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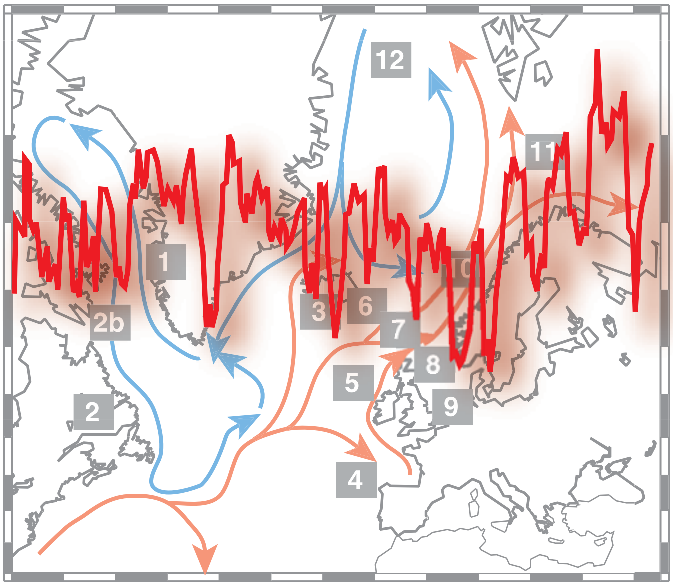
NO. 251

The Annual ICES Ocean Climate Status Summary 2001/2002



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Overview

The NAO: The North Atlantic Oscillation (NAO) index has been slowly recovering to positive values since the extreme negative value of 1996. However, during the winter preceding 2001 it again became negative. The response seen throughout the ICES area to the 1996 switch of the NAO has not been observed in 2001, probably due to a different pattern of sea level pressure over the North Atlantic. In 2001 the pattern exhibited a large weak positive anomaly stretching from northern Scandinavia to Newfoundland.

Area 1: Ocean temperatures off West Greenland showed considerable warming during the summer and autumn of 2001. This warming was similar to that observed during the 1960s. Anomalously high salinities were observed in the off-slope surface waters during the autumn.

Area 2: Annual mean air temperatures over all areas of the Northwest Atlantic were above normal during 2001, but decreased compared to the records set in 1999. The amount of sea ice on the eastern Canadian continental shelf continued to be below normal for the fourth consecutive year. Except for southern areas of the Newfoundland and the northern Scotian shelves, ocean temperatures were above normal, continuing the warm trend established in the late 1990s.

Area 2a: Surface waters over the entire Scotian Shelf have been warmer and fresher than average during the past several years, including 2001. The higher temperatures are due to the warmer atmospheric conditions and the low salinities have been related to upstream influences off Newfoundland.

Area 2b: The upper layers of the Labrador Sea were observed to be warmer, saltier, and less dense in the summer of 2001 compared with conditions in 2000. These changes seem to be due largely to the inflow of Atlantic waters. There is no evidence that convective overturning during the winter of 2000–2001 reached depths greater than 400–500 m.

Area 3: In Icelandic waters there were relatively high temperatures and salinities, as there have been for the previous 3 – 4 years following the very cold years of 1995 and 1996. However, 2001 temperatures and salinities were slightly cooler and fresher than in 1999 and 2000.

Area 4: The Bay of Biscay continued to show a progressive decrease in salinity, which began in 1999. Averaged upper water layer temperature was low compared to values obtained during the last decade, whereas yearly averaged air temperature remained at the same level as the preceding three years.

Area 5: The Rockall Trough began to cool and freshen slightly during 2001, although both temperature and salinity remained high compared to the long-term mean, with values similar to previous peaks in the early 1980s.

Area 6: The temperature and salinity of Atlantic water passing through the Faroe Bank Channel and across the Iceland-Faroe Ridge have remained fairly constant since 1997.

Area 7: With respect to the last four decades, Atlantic waters in the Faroe Shetland Channel are generally warming and becoming more saline. However, there was little change between 2000 and 2001.

Areas 8 and 9: In terms of the surface temperatures of the North Sea, 2001 was generally warmer than normal. The summer of 2001 exhibited a reduced influence of Atlantic water in the northern North Sea and also in the Southern Bight. The low salinities in the southern North Sea suggest stronger than normal run-off from the continental rivers. The Baltic outflow south-west of Norway in summer 2001 was stronger than normal.

Area 9b: In the Baltic, surface waters generally became fresher due to high freshwater inputs following a wet winter. Surface temperatures were warmer than average. There were deep-water inflows into the Baltic Sea from the North Sea in the autumn of 2001.

Area 10: In the Norwegian Sea a long term warming trend continued, and in 2001 the area occupied by Atlantic water was the greatest since 1991.

Area 11: The Barents Sea was warmer than average during 2001, but the temperature gradually decreased throughout the year from nearly 1°C to just 0.1°C above average. As a result the area remains comparatively ice-free.

Area 12: Conditions in the Greenland Sea were generally warmer and more saline in 2001 compared to 2000. Although on average winter convection went down to 800 m, in small isolated patches it reached 2500 m.

Prognosis

Though March is still in progress at the time of writing, the winter NAO index for 2002 is likely to show a limited recovery from 2001, in an overall pattern across the ICES area, which is unlike the classical dipole pattern normally observed. Hence continued near average conditions in most areas may be expected, with room for surprises.

The North Atlantic Oscillation (NAO) Index

Since the NAO is known to control or modify three of the main parameters which drive the circulation in the ocean area covered by this climate summary (i.e., wind speed, air/sea heat exchange and evaporation/precipitation) knowledge of its past and present behaviour forms an essential context for the interpretation of observed ocean climate change in 2001/2002.

The NAO alternates between a "high index" pattern, characterised by strong mid-latitude westerly winds, and a "low index" pattern in which the westerly winds over the Atlantic are weakened. High index years are associated with warming in the southern North Atlantic and northwest European shelf seas, and with cooling in the Labrador and Nordic Seas. Low index years generally show the reverse.

When the winter NAO index is considered in the context of the present decade and also the 20th century (Figure 1), the 1960s were generally low-index years while the 1990s were high index years. There was a major exception to this pattern occurring between the winter preceding 1995 and the winter preceding 1996, when the index flipped from being one of its most positive values to its most negative value this century. The index subsequently rose from the extreme low of 1996, and the recovery continued during the winter preceding 2000. However, during the winter preceding 2001 the NAO index again became negative.

Although this simple index continued to increase back to positive values during the winters preceding 1999 and 2000, the actual pattern of the NAO over the ICES area did not recover to the "normal" distribution expected during high NAO years, but was rather displaced towards the east or northeast. This subtle change had most impact in the Northwest Atlantic, where instead of a chill and strong north-westerly airflow promoting cooling there, as it did in the early 1980s and 1990s, any north-westerly airflow was mainly confined to the east of Greenland, while the Labrador Sea was occupied by light or southerly anomaly-winds (see the 2000/2001 IAOCSS).

It would appear that the winter of 2000/2001, while exhibiting another reversal similar to that seen in 1995/1996, has experienced a different dipole pattern resulting in far less dramatic effects compared to the earlier reversal event. Text Box 1 provides more details of this.

In the remainder of this ICES Annual Ocean Climate Status Summary (IAOCSS) for 2001/2002, the regional descriptions will proceed in an anti-clockwise manner around the North Atlantic, commencing in the waters west of Greenland. This follows the main circulation pattern of the North Atlantic (Figure 2).

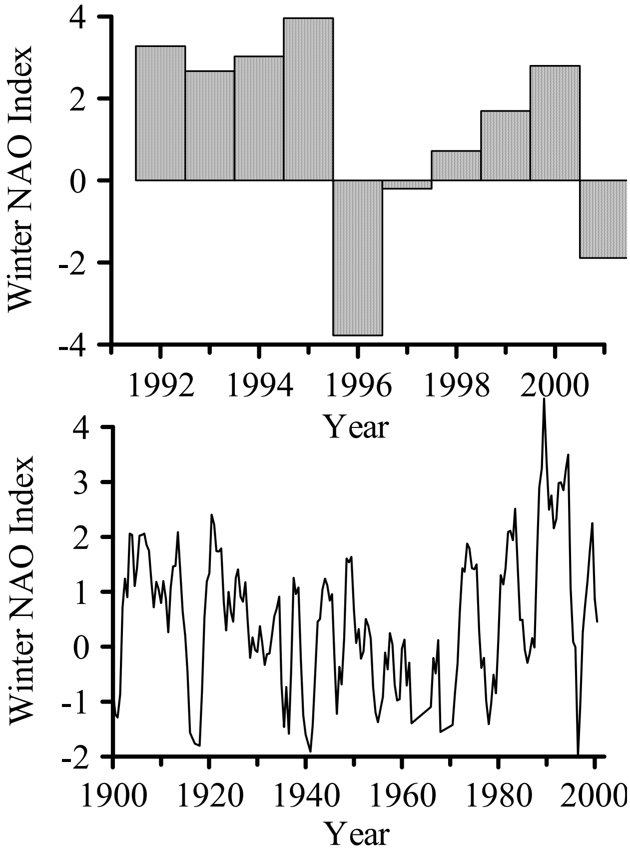

Figure 1. The winter NAO index in terms of the present decade (upper figure) and the present century (lower figure - a 2 year running mean has been applied).

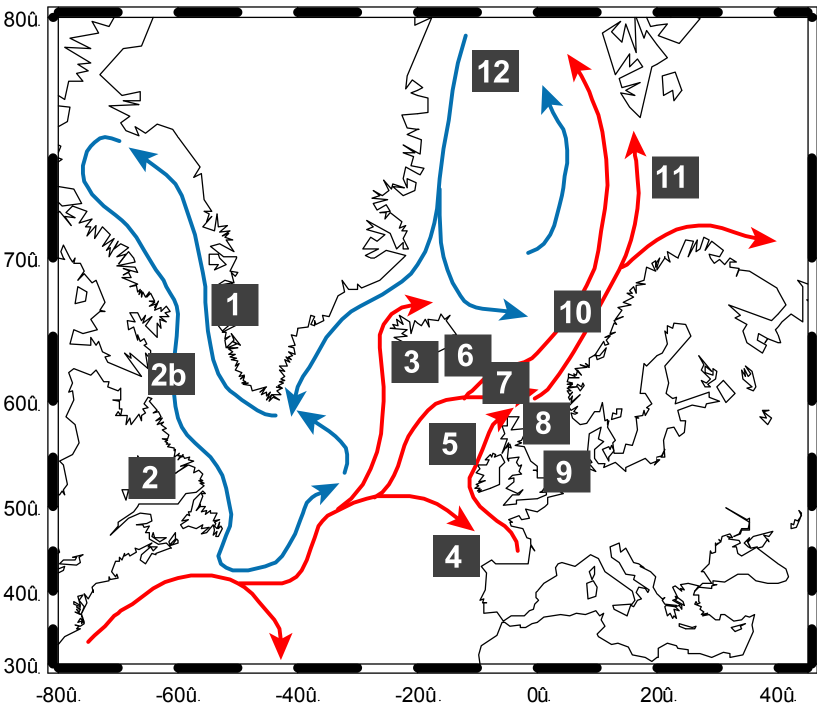

Figure 2. Schematic of the general circulation of the North Atlantic in relation to the numbered areas presented in the 2001/2002 Annual ICES Ocean Climate Status Summary. The blue (light grey) arrows indicate the cooler waters of the sub-polar gyre. The red (dark grey) arrows show the movement of the warmer waters in the sub-tropical gyre.

