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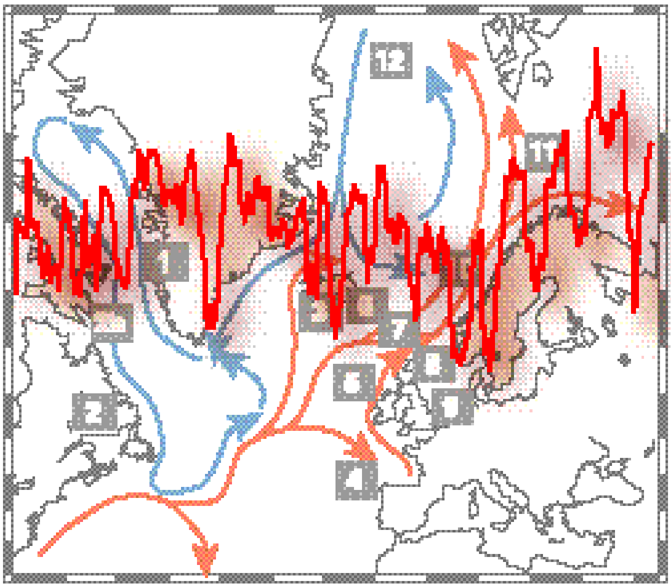
The Annual ICES Ocean Climate Status Summary 2003/2004



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Contents

1 Overview

In most areas of the North Atlantic during 2003, temperature and salinity in the upper layers remained higher than the long-term average, with new records set in several regions.

Following the strongly negative North Atlantic Oscillation (NAO) index during the winter preceding 2001, the winter NAO index values for 2002 and 2003 were both weak. The pattern of sea level pressure anomaly for the winter of 2003 was meridional with an east-west dipole as opposed to the zonal pattern caused by the north-south dipole of the NAO. This led to increased southerly winds over the northern North Atlantic.

Figure 1 shows annual-mean normalised temperature and salinity anomalies for selected time-series in the upper layers of the ocean around the North Atlantic region. The trends in these data over the past 10 years are illustrated in Table 1. Table 2 contains additional information about each time-series included in Figure 1 and Table 1.

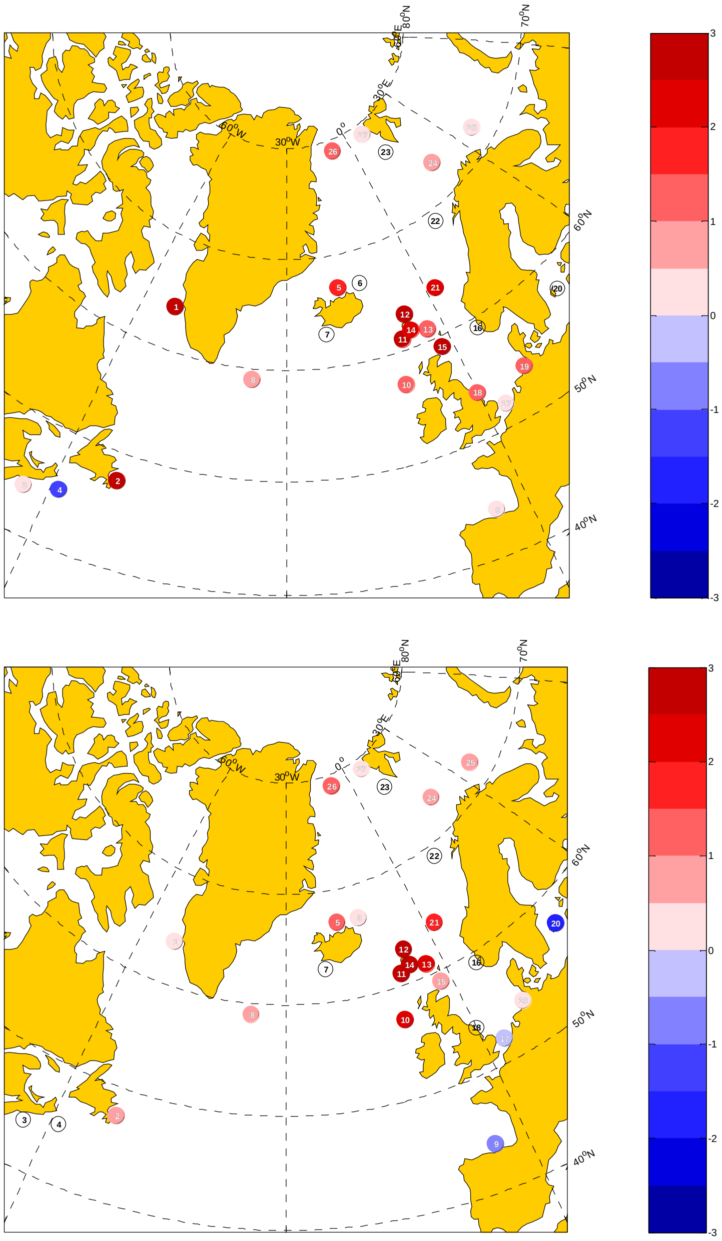

Figure 1. Map of annual anomalies in 2003 of temperature (upper panel) and salinity (lower panel) over the North Atlantic region. The position of each dot represents the area in which measurements are taken. Unless specified these are upper layer anomalies. Normalised anomalies are presented to allow comparison between datasets.

Table 1. Changes in temperature and salinity at selected stations in the North Atlantic region over the last decade. Normalised anomalies are presented to allow comparison between datasets. Details of each dataset are presented in Table 2.

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1	0.88	0.20	1.71	0.76	1.60	1.02	1.66	1.91	-0.39	2.89
2	0.14	-0.39	2.47	-0.04	-0.04	1.18	1.15	1.24	0.72	4.12
3	1.13	0.57	0.98	0.51	-2.64	-0.28	0.28	0.47	0.07	0.07
4	-0.46	-0.80	-0.35	-0.17	0.19	0.84	1.33	-0.16	0.40	-1.43
5	0.83	-2.13	-0.10	-0.09	-0.45	1.35	0.78	0.48	-0.17	1.87
6	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
7	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
8	0.03	-0.43	-0.47	-0.11	0.15	0.75	0.14	0.68	NaN	0.61
9	-0.92	-1.26	0.58	0.63	1.85	-0.10	-0.60	-0.57	-0.46	0.31
10	-1.27	0.40	0.68	2.19	0.67	1.86	0.71	0.07	NaN	1.37
11	-1.58	-0.83	0.45	0.76	2.26	-0.13	0.62	1.55	1.62	4.99
12	-1.43	-1.92	0.64	0.57	1.80	0.51	0.62	0.57	0.94	3.00
13	-0.74	-0.22	0.27	0.80	0.72	0.54	0.49	0.54	1.17	1.46
14	-0.75	-0.29	0.26	0.39	0.64	0.91	1.03	1.33	1.89	2.03
15	-1.17	-0.47	0.20	0.96	1.02	0.67	0.57	0.66	1.34	2.85
16	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
17	0.40	0.80	-0.34	0.23	0.47	0.53	0.66	0.63	0.90	0.44
18	-0.46	0.91	0.43	0.26	0.59	0.63	0.72	1.19	1.56	1.45
19	0.73	1.52	-1.61	0.18	0.62	1.50	1.11	1.09	1.60	1.29
20	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
21	-1.02	0.60	-1.11	1.47	1.21	-0.23	1.32	0.41	2.92	2.26
22	NaN	0.92	-2.16	0.55	0.51	1.18	-0.46	0.65	NaN	NaN
23	0.85	1.61	-0.32	-0.03	-0.17	0.31	-0.04	0.54	0.10	NaN
24	0.23	0.82	-0.33	-0.40	0.24	1.32	0.90	0.56	1.09	0.66
25	-0.16	0.85	-0.34	-0.75	-0.57	0.65	1.47	1.16	1.04	0.48
26	NaN	NaN	NaN	-0.62	-0.95	1.05	0.32	1.42	0.93	1.01
27	NaN	NaN	NaN	-0.05	-0.25	0.68	0.06	0.60	-1.52	0.32

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1	0.26	0.09	0.29	-0.03	0.19	0.21	0.14	0.50	-0.51	0.48
2	-1.15	-1.73	-0.08	0.33	0.33	-0.45	0.41	-0.87	1.15	0.54
3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
4	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
5	0.78	-0.75	-0.33	-0.46	-0.80	1.29	0.52	0.86	0.27	1.37
6	0.82	0.68	-0.88	-0.60	-2.45	0.11	1.10	0.68	-0.32	0.11
7	-0.38	-0.68	-0.38	0.54	2.67	2.06	0.84	0.84	NaN	NaN
8	0.06	-0.56	-0.59	-1.14	-0.57	2.09	0.12	0.97	NaN	0.73
9	-0.79	-1.93	0.33	0.69	1.16	0.45	-0.46	-1.80	-0.41	-0.93
10	-0.63	0.38	-0.46	1.03	1.63	1.45	0.76	0.78	NaN	2.45
11	-1.27	-0.89	-0.97	0.05	1.62	0.89	1.03	0.78	0.84	3.17
12	-1.66	-0.93	-0.36	0.33	1.36	1.18	0.86	0.80	1.05	2.57
13	-0.60	0.01	0.45	0.81	0.95	0.52	0.04	0.31	1.20	2.25
14	-0.76	-0.24	-0.16	-0.17	0.50	0.83	0.95	1.03	1.58	2.89
15	-0.50	-0.63	0.16	0.56	0.70	0.59	-0.26	-0.52	0.09	0.72
16	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
17	-0.53	-1.07	0.24	0.25	0.94	0.49	0.05	-1.06	-1.23	-0.42
18	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
19	0.01	-1.33	0.37	0.52	1.11	0.52	0.08	-0.92	-0.26	0.46
20	-1.04	-0.92	-1.25	-1.37	-1.45	-2.03	-1.12	-1.99	-1.50	-1.78
21	-1.20	0.55	-0.78	0.83	1.19	0.33	0.77	0.35	1.37	1.60
22	NaN	0.30	-1.01	-0.16	-0.03	0.72	-0.09	0.23	NaN	NaN
23	-0.37	-0.03	-0.70	-0.49	-0.63	0.16	-0.17	0.55	0.25	NaN
24	0.90	1.17	0.57	0.10	-0.14	-0.50	1.26	1.28	0.58	0.89
25	1.62	-1.05	-0.38	1.45	0.28	-0.05	0.12	-0.72	-0.22	0.95
26	NaN	NaN	NaN	-0.50	-0.50	1.39	0.25	1.76	1.39	1.39
27	NaN	NaN	NaN	0.32	-0.04	0.78	-0.95	0.69	-1.40	0.41

Table 2. Details of datasets included in Figure 1 and Table 1. Grey boxes indicate area where no measurements are taken. Blank boxes indicate areas where information was unavailable at the time of preparing this report.

	Description	**Measurement Depth**	**Long-term Average**	**Latitude**	**Longitude**	**Mean T**	**Sdev T**	**Mean S**	**Sdev S**
1	Station 4 – Fylla Section – Greenland Shelf	0–200 m	1971–2000	63.88	−53.37	2.70	0.93	33.51	0.33
2	Station 27 – Newfoundland Shelf Temperature	0–175 m	1971–2000	47.55	−52.59		0.28		0.24
3	Emerald Bank – Central Scotian Shelf	Near Bottom	1971–2000	44.00	−63.00	9.16	0.83		
4	Misaine Bank – North East Scotian Shelf	Near Bottom	1971–2000	45.00	−59.00	1.57	0.67		
5	Siglunes Station 3 – North Iceland Irminger Current	50 m	1971–2000	67.00	−18.00	3.33	1.45	34.73	0.24
6	Section Average Longanes NE – North East Iceland – East Icelandic Current	25 m	1971–2000	67.00	−13.00			34.70	0.07
7	Selvogsbanki Station 5 – South West Iceland – Irminger Current	100 m	1971–2000	63.00	−22.00			35.16	0.03
8	Central Irminger Sea	200–400 m	1991–2000	59.00	−36.00	3.99	0.38	34.88	0.38
9	Santander Station 6 (shelf break) – Bay of Biscay – Spain	5–300 m	1993–2000	44.00	−4.00	12.71	0.17	35.61	0.06
10	Ellett Line – Rockall Trough – UK (Section Average)	0–800 m	1975–2000	57.00	−10.00	9.27	0.21	35.33	0.03
11	Faroe Bank Channel – South Faroe Islands	Upper layer HSC*	1988–2000	61.00	−8.00	8.23	0.18	35.24	0.03
12	Faroe Current – North Faroe Islands (Modified North Atlantic Water)	Upper layer HSC*	1987–2000	63.00	−6.00	7.92	0.29	35.22	0.03
13	Faroe Shetland Channel – Shetland Shelf (North Atlantic Water)	Upper layer HSC*	1971–2000	61.00	−3.00	9.61	0.48	35.36	0.05
14	Faroe Shetland Channel – Faroe Shelf (Modified North Atlantic Water)	Upper layer HSC*	1971–2000	61.50	−6.00	7.85	0.56	35.21	0.04
15	Fair Isle Current Atlantic Water Inflow to North Sea	Upper layer HSC*	1971–2000	59.00	−2.00	9.42	0.53	34.84	0.15
16	Western Edge Norwegian Trench – Atlantic Water Inflow to North Sea	Near Bottom	1971–2000	59.00	5.00				
17	Section Average – Felixstowe – Rotterdam – 52°N	Near Surface	1971–2000	52.00	3.00				
18	Scarborough – Coastal Waters – Southern Bight North Sea	Surface	1971–2000	54.00	0.00	16.7	1.7		
19	Helgoland Roads – Coastal Waters – German Bight North Sea	Surface	1971–2000	54.00	8.00	9.93	0.67	32.11	0.56
20	Baltic Proper – East of Gotland – Baltic Sea	Surface	1971–2000	57.50	19.50			7.35	0.24
21	Southern Norwegian Sea – Svinøy Section – Atlantic Water	50–200 m	1978–2000	64.00	2.00	8.07	0.40	35.23	0.05
22	Central Norwegian Sea – Gimsøy Section – Atlantic Water	50–200 m	1978–2000	69.00	10.00	6.66	0.37	35.25	0.03
23	Northern Norwegian Sea – Sørkapp Section – Atlantic Water	50–200 m	1978–2000	76.50	11.00	3.84	0.68	35.06	0.04
24	Fugloya – Bear Island Section – Western Barents Sea – Atlantic Inflow	50–200 m	1971–2000	73.00	20.00	5.22	0.49	35.05	0.04
25	Kola Section. Eastern Barents Sea	0–200 m	1971–2000	72.00	35.00	3.92	0.49	34.76	0.06
26	Fram Strait – West Spitsbergen Current – Section Average 5°E to Shelf edge	50–500 m	1980–2000	79.00	−8.00	2.61	0.58	34.99	0.03
27	Fram Strait – East Greenland Current – Section Average 3°W to Shelf edge	50–500 m	1980–2000	79.00	8.00	0.58	0.39	34.67	0.11

2 Area summaries

Area 1: West Greenland
West Greenland waters were warmer than normal in the summer and autumn of 2003. Polar water inflows were weak in spring 2003. Warm and saline Irminger waters were observed along the West Greenland slope as far north as Fylla Bank at 64°N.

