ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

ICES COOPERATIVE RESEARCH REPORT
RAPPORT DES RECHERCHES COLLECTIVES

NO. 289 SPECIAL ISSUE
SEPTEMBER 2007

ICES Report on Ocean Climate 2006

Prepared by the Working Group on Oceanic Hydrography

Sarah L. Hughes and N. Penny Holliday, Editors

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:
Hughes, S. L., and Holliday, N. P. (Eds). 2007. ICES Report on Ocean Climate 2006. ICES Cooperative Research Report No. 289. 55 pp.
https://doi.org/10.17895/ices.pub.5129

ISBN [redacted] 978-87-7482-347-6
ISSN 2707-7144

TABLE OF CONTENTS

1 Introduction **4**
1.1 ICES Report on Ocean Climate 2006 highlights 4
2 North Atlantic upper ocean temperature overview **5**
3 North Atlantic upper ocean salinity overview **6**
4 Summary of sustained observations **7**
5 The North Atlantic atmosphere 13
5.1 North Atlantic Oscillation index 13
5.2 North Atlantic sea level pressure 14
5.3 North Atlantic surface air temperature 15
6 Detailed area descriptions **16**
6.1 Introduction 16
6.2 Area 1 – West Greenland 16
6.3 Area 2 – Northwest Atlantic: Scotian Shelf and the Newfoundland and Labrador Shelf 19
6.4 Area 2b – Labrador Sea 24
6.5 Area 2c – Mid-Atlantic Bight 26
6.6 Area 3 – Icelandic waters 29
6.7 Area 4 – Bay of Biscay and eastern Atlantic 32
6.8 Area 5 – Rockall Trough 24
6.9 Area 5b – Irminger Sea 36
6.10 Area 6 – Faroe Bank Channel and Faroe Current 39
6.11 Area 7 – Faroe Shetland Channel 41
6.12 Areas 8 and 9 – northern and southern North Sea 43
6.13 Area 9b – Skagerrak, Kattegat, and the Baltic 47
6.14 Area 10 – Norwegian Sea 50
6.15 Area 11 – Barents Sea 52
6.16 Area 12 – Greenland Sea and Fram Strait 54
6.17 Nordic Seas Deep Waters 56
Contact information **59**

1. INTRODUCTION

This report describes the present (2006) status of sea temperature and salinity in the ICES region of the North Atlantic and Nordic Seas, as well as trends observed. Some additional datasets are provided, including those on sea level pressure, air temperature, and ice cover. Although the focus is on the variations in the upper ocean (the top 1000 m), information about changes in the deeper layers of the ocean is also included in specific regions of interest.

A new edition of the report is published annually in the ICES Cooperative Research Report series.

The North Atlantic region is unusual in having a relatively large number of locations at which oceanographic data have been collected for several years or even decades. The longest records go back more than a century. In this report, we provide the very latest information from places where the ocean is currently being measured regularly. Although the North Atlantic is rich in measurements compared with other parts of the global ocean, there is still only a thin scattering of long records of deep ocean measurements. In the first part of the report, we draw together the sparse information and give the best possible overview of the region. Numerical models using real ocean measurements to simulate variations over time are continually being improved. In future editions, we hope to develop this part of the report to present the new information provided by the combination of models and data.

The data presented here represent an accumulation of knowledge collected by numerous individuals and institutions through decades of observations. It would be impossible to list them all, but at the end of the report we provide a list of contacts for each dataset, including e-mail addresses for the individuals who provided the information, and the data centres at which the full archives of data are held.

1.1 ICES Report on Ocean Climate 2006 highlights

The North Atlantic Ocean in 2006

The upper layers of the North Atlantic and Nordic Seas were warmer and more saline in 2006 than the long-term average. The largest anomalies were observed at high latitudes; the highest temperature in 100 years was recorded at the Kola Section in the Barents Sea.

The warm surface anomaly located in the Norwegian Sea and Barents Sea in 2005 moved into the West Spitsbergen Current and Fram Strait.

The North Sea, Baltic Sea, and Bay of Biscay had a cold winter and low sea surface temperatures, followed by an unusually warm summer and autumn, and correspondingly high sea surface temperatures.

The trend in the past decade (1996–2006) has been of warming and increasing salinity in the upper ocean.

The North Atlantic atmosphere in winter 2005/2006

The Iceland Low and the Azores High were both weaker than normal, and the centre of the Iceland Low was displaced towards the southwest to the entrance to the Labrador Sea.

The mean mid-latitude winds were weaker than normal, and the storm track was displaced.

The eastern North Atlantic and Nordic Seas winter surface air temperatures were near normal, but over much of the central and western North Atlantic surface air temperatures were more than 1°C warmer than normal.

2. NORTH ATLANTIC UPPER OCEAN TEMPERATURE OVERVIEW

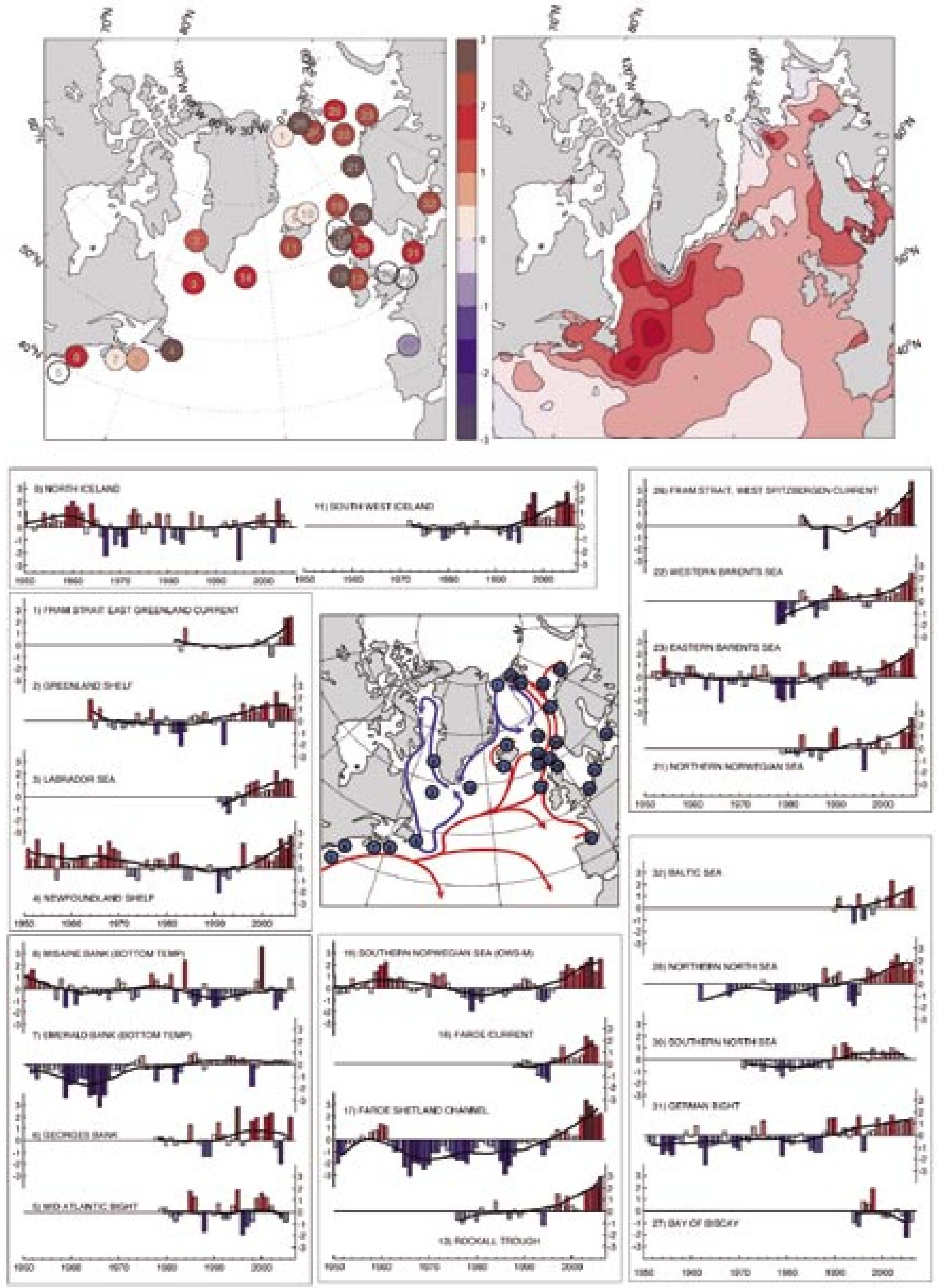


__Figure 1.__ Overview of upper ocean temperature anomalies from the long-term mean across the North Atlantic. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations above normal). The maps show conditions in 2006 (colour intervals 0.5, reds are positive/warm and blues are negative/cool). See Figure 3 for a larger version of the top map.

ICES Cooperative Research Report No. 289

3. North Atlantic upper ocean salinity overview

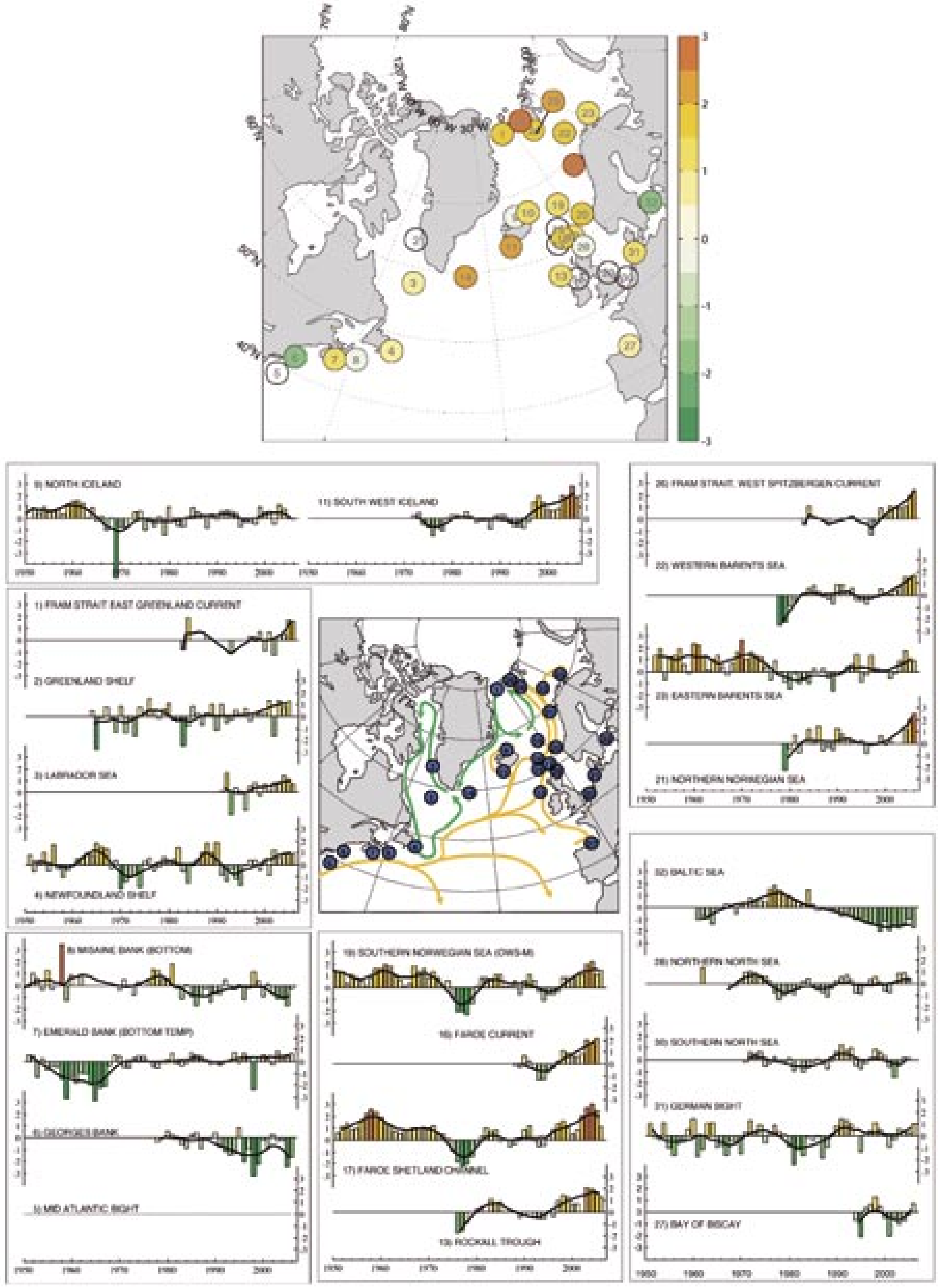


__Figure 2.__ Overview of upper ocean salinity anomalies from the long-term mean across the North Atlantic. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations above normal). The maps show conditions in 2006 (colour intervals of 0.5, oranges are positive/saline, green are negative/fresh); the curves show selected time-series. See Figure 3 for a larger version of the top map. Note that the colour scale is opposite to that shown in the previous edition of this report (ICES Cooperative Research Report No. 280).

4. Summary of sustained observations

This part of the report summarizes the sustained observations collected on oceanographic sections and stations, repeated annually or more frequently. The time-series have been extracted from larger datasets as indicators of the conditions in a particular area. Further details of each region are given in Section 6 of this report. Where appropriate, data are presented as anomalies to demonstrate how the values compare with the average or "normal" conditions (usually the long-term mean 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.

In places, the seasonal cycle has been removed from a dataset, either by calculating the average seasonal cycle during the period 1971–2000 or by drawing on other sources such as regional climatological datasets. Smoothed versions of most time-series are included, using a Loess smoother, a locally weighted regression with a two- or five-year window.

In the summary tables and figures, normalized anomalies have been presented to allow comparison of trends in the data from different regions (Figures 1–3 and Table 1). The anomalies have been normalized by dividing the values by the standard deviation of the data during the period 1971–2000. A value of +2 thus represents data (temperature or salinity) at 2 standard deviations higher than normal.

Sea surface temperatures across the whole North Atlantic can also be obtained from a combined satellite and *in situ* gridded dataset. Figure 4 shows the annual and seasonal sea surface temperature anomaly for 2005 extracted from the Optimum Interpolation SSTv2 dataset, provided by the NOAA-CIRES Climate Diagnostics Center in the USA. In high latitudes, where *in situ* data are sparse and satellite data are hindered by cloud cover, the data may be less reliable. Regions with ice cover for >50% of the averaging period are left blank.

The annual pattern of sea surface temperature anomalies for 2006 matches very closely that from the in situ data. There is a large band of positive anomalies stretching across both sides of the North Atlantic Ocean.

"SUSTAINED OBSERVATIONS" OR "TIME-SERIES" ARE REGULAR MEASUREMENTS OF OCEAN TEMPERATURE AND SALINITY MADE OVER A LONG PERIOD (10–100 YEARS). MOST MEASUREMENTS ARE MADE BETWEEN ONE AND FOUR TIMES A YEAR, BUT SOME ARE TAKEN MORE FREQUENTLY

"ANOMALIES" ARE THE MATHEMATICAL DIFFERENCE BETWEEN EACH INDIVIDUAL MEASUREMENT AND THE AVERAGE VALUES OF TEMPERATURE, SALINITY, OR OTHER VARIABLES AT THAT LOCATION. POSITIVE ANOMALIES MEAN WARM OR SALINE CONDITIONS; NEGATIVE ANOMALIES MEAN COOL OR FRESH CONDITIONS.

THE "SEASONAL CYCLE" DESCRIBES THE SHORT-TERM CHANGES AT THE SURFACE OF THE OCEAN BROUGHT ABOUT BY THE PASSING OF THE SEASONS; THE OCEAN SURFACE IS COLD IN WINTER AND WARMS THROUGH SPRING AND SUMMER. THE TEMPERATURE AND SALINITY CHANGES CAUSED BY THE SEASONAL CYCLE ARE USUALLY MUCH LARGER THAN THE PROLONGED YEAR-TO-YEAR CHANGES WE DESCRIBE HERE.

THE UPPER LAYERS OF THE NORTH ATLANTIC AND NORDIC SEAS WERE WARMER AND MORE SALINE THAN THE LONG-TERM AVERAGE

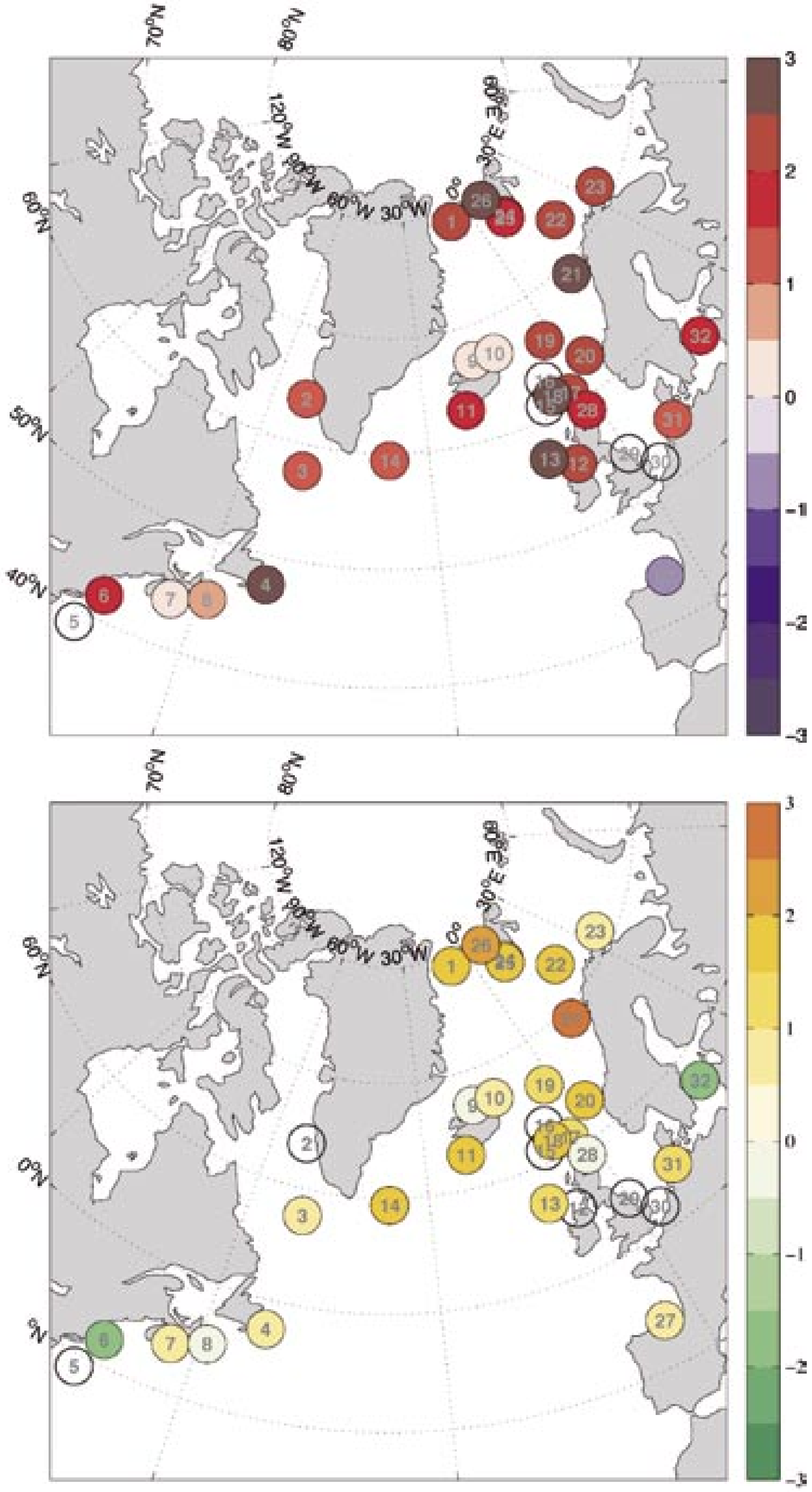


Figure 3. *Annual anomalies in 2006 of temperature (upper panel) and salinity (lower panel) over the North Atlantic region. The index numbers can be used to cross-reference each point with data in Tables 1 and 2. Unless specified (in Table 2), these are upper layer anomalies. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates that the data (temperature or salinity) for that year was 2 standard deviations above normal). Open circles indicate that no data were available for 2006 at the time of publication.*

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1 (12)	−0.03	−0.16	0.41	0.03	0.37	−0.94	0.19	0.75	2.31	2.39
2 (1)	0.52	1.27	0.75	1.34	1.58	−0.51	2.46	1.30	1.41	1.00
3 (2b)	0.99	1.22	1.41	0.32	0.55	0.57	2.17	1.08	1.48	1.41
4 (2)	−0.03	−0.03	1.00	0.97	1.06	0.58	1.00	2.48	1.66	2.75
5 (2c)	−1.29	−0.80	1.14	1.58	1.20	0.54	−0.13	−0.56	−0.83	
6 (2c)	−0.05	1.82	1.00	0.35	2.06	2.34	−0.64	[illegible]	0.20	2.00
7 (2)	0.36	[illegible]	−0.22	0.22	0.11	0.09	0.37	0.36	0.11	0.30
8 (2)	−0.41	−0.03	0.75	3.55	−0.31	0.14	[illegible]	−1.01	−0.02	0.88
9 (3)	0.07	−0.11	0.84	1.02	0.07	−1.19	2.11	0.94	0.44	0.05
10 (3)	−0.81	−0.34	0.08	−0.44	−0.49	−1.04	1.64	0.39	−0.16	0.14
11 (3)	1.58	2.57	0.95	0.53	0.70	0.49	1.89	1.84	2.58	1.68
12 (4b)	1.38	1.80	1.38	1.38	0.50	1.38	1.62	2.69	2.48	2.26
13 (5)	1.44	0.47	1.23	0.50	0.09		1.56	1.94	2.16	2.95
14 (5b)	0.28		1.37	0.26	1.24	1.04	1.11	2.72	1.58	1.22
15 (6)	0.42	1.24	−0.07	0.34	0.86	0.89	2.75	2.43	1.53	
16 (6)	0.45	1.42	0.41	0.49	0.45	0.74	2.37	1.96	1.50	
17 (7)	0.81	0.58	0.60	0.29	0.29	1.96	3.36	2.86	2.06	2.21
18 (7)	−0.02	0.64	0.90	1.05	1.64	2.44	2.79	2.44	2.20	2.62
19 (10)	0.12	1.39	1.97	1.69	1.18	1.85	2.21	2.57	1.39	2.45
20 (10)	1.21	1.01	−0.16	1.09	0.35	2.41	1.80	1.81	1.05	2.04
21 (10)	0.46	0.44	1.02	−0.39	0.55			1.35	1.32	2.58
22 (11)	−0.51	0.08	1.09	0.70	0.39	0.89	0.69	1.32	1.44	2.41
23 (11)	−0.74	−0.56	0.62	1.43	1.13	1.00	0.46	1.75	1.81	2.33
24 (12)	−1.47	−1.01	−0.21	0.12	0.13	−0.08	−0.68	0.50	1.10	2.13
25 (10)	0.04	−0.10	0.37	0.03	0.58	0.15		0.81	1.54	1.73
26 (12)	−0.22	−0.93	1.07	0.34	1.45	0.95	1.03	2.29	2.33	3.71
27 (4)	0.61	1.91	−0.06	−0.48	−0.53	−0.44	0.15	−0.35	[illegible]	−0.93
28 (8b)	1.30	1.04	0.86	0.80	1.05	1.91	2.45	1.83	1.23	1.80
29 (8b)	0.57	0.19	0.74	0.60	0.49	0.69	0.84	0.68	0.17	
30 (8b)	−0.11	0.90	0.10	0.74	0.64	0.96	0.70	0.34	0.17	
31 (8b)	0.28	0.40	1.47	0.97	0.95	1.88	1.17	0.95	1.15	1.43
32 (9b)	0.11	−0.55	0.83		0.99	2.34	0.24	0.80	1.44	1.83

