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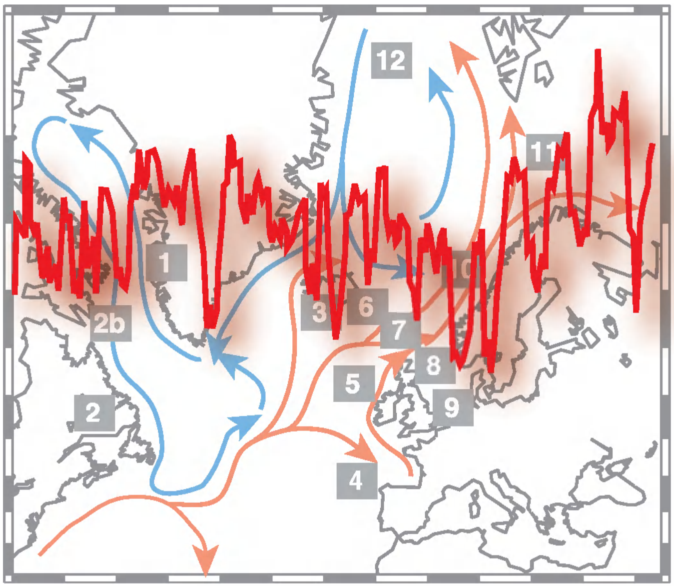
NO. 259

The 2002/2003 ICES Annual Ocean Climate Status Summary



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The 2002/2003 ICES Annual Ocean Climate Status Summary

Overview

In most areas of the North Atlantic during 2002 temperature and salinity were higher than the long-term average.

The North Atlantic Oscillation (NAO) index switched back to negative conditions during the winter preceding 2001, having recovered in the previous four years from the extreme negative value of 1996, which had brought to an end a period of extreme and persistent positive NAO index in the late 1980s/early 1990s. The 2002 NAO index showed a return to positive values which for the winter as a whole were not extreme, although individual months exhibited extreme and opposing sea-level pressure anomaly patterns.

Area summaries

Area 1 – West Greenland

Summer temperatures off West Greenland were slightly above average, but autumn temperatures were slightly below average. Unusually low salinities were observed in the off-slope surface waters during autumn.

Area 2 – NW Atlantic: Scotian Shelf, Newfoundland and Labrador Shelf

Annual mean air temperatures remained slightly above normal, but have decreased from 2001 levels. The amount of sea ice on the eastern Canadian Continental Shelf was below normal for the 7th consecutive year. Ocean temperatures remained above normal, thus continuing the warm trend experienced throughout much of the NW Atlantic during the past several years. Ocean salinities increased to the highest levels observed in over a decade.

Area 2b – The Labrador Sea

The 2001/2002 winter was more severe than the previous winter but still milder than normal. Observations in early summer 2002 showed remnants of convective overturning to maximum depths of 1200–1400 m, about 400 m deeper than seen in the preceding two years. Apart from the slight increase in winter convection, the general trend was to warmer and more saline conditions. This was true both in waters shallower than the maximum depth of convection and in the intermediate depths below 1400 m. The net result is that the mean 0–2000 m salinity was the highest in the past thirteen years of regular spring–summer observations. The corresponding mean temperature was the second highest observed during this period.

Area 3 – Icelandic Waters

Temperature and salinity during winter and spring were below the long-term mean on the shelf north, northeast, and east of Iceland. Summer and autumn values in this area were about average. The salinity and temperature of the Atlantic water originating from south of Iceland remained at high levels, similar to previous years though slightly lower than the peak values of 1998.

Area 4 – Bay of Biscay and E Atlantic

Very cold weather in the spring–summer period in the southern Bay of Biscay area made 2002 the coldest sea surface temperature year since 1992. Upper water (0–300 m) mean temperature was close to the long-term average. Salinity levels are now recovering following the minimum in 2001, and values at shallower depths are now average.

Area 5 – Rockall Trough

No data available for 2002.

Area 5b – NE Atlantic

On the WOCE/CLIVAR Section A1E temperature and salinity were relatively high in the upper layer. These suggest that a new positive salinity anomaly is in progress. In the upper 1200 m of the water column the tendency is towards warmer and more saline conditions. This is due to the deepening and decay of the Labrador Sea Water mass produced in the 1990s.

Area 6 – Faroe Bank Channel and Faroe Current

No data available for 2002.

Area 7 – Faroe Shetland Channel

With respect to the last four decades, Atlantic waters in the Faroe Shetland Channel are generally warming and becoming more saline. This trend is continuing.

Areas 8 and 9 – Northern and Southern North Sea

Surface water temperatures were higher than average in most areas for the whole of the year. Salinities in the North Sea returned to normal following the extreme low values observed in 2001.

Area 9b – Skagerrak, Kattegat, and Baltic

Late summer was unusually warm, which resulted in higher than normal sea surface temperatures at that time. Low surface salinities were found in the Kattegat and Skagerrak in April–June owing to large outflows from the Baltic.

Area 10 – Norwegian Sea

The long-term warming trend continued, and the temperature of Atlantic water was the highest since the time-series started in 1978.

Area 11 – Barents Sea

Temperatures were warmer than average. Positive temperature anomalies increased from average levels in January to a maximum in June, which was the highest of the last 30 years. Temperature anomalies then decreased to the long-term mean by the end of the year.

Area 12 – Greenland Sea

The Atlantic waters of the West Spitsbergen Current were characterised by high temperature and salinity in summer, similar to those observed during the last three years. Polar waters in the East Greenland Current were significantly colder and less saline than in summer 2001.

Prognosis

It appears likely that the winter 2003 NAO index will be negative overall although March 2003 data is not available at the time of writing. The sea level pressure anomaly pattern does not appear to be that of a typical NAO year as anti-cyclonic conditions over Scandinavia dominate.

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 2002/2003.

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 we consider the NAO index for the present decade, and the last 10 years in the context of the last 100 years (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 one of its most positive values to its most negative value this century. The index subsequently rose from the extreme low of 1996 until 2001 when the NAO Index again became negative.

The winter of 2002 showed an overall positive index, which for the winter as a whole was not extreme, but where individual months exhibited extreme and opposing sea level pressure anomaly patterns. Whilst the simple index for 2002 suggested weakly positive NAO conditions, the winter sea level pressure anomaly was not dominated by the NAO pattern and conditions in the west were more consistent with conditions associated with a negative NAO pattern. (See Text Box 1.)

In the remainder of this ICES Annual Ocean Climate Status Summary (IAOCSS) for 2002/2003, 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).

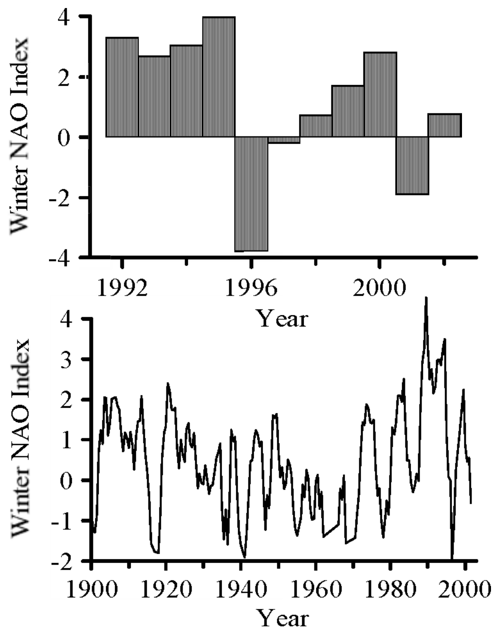

Figure 1. The winter NAO index in terms of the present decade (upper figure) and the last 100 years (lower figure – a 2-year running mean has been applied).

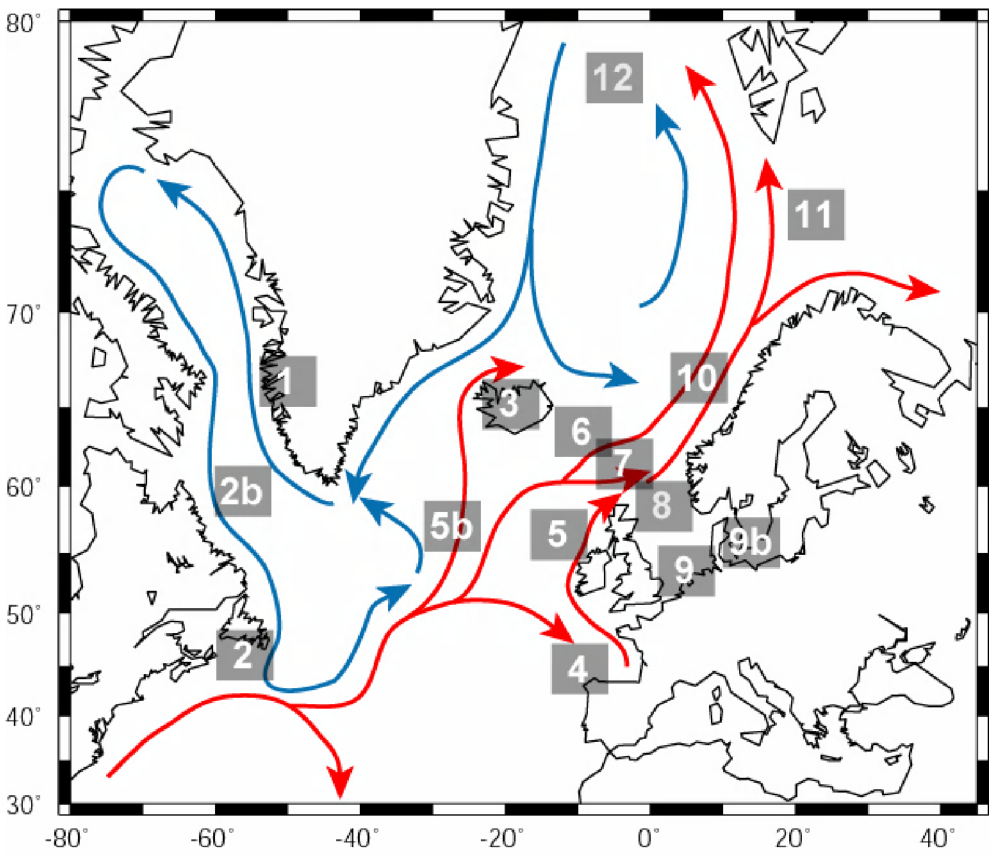

Figure 2. Schematic of the general circulation of the North Atlantic in relation to the numbered areas presented in the Annual ICES Ocean Climate Status Summary, 2002/2003. The blue (light grey) arrows indicate the cooler waters of the sub-polar gyre. The red (dark grey) arrows show the movement of the warmer waters in the sub-tropical gyre.

Text Box 1 - The NAO in winter 2002

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 and early 1990s, the NAO index underwent a large and rapid decrease during the winter preceding 1996. Recent IAOCSS describe the recovery of the NAO to positive conditions in the years following 1996 until a further reversal occurred over the winter preceding 2001. Here we report that the NAO over the winter months preceding 2002 exhibited opposing extremes resulting in an overall positive (but not extreme) NAO index.

NAO Winter in 2002

The Jones NAO_{DJFM} index (www.cru.uea.ac.uk) for the winter of 2002 was 0.79 and the Hurrell NAO_{DJFM} index (www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html) was 0.76. Figure 3a shows the SLP anomaly field in the North Atlantic for the composite of the four winter months (NCEP/NCAR Reanalysis data) with little of the typical NAO pattern. The cause of the overall weak positive NAO_{DJFM} index stems from a weak anti-cyclonic anomaly centred on Switzerland showing little zonal extension into the Atlantic. SLP anomaly over Iceland was weak and slightly positive but still small enough to make the difference in SLP with the Iberian Peninsula positive.

Overall the winter of 2002 was not an extreme NAO_{DJFM} year as shown by the SLP anomaly field and by the two instrument-based indices both reporting an index less than one standard deviation different from the mean. However, of the four months that make up the Jones NAO_{DJFM}, December showed an extreme negative anomaly, -2.25, whilst January and February were both extremely positive, 2.31 and 3.01. Figure 3b shows the SLP anomaly for the individual winter months. December is dominated by an anti-cyclonic anomaly south of Iceland, leading to northeasterly wind anomaly over the North Sea and anomalous southeasterly airflow across the Labrador Sea and southern Greenland. The pressure dipole is more east–west than the usual pattern in January 2002 with a deep low south of Greenland. February shows much of the strong zonal character of the NAO positive but with the northern low pressure anomaly centred over Sweden. March shows no strong pattern over the northeastern North Atlantic and is comparable to the composite SLP anomaly for all four months.

Early indications for the winter of 2003 are for a decrease in the NAO index with the overall SLP anomaly (Figure 4) this year showing an east–west dipole featuring a Scandinavian anti-cyclone.