Area 2: Northwest Atlantic, Scotian Shelf, Newfoundland and Labrador Shelf
Annual mean air temperatures over the Northwest Atlantic remained above normal during 2003, but spring values were below normal in many regions. Sea-ice coverage during 2003 increased over conditions in 2002, but it remained below normal for the 9th consecutive year on the Newfoundland Shelf. With the exception of spring conditions, ocean temperatures in the Newfoundland region remained above normal, continuing the warm trend of the past several years. Further south on the Scotian Shelf, sea-ice was more extensive than usual and water temperatures decreased from 2002 values to below normal. Shelf water salinities, which increased during 2002 to the highest level observed in over a decade, remained above normal in 2003.

Area 2b: Labrador Sea
The 2002/2003 winter was milder than normal in the Labrador Sea, as were the previous two winters. The upper waters (150–1000 m) were slightly warmer and saltier in July 2003 than in July 2002. Warm and saline Irminger water was more abundant in July 2003 than in July 2002. In spite of the mild conditions, convective renewal apparently took place at depths of at least 1000 m during the winter of 2002/2003.

Area 3: Icelandic Waters
The hydrographic conditions in 2003 revealed values of temperature and salinity among the highest observed for the last 30 years for all seasons, especially on the shelf north, northeast and east of Iceland. The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years, though slightly lower than the peak values in 1998.

Area 4: Bay of Biscay and Eastern Atlantic
Air temperatures in 2003 were among the highest observed in the 1960–2003 time-series. Spring-summer air temperature values were 1.5ºC above the mean. Sea surface temperatures were also 1°C above the monthly means between March and September. The seasonal thermocline layer was shallow. No substantial changes in temperature and salinity were detected in the water column below the thermocline to 300 m due to low advection of warmer and saltier water (winter poleward current) in the southern Bay of Biscay in 2003.

Area 5: Rockall Trough
In the Rockall Trough the trend of increasing surface water temperature and salinity since 1995 continued in 2003. Salinity reached the highest value of the time-series and temperatures were above average, just over 0.5°C.

Area 5b: North Atlantic
In the North Atlantic between Ireland and Greenland the temperature and salinity in the upper 1000 m increased relative to previous years. At deeper levels the changes since 2000 were smaller, but still significant.

Area 6: Faroe Bank Channel and Faroe Current
Faroese waters were relatively cold and fresh in the early 1990s, but returned to warmer and more saline conditions, which were maintained at fairly constant levels into the new millennium. By the end of 2002 and throughout 2003, conditions became unusually warm and saline.

Area 7: Faroe Shetland Channel
Surface waters in the Faroe Shetland Channel continued the general warming trend observed over the last 20 years. Modified Atlantic waters in the Faroe Shetland Channel were warmer and saltier in 2003 than at any period during the last 50 years.

Areas 8 and 9: Northern and Southern North Sea
Sea surface temperatures in the North Sea were much higher than average due to an extremely warm summer during 2003. Surface salinities over most of the North Sea returned to near normal values after a period of very low salinity in 2001/2002.

Area 9b: Baltic, Kattegat, and Skagerrak
The winter of 2002/2003 was severe with ice cover extending into the Baltic Proper. An inflow of cold and saline water into the Baltic took place in January.

Area 10: Norwegian Sea
High values of temperature were observed in the southern Norwegian Sea. There the Atlantic water was about 0.7°C above the long-term mean. In 2003 there was a more westerly distribution of Atlantic water in the Norwegian Sea compared to the long-term average, and consequently warmer conditions than normal in the upper layer.

Area 11: Barents Sea
The Barents Sea was warmer than average during 2003. The temperature was close to average in January and February. For the rest of the year, the temperature was approximately 0.5°C above the long-term average in the entire southern Barents Sea.

Area 12: Greenland Sea
In 2003 temperature and salinity of both Atlantic water and Return Atlantic Water were much lower than average. In the Fram Strait temperature and salinity in the West Spitsbergen Current remained high, as in 2002, while in the Return Atlantic Current they significantly increased. The Polar water in the East Greenland Current was warmer and more saline than last year. The heat flux through the Fram Strait to the Arctic Ocean increased slightly and net volume transport was northward and significantly higher than the year before.

3 Introduction

Ocean climate data from 14 areas around the North Atlantic are summarised in this report. Observations in 2003 are compared to the average conditions and the longer-term trends in each dataset. Throughout the report, all temperatures are quoted in °C. The key parameters described in the report are seawater temperature and salinity, but other oceanographic and meteorological parameters such as heat flux, air temperature and sea level pressure have been included for some areas. Figure 2 illustrates the general pattern of oceanic circulation in the North Atlantic in relation to the areas described in this report.

In order to describe the ocean climate of area, key datasets or time-series have been identified and presented. The time-series have been carefully chosen to represent conditions in a particular area. Sometimes the time-series presented are measurements from a single location, but frequently they have been constructed from much larger and more complex datasets.

Where appropriate, data in this report are presented as anomalies in order to show how the values compare to the average or 'normal' conditions. For this report the normal conditions refer to the long-term average of each parameter during the period 1971–2000. For datasets that do not extend as far back as 1971, the average conditions have been calculated from the start of the dataset up to 2000.

Where necessary, the seasonal cycle has been removed from each dataset, either by calculating the average seasonal cycle over the period 1971–2000, or drawing on other sources such as regional climatological datasets.

In the summary tables and figures, normalised anomalies have been presented to allow intercomparison of trends in the data from different regions (Figure 1 and Table 1). The anomalies have been normalised by dividing the values by the standard deviation of the data during the period 1971–2000.

The North Atlantic Oscillation index (NAO) is a measure of the difference in normalised sea level pressure between Iceland and the subtropical Eastern North Atlantic. When the NAO index is positive there is a strengthening of the Icelandic low and Azores high.

This strengthening results in an increased north–south pressure gradient over the North Atlantic, causing colder and drier conditions over the western North Atlantic and warmer and wetter conditions in the eastern North Atlantic. During a negative NAO, a weakening of the Icelandic low and Azores high decreases the pressure gradient across the North Atlantic and tends to reverse these effects.

The NAO index has been useful in the past to describe the climate of the North Atlantic region. Many of the area descriptions in this report refer to the NAO index and relate it to conditions observed in that region. In this report all references to the NAO relate to the extended winter index calculated from sea level pressure data over the winter months. For example the NAO index for 2003 was calculated from sea level pressure anomalies between December 2002 and March 2003. Two slightly different versions of the index are referenced in this report. The Rogers Index is more closely correlated with conditions in the western North Atlantic and the Hurrell Index is more closely correlated with conditions over the eastern North Atlantic. (See Text Box: The Winter North Atlantic Oscillation index (NAO) in 2003 and 2004 on pages 12 and 13) for a full description of the derivation of each index)

Following a long period of increase from an extreme and persistent negative phase in the 1960s to a 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 ICES Annual Ocean Climate Status Summaries (IAOCSS) describe the return of the NAO to positive conditions in the years following 1996 until a further reversal occurred over the winter preceding 2001.

The NAO index is limited in that it can only describe the strength of the north–south dipole in sea level pressure (SLP) anomaly. Although this has been the predominant pattern over the last 30 years, it is not always the case. During the winter of 2002 the SLP anomaly pattern did exhibit a north–south dipole, but this was limited to the eastern region. Therefore the Rogers NAO index was weakly negative and the Hurrell NAO index was weakly positive. During 2003, the typical north-south NAO pattern was replaced by an east–west sea level pressure anomaly leading to a low value for both NAO indices in 2003.

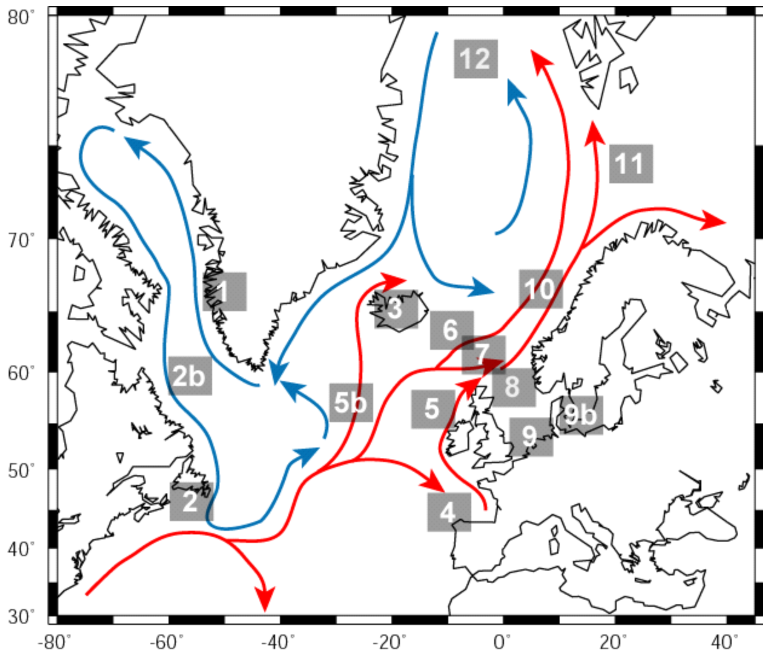

Figure 2. Schematic of the general circulation of the North Atlantic in relation to the numbered areas presented in the 2002/2003 Annual ICES Ocean Climate Status Summary. The blue (light grey) arrows indicate the cooler waters of the sub-polar gyre. The red (dark grey) arrows show the movement of the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

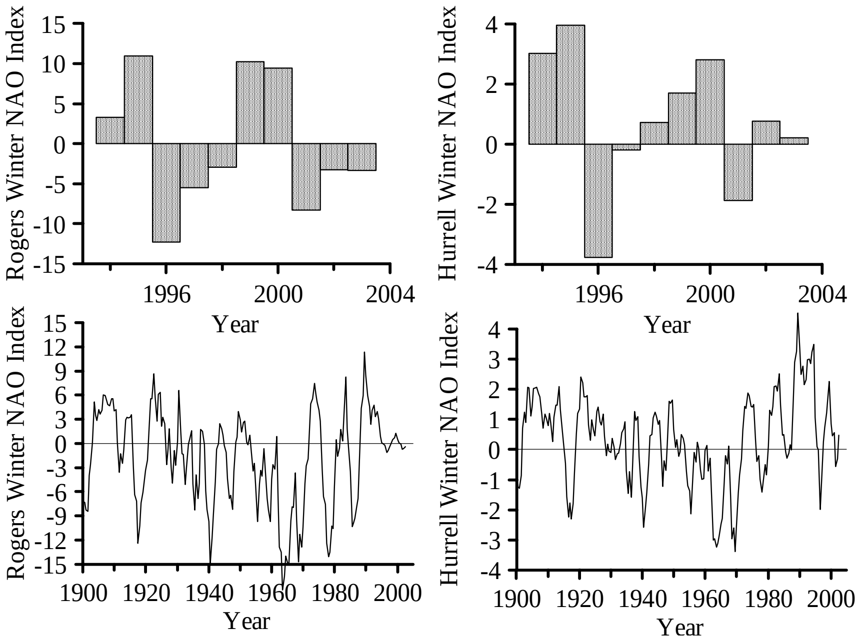

Figure 3. The winter NAO index in terms of the present decade (upper figure) and the last 100 years (lower figure–a two-year running mean has been applied). The Rogers Index is presented on the left and the Hurrell Index is presented on the right.

Winter North Atlantic Oscillation Index (NAO) in 2003 and 2004

The Hurrell Winter NAO index (www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html) for 2003 was 0.20, based upon the pressure difference between Iceland and the southern Iberian Peninsula. The Rogers NAO index for 2003 using the Azores as the southern node was (as in 2002) weak and negative.

Figure 4a shows the sea level pressure (SLP) anomaly field in the North Atlantic for the composite of the four winter months (NCEP/NCAR reanalysis data) with none of the typical NAO pattern. The cause of the overall weak positive Hurrell NAO index is the small difference in SLP anomaly between Iceland and Lisbon/Gibraltar. Overall, it appears that the NAO pattern was not a strong influence upon the SLP anomaly over the North Atlantic during the winter of 2003. The east–west dipole evident in the winter SLP anomaly for 2003 suggests anomalous southerly airflow over much of the North Atlantic, resulting in warmer-than-usual air temperatures over most of the North Atlantic, particularly north of 55°N (Figure 4b). At the eastern edge of the Scandinavian anticyclonic anomaly, air temperatures were generally colder than usual and there is also an indication of cooler-than-usual temperatures south of Newfoundland.

Early indications for the Hurrell Winter NAO index in 2004 (December 2003–March 2004) suggest a decrease in the NAO Index, possibly to negative values. Conditions in the western North Atlantic are likely to be those usually associated with the negative NAO.

The SLP anomaly for the first three months of the winter (Figure 5) shows an anticyclonic anomaly west of Iceland between low pressure anomalies over Scandinavia/Eastern Europe and Newfoundland resulting in anomalous south-easterly airflow towards the Labrador Sea. The Nordic Seas and North Sea are likely to show the effects of anomalously north-easterly airflow.