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
1 (12)	0.31	−0.03	0.73	−0.88	0.65	−1.31	0.39	0.48	1.67	1.58
2 (1)	−0.33	0.27	0.30	0.24	1.33	−1.69	1.30	0.75	1.24	
3 (2b)	0.57	0.85	−0.28	0.71	0.14	0.85	0.71	1.42	1.14	0.71
4 (2)	0.34	0.34	−0.46	0.42	−0.88	1.18	0.55	0.97	1.01	0.92
5 (2c)										
6 (2c)	−0.95	−3.19	−2.24	−0.17	−0.99	0.23	−0.31	−0.26	−2.44	−1.64
7 (2)	0.27	−2.34	0.37	0.53	0.25	−0.22	0.84	0.30	0.43	0.69
8 (2)	−0.24	1.15	0.36	−0.97	0.12	−0.70	−1.15	−1.16	−1.73	−0.29
9 (3)	−0.35	−0.48	0.95	0.56	0.61	−0.48	1.14	0.81	0.02	−0.09
10 (3)	−0.85	−1.33	0.19	0.59	0.34	−0.12	0.29	0.35	0.18	0.70
11 (3)	1.42	1.98	1.44	0.79	0.66	0.78	2.03	1.89	2.77	1.89
12 (4b)										
13 (5)	0.89	1.41	1.25	0.66	0.67		2.07	1.93	1.69	1.27
14 (5b)	−0.41		1.53	0.10	0.70	1.37	0.54	2.45	1.84	1.53
15 (6)	0.04	1.10	0.61	0.70	0.54	0.57	2.16	2.37	1.92	
16 (6)	0.26	1.07	0.93	0.67	0.63	0.83	2.02	1.73	2.15	
17 (7)	1.39	1.61	1.11	0.48	0.83	2.02	2.74	3.00	2.48	1.16
18 (7)	0.09	0.67	1.07	1.12	1.35	1.71	2.05	2.09	2.01	1.66
19 (10)	−0.38	0.81	0.81	0.81	1.05	1.05	2.01	2.25	1.05	1.42
20 (10)	0.78	1.10	0.34	0.72	0.35	1.25	1.55	1.73	1.78	1.75
21 (10)	−0.14	−0.03	0.60	−0.08	0.19			1.12	1.99	2.51
22 (11)	−0.30	−0.10	0.56	0.16	0.06	0.34	0.72	1.55	1.51	1.68
23 (11)	1.33	0.29		0.15	−0.59	−0.15	0.88	1.77	0.88	0.88
24 (12)	−1.53	−1.02	−0.74	−0.32	0.13	0.17	−0.18	0.50	1.41	1.89
25 (10)	−0.42	−0.55	0.20	−0.11	0.57	0.29		0.94	1.76	2.00
26 (12)	−1.32	−0.22	0.88	0.22	1.10	0.88	0.88	1.10	1.98	2.42
27 (4)	0.66	1.24	0.46	−0.52	−1.99	−0.50	−1.02	−0.77	−0.21	0.70
28 (8b)	0.36	0.54	0.14	−0.67	−0.77	0.03	0.86	0.88	0.46	−0.02
29 (8b)										
30 (8b)	0.12	0.86	0.63	0.28	−0.59	−1.52	−0.56	0.16	0.12	
31 (8b)	0.43	1.13	0.55	0.04	−0.95	−0.27	0.60	0.44	0.27	1.01
32 (9b)	−1.36	−1.44	−2.02	−1.11	−1.98	−1.48	−1.77	−1.40	−0.99	−1.89

Table 1. *Changes in temperature (upper panel) and salinity (lower panel) at selected stations in the North Atlantic region during the past decade. The index numbers on the left can be used to cross-reference each point with information in Figures 1–3 and Table 2. The numbers in brackets refer to detailed area descriptions later in the report. Unless specified, these are upper layer anomalies. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates that the data (temperature or salinity) for that year was 2 standard deviations above normal). Blank boxes indicate that no data were available for that particular year at the time of publication. Note that no salinity data at all are available for regions 5, 12, and 29.*

ICES Cooperative Research Report No. 289

Table 2. *Details of the datasets included in Figures 1–3 and Table 1. Blank boxes indicate areas for which information was unavailable at the time of publication.*

Index	Description	Area	Measurement depth	Long-term average	Lat	Lon	Mean *T*	Mean *S*	Stdev *T*	Stdev *S*
1	Fram Strait – East Greenland Current Section Average 3°W to Shelf edge	12	50–500 m	1980–2000	78.83	-8.00	0.58	0.39	34.67	0.11
2	Station 4 – Fylla Section – Greenland Shelf	1	0–200 m	1971–2000	63.88	-53.37	2.86	0.91	33.56	0.29
3	Section AR7W – Central Labrador Sea	2b	0–150 m	1990–2000	57.73	-51.07	3.57	0.43	34.67	0.08
4	Station 27 – Newfoundland Shelf Temperature – Canada	2	0–175 m	1971–2000	47.55	-52.59		0.28		0.24
5	Oleander Section (120–400 km) – Mid Atlantic Bight USA	2c	Surface	1978–2000	39.00	-71.50		0.91		
6	Georges Bank – Mid Atlantic Bight USA	2c	0–30 m	1977–2000	42.00	-70.00		0.54		0.27
7	Emerald Bank – Central Scotian Shelf – Canada	2	Near Bottom	1971–2000	44.00	-63.00		0.81		0.14
8	Misaine Bank – Northeast Scotian Shelf– Canada	2	Near Bottom	1971–2000	45.00	-59.00		0.60		0.14
9	Siglunes Station 2–4 – North Iceland – Irminger Current	3	50–150 m	1971–2000	67.00	-18.00	3.34	1.01	34.82	0.12
10	Longanes Station 2–6 – Northeast Iceland – East Icelandic Current	3	0–50 m	1971–2000	67.00	-13.00	1.24	0.69	34.70	0.08
11	Selvogsbanki Station 5 – Southwest Iceland – Irminger Current	3	0–200 m	1971–2000	63.00	-22.00	7.58	0.39	35.15	0.04
12	Malin Head Weather Station	4b	Surface	1971–2000	55.37	-7.34	10.57	0.46		
13	Ellett Line – Rockall Trough – UK (section average)	5	0–800 m	1975–2000	56.75	-11.00	9.21	0.22	35.33	0.03
14	Central Irminger Sea – Subpolar Mode Water	5b	200–400 m	1991–2005	59.40	-36.80	3.99	0.38	34.88	0.02
15	Faroe Bank Channel – South Faroe Islands	6	Upper layer high salinity core	1988–2000	61.00	-8.00	8.23	0.18	35.24	0.03
16	Faroe Current – North Faroe Islands (Modified North Atlantic Water)	6	Upper layer high salinity core	1988–2000	63.00	-6.00	7.92	0.29	35.22	0.03
17	Faroe Shetland Channel – Shetland Shelf (North Atlantic Water	7	Upper layer high salinity core	1971–2000	61.00	-3.00	9.61	0.17	35.36	0.03
18	Faroe Shetland Channel – Faroe Shelf (Modified North Atlantic Water)	7	Upper layer high salinity core	1971–2000	61.50	-6.00	7.85	0.25	35.21	0.04
19	Ocean Weather Station Mike – 50 m	10	50 m	1971–2000	66.00	-2.00	7.49	0.34	35.15	0.04
20	Southern Norwegian Sea – Svinoy Section – Atlantic Water	10	50–200 m	1977–2000	63.00	3.00	8.06	0.39	35.23	0.05
21	Central Norwegian Sea – Gimsoy Section – Atlantic Water	10	50–200 m	1978–2000	69.00	12.00	6.66	0.37	35.15	0.03
22	Fugloya–Bear Island Section – Western Barents Sea – Atlantic Inflow	11	50–200 m	1977–2006	73.00	20.00	5.35	0.55	35.06	0.04
23	Kola Section – Eastern Barents Sea	11	0–200 m	1971–2000	71.50	33.30	3.92	0.48	34.76	0.06
24	Greenland Sea Section – West of Spitsbergen 76.5°N	12	200 m	1996–2006	76.50	10.50	3.08	0.66	35.05	0.04
25	Northern Norwegian Sea – Sorkapp Section – Atlantic Water	10	50–200 m	1977–2000	76.33	10.00	3.80	0.70	35.05	0.04
26	Fram Strait – West Spitsbergen Current – Section average 5°E to shelf edge	12	50–500 m	1980–2000	78.83	8.00	2.60	0.58	34.99	0.03
27	Santander Station 6 (shelf break) – Bay of Biscay – Spain	4	5–300 m	1993–2000	43.70	-3.78	12.72	0.18	35.61	0.05
28	Fair Isle Current Water (waters entering North Sea from Atlantic)	8 & 9	0–100 m	1971–2000	59.00	-2.00	9.84	0.38	34.90	0.11
29	UK Coastal Waters – Southern Bight – North Sea	8 & 9	Surface	1971–2000	54.00	0.00				
30	Section average – Felixstowe – Rotterdam – 52°N	8 & 9	Surface	1971–2000	52.00	3.00	12.14	1.12	34.64	0.21
31	Helogoland Roads – Coastal Waters – German Bight North Sea	8 & 9	Surface	1971–2000	54.19	7.90	10.10	0.68	32.11	0.54
32	Baltic Proper – East of Gotland – Baltic Sea	9b	Surface	1971–2000	57.50	19.50	8.57	0.86	7.35	0.24

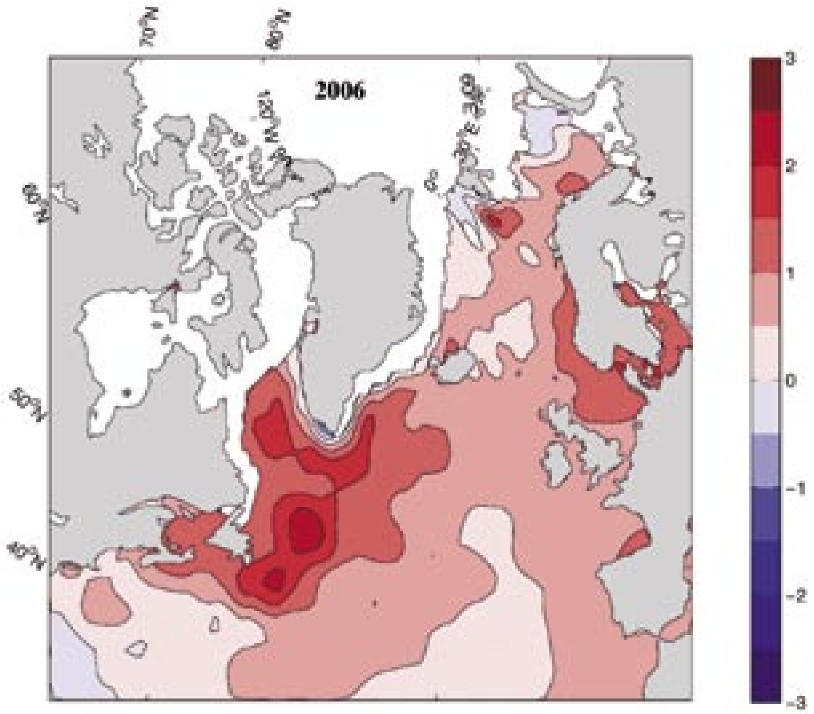
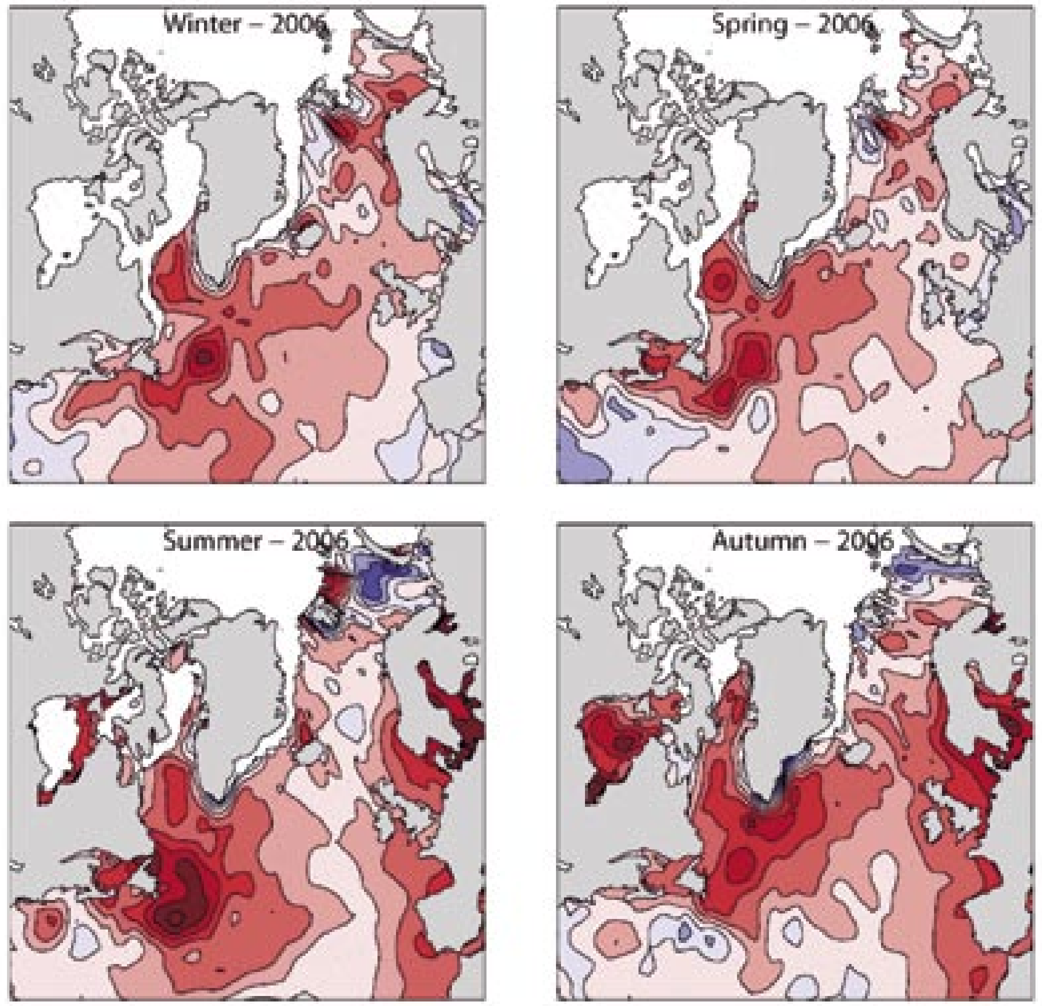


Figure 4. *Map of annual (upper panel) and seasonal (lower panels) sea surface temperature anomalies (°C) over the North Atlantic for 2006 from the NOAA Optimum Interpolation SSTv2 dataset, provided by the NOAA-CIRES Climate Diagnostics Center, USA. The colour-coded temperature scale is the same in all panels. The anomaly is calculated with respect to normal conditions for the period 1971–2000. The data are produced on a one-degree grid from a combination of satellite and in situ temperature data. Regions with ice cover for >50% of the averaging period are left blank.*



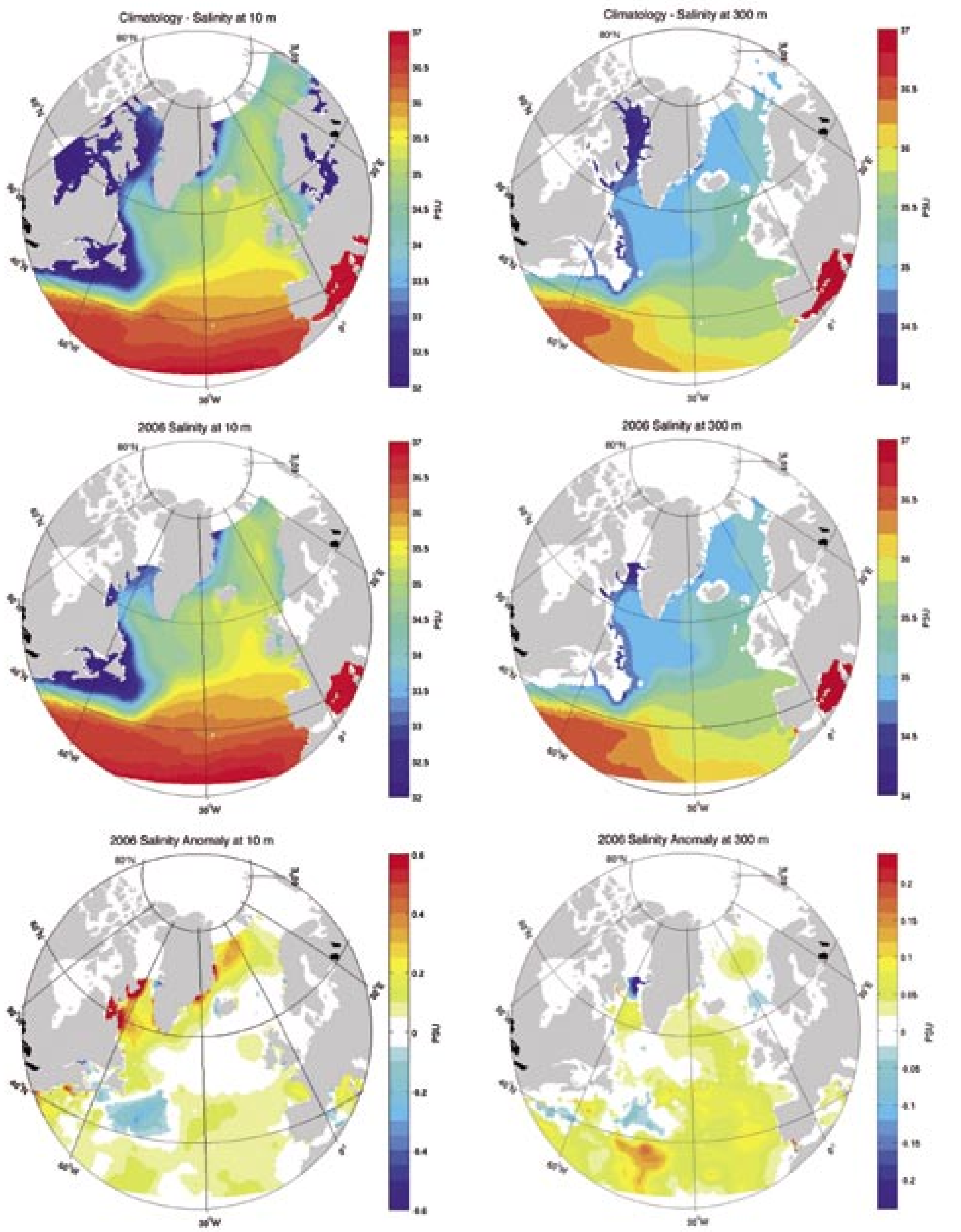


Figure 5. Maps of North Atlantic salinity at 10 m (left column) and 300 m (right column), showing climatology (top), 2006 annual mean (middle), and 2006 anomaly from the climatology (bottom). These products are generated by the Coriolis operational oceanography centre, which compiles in situ data (including Argo float salinity profiles) and satellite data into an ocean circulation model. Maps provided by Fabienne Gaillard, www.coriolis.eu.org/default.htm.

ICES Cooperative Research Report No. 289

5. The North Atlantic Atmosphere

5.1 North Atlantic Oscillation index

The North Atlantic Oscillation (NAO) is a pattern of atmospheric variability that has a significant impact on oceanic conditions. It affects windspeed, precipitation, and evaporation, and the exchange of heat between the ocean and atmosphere, and its effects are most strongly felt in winter. The NAO index is a simple device used to describe the state of the NAO. It is a measure of the strength of the sea level air pressure gradient between Iceland and the Azores. When the NAO index is positive, there is a strengthening of the Icelandic low-pressure system and the Azores high-pressure system. This produces stronger mid-latitude westerly winds, with colder and drier conditions over the western North Atlantic and warmer and wetter conditions in the eastern North Atlantic. When the NAO index is negative, there is a reduced pressure gradient and the effects tend to be reversed.

There are several slightly different versions of the NAO index calculated by climate scientists. The Hurrell winter (DJF) NAO index is most commonly used and has particular relevance to the eastern North Atlantic. 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 Hurrell NAO index underwent a large and rapid decrease during the winter preceding 1996. Since then, the Hurrell NAO index has been fairly weak and a less useful descriptor of atmospheric conditions (see the green text below).

The ocean can respond quickly to the state of the NAO, particularly in winter when atmospheric conditions affect the ocean so intensely that the effects are felt throughout the following year. Some regions, such as the northwest Atlantic and the North Sea, are more responsive to the NAO than other regions, such as the Rockall Trough. However, the NAO is not the only, or even the main control on ocean variability. Over the Atlantic as a whole, the NAO still only accounts for one-third of the total variance in winter sea level pressure. The chaotic nature of atmospheric circulation means that even during periods of strongly positive or negative NAO winters, the atmospheric circulation typically exhibits significant local departures from the idealized NAO pattern.

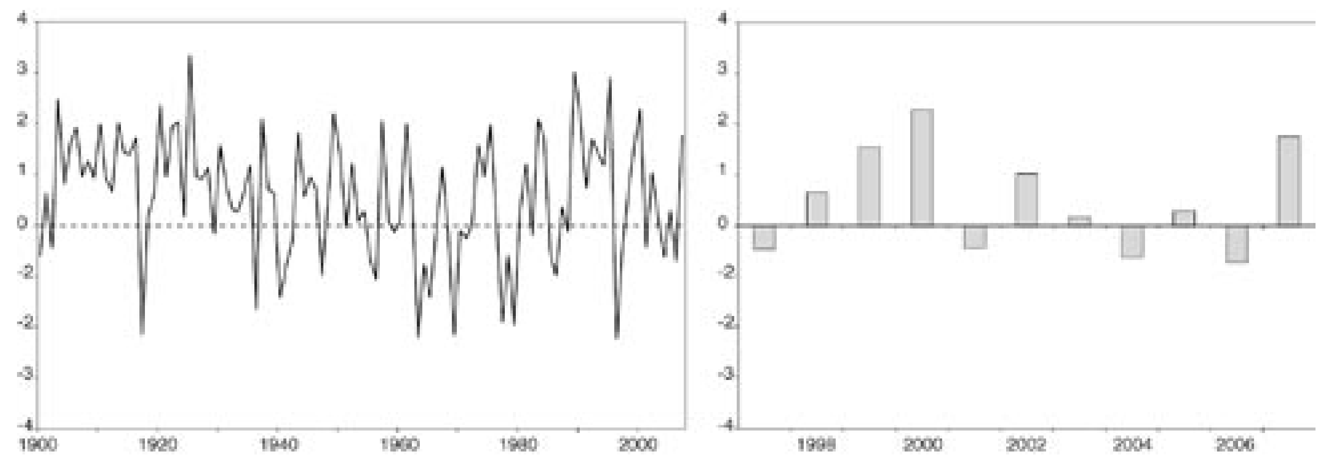


Figure 6. The Hurrell winter (DJF) NAO index for the past 100 years (left panel) and the current decade (right panel). Data from Climate Research Unit, UK, www.cru.uea.ac.uk/~timo/projpages/nao_update.htm

5.2 North Atlantic sea level pressure

The NAO index is an indicator of the gradient of sea level pressure, but maps can provide more information about the windfield. Winter conditions dominate the ocean properties in particular, so Figure 7 shows maps of sea level pressure in winter (December–January–February–March, DJFM). The top panel in Figure 7 shows the winter sea level pressure averaged over 30 years from 1971 to 2000. The dominant features ("action centres") are the Iceland Low (the purple patch situated southwest of Iceland) and the Azores High (the orange patch west of Gibraltar).

NORTH ATLANTIC MEAN WINDS WERE WEAKER THAN NORMAL

The middle panel in Figure 7 shows the mean sea level pressure for winter 2006 (December 2005, January–March 2006) and the bottom panel shows the 2006 winter sea level pressure anomaly, the difference between the top and middle panels. We see that, in winter 2006, both the Iceland Low and the Azores High were weaker than normal (higher central pressure in the Iceland Low, and lower central pressure in the Azores High). Also, the centre of the Iceland Low was displaced towards the southwest to the entrance to the Labrador Sea. The results show that the North Atlantic mean winds were weaker than normal and that the storm track (approximated by the white and blue bands in the middle and bottom panels of Figure 7) was displaced and rotated somewhat, starting farther south by North America than usual, and ending farther north of Norway than usual.

THE FIGURES SHOW CONTOURS OF CONSTANT SEA LEVEL PRESSURE (ISOBARS). THE GEOSTROPHIC (OR "GRADIENT") WIND BLOWS PARALLEL WITH THE ISOBARS. THE CLOSER THE ISOBARS, THE STRONGER THE WIND.