Figure 3a) 2002

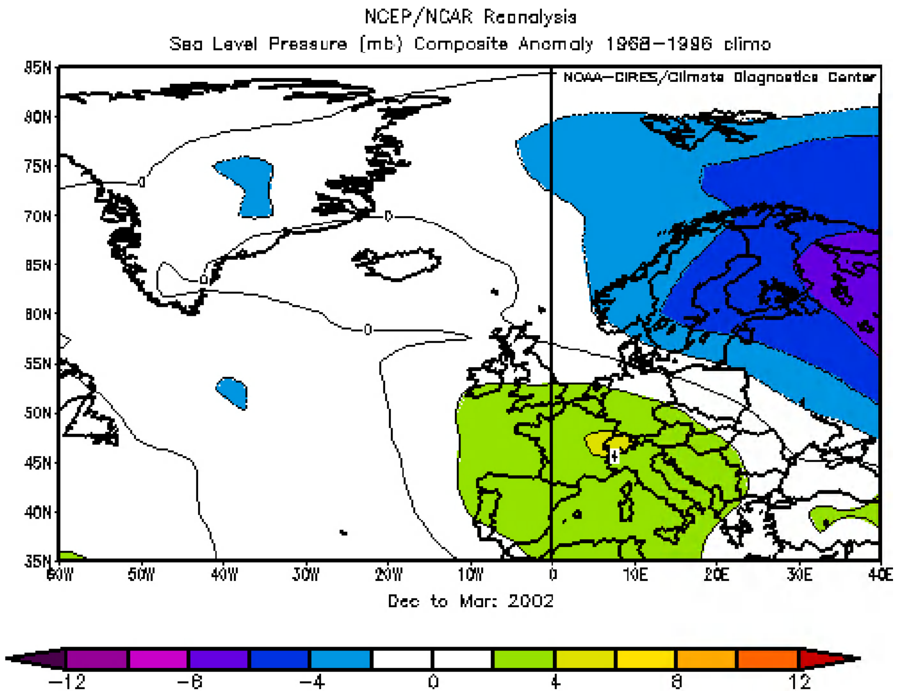

Figure 3b) 2002 individual months

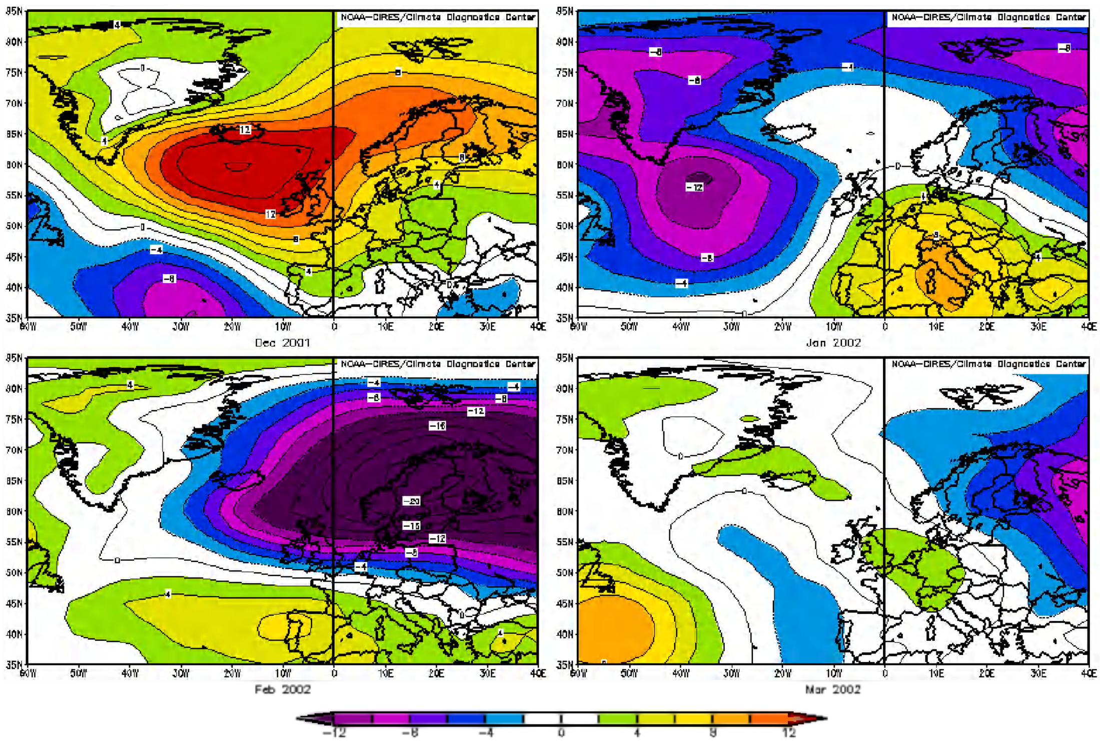

Figure 3. NAO. The North Atlantic distribution of SLP anomaly in the North Atlantic for (a) composite of December 2001 to March 2002, (b) individual months December 2002 and January 2003 upper panels, February 2003 and March 2003 below (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

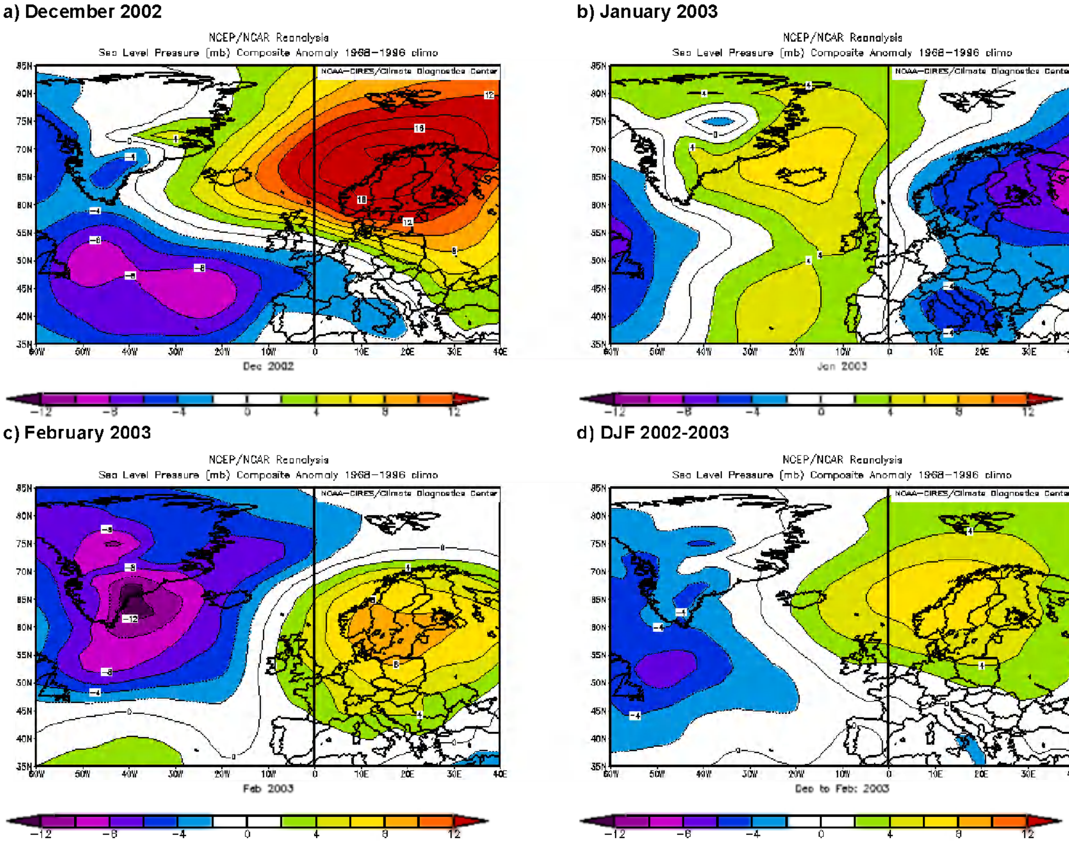

Figure 3

Figure 4. NAO. The Atlantic distribution of SLP anomaly in the North Atlantic for (a) December 2002, (b) January 2003, (c) February 2003, and (d) the composite of those three months (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

Regional descriptions

Area 1 – West Greenland

West Greenland lies within the area which normally experiences warm conditions when the NAO index is negative. Atmospheric conditions off West Greenland during the summer of 2002 were slightly warmer than normal following even warmer conditions during 2001 (Figure 5). The 2002 summertime temperatures at Fylla Bank, on the continental slope west of Nuuk, were slightly above the average for the past 50 years. In the summer, the 2002 mean salinity values on top of Fylla Bank were similar to the 2001 conditions and equal to the average value for the entire period.

There was considerable cooling and freshening during autumn 2002 at Fylla Bank Station 4. The upper 200 m of the water column indicated cooling of 0.29°C (Figure 6) below the climatic mean (1963–1990). This cooling is similar to that observed during the early 1970s and early 1980s. The salinity anomaly at Station 4 was also unusually low, being 0.54 (Figure 6) below the long-term mean. Sea surface temperature anomaly maps, as published by IGOSS (Figure 7) indicate, for the month of November, a temperature anomaly in the Fylla Bank area that is in the same range as given for the Fylla Bank Station 4.

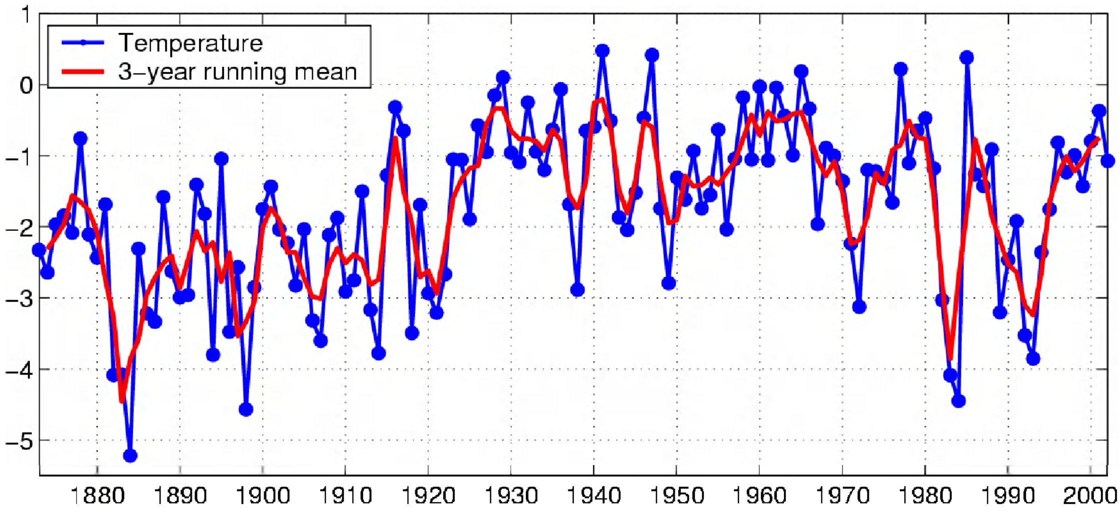

Figure 5. Area 1 – West Greenland. Annual mean air temperature observed at Nuuk for the period 1873–2002.

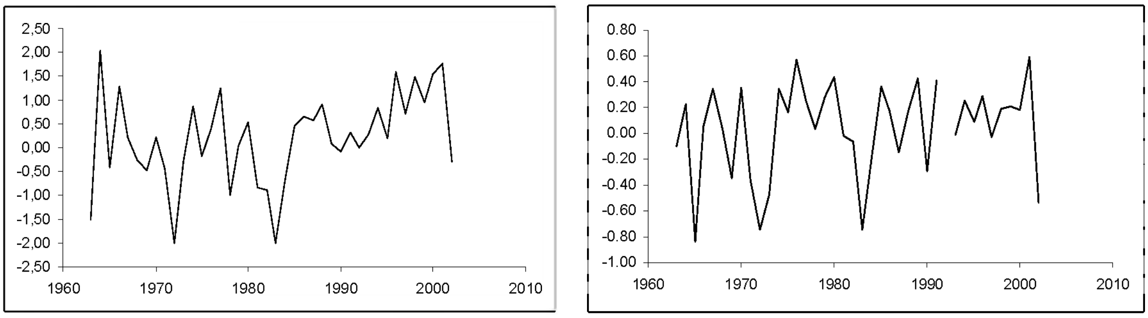

Figure 6. Area 1 – West Greenland. Fylla Bank (Station 4) temperature (left) and salinity (right) autumn anomaly, 0–200 m; data 1963–2002.

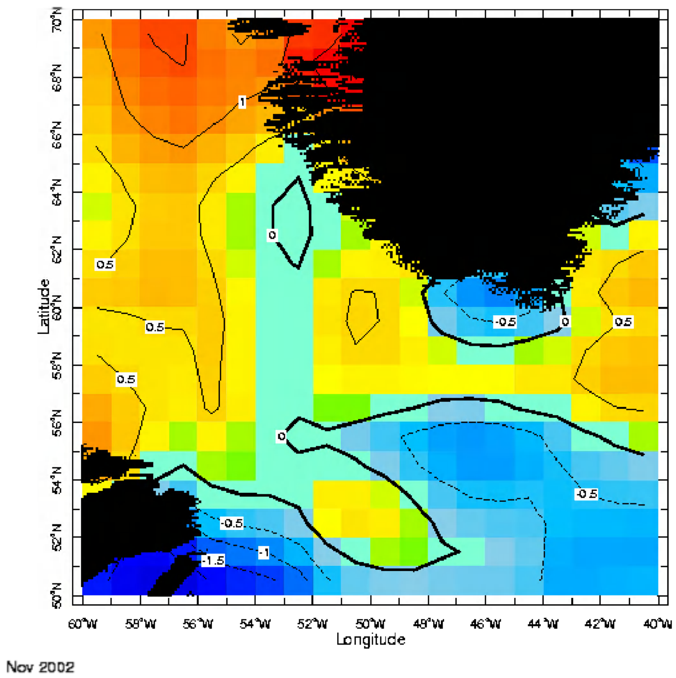

Figure 7. Area 1 – West Greenland. Sea surface temperature anomaly (K) off West Greenland during November 2002 (from: http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS).

Area 2 – NW Atlantic: Scotian Shelf, 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 NW Atlantic. In general, when the normal cyclonic circulation is weak during the winter months, corresponding to a negative NAO index, warm saline ocean conditions predominate.

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 southwest. The surface circulation is dominated by a general south-westward flow interrupted by clockwise movement around the banks and counterclockwise 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 and offshore "Slope" waters.

In 2002, annual mean air temperatures over the Scotian Shelf as represented by those recorded at Sable Island remained above average (based upon 1971–2000) but continued their decline from the record high set in 1999 (Figure 8). The higher-than-normal annual mean temperature is consistent with annual air temperature anomalies from West Greenland to Cape Hatteras. Seasonally, air temperatures from winter to summer declined from warmer than normal during the first five months of 2002 to below normal during June and July. For the remainder of the year, air temperatures varied near to and about the long-term mean.

The amount of sea ice on the Scotian Shelf, as measured by the area of ice seaward of Cabot Strait between Nova Scotia and Newfoundland, remained low in 2002. These conditions have persisted for the past five years. The number of days of ice seaward of Cabot Strait was the third lowest in the 41-year record, and the integrated ice area (sum of the area of ice over all days) was the second lowest on record.