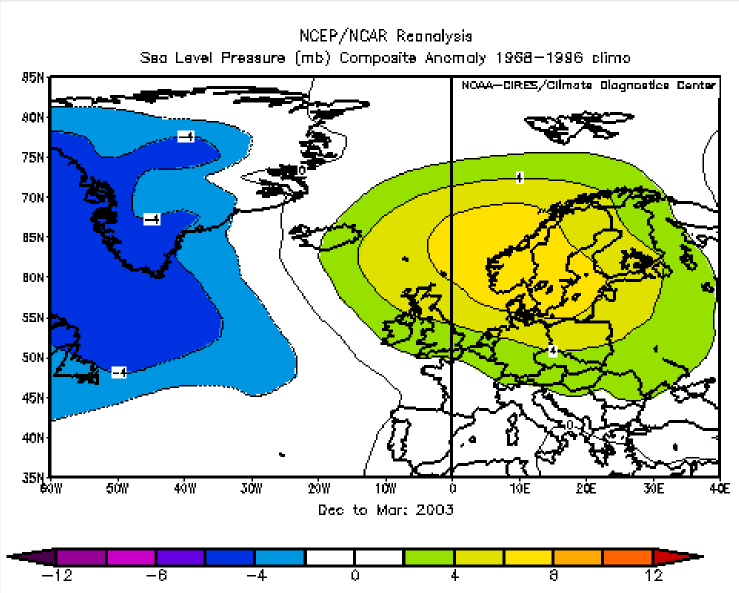

Figure 4a

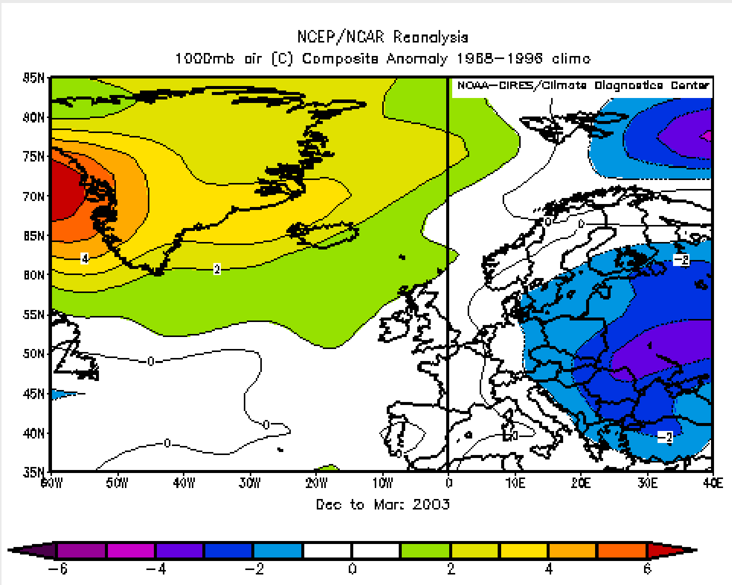

Figure 4b

Figure 4. NAO. The North Atlantic distribution of (a) SLP anomaly (b) Air Temperature anomaly for the composite period of December 2002 to March 2003, relative to 1968–1996. (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

Winter North Atlantic Oscillation Index (NAO) in 2003 and 2004 (continued)

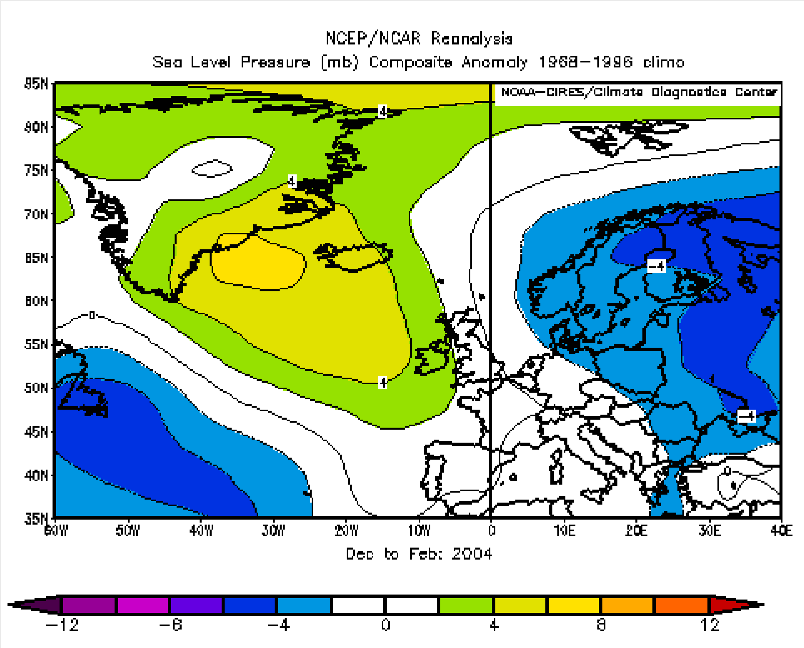

Figure 5. NAO. The Atlantic distribution of SLP anomaly in the North Atlantic for the composite period of December 2003 to February 2004. (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

4 Area descriptions

Area 1 – West Greenland

West Greenland lies within the area which normally experiences warmer conditions when the Rogers NAO index is negative. Conditions at Nuuk during 2003 were consistent with the Rogers NAO index.
Warmer-than-normal conditions were observed around Greenland during most of the year 2003 with mean air temperatures at Nuuk indicating positive anomalies of around 2.0°C (Figure 6). The distribution of sea ice in the waters around Greenland was favourable. Data from Fylla Bank show considerable warming in the upper 200 m of the water column during autumn 2003 (Figure 7). Cold “polar events” during 1983, 1992, and 2002 characterise the long-term ocean temperature time-series.

There is no significant correlation between variations of water temperature anomalies and variations of NAO index. The correlation found is negative and the correlation coefficients are $r = -0.33$ for the 0–50 m layer, and $r = -0.35$ for the 0–200 m layer. Irminger Water was found off Cape Desolation and at Fylla Bank during autumn 2003. In the near-bottom water layer off Cape Desolation/West Greenland, at depths of about 3000 m the Denmark Strait Overflow water mass was observed with salinities of 34.865—a value which has been maintained since the year 2000.

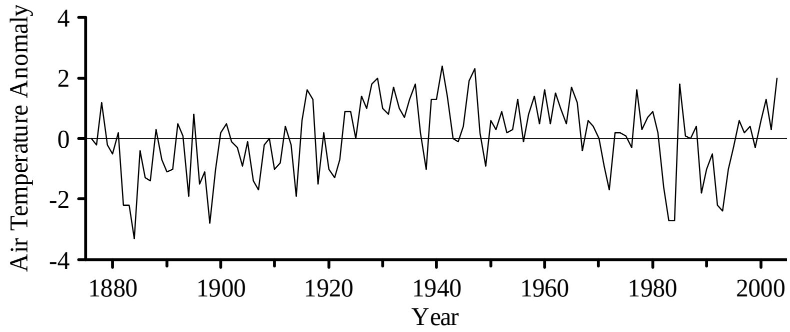

Figure 6. Area 1 – West Greenland. Annual mean air temperature observed at Nuuk for the period 1873–2002.

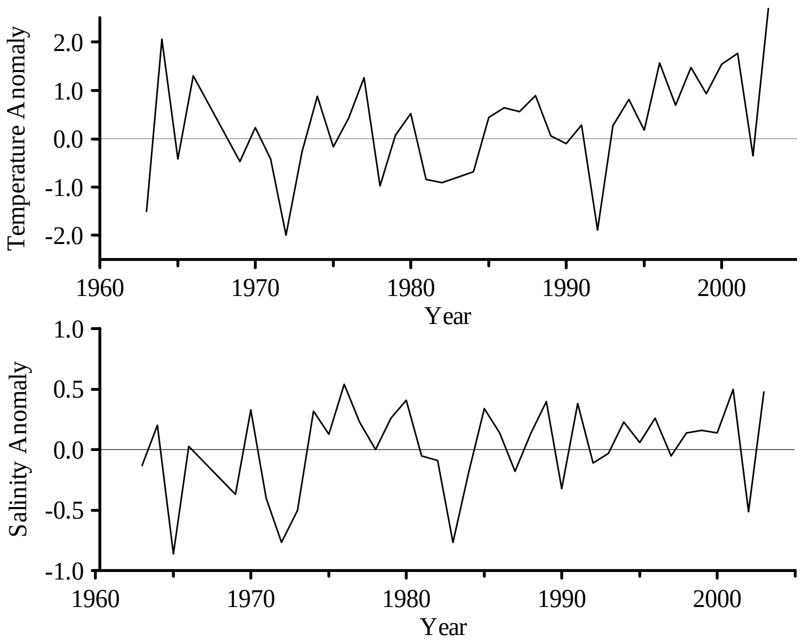

Figure 7. Area 1 – West Greenland. Fylla Bank Station 4 temperature (upper panel) and salinity (lower panel) anomaly autumn, 0–200 metres; data from 1963–2002.

Area 2 – North West 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 Northwest Atlantic. In general, when the normal cyclonic circulation is weak during the winter months, usually corresponding to a negative Rogers NAO index, warm and 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. 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 2003 annual mean air temperatures over the Scotian Shelf, as represented by those recorded at Sable Island, remained above average by about 0.2°C but continued their decline from the record high set in 1999 (Figure 8). Air temperatures in the first half of the year were below the seasonal long-term average and in the second half they were above. In March 2003, the monthly mean ice area on the Scotian Shelf, as measured by the area of ice seaward of Cabot Strait between Nova Scotia and Newfoundland, was the highest recorded (Figure 8). However, the annual mean ice coverage in 2003 was only the third highest in the 42-year record. The previous five years have seen lower than normal ice cover.

In the northeast, the bottom tends to be covered by relatively cold waters (1–4°C), whereas the basins in the central and southwestern regions have bottom temperatures that are typically 8–10°C. The interannual variability of the two water masses differs. Misaine Bank temperatures at 100 m capture the changes in the northeast. They show colder-than-normal conditions in 2003 by about 1°C, the coldest since the early 1990s (Figure 9). In Emerald Basin, temperatures in 2003 were up to 2°C below normal in the upper 100 m and about 0.5°C above average from 100–250 m. The warmer-than-average deep temperatures continue a trend that has existed since the mid-1980s except for an exceptionally 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 Rogers NAO index in 1996.

Sea surface waters over the entire Scotian Shelf were colder and saltier than average during 2003. The higher salinities continue from 2002. Surface salinity conditions on the Shelf are primarily related to upstream conditions off Newfoundland. The 0–50 m density difference over the Scotian Shelf increased on average in 2003, although there was considerable spatial variability with stratification decreasing in some areas.

Newfoundland and Labrador Shelf

The Rogers NAO index for 2003 was below normal. However, a deep cyclonic circulation pattern dominated the Labrador Sea resulting in below normal air temperatures during winter and early spring in Newfoundland and Labrador. Throughout the remainder of the year conditions improved significantly, with annual air temperatures throughout most of the Newfoundland and Labrador region remaining above normal for the 9th consecutive year (+1.2°C at Cartwright, for example). Sea ice on the Newfoundland and Labrador Shelves during 2003 increased over conditions in 2002, but averaged over the ice-season the total coverage remained below normal for the 9th consecutive year (Figure 10).

Off eastern Newfoundland, the depth-averaged ocean temperature has ranged from a record low during 1991 (high Rogers NAO index) to a near record high in 1996 (near record low Rogers NAO index) and was above the long-term average in 1999 through to 2003. Shelf water salinities increased to saltier-than-normal conditions during 2002 and 2003 (Figure 11), ending the decade-long fresh anomaly on the Newfoundland Shelf. 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 fall months. During the 1960s, when the Rogers NAO index was well below normal and had the lowest value ever in this century, the volume of CIL water was at a minimum. In the high NAO years of the early 1990s, the CIL volume reached near record high values. During 2003, the CIL remained below normal on the Newfoundland Shelf for the 9th consecutive year.

Although seasonally 2003 was a year of extremes, ocean temperatures in the Northwest Atlantic remained above normal in many areas, thus continuing the warm trend experienced in much of the Northwest Atlantic during the past several years. Salinities in the Northwest Atlantic, which increased to the highest observed values in over a decade during 2002, remained above normal in 2003.

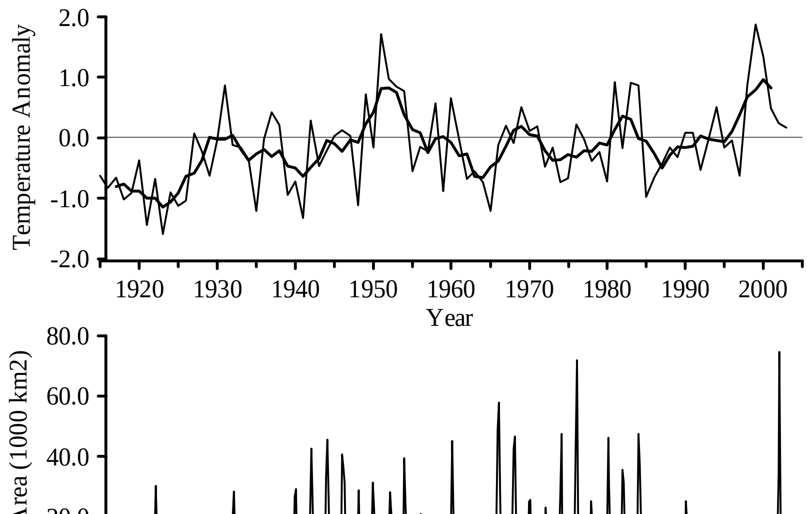

Figure 8. Area 2 – North West Atlantic: Scotian Shelf. Upper panel: Annual air temperature anomalies at Sable Island on the Scotian Shelf. Anomalies are relative to the 1971–2000 long-term mean. The thin line represents annual temperature and the solid line shows five-year running average. Lower panel: Monthly means of ice area seaward of Cabot Strait.