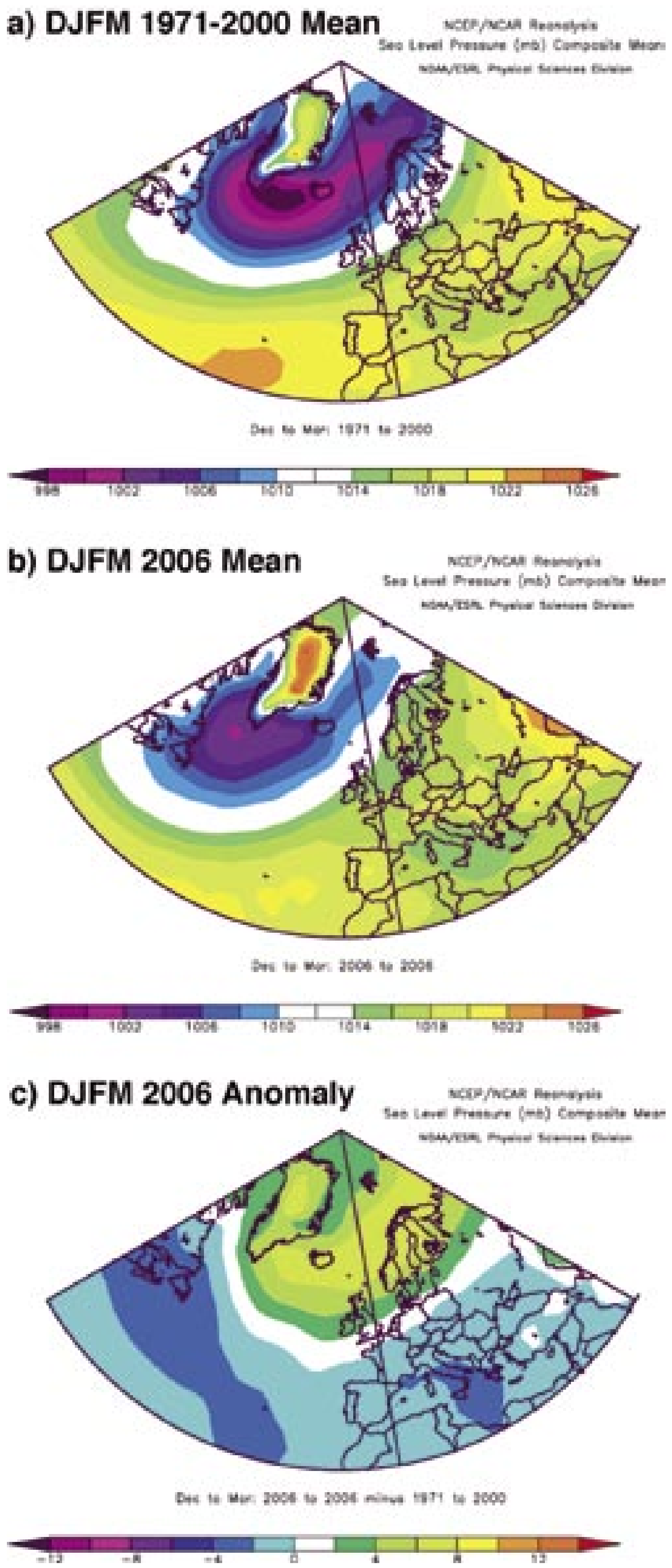


Figure 7. *Winter (DJFM) sea level pressure fields. Top panel shows sea level pressure averaged over 30 years from 1971 to 2000. Middle panel shows mean sea level pressure in winter 2006 (December 2005, January–March 2006). Bottom panel shows the winter 2006 sea level pressure anomaly, the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado from their website at www.cdc.noaa.gov/.*

5.3 North Atlantic surface air temperature

North Atlantic winter mean surface air temperatures are shown in Figure 8. The 1971–2000 mean conditions (Figure 8 top panel) show warm temperatures penetrating far to the north on the east side of the North Atlantic and Nordic Seas, caused by northwards movement of warm oceanic water. The middle panel in Figure 8 shows the conditions in winter (DJFM) 2006 and the bottom panel shows the difference between the two. In winter 2006, the eastern North Atlantic and Nordic Seas surface air temperatures were near normal. In contrast, over much of the central and western North Atlantic, surface air temperatures were more than 1°C warmer than normal in 2006. The exceptions are the three orange/red areas, which show warmer-than-normal conditions (by 6–10°C); this is the consequence of sea-ice edges retreating in the northern Labrador Sea, northeast Greenland, and northeast of Svalbard. The bottom panel in Figure 8 also shows that it was a cold winter over Europe.

OVER MUCH OF THE CENTRAL AND WESTERN NORTH ATLANTIC SURFACE AIR TEMPERATURE WAS MORE THAN 1°C WARMER THAN NORMAL

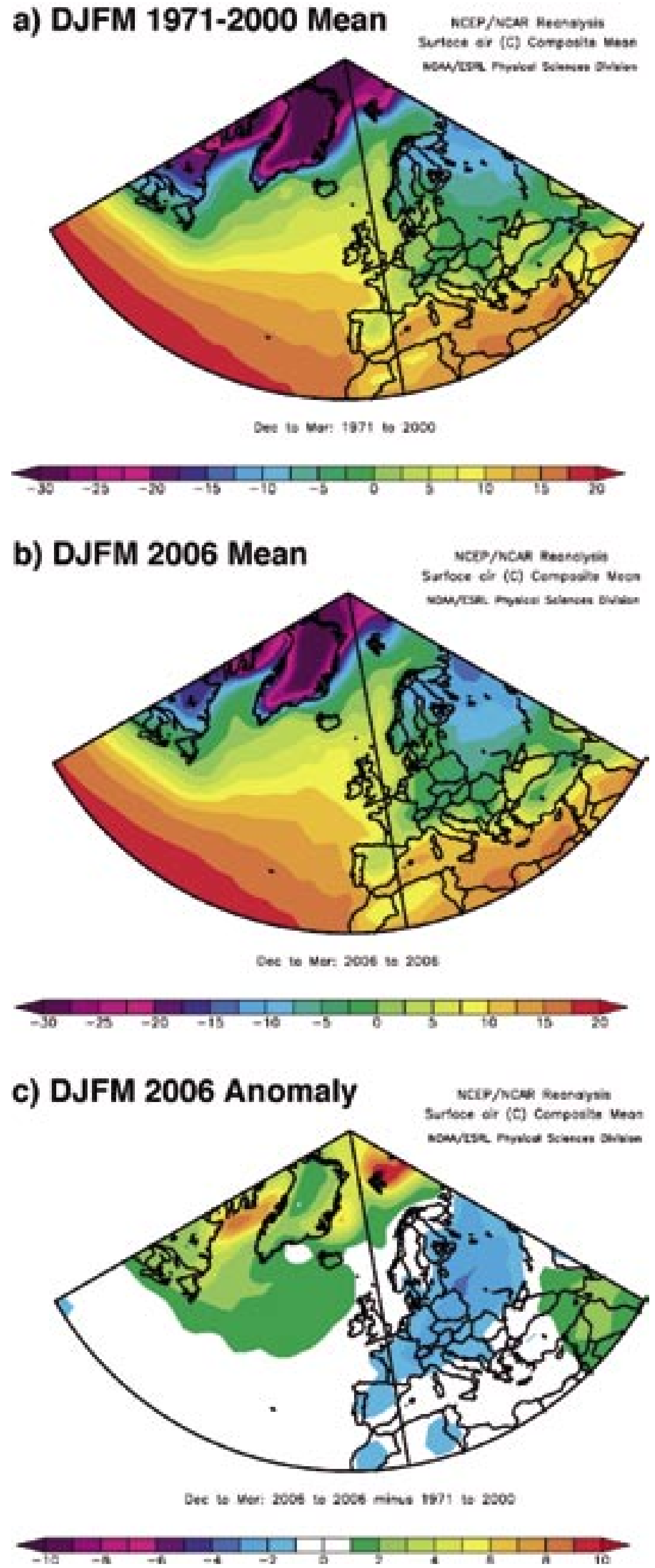


Figure 8. *Winter (DJFM) surface air temperature fields. Top panel shows surface air temperature averaged over 30 years from 1971 to 2000. Middle panel shows temperatures in winter 2006 (December 2005, January to March 2006). Bottom panel shows winter 2006 surface air temperature anomaly from 1971–2000, the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, Colorado from their website at www.cdc.noaa.gov/.*

6. Detailed area descriptions

6.1 Introduction

The general pattern of oceanic circulation in the North Atlantic, in relation to the areas described here, is given in Figure 9. Information about each area has been distilled from larger datasets, which have been collected under programmes of sustained observations.

Most standard sections or stations are repeated annually or more frequently. The text summarizes the regional context of the sections and stations, noting any significant recent events. Key parameters are plotted against time.

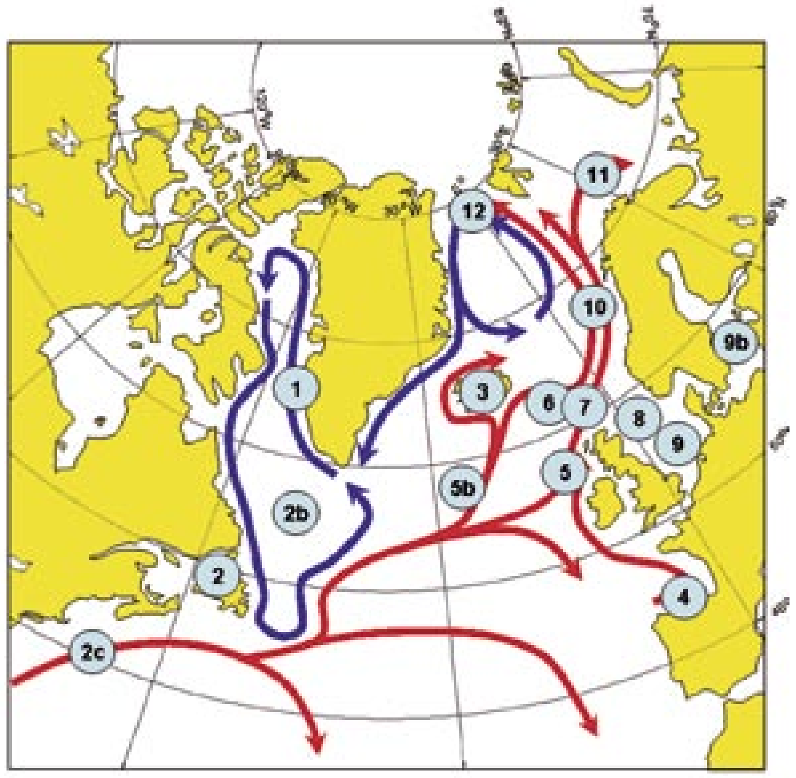


***Figure 9**. Schematic of the general circulation of the North Atlantic in relation to the numbered areas presented below. The blue arrows indicate the movement of the cooler waters of the subpolar gyre. The red arrows indicate the movement of the warmer waters of the subtropical gyre.*

6.2 Area 1 – West Greenland

West Greenland lies at the northern boundary of the subpolar gyre and is thus subject to climatic variations within this gyre. The West Greenland Current follows the continental slope off West Greenland and travels northwards through the Davis Strait. The Fyllas Bank Station 4, located on the bank slope in about 900 m of water, is governed mostly by the warm component of the West Greenland Current (below 150 m). In some years, shallow shelf water extends farther offshore, bringing colder water to Station 4 (e.g. 1983, 1992, and 2002). Located farther offshore, Cape Desolation Station 3 has a 3000-m-deep water column and samples the West Greenland Current and the Deep Boundary Current of the Labrador Sea.

West Greenland lies within an area that normally experiences cooler conditions when the NAO index is positive. Despite the positive NAO winter 2006 index, however, air temperature conditions around Greenland continued to be warmer than normal; mean air temperatures at Nuuk show positive anomalies.

At Fyllas Bank, the 2006 subsurface temperatures were high, similar to the warm 1960s, but lower than autumn 2003, when temperatures were 2.69°C above normal. The long-term mean (1963–1990) for the 0–200 m layer is 2.70°C.

At Cape Desolation Station 3, the upper layer has demonstrated a significant warming and increasing salinity trend since 1983. At 2000 m, the first part of the time-series shows a cooling, freshening trend to 1997, but since then, the trend has been towards increasing temperature and salinity.

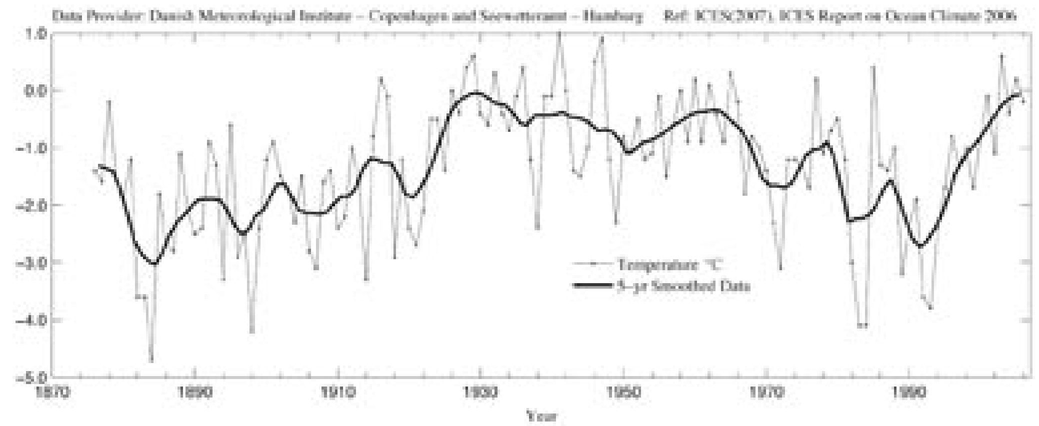


***Figure 10**. Area 1 – West Greenland. Annual mean air temperature observed at Nuuk.*

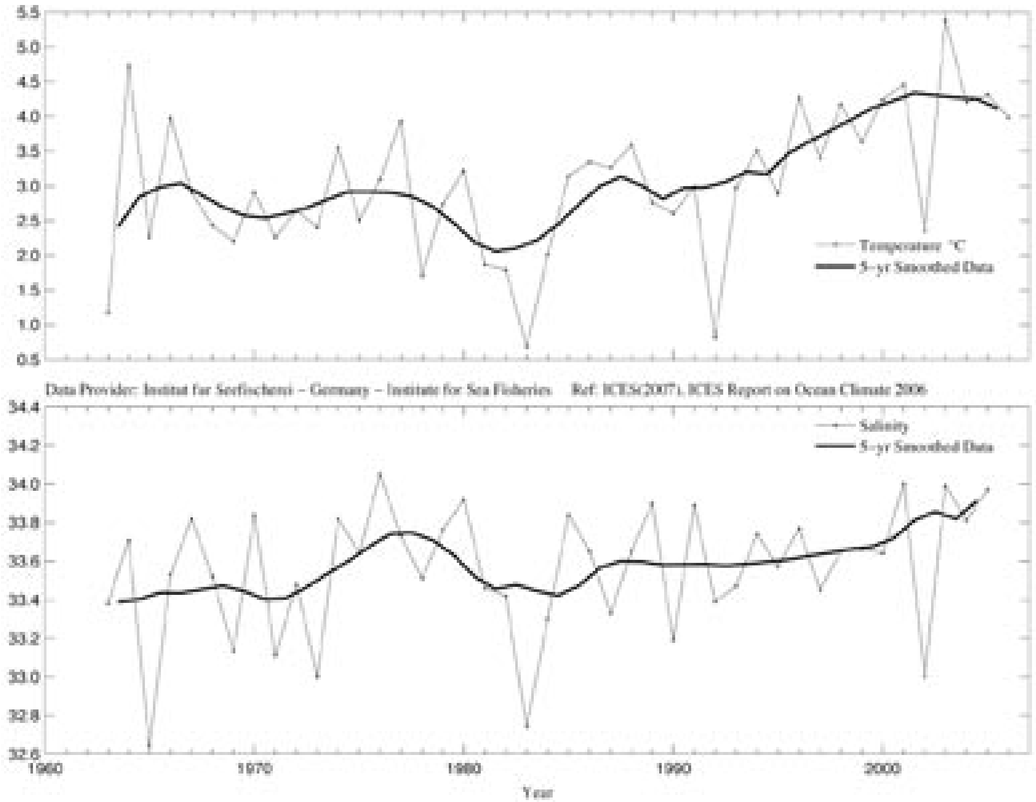


***Figure 11**. Area 1 – West Greenland. Fyllas Bank Station 4 autumn temperature (upper panel) and salinity (lower panel), 0–200 m.*

Figure 12. *Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 50 m at Cape Desolation Station 3.*

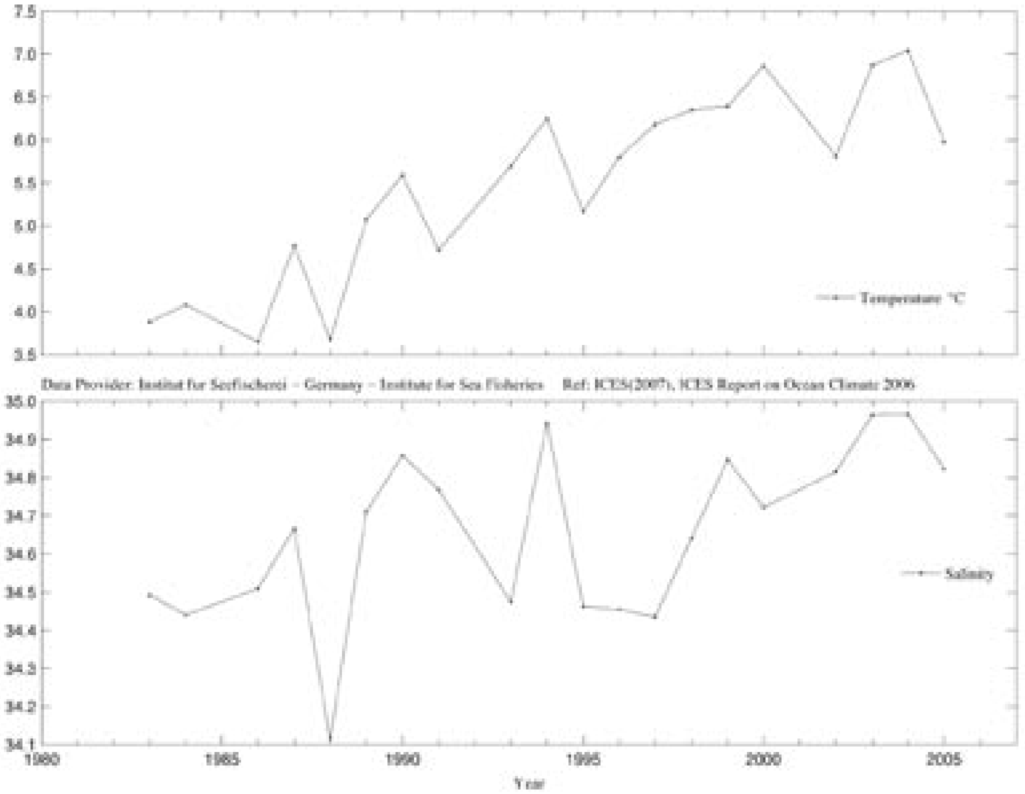
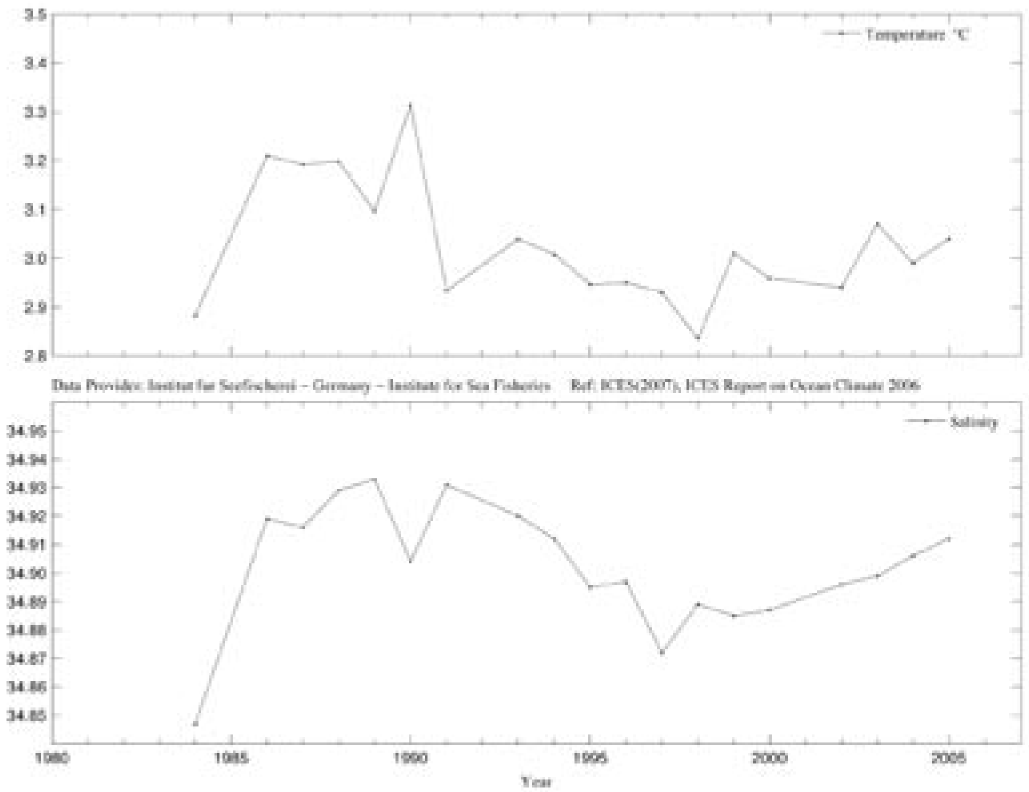


Figure 13. *Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 2000 m at Cape Desolation Station 3, in the West Greenland Current.*



6.3 Area 2 – Northwest Atlantic: Scotian Shelf and the Newfoundland and Labrador Shelf

Oceanographic conditions in this area are determined largely 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 (sometimes corresponding to a negative NAO index), warm and saline ocean conditions predominate.

Scotian Shelf

The continental shelf off the coast of Nova Scotia is characterized by complex topography consisting of many offshore shallow (<100 m) banks and deep (>200 m) midshelf 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 flow towards the southwest, interrupted by clockwise movement around the banks and anticlockwise movement around the basins, with the strengths varying seasonally. Temperature and salinity conditions over the shelf are largely determined by advection of water from southern Newfoundland and the Gulf of St Lawrence, as well as offshore "slope" waters.

In 2006, annual mean air temperatures over the Scotian Shelf, represented by Sable Island observations, were above average by approximately 1.4°C (based on 1971–2000 mean values), up 0.6°C from 2005. West of Sable Island, air temperature anomalies decreased slightly to 1.3°C over the eastern Gulf of Maine.

The amount of sea ice on the Scotian Shelf in 2006, as measured by the area of ice seaward of the Cabot Strait between Nova Scotia and Newfoundland from January to April, was well below normal, continuing the downwards trend from the exceptionally large cover in 2003. Overall, the ice cover in 2006 was the third lowest in 38 years, whereas the 2003 cover was the second highest in the entire record.

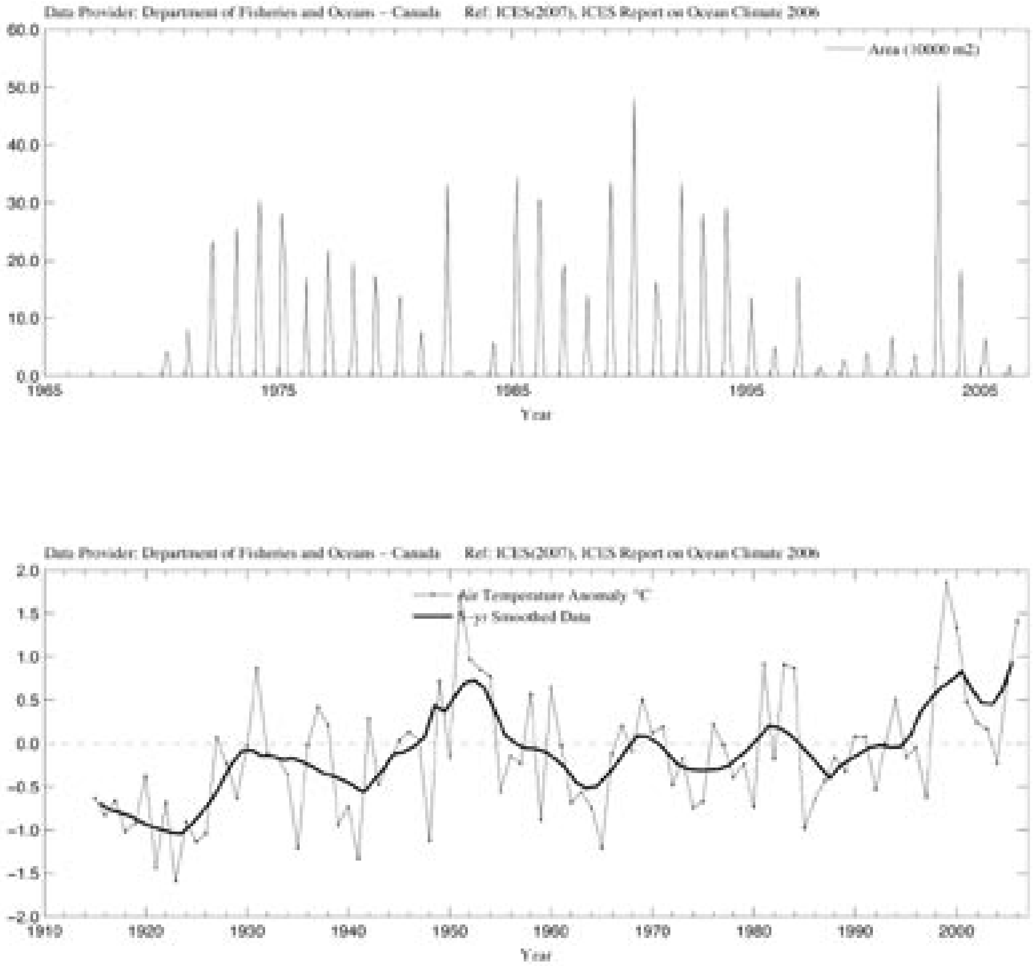
Topography separates the northeastern Scotian Shelf from the rest of the shelf. In the northeast, the bottom tends be covered by relatively cold waters (1–4°C) whereas the basins in the central and southwestern regions typically have bottom water temperatures of 8–10°C. The origin of the latter is the offshore slope waters, whereas in the northeast, the water comes principally from the Gulf of St Lawrence. The interannual variability of the two water masses differs. Measurements of temperatures at 100 m at the Misaine Bank station capture the changes in the northeast. They reveal warmer-than-normal conditions in 2006 by 0.6°C, an increase from near-normal conditions in 2005. In Emerald Basin, temperatures in 2006 were 0.7°C above normal at 100 m, an increase of approximately 2.4°C from 2005. There was a slight increase (by 0.25°C) at 250 m to annual values nearly 0.4°C above normal. The warmer than average deep temperatures continue a trend that has persisted since the mid-1980s, except for the cold year of 1998.