Text Box 1 – The NAO in winter 2001: a return to NAO-negative conditions

Background

Following a long period of amplification from its most extreme and persistent negative phase in the 1960s to its most extreme and persistent positive phase during the late 1980s early 1990s, the NAO index underwent a large and rapid decrease during the winter preceding 1996 and recent IAOCSS' describe the recovery to more positive values since then. During the winter preceding 2001, the "recovering" NAO index has undergone a further reversal to negative values

The NAO in winter 2001

The 2000/2001 IAOCSS reported early indications of a sharp return to NAO negative conditions, although at the time of writing only December 2000 and January 2001 values of the Jones index (www.cru.uea.ac.uk) were available. Sea Level Pressure (SLP) anomaly fields for the first 3 months of the 2001 winter (December, January, February) showed a pattern which we would associate with a negative NAO index. Once the full 2001 winter data became available, the early indications were confirmed. The Hurrell winter NAO index reported a value of −1.89 (www.cgd.ucar.edu/~jhurrell/nao.html). The NCEP/NCAR reanalysis SLP anomaly composite for the winter 2001 (Figure 3a) shows a clear negative anomaly in the pressure dipole.

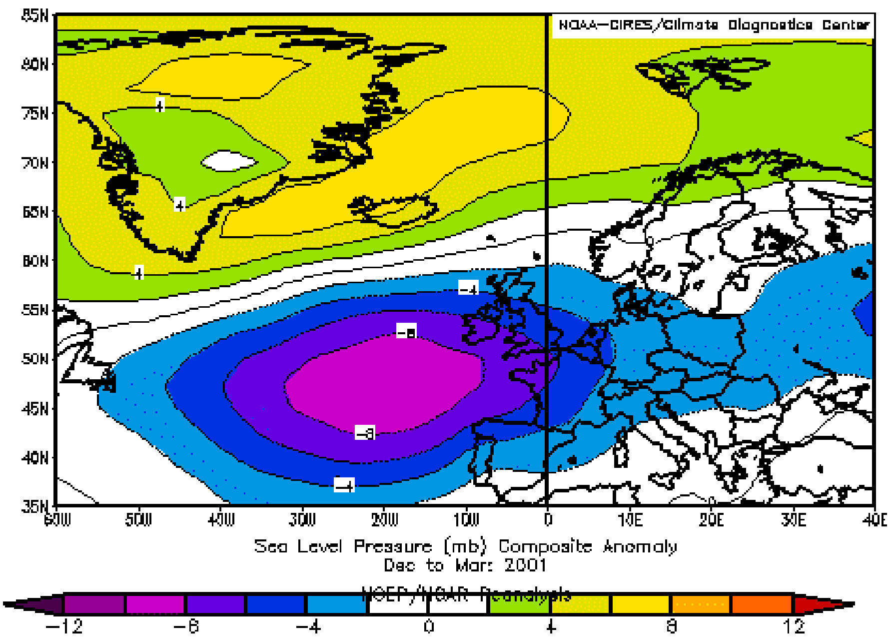

Figure 3a. The pattern of Sea Level atmospheric pressure during the winter (December, January, February, March) of 2001 from which the NAO index is calculated (Iceland to the Azores).

The 2001 Reversal compared to the 1996 Reversal

The reports from the ICES regions contained in this IAOCSS do not suggest a repeat of the extreme conditions observed following the 1996 NAO reversal. Examination of the SLP anomaly patterns for the two winters (Figure 3a and 3b) illustrates a possible reason for the markedly different response to the negative NAO forcing. Firstly 1996 was a much stronger negative NAO year. Secondly, the SLP anomaly of 1996 suggests strong south-easterly wind anomalies over the North Sea, the northeast Atlantic and the Labrador Sea. The 2001 dipole pattern is more zonally constant, with maximum gradients further north than in 1996.

Is the North Atlantic Oscillation always the dominant control on Atlantic variability?

In previous IAOCSS' possible associations between various parameters of Atlantic hydrography and the winter pattern and amplitude of the NAO are described. The NAO dictates much of the climate variability from the eastern seaboard of the United States to Siberia and from the Arctic to the tropical Atlantic. Also, from the mid 1960s to the 1990s, the NAO index has been observed to oscillate slowly between one extreme state and the other in an instrumental record that extends back to at least 1865. However, there are areas and times when the influence of the NAO will be less dominant in long-term records. Examples include the warm period between 1925 and 1960 (See ICES CM2001/C:06, the 2001 Report of the ICES Working Group on Oceanic Hydrography for more details), and zones of minimal correlation with the NAO such as the Rockall Trough. In addition, over the Atlantic as a whole, the NAO explains only about one-third of the total variance in winter sea level pressure, and the chaotic nature of the atmospheric circulation means that, even during periods of strongly positive or negative NAO index, the atmospheric circulation typically exhibits significant local departures from the idealized NAO pattern. Finally, it is worth stressing that the causes of longer-term NAO behaviour are not known, the periods when anomalous NAO-like circulation patterns persist over many consecutive winters, or the fact that the magnitude of the recent upward trend is unprecedented in the observational record.

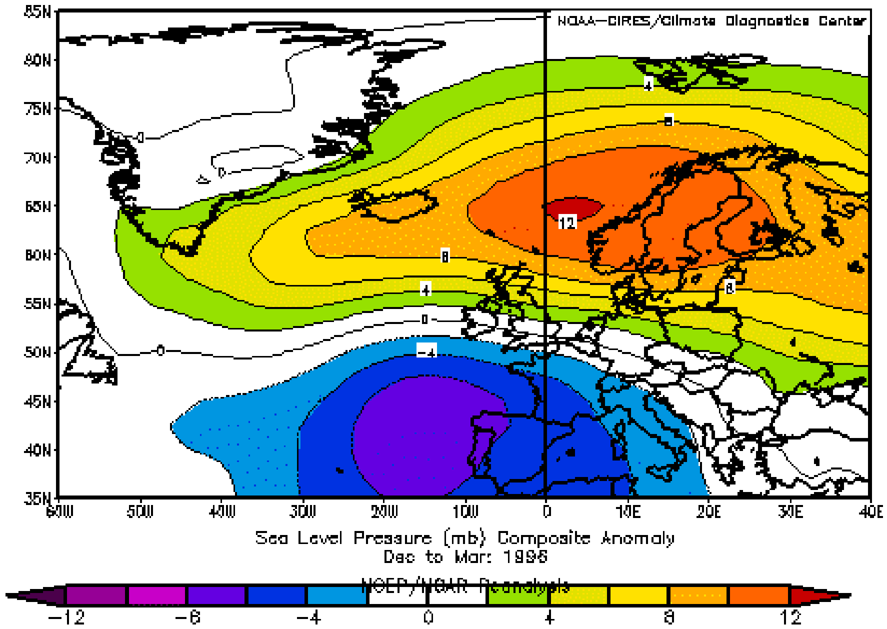

Figure 3b. The pattern of Sea Level atmospheric pressure during the winter (December, January, February, March) of 1996 from which the NAO index is calculated (Iceland to the Azores)

Regional Descriptions

Area 1 – West Greenland

West Greenland lies within the area, which normally experiences warm conditions when the NAO index is negative, which it was in the winter preceding 2001 and hence climatic conditions at West Greenland were anomalously warm. The 2001 mean annual air temperature at Nuuk was −0.1°C, which is about 1.3°C above normal (Figure 4). Changes in the ocean climate in the waters off West Greenland generally follow those of the air temperatures. The relatively mild atmospheric conditions were reflected in the mean water temperature at Fyllas Bank during autumn (Figure 5), with the 2001 temperature value for the upper 200 m being the second highest temperature anomaly observed since 1963 (1.78°C).

In summary, oceanographic conditions off West Greenland during autumn of 2001 were warmer and more saline due to mild atmospheric conditions and an inflow of Irminger water which was found as far north as 62°N (Frederikshaab Bank).

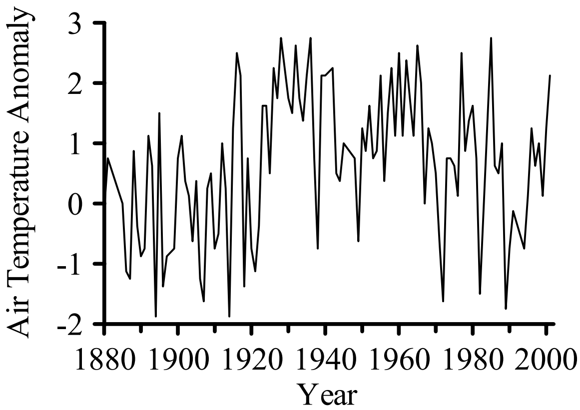

Figure 4. Area 1 – West Greenland. Nuuk mean annual air temperature anomaly (relative to the 1961–1990 climatic mean).

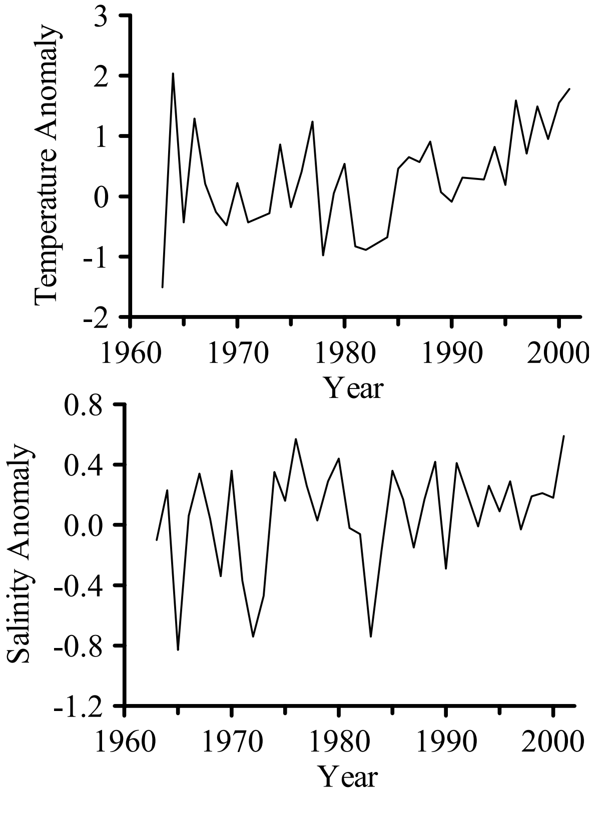

Figure 5. Area 1 – West Greenland. Fyllas Bank (Station 4) autumn temperature (upper figure) and salinity (lower figure) anomaly averaged over the 0–200 m layer.

Area 2 – North West Atlantic: Newfoundland and Labrador Shelf

Oceanographic conditions in this region are to a large degree determined by the strength of the winter atmospheric circulation over the Northwest Atlantic. In general, when the normal cyclonic circulation is weak during the winter months, corresponding to a negative NAO index, warm saline ocean conditions generally predominate.

Annual mean air temperatures warmed slightly during 2001, compared to 2000, values in northern areas and remained above normal in many regions of the Northwest Atlantic (Figure 6). Maximum air temperature anomalies occurred on southern Baffin Island, where values were up to 1.5°C above their long-term mean. Seasonally, air temperatures in these areas were above normal in nine out of the 12 months of 2001. Air temperature in the southern regions, St. John's Newfoundland for example, cooled slightly over 2000 values but remained above normal for eight out of 12 months, with an annual anomaly of +0.5°C.

Sea ice on the Newfoundland and Labrador Shelves during 2001 generally appeared late and left early, resulting in a shorter duration of ice than normal. The total ice coverage in these areas during 2001 decreased slightly over conditions in 2000, remaining below average for the fourth consecutive year. Off eastern Newfoundland, the depth-averaged ocean temperature ranged from a record low during 1991 (high NAO index in preceding winter), a near record high in 1996 (following the reversal in the preceding winter to the near record low NAO index), and above the long-term (1971–2000) average in 1999 through to 2001. Summer salinities, which were below normal during most of the early 1990s, returned to near normal values during 2000 but decreased again to below normal values in 2001.

A robust index of the general oceanic environmental conditions off the eastern Canadian continental shelf is the extent of the cold intermediate layer (CIL) of sub-zero water. This winter cooled water remains trapped between the seasonally heated upper layer and the warmer shelf-slope water throughout the summer and autumn months. During the 1960s, when the NAO was well below normal and had the lowest value ever in this century, the volume of CIL water was at a minimum, and during the high NAO years of the early 1990s, the CIL volume reached near record high values. During 2001, the CIL remained below normal and on the Newfoundland Shelf it was the lowest observed in 23 years.