Topography separates the NE Scotian Shelf from the rest of the Shelf. In the northeast, the bottom tends be covered by relatively cold waters (1°–4°C) whereas the basins in the central and southwestern regions have bottom temperatures that typically are 8°–10°C. The origin of the latter is the offshore Slope waters whereas in the northeast their source is principally from the Gulf of St. Lawrence. The interannual variability of the two water masses differs. Misaine Bank temperatures at 100 m capture the changes in the northeast. They show warmer-than-normal conditions in 2002 and an increase from the below average temperatures in 2001. These followed an extended period from 1985 to 1997 of below average temperatures and generally above normal temperatures from 1998 to 2000. In Emerald Basin, temperatures in 2002 were slightly above average and continue a trend that has existed since the mid-1980s except for the unusually cold period in 1998. The latter occurred when cold Labrador Slope Water replaced Warm Slope Water at the edge of the continental shelf. These cold waters subsequently penetrated onto the Scotian Shelf and into Emerald Basin. The presence of the Labrador Slope Water was caused by an increase in the volume transport of the Labrador Current, which in turn is believed to have been a delayed response to the large decline in the NAO index in 1996.

Sea surface waters over the entire Scotian Shelf were warmer and saltier than average during 2002. The higher temperatures have persisted for several years and are believed to be associated with the warmer atmospheric conditions. The higher salinities are a change from previous years. Surface salinity conditions on the Shelf are primarily related to upstream conditions off Newfoundland. The higher salinities led to a decrease in the stratification over the shelf in 2002 to levels below the long-term mean.

Newfoundland and Labrador Shelf

The Rogers' North Atlantic Oscillation (NAO) index for 2002 was slightly below normal, indicating a weak Arctic outflow to the NW Atlantic during the winter months. As a result annual air temperatures throughout most of the Newfoundland and Labrador Region were still slightly above normal during 2002, but decreased over 2001 values. Annual mean air temperatures at Cartwright, for example, on the southern Labrador Shelf cooled over 2001 values from 1.4°C above normal to 0.2°C above normal in 2002 (Figure 9). Seasonally, air temperatures were either near normal or above normal in seven to nine months of 2002. Sea ice on the Newfoundland and Labrador Shelves during 2002 generally appeared late, resulting in a shorter duration of ice than normal. The total ice coverage during 2002 however, increased over conditions in 2001 during both winter and spring, but remained below average for the seventh consecutive year.

Off eastern Newfoundland, the depth-averaged ocean temperature ranged from a record low during 1991 (high NAO index), a near-record high in 1996 (near-record low NAO index), and above the long-term (1971–2000) average in 1999 through to 2002, although the 2002 value decreased over 2001. Summer salinities on the Newfoundland Shelf, which were below normal throughout most of the 1990s, increased to above normal conditions during 2002, the highest values observed in about 12 years (Figure 10).

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 <0°C 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 2002, the CIL remained below normal on the Newfoundland Shelf for the eight consecutive years and among the lowest observed since the late-1970s.

In general, ocean temperatures in the NW Atlantic during 2002 remained above normal, thus continuing the warm trend experienced in much of the NW Atlantic during the past several years. Temperatures however have been decreasing since the near-record highs of 1999. Salinities in the NW Atlantic during 2002 increased to the highest observed values in over a decade, compared with the fresher-than-normal trend experienced throughout most of the 1990s.

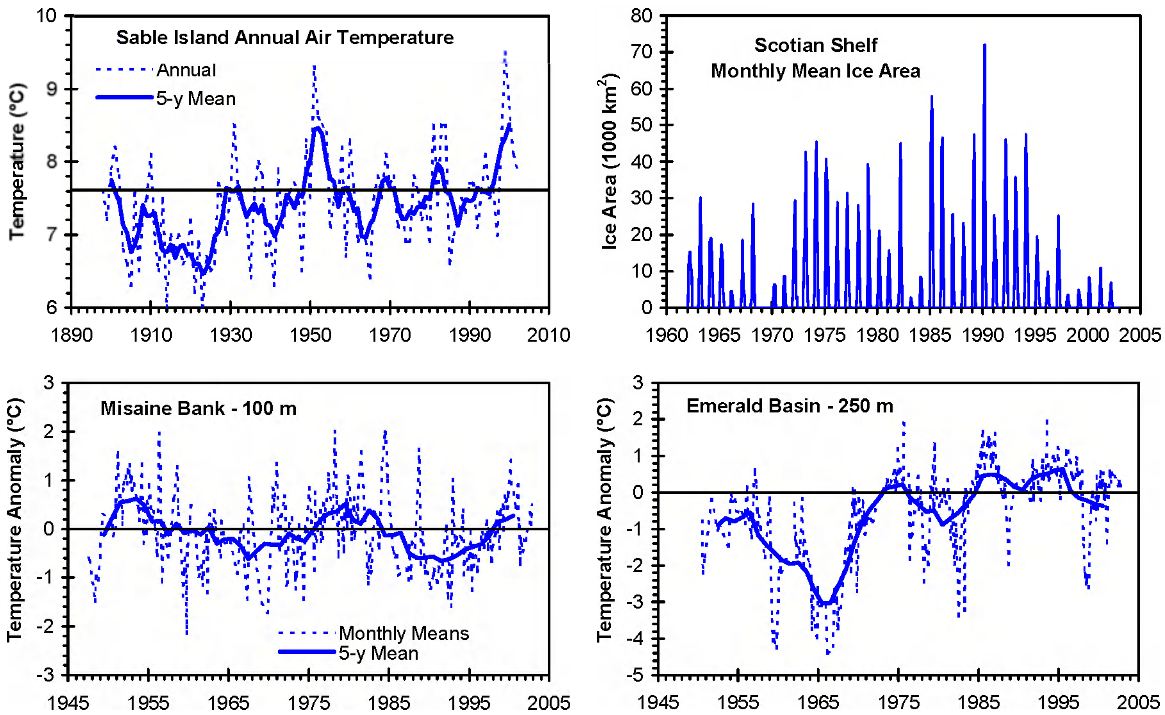

Figure 8. Area 2 – NW Atlantic: Scotian Shelf. Annual air temperatures at Sable Island on the Scotian Shelf, monthly means of ice area seaward of Cabot Strait, and the near-bottom temperature anomalies in the northeastern Scotian Shelf (Misaine Bank, 100 m) and central Scotian Shelf (Emerald Basin, 250 m). The vertical line in the plot of air temperatures represents the long-term (1971–2000) average.

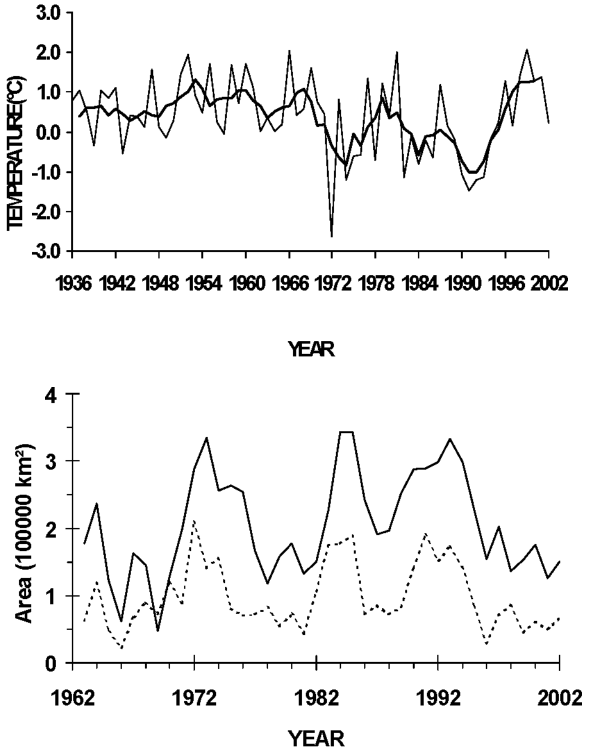

Figure 9. Area 2 – NW Atlantic: Newfoundland and Labrador Shelf. *Top panel:* Annual air temperature anomalies at Cartwright on the Labrador Coast; heavy line is a 5-year running mean. *Bottom panel:* Annual sea-ice off Newfoundland and Labrador between 45°N–5°N for the winter (solid line) and for spring (dashed line).

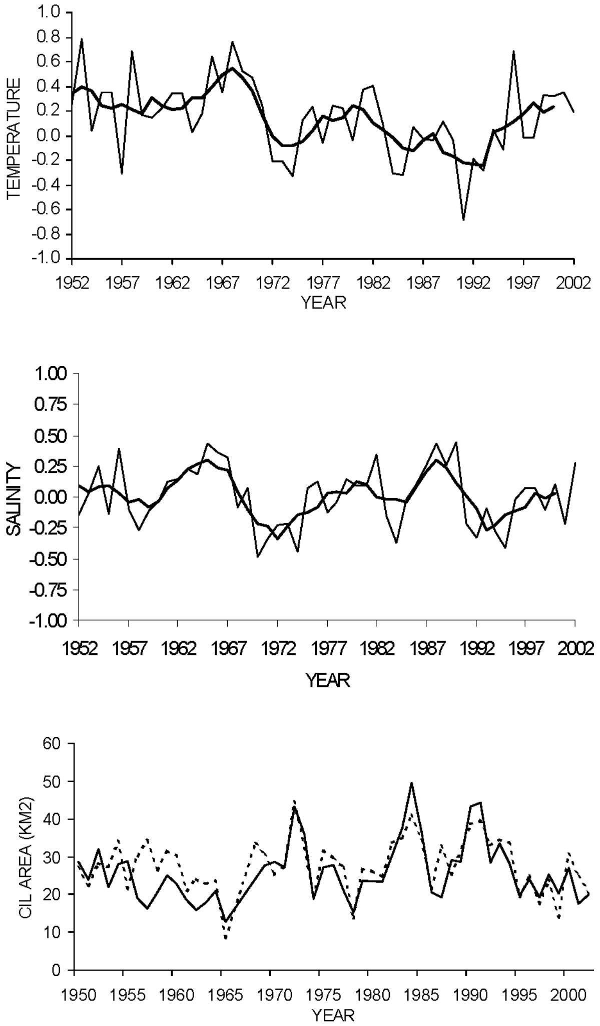

Figure 10. Area 2 – NW Atlantic: Newfoundland and Labrador Shelf. *Top panel:* Annual depth-averaged (0–175 m) temperature anomaly (in °C) on the Newfoundland Shelf (heavy line is a 5-year running mean). *Middle panel:* Summer depth-averaged (0–5 m) salinity anomaly on the Newfoundland Shelf (heavy line is a 5-year running mean). *Bottom panel:* Cross-sectional area of cold intermediate layer (CIL) on the Newfoundland Shelf (solid line) and Labrador Shelf (dashed line).

Area 2b – The Labrador Sea in 2002

Hydrographic conditions in the Labrador Sea depend on a balance of atmospheric forcing, advection, and ice melt. Wintertime heat loss to the atmosphere in the central Labrador Sea is offset by warm waters carried northward by the offshore branch of the West Greenland Current. The excess salt accompanying the warm inflows is balanced by exchanges with cold, fresh polar waters carried by the Labrador Current, freshwater from river run-off, and ice melt. Atmospheric forcing plays a relatively small role in the mean freshwater balance of the Labrador Sea compared with advective effects.

Wintertime cooling and evaporation increase the density of surface waters in the central Labrador Sea. Wind mixing and vertical overturning form a mixed layer whose depth increases through the cooling season. The winter heat loss, the resulting density increase, and the depth to which the mixed layer penetrates, vary with the severity of the winter. The density of the mixed layer and the depth of convection depend critically on the salinity of the waters exposed to the atmosphere. In extreme winters, mixed layers deeper than 2000 m have been observed. The intermediate-depth Labrador Sea Water formed by these deeper overturning events spreads throughout the northern North Atlantic. During milder years, the vertical stratification of temperature, salinity, and density is re-established.

Since the winter of 1994/1995, mild winters have produced only shallow convection. This pattern persisted through the winter of 2001/2002. Annual sea–air heat fluxes (June 2001 – May 2002) in the central Labrador Sea estimated from the NCEP Reanalysis Project were about 14 Wm^{-2} less than the mean for the 31-year normal period June 1970 to May 2001 (Figure 11). This places the 2001/2002 12-month average in the 26th percentile for the normal period.

Wintertime (December–February) heat fluxes were nearly 60 Wm^{-2} less than the winter normals but were balanced by higher than normal spring (March–May) heat fluxes. A July 2002 transect of the Labrador Sea showed evidence of vertical overturning during the previous winter to maximum depths of 1200–1400 m. This evidence consisted of remnants of a weakly stratified layer at these depths with relative minimum potential temperature and higher dissolved oxygen than in the preceding years. The inferred winter mixed layer had potential temperature 3.15°C, salinity 34.83, and potential density anomaly 27.74 kg m^{-3}. In contrast, the deep mixed layers observed in the early 1990s had potential density anomalies near 27.78 kg m^{-3}.

In spite of a cooling and freshening near 1000-m depths associated with the moderate 2001/2002 winter overturning, the upper layers of the Labrador Sea became warmer and saltier. This suggests an increased input of warm, saline waters from the offshore branch of the West Greenland Current. The mean 0–1000 m temperature in the central Labrador Sea was the second highest in thirteen recent annual surveys, surpassed only by 1999. The salinity of the upper 1000 m was greater than observed since the period of deep convection of the early 1990s when higher-salinity waters from deeper levels were entrained into the upper 1000 m. In addition, the dissolved oxygen content of this warm and saline water was lower than observed in the preceding two years.

Since the mid-1990s, a notable trend to higher temperature and salinity in the 1000–2000 m layer has emerged. In spite of the effects of winter overturning noted above, the mean temperature of this layer in early summer 2002 was the highest observed at comparable seasonal times during the previous thirteen years. Salinity in this depth range showed a very slight decrease from the record-high conditions of the previous year. The dissolved oxygen content of this intermediate layer also decreased compared with the preceding two years.