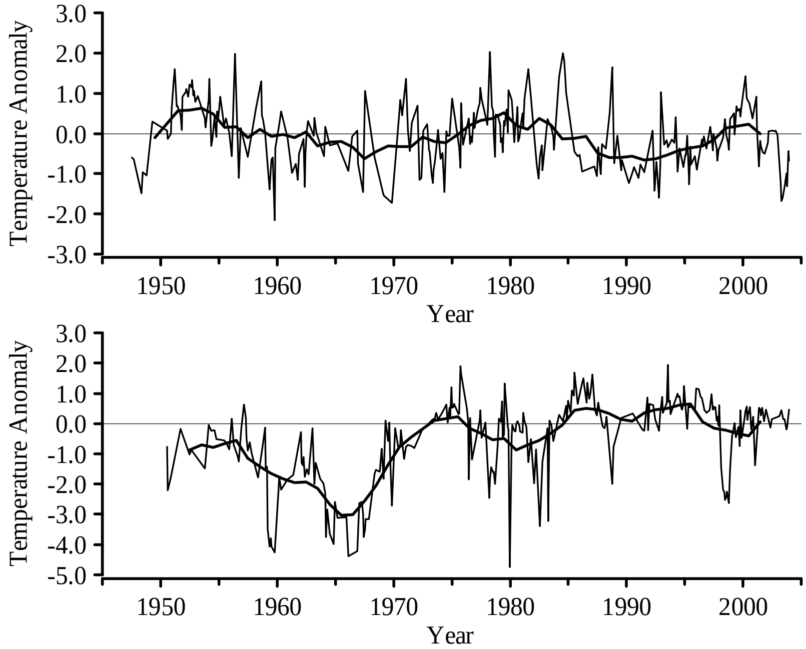

Figure 9. Area 2 – North West Atlantic: Scotian Shelf. Upper panel: Near-bottom temperature anomalies in the northeastern Scotian Shelf (Misaine Bank, 100 m). Lower panel: Near-bottom temperature anomalies central Scotian Shelf (Emerald Basin, 250 m). The solid lines show five-year running mean.

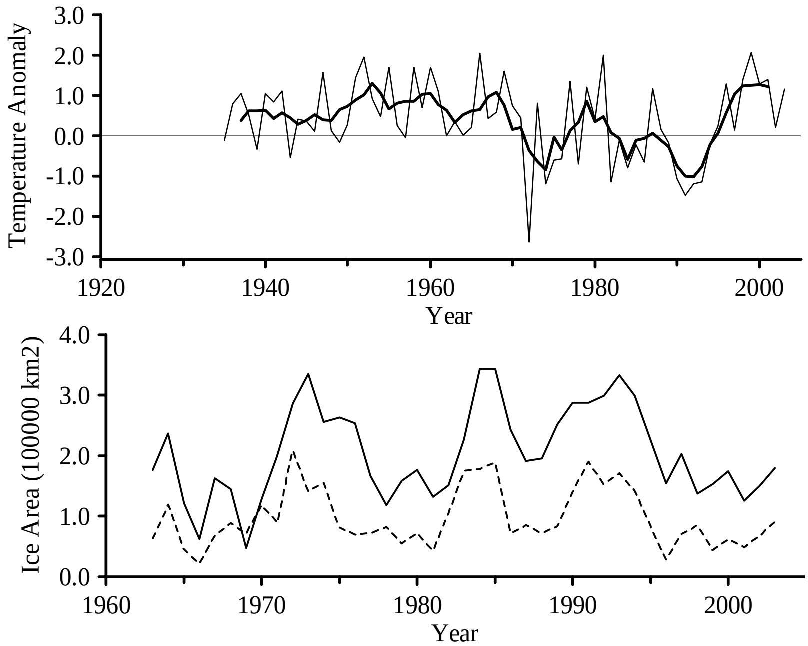

Figure 10. Area 2 – North West Atlantic. Upper panel: Newfoundland and Labrador Shelf. Annual air temperature anomalies at Cartwright on the Labrador Coast (solid line shows five-year running mean). Lower panel: Sea-ice area off Newfoundland and Labrador between 45°N–55°N for the winter (solid line) and for spring (dashed line).

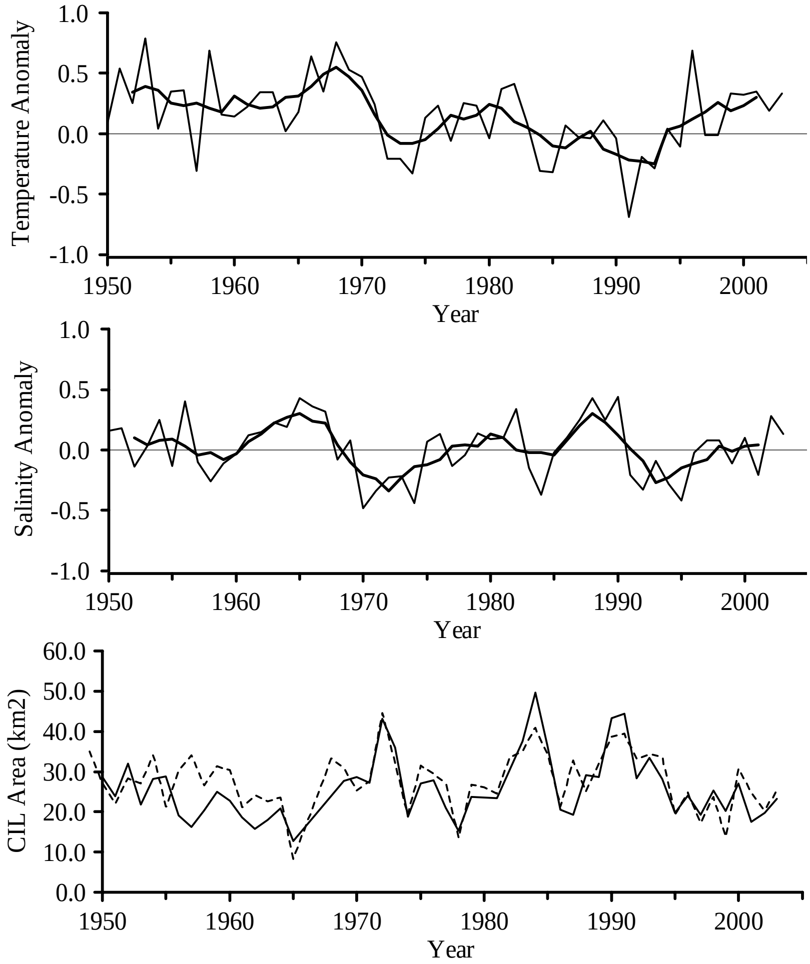

Figure 11. Area 2 – North West Atlantic: Newfoundland and Labrador Shelf. Annual depth-averaged Newfoundland Shelf temperature (ºC) summer salinity anomalies and the time-series of cold intermediate layer (CIL) on the Newfoundland (solid line) and Labrador (dashed line) Shelves.

Area 2b – Labrador Sea

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 saline waters (Irminger Water) carried into the Labrador Sea by an offshore branch of the West Greenland Current.

Wintertime cooling, evaporation and wind mixing cause vertical overturning and form a mixed layer, the depth of which increases through the cooling season. The extreme winters of the early 1990s produced winter mixed layers deeper than 2000 m. From 1995 to 2000, mild winters produced only limited vertical convection. Even though the Labrador Sea was still losing heat to the atmosphere over the annual cycle, advective effects led to a net warming of the upper layers of the Labrador Sea. During this period, intermediate-depth layers that were no longer in direct contact with the atmosphere become notably warmer and saltier. The relatively cold, fresh waters produced by deep convection in the early 1990s were gradually exported and replaced by warm and more saline waters from the eastern side of the Labrador Sea.

Each of the past three winters has been milder than normal (Figure 12). During these years, a quasi stationary state has been established. The upper layers observed in spring/summer 2003 showed a continuation of a decade-long warming trend, but at a much lower rate than in 1995–2000. Warm and saline Irminger water was prominent in the upper layers in 2003.

Intermediate depths (1000–2000 m) remained warm and salty in mid-2003 compared with conditions in the early 1990s, showing little change from 2002. The net changes during 2003 still gave the highest and saltiest 0–2000 m mean conditions in the past 14 annual surveys.

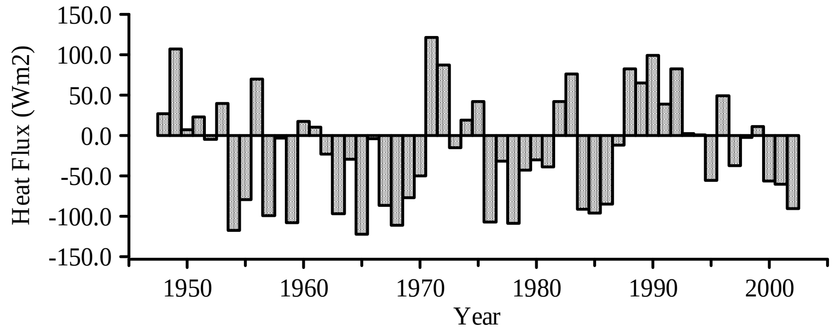

Figure 12. Area 2b – Labrador Sea. Anomalies of winter (DJF mean) sea–air heat flux at 56.2°N 52.5°W in the central Labrador Sea from the co-operative Reanalysis Project of the U.S. National Centers for Environmental Prediction and National Center for Atmospheric Research. The anomalies are relative to the 300 W m^{-2} mean for the 30-year period from 1971 to 2000. Negative values indicate that the ocean lost less heat to the overlying atmosphere than normal. By this measure, the past three winters in the Labrador Sea have been milder than normal.

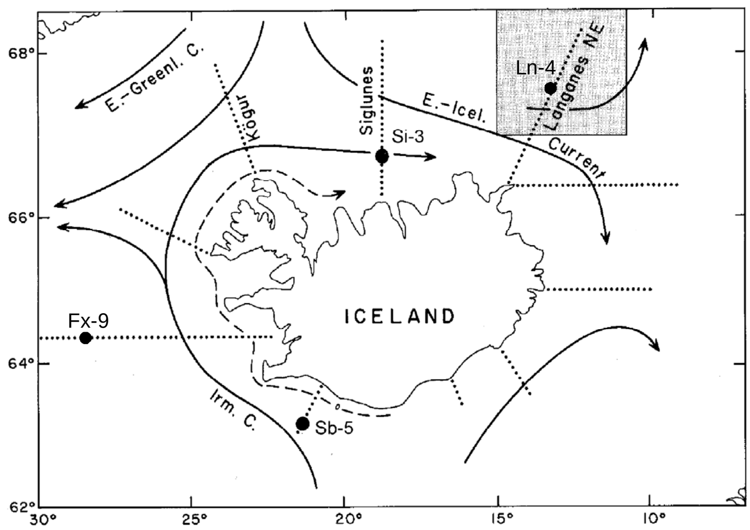

Figure 13. Area 3 – Icelandic Waters. Main currents and location of standard hydro-biological sections in Icelandic Waters. Selected areas and stations dealt with in this report are indicated.

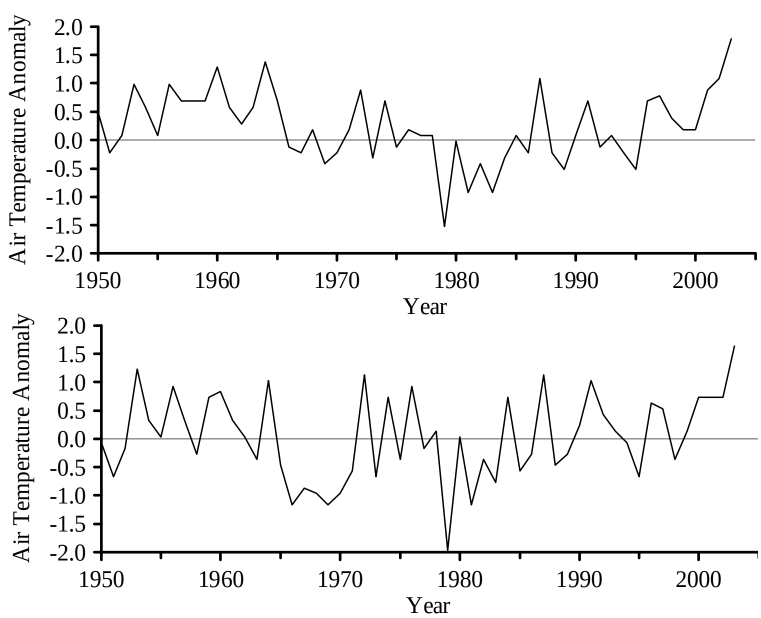

Figure 14. Area 3 – Icelandic Waters. Mean annual air-temperature anomalies at Reykjavík (upper panel) and Akureyri (lower panel) 1950–2003. Anomalies are relative to the 1971–2000 mean.

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, Kolbeinsey Ridge), which form natural barriers against the main ocean currents (Figure 13). 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 2003 revealed winter, spring, summer, and autumn values on the shelf (Figures 14 and 15) above the long-term average (1970–2003) for both temperature and salinity. The salinity and temperature in the Atlantic water from the south (Figure 16) remained at high levels similar to previous years and equal to the highest values observed earlier.

Atlantic water extended relatively far to the north in the northern area. The cold water north, northeast, and east of Iceland and in the East Icelandic Current was found far offshore in 2003. Salinity in the East Icelandic Current in spring 2003 (Figure 16) was about average and temperature was well above average.

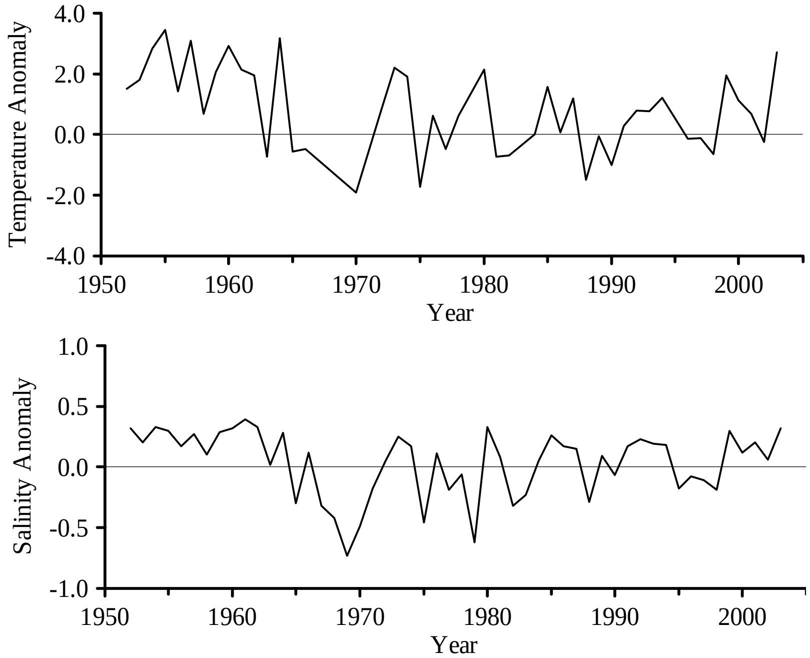

Figure 15. Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) anomalies at 50 m depth in spring at Station Si-3 in North Icelandic waters 1952–2003. Anomalies are relative to the 1971–2000 mean.