Annual mean bottom temperature for the Grand Bank and Hamilton Bank have recently increased over the lows of the early 1990s, with average values during 1999 greater than 1.5°C on the Grand Bank and greater than 1°C on the southern Labrador Shelf. During 2001 mean bottom temperatures decreased over 2000 values during the spring but increased by about 0.5°C during the autumn.

In general, ocean conditions in the Northwest Atlantic during 2001 (except for the spring) warmed slightly over 2000 values thus continuing the warm trend experienced in the Northwest Atlantic during the past several years.

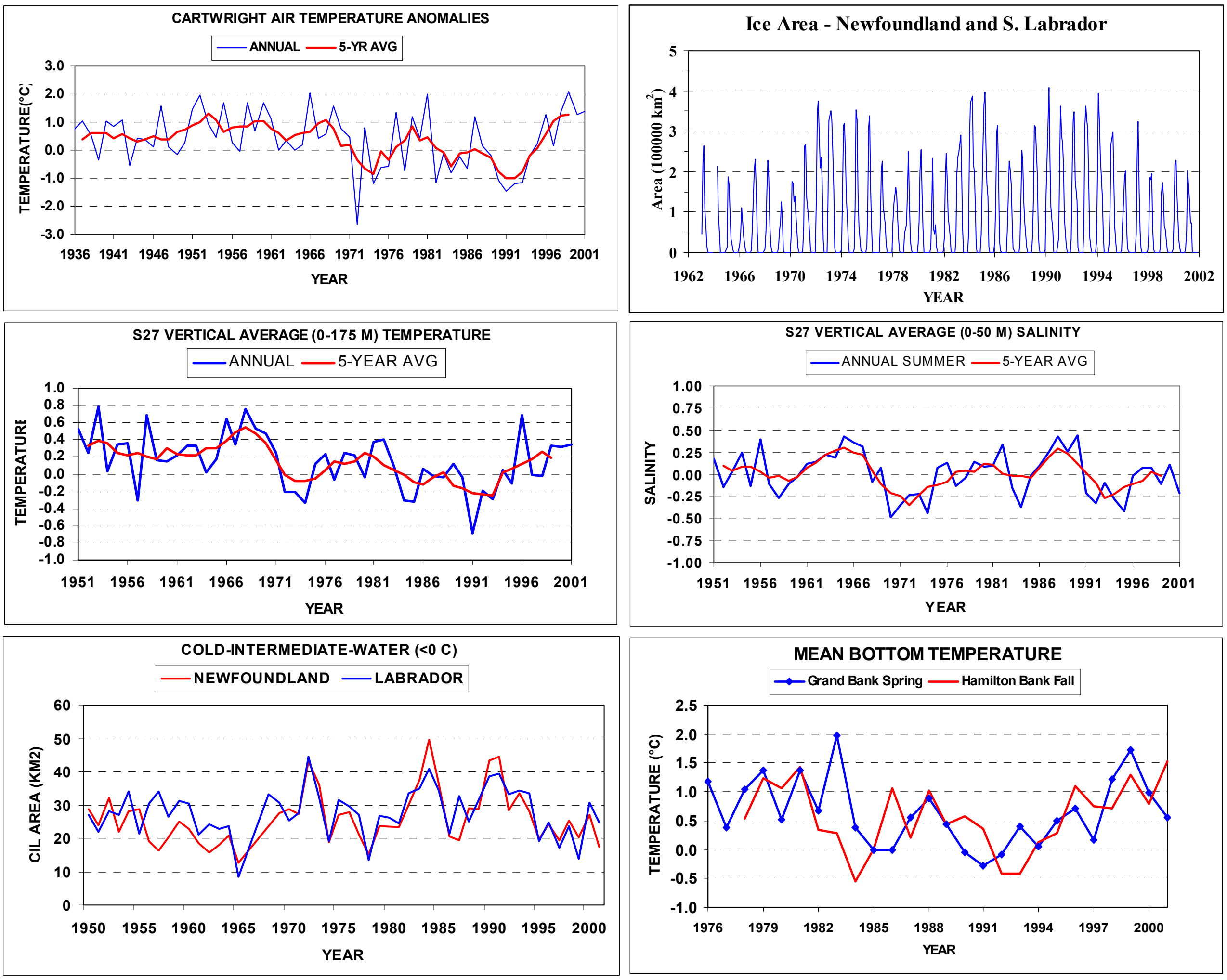

Figure 6. Area 2 – North West Atlantic: Newfoundland and Labrador Shelf. Annual air temperature anomalies at Cartwright on the Labrador Coast, sea-ice area off Newfoundland and Labrador between 45°N–55°N, the depth-averaged Station 27 annual temperature and summer salinity anomalies, the time series of cold intermediate layer (CIL) on the Newfoundland and Labrador Shelves and the annual mean bottom temperatures on the Grand Bank and Hamilton Bank.

Area 2a – Northwest Atlantic: Scotian Shelf

The continental shelf off the coast of Nova Scotia is characterised by complex topography consisting of numerous offshore shallow (< 100 m) banks and deep (> 200 m) mid-shelf basins. It is separated from the southern Newfoundland Shelf by the Laurentian Channel and borders the Gulf of Maine to the south-west. The surface circulation is dominated by a general south-westward flow interrupted by clockwise movement around the banks and counter-clockwise around the basins with the strengths varying seasonally. Temperature and salinity conditions over the Shelf are largely determined by advection of water from southern Newfoundland and the Gulf of St. Lawrence as well as offshore slope waters.

In 2001, annual mean air temperatures over the Scotian Shelf were above average but have been declining from the records set in 1999 (Figure 7). These higher-than-normal values have been observed from southern Labrador to the southern Gulf of Maine. Seasonally, air temperatures from winter to summer were near their long term (1971–2000) means but the autumn (October, November and December) in 2001 was very warm.

The amount of sea ice on the Scotian Shelf was low in 2001, conditions that have persisted for the past four years. The area and duration of ice have been increasing, however, since the minimum in 1998.

The Scotian Shelf is divided by topography into at least two separate regions. The lower layers in the northeast tend to be covered by relatively cold waters (1°C–4°C), whereas the basins in the central and south-western regions contain bottom temperatures of 8°C–10°C. The origin of the latter is the offshore slope waters whereas in the northeast their source is from the Gulf of St. Lawrence. The interannual variability of the two water masses is different. Misaine Bank temperatures at 100 m capture the changes in the northeast. Monthly mean temperatures from Misaine Bank indicate colder-than-normal conditions in 2001 after two years of above normal temperatures. These followed an extended period from 1985 to 1997 of below average temperatures. In Emerald Basin, temperatures in 2001 were slightly above average and continue a trend that has existed since the mid 1980s, except for the exceptionally cold period in 1998. The latter occurred when cold Labrador slope water replaced warm slope water at the edge of the continental shelf and subsequently penetrated onto the Scotian Shelf. The presence of the Labrador slope water was caused by an increase in the volume transport of the Labrador Current and was believed to have been a delayed response to the large decline in the NAO index in 1996.

Surface waters over the entire Scotian Shelf have been warmer and fresher than average during the past several years, including 2001. The higher temperatures are due to the warmer atmospheric conditions and the low salinities have been related to upstream influences off Newfoundland.

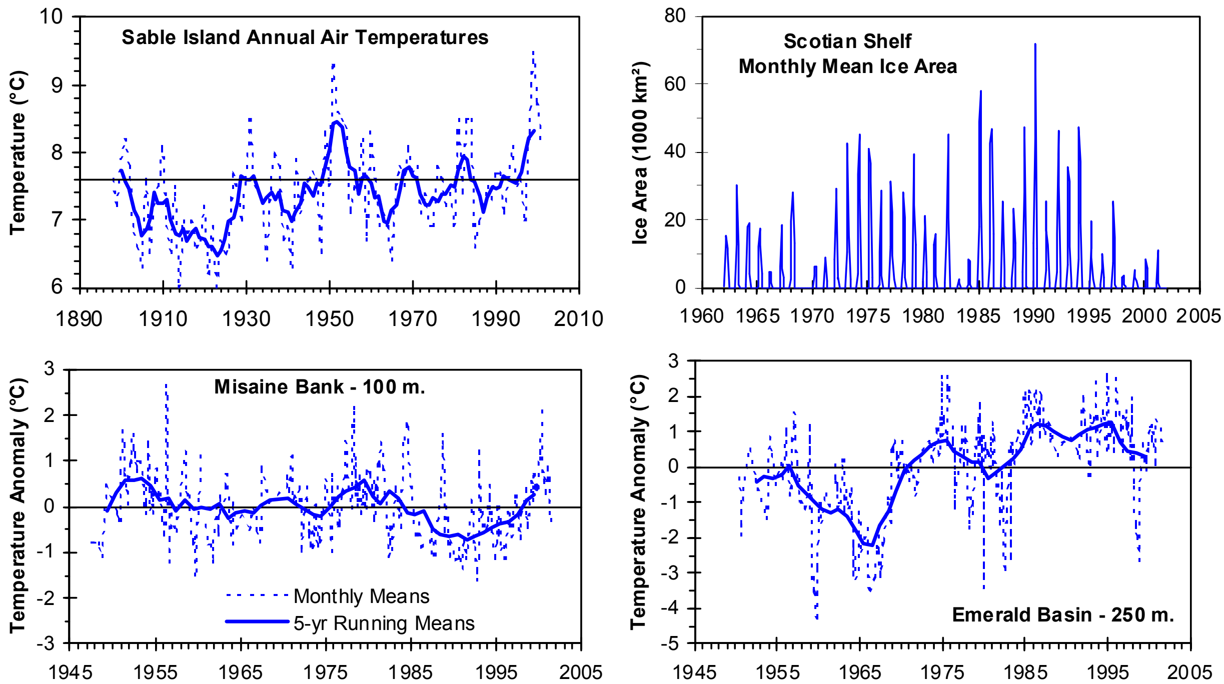

Figure 7. Area 2a – Northwest Atlantic: Scotian Shelf. Annual air temperatures at Sable Island on the Scotian Shelf, monthly means of ice area seaward of Cabot Strait and the near-bottom temperatures in the north-eastern Scotian Shelf (Misaine Bank, 100 m) and central Scotian Shelf (Emerald Basin, 250 m). The vertical line in the plot of air temperatures represents the long-term (1971–2000) average.

Area 2b – The Labrador Sea

The Labrador Sea is located between Greenland and the Labrador coast of eastern Canada. Cold, low salinity waters of polar origin circle the Labrador Sea in a counter-clockwise current system that includes both the northward flowing West Greenland Current on the eastern side and the southward flowing Labrador Current on the western side. Warm and saline waters from more southern latitudes flow northwards into the Labrador Sea on the Greenland side and become colder and fresher as they penetrate northward and eventually recirculate to the south on the Labrador side.

Wintertime cooling and evaporation increase the density of surface waters in the central Labrador Sea. In some years, the wintertime density increase is so large that the surface layers overturn, a process that has been observed to penetrate to depths as great as 2000 m. The temperature, salinity, and density of Labrador Sea water formed by these overturning processes vary from one year to another depending on the winter conditions. The intermediate-depth Labrador Sea water mass created in this way spreads throughout the northern North Atlantic. Cold winters and strong winds during the high NAO-index conditions of the first half of the 1990s gave rise to the formation of a notably dense, deep Labrador Sea water mass.

Since the winter of 1994–1995, mild winters (low values of the NAO index) have produced only shallow wintertime convection. During the 1999–2000 winter, winter heat loss was great enough to reverse the warming trend and overturn the surface waters to a maximum depth of about 1000m. The recent mild 2000–2001 winter saw a return to shallower winter mixed layers and a warming trend in the upper waters, but still less than the maximum observed in the summer of 1999. The upper 1000 m warmed by up to 0.3°C in spring 2001 relative to the previous year. At the same time, the upper waters increased in salinity by up to 0.02, but the overall trend was to less-dense waters in the upper 1000 m.