The amount of sea ice was well below normal in 2006

Annual sea surface temperature anomalies were high: about 1.2°C over the eastern, 1.25°C over the central and 0.4°C over the western Scotian Shelf during 2006. The Lurcher Shoal area west of Nova Scotia had an annual anomaly of 0.6°C, the Bay of Fundy 1.1°C. The density difference between 0 and 50 m over the Scotian Shelf increased on average in 2006 to above normal, although there was considerable spatial variability, with stratification below normal in some areas.

ICES Cooperative Research Report No. 289

__Figure 14__. Area 2 – Northwest Atlantic: Scotian Shelf. Monthly means of ice area seaward of Cabot Strait (upper panel) and filtered air temperature anomalies at Sable Island on the Scotian Shelf (lower panel).



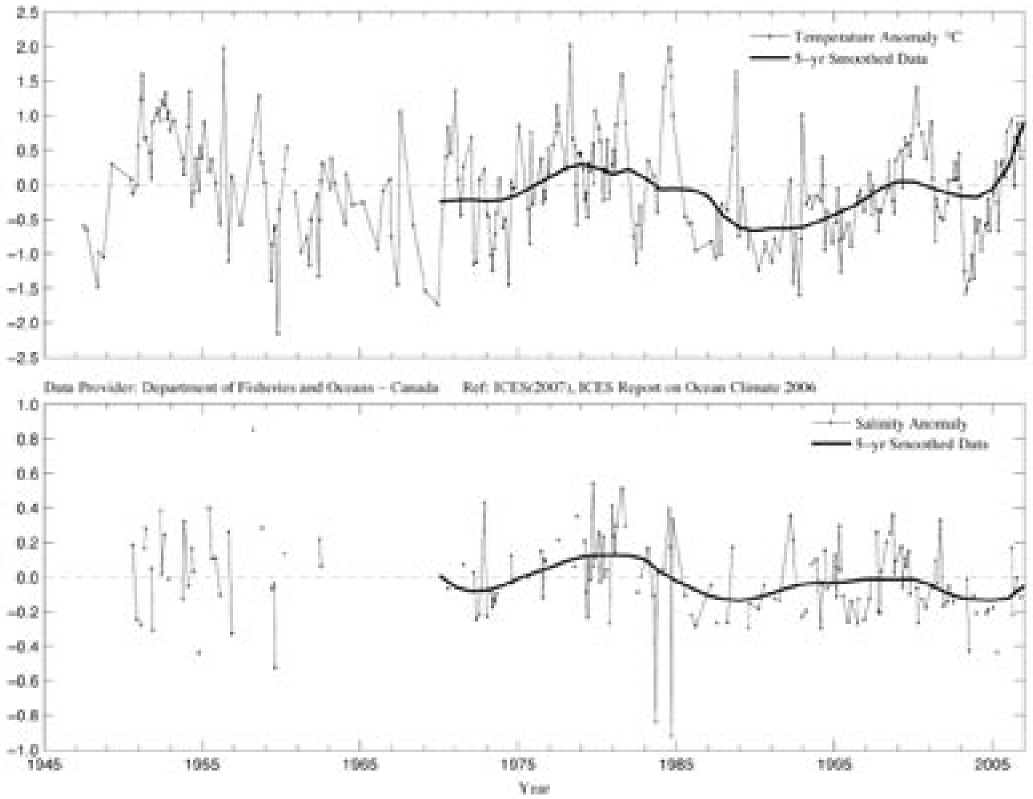


__Figure 15.__ Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature anomalies (upper panel) and salinity anomalies (lower panel) in the northeastern Scotian Shelf (Misaine Bank, 100 m).

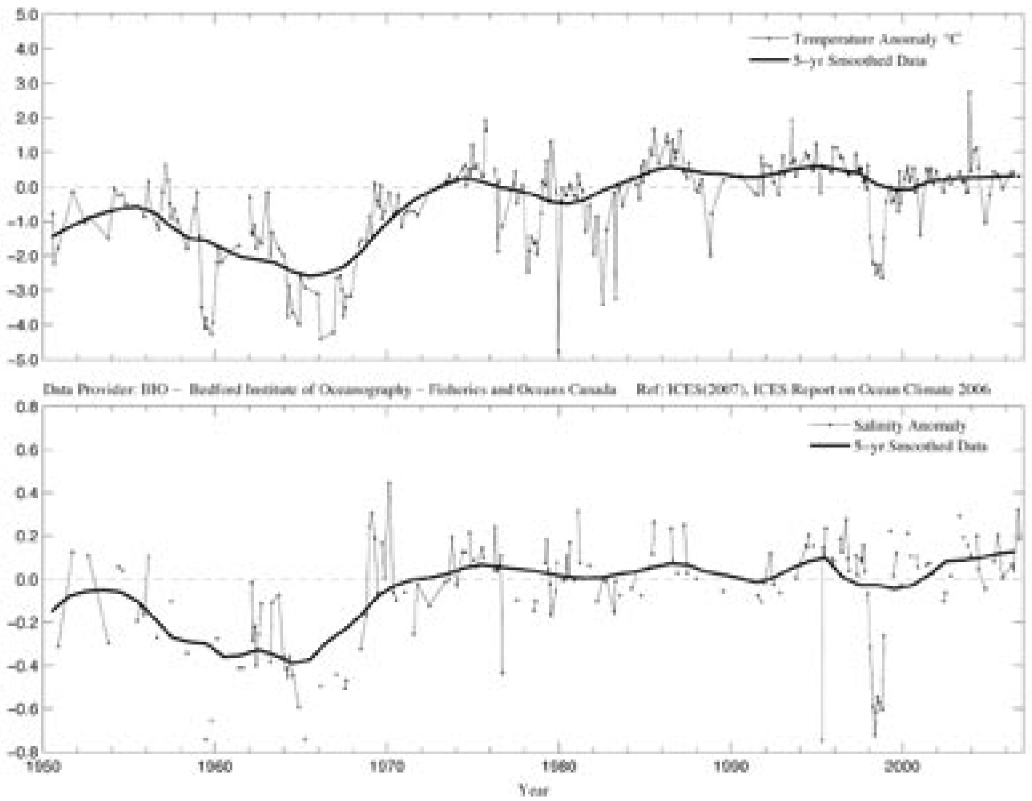


Figure 16. *Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature anomalies (upper panel) and salinity anomalies (lower panel) in the central Scotian Shelf (Emerald Basin, 250 m).*

ICES Cooperative Research Report No. 289

Newfoundland and Labrador Shelf

The NAO index for 2006 was negative, and as a result Arctic outflow to the Northwest Atlantic was weaker than normal. Annual air temperatures were above normal at Labrador (Cartwright) and Newfoundland (St John's) by 1°C to near 3°C. Sea-ice extent on the Newfoundland and Labrador Shelf for 2006 was below average for the 12th consecutive year, the lowest on record during the spring months. Sea ice also appeared late and left early in 2006, resulting in a shorter ice season than normal.

SEA-ICE EXTENT WAS THE LOWEST ON RECORD DURING SPRING MONTHS, WHILE ANNUAL WATER TEMPERATURES REACHED A 61-YEAR HIGH

At the standard monitoring site off eastern Newfoundland (Station 27), the depth-averaged annual water temperature increased to near 1°C, the highest in the 61-year record. Surface temperatures at Station 27 were also at a 61-year record high. Bottom temperatures were above normal by 0.8°C.

A robust index of ocean climate conditions in eastern Canadian waters is the extent of the cold intermediate layer (CIL) of <0°C water overlying the continental shelf. 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 2006, the CIL remained below normal on the eastern Newfoundland Shelf for the 12th consecutive year.

The near-bottom thermal habitat on the Newfoundland and Labrador Shelf continued to warm in 2006, with bottom temperatures ranging from 0.5°C to 1°C above the long-term mean in many areas, although they cooled substantially during late autumn, particularly in northern areas.

In general, ocean temperatures on the Newfoundland and Labrador Shelf during 2006 increased over 2005 values, reaching a record high at Station 27, continuing the warm trend experienced since the mid to late 1990s. Shelf water salinities, which were lower than normal throughout most of the 1990s, have increased to above normal values during the past five years, although there was considerable local variability.

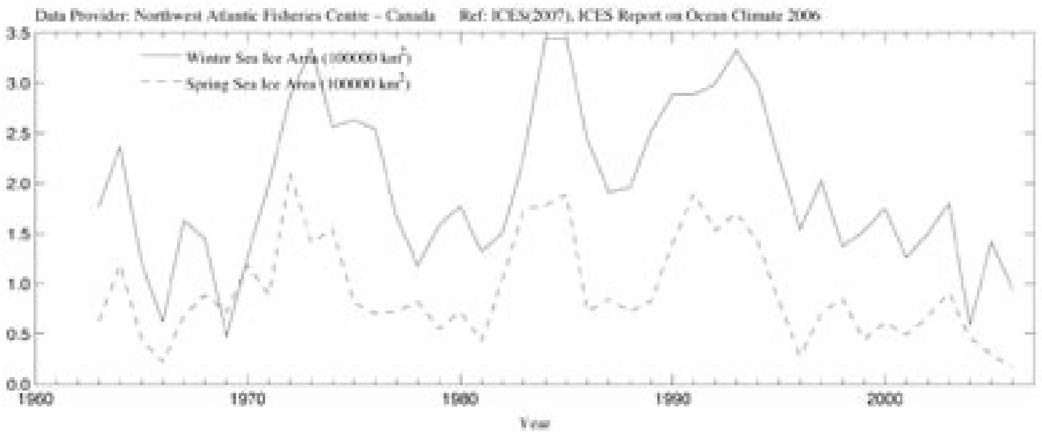


Figure 17. *Area 2 – Northwest Atlantic: Newfoundland and Labrador Shelf. Monthly sea-ice areas off Newfoundland and Labrador between 45°N and 55°N.*

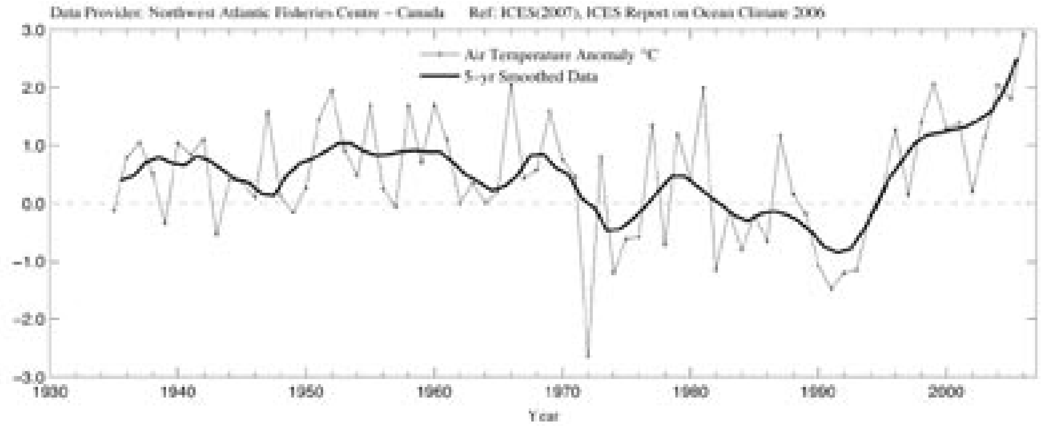


Figure 18. *Area 2 – Northwest Atlantic: Newfoundland and Labrador Shelf. Annual air temperature anomalies at Cartwright on the Labrador Coast.*

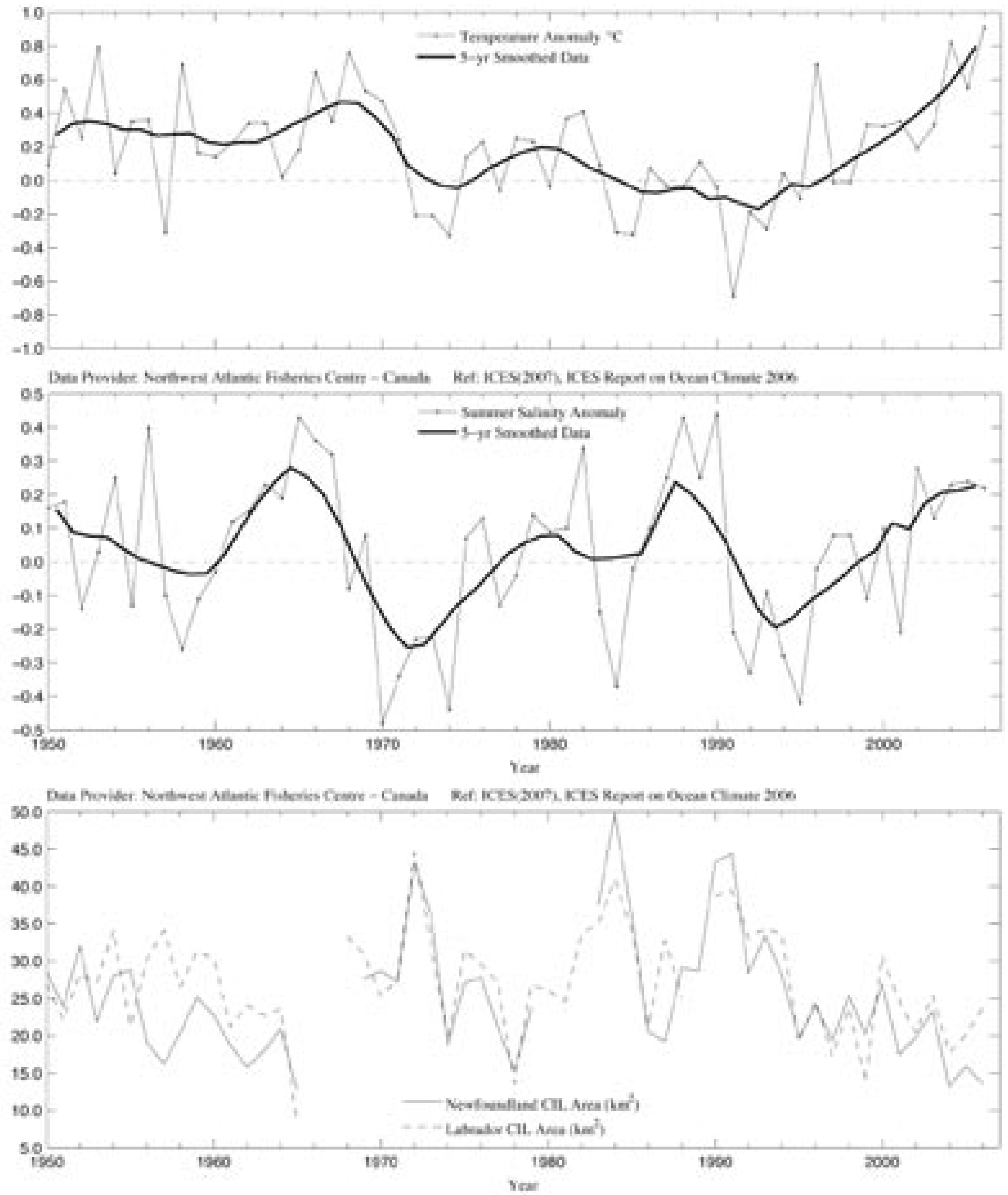


Figure 19. *Area 2 – Northwest Atlantic: Newfoundland and Labrador Shelf. Annual depth-averaged Newfoundland Shelf temperature anomalies (top panel) and salinity anomalies (middle panel), and spatial extent of cold intermediate layer (CIL; bottom panel).*

ICES Cooperative Research Report No. 289

6.4 Area 2b – Labrador Sea Scotian Shelf

THE LABRADOR SEA IS LOCATED BETWEEN GREENLAND AND THE LABRADOR COAST OF EASTERN CANADA. COLD, LOW-SALINITY WATERS OF POLAR ORIGIN CIRCLE THE LABRADOR SEA IN AN ANTICLOCKWISE CURRENT SYSTEM THAT INCLUDES BOTH THE NORTH-FLOWING WEST GREENLAND CURRENT ON THE EASTERN SIDE AND THE SOUTH-FLOWING LABRADOR CURRENT ON THE WESTERN SIDE. WARM AND SALINE WATERS FROM MORE SOUTHERN LATITUDES FLOW NORTHWARDS INTO THE LABRADOR SEA ON THE GREENLAND SIDE AND BECOME COLDER AND FRESHER AS THEY CIRCULATE.

LABRADOR SEA HYDROGRAPHIC CONDITIONS DEPEND ON A BALANCE BETWEEN HEAT LOST TO THE ATMOSPHERE AND HEAT GAINED FROM WARM, SALINE ATLANTIC WATERS. SEVERE WINTERS UNDER HIGH NAO CONDITIONS LEAD TO GREATER COOLING: IN EXCEPTIONAL CASES, THE RESULTING INCREASES IN THE SURFACE DENSITY CAN LEAD TO CONVECTIVE MIXING OF THE WATER COLUMN TO DEPTHS UP TO 2 KM. MILDER WINTERS UNDER LOW NAO CONDITIONS LEAD TO LOWER HEAT LOSSES AND AN INCREASED PRESENCE OF THE WARM, SALINE ATLANTIC WATERS.

A series of severe winters in the early 1990s led to the most recent period of deep convection, which peaked in 1993–1994. Subsequent winters have generally been milder than normal, and the upper levels of the Labrador Sea have become warmer and more saline. The upper 150 m of the west-central Labrador Sea have warmed by more than 1°C and increased in salinity by more than 0.1 since the early 1990s. Conditions in 2006 were similarly warm and saline.
The 2006 annual mean sea surface temperature in the west-central Labrador Sea was warmer than normal for the 13th consecutive year. The last four years (2003–2006) have been exceptionally warm.

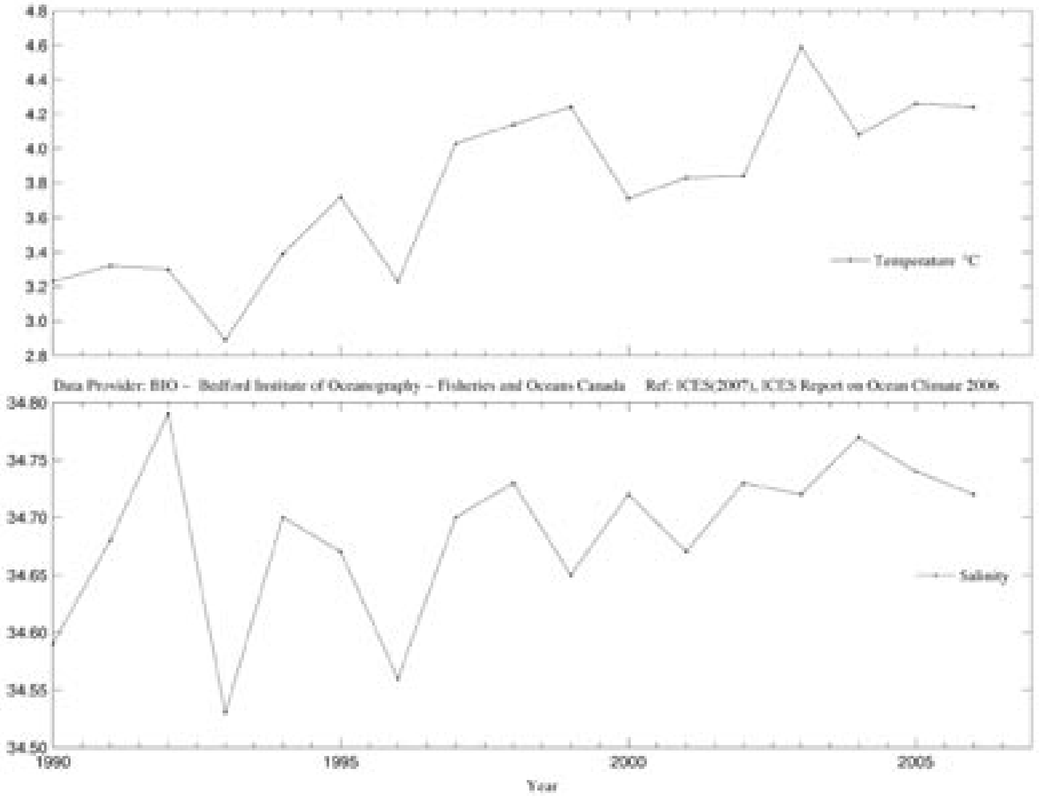


Figure 20. *Area 2b – Labrador Sea. Spring/early summer potential temperature (upper panel) and salinity (lower panel) values for 0–150 m depth from four stations in the west-central Labrador Sea (centred at 56.7°N 52.5°W).*

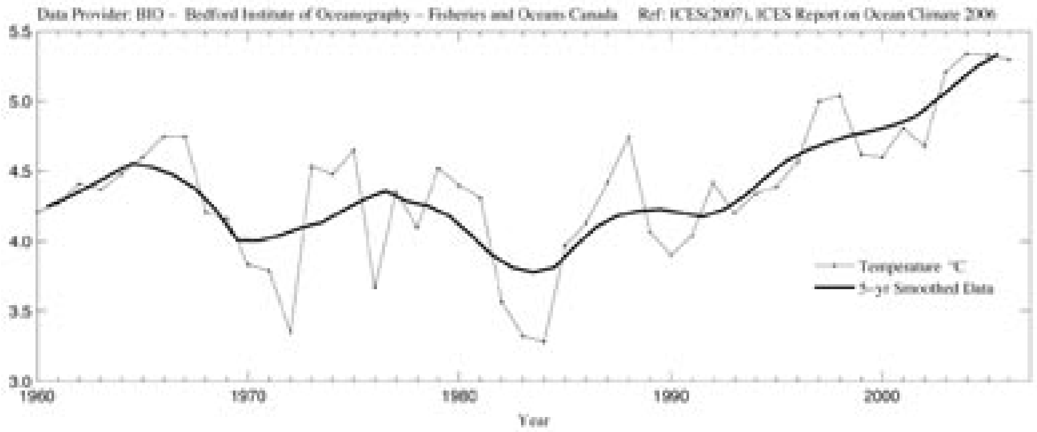


Figure 21. *Area 2b – Labrador Sea. Annual mean sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 Global Sea Surface Temperature dataset, UK Meteorological Office, Hadley Centre.*

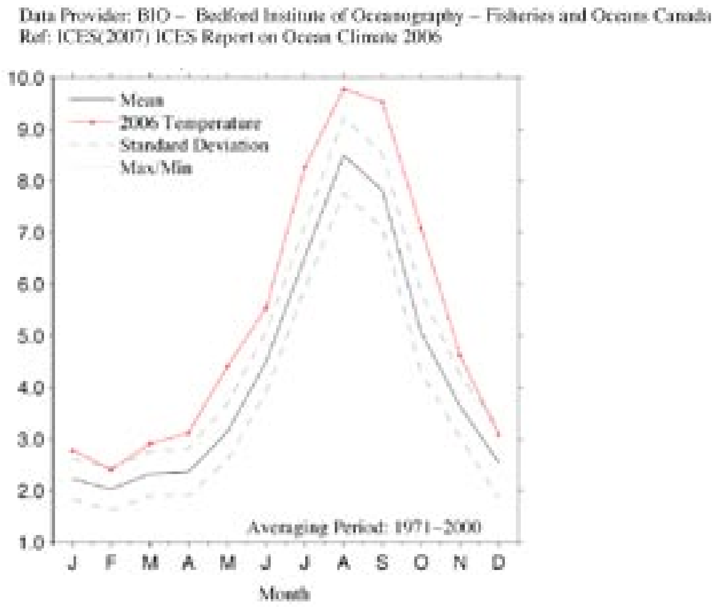


Figure 22. *Area 2b – Labrador Sea. Monthly sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 Global Sea Surface Temperature dataset, UK Meteorological Office, Hadley Centre.*

6.5 Area 2c – Mid-Atlantic Bight

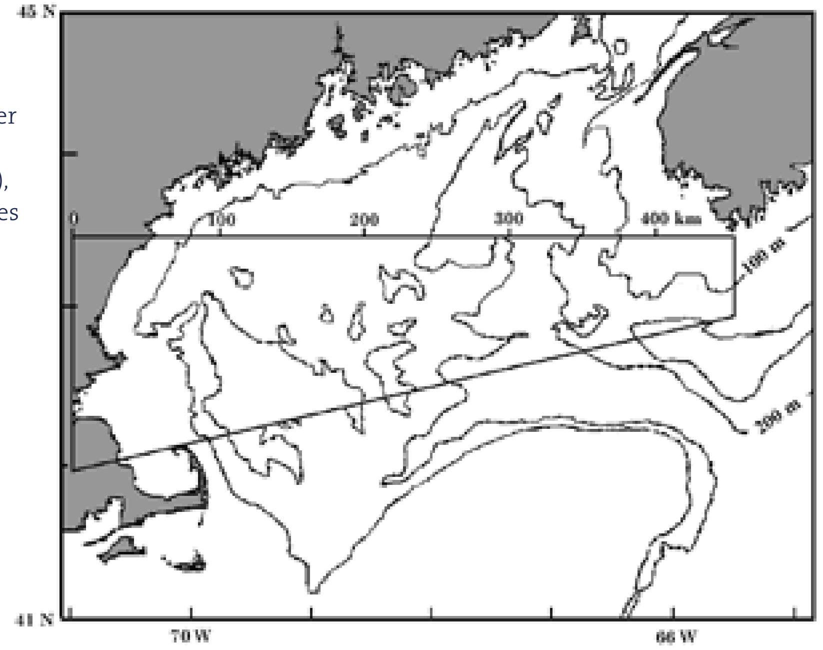
THE HYDROGRAPHIC CONDITIONS IN THE WESTERN SLOPE SEA, THE MID-ATLANTIC BIGHT, AND THE GULF OF MAINE DEPEND UPON THE SUPPLY OF WATERS FROM THE LABRADOR SEA, BOTH ALONG THE SHELF AND ALONG THE CONTINENTAL SLOPE. THESE WATERS HAVE BEEN MONITORED BY MEANS OF REGULAR EXPENDABLE BATHYTHERMOGRAPH (XBT) AND SURFACE SALINITY OBSERVATIONS FROM COMMERCIAL AND FISHING VESSELS SINCE 1978. ONE SECTION RUNS BETWEEN NEW JERSEY AND BERMUDA AND THE OTHER TRAVERSES THE GULF OF MAINE EAST OF BOSTON. HYDROGRAPHIC CONDITIONS ARE ALSO MONITORED ON GEORGES BANK. UNFORTUNATELY, THE XBT PROGRAMME ALONG THE NEW JERSEY–BERMUDA ROUTE WAS INTERRUPTED IN 2006, SO THERE IS NOTHING TO REPORT FROM THIS LINE. IN 2007, THE PROGRAMME WAS BEEN RE-ESTABLISHED, SO WE ANTICIPATE INCLUDING A REPORT NEXT YEAR.

