explained. Again, the variation in the current activity could be forced upon the sea from outside, but may as well be a result of processes taking place in the Barents Sea itself.

Water of high density is formed during the winter as a result of cooling and ice formation and drained out from the sea as bottom currents. The process of ice formation is also the source to formation of the light surface water brought out by the Arctic currents. The process is described in detail by MIDTTUN (1985) and can be regarded as a separator transferring salt from surface water to deep water and in this way gradually building up dense bottom water and light surface water. The bottom water forms bottom currents along the righthand side of channels leading out from the Barents Sea to the Norwegian Sea through the Bear Island Channel and to the Polar Sea through the Novaya Zemlya-Franz Josef Land Channel. The water volume, which in this way leaves the sea, has to be replaced by inflowing water from west. The activity in building up dense bottom water may vary from one year to another followed by variations in the outflow with corresponding change in the inflow as reaction. After a great inflow it may take more than one year to again build up the required conditions to initate the next dense water outflow. To some degree the rate of dense water formation will depend on the salinity of the inflowing water since density is a function of salinity.

Fig 7 shows that the areas with high density water formations are located over the Central Bank and on the Novaya Zemlya Bank. This is the same area where the winter ice coverage changes (Fig. 4). Fig. 8 shows the effect of the large water exchanges between 1982 and 1983. The inflow and outflow from the Norwegian Sea to the Barents Sea has been measured in the section between Fugløya and Bjørnøya from a series of anchored current metres. The results are presented in Fig. 9. Transport calculations indicate about 3 Sv. in and around 1 Sv out through the section. This would require another outflowing current, most likely located in the channel between Novaya Zemlya and Franz Josef Land. Outflow of high density water in this area has been recently described by MIDTTUN (1985).
The above considerations lead us to formulate the following tentative conclusions:

1. The mechanisms behind the climatic variations in the Barents Sea can be described as the result of dense water formation during winter cooling and ice formation. This process transforms the inflowing water mass into two outflowing waters, viz. bottom water of high density and surface water of low density.

2. The transforming process is time dependent on the property and quantity of the influx. After a period of high influx, the transformation requires

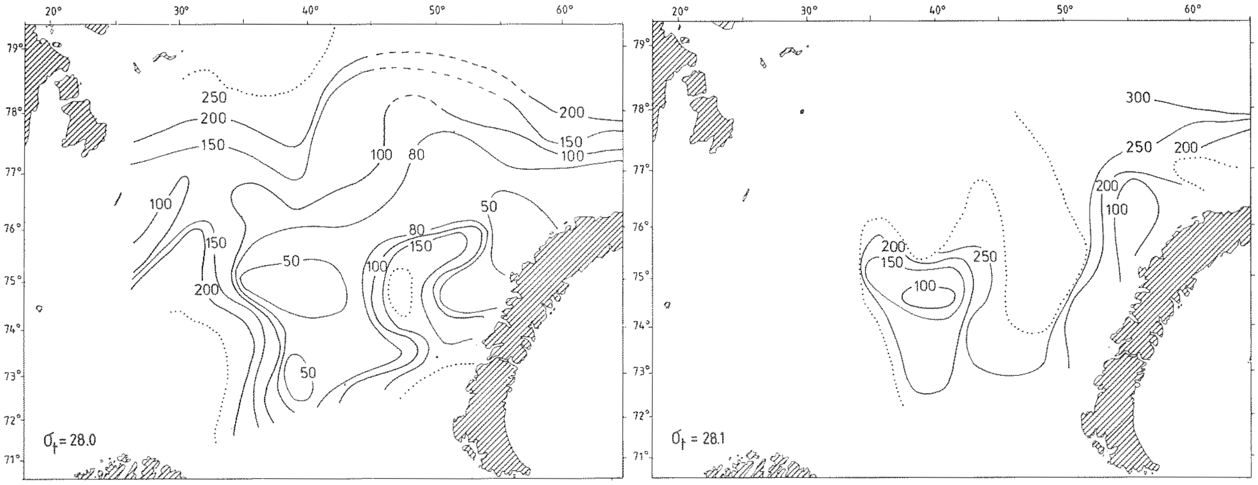

Fig. 7. Depth of the σ_t surfaces 28.0 and 28.1 in 1977. Dotted lines indicate area limitations.