The decrease in density of the upper layers of the Labrador Sea was accompanied by a 1–2 cm rise in sea level that is also seen in satellite altimeter measurements (Figure 8). Average mid-Labrador Sea sea level was slightly above the mean for the available record beginning in late 1992.

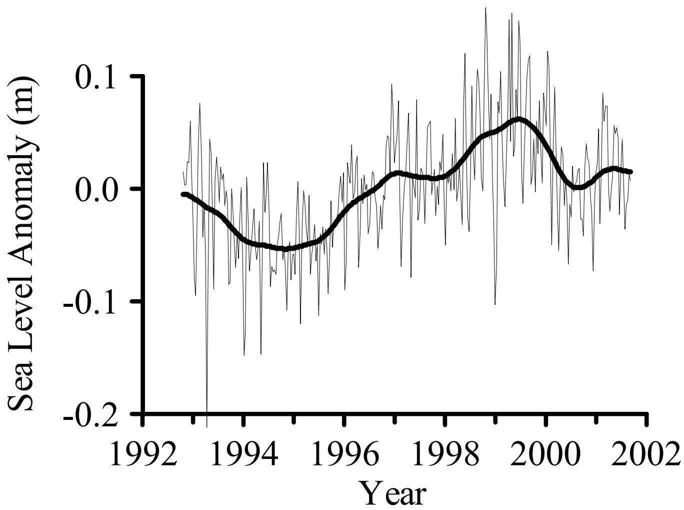

Figure 8. Area 2b – The Labrador Sea. Central Labrador Sea TOPEX/POSEIDON sea level (56.6°N, 52.6°W). Thin line - residual after seasonal cycle removed. Thick line - smoothed residual.

Area 3 – Icelandic Waters

Iceland is situated at the meeting point of warm currents and cold currents on the Greenland-Scotland Ridge (Figure 9). The warm Irminger Current arrives from the south, and the East Greenland Current and the East Icelandic Current from the north. The ocean climate influences the climate of Iceland to a great extent, as well as the biological conditions in the waters around Iceland.

Hydrographic conditions in Icelandic waters in 2001 revealed generally favourable temperatures and salinities. The salinity of the warm water from the south continued at a relatively high level in 2001 (> 35.15), although it was slightly lower than in 1999 and 2000 (Figure 10). The inflow during 2001 of warm and saline water into North Icelandic waters was also relatively strong as in previous years (Figure 11). No trace was found of the low-saline surface layer above the warm inflow as was observed in 1996–1998. Temperature and salinity in the cold East Icelandic Current were relatively high in 2001 as in the previous two years (Figure 12). The relatively mild conditions in Icelandic waters in 2001 continued the improved conditions during the last years following the extremely cold conditions in 1995.

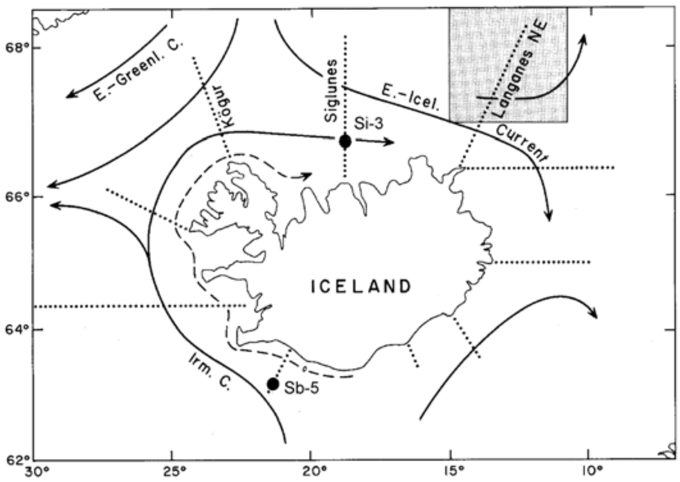

Figure 9. Area 3 – Icelandic Waters. Main currents and location of standard hydro-biological sections in Icelandic waters.

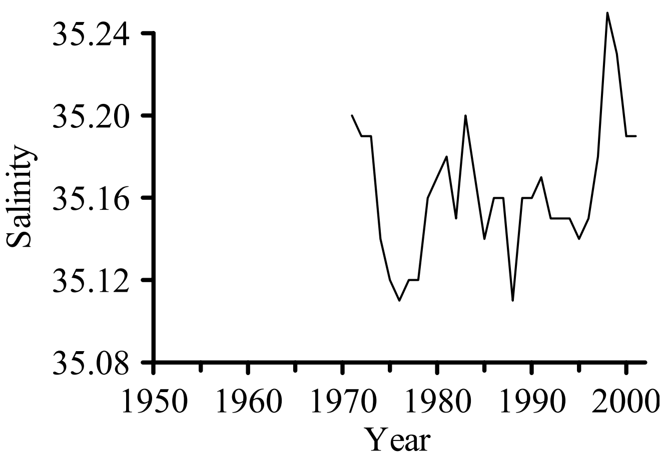

Figure 10. Area 3 – Icelandic Waters. Salinity at 100 m depth in the Irminger Current south of Iceland (Station Sb-5) for the period 1971–2001.

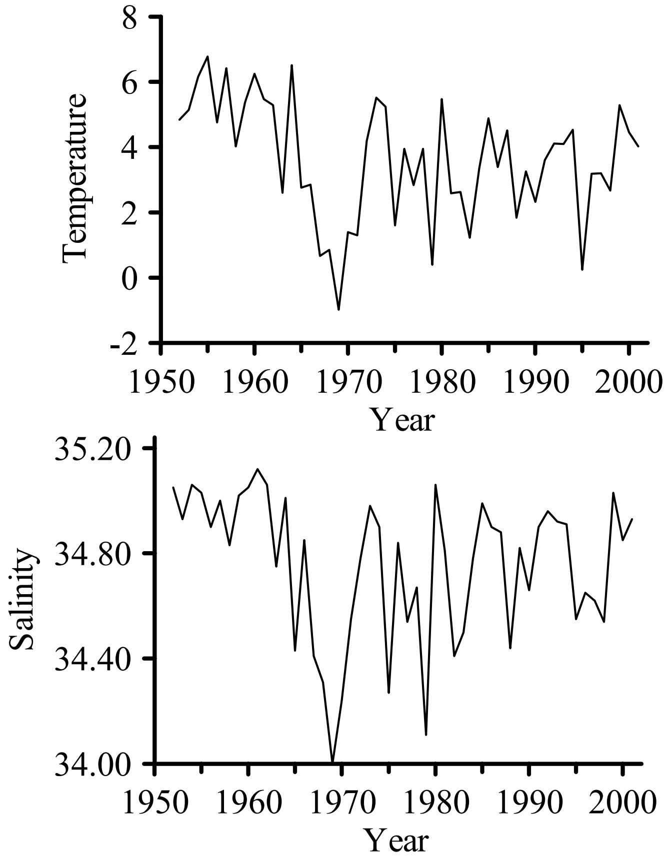

Figure 11. Area 3 – Icelandic Waters. Temperature and salinity at 50 m depth in spring in north Icelandic waters (Station Si-3) for the period 1952–2001.

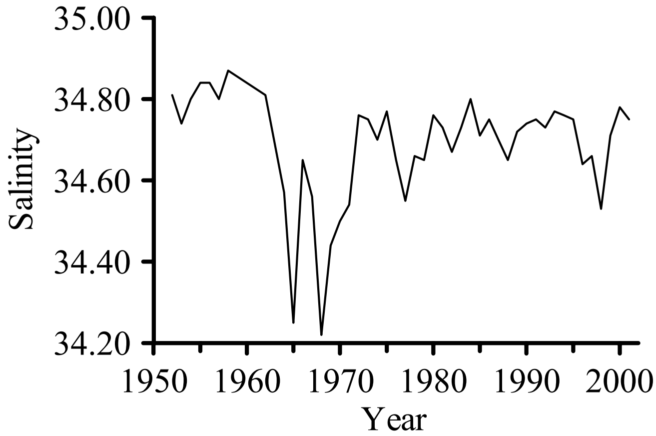

Figure 12. Area 3 – Icelandic Waters. Mean salinity at 25 m depth in the East Icelandic Current northeast of Iceland for the period 1952–2001.

Area 4 – Bay of Biscay and Eastern Atlantic

The Bay of Biscay is located in the eastern part of the North Atlantic. Its general circulation, which follows the subtropical anticyclonic gyre, is relatively weak (1–2 cm/s). In the southern part of the Bay of Biscay, east-flowing shelf and slope currents are common in autumn and winter due to westerly winds, whereas in spring and summer eastern winds are predominant and coastal upwelling events are frequent.

During 2001, salinity continued a progressive decline, which began in 1999 following the relative maximum in 1997–1998. By September, average salinity for the upper 300 m reached its minimum value for the 9-year time series and remained at very low values until the end of the year (Figure 13). This behaviour is caused by a reduction in advection of western Iberia Peninsula waters, as a consequence of changes in the wind regime and of runoff from the major rivers.

The presence of fresher water occupying the surface layer in the region supported the formation of an anomalously sharp thermocline in summer. Despite winter 2001 being mild in the area and summer weather conditions extended until late October, the mean temperature for the whole mixing layer remained moderate without the common autumn-winter temperature peak (Figure 13). A similar situation for both temperature and salinity has been previously observed in 1995.

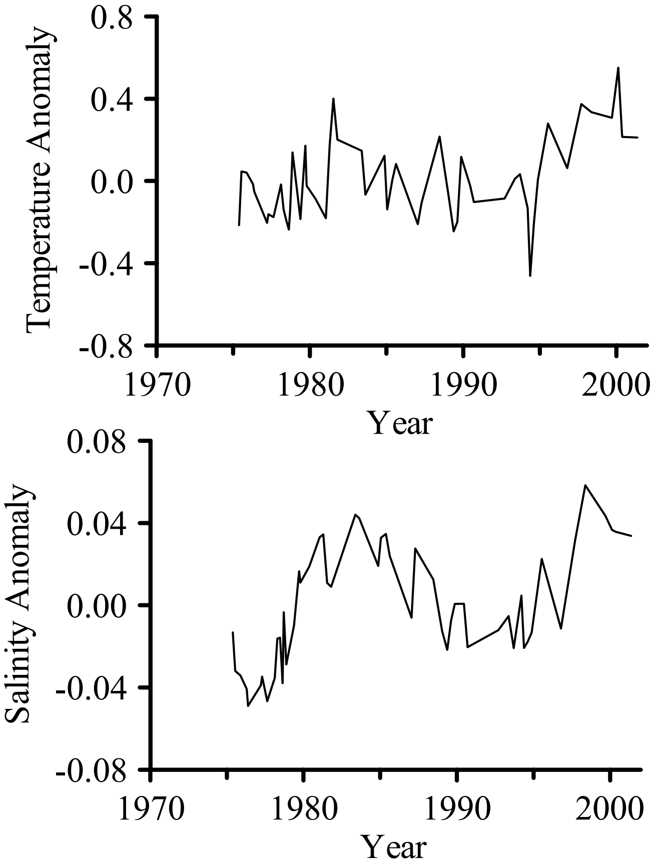

Figure 13. Area 4 – Bay of Biscay. Potential temperature (upper figure) and salinity (lower figure) averaged over the upper 300 meters layer waters.

Area 5 – Rockall Trough

The Rockall Trough is situated west of the British Isles and separated from the Iceland Basin by the Hatton and Rockall Banks and from the Nordic Seas by the shallow (500 m) Wyville-Thomson Ridge. It is one pathway by which warm North Atlantic upper water reaches the Norwegian Sea, where it is converted into cold dense overflow water as part of the thermohaline overturning in the North Atlantic. The upper water column is characterised by poleward moving eastern North Atlantic water, which is warmer and saltier than waters of the Iceland Basin, which also contribute to the Nordic Sea inflow. Below 1200 m, the deep Labrador Sea water is trapped by the shallowing topography to the north, which prevents through-flow but allows recirculation within the basin.