Figure 23 shows the area from which the temperature information has been compiled. Note the distance scale in kilometres east of Boston towards Yarmouth, Nova Scotia. Figure 23 shows surface and bottom temperatures from XBTs taken along the line since the start of the programme in 1978. The lower panels show anomalies normalized by standard deviation for the 1978–1990 period. It can be seen that most anomalies span the entire Gulf of Maine when they occur. The year 2006 was warmer than average, a clear change from the mostly cooler previous 2.5 years. The Gulf of Maine has been average to warm for the past ten years. The bottom temperatures along this section demonstrate a somewhat different character, with cooler periods occurring much less frequently, only in 1998/1999 and 2004/2005. Because the bottom is rather shallow at each end, these regions demonstrate some evidence of being decoupled from the interior of the Gulf of Maine. During 2006, a strong warm anomaly spanned the entire section. Because the bottom waters are out of contact with the atmosphere, we must assume that this variation originates from the continental shelf and has been advected into the Gulf of Maine.

The Georges Bank surface observations (0–30 m) all come from the region enclosed by the red polygon in Figure 24. The depth contours are the same as before, 100 and 200 m, with an added dashed line at 50 m depth. The lower panels in Figure 24 show temperature and salinity anomalies. The anomalies are in original units relative to the mean for the 1978–1987 period. Note the continued warmer-than-normal temperatures; this is quite consistent with the XBT values.

What is perhaps more surprising is that the surface salinities are quite low, nearly 0.5 below the 1978–1987 period. Indeed, the waters have overall been warmer and fresher since approximately 1990. More usually in the Slope Sea (offshore of the Gulf of Maine), high salinities accompany high temperatures and vice versa. There is much we still do not understand about the shelf and Slope Sea waters.

GEORGES BANK WATERS HAVE BEEN WARMER BUT FRESHER SINCE 1990



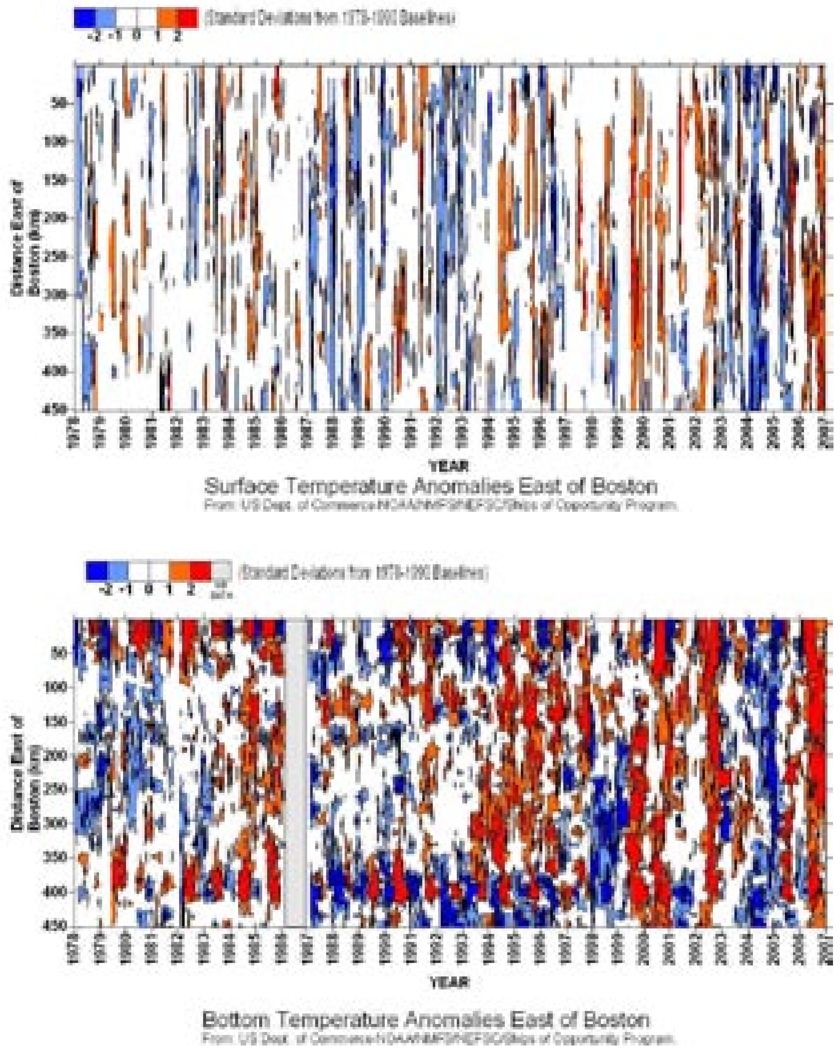


Figure 23. *Area 2c – Mid-Atlantic Bight. Upper panel is a chart showing the area from which expendable bathythermograph (XBT) observations are used to construct the time-series. Note the distance scale east from the longitude of Boston. The 100 and 200 m isobaths are shown. Sea surface temperature (middle panel) and bottom temperature (lower panel) east of Boston as a function of time since 1978 shown as normalized anomalies for the 1978–1990 period. Courtesy J. Jossi, National Marine Fisheries Service.*

ICES Cooperative Research Report No. 289

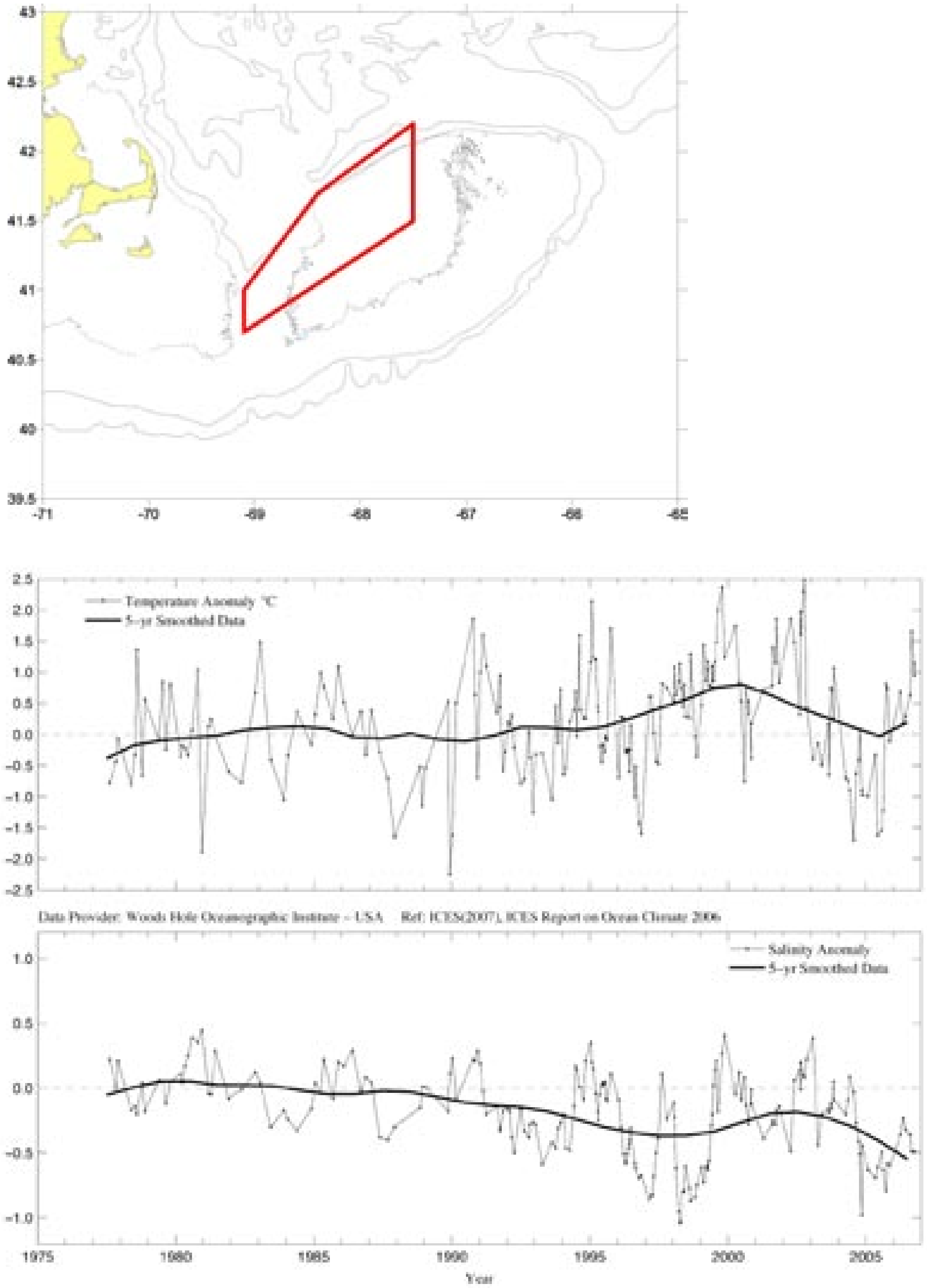


Figure 24. *Area 2c – Mid-Atlantic Bight. Upper panel is a chart of the northwest portion of Georges Bank. The 60 and 200 m isobaths (solid) and 60 m (dashed) are shown. Lower panels show time-series plots of 0–30 m averaged temperature and salinity at Georges Bank.*

► **Voluntary observing ships**

Many of the data presented here are collected from commercial vessels that voluntarily make ocean measurements along their journeys. The results from monthly sampling of surface and bottom temperatures for nearly three decades reveal the power of systematic or repeat sampling from merchant marine vessels. A number of vessels are now operating automated systems to sample temperature and salinity while under way. The key to success with these is to ensure that the data become available as soon as the vessel makes a port call. There is a pressing need for merchant marine-optimized techniques to track and report data from the ocean in a timely fashion.

The section east of Boston has depended upon observations from various vessels, including those from Eimskipafelag, Caribou Seafoods, the US Coast Guard, and Hans Speck and Son. Their cooperation is greatly appreciated.

6.6 Area 3 – Icelandic waters

Iceland is at a meeting place of warm and cold currents. These converge in an area of submarine ridges (Greenland–Scotland Ridge, Reykjanes Ridge, Kolbeinsey Ridge), which form natural barriers against the main ocean currents. The warm Irminger Current, which is a branch of the North Atlantic Current (6–8°C), flows from the south, and the cold East Greenland and East Icelandic currents (–1°C to 2°C) flow from the north. Deep and bottom currents in the seas around Iceland are principally the overflow of cold water from the Nordic Seas and the Arctic Ocean over the submarine ridges into the North Atlantic.

Hydrographic conditions in Icelandic waters are generally closely related to the atmospheric or climatic conditions in and over the country and the surrounding seas, mainly through the Iceland Low and the High Pressure over Greenland. These conditions in the atmosphere and the surrounding seas affect biological conditions, expressed through the food chain in the waters, including recruitment and abundance of commercial fish stocks.

In 2006, mean air temperatures in the south (Reykjavik) and north (Akureyri) were above long-term averages. During the year, temperature and salinity south and west of Iceland remained high. In spring and autumn, some influence of sea ice was reflected in the northern area in the lowest temperatures for ten years, accompanied by lower salinities. The temperature and salinity conditions had changed back to values above long-term means in February 2007. Salinity and temperature measurements in the East Icelandic Current in spring 2006 were above average.

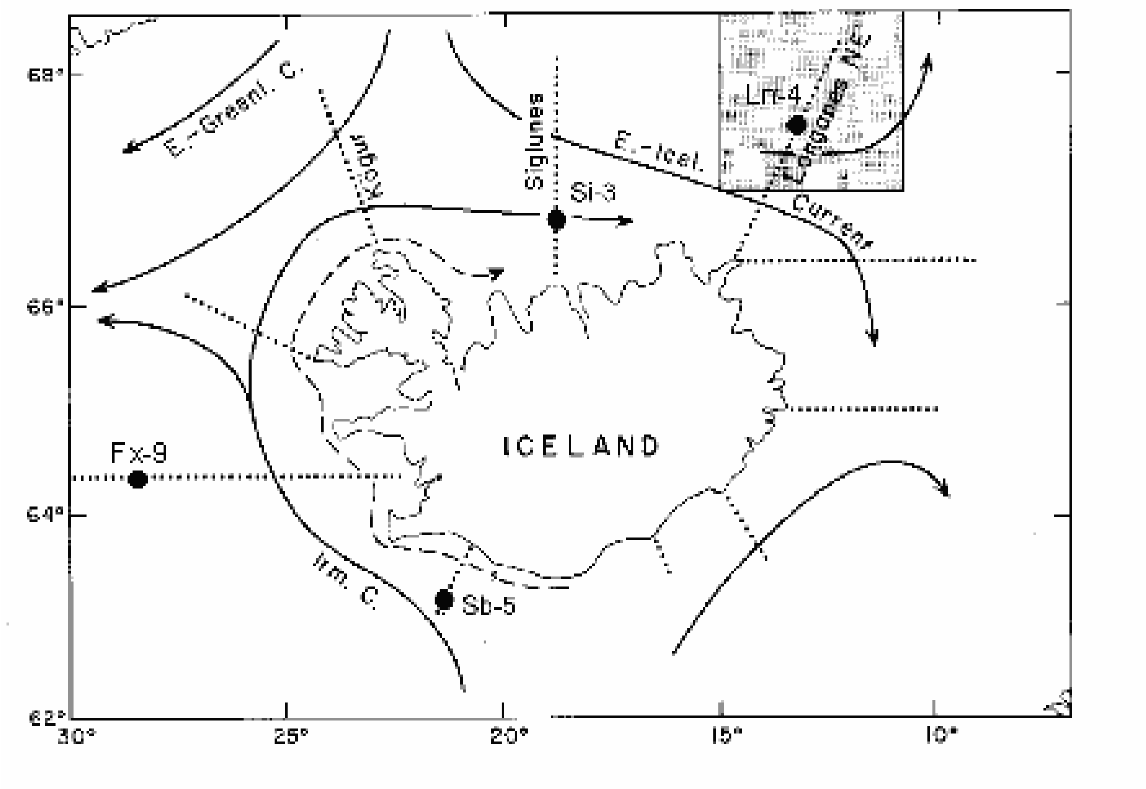


Figure 25. *Area 3 – Icelandic waters. Main currents and location of standard hydrobiological sections in Icelandic waters.*

ICES Cooperative Research Report No. 289

Figure 26. *Area 3 – Icelandic waters. Mean annual air temperature at Reykjavik (upper panel) and Akureyri (lower panel).*

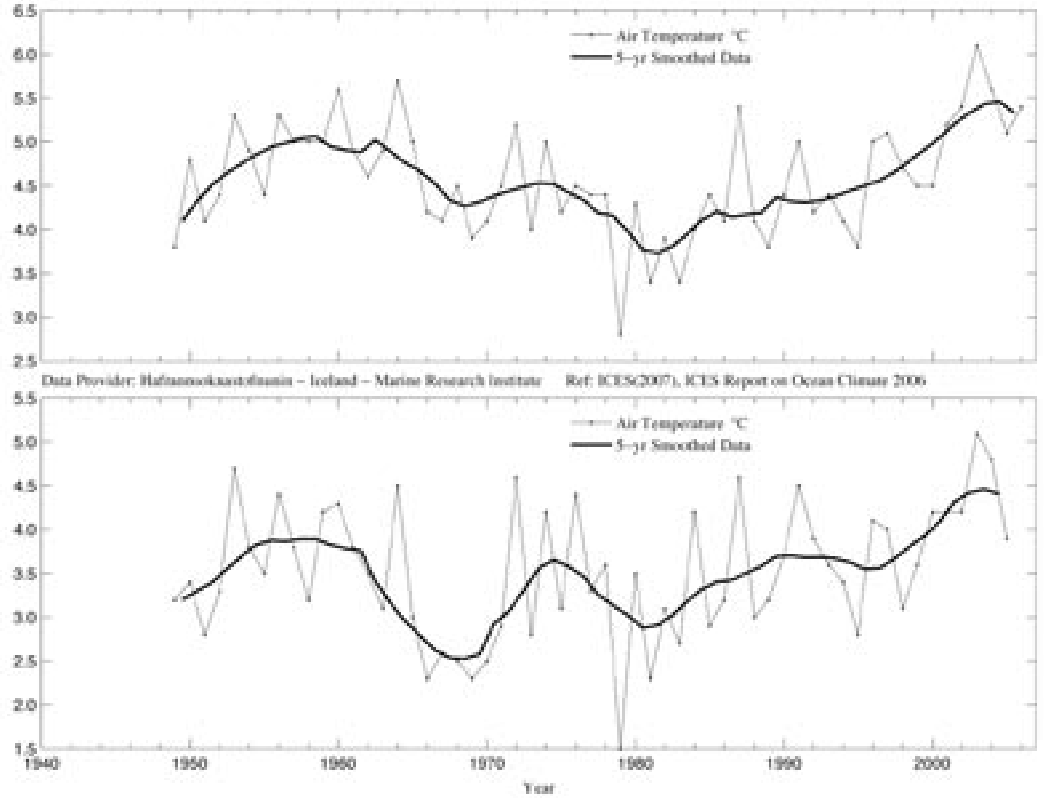


Figure 28. *Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) between 0 and 200 m at Station Sb5 in South Icelandic waters.*

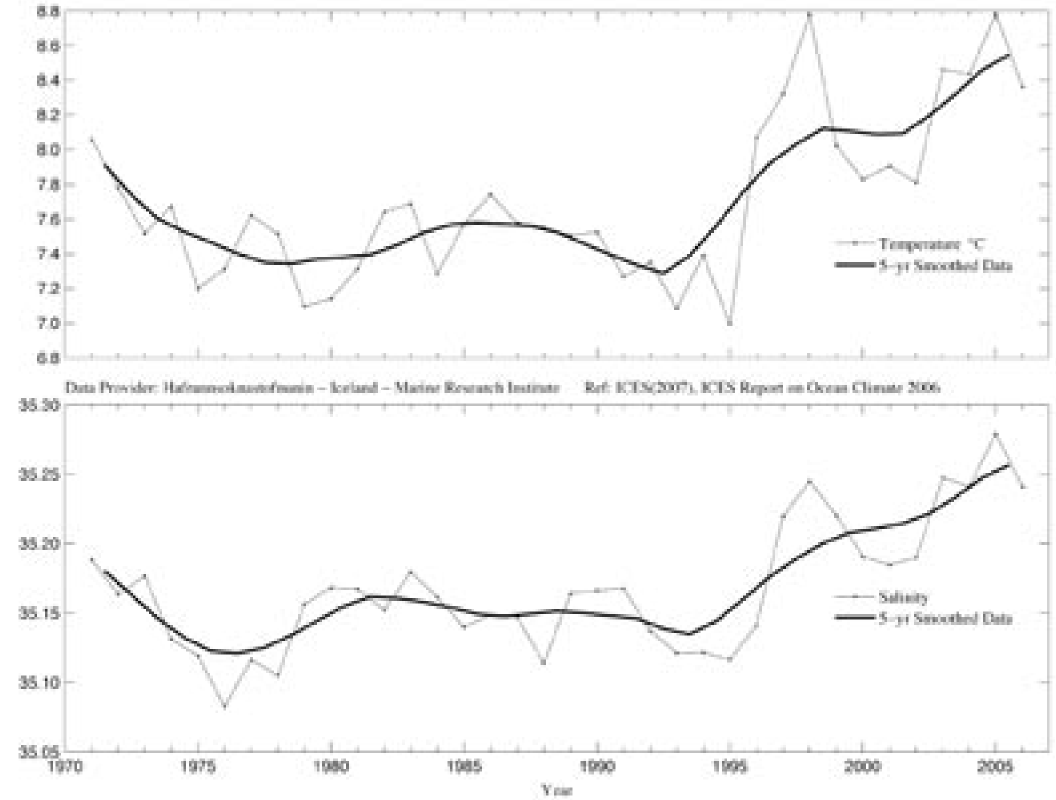


Figure 27. *Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 50–150 m depth at Stations Si2–4 in North Icelandic waters.*