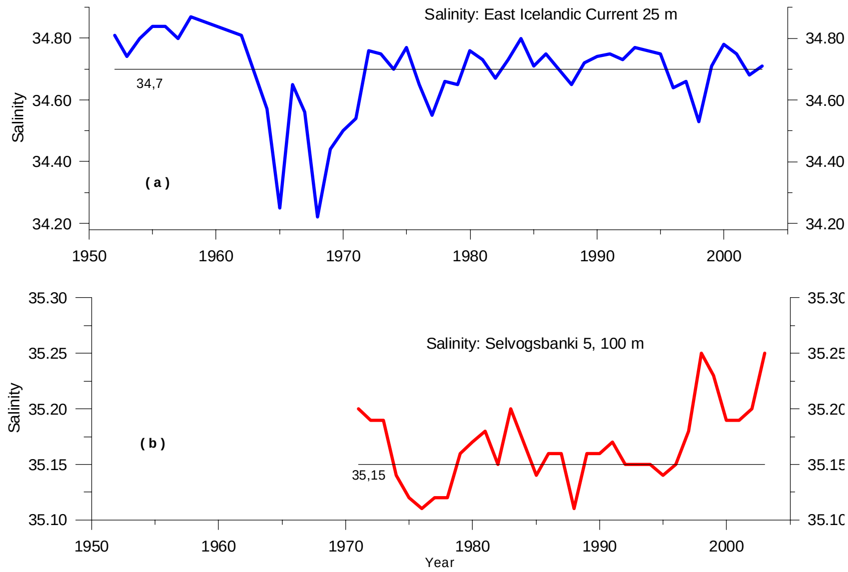

Figure 16. Area 3 – Icelandic waters. Salinity at 25-m depth in the East Iceland Current and 100-m depth at Station Sb-5.

Area 4 – Bay of Biscay and Eastern Atlantic

The Bay of Biscay is situated between the eastern part of the subpolar and subtropical North Atlantic gyres. The general circulation in the area mainly follows the subtropical anticyclonic gyre in a relatively weak manner (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 easterly winds are predominant and coastal upwelling events are frequent.

Air temperatures at Santander in 2003 were among the highest of the meteorological time-series for 1960-2003. The annual mean value (15.3ºC) was similar to values of the mid-nineties, but slightly lower than the 1989 record high value. The range of air temperatures (August–February) was 13.2ºC, the highest in the time-series. From March to September the mean anomaly of air temperatures was 1.5ºC; August 2003 presented the highest value in the monthly time-series. Precipitation was half of the mean during that period.

Sea surface temperature in summer 2003 was the warmest in the time-series (1993–2003). Values were 1ºC above the mean from June to October. The thermocline was shallow; heat stored in the upper layer was high but below the mixed layer values remained around average. The mean potential temperature in the upper 300 m presented high values in the second part of the year, but not as high as during 1997 and 1998 (Figure 17).

Salinity contours in the southern Bay of Biscay show high salinity at the beginning of winter due to the poleward current and in spring and autumn due to seasonal upwelling, but in 2003 neither of these features was evident and advection and river runoff were low. Between 1998 and 2001 evidence of a decline in salinity was found up to a depth of 300 m. In 2002 this trend was reversed, particularly during the poleward episode at the beginning of the year. The weakened poleward current, upwelling and precipitation have kept salinity values close to late 2002 values and near the average (Figure 17).

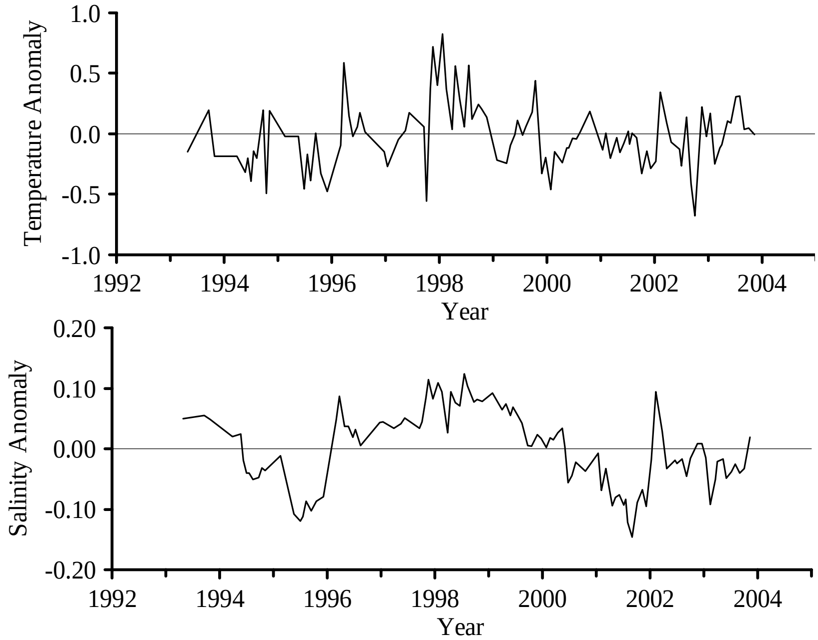

Figure 17. Area 4 – Bay of Biscay and Eastern Atlantic. (Upper panel) Potential temperature anomaly (5–300 m) at Santander station 6 (shelf-break). (Lower panel) Salinity anomaly (5–300 m) at Santander station 6. Seasonal cycle has been removed from the data.

Area 5 – Rockall Trough

The Rockall Trough is situated west of the British Isles and is 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 that 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 throughflow but allows recirculation within the basin.

2003 was another record year in the Rockall Trough with high surface temperatures and salinities continuing a rise which began in 1995 (Figure 18). Salinity values over the top 800 m were the highest on record, and corresponding temperatures were more than 0.5°C above the long-term average. Meanwhile the temperature and salinity in the deep Labrador Sea water were at a record low, possibly reflecting changes in the Labrador Sea itself some years earlier (Figure 19).

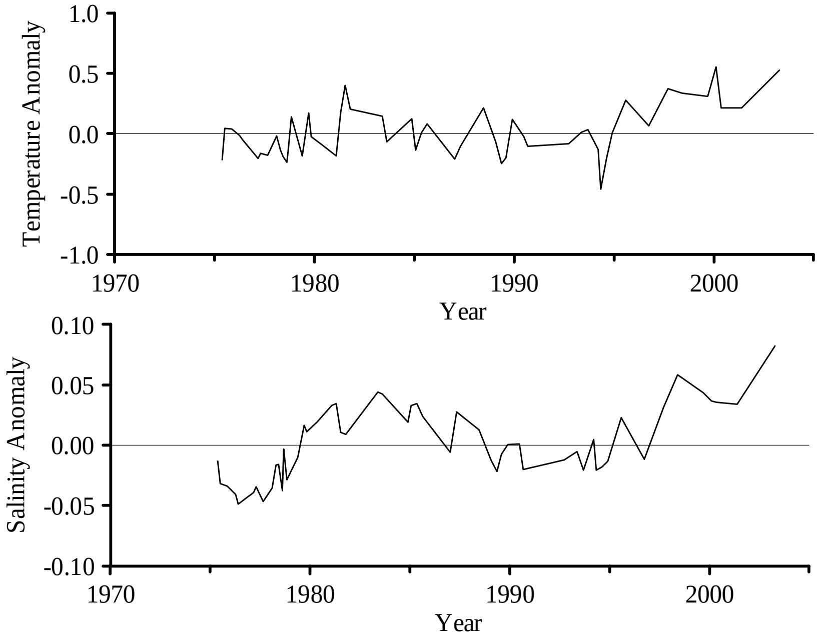

Figure 18. Area 5 – Rockall Trough temperature and salinity anomalies for the upper ocean (0–800 m) of the northern Rockall Trough. Average across section, seasonal cycle removed.

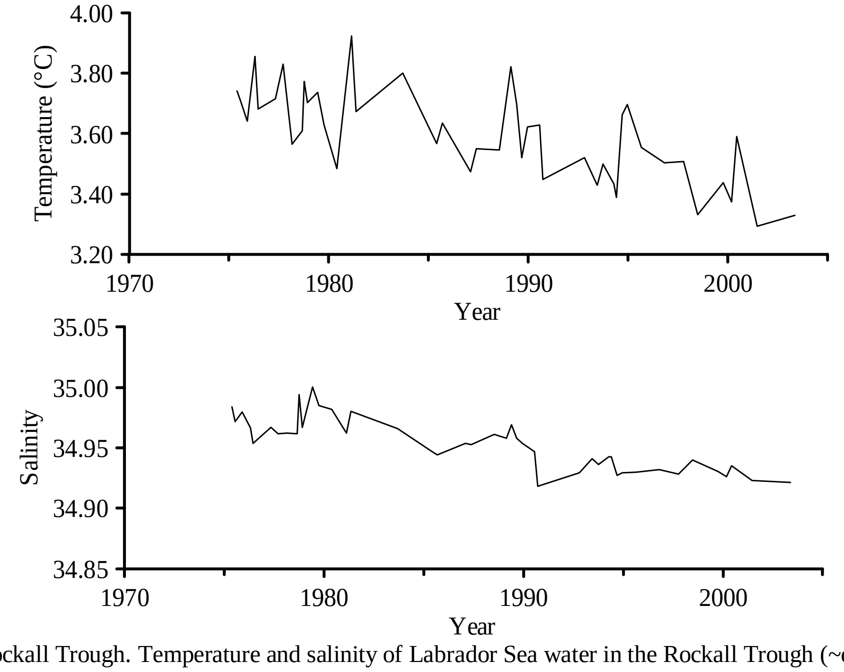

Figure 19. Area 5 – Rockall Trough. Temperature and salinity of Labrador Sea water in the Rockall Trough (~depth 1800 m).

Area 5b – North Atlantic

The A1E section between Greenland and Ireland was surveyed again in 2003 with RV Pelagia.

Nearly everywhere along this line temperature and salinity in the upper 1000 m had increased since the previous survey in 2000. In the Irminger Basin this increase was probably related to re-stratification by exchange with the surrounding cyclonic current transporting warm and saline Atlantic water (Figure 20). In the Iceland Basin the main mechanism probably was a westward shift in the position of the North Atlantic current.

The distribution of hydrographic properties at intermediate depths reflected the ongoing north-eastward advection of cold Labrador Sea Water (LSW) produced around 1990 as well as the decay of the cold Labrador Sea Water core due to mixing (Figure 21), while the Iceland-Scotland overflow water in the Iceland Basin hardly showed any changes. The North East Atlantic deep water and Denmark Strait overflow water in the Irminger Basin showed changes in their hydrographic properties that may be attributed to mixing with the overlying LSW (Figure 22).

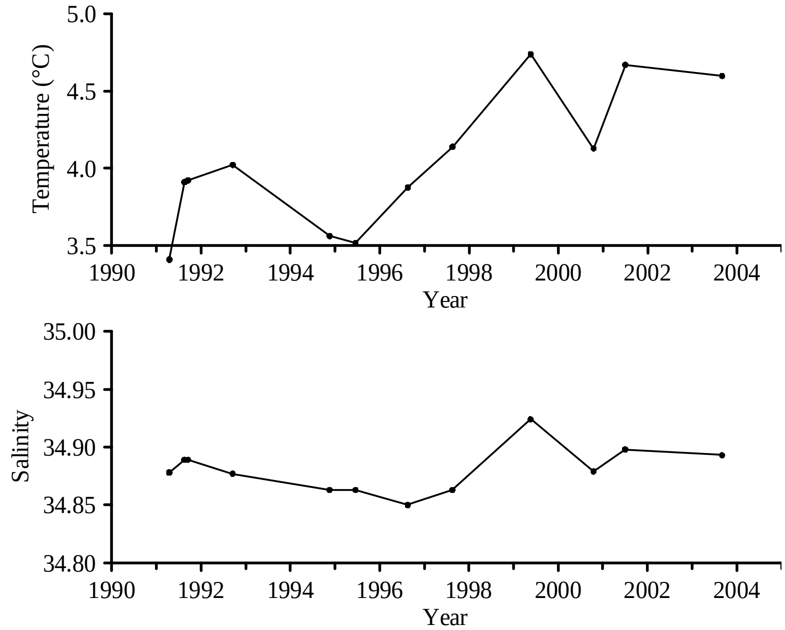

Figure 20. Area 5b – Northern North Atlantic. Temperature (upper panel) and salinity (lower panel) of Sub-Polar mode water (averaged over 200–400 m) in the Central Irminger Sea.