In 2001 the Rockall Trough began to cool and freshen slightly, following a peak in temperature and salinity in 1998–2000 (Figure 14). However both temperature and salinity remained high compared to the long-term mean, with values similar to previous peaks in the early 1980s.

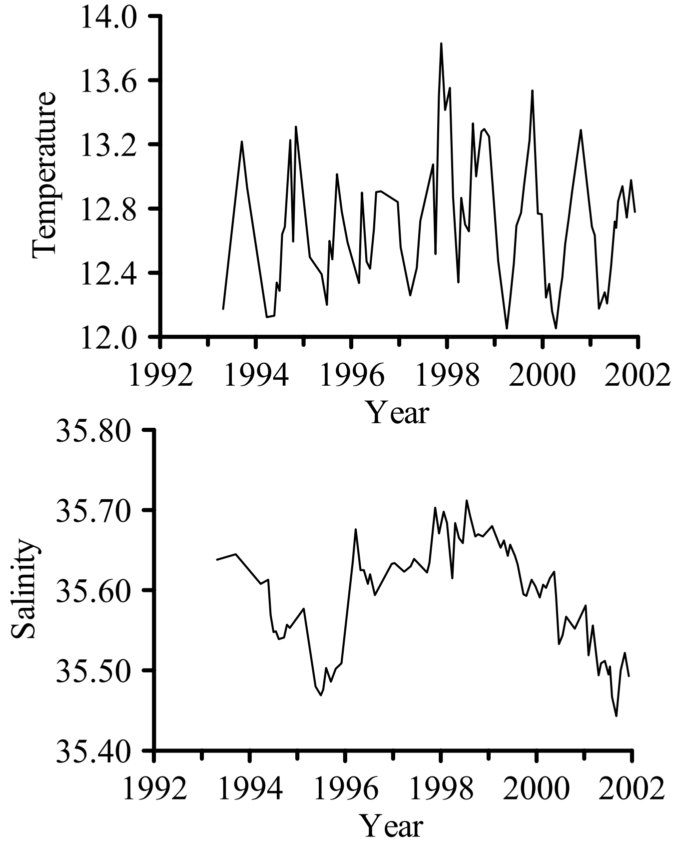

Figure 14. Area 5 – Rockall Trough. Temperature and salinity anomalies for the upper ocean (0-800 m) of the northern Rockall Trough (average across the section, seasonal cycle removed).

Area 6 – Faroe Bank Channel and Faroe Current

One branch of the North Atlantic Current crosses the Greenland-Scotland Ridge on both sides of the Faroes and onwards into the Nordic Seas. The water mass transported by this flow is traditionally described as Modified North Atlantic water and in the upper layers of the Faroe Bank Channel its characteristics can be monitored before it crosses the Ridge.

Average temperature and salinity values from this layer were fairly low in the mid 1990s, and have remained almost constant since 1997 (Figure 15). A part of the modified North Atlantic water crosses the ridge between Iceland and the Faroes where it is termed the Faroe Current. Interannual changes of temperature and salinity in the core of this current are similar to those in the Faroe Bank Channel and have remained fairly constant since 1997.

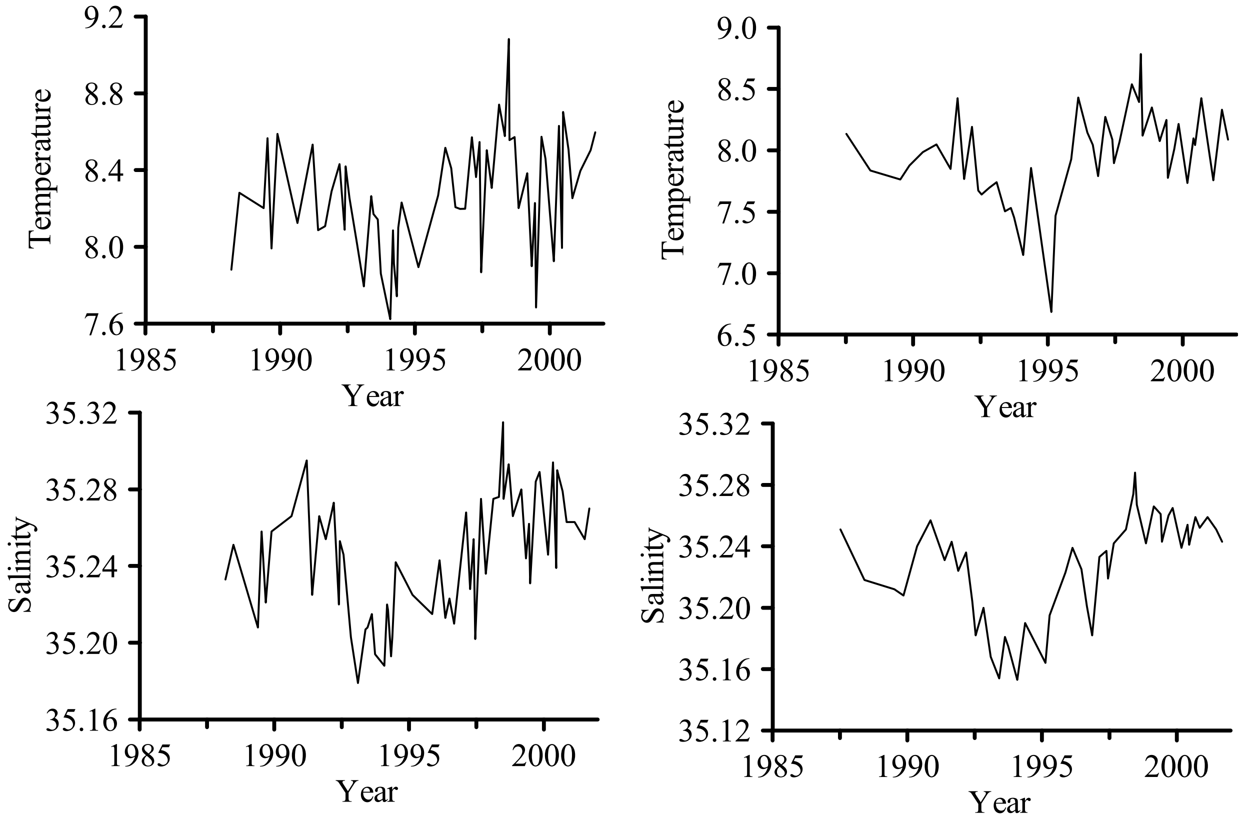

Figure 15. Area 6 – Temperature and salinity at standard stations in the Faroe Bank Channel (southwest of Faroe – left figures) and the Faroe Current (north of Faroe – right figures). Faroe Bank Channel values are averages over the 100–300 m depth layer at two stations. Faroe Current values are from the core of the current (defined as having maximum salinity averaged over a 50 m depth layer). The seasonal variation has been removed from all curves.

Area 7 – Faroe Shetland Channel

The Continental Slope Current flows along the edge of the northwest European Shelf, originating in the southern Rockall Trough. It carries warm, saline Atlantic water into the Faroe Shetland Channel. A proportion of this Atlantic water crosses onto the shelf itself, and enters the North Sea, where it is diluted with coastal water, and eventually leaves that area in the Norwegian Coastal Current. The remainder enters the Norwegian Sea to become the Norwegian Atlantic Current. Cooler, less saline Atlantic water also enters the Faroe Shetland Channel from the north, after circulating around the Faroe islands. This second branch of Atlantic water joins the waters originating in the Slope Current, and also enters the Norwegian Sea.

Atlantic water in the Slope Current is generally becoming warmer and more saline (Figure 16). Temperatures have been rising from a minimum in the late 1960s at a rate of approximately 0.3°C/decade. Salinity has increased from minimum values in the mid 1970s, with the trend showing a decadal scale variability associated with the NAO. However, temperature and salinity in 2001 were similar to those in 2000.

Trends in the cooler, fresher modified Atlantic water flowing around Faroe and entering the Channel from the north are similar to those in the Atlantic water of the Slope Current (Figure 17). The warming trend is slightly less in the modified water, while the mid-1970s low salinity period was more extreme. Again conditions in this water in 2001 were similar to those in 2000.

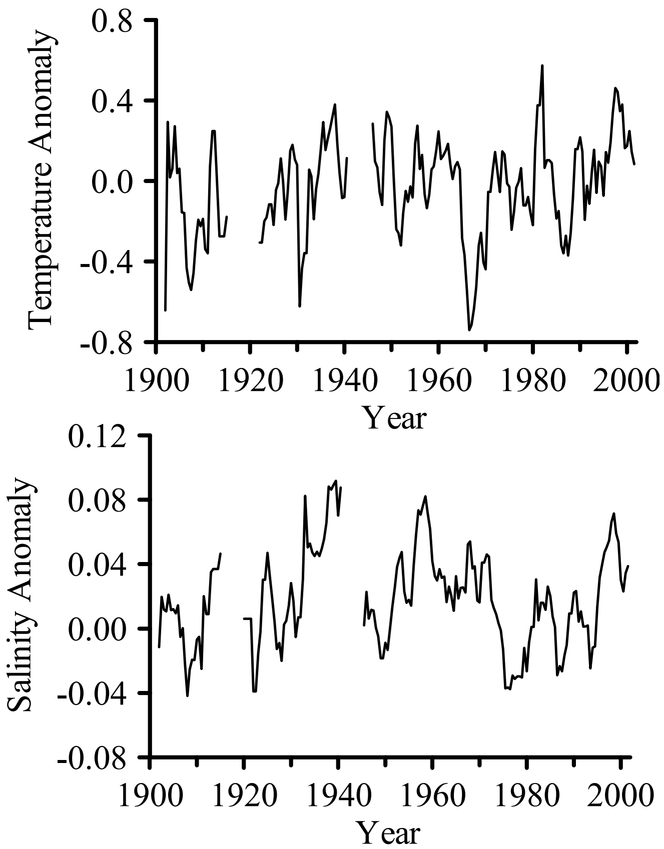

Figure 16. Area 7 – Faroe Shetland Channel. Temperature and salinity anomalies in the Atlantic water in the Slope Current.

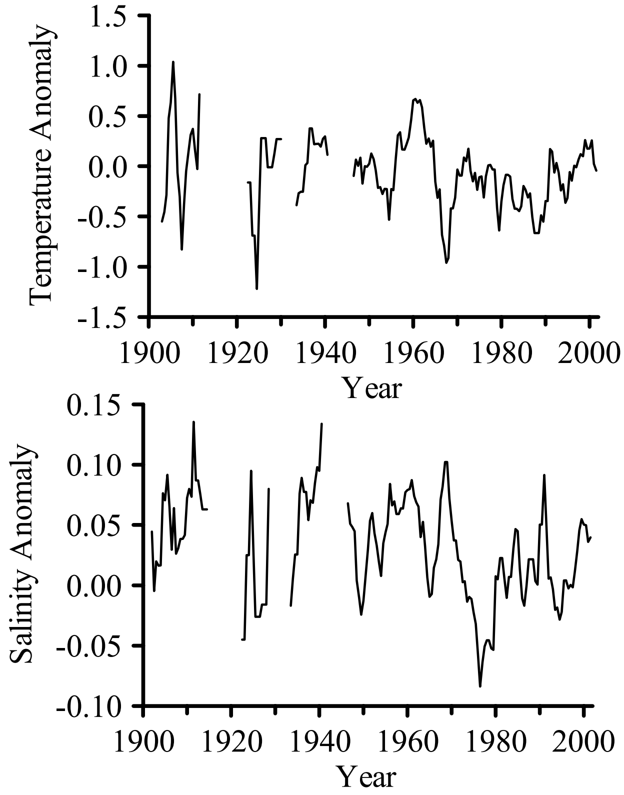

Figure 17. Area 7 – Faroe Shetland Channel. Temperature and salinity anomalies in the modified Atlantic water entering the Faroe Shetland Channel from the north after circulating around Faroe.