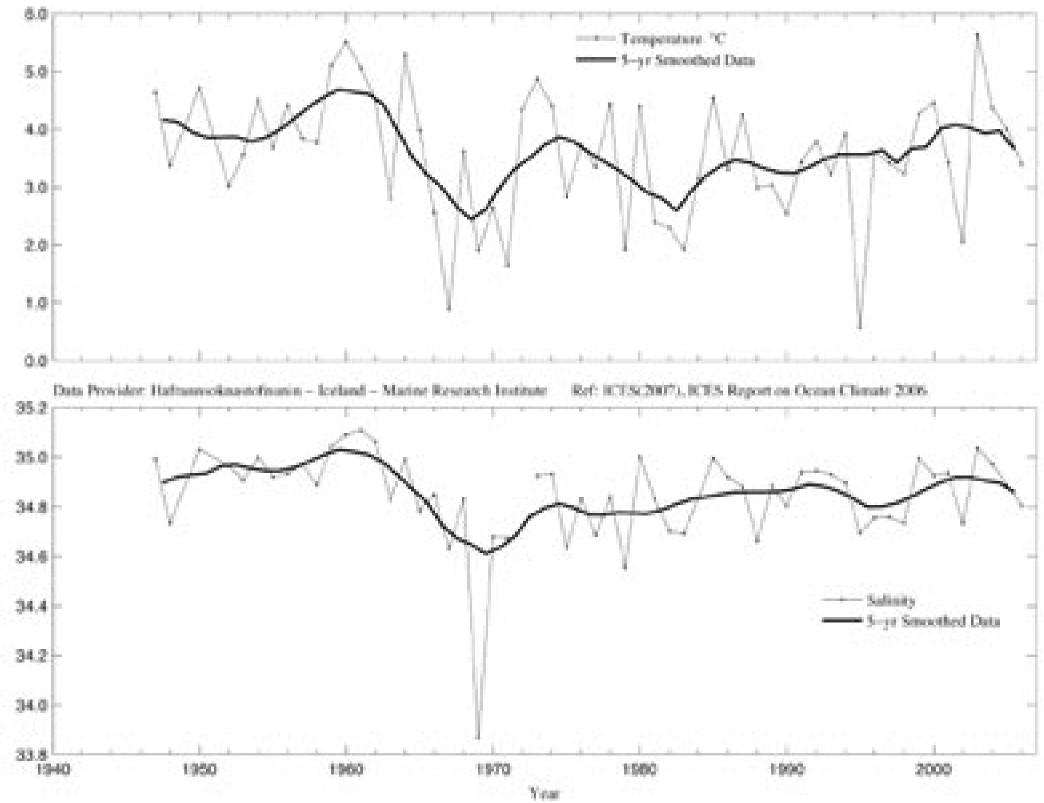
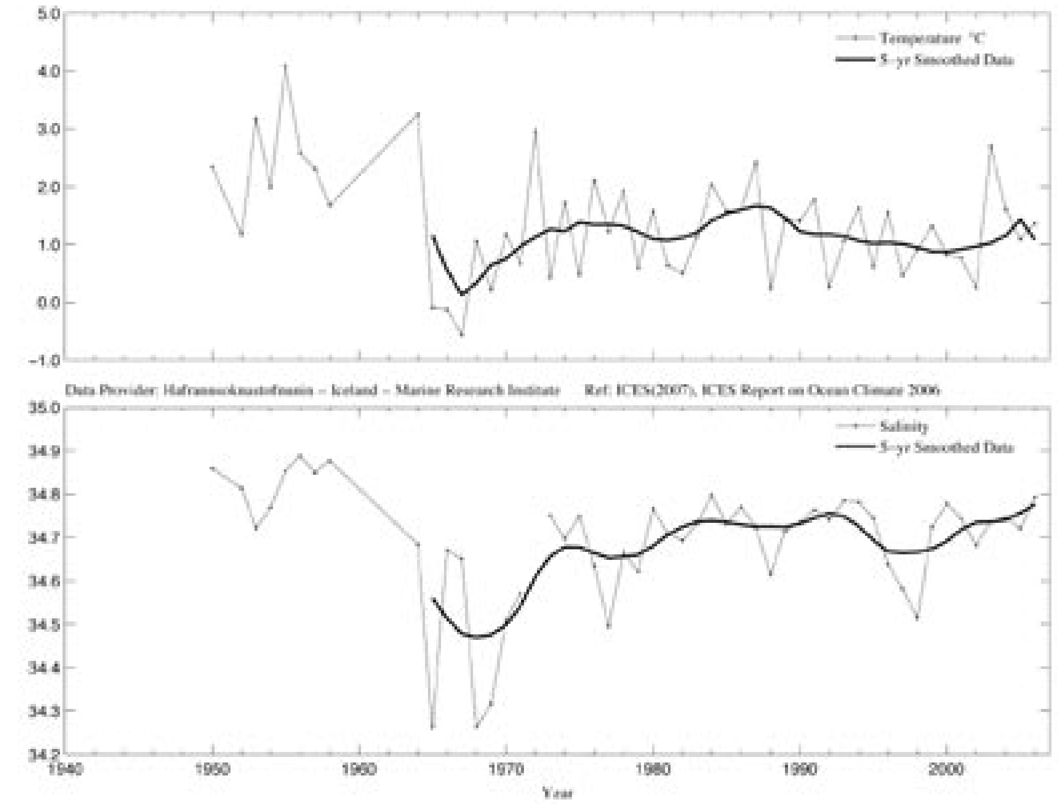


Figure 29*. Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) between 0 and 50 m in the East Icelandic Current (Station Lna2–6).*



ICES Cooperative Research Report No. 289

6.7 Area 4 – Bay of Biscay and eastern Atlantic

THE BAY OF BISCAY IS LOCATED IN THE EASTERN PART OF THE NORTH ATLANTIC. ITS GENERAL CIRCULATION FOLLOWS THE SUBTROPICAL ANTICYCLONIC GYRE AND IS RELATIVELY WEAK (1–2 CM S^{-1}). IN THE SOUTHERN PART OF THE BAY OF BISCAY, EAST-FLOWING SHELF AND SLOPE CURRENTS ARE COMMON IN AUTUMN AND WINTER AS A RESULT OF WESTERLY WINDS. IN SPRING AND SUMMER, EASTERLY WINDS ARE DOMINANT, AND COASTAL UPWELLING EVENTS ARE FREQUENT.

The annual mean air temperature in the southern Bay of Biscay during 2006 has exceeded 15.5°C, more than 1°C over the 1961–2000 average, making 2006 one of the warmest years of the past three decades. As in recent years, however, the annual average disguises unusually cold winters and warm summers. In fact, for 2006, early winter was especially cold while July was extremely warm. A similar pattern was seen in the sea surface temperature; the average value for 2006 is the highest of the time-series (17.43°C).

Between 1998 and 2001, freshening was observed in the water from 0 to 300 m. In 2002, this trend was reversed during a period of the episodic Iberian Poleward Current. From 2003 to 2006, an increase in salinity was observed in the upper 300 m. The salinity is related to both atmospheric forcing in the formation area of the ENACW (precipitation and evaporation) and the Iberian Poleward Current. The marked increase in salinity in the ENACW in 2005 and 2006 is also observed between 300 m and 600 m.

THE ANNUAL AVERAGE DISGUISES UNUSUALLY COLD WINTERS AND WARM SUMMERS

In 2006, a cold winter and warm summer and autumn produced a high sea surface temperature, but in the subsurface water column (0–300 m), the cold, deep, winter mixed layer from the previous years remained. The deepening of the mixed layer that was the main feature during 2005 occurred again in 2006. The cold sea surface temperature and strong winds combined with the low stratification from the previous year to produce a newly ventilated mixed layer 300 m deep. This event effectively reversed the recent warming trend of the upper layers of the Eastern North Atlantic Central Water (ENACW). Moreover, relatively low precipitation and river run-off kept the salinity high in the waters below the seasonal thermocline.

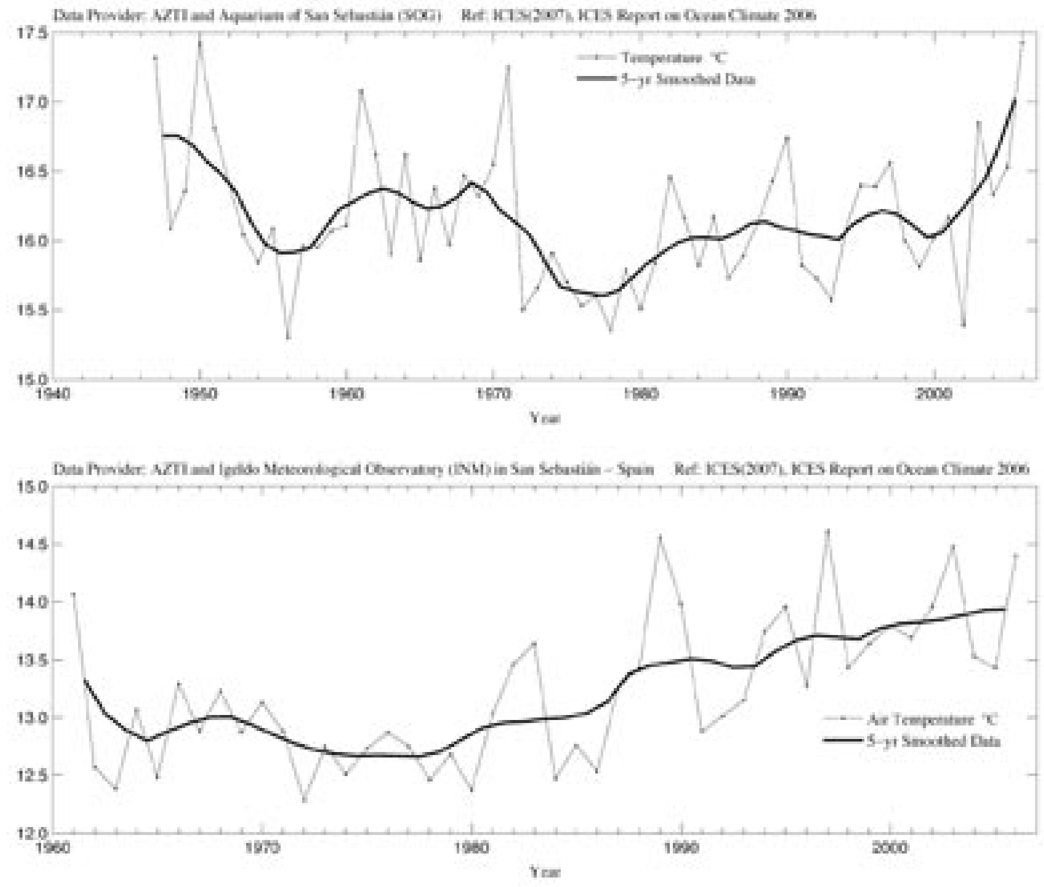


Figure 30. *Area 4 – Bay of Biscay and eastern Atlantic. Sea surface temperature (upper panel) and air temperature (lower panel) at San Sebastian (43°18.5′N 02°2.37′W).*

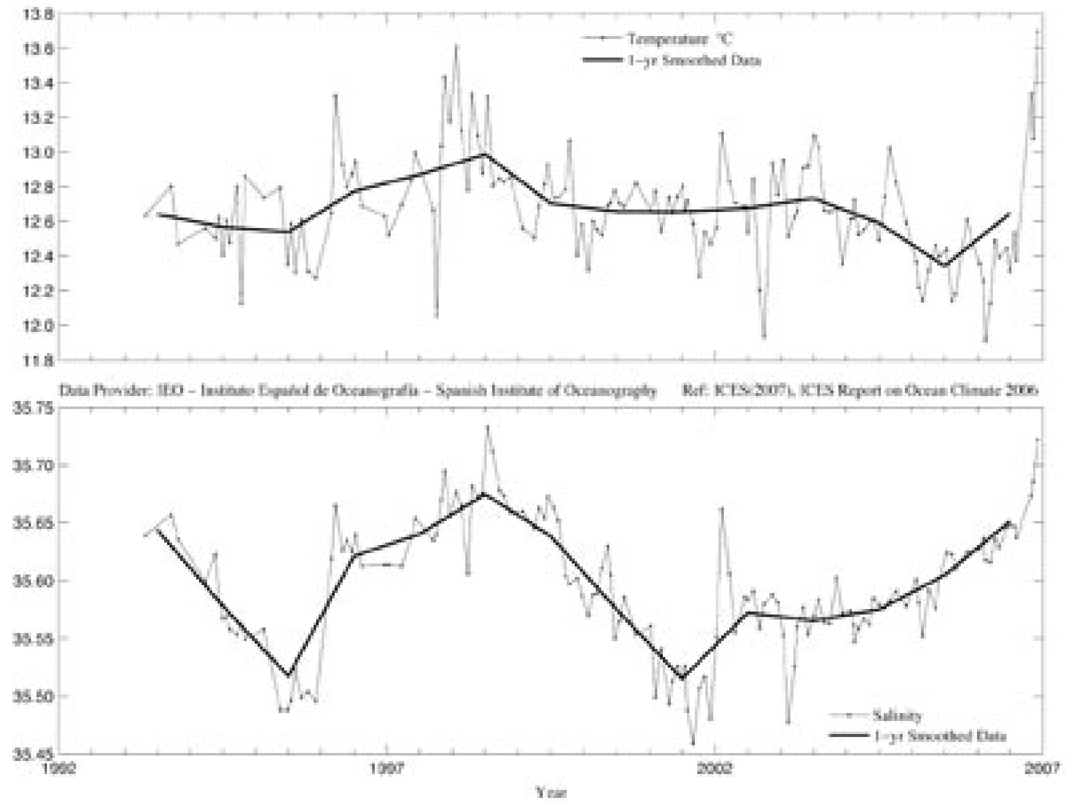
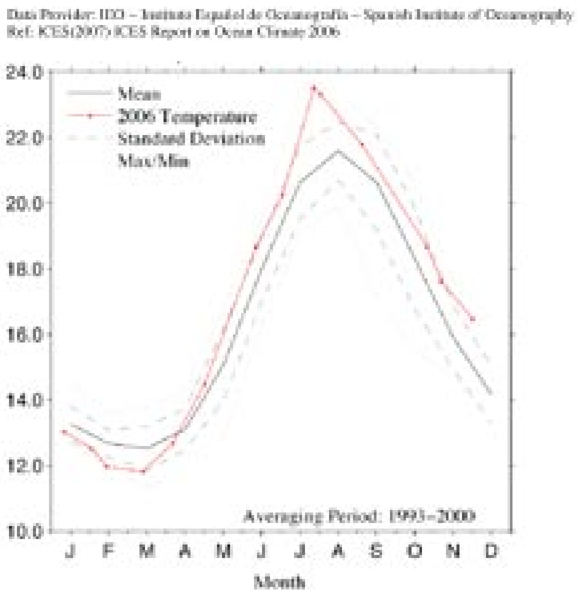


Figure 31. *Area 4 – Bay of Biscay and eastern Atlantic. Potential temperature (upper panel) and salinity (lower panel) at Santander Station 6 (5–300 m).*

Figure 32. *Area 4 – Bay of Biscay and eastern Atlantic. Monthly potential temperature at Santander Station 6 (5–300 m).*



6.8 Area 5 – Rockall Trough

The Rockall Trough is situated west of Britain and Ireland, 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 allows warm North Atlantic upper water to reach 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 characterized by polewards-moving Eastern North Atlantic Water, which is warmer and saltier than waters of the Iceland Basin (that also contribute to the Nordic Sea inflow). This also contributes to the Nordic Sea inflow. Below 1200 m, the intermediate water mass, the Labrador Sea Water, is trapped by the shallowing topography to the north, which prevents through-flow, but allows recirculation within the basin.

In 2006, the warm and saline conditions persisted in the upper ocean of the Rockall Trough, though salinity has been decreasing since a peak in 2003. The notable decrease in mean salinity in 2006 was caused by the presence of fresher water between the Anton Dohrn Seamount (11°W) and the Rockall Bank (13°W); however, the shelf edge current (at 9°W) had persistently high salinities. Temperatures once again reached record levels, though most of the additional warming since 2005 was confined to the upper 400 m. Upper ocean temperatures (0–800 m) were 0.8°C and salinity 0.04 above the long-term mean (1975–2000).

Warm and saline conditions persisted

The time-series of surface observations at the Malin Head coastal station (the most northerly point of Ireland) demonstrate a similar pattern in the upper layer open ocean measurements. The coastal station is inshore of coastal currents and influenced by run-off. Since the late 1980s, temperatures have been increasing, with the mid-2000s being the highest recorded since the records began in 1960. The seasonal cycle on the Irish Shelf is illustrated by data from the M1 weather buoy west of Galway.

The core of the deep Labrador Sea Water demonstrated continued cooling, a trend that has dominated the entire time-series. The salinity in 2006 was lower than that in 2005, and the long-term freshening trend has continued. The core of the water mass is defined here as the part of the water column with the lowest stratification.

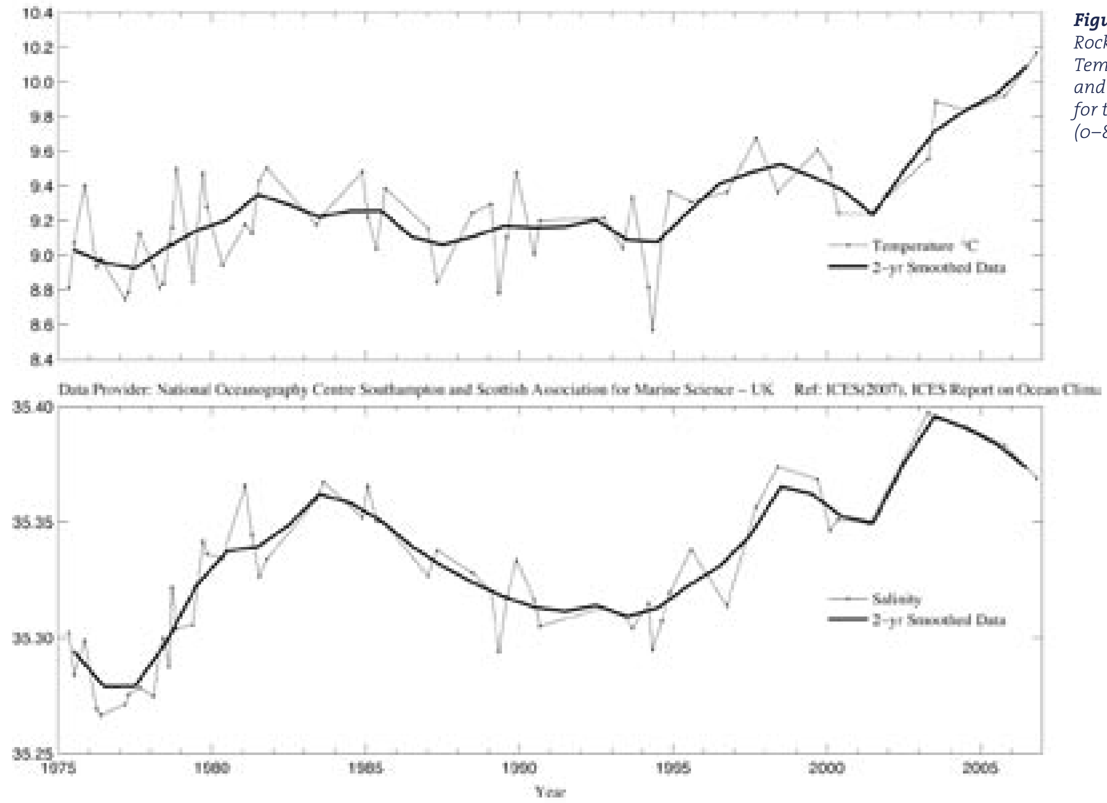


Figure 33. *Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) for the upper ocean (0–800 m).*

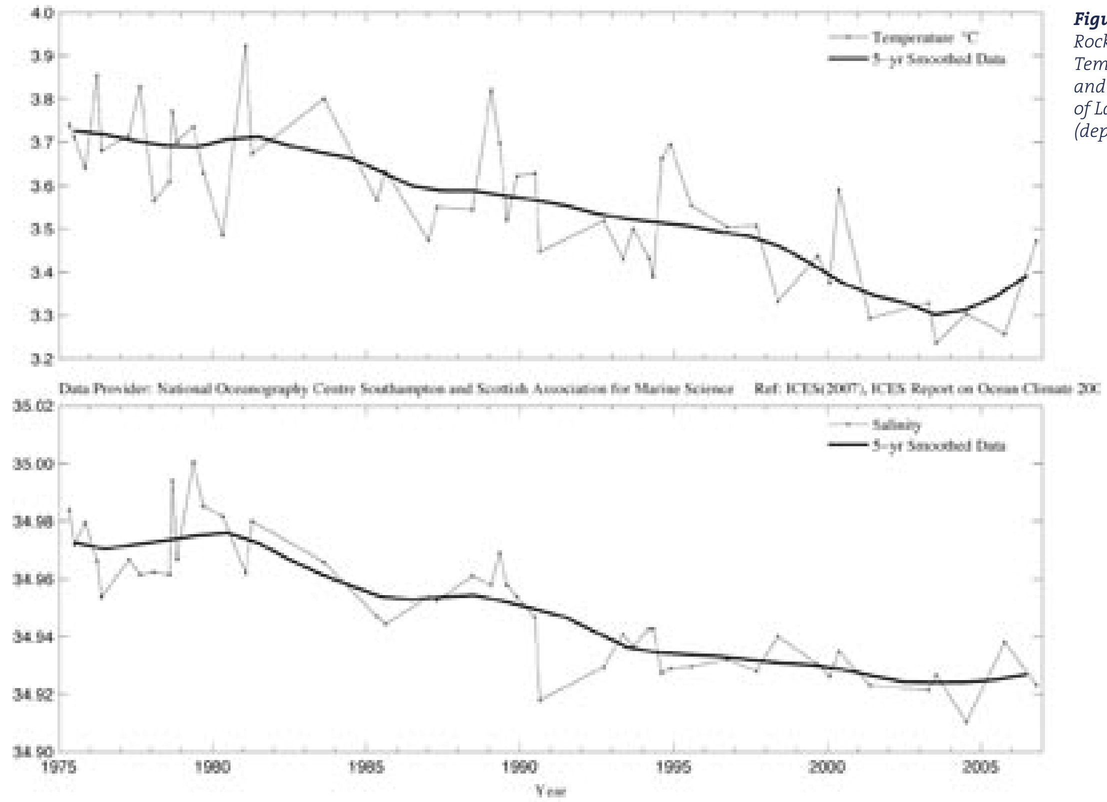


Figure 34. *Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (depth 1800–2000 m).*

ICES Cooperative Research Report No. 289

Figure 35. *Area 5 – Rockall Trough. Temperature at the Malin Head coastal station (55.39°N 7.38°W).*

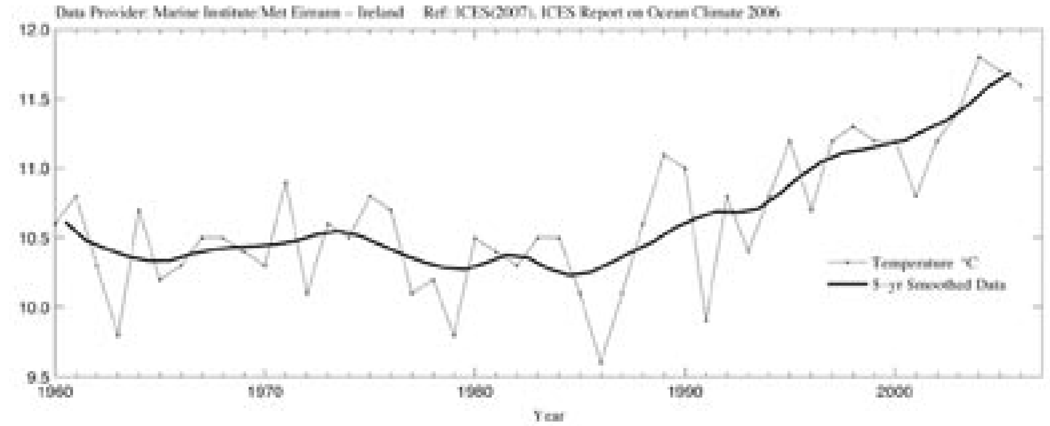
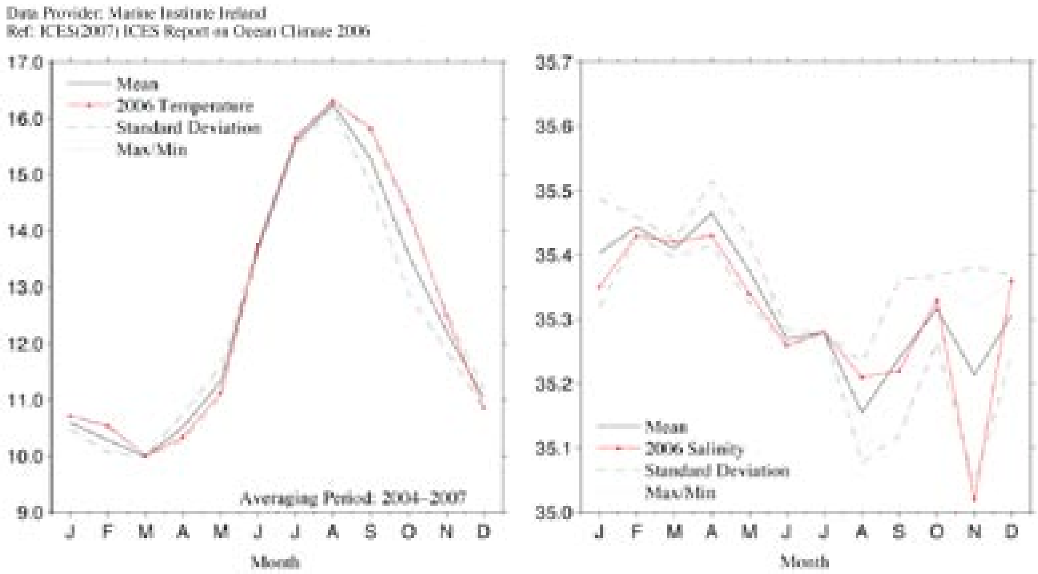


Figure 36. *Area 5 – Rockall Trough. Monthly temperature (left panel) and salinity (right panel) at the M1 weather buoy west of Galway, Ireland.*



6.9 Area 5b – Irminger Sea

THE IRMINGER SEA IS THE OCEAN BASIN BETWEEN SOUTHERN GREENLAND, THE REYKJANES RIDGE, AND ICELAND. THIS AREA FORMS PART OF THE NORTH ATLANTIC SUBARCTIC ANTICYCLONIC GYRE. BECAUSE OF THIS GYRE, THE EXCHANGE OF WATER BETWEEN THE IRMINGER SEA AND LABRADOR SEA IS RELATIVELY FAST. IN THE BOTTOM LAYERS OF THE IRMINGER SEA COLD WATER, ORIGINATING IN THE (SUB)ARCTIC SEAS FLOWS FROM THE DENMARK STRAIT SOUTHWARDS OVER THE CONTINENTAL SLOPE OF GREENLAND.