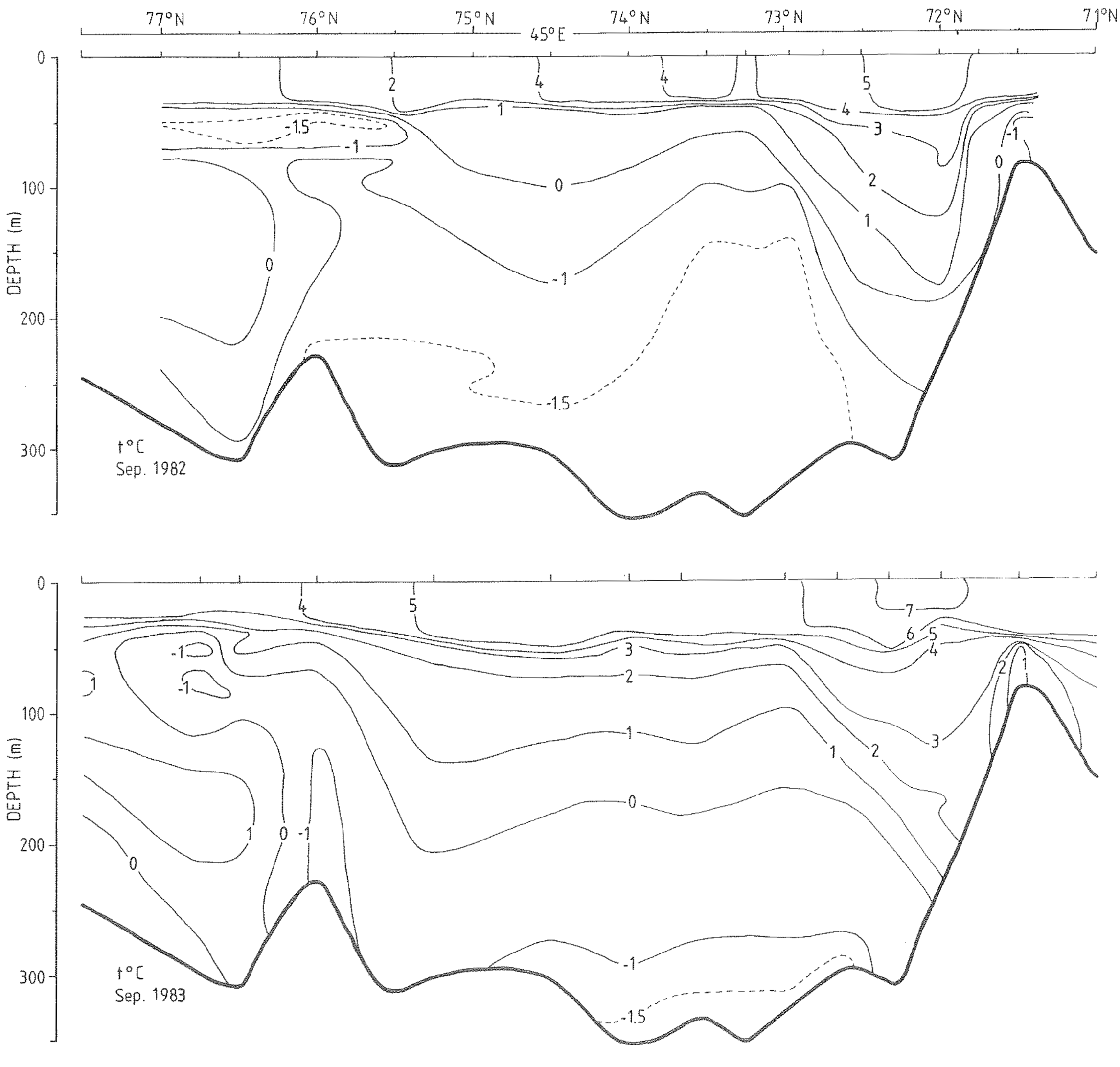

Fig. 8. Temperature in the meridional section of 45°E in September 1982 and 1983.

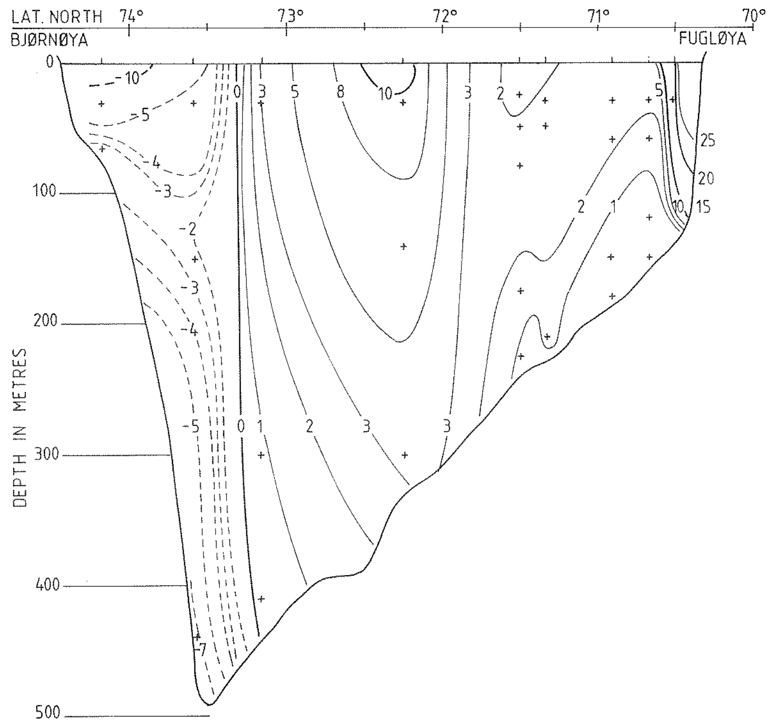

Fig. 9. Mean current component ($cm \cdot s^{-1}$) through the Fugløya-Bjørnøya section from measurements at mooring stations in September-October 1978. The observation depths are indicated by +. (BLINDHEIM, personal communication).

more than a one year's winter cooling to build up the bottom water density high enough to initiate a new outflow.

3. The bottom water outflow takes place mainly in the northern Bear Island Channel and along the southern part of the Novaya Zemlya - Franz Josef Land Channel.

4. To confirm this hypothesis direct current observations in the above mentioned areas of outflow are strongly recommended.

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