Areas 8 and 9 – Northern and Southern North Sea

North Sea oceanographic conditions are determined by the inflow of saline Atlantic water mainly through the northern entrances and to a lesser degree through the English Channel. The Atlantic water mixes with run-off mainly from the continent and the lower salinity Baltic outflow along the Norwegian coast. The temperature of the North Sea is mainly controlled by local solar heating and heat exchange with the atmosphere. Both the salinity and the temperature of the North Sea reflect the influence of the NAO on the movement of Atlantic water into the North Sea and the meteorological forcing of the ocean-atmosphere heat exchange. The balance of tidal mixing and local heating force the development of seasonal stratification from April/May to September in most parts of the North Sea. Numerical model simulations show strong differences in the North Sea circulation depending on the state of the NAO.

In terms of the surface temperature of the North Sea in 2001, the area averaged mean surface temperature of 10.4°C (same as 2000) made 2001 the sixth warmest year on the record dating from 1971. Except for April and June, North Sea surface temperatures exceeded climatological monthly means at all times. The strong heating from June to July caused a persistent warm anomaly, which peaked in October and November and made these months the warmest in the time series dating from 1971 (Figure 18). In both months the surface temperature anomaly amounted to 1.4°C. Again the tendency of warmer than normal autumn surface temperature during the decade of the 1990s continued at the beginning of the new century (Figure 19).

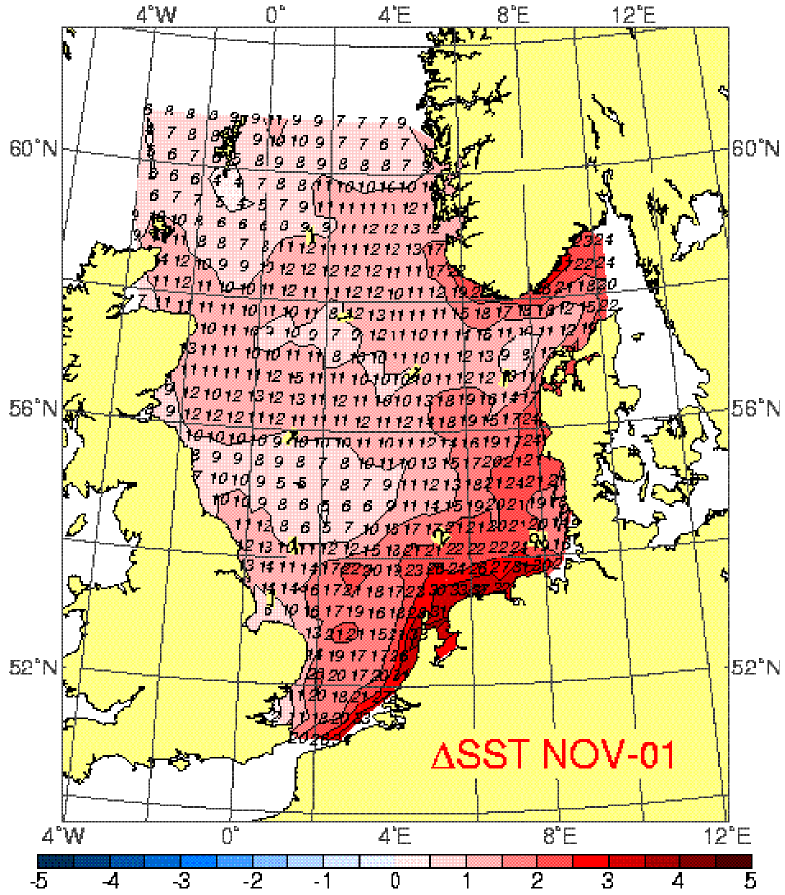

Figure 18. Areas 8 and 9 – North Sea. Surface temperature anomalies in November 2001.

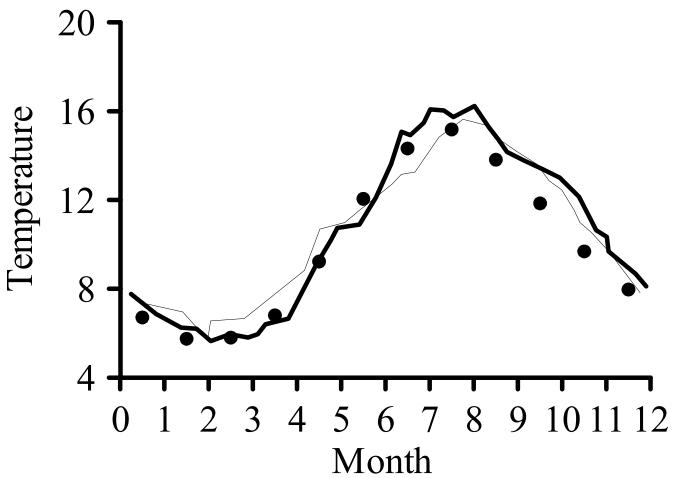

Figure 19. Areas 8 and 9 – North Sea. Annual surface temperature cycle of the area averaged North Sea surface temperature, 2000 (thin line), 2001 (thick line) and monthly climatology (symbols).

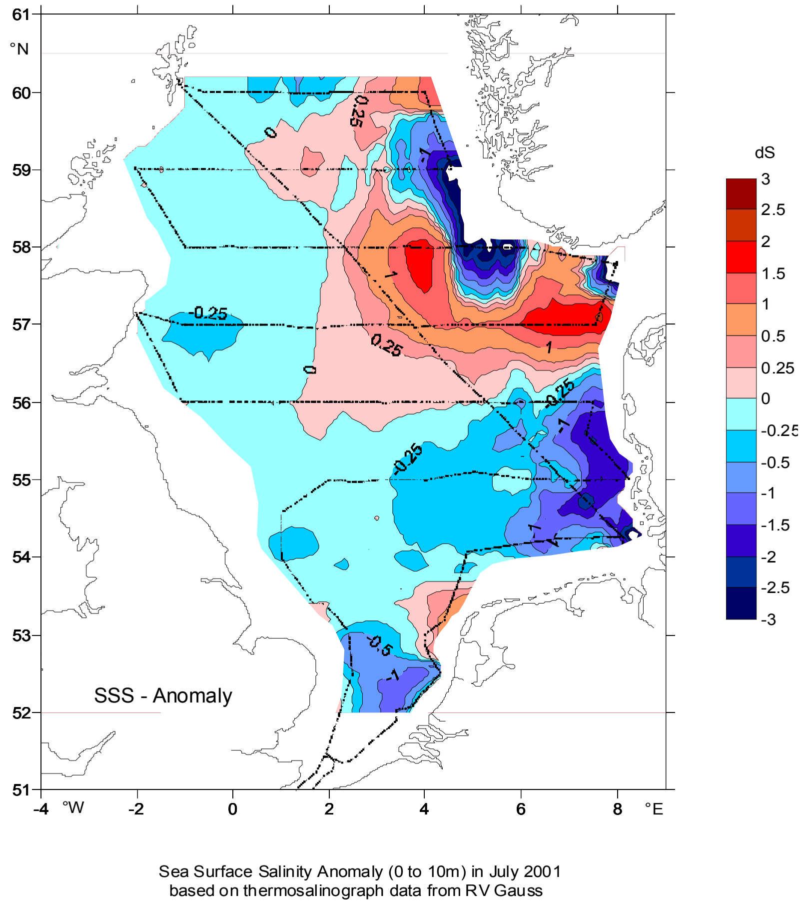

Figure 20. Areas 8 and 9 – North Sea. Surface salinity anomaly distribution, surface layer 0–10 m. Anomaly is departure from the North Sea digital data Atlas.

Oceanographic measurements made in summer 2001 show a lower influence of Atlantic water in the northern North Sea and also in the Southern Bight. The surface salinity anomaly calculated as departures from the long-term monthly means for July shows differences of up to 0.5 in both areas (Figure 20). Only in the central North Sea and west of the Skagerrak was a belt of higher salinities observed. The salinity distribution in the German Bight suggested a stronger than normal run-off from the continental rivers. The Baltic outflow southwest of Norway in summer 2001 was stronger than normal resulting in negative salinity departures of up to 1.5. On the southern side of the Skagerrak the salinity was above the long-term average.

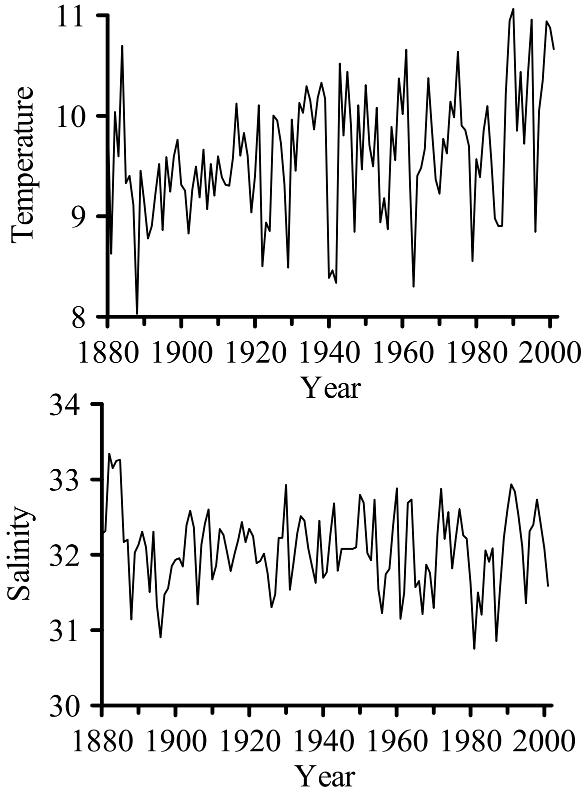

Figure 21. Area 9 – Southern North Sea. Annual mean surface temperature and salinity at Station Helgoland Roads.

The long time series of the annual mean sea surface temperature and salinity at the Helgoland station showed the long-term warming of the German Bight with a pronounced decadal variability (Figure 21). The large variability in salinity did not allow a long-term trend to be determined. However, in general the year 2001 was warmer than normal and the salinity lower than average.

Area 9b – Baltic, Kattegat and Skagerrak

The seas around Sweden are characterised by large salinity variations. In the Skagerrak, water masses from different parts of the North Sea are present. The Kattegat is a transition area between the Baltic and the Skagerrak. The water is strongly stratified with a permanent halocline (sharp change in salinity at depth). The deep water in the Baltic proper, which enters through the Belts and the Sound, can be stagnant for long periods in the inner basins. In the relatively shallow area south of Sweden, smaller inflows pass relatively quickly and the conditions in the deep water are very variable. The surface salinity is very low in the Baltic proper and the Gulf of Bothnia. The latter area is ice covered during winter.

The effect of the high freshwater discharge to the Gulf of Bothnia in 2000 was reflected in the lower than normal values of the surface salinity in the Baltic this year (Figure 22). The trend of decreasing values of the surface salinity in this area, which has occurred since the late 1970s, thus continues. During the first half of the year the river runoff to the west coast of Sweden was unusually large. The changes in surface salinity were in evidence mainly at the coastal stations. In the late autumn of 2001 deep-water inflows of comparatively high salinity took place through the Sound and the Belts. The surface temperatures were generally higher than normal during the first part of the summer (Figure 23). In the Baltic, high values were also found during the beginning of the year, and these continued the warm period that occurred at the end of 2000.