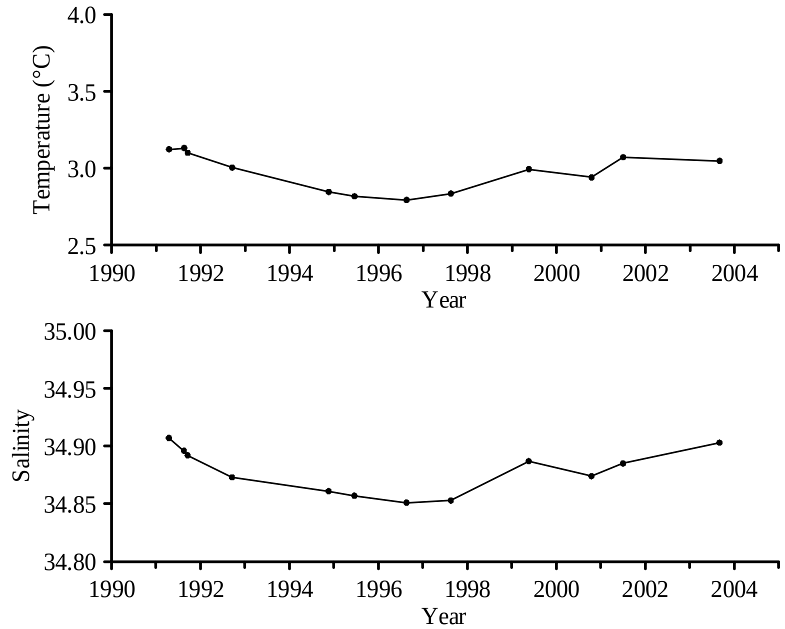

Figure 21. Area 5b – Northern North Atlantic. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (averaged over 1600–2000 m) in the Central Irminger Sea.

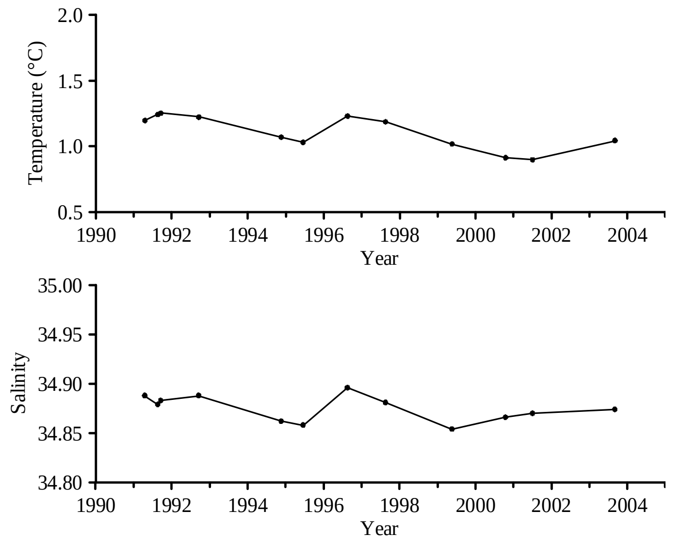

Figure 22. Area 5b – Northern North Atlantic. Temperature (upper panel) and salinity (lower panel) of Denmark Strait overflow water on the East Greenland Slope.

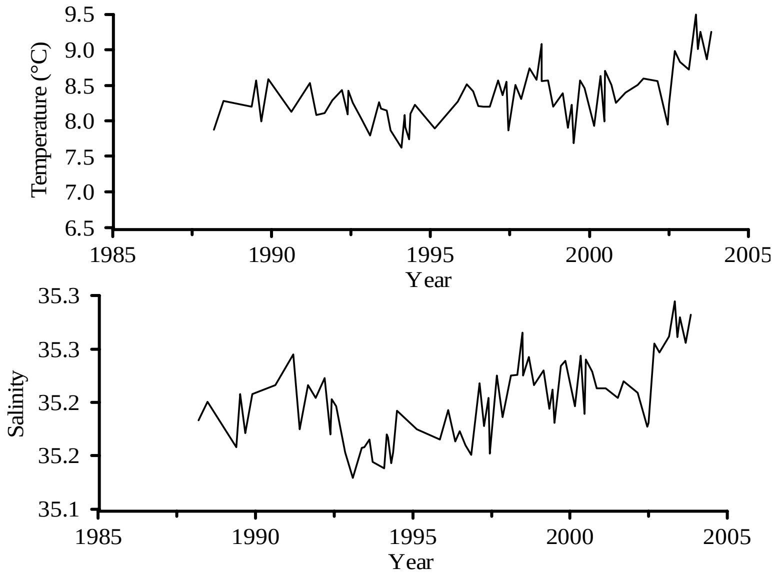

Figure 23. Area 6 – Faroe Bank Channel. Temperature and salinity from CTD profiles in the Faroe Bank Channel. The curves show averages over the 100–300 m depth layer at two standard stations in the channel. The typical seasonal variation has been removed from the curves.

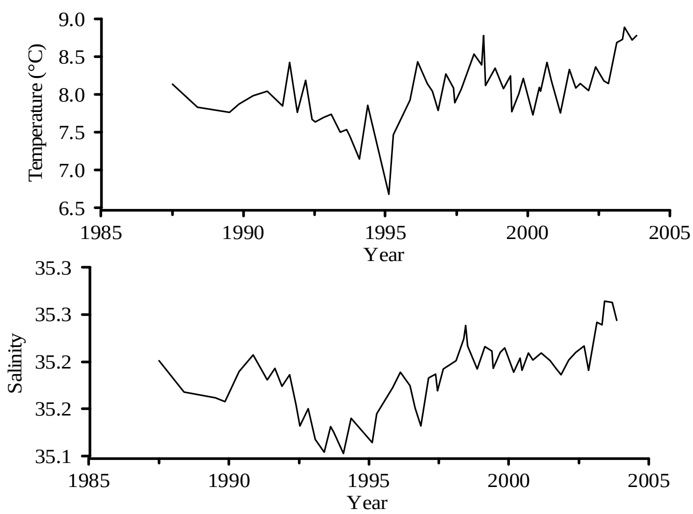

Figure 24. Area 6 – Faroe Current. Temperature and salinity in the core of the Faroe Current (defined as having maximum salinity averaged over a 50-m depth layer). The typical seasonal variation has been removed from the curves.

Area 6 – Faroe Bank Channel and Faroe Current

The North Atlantic Current sends one branch towards the Nordic Seas that crosses the Greenland-Scotland Ridge on both sides of the Faroes. The water mass transported by this flow is traditionally termed Modified North Atlantic Water (MNAW). Its characteristics can be monitored in the upper layers of the Faroe Bank Channel (Figure 23), before it crosses the ridge.

A part of the MNAW 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 (Figure 24) are similar to those in the Faroe Bank Channel. In both areas, the waters were relatively cold and fresh in the early 1990s, but returned to warmer and more saline conditions that were maintained at fairly constant levels into the new millennium. By the end of 2002 and throughout 2003, conditions became unusually warm and saline.

Area 7 – Faroe Shetland Channel

The continental Slope Current flows along the edge of the north-west 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.

Surface waters in the Faroe Shetland Channel continued the general warming trend observed over the last 20 years. Modified Atlantic Waters in the Faroe Shetland Channel were warmer and saltier in 2003 than at any period during the last 50 years (Figures 25 and 26).

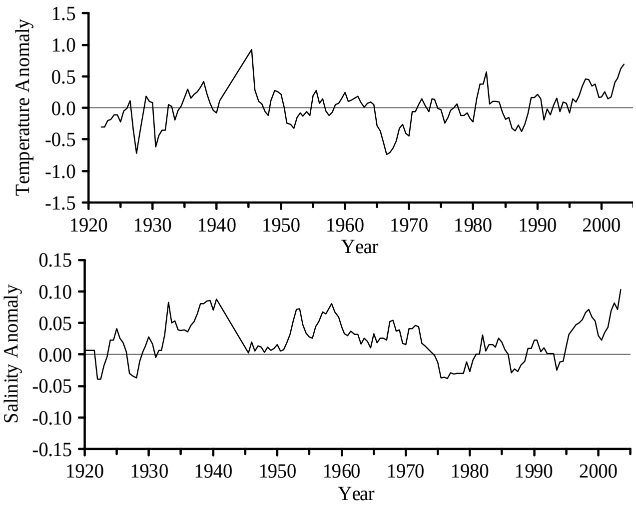

Figure 25. Area 7 – Faroe Shetland Channel. Temperature and salinity anomalies in the North Atlantic Water (NAW) in the Slope Current.

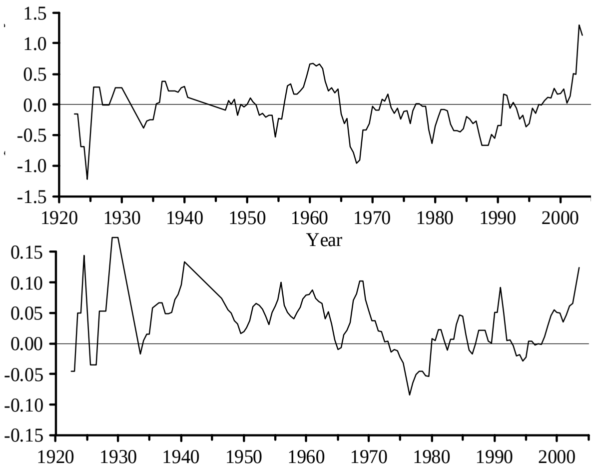

Figure 26. Area 7 – Faroe Shetland Channel. Temperature and salinity anomalies in the Modified Atlantic Water (MNA) entering the Faroe Shetland Channel from the north after circulating around Faroe.

Areas 8 and 9 – Northern and Southern North Sea

North Sea oceanographic conditions are determined by the inflow of saline Atlantic water through the northern entrances and to a lesser degree through the English Channel. The Atlantic water mixes with the river run-off mainly and with lower-salinity Baltic outflow along the Norwegian coast. The temperature of the North Sea is controlled by local solar heating and heat exchange with the atmosphere.

The salinity and the temperature of the North Sea generally reflect the influence of the NAO on the movement of Atlantic water into the North Sea and the ocean-atmosphere heat exchange. A 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.

During the summer of 2003 extremely warm conditions were observed all over the North Sea (Figures 27, 28, 29, and 30). Area-averaged sea surface temperatures in the North Sea exceeded 18°C during August 2003, the highest values observed since 1968 (Figure 30).

Warm conditions were also evident throughout the water column. The heat content of the North Sea measured along the 58°N section was the highest observed during the 1998–2003.

During 2003 the primary production period in the North Sea was much longer than normal.

In most areas of the North Sea surface salinities showed a similar trend, increasing to near-normal values after the low salinities observed during 2001/2002. This trend is clear in the salinity time-series at Helgoland, which is strongly influenced by freshwater runoff (Figure 31), as well as data recorded in more northerly areas (Figures 27, 28, and 29).

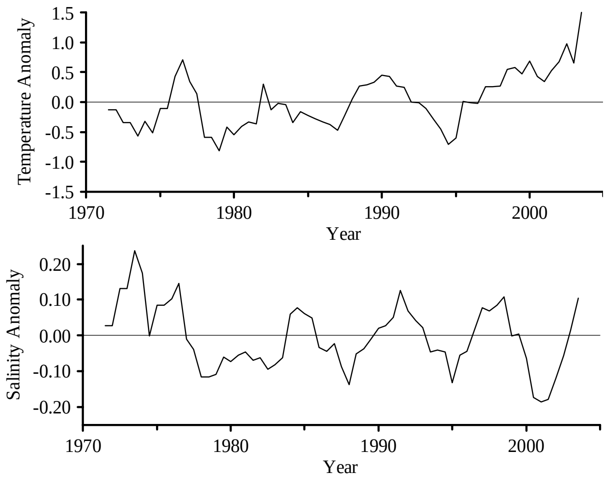

Figure 27. Areas 8 and 9 – Northern and Southern North Sea. Temperature and salinity anomalies in the Fair Isle Current (FIC) entering the North Sea from the North Atlantic.

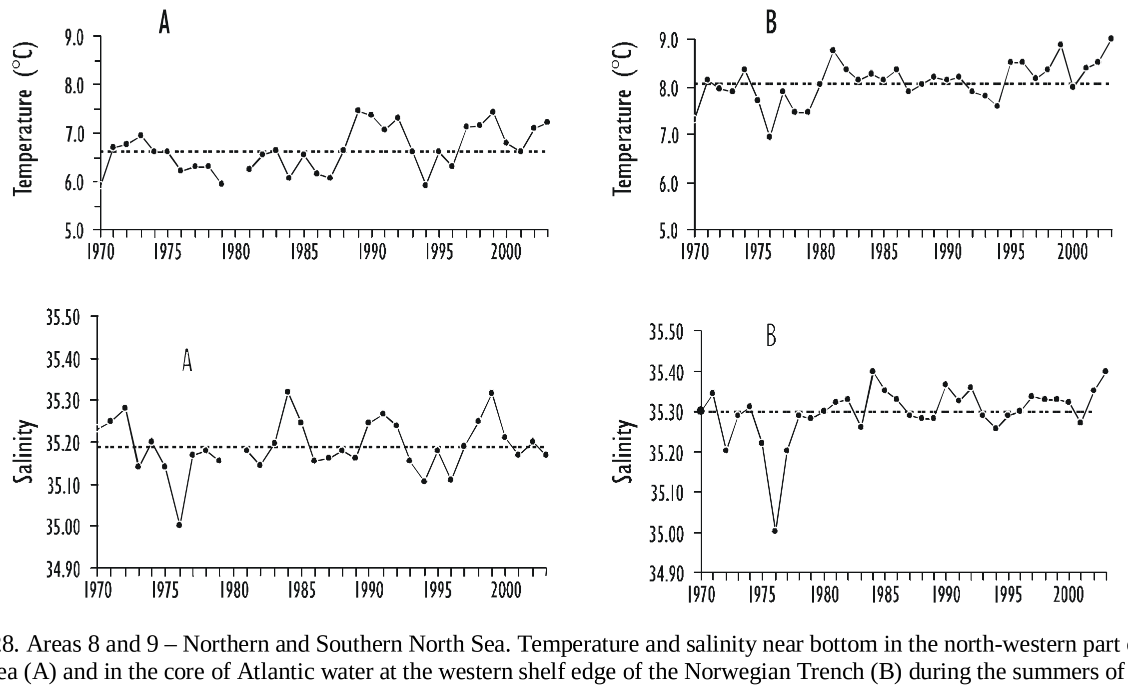

Figure 28. Areas 8 and 9 – Northern and Southern North Sea. Temperature and salinity near bottom in the north-western part of the North Sea (A) and in the core of Atlantic water at the western shelf edge of the Norwegian Trench (B) during the summers of 1970–2003.

