Climatic fluctuations in the Barents Sea

Lars Midttun


The circulation system of the Barents Sea is described. Warm water flows into the sea from the west and is gradually transformed into Arctic water, which then flows out of the sea, partly as surface currents, partly as dense bottom water. The climatic conditions of the Barents Sea are determined both by the variations in the inflow and by processes taking place in the sea itself. The great variations in temperature and salinity observed along standard sections crossing the inflowing water masses are examined, and possible explanations are discussed.

Lars Midttun: Institute of Marine Research, P.O. Box 1870 – Nordnes, N-5024 Bergen, Norway.

Introduction

The main purpose of this paper is to present and discuss the rather marked climatic variations observed in the Barents Sea. However it may be worth while first to give a short description of the circulation system as known from the literature.

Based on early observations, Knipowich (1905) gave a description of the water masses of the Barents Sea, and Nansen (1906) devised 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 Nansen's 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 Josef Land.

The majority of the contributions to the oceanography of the Barents Sea are presented by scientists from the USSR. Tantsiura (1959) made a comprehensive analysis of the currents in the Barents Sea. Agenorov (1946) studied a large number of current observations. The detailed work by Novitskiy (1961) dealt with the currents of the northern Barents Sea. Sarynina (1972) 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 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) studied temperature variations in relation to solar activity. Three sections observed by the Institute of Marine Research were analysed by Blindheim and Loeng (1981) and later by Loeng and Midttun (1984). The section Fugloya–Bjørnøya (Bear Island) was studied by Dickson and Blindheim (1984). Variability at the fixed station Nordkapp was studied by Midttun (1969), while Blindheim et al. (1981) compared the climatic variations in Norwegian coastal water with the observations from the Kola sections. Dickson et al. (1970) presented results from the hydrographic work done during the joint 0-group fish surveys in the Barents Sea from 1965 to 1969. The climatic variations in the Barents Sea were studied by Midttun and Loeng (1987).

General description of physical conditions

Principally on the basis of the above-mentioned literature, Loeng (1987) gave a brief review of the main circulation and water masses of the Barents Sea. This review is summarized below.
The current systems

The current systems are as follows: The bottom topography is given in Figure 1. Figure 2 shows a simplified picture of the surface current system, based mainly on current maps made by Tantsiura (1959) and Novitskiy (1961). Only minor corrections have been made as a result of some recent observations. The map indicates two main current directions. In the southern part, the currents are towards the east, while the current directions in the north are 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 Norwegian Atlantic Current along the Norwegian continental shelf. Off the coast of northern Norway the Atlantic Current splits into 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.
Figure 2. Surface currents in the Barents Sea. Arctic currents (\(--\rightarrow\)), Atlantic currents (\(\rightarrow\)), and coastal currents (\(\cdots\rightarrow\)). (Simplified after Tantsura, 1959; and Novitskiy, 1961). Locations of sections discussed are indicated.

together with the Norwegian Coastal Current and proceeds along the Murmansk coast as the Murmansk Current. The northern part of the Nordkapp Current divides along three major routes at about 30°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 Murmansk 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 Arctic water to the Barents Sea takes place along two main routes: 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.

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 residence time for the water masses and possibilities for vertical mixing during the winter season (Nansen, 1906). Current measurements indicate almost the same 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 beneath the lighter Arctic water, as it does west and south of the Great Bank, one must expect different current directions with depth. Also in areas with outflowing dense bottom water, the current directions probably differ from surface to bottom. Therefore Figure 2 represents the current systems in intermediate and bottom layers only to a certain extent.

Water masses

Following Helland-Hansen and Nansen (1909), Atlantic water is defined by a salinity higher than 35.0. At the entrance to the Barents Sea, the mean autumn salinity and temperature in the core from 1966 to 1977 were 35.13 and 6.2°C, respectively (Blindheim and Loeng, 1981). Farther east in the Barents Sea the salinity and temperature were lower, as shown in Figure 3, and as clearly demonstrated by Loeng and 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) and relatively high temperature (t > 3°C). This mass is also most easily traced by the salinity (Fig. 3). The light coastal water spreads out in a wedge-shaped 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 Liøen, 1971).