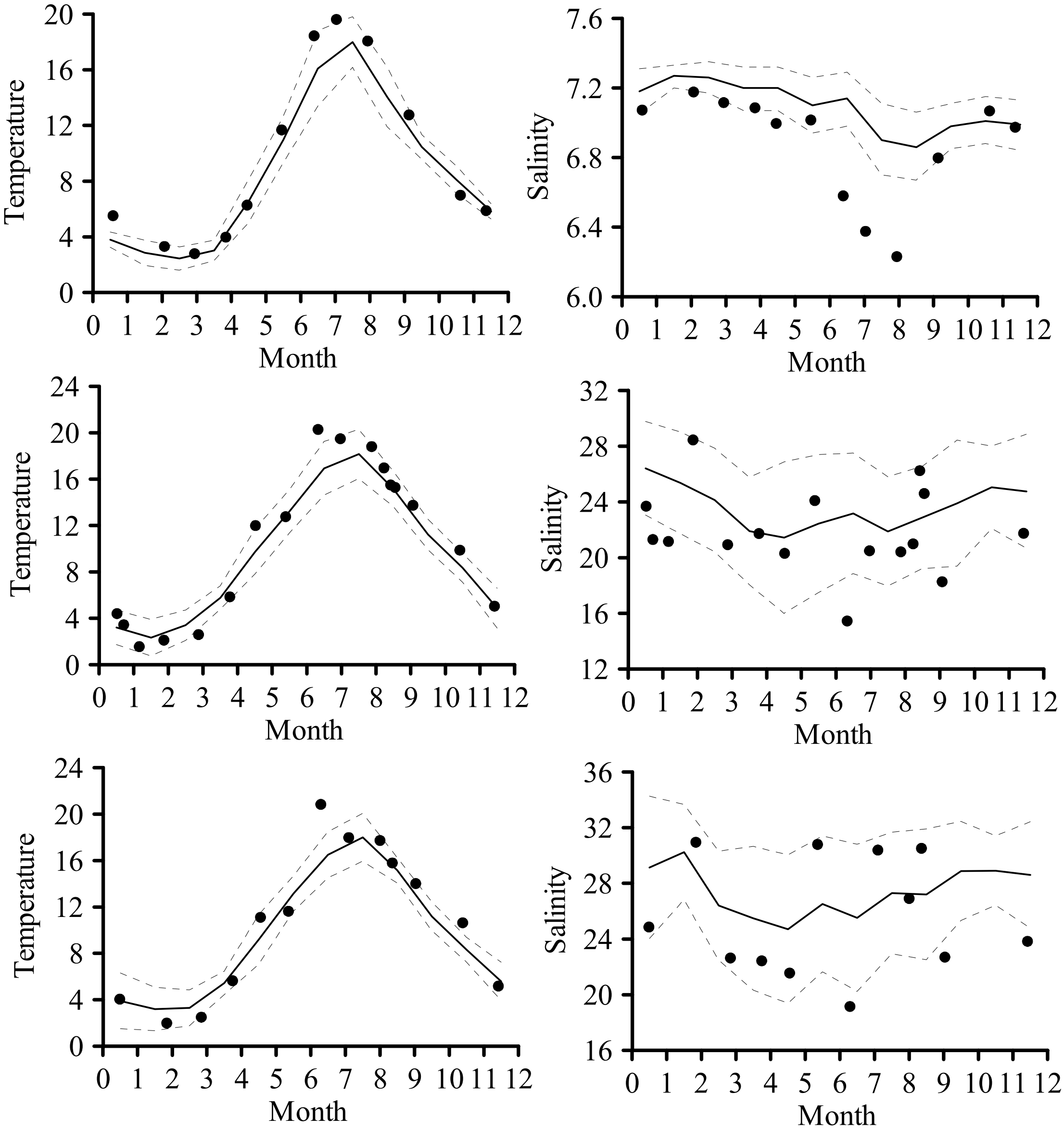

Figure 22. Area 9b – Surface temperature and salinity in the Gulf of Bothnia (coastal Station BY15 – upper figures), Fladen (Kattegat – central figures) and Skagerrak (lower figures). Mean values (from the period 1986–1995) are shown (solid lines) as well as associated standard deviations (dashed lines) and values for 2001 (symbols).

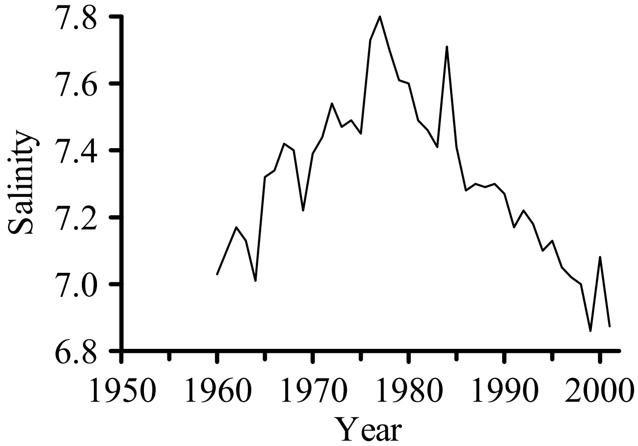

Figure 23. Area 9b – Baltic. Annual mean surface salinity east of Gotland.

Area 10 – Norwegian Sea

The Norwegian Sea is characterised by warm Atlantic water on the eastern side and cold Arctic water on the western side. The border zone between these two water masses is known as the Arctic Front. Atlantic water enters the Norwegian Sea through the Faroe Shetland Channel and modified Atlantic water enters between the Faroes and Iceland, flowing eastward along the Iceland Faroe Front, into the Norwegian Sea. A smaller branch, the North Icelandic Irminger Current, enters the Nordic Seas on the western side of Iceland. The Atlantic water that flows northward along Norway as the Norwegian Atlantic Current splits when it reaches northern Norway. One part enters the Barents Sea while the other part continues northward into the Arctic Ocean as the West Spitsbergen Current. Arctic waters are transported into the Norwegian Sea from the southward flowing East Greenland Current mainly via the East Icelandic and Jan Mayen Currents. Fluctuations in fluxes and water-mass properties in this current system are of decisive importance for the distribution and structure of the water masses in the Norwegian Sea.

In the southern Norwegian Sea there is a long-term trend towards higher temperature in the Atlantic Water. The temperature has increased since 1981 by 0.3°C. In 1997–1999 the temperature was the highest observed in the time series, but in 2000 it fell considerably followed by approximately the same value in 2001. The area occupied by Atlantic water has shown a long-term decrease. However, since the mid-1990s there has been a positive trend and in 2001 the area had the largest value since 1991.

Over the slope, east in the Norwegian Sea, a warming has taken place since 1996 (Figure 24). In 2001 the warming continued in the central (69°N) and northern section (76°N) while a cooling occurred in the southern section (63°N). The northern section has long-term trends toward higher temperature and lower salinity. Since 1996 the temperature in that section has been below the long-term average, except for 2001 when it reached that level.

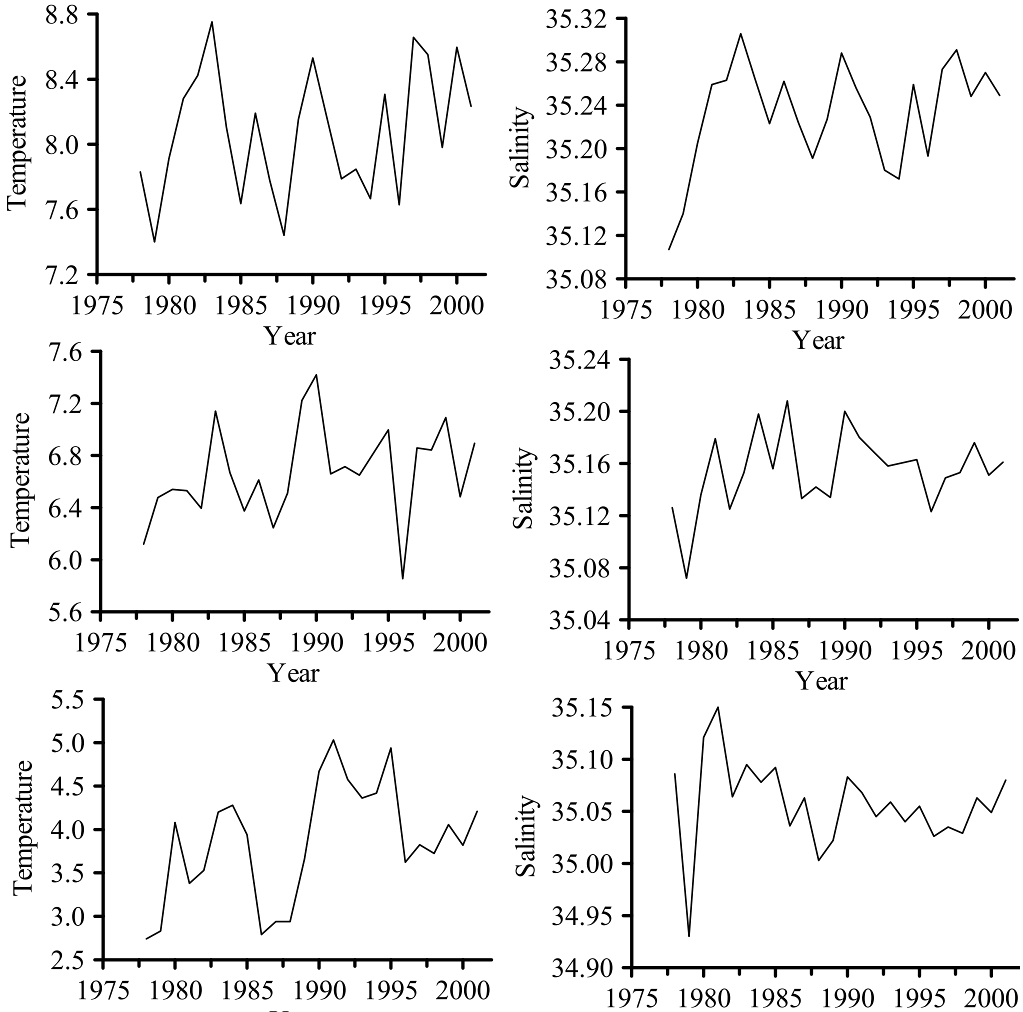

Figure 24. Area 10 – Norwegian Sea. Average temperature and salinity above the slope at three sections, Svinøy (approx. 63°N – upper figures), Gimsøy (approx. 69°N – central figures) and Sørkapp (approx. 76°N – lower figures), representing the southern, central and northern Norwegian Sea.

Area 11 – Barents Sea

The Barents Sea is a shelf sea, receiving an inflow of warm Atlantic water from the west. The inflow demonstrates considerable seasonal and interannual fluctuations in volume and water mass properties, particularly in heat content and consequently ice coverage. Regular measurements of the magnitude of the Atlantic inflow to the Barents Sea started in 1997. The first half of 2001 had the lowest inflow ever observed for that period.

After a period with high temperatures in the first half of the 1990s, temperatures dropped to slightly below the long-term average over the whole area in 1996 and 1997. From March 1998, the temperature in the western area increased to just above average (Figure 25), whilst in eastern areas it remained below average during 1998 (Figure 26). From the beginning of 1999 there was a rapid temperature increase in the western Barents Sea, which also spread to the eastern part of the Barents Sea, and the temperature has remained above average since then.

The temperature of the western Barents Sea was more than 0.5°C above the long-term average during the first half of 2001. During the second half, the temperature decreased gradually, and at the end of the year the temperature was only 0.1°C above average. In the eastern Barents Sea, temperatures have been relatively higher throughout the year than in the western areas. In the beginning of 2000, the temperature was 0.9°C higher than the average but there was also a gradual decrease to 0.3°C above the mean at the end of the year. The annual mean temperature for the eastern Barents Sea was 0.6°C above average. As a consequence of these relatively high temperatures, the Barents Sea was more free of ice than since satellite observations started in 1970. It is expected that 2002 will have lower temperatures than 2001.