The Subpolar Mode Water in the centre of the Irminger Sea, in the pressure interval 200–400 dbar, reached its highest temperature and salinity since 1991 in 2004. Since then a slight cooling and freshening has occurred. Although convection that reached depths of more than 600 m in the following winters reduced temperature and salinity slightly, the values of these parameters for the Subpolar Mode Water in summer 2005 were still considerably higher than those observed before 1998. Thus, the trend of increasing temperature and salinity that started in 1995/1996 seems to have continued during 2006.

From 1600 to 2000 dbar, a cold and low-salinity core was observed in the Irminger Sea during the early 1990s. This was the result of the presence of deep Labrador Sea Water formed in the period 1988–1995. Since summer 1996, this Labrador Sea Water core has been increasing in temperature and salinity as it mixes with surrounding water masses. The salinity increase levelled off in 2002 and remained constant until 2005; it increased again in 2006 to the highest value observed since 1991.

The salinity and potential temperature of the Denmark Strait Overflow Water (DSOW) near Cape Farewell demonstrate considerable well-correlated interannual variations between 1991 and 2006 (correlation = 0.7). The long-term trends of salinity and temperature since 1991 are hardly significant (temperature) or not significant (salinity). The long-term standard deviations of temperature and salinity are 0.15°C and 0.014, respectively. The highest DSOW temperature since 1991 was observed in 2006 and the second highest in 1991.

► **Understanding patterns of variability**
The ocean at any one location varies on many timescales from hours and days, to decades, centuries and millennia. In this report, we aim to identify variations on a timescale of months to decades, so when we interpret time-series that sample the ocean only a few times per year, or even once per year, we need to understand how the shorter timescales or higher frequency changes might affect the results. A good example is the apparently erratic behaviour of the annual time-series from deep water in the Irminger Sea. A new set of daily measurements with a moored sensor system over three years (2003–2006) reveals that the erratic annual time-series is, in fact, a poor representation of variability within each year. This is known as "aliasing" and is a significant problem in interpreting long-term changes.

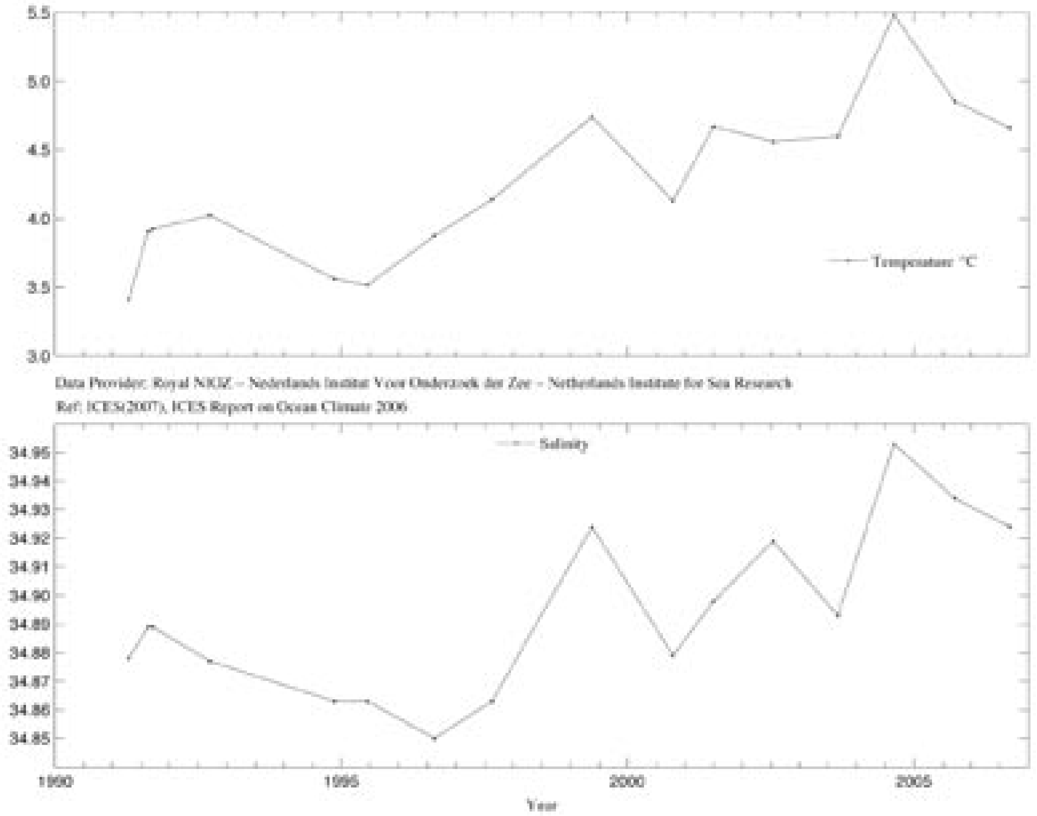


Figure 37. *Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Subpolar Mode Water (averaged over 200–400 m).*

HIGHEST DENMARK STRAIT OVERFLOW WATER TEMPERATURE WAS OBSERVED IN 2006

ICES Cooperative Research Report No. 289

Figure 38. *Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (averaged over 1600–2000 m).*

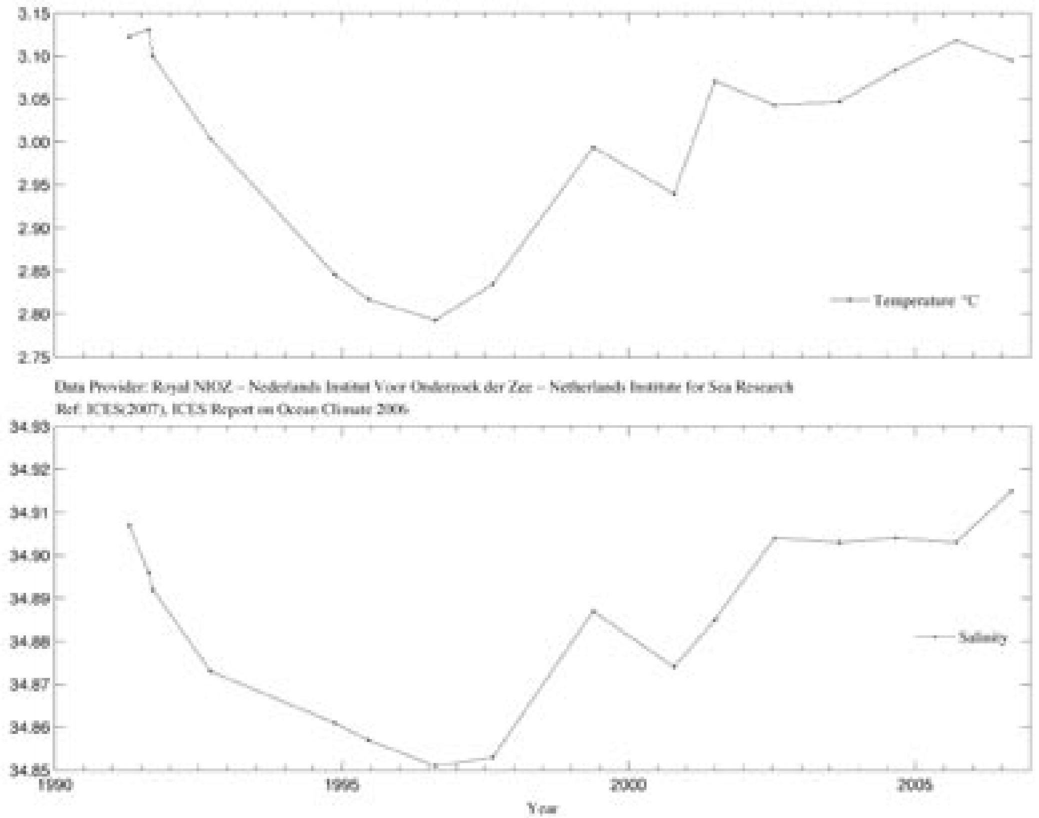
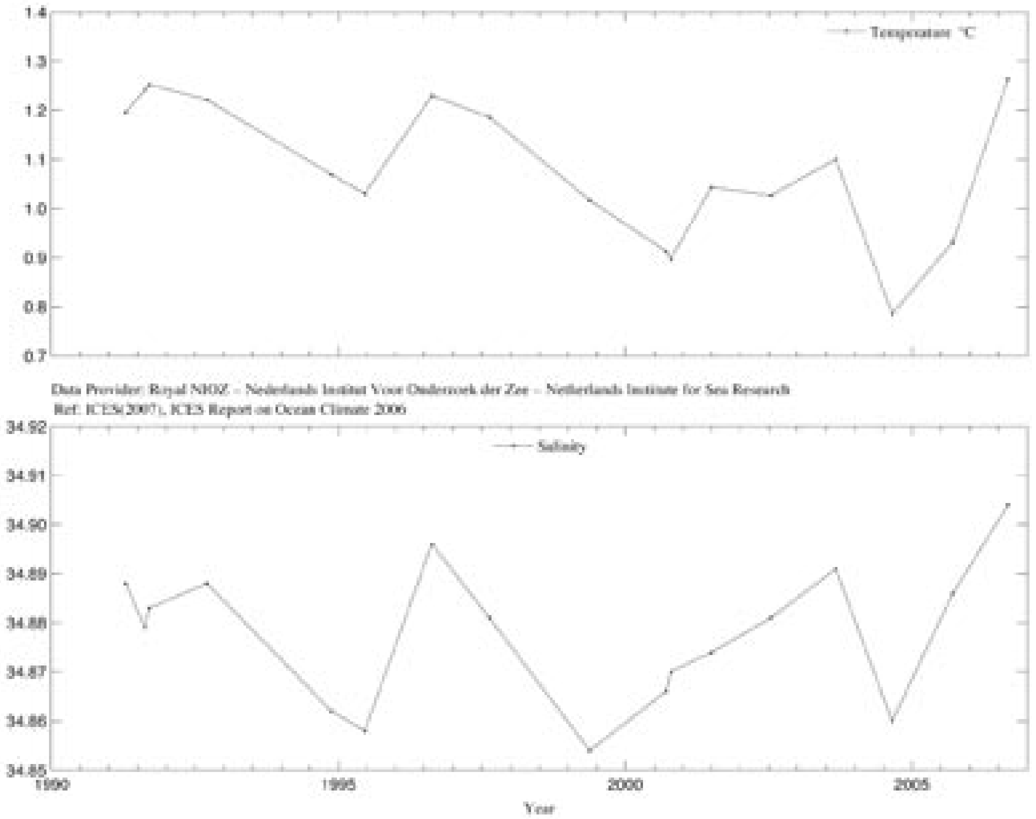


Figure 39. *Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Denmark Strait Overflow Water on the East Greenland Slope.*



6.10 Area 6 – Faroe Bank Channel and Faroe Current

ONE BRANCH OF THE NORTH ATLANTIC CURRENT CROSSES THE GREENLAND–SCOTLAND RIDGE ON BOTH SIDES OF THE FAROES (TO THE SOUTH THROUGH THE FAROE BANK CHANNEL, TO THE NORTH IN THE FAROE CURRENT).

Since 1988, temperature and salinity of the upper waters have been steadily increasing. Values were slightly down from 2004, but remained higher than the average value for the time-series.

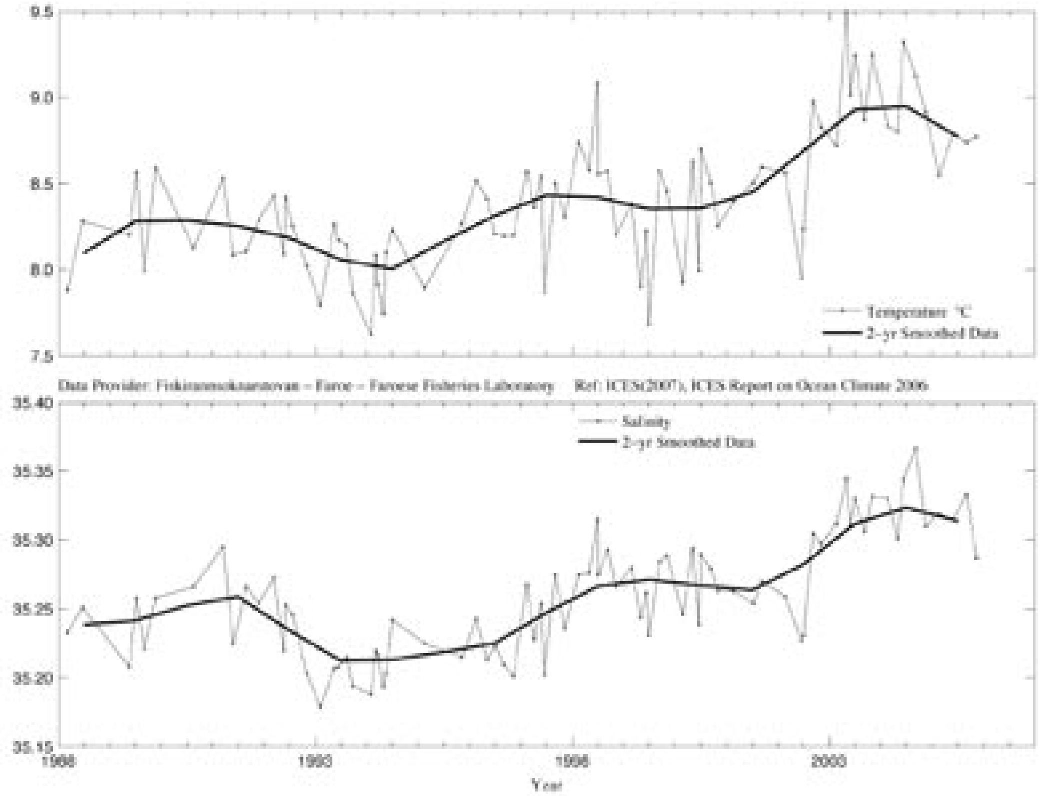


Figure 40. *Area 6 – Faroe Bank Channel. Temperature (upper panel) and salinity (lower panel) from the layer 100–300 m deep at two standard stations in the channel.*

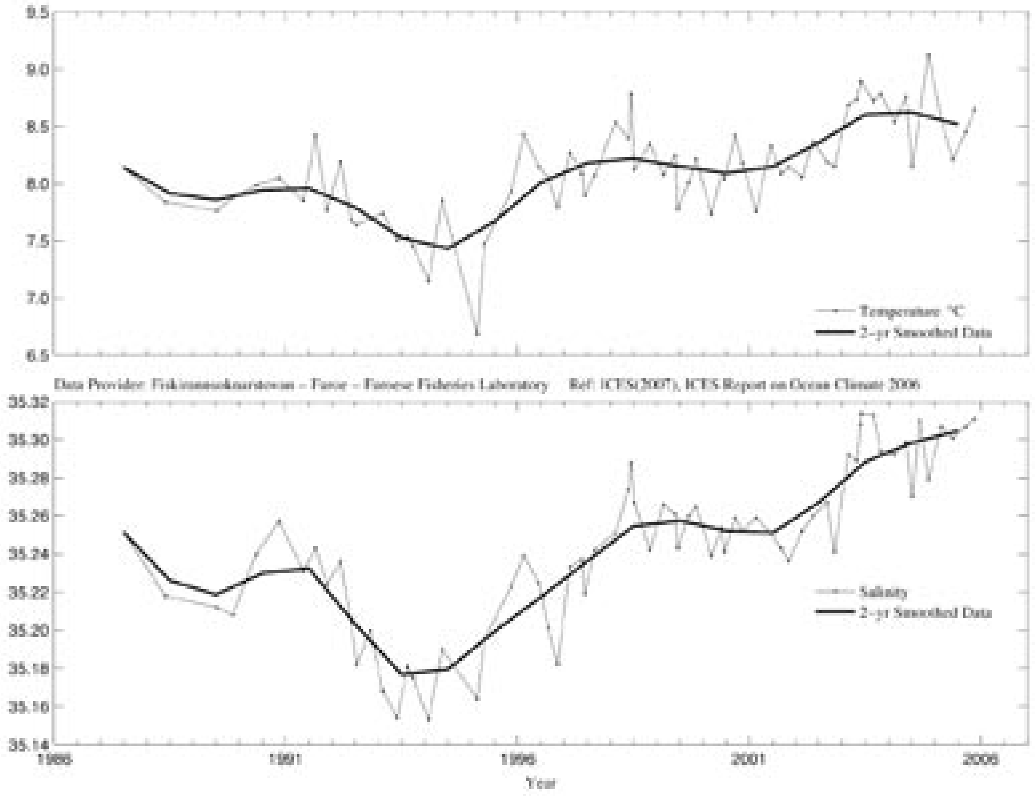


Figure 41. *Area 6 – Faroe Bank Channel. Temperature (upper panel) and salinity (lower panel) in the core of the Faroe Current (maximum salinity averaged over a layer 50 m in depth.*

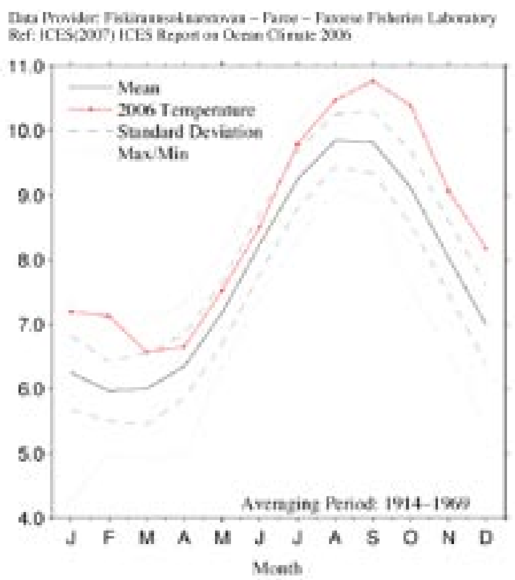


Figure 42: *Area 6 – Faroe Bank Channel. Monthly temperature data from the Faroe coastal stations Mykines (1914–1969, 69.10°N 7.66°W) and Oyrargjogv (1991 onwards, 62.12°N 7.17°W).*

6.11 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.

The surface waters of the Faroe Shetland Channel have generally increased in temperature and salinity over the past two decades, with record high temperatures observed in 2003. Both temperature and salinity have declined slightly since 2003. Although salinity values were high in 2003, they have been at this level in the past.

In the deeper layers, the properties at 800 m are the same as those of Norwegian Sea Deep Water as it passes through the channel back into the North Atlantic. The salinity at 800 m has remained relatively stable since the early 1990s, after a period of decline. The temperature has increased slightly since 2000, but is still lower than temperatures observed during the 1960s.

TEMPERATURE AND SALINITY HAVE DECLINED SLIGHTLY SINCE 2003

► Since 1970, the sampling frequency in the Faroe Shetland Channel has increased and, over that period, a decadal scale cycle of temperature and salinity has emerged in the properties of the Atlantic Water, thought to be related to wider scale changes in atmospheric and oceanic circulation. This pattern is not so clear in the Modified North Atlantic Water, which travels into the Faroe Shetland Channel from around the north of Faroe.

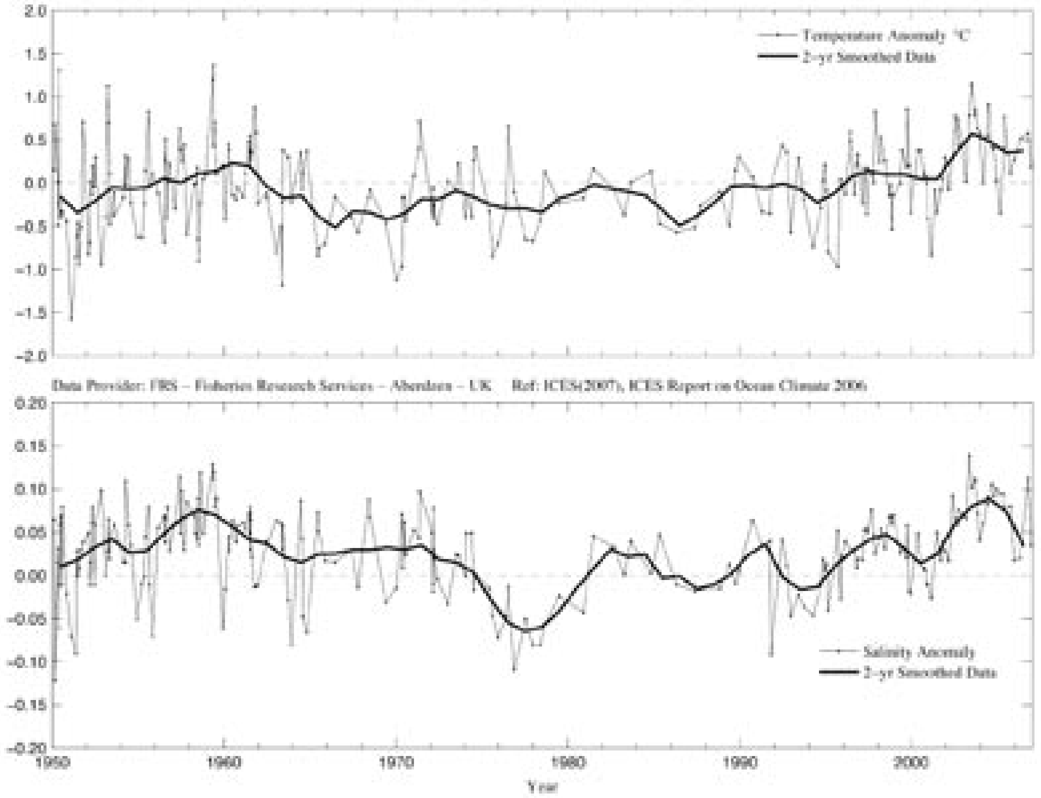


Figure 43. *Area 7 – Faroe Shetland Channel. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Atlantic Water in the Slope Current.*

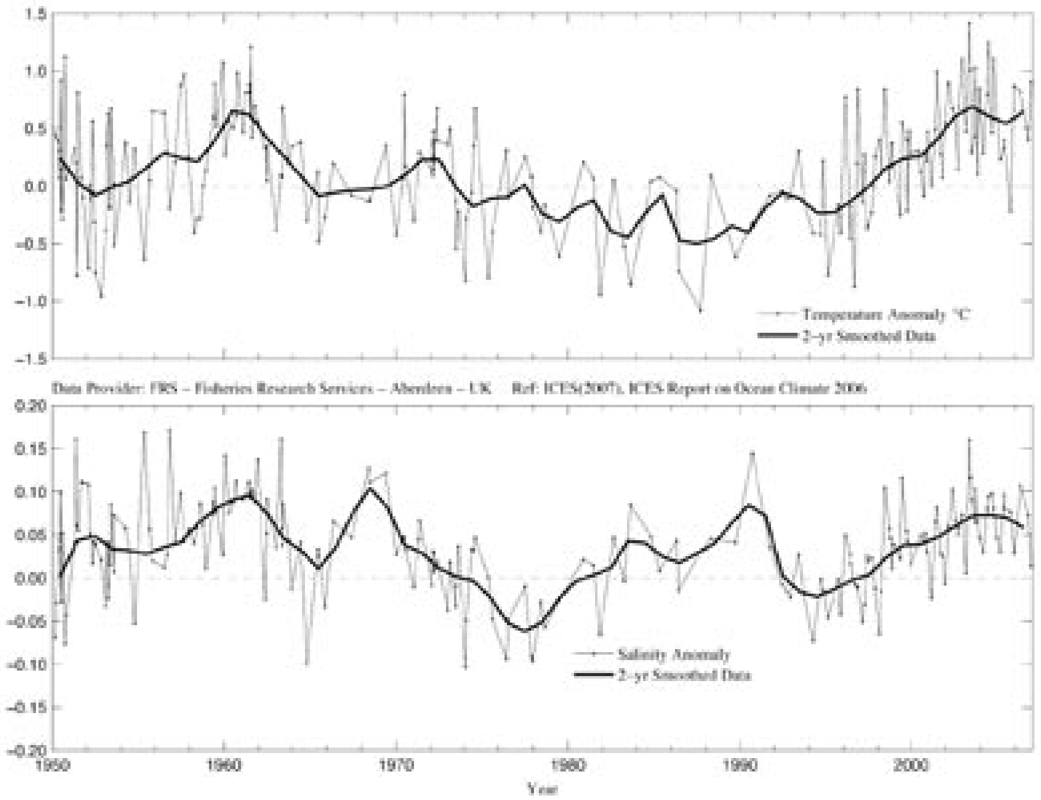


Figure 44. *Area 7 – Faroe Shetland Channel. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Modified Atlantic Water entering the Faroe Shetland Channel from the north after circulating around Faroe.*