The net result is that the mean 0–2000 m salinity in early summer 2002 was the highest observed in the previous thirteen spring–summer periods. The corresponding mean temperature was the second highest observed during this period. The density of seawater decreases with increasing temperature and increases with increasing salinity. The 2002 survey showed slightly denser waters in the 0–1000 m depth range and slightly less dense waters in the 1000–2000 m depth range, compared with results from 2001. The net effect was a small decrease in 0–2000 m mean density, equivalent to a rise in steric sea level by less than 0.01 m. The TOPEX/POSEIDON altimetric satellite measured a consistently small increase in sea level over the corresponding period.

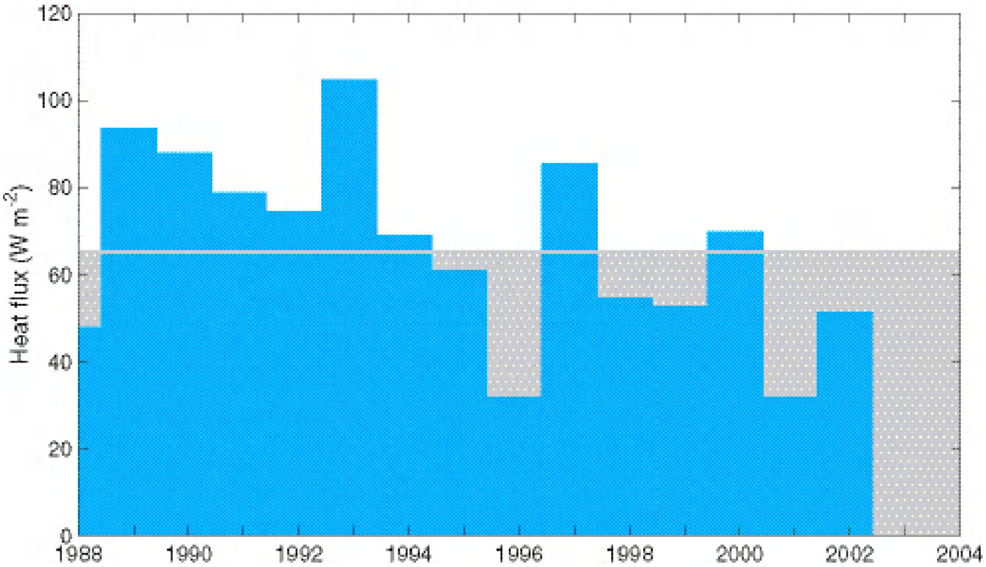

Figure 11. Area 2b – The Labrador Sea. Twelve-month averages (June–May) of monthly-mean sea–air heat flux at 56.2°N 52.5°W in the central Labrador Sea from the cooperative Reanalysis Project of the U.S. National Centres for Environmental Prediction (NCEP) and National Centre for Atmospheric Research. Values within the shaded area are lower than the mean (65 Wm^{-2}) for the 31-year normal period June 1970 – May 2001. Values for the most recent two 12-month periods were lower than normal: 51 Wm^{-2} (26th percentile) for June 2001 – May 2002 and a near-record low of 32 Wm^{-2} for June 2000 – May 2001.

Area 3 – Icelandic Waters

Iceland is situated at a meeting place of warm and cold currents which meet in an area of submarine ridges (Greenland–Scotland Ridge, Reykjanes Ridge, and Kolbeinsey Ridge), which form natural barriers against the main ocean currents (Figure 12). To the south is the warm Irminger Current which is a branch of the North Atlantic Current (6° – 8°C), and to the north are the cold East Greenland and East Icelandic Currents (-1° –2°C).

The hydrographic conditions in 2002 revealed winter and spring values on the shelf north, northeast, and east of Iceland, below the long-term mean for both temperature and salinity (Figure 13). Summer and autumn values in this area were about average and higher. The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years (Figure 14), though slightly lower than the peak values in 1998.

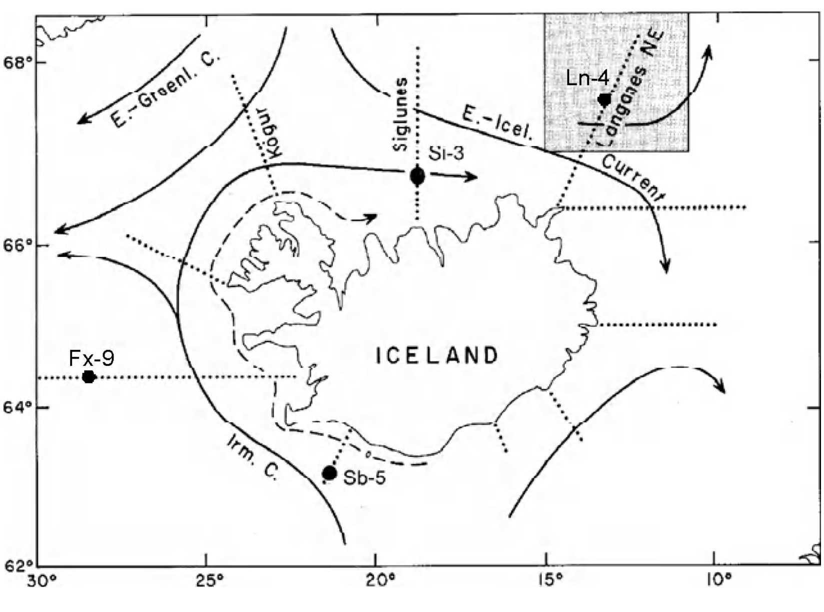

Figure 12. Area 3 – Icelandic Waters. Main currents and location of standard hydro-biological sections in Icelandic waters. Selected areas and stations dealt with in this report are indicated.

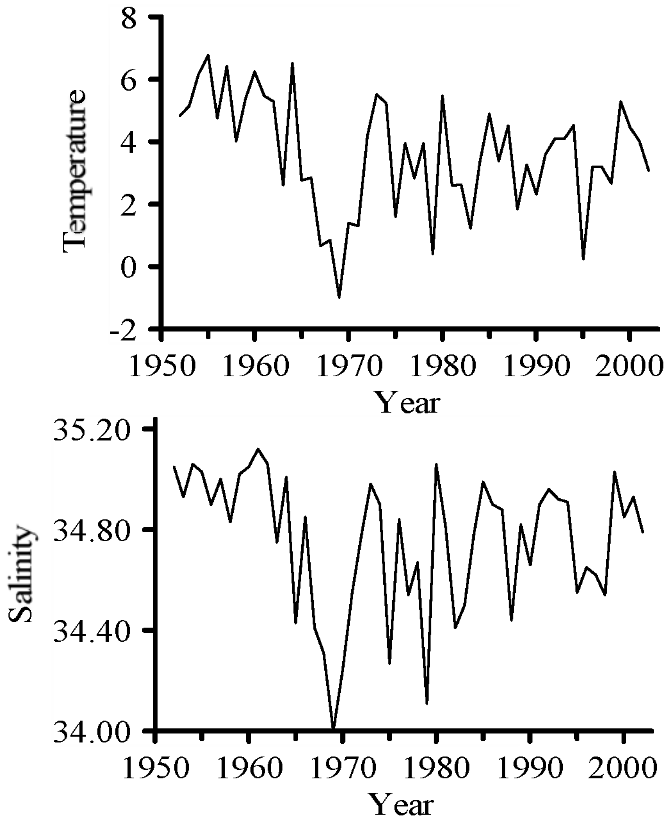

Figure 13. Area 3 – Icelandic Waters. Temperature and salinity at 50-m depth in spring at Station Si-3 in North Icelandic waters, 1952–2003.

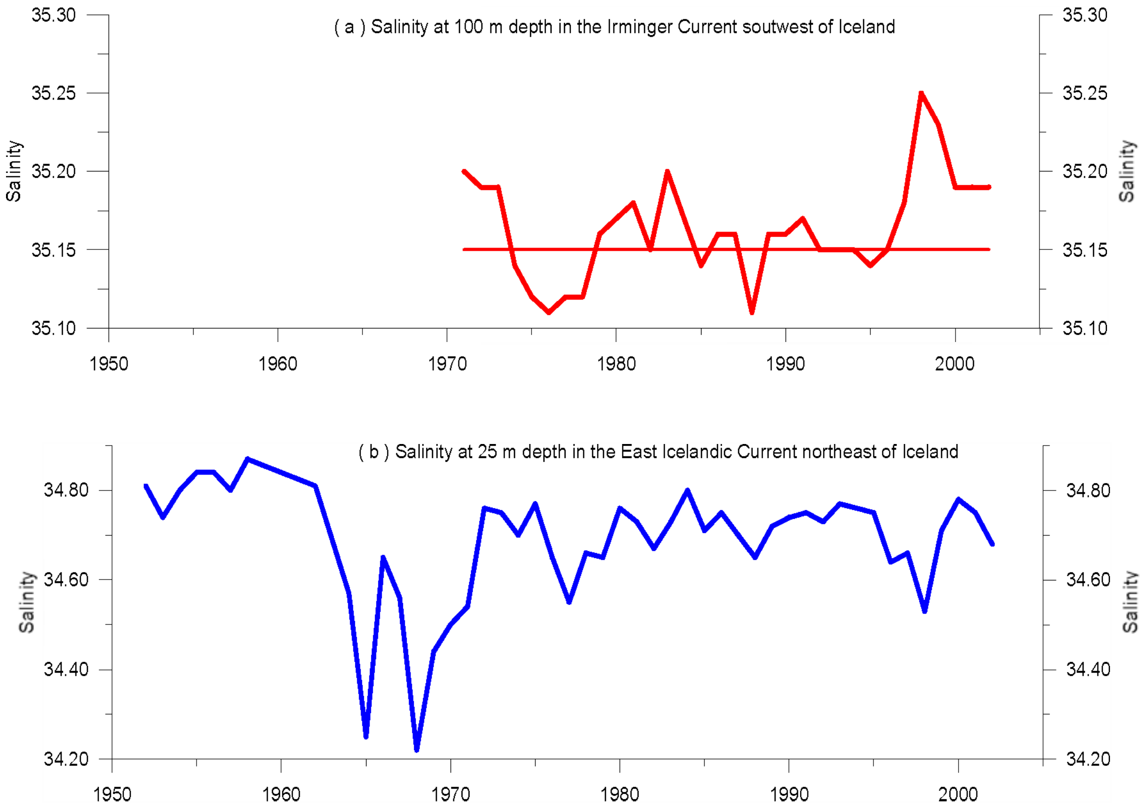

Figure 14. Area 3 – Icelandic Waters. Salinity in spring at:

a) 100-m depth in the Irminger Current southwest of Iceland (Sb-5), 1971–2002.

b) 25-m depth in the East Icelandic Current northeast of Iceland, 1952–2002, mean from shaded area in Figure 1.

Area 4 – Bay of Biscay and E Atlantic

The Bay of Biscay is located between the eastern part of the sub-polar and subtropical North Atlantic gyres. The general circulation in the area mainly follows the subtropical anti-cyclonic gyre in a relatively weak manner (1–2 cm^{-1}). At the southern part of the Bay of Biscay east-flowing shelf and slope currents are common in autumn and winter owing to westerly winds whereas in spring and summer easterly winds are predominant and coastal upwelling events are frequent.

Summer 2002 was the coldest since 1987 and one of the coldest of the meteorological time-series (1960–2002) of the INM. Comparing year 2002 with the climatological mean from 1991 for surface waters, we found a slightly cool winter followed by a persistent cool summer for the upper water layer (Figure 15). The warming period is short, in fact the shortest in the time-series. Upper water (0–300 m) mean temperature is on the time-series average. Salinity has begun to recover after the minimum found in 2001 resulting in average values for shallower depths.

Salinity contours show high salinity at the beginning of the winter due to the poleward current and in spring and autumn due to seasonal upwelling with two marked events in June and October. During 2002 the advection and river overflow was low compared with the previous years. Between 1998 and 2001, the evidence of a decline in salinity was found up to a depth of 300 m. In 2002 this tendency was inverted, especially during the poleward episode at the beginning of the year (Figure 16).

Thermosalinograph measurements in the E Atlantic and Bay of Biscay show some strong coherency of the surface salinity anomaly evolution over an extended area (in particular around Cape Finisterre). This shows this signal is associated with large-scale processes. A strong coherency has also been found with integrated measurements from 5 to 300 m in the Southern Bay of Biscay, which proves this process affects a significant part of the water column.

For the time-series centred on 42–43°N 10°W one notices for example the episodes of high salinity in 1990 as well as in 1998, which are typical of a large area of the NE Atlantic extending at least from 42°N to 48°N and across the Bay of Biscay (Figure 17). The low salinity in 2001 seems also to be present in a large area that is probably related to anomalously high rainfall extending from northwest Spain to the English Channel in late 2000–early 2001.

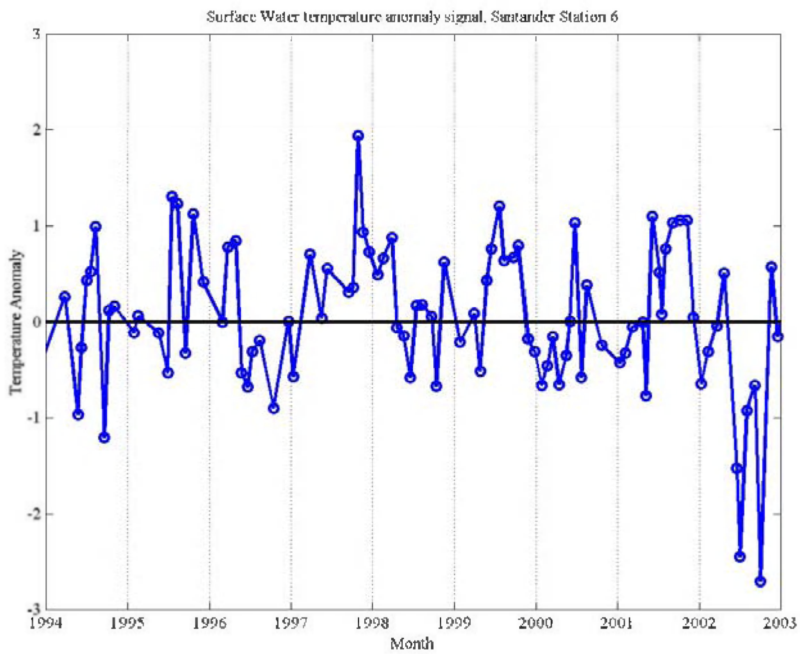

Figure 15. Area 4 – Bay of Biscay and E Atlantic. Sea surface temperature anomaly at Santander Station 6 (shelf-break).