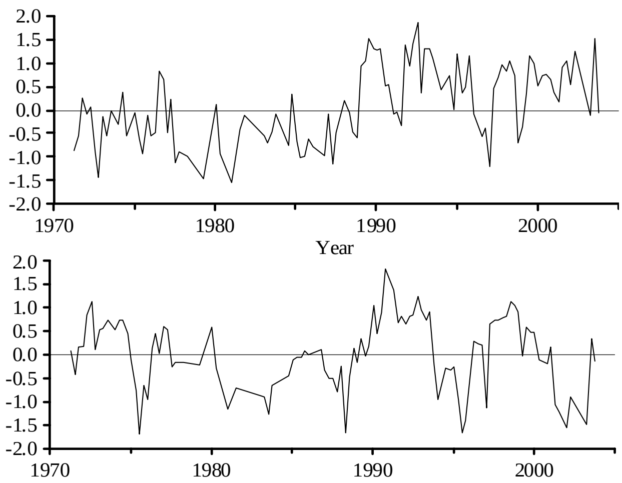

Figure 29. Areas 8 and 9 – Northern and Southern North Sea. Time-series of normalised sea surface temperature and salinity anomaly relative to the period 1971–2000 measured along 52°N by a regular ferry at six standard stations. The time-series in black shows the seasonal section average (DJF, MAM, JJA, SON) of the normalised variable.

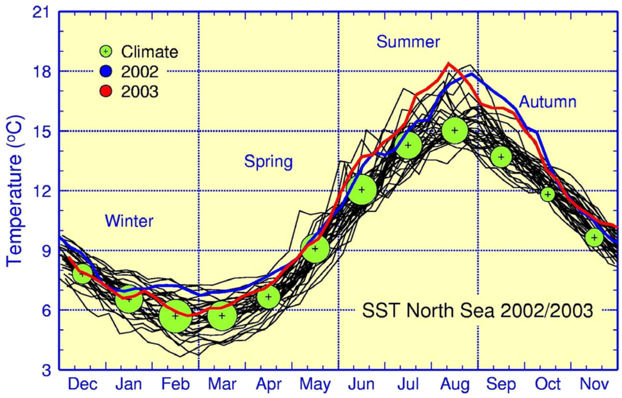

Figure 30. Areas 8 and 9 – Northern and Southern North Sea. North Sea area averaged SST annual cycle, monthly means based on operational weekly North Sea SST maps. Climatology 1971–1993 green dots; blue line 2002, red line 2003; black thin lines individual years.

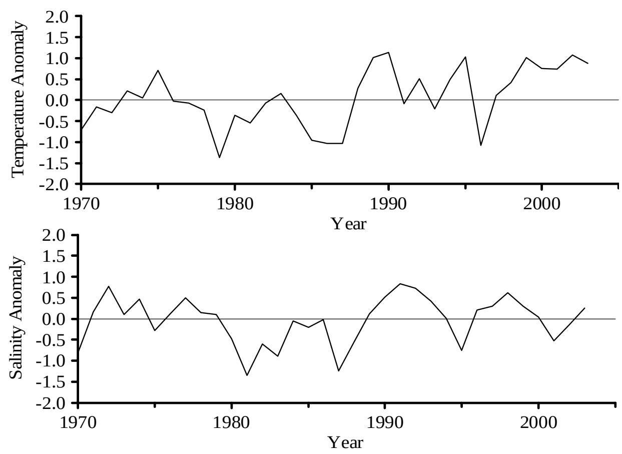

Figure 31. Areas 8 and 9 – Northern and Southern North Sea. Annual mean surface temperature and salinity at Station Helgoland Roads.

Area 9b – Skagerrak, Kattegat, and the Baltic

The seas around Sweden are distinguished by large salinity variations. In Skagerrak water masses from different parts of the North Sea are found. The Kattegat is a transition area between the Baltic Sea 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 be stagnant for long periods in the inner basins. In the relatively shallow area south of Sweden small inflows pass fairly quickly causing large variations, and the conditions in the deeper parts are here 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 ice in winter 2002/2003 was classified as severe with the maximum ice extent occurring on 3 March 2003. The Gulf of Bothnia, the Gulf of Finland and the northeastern parts of the Baltic Proper were covered with ice (Figure 32). The cold winter conditions were manifested in most sea surface temperature records with values below average during winter and spring. The time-series from station BY15 (east of Gotland) is shown in Figure 33. Higher-than-average sea surface temperatures were found at most stations in August. The trend of decreasing values of the surface salinity in the Baltic Proper continued in 2003 (Figure 34). An inflow of saline water into the Baltic took place in January and the effect was clearly seen in salinity sections.

After nearly a decade without a major inflow (since 1993), between August 2002 and July 2003 the Baltic Sea experienced two small and one medium inflow of highly saline water from Kattegat. All of them were quite unusual and different than previously observed. The summer inflows, both of unusual timing because most of the inflows occur in autumn or winter, brought the warm waters to the Baltic Sea. They caused a temperature jump in the deep layer up to 10–12°C, values not observed before there. The medium size inflow of about 200 km^3 took place in January 2003, in the typical season of inflows, but it brought exceptionally cold water with temperatures below 1°C, much lower than usually seen in the inflow origin waters. The influence of summer inflows on the Baltic Sea regime was limited to the intermediate and bottom layers of its western and southern parts. The January inflow introduced salty, cold and well-oxygenated water into all main basins of the Baltic Sea, including the Gotland Deep, thus improving the living conditions there (Figure 35).

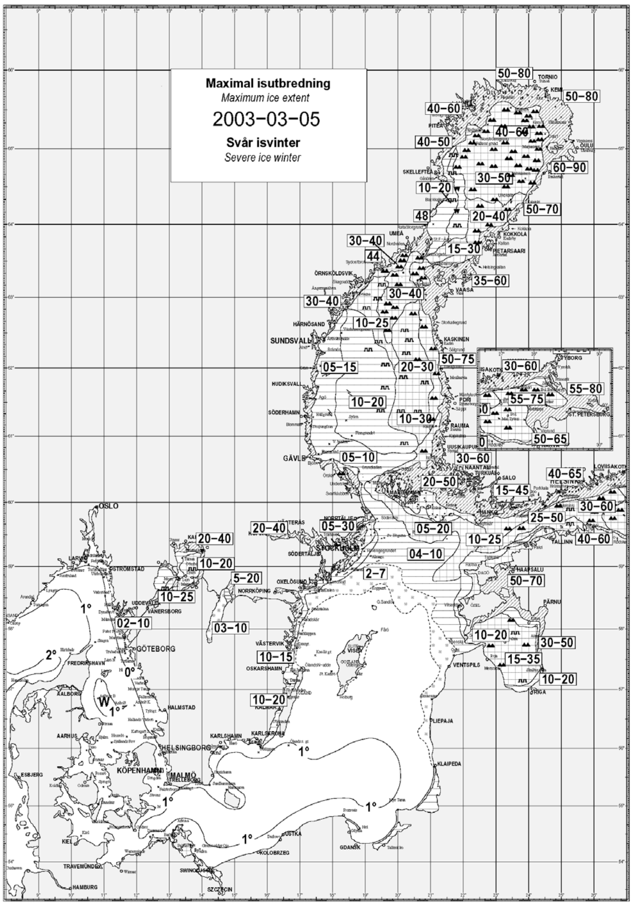

Figure 32. Area 9b –Skagerrak, Kattegat and the Baltic. The maximum ice extent in the Baltic during the winter 2001/2002. The map was constructed by SMHI.

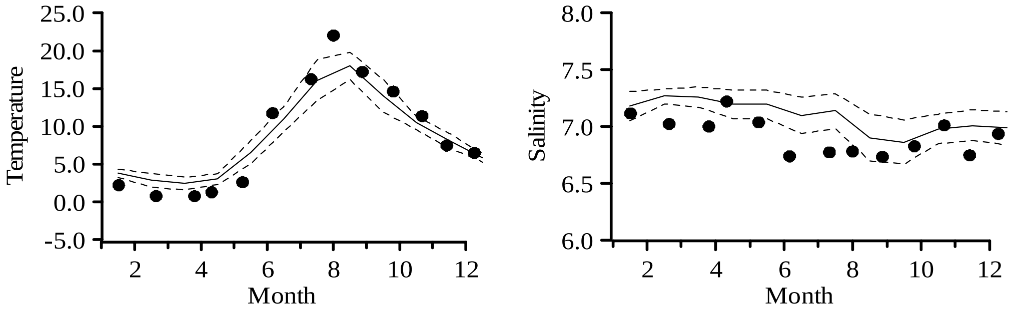

Figure 33. Area 9b – Skagerrak, Kattegat, and the Baltic. Annual cycles of surface temperature and salinity at station BY15 in the southern part of Skagerrak. The data were collected by R/V Argos within the Swedish National Monitoring Programme. Dots indicate data for 2003, the solid line shows the mean monthly values for the period 1990–1999, and the dashed lines indicate the standard deviation.

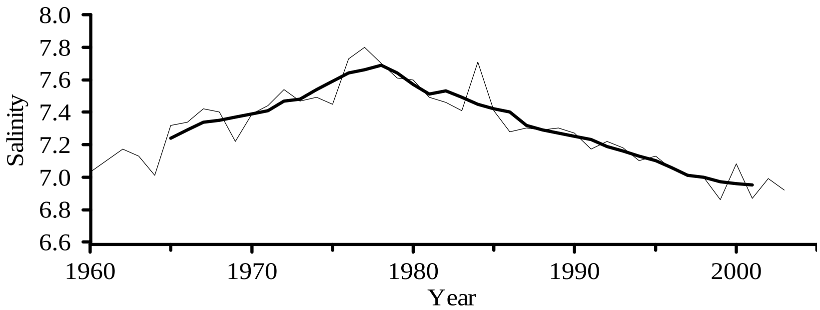

Figure 34. Area 9b – Skagerrak, Kattegat, and the Baltic. The surface salinity at station BY15 (east of Gotland) in the Baltic Proper (bold line is a five-year running mean).

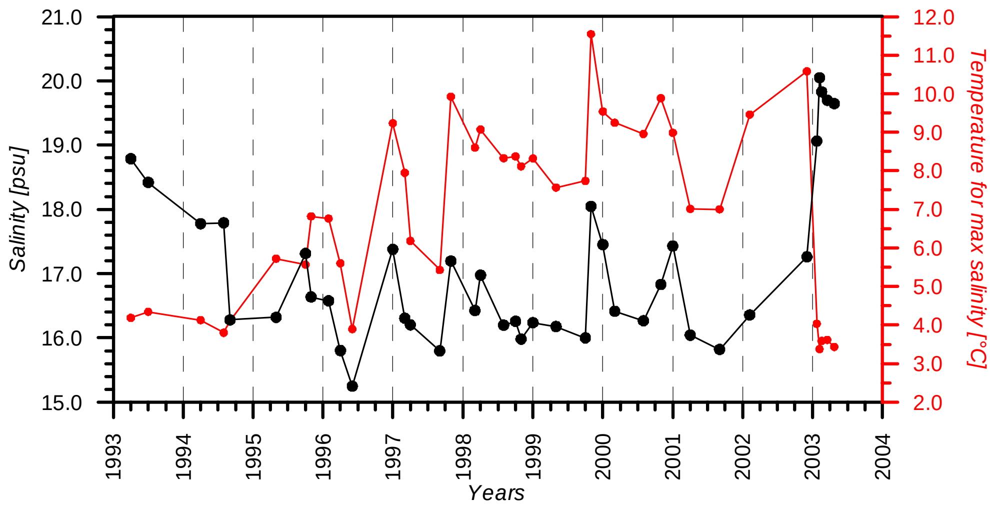

Figure 35. Area 9b – Skagerrak, Kattegat, and the Baltic. Maximum salinity of the bottom water in the Bornholm Basin (the Baltic Proper) and its temperature in 1993–2003.

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 waters enter 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 flowing 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 system of currents are of decisive importance for the distribution and structure of the water masses in the Norwegian Sea.

Waters over the eastern slope of the Norwegian Sea have warmed since 1996. Figure 36 shows the development in temperature and salinity in three different sections from south to north in the Norwegian Sea. During the last seven years the temperature and salinity in the Svinøy section have been above the long-term mean while they were about average in the Gimsøy and Sørkapp sections. In 2003 the salinity in the Svinøy section had the highest value in the time-series, about 0.08 above normal. The temperature was the next highest in the time-series, about 0.9°C above normal. Only in 2002 was the temperature higher.

The area of Atlantic water (S>35.0) in the Svinøy section and the mean temperature within the water mass show considerable variations. The distribution area of Atlantic water has decreased since the beginning of the 1980s, while the temperature has shown a steady increase. Since 1978 the temperature of Atlantic water has increased by about 0.6°C.

The sea surface temperature in 2003 was higher than normal over most of the Norwegian Sea. At Ocean Weather Station "M" sea surface temperatures reached record high values. The thickness of the intermediate water mass is still increasing but the temperature increase at 2000-m depth has stopped.