During the summer the Arctic water (or Barents Sea winter water) is mainly found in the intermediate layer, between 20 and 150 m, in the northern Barents Sea. The core is usually found between 30 and 60 m, with temperatures below −1.5°C and the salinity between 34.4 and 34.6. In the horizontal map (Fig. 3) most of the water with a temperature below 0°C is Arctic water.

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

Bottom water of different kinds may be formed in various places in the Barents Sea. Dense bottom water is formed through brine rejection when ice freezes 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 (Midttun, 1961). The bottom water of the Bear Island Channel, however, may also be formed in the frontal zone (Arctic Front area) during the period of vertical winter circulation on the southeastern slope of the Svalbard Bank (Sarynina, 1972). The winter and summer situations differ with respect
to the vertical structure of the water masses. During winter, vertical mixing takes place throughout the Barents Sea. Over shallow bank areas, convection may reach the bottom and contribute to bottom-water formation as already mentioned. In the deeper areas, the water masses may be homogeneous to more than 200 m. In the ice-covered areas, the temperature will be homogeneous, while a salinity gradient may maintain a weak vertical stability. Ice-freezing with brine rejection may break down the salinity gradient.
Sea-ice conditions

The variation in the position of the ice edge, based on satellite images over a period of ten years (1971–1980), is shown in Figure 4 for the months February, April, June, August, October, and December (Vinje, 1983). The figure shows considerable variations in ice extension, which may take place from year to year. In some months, especially in summer and autumn, these variations may exceed 500 km. Generally, the seasonal variations of the sea-ice extension are, in their broad features, similar from one year to another, with the maximum and minimum extensions 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 Arctic 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 early August.

Figure 5 shows the variations of maximum ice coverage in the years 1979–1986. In the vicinity of Bear Island, there is almost no variation from one year to another. In the eastern Barents Sea, however, the variations are considerable.

Some authors have suggested the presence of cyclic variations of three to five years in the sea-ice conditions (Kissler, 1934; Lunde, 1965). Long-term variations, not necessarily of a cyclic nature, are also well known from other marginal areas of the Arctic, e.g., the west coast of Greenland (Dunbar, 1972).

Climatic variations

General description

Climatic variations can be recorded in sections crossing the inflowing water masses. Figure 6 shows temperature and salinity variations in the three Norwegian sections A, B, and C, and the corresponding temperature observed in the Kola section, the latter taken from Anon. (1986). The curves represent mean values in the 50–200-m layer observed in late August–early September each year. Locations of sections can be seen in Figure 2.

The salinity curves have similar trends in all three sections, A, B, and C. The salinity gradually decreased from 1970 until 1978/1979, when the lowest values were observed. Later on the salinities generally increased, reaching normal values in 1983.

The variations are greatest in the east (section C), where the standard deviation for the period 1970–1986 is 0.07, compared with 0.05 in the west (section A).
Figure 7. Temperature anomalies in the Kola section for the period 1900–1985 (continuous line) and ice index for the Barents Sea (dotted line).
The temperature curves also show parallel trends. Most pronounced is the cold period 1977–1981, which in the Kola section is the longest period with negative anomalies observed since 1920.