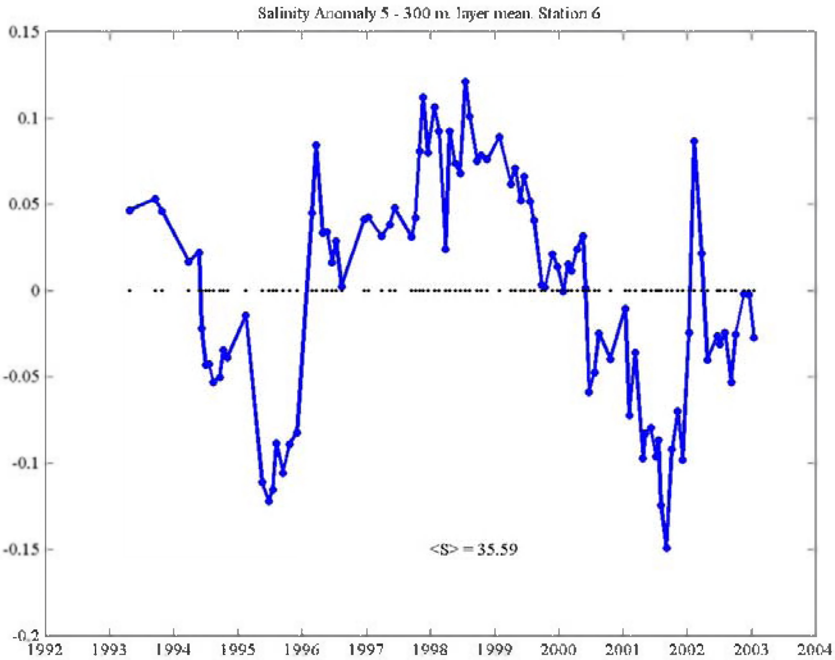

Figure 16. Area 4 – Bay of Biscay and E Atlantic. Salinity anomaly evolution (5–300 m) at Santander Station 6.

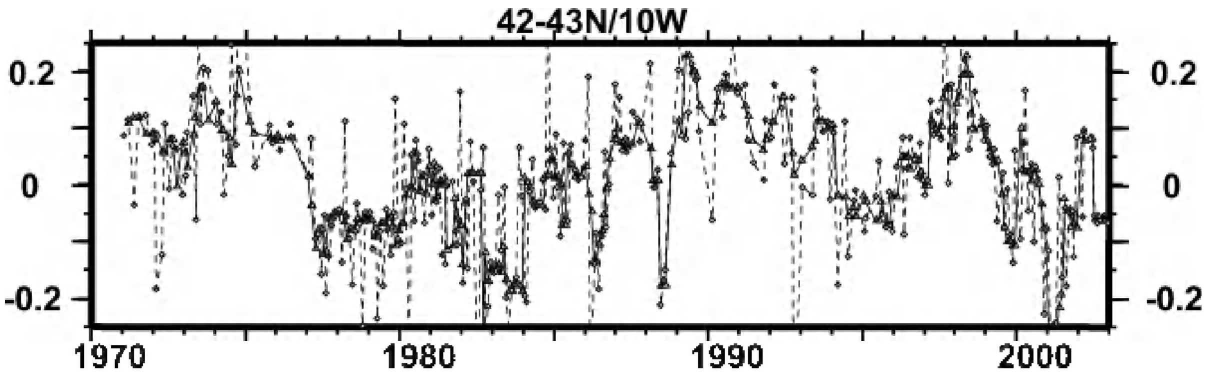

Figure 17. Area 4 – Bay of Biscay and E Atlantic. Surface salinity anomaly evolution at 42–43°N 10°W. Dashed line from monthly anomalies, solid line for three-month averages.

Area 5 – Rockall Trough

No data available for 2002.

Area 5b – NE Atlantic

The ongoing work on the WOCE/CLIVAR section A1E (Figure 18) is reported here. This section has been repeated nine times since 1991 with approximately 54 CTD Stations between Cape Farewell (Greenland) and Porcupine Bank (SW Ireland). The eastern part of the section is occupied by warm and saline waters of the North Atlantic Current (NAC) whereas the western part of the section is occupied by less warm and saline waters of the sub-polar gyre. The boundary between these two waters is the Sub-polar Front.

The recent 11-year variation of the position of the Sub-polar Front along section A1E is illustrated in Figure 19. The position of the Sub-polar Front is closely linked to the NAO index. During positive NAO the location of the front is more easterly, hampering the northwestward transport of the warm and saline waters of the NAC.

During negative NAO conditions the situation is reversed, giving rise to northward progress of warm and saline anomalies. The timing of these anomalies is illustrated in Figure 20, which shows the temporal changes of the mean salinity in different regions of section A1E in the upper 1200 m between 1991 and 2002. The positive salinity anomaly is first observed in the Iceland Basin and Rockall Trough and arrives at the Irminger Sea about two years later.

The 2002 data set suggests that a warm and saline anomaly is in progress, seen as rising salinity (and temperature) in the upper layer in all three regions in Figure 20 and a westerly position of the sub-polar front.

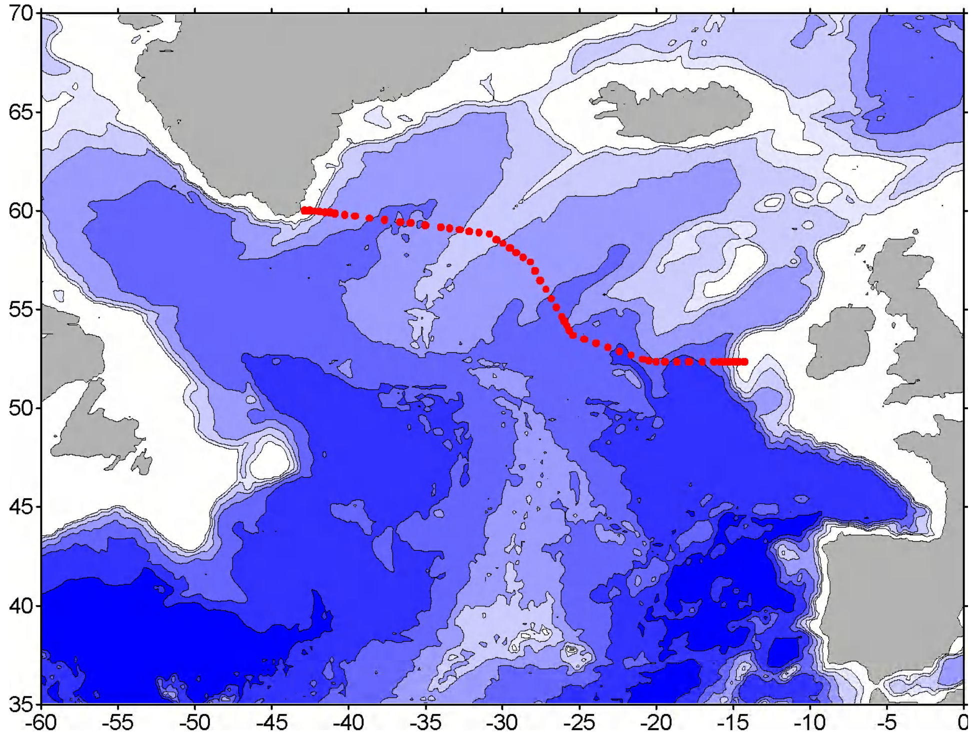

Figure 18. Area 5b – NE Atlantic. Location of the WOCE/CLIVAR hydrographic section A1E and bottom topography in the northern North Atlantic. Contours are at 500, 1000, 2000, 3000, 4000, and 5000 m.

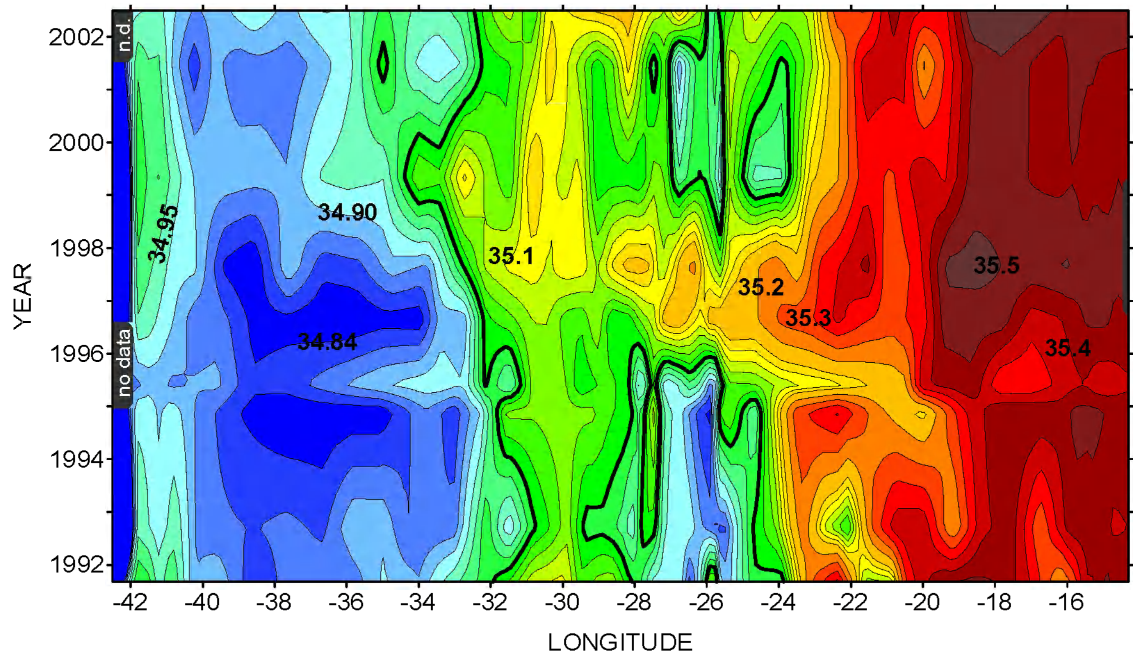

Figure 19. Area 5b – NE Atlantic. Temporal changes of the mean salinity of the upper 600 m along section A1E, recorded nine times between September 1991 and July 2002.

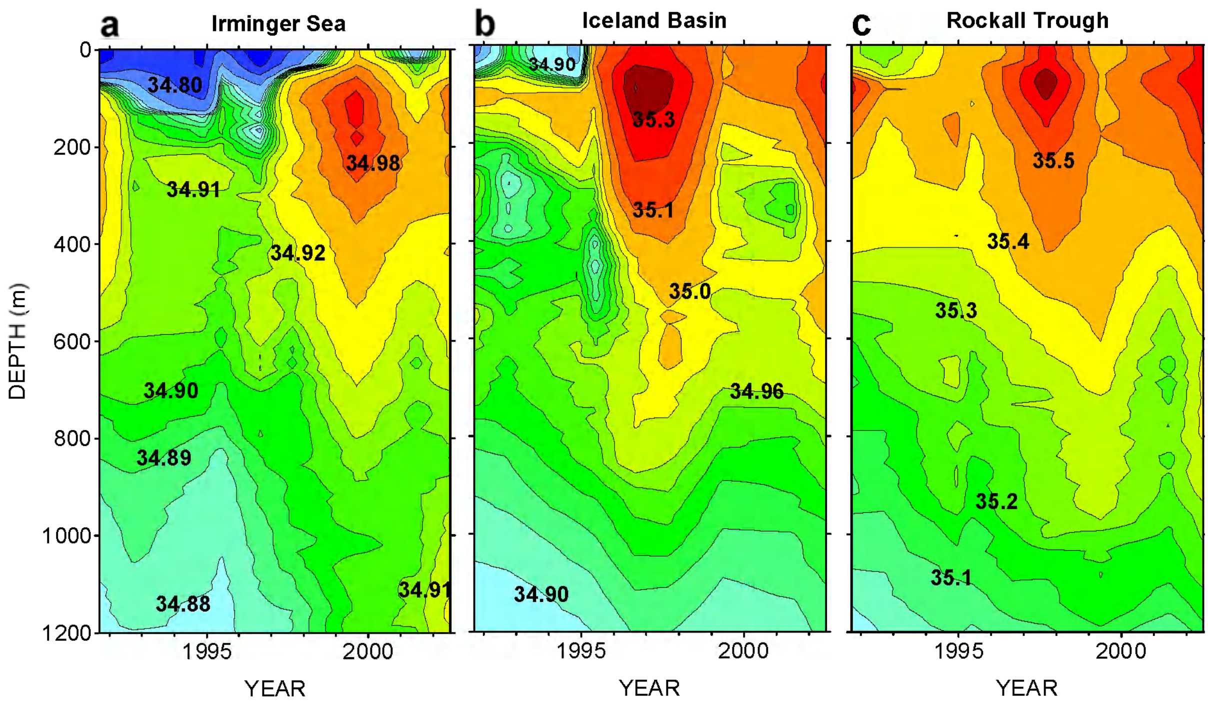

Figure 20. Area 5b – NE Atlantic. Temporal changes of the mean salinity in different regions of section A1E in the upper 1200 m between 1991 and 2002: (a) Irminger Sea (30.8° to 41.8°W), (b) Iceland Basin (24.0° to 28.0°W), and (c) Rockall Trough (15.2° to 20.0°W). Notice that different colour codes are used in the different regions.

Area 6 – Faroe Bank Channel and Faroe Current

No data available for 2002.

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 warming and becoming more saline (Figure 21). 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. In 2000 and 2001, the temperature and salinities decreased slightly. During 2002, the trend reversed and the values are increasing once again.

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 22). The warming trend is slightly less in the modified water, while the mid-1970s low-salinity period was more extreme. During 2002, temperature and salinity continued to increase slightly from the values observed in 2000 and 2001.