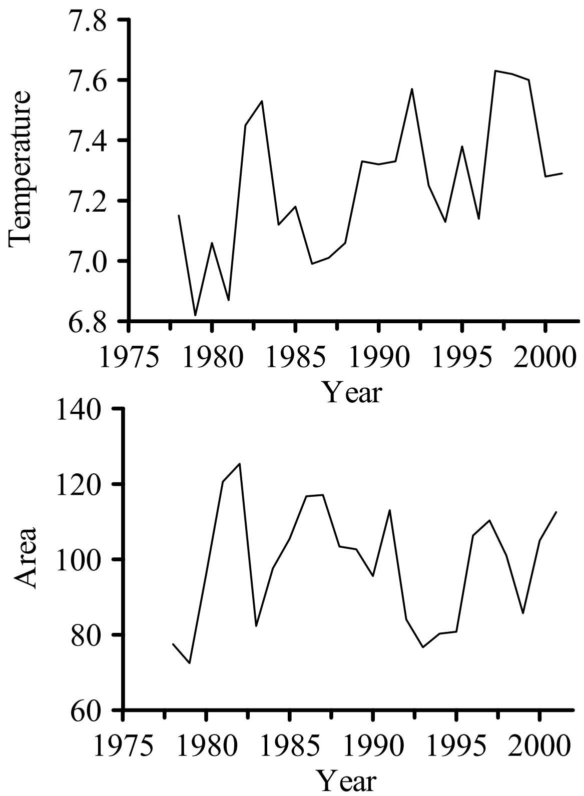

Figure 25. Area 11 – western Barents Sea. Temperature anomalies and area of Atlantic inflow through the section Norway-Bear Island in the western Barents Sea.

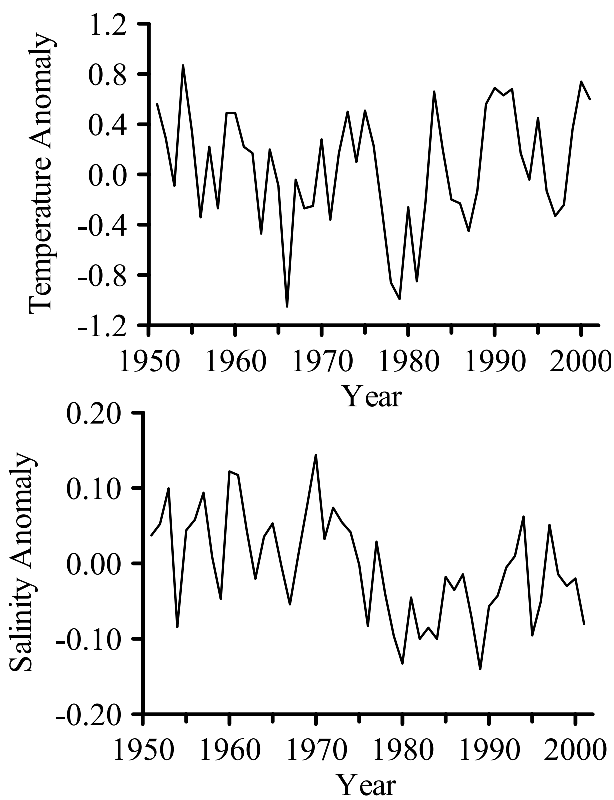

Figure 26. Area 11 – eastern Barents Sea. Temperature and salinity anomalies in the Kola section (0–200 m).

Area 12 – Greenland Sea

The Greenland Sea and its northern border, the Fram Strait, form one of the pathways which the Atlantic water takes before entering the Arctic Ocean. Part of the Atlantic water also recirculates within Fram Strait and returns towards the south in the East Greenland Current. Besides the advection, water mass modification such as deep water renewal, determine the hydrographic conditions in the region.

At the eastern side of the Greenland Sea, within the West Spitsbergen Current, the Atlantic water along 75°N (between 10°E and 13°E and in 50–150 m depth) was colder in summer 2001 (3.90°C) than in the previous summer (3.98°C). This was the lowest value in the time series, which started in 1989. The salinity of this area was the same in the summer of 2001 as in the previous summer (35.08).

The returning Atlantic water on the western side of the Greenland Sea, characterized by the temperature and salinity maxima below 500 m averaged over three stations west of 11.5°W along 75°N, was slightly colder (2.04°C instead of 2.06°C) and more saline (34.97 instead of 34.96) in summer 2001 than in the previous summer.

The subsurface conditions in the centre of the Greenland Sea (between 5°W and 3°E along 75°N) below 300 m depth (and more than 300 m above the intermediate temperature maximum) underwent an increase in temperature and salinity between summer 2000 and summer 2001. Despite this increase, moored deep-sea profilers found an average ventilation depth of 800 m in the central Greenland Sea during the winter of 2000–2001. Further hydrographic measurements also suggested that during the winter 2000–2001 the ventilation reached down to 2500 m depth in isolated areas, with diameters of about 10 km.

Further north, within the Fram Strait (ca. 79°N), temperatures and salinities were higher in summer 2001 than in the previous summer in all three surveyed areas (West Spitsbergen Current between 3°E and eastern shelf edge, returning Atlantic water between 3°W and 5°E and East Greenland Current between the western shelf edge and 3°W) and at both depth intervals (5–30 m and 50–500 m). Nevertheless, the values stayed in the usual range without forming any obvious trend (Figures 27, 28 and 29).

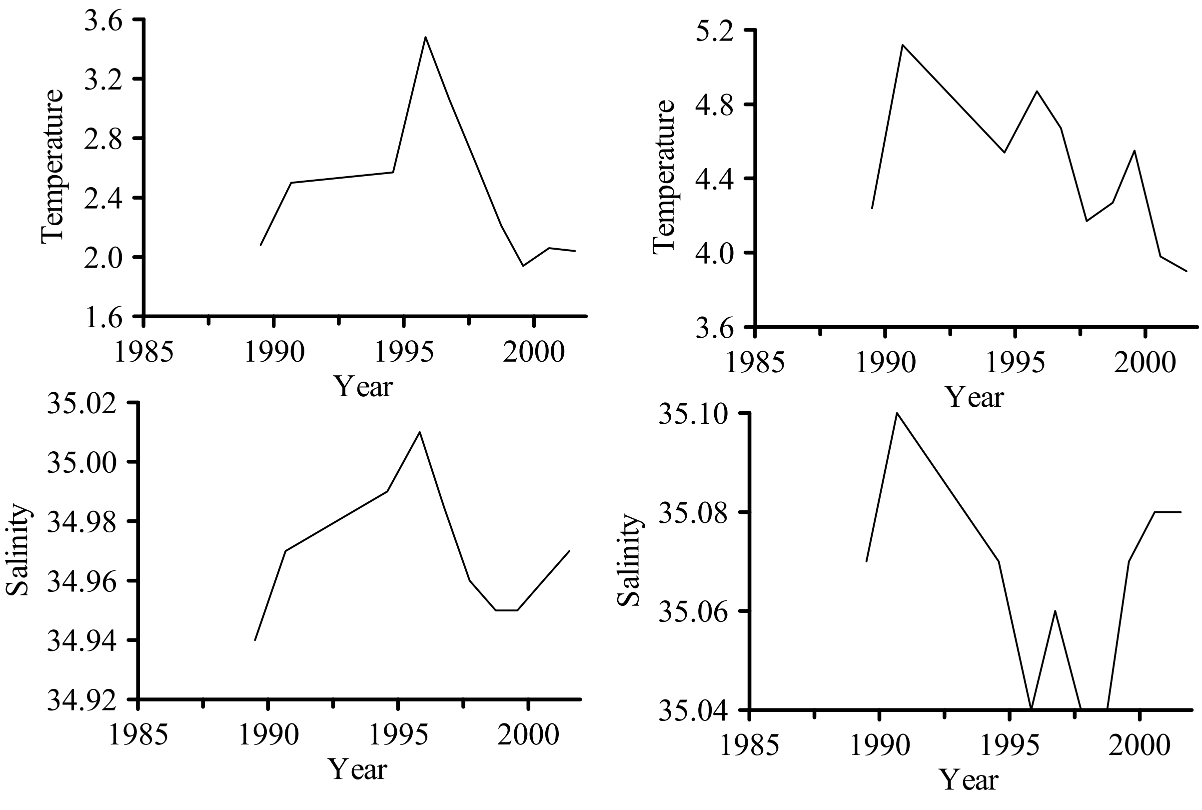

Figure 27. Area 12 – Greenland Sea. Temperature and salinity in the returning Atlantic water in the East Greenland Current (left figures) and the Atlantic water in the West Spitsbergen Current (right figures) at 75°N.

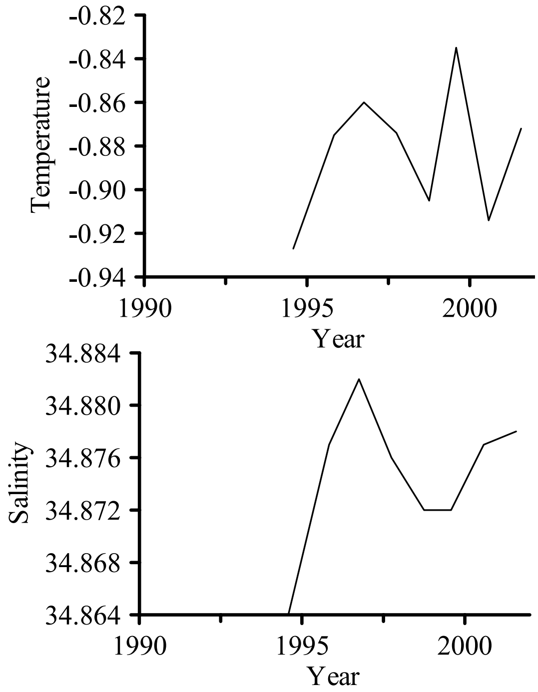

Figure 28. Area 12 – central Greenland Sea. Temperature and salinity in the central Greenland Sea.

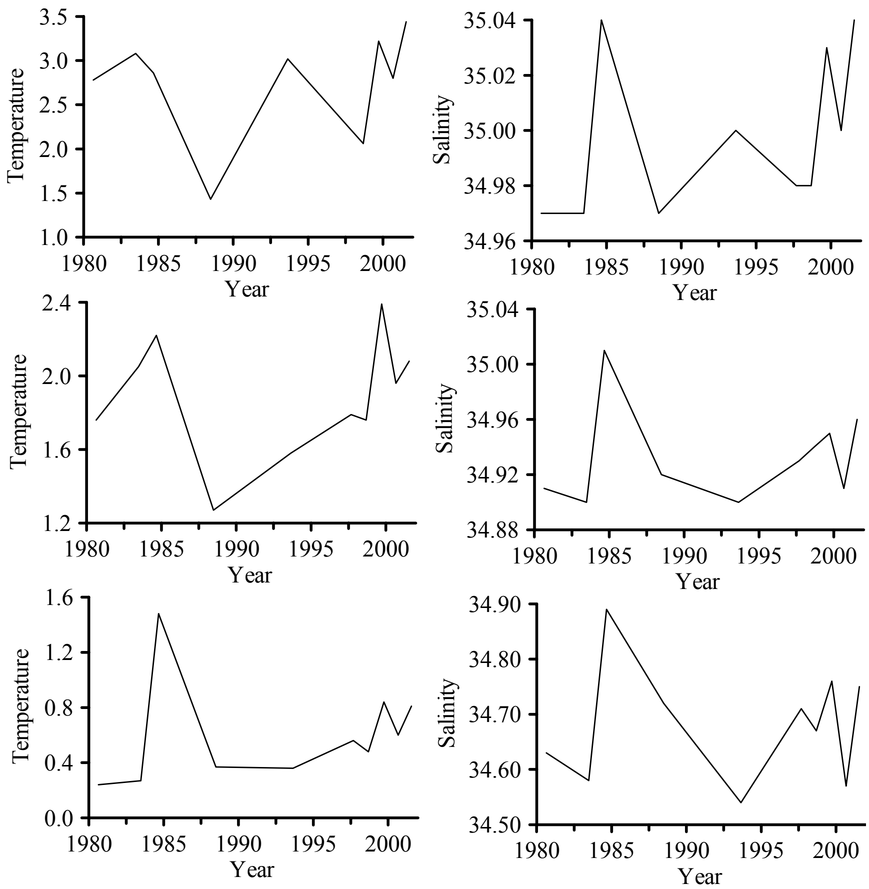

Figure 29. Area 12 – northern Greenland Sea. Temperature and salinity at 50–500 m depth in the Fram Strait. Upper figures are the West Spitsbergen Current, central figures are the returning Atlantic water and lower figures are the East Greenland Current.