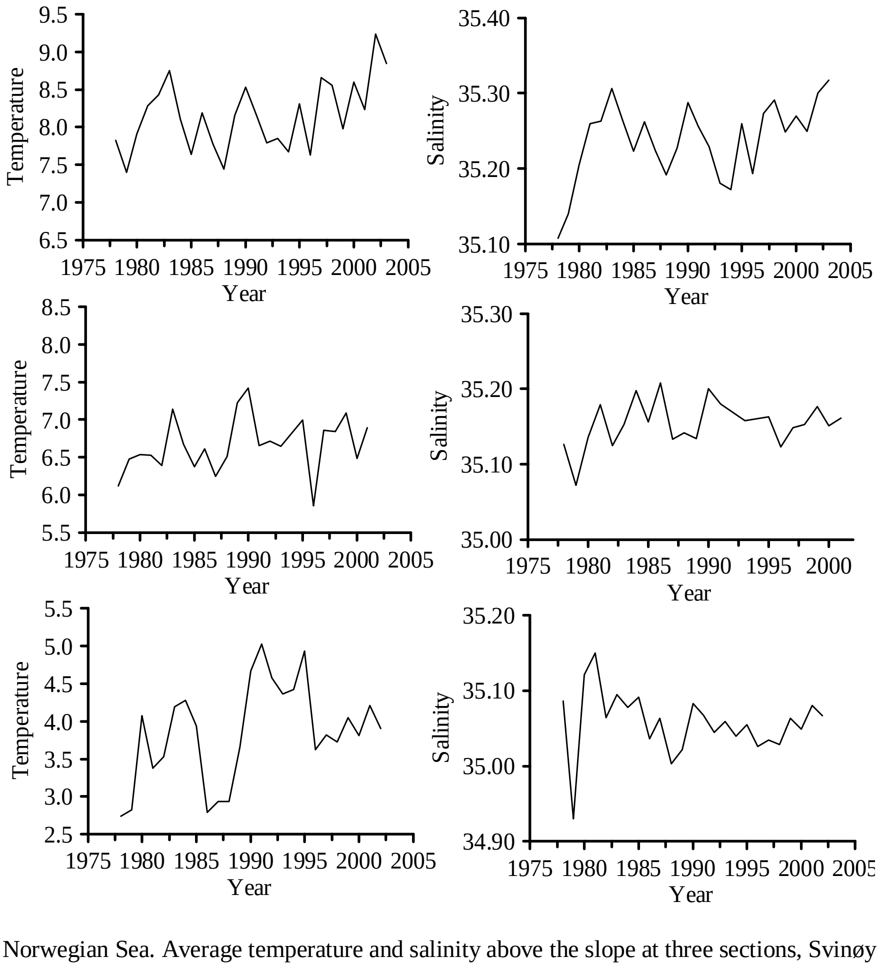

Figure 36. Area 10 – Norwegian Sea. Average temperature and salinity above the slope at three sections, Svinøy (approx. 63°N – upper figures), Gimsøy (approx. 69°N – central figures) and Sørkapp (approx. 76°N – lower figures), representing the southern, central, and northern Norwegian Sea.

Area 11 – Barents Sea

The Barents Sea is a shelf sea, receiving an inflow of warm Atlantic water from the west. The inflow shows 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. The first half of 2003 had higher inflow than average for the observing period.

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 37), while the temperature in the eastern areas stayed below the average during 1998 (Figure 38). From the beginning of 1999 there was a rapid temperature increase in the western Barents Sea, that also spread to the eastern part of the Barents Sea. Since then, the temperature has stayed above average.

In January and February 2003 the temperature was close to the long-term average in the whole Barents Sea. In March the temperature increased rapidly to 0.5°C above the long-term mean in the entire southern Barents Sea, and the temperature remained approximately 0.5°C above average. At the start of 2004 the temperature was higher than normal in both the western (0.3–0.7°C) and eastern (0.5–1.0°C) Barents Sea. In the western Barents Sea the salinity was also relatively high most of the year. The mean annual heat content in the southern Barents Sea in 2004 is expected to be somewhat higher than the long-term mean, especially during the first half of the year.

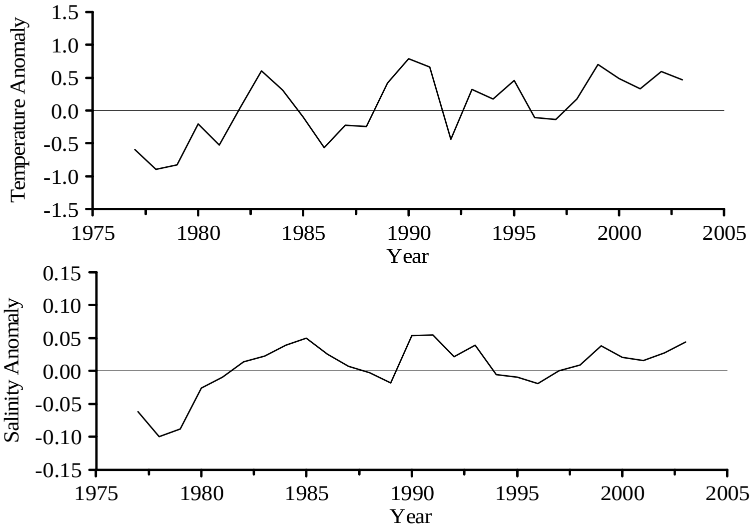

Figure 37. Area 11 – Barents Sea. Temperature anomalies (upper panel) and salinity anomalies (lower panel) in the Fugløya – Bear Island section.

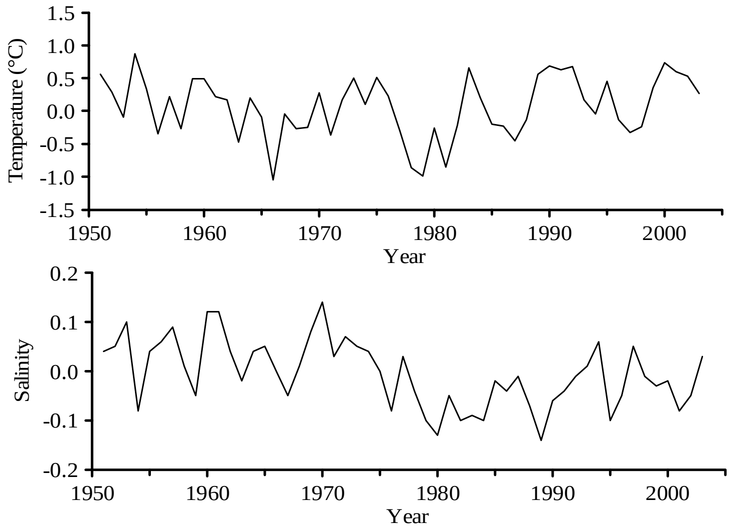

Figure 38. Area 11 – Barents Sea. Temperature and salinity anomalies in the Kola section (0–200 m).

Area 12 - Greenland Sea

The Greenland Sea and its northern border, Fram Strait, form the main pathway for Atlantic water entering the Arctic Ocean. Warm and salty Atlantic Water is carried northward by the West Spitsbergen Current. Both volume and heat fluxes show strong seasonal and interannual variations. Part of the Atlantic water re-circulates within Fram Strait and returns southward. Polar water from the Arctic Ocean is transferred south by the East Greenland Current and affects the water mass modification in the Nordic Seas. Bottom water renewal by deep convection also influences hydrographic conditions in the Greenland Sea.

Since the late 1980s no bottom water renewal has taken place. The deepwater properties changed towards higher temperatures and salinities. A doming structure in the Greenland Gyre was replaced by a two-layer water mass arrangement with a density step located presently at about 1700 m. In 2003, bottom water temperatures continued to increase in the Greenland Sea, but there was no further deepening of the temperature maximum. The winter convection reached only a few hundred meters except for in small-scale eddies.

In the Greenland Sea, the mean values of Atlantic Water (AW) temperature and salinity during 2003 were significantly lower than the previous year, which saw extremely high values. In 2003, AW temperature in the Greenland Sea was the lowest observed since 1989, while mean salinity was close to the long-term average. This can be partly attributed to seasonal variations (spring conditions were measured in 2003). The mean temperature and salinity in the Return Atlantic Water (RAW) has continually decreased for the last three years. Both values were below the long-term average in 2003.

In the Fram Strait, three characteristic areas can be distinguished in relation to the main flows: the West Spitsbergen Current (WSC), the Return Atlantic Current (RAC), and Polar water in the East Greenland Current (EGC). The lower boundary of the Atlantic water was slightly shallower than in 2002, but at the same time AW spread much farther to the west in the recirculation area, reaching nearly 4°W. Mean salinities observed in the WSC were similar to values observed in 2002, while the mean temperature in the surface layer decreased slightly. Both mean temperature and salinity in the lower layer remained higher than the long-term average. A significant increase of mean temperature and salinity was found in the Return Atlantic Current in both layers. The southward flow of Polar water in EGC was more confined to the west as compared with 2002. In 2003 the mean salinity in the EGC increased significantly from extremely low values observed in 2002, nearly reaching the high values of 2001. A drop of temperature in the upper layer reflects the severe ice conditions in the western part of Fram Strait. However, in the deeper layer of the EGC the mean temperature rose and was close to the long-term average.

Hydrographic properties of the Atlantic Water (T>2 C and S>34.92) reveal a clear trend over the past seven years. Although the cross-sectional area occupied by AW varied strongly between years, the mean temperature and salinity increased from 1997 to 2002. The 2002 AW with the highest mean temperature and salinity occupied a relatively small area, and the 2003 decrease in mean temperature and salinity was accompanied by a larger spatial extent of the AW layer.

The 2003 observations show greater component of Atlantic Water returning to the west as Return Atlantic Water and a smaller volume transport to the Arctic Ocean through both the Fram Strait and the Barents Sea Opening, compared with conditions during summer 2002.

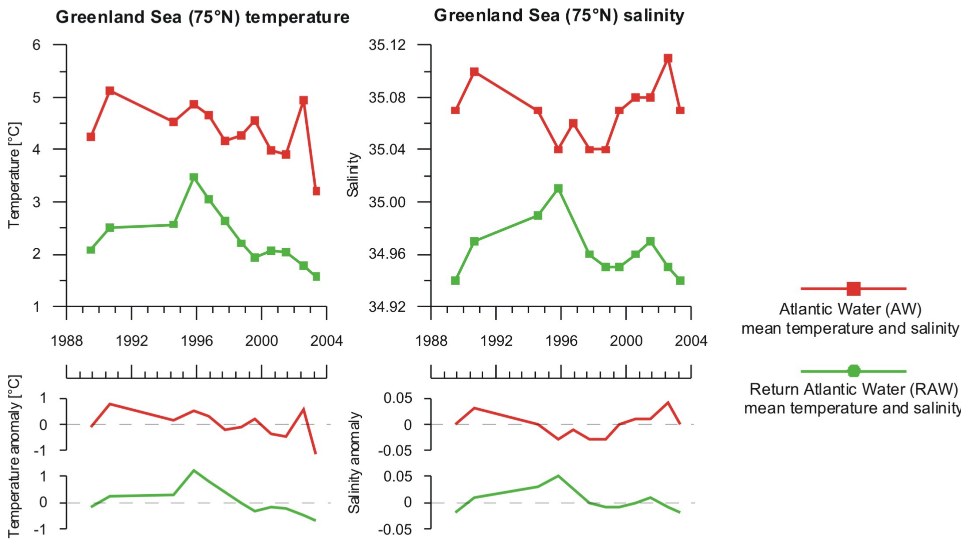

Figure 39. Area 12 – Greenland Sea. Properties of the Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea, section at 75°N. Anomalies from the long-term averages are shown in the bottom plots. The properties of the Atlantic Water (AW) are given as temperature and salinity averages over 50 to 150 m for stations between 10 and 13°E. The Return Atlantic Water (RAW) is characterised by the temperature and salinity maximum below 50 m averaged over three stations west of 11.5°W.

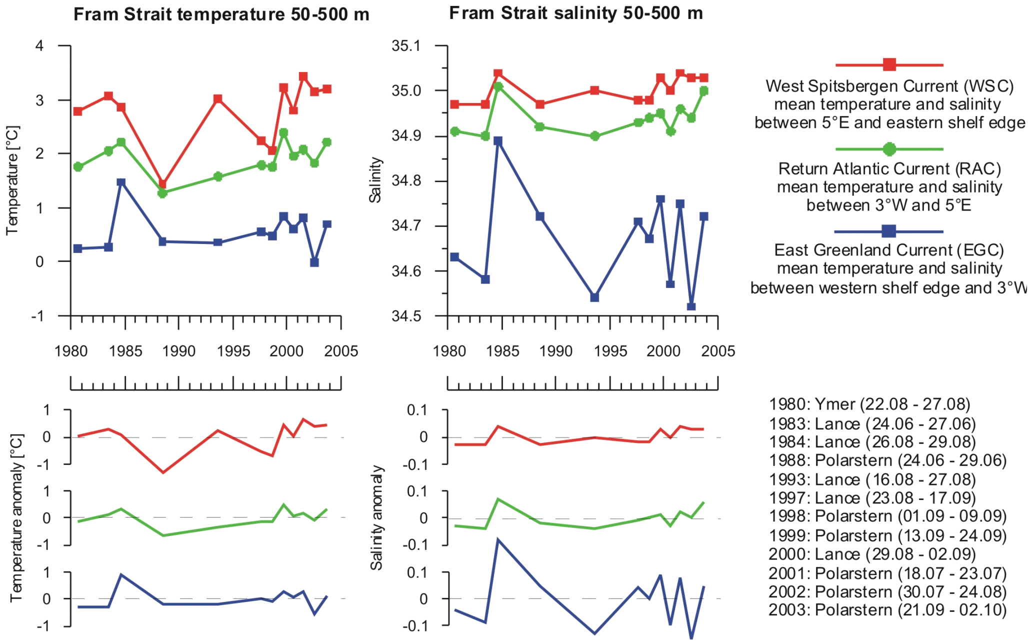

Figure 40. Area 12 – Greenland Sea. The variations of the mean temperatures and salinities in Fram Strait (section at 78°50'N) in the West Spitsbergen Current (WSC) between the shelf edge and 5°E, Return Atlantic Current (RAW) between 3°W and 5°E and Polar water in the East Greenland Current (EGC) between 3°W and the Greenland Shelf for the layer 50–500 m. Anomalies from the long-term averages are shown in the bottom plots.

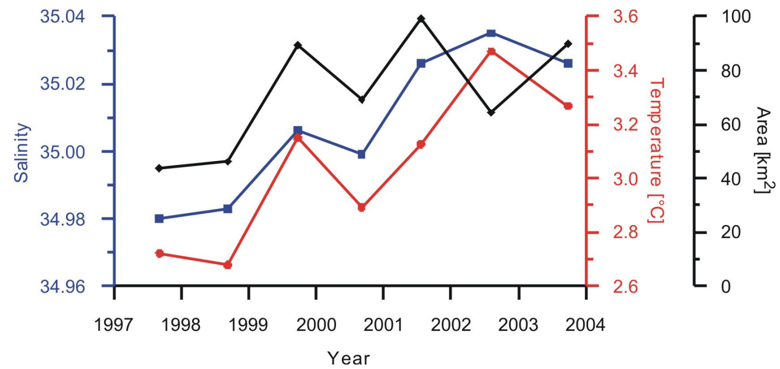

Figure 41. Area 12 – Greenland Sea. Mean properties of Atlantic water (T > 2°C, S > 34.92) in the Fram Strait (78°50'N) in 1997–2003.

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