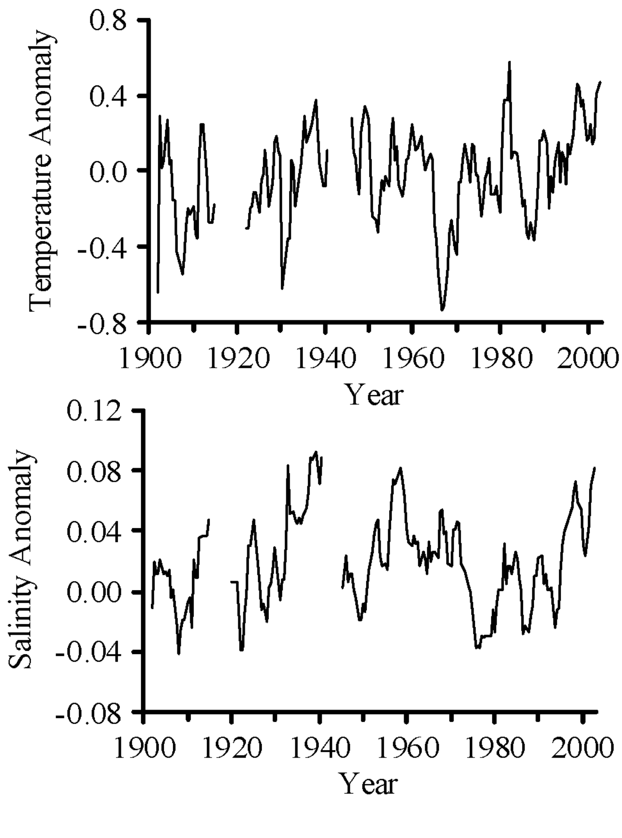

Figure 21. Area 7 – Faroe Shetland Channel. Temperature and salinity anomalies in the North Atlantic Water (NAW) in the Slope Current.

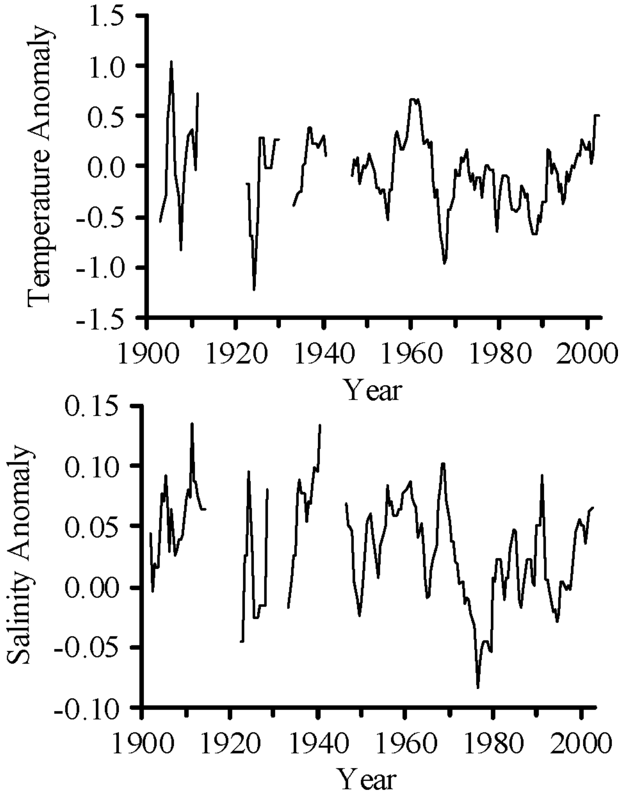

Figure 22. Area 7 – Faroe Shetland Channel. Temperature and salinity anomalies in the Modified Atlantic Water (MNA) entering the Faroe Shetland Channel from the north after circulating around Faroe.

Areas 8 and 9 – Northern and Southern North Sea

The North Sea oceanographic conditions are determined by the inflow of saline Atlantic water mainly through the northern entrances (Fair Isle Current) and to a lesser degree through the English Channel. The Atlantic water mixes with the 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 the 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 a 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 the Fair Isle Current (Figure 23), temperature increased during 2002 to reach the highest values since the data set began in 1972. The Fair Isle Current also appears to be freshening; the lowest values observed since 1972 were seen during 2001 but these values increased to more normal levels during 2002.

In terms of the surface temperatures of the whole North Sea in 2002, the area-averaged annual mean SST of 11.0°C made 2002 the warmest year on record. Another record was set in September (16.2°C), while the months of April, August, and October were the second warmest after 1990, 1997, and 2001, respectively. As is apparent from Figure 24, seasurface temperatures exceeded the climactic normal nearly basin-wide and throughout the year. The warm period observed throughout 2001 and 2002 form a long period of positive seasurface temperature anomalies that point to an overall warming trend.

The temperature of the upper layer of most of the North Sea was about one degree Celsius warmer than normal during most of 2002. Along the Norwegian westcoast it was the warmest September since the monitoring began in 1942. Figure 25 shows the development of temperature and salinity at two positions, one (A) near bottom in the northwestern part of the North Sea and the second (B) in the core of Atlantic water at the western shelf edge of the Norwegian Trench. The measurements are carried out during summer and represent the last winter situation. At both positions, the values from 2000 and 2001 were rather close to the long-term average, while in 2002 we see a certain increase in temperature. Owing to the warmer and deeper upper mixed layer and the warmer bottom layer the total heat content of the North Sea in summer 2002 was definitely above normal.

Low salinities persisted during the first half of 2002 across the Southern Bight following the extreme low-salinity year of 2001 (Figure 26). By mid-year a positive anomaly was observed at the Smartbuoy deployment (not shown here) and persisted into the autumn. SST in winter and spring months of 2002 was above normal without much of the cooling usually occurring in February and March.

Oceanographic measurements made in summer 2002 (RV "GAUSS" July) show an increasing influence of Atlantic water in the northern North Sea compared with the previous year. In larger parts the Sea Surface Salinity (SSS) anomaly distribution (Figure 27) shows only insignificant deviations from the long-term mean. Above the western flank of the Norwegian Trench SSS anomalies of up to 1 PSS point to a stronger Atlantic water inflow. In the German Bight and off the Danish coast a stronger than normal run-off led to negative SSS anomalies

German Bight

The temperature data (Figure 28) from the MARNET Station "German Bight" support the results of the area-averaged North Sea SST data. The whole year the SST in the German Bight was above (or close to) the long-term mean. The salinity data show the normal high variability in the German Bight. The sharp drop in the salinity in September 2002 was caused by the exceptional flooding of the River Elbe in August 2002, which reached the German Bight Station in September 2002.

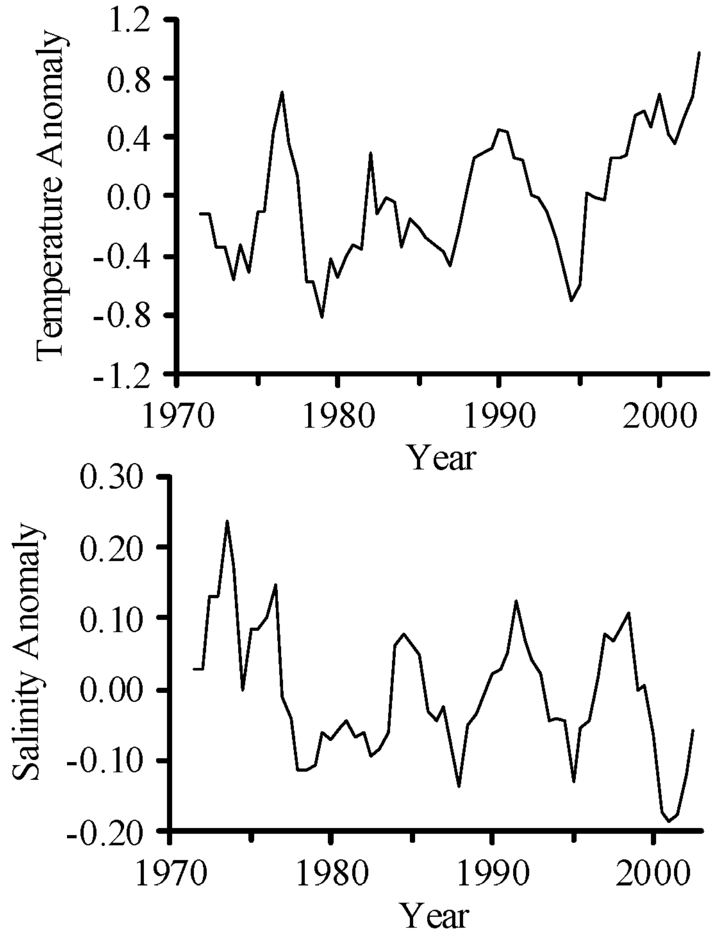

Figure 23. Areas 8 and 9 – Northern and Southern North Sea. Temperature and salinity anomalies in the Fair Isle Current (FIC) entering the North Sea from the North Atlantic.

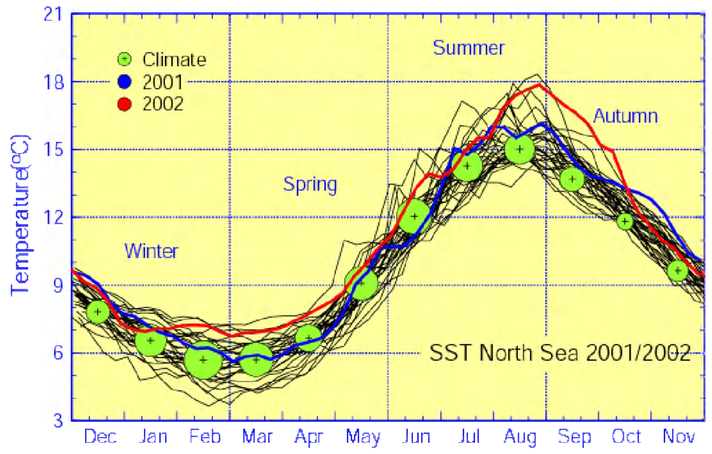

Figure 24. Areas 8 and 9 – Northern and Southern North Sea. North Sea area-averaged SST annual cycle, monthly means based on operational weekly North Sea SST maps. Climatology 1971–1993 green dots; blue line 2001, red line 2002; thin black lines individual years.

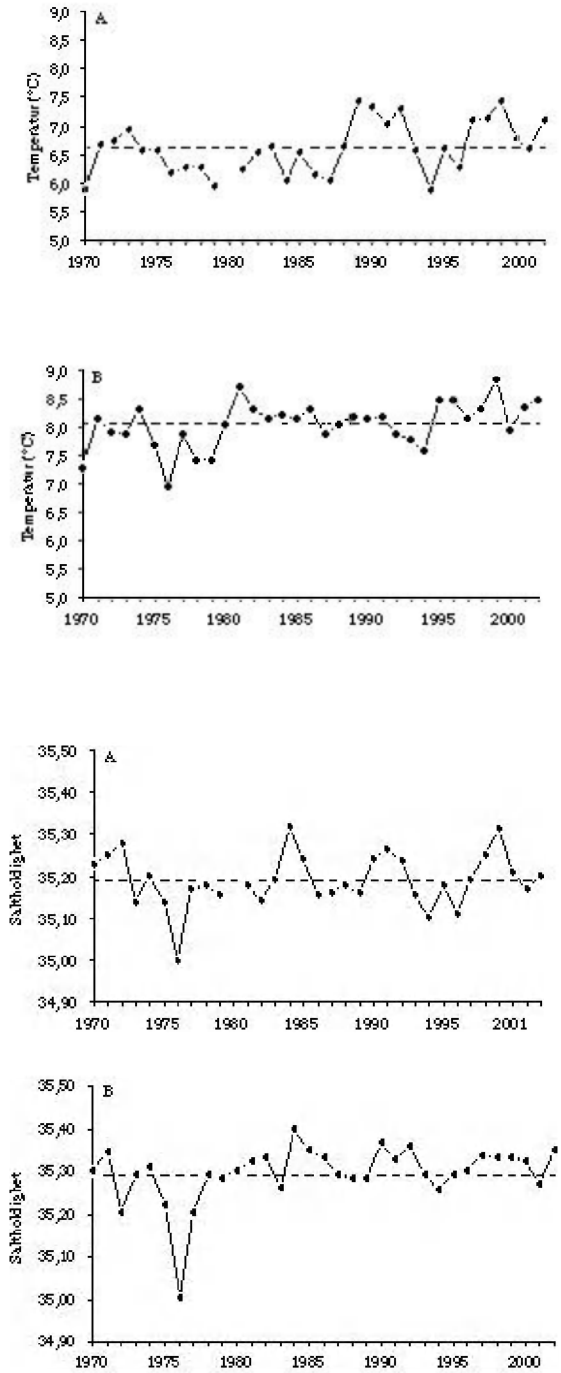

Figure 25. Areas 8 and 9 – Northern and Southern North Sea. Temperature and salinity near bottom in the northwestern part of the North Sea (A) and in the core of Atlantic water at the western shelf edge of the Norwegian Trench (B) during the summers of 1970–2002.