Midttun et al. (1981), using the Kola section, calculated monthly mean temperatures on the basis of data from the period 1921–1980, and anomalies from those means have been calculated for the whole period up to 1987 (Fig. 7).
Figure 7 shows that the years up to 1906 were cold. According to Sætersdal and Loeng (1984), almost the whole missing period, 1907–1920, was also cold. After some years with higher temperatures in the beginning of the 1920s, the years up to 1930 had lower temperatures than normal. The longest period with a warm regime was between 1930 and 1939, with a maximum in 1938. The years after 1945 are characterized by fluctuations with a duration of three to five years. These periods coincide with cyclic variations in sea-ice conditions, 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 1970s, great variations in climatic conditions were observed in the Barents Sea. The period 1970–1976 was warm, while the second half of the decade was characterized by low temperatures. Throughout the early 1980s, temperatures increased. An ice index for the period after 1970 shows similar trends, indicating a close relationship between variation in sea temperature and ice conditions (Fig. 7).

As early as 1909 Helland-Hansen and Nansen (1909) suggested that climatic variations in the Barents Sea are probably of an advective nature. They observed a time lag of one year between the Lofoten and the Kola sections. Loeng et al. (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, climatic variations seem to be due to advective processes in the Atlantic inflow (Blindheim, 1987).
Discussion of possible causes

The notable variations observed in the physical environment of the Barents Sea have a great effect on the biological conditions for the large fish stocks in the sea. It is therefore important to discuss possible explanations and to try to understand the physical causes behind the climatic variations observed in the inflowing water masses. The variations are seen in the long series of temperature observations in the Kola section crossing the main branch of the Murmansk Current (Fig. 2). The temperature alternates, with successive warm and cold periods of about three to five years (Fig. 7). Similar variations are observed in other sections of the Barents Sea (Fig. 6), and are also reflected in the ice coverage. It may be seen from Figures 3 and 4 that the winter ice coverage has the greatest variations over the Central Bank and in the eastern part of the Barents Sea.

The variations may be hypothetically explained as arising from similar variations in the properties of the inflowing water; that is, the current system of constant velocity and volume brings in a water mass with changing temperature and salinity. But the variations could just as well be a result of variations in the current system itself. Since both temperature and salinity increase in the direction of the countercurrents, high velocity should result in high temperature and salinity, and low velocity in low temperature and salinity. In the last case the variation in the current system has to be explained. Again, the variation in the current activity could be forced upon the sea from outside, but it could just 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 then draining from the sea in bottom currents. The process of ice formation is also the source of the light surface water carried by the Arctic currents. The process is described in detail by Midttun (1985) and can be regarded as a separator, transferring salt from the 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 right side of the channels leading from the Barents Sea to the Norwegian Sea through the Bear Island Channel and to the polar seas 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 the west. The activity in building up dense bottom water may vary from one year to another, followed by variations in the outflow with corresponding changes in the inflow. After a large inflow it may take more than one year to build up the required conditions again to initiate 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.

Figure 8 shows that areas with formations of high-density water are located near the Central Bank and on the Novaya Zemlya Bank. This is the same area where the interannual changes of winter ice coverage are greatest (Fig. 5).

Figure 9 shows the effect of the extensive water exchanges between 1982 and 1983. The inflow and outflow between the Norwegian Sea and the Barents Sea have been measured in the section between Fugløya and Bjørnøya from a series of anchored current meters (Blindheim, 1989). Results are presented in Figure 10. Transport calculations indicate about 3 Sv into, and around 1 Sv out of, the section. This would require another outflowing current, most likely located in the channel between Novaya Zemlya and Franz Josef Land. The outflow of high-density water in this area has recently been described by Midttun (1985).

The above considerations lead to the following hypotheses:

1. The mechanisms behind the climatic variations in the Barents Sea might be described as the result of dense water formation during cooling and ice formation. This process transforms the inflowing water mass into two outflowing types, viz. bottom water of high density and surface water of low density.
2. The transforming process is time dependent on the properties and quantity of the influx. After a period of high influx, the transformation requires more than one year of cooling before the density of the bottom water is 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 these hypotheses, direct current observations in the above-mentioned areas of outflow are strongly recommended.

Acknowledgements
My appreciation to H. Kismul for preparing the figures and to Ms I. Byrkjedal for typing the manuscript. Harald Loeng has contributed to this paper.

References