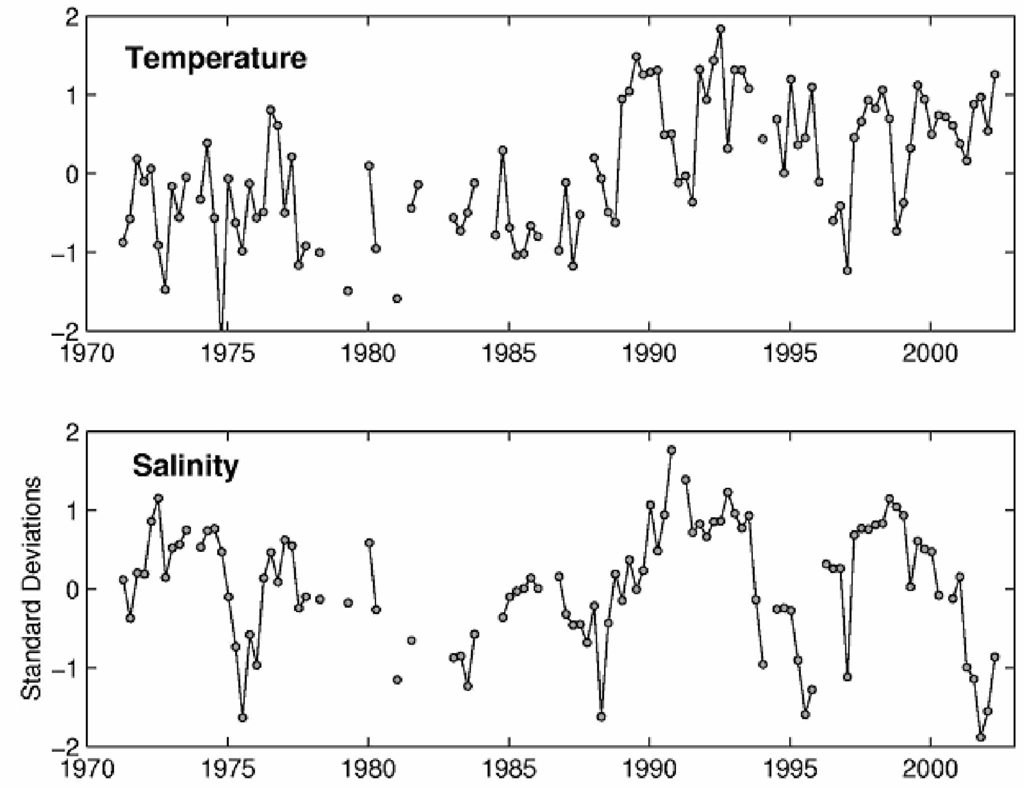

Figure 26. Areas 8 and 9 – Northern and Southern North Sea. Normalised seasonal a) Temperature b) Salinity anomaly along the 52°N Felix-Rotterdam Route.

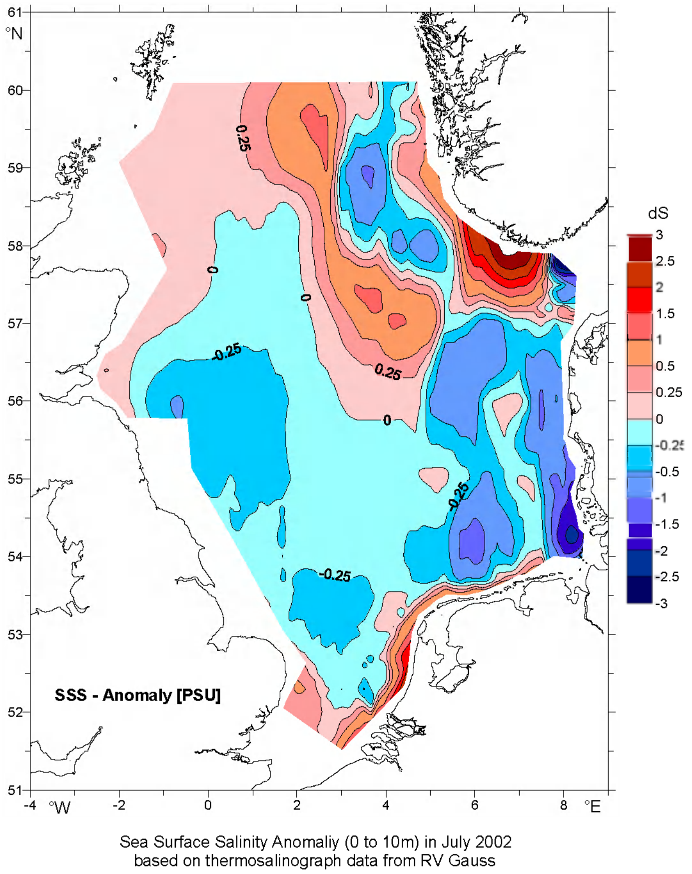

Figure 27. Areas 8 and 9 – Northern and Southern North Sea. Sea Surface Salinity anomalies based on thermosalinograph data taken in July 2002.

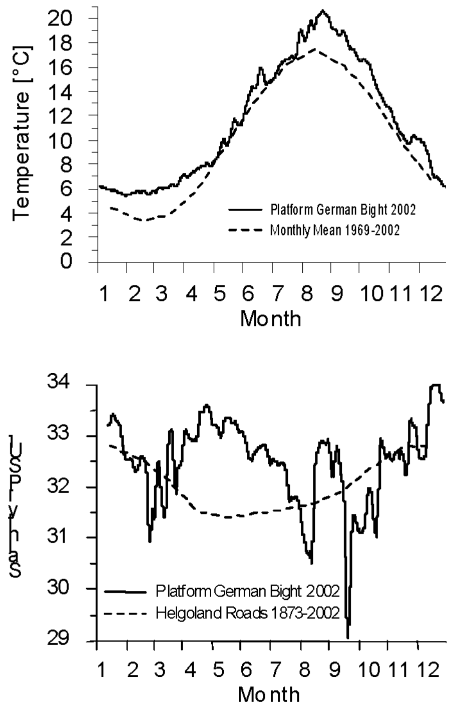

Figure 28. Areas 8 and 9 – Northern and Southern North Sea. Annual cycle 2002 temperature and salinity from MARNET Station "German Bight". Temperature climatology taken from weekly SST maps, salinity climatology from data taken at the island of Helgoland.

Area 9b – Skagerrak, Kattegat, and the Baltic

The seas around Sweden are distinguished by the large salinity variations. In the Skagerrak, water masses from different parts of the North Sea are found. The Kattegat is a transition area between the Baltic and Skagerrak. The water is strongly stratified with a permanent halocline. The deep water in the Baltic Proper, which enters through the Belts and the Sound, can in the inner basins be stagnant for long periods. In the relatively shallow area south of Sweden small inflows pass fairly quickly, causing large variations in the deep water. The surface salinity is very low in the Baltic Proper and the Gulf of Bothnia. The latter area is ice-covered during winter.

The year of 2002 was characterised by the late summer being unusually warm. Higher than normal sea surface temperatures were recorded for the whole area in August and early September. This state of affairs is demonstrated in the temperature record from Station P2 in the Skagerrak displayed in Figure 29. The diagram also depicts high values in the beginning of June, a feature representative for the situation in the Kattegat as well. The weather changed rapidly in the autumn; on the Swedish west coast, for example, the transition from swimming conditions to a 10 cm thick snow cover took a little bit more than a month.

For 2002 the outflow from the Baltic into the Kattegat was less than normal until the middle of March when a longer period with sizeable outflows took place. This feature is illustrated in Figure 30 showing the accumulated inflow through the Öresund for 2002. The diagram also includes the values for 2001 and 1993 as well as the maximum, minimum and mean values obtained from measurements during the period 1977–2001. The effect of large volumes of low-saline water entering into the Kattegat-Skagerrak is clearly visible in Figure 30, showing the salinity at P2 for 2002. No major inflows of high-salinity water to the Baltic took place during the year.

The ice cover in the Baltic during the winter 2001/2002 had its maximum extent on 14 March 2002. The ice winter was considered fairly mild. The onset of cold weather during the autumn of 2002 caused an early start of the Baltic freeze-up.

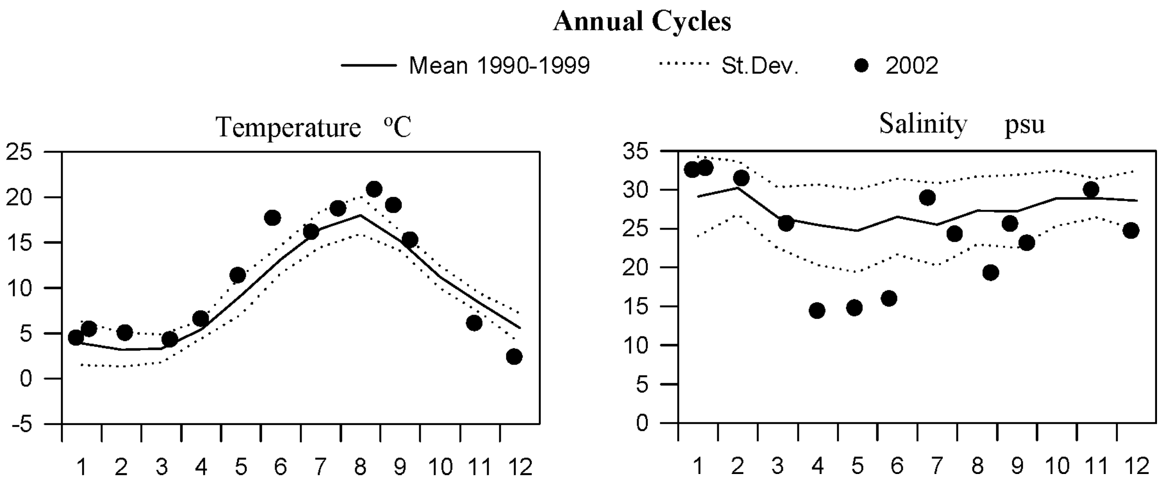

Figure 29. Area 9b – Skagerrak, Kattegat, and the Baltic. Annual cycles of surface temperature and salinity at Station P2 in the southern part of the Skagerrak. The data were collected by RV "Argos" within the Swedish National Monitoring Programme.

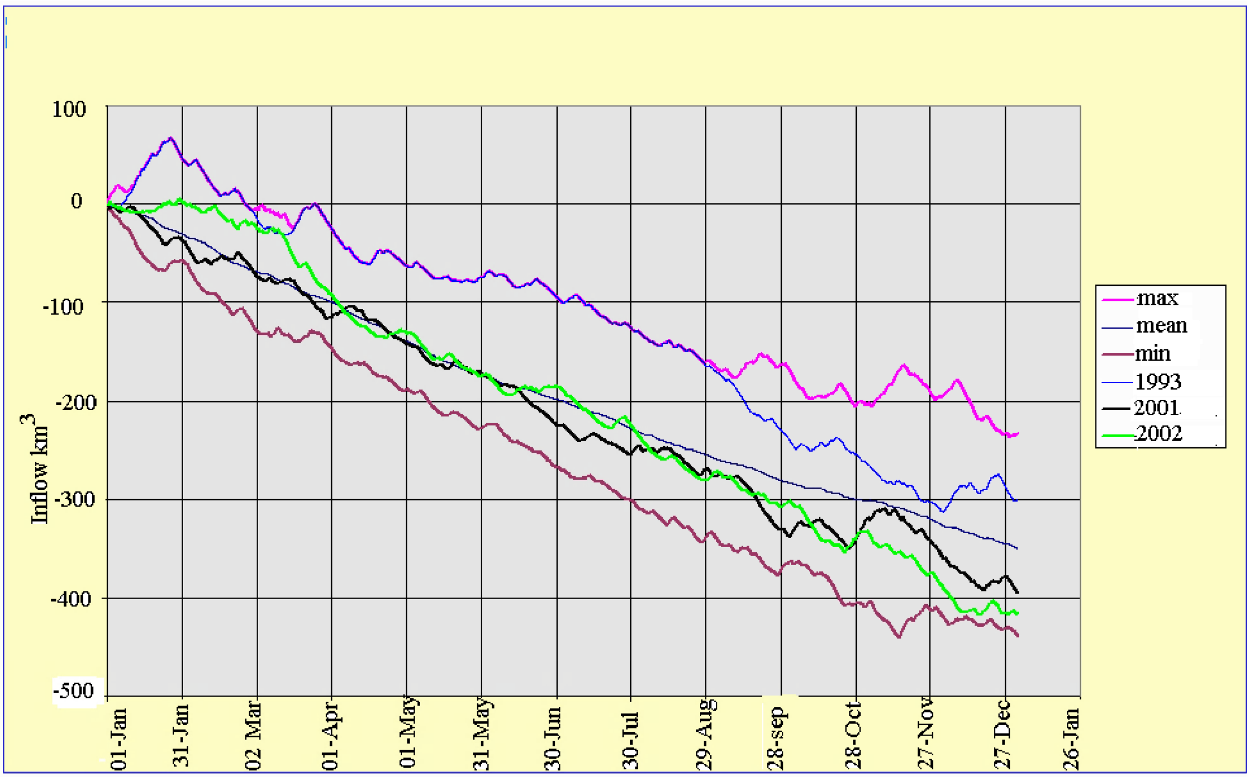

Figure 30. Area 9b – Skagerrak, Kattegat, and the Baltic. Accumulated inflow in km^3 through the Öresund in 1993, 2001, and 2002 compared with the period 1977–2001. The map was constructed by SMHI.

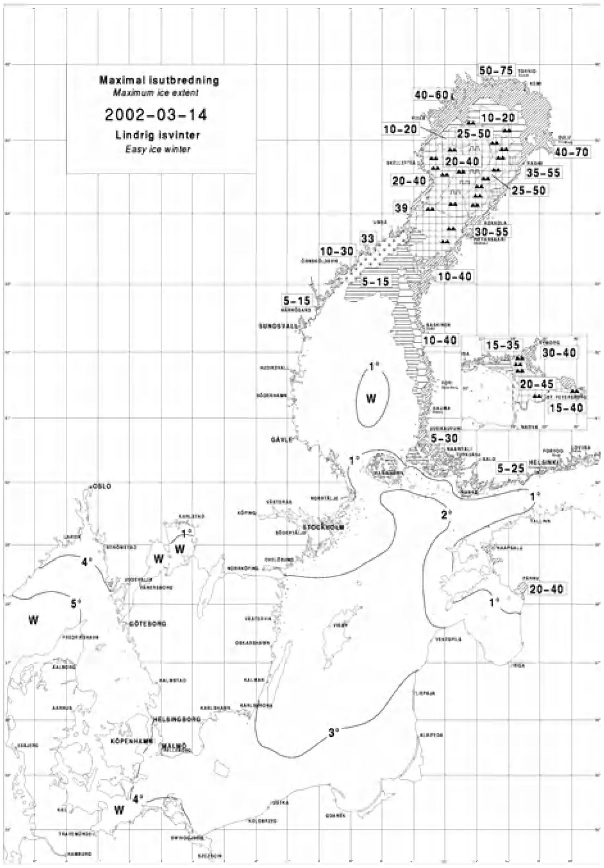

Figure 31. Area 9b – Skagerrak, Kattegat, and the Baltic. The maximum ice extent in the Baltic during winter 2001/2002. The map was constructed by SMHI.

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 since 1978 increased by 0.5°C. In 2002 the temperature was the highest observed in the time-series. The area occupied by Atlantic water has shown a long-term decrease. However, since the mid-1990s with several years of low values in the area there has been a positive trend.

Over the slope, in the eastern Norwegian Sea, a warming has taken place since 1996 (Figure 32). In 2002 the warming continued in the southern section (63°N) while a cooling occurred in the northern section (76°N). Unfortunately, there were no observations in the central section (69°N) in 2002. The northern section has long-term trends toward higher temperature and lower salinity. Since 1996, the temperature in that section has however, been close to the long-term average. The vertically averaged temperature in the upper 200-m layer in the Norwegian Atlantic Current was 0.8°–1.2°C above normal during summer 2002.

The SST was for 2002 higher than normal practically over the entire Norwegian Sea. At the Ocean Weather Station "M" it reached record-high values. The thickness of the intermediate water mass is still increasing but the temperature increase at 2000-m depth has stopped.

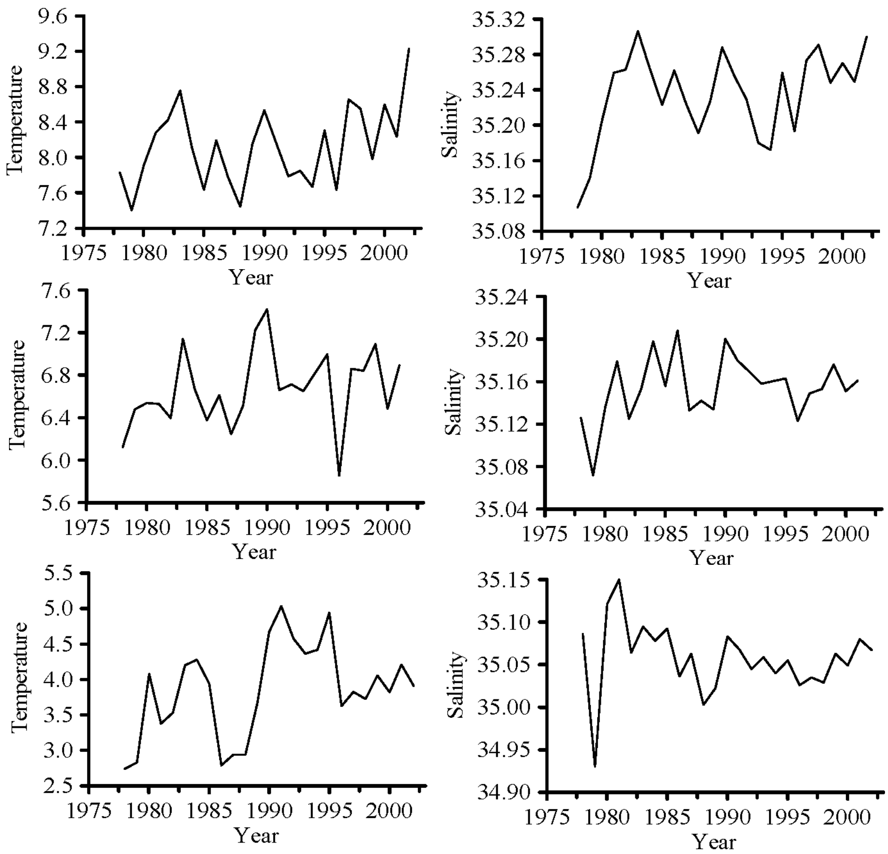

Figure 32. Area 10 – Norwegian Sea. Average temperature and salinity above the slope at three sections, Svinøy (approx. 63°N – upper figures), Gimsøy (approx. 69°N – central figures), and Sørkapp (approx. 76°N – lower figures), representing the southern, central, and northern Norwegian Sea.

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 Atlantic inflow to the Barents Sea started in 1997. During the first three months of 2002 there was a relatively high inflow, while the inflow was below average during the last months of the year.

After a period with high temperatures in the first half of the 1990s, the temperatures in the Barents Sea dropped to values 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 the average (Figure 33), while the temperature in the eastern areas stayed below the average during 1998 (Figure 34). 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 stayed above average since then.

In January 2002 the temperature was close to the long-term average in the whole Barents Sea. However, there was a rapid temperature increase during spring, most likely due to the increased inflow during the first three months. The increased heat content was observed both in the northwestern and eastern Barents Sea. The highest positive anomaly of depth-averaged temperature both in the Atlantic and coastal waters (to 0.9° – 1.0°C) was observed in June. During autumn and early winter the temperature decreased rapidly, and fell to the long-term mean in January and February 2003 in the whole Barents Sea. The mean annual heat content in the southern Barents Sea is expected to be close to normal in 2003.

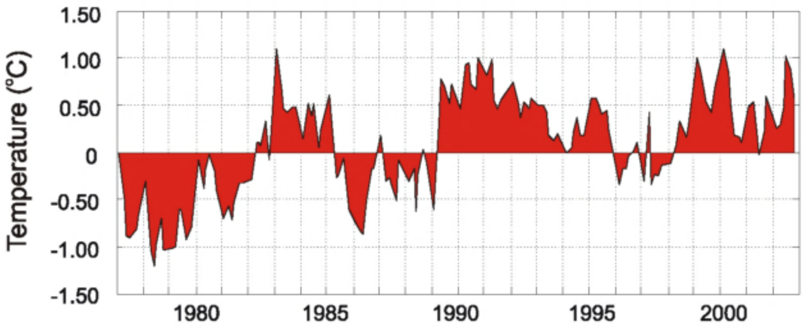

Figure 33. Area 11 – Barents Sea. Temperature anomalies (upper panel) in the section Fugløya – Bear Island.

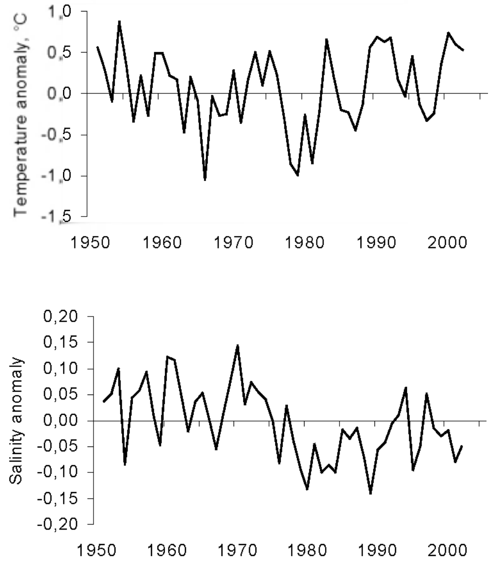

Figure 34. Area 11 – Barents Sea. Temperature and salinity anomalies in the Kola section (0–200 m).

Area 12 – Greenland Sea

The Greenland Sea and its northern border, the Fram Strait, form one of the pathways that 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 deepwater renewal, determines the hydrographic conditions in the region.

At the eastern side of the Greenland Sea, within the West Spitsbergen Current, there was a significant increase in temperature and salinity of the Atlantic water along 75°N (between 10°E and 13°E and in 50–150 m depth) when compared with previous years (Figure 35).

The returning Atlantic water on the western side of the Greenland Sea, characterised by the temperature and salinity maxima below 50 m averaged over three stations west of 11.5°W along 75°N, was slightly colder and less saline in summer 2002 than in the previous summer.

In the central Greenland Sea during the winter of 2001/2002 convection was confined mostly to about 1500 m except in the area of a small-scale eddy, where the temperature maximum was shifted downward to the depth of 2800 m. A tendency to increase in the depth of maximum temperature was observed between 2001 and 2002 as well as a rise in the lowest temperatures in the bottom waters.

In the eastern part of the Greenland Sea (at 76°30′N) mean temperature and salinity of the Atlantic Water (defined as a layer with salinity higher than 34.92) were a little lower than observed in summer 2001 but still significantly higher than minimum values found in 1997 and 1998 (Figure 36).

Further north, within the Fram Strait, at 79°N, mean salinity observed in the West Spitsbergen Current was close to the last year value while the mean temperature decreased slightly (from 3.44°C in 2001 to 3.15°C in 2002). Nevertheless, both values remained similarly high as observed during the last three years. A small drop in temperature and salinity of the Return Atlantic Current was noticeable. A strong decrease was noticed in the East Greenland Current in the layer 50–500 m, where the mean salinity (34.52) as well as the mean temperature (-0.01°C) were the lowest since 1980 (Figure 37).

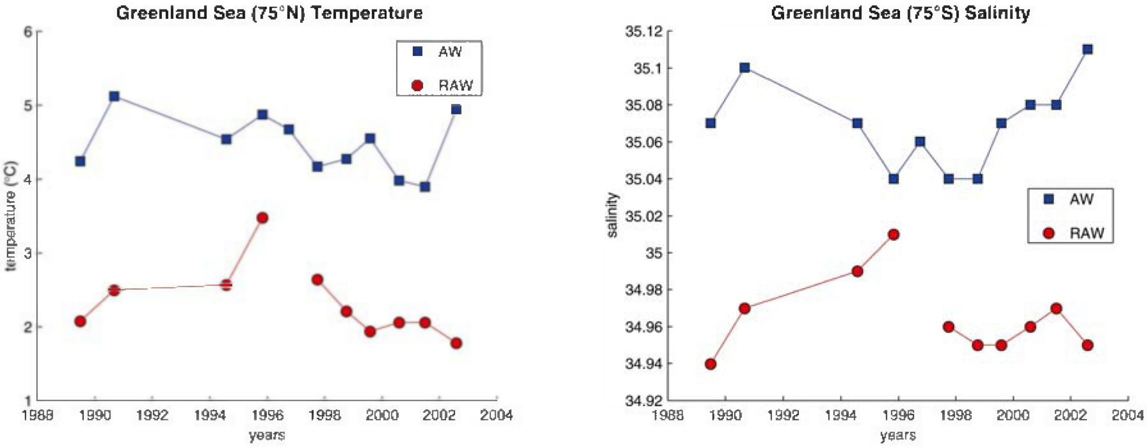

Figure 35. Area 12 – Greenland Sea. Temperature (left figure) and salinity (right figure) in the Returning Atlantic Water (RAW) in the East Greenland Current and the Atlantic Water in the West Spitsbergen Current at 75°N.

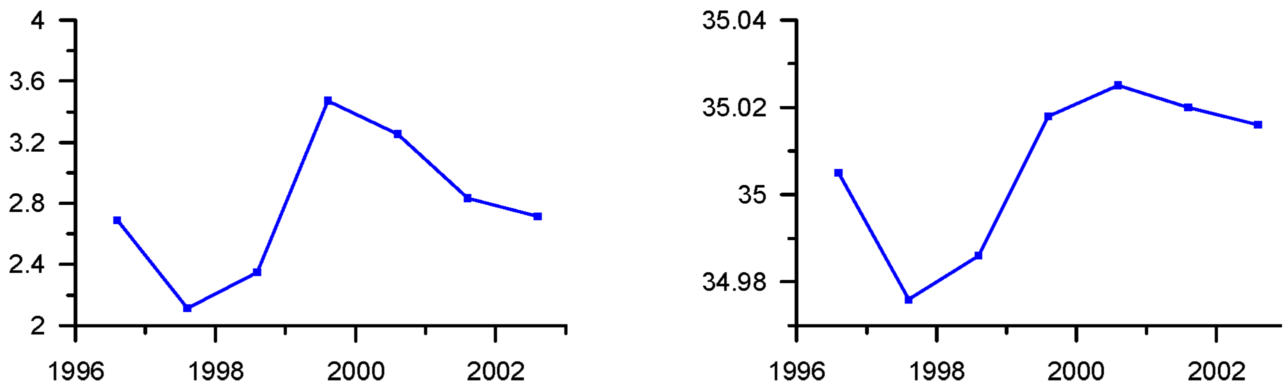

Figure 36. Area 12 – Greenland Sea (Eastern). Mean temperature (left figure) and salinity (right figure) of the Atlantic Water (layer with salinity higher than 34.92) in the West Spitsbergen Current at 76°30’N.

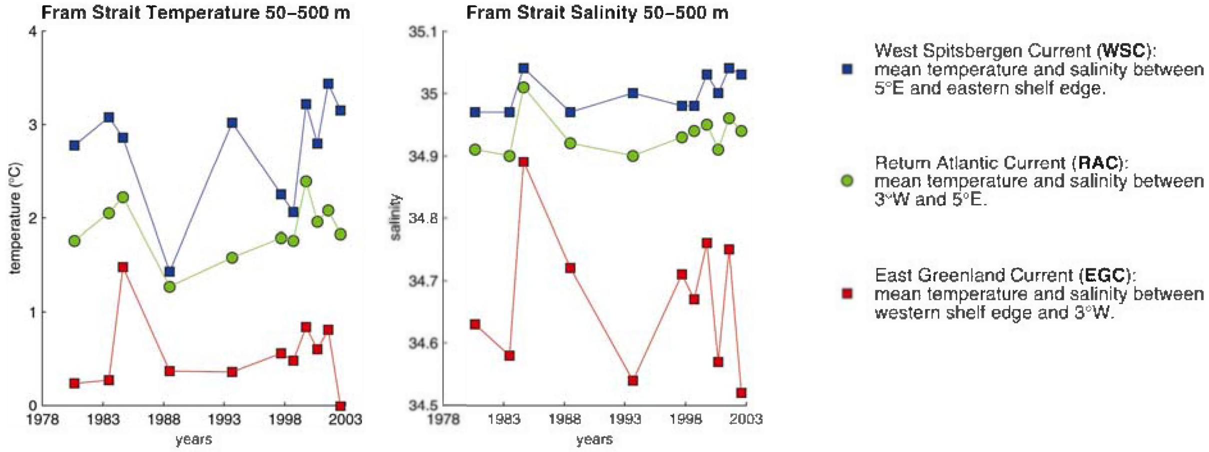

Figure 37. Area 12 – Greenland Sea (Northern). Averaged temperature and salinity at 50–500 m depth in the Fram Strait (at 78°50′N /79°N). The West Spitsbergen Current data (between 5°E and eastern shelf edge) shown in blue, the Return Atlantic Current data (between 3°W and 5°E) shown in green, the East Greenland Current data (between western shelf edge and 3°W) shown in red.

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