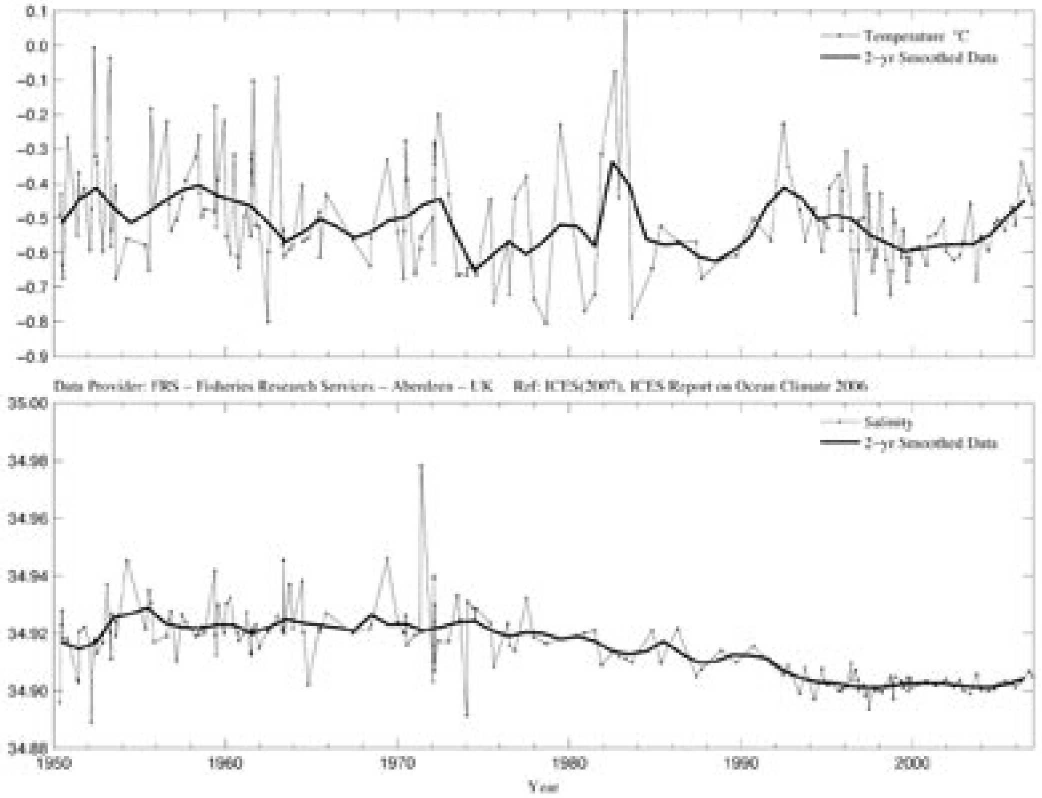


Figure 45. *Area 7 – Faroe Shetland Channel. Temperature (upper panel) and salinity (lower panel) at 800 m in the Faroe Shetland Channel.*

6.12 Areas 8 and 9 – northern and southern North Sea

NORTH SEA OCEANOGRAPHIC CONDITIONS ARE DETERMINED BY THE INFLOW OF SALINE ATLANTIC WATER AND THE OCEAN–ATMOSPHERE HEAT EXCHANGE. THE INFLOW THROUGH THE NORTHERN ENTRANCES (AND, TO A LESSER DEGREE, THROUGH THE ENGLISH CHANNEL) CAN BE STRONGLY INFLUENCED BY THE NAO. NUMERICAL MODEL SIMULATIONS ALSO DEMONSTRATE STRONG DIFFERENCES IN THE NORTH SEA CIRCULATION, DEPENDING ON THE STATE OF THE NAO. THE ATLANTIC WATER MIXES WITH THE RIVER RUN-OFF AND LOWER SALINITY BALTIC OUTFLOW ALONG THE NORWEGIAN COAST. A BALANCE OF TIDAL MIXING AND LOCAL HEATING FORCES THE DEVELOPMENT OF A SEASONAL STRATIFICATION FROM APRIL/MAY TO SEPTEMBER IN MOST PARTS OF THE NORTH SEA.

Area-averaged sea surface temperatures of the North Sea have been increasing since June 2001. The vegetation period (primary production) was much longer than usual in 2006.

During the first two months of 2006, the mean sea surface temperatures in the North Sea clearly exceeded the long-term mean (0.7–0.8°C), because of the warm temperatures in autumn 2005. Between March and June the values were comparable with the climatological means (1971–1993). From July onwards, the sea surface temperatures exceeded the climatological mean significantly, with October and December (2.4 and 1.7°C above the long-term mean) being the warmest since the beginning of these observations in 1971. The August surface temperatures along the eastern coast of the North Sea were approximately 3°C higher than in 2005, and along the open northern boundary along 60°N they were approximately 1°C higher than in 2005.

The Helgoland Roads standard station demonstrates that, since the cold winter of 1996, sea surface temperature has been above the 30-year mean (1971–2000), with positive anomalies of 0.5–1.0°C. In 2006, March and April revealed negative anomalies up to –1°C, but positive anomalies exceeded 1°C continuously from June to December, with maximum anomalies of 2.7°C in October and 2.3°C in December.

The vegetation period (primary production) was much longer than usual

The sea surface salinity pattern in 2006 was comparable with that in 2005, but the 35-isohaline penetrated farther south into the central North Sea, covering a larger area. The 34-isohaline, which marks the boundary between the saline North Sea water and the less saline water modified by the Baltic and river outflows, was closer to the coast than it was in 2005. Near the bottom, the southern North Sea was fresher than in the preceding year; the total North Sea salt content decreased from 1.153 - 10^{12} tonnes in August 2005 to 1.138 - 10^{12} tonnes in August 2006. In 2005 and 2006, run-off from the rivers Elbe and Weser were close to the long-term mean after a minimum run-off in 2004. There was an extreme Elbe run-off in April 2006, however, caused by extraordinary snowfall in the winter of 2005/2006.

Temperature and salinity at two positions in the northern North Sea illustrate conditions in the Atlantic inflow (Figure 47). The first (Location A) is at the near bottom in the northwestern part of the North Sea, and the second (Location B) is in the core of the Atlantic Water at the western shelf edge of the Norwegian Trench. The measurements were carried out during summer and represent the previous winter's conditions. The average temperature at Location A was 1–2°C lower than that at Location B, and the salinity was also slightly lower. In both places, there were high temperatures and salinities in 2005. This was the result of the high salinity of the inflowing Atlantic Water and the effect of a mild winter (though the relatively cold winter and spring of 2005 led to less extreme temperatures in the deep layers than in 2004).

▶ In the Skagerrak, in addition to overall increased temperature, the length of the warm season has increased significantly over the last few years (conditions in the Skagerrak are thought to be representative of conditions throughout the North Sea). This is unlike most of the past 45 years, though similar conditions were observed around 1990. The result is that cold water, previously observed during large parts of the year, has now been absent for several years. Together with the high temperatures, this will have significant effects on ecosystem dynamics in the North Sea and the Skagerrak.

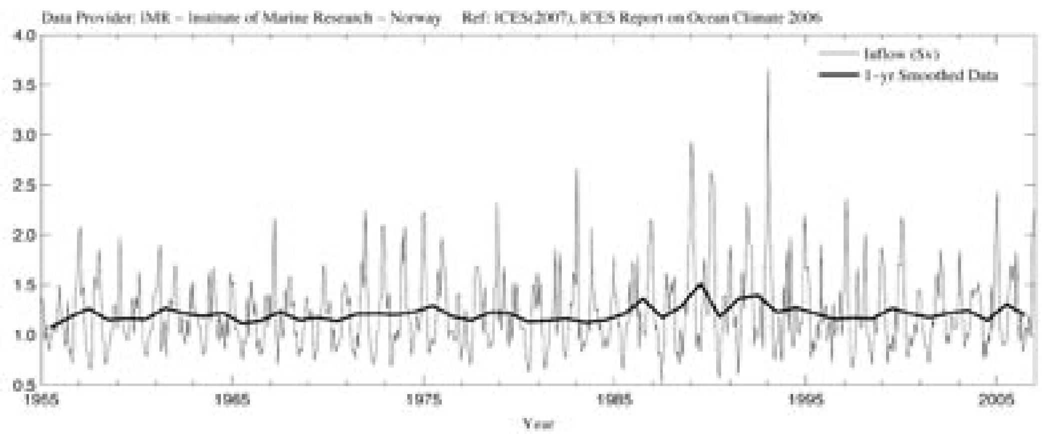


Figure 46. *Area 8 – Northern North Sea. Modelled annual mean (bold) and monthly mean volume transport of Atlantic Water into the northern and central North Sea, southwards between the Orkney Islands and Utsira, Norway.*

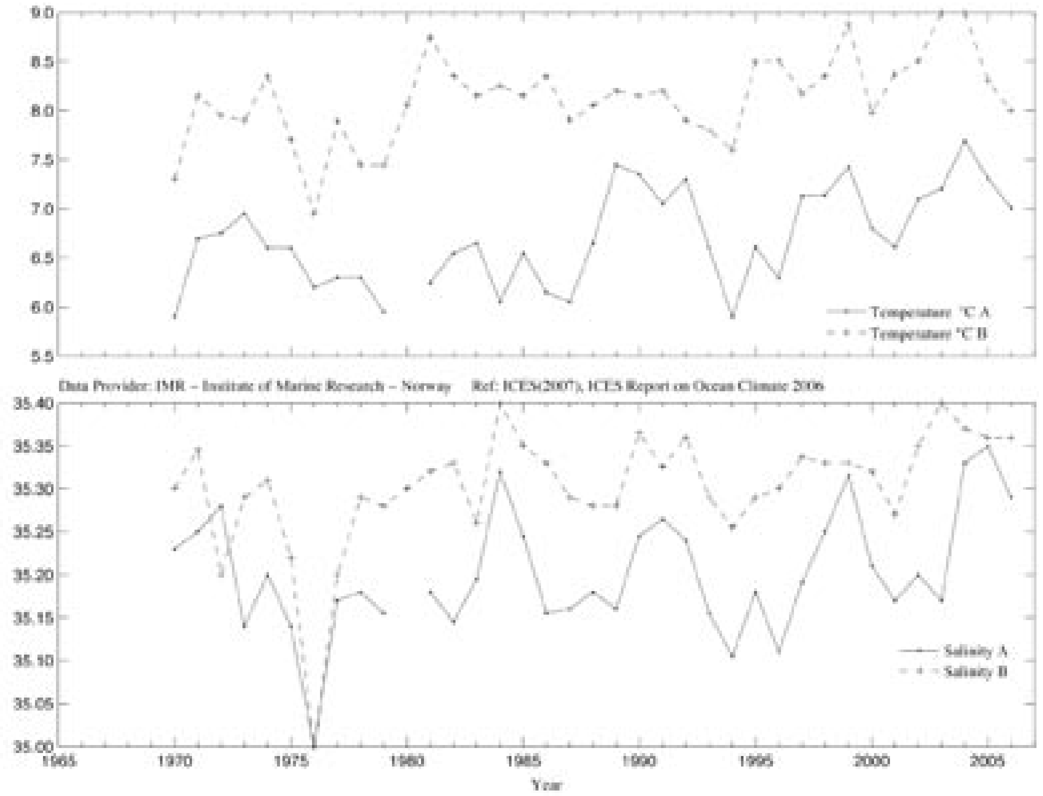


Figure 47. *Area 8 – Northern North Sea. Temperature (upper panel) and salinity (lower panel) near the seabed in the northwestern part of the North Sea (Location A) and in the core of Atlantic Water at the western shelf edge of the Norwegian Trench (Location B) during the summers of 1975–2006.*

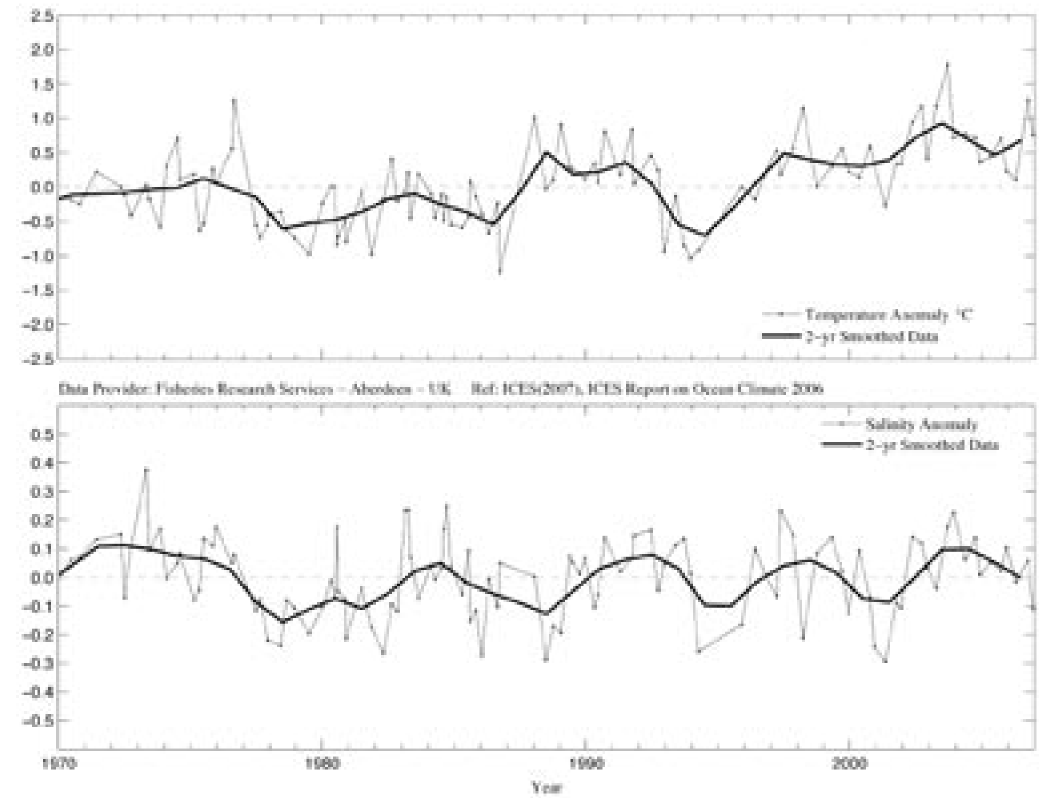


Figure 48. *Area 8 – Northern North Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Fair Isle Current entering the North Sea from the North Atlantic.*

ICES Cooperative Research Report No. 289

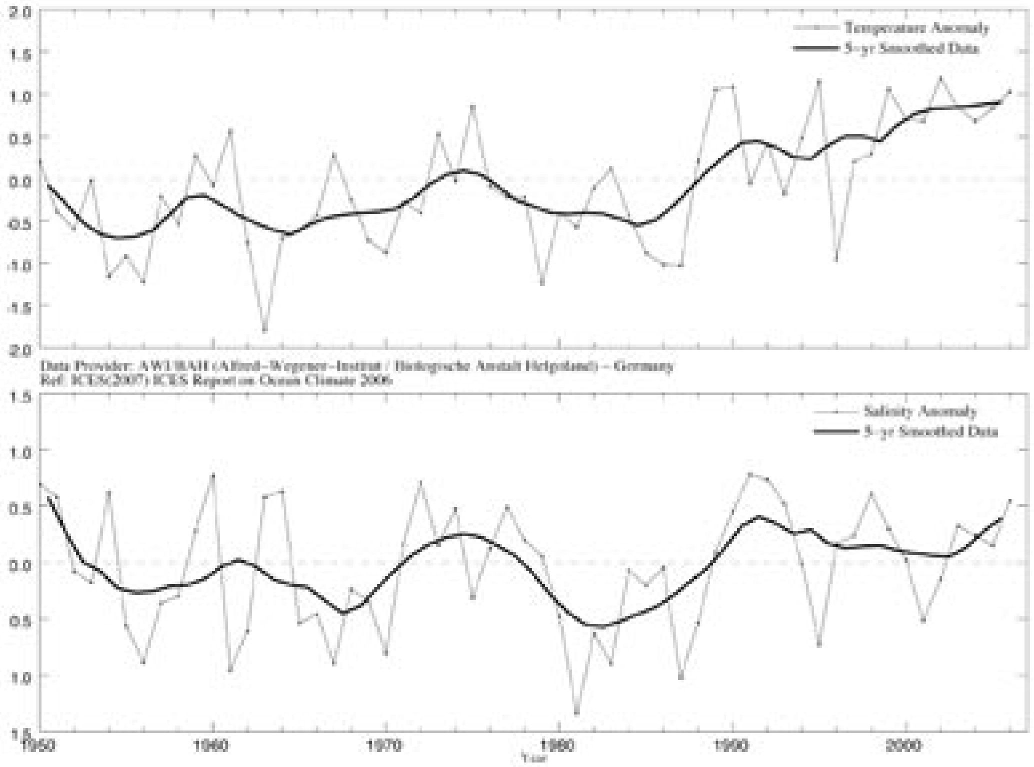


Figure 49. *Area 9 – Southern North Sea. Annual mean surface temperature (upper panel) and salinity (lower panel) at Station Helgoland Roads.*

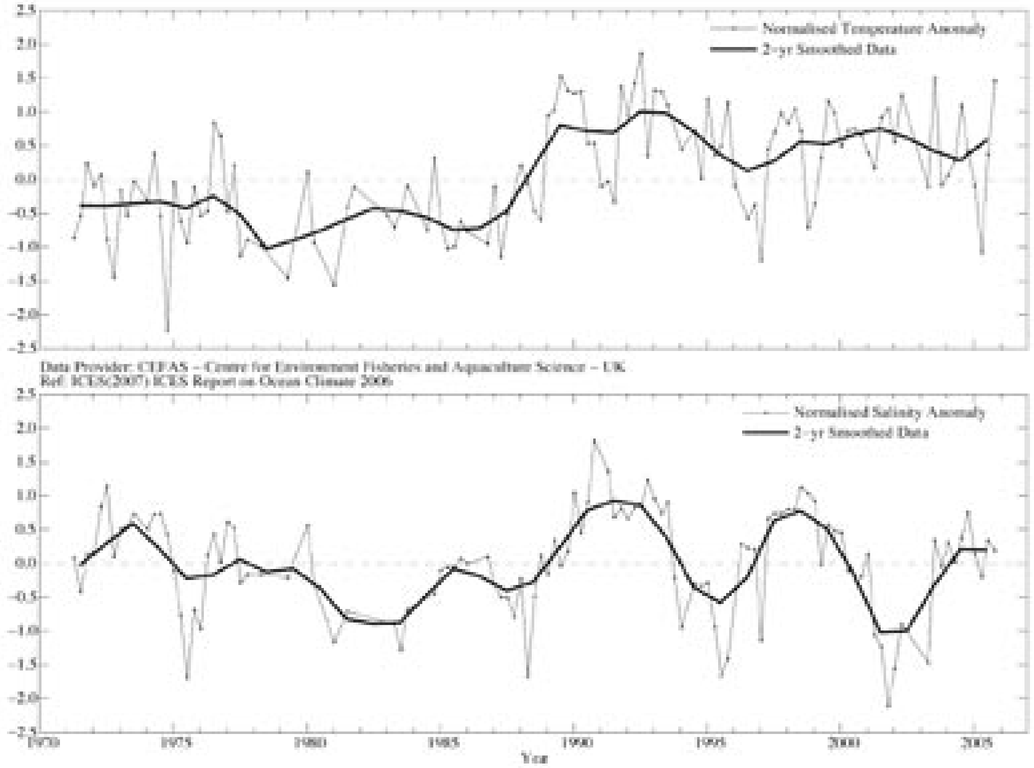


Figure 50. *Area 9 – Southern North Sea. Normalized sea surface temperature anomaly (upper panel) and salinity anomaly (lower panel) relative to the period 1971–2000 measured along 52°N, a regular ferry at six standard stations. The time-series reveals the seasonal section average (DJF, MAM, JJA, SON) of the normalized variable.*

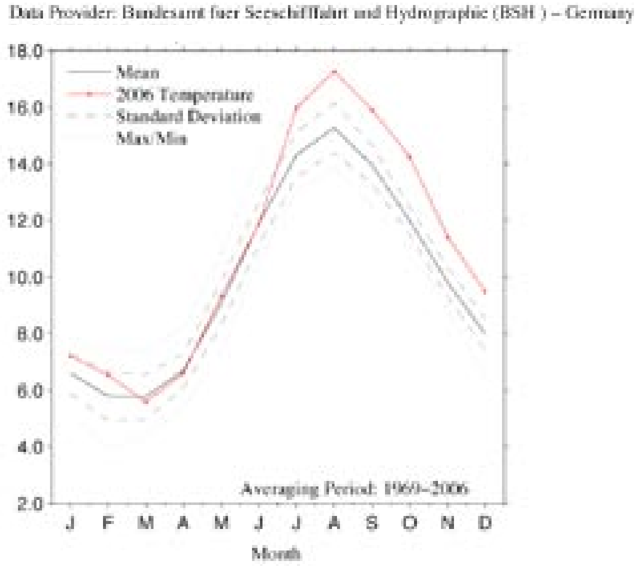


Figure 51. *Areas 8 and 9 – Northern and southern North Sea. North Sea area-averaged sea surface temperature annual cycle; monthly means based on operational weekly North Sea sea surface temperature maps.*

6.13 Area 9b – Skagerrak, Kattegat, and the Baltic

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

The mean atmospheric temperature was higher than normal for the year 2006, caused by an unusually warm second half of the year. The winter was cold and prolonged in the south, but milder in the north. March was colder than normal in general. The summer and autumn were warm, with many temperature records set in September. A short period of cold weather at the end of October and beginning of November was followed by a much warmer-than-normal December. The precipitation over Sweden was above mean during autumn, especially on the west coast, where there was some flooding.

Sea surface temperatures were close to normal at the beginning of the year but the cold period in March in the southern parts of the area lowered the temperatures below normal in Skagerrak, Kattegat, and the southern Baltic Sea. Summer temperatures were above normal in the whole region. The beginning of autumn was close to normal, while in October the sea surface temperatures were higher than normal, especially in the Baltic Sea.

In the Archipelago Sea and the Northern Quark, the values reached record highs for the past 30 years. After a normal November, December was again above mean, but mainly so in Skagerrak and Kattegat.

The slight increase in the yearly mean surface salinity at Station BY15 came to an end, and the five-year running mean has levelled out (Figure 52).

There were several inflows to the Baltic during autumn 2006. The first one, lasting from 20 October to 15 November, transported about 40 km^3 of water through the Øresund. During the first half of December, another

30 km³ entered the Baltic this way. There was no renewal of the bottom water, however. The reason for this is that the Kattegat water was unusually warm and, consequently, the inflowing water was not dense enough to reach the deeper parts of the Baltic. Later expeditions revealed a slight increase in the oxygen values at intermediate levels in the Baltic proper.

The freeze-up was quite late during the winter 2005/2006, but the ice extent was much larger than the previous year and the ice winter was classified as normal/severe. The maximum ice extent was reached on 15 March. In Figure 57, the ice extent since 1961 is shown.

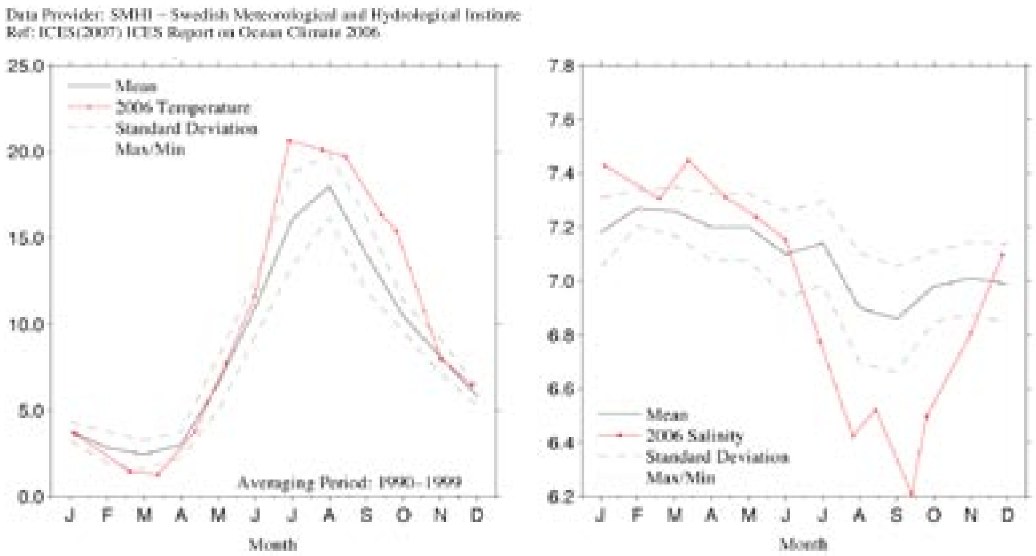


Figure 53. Area 9b – Skagerrak, Kattegat, and the Baltic. Monthly surface temperature (left panel) and salinity (right panel) at Station BY15 (east of Gotland) in the Baltic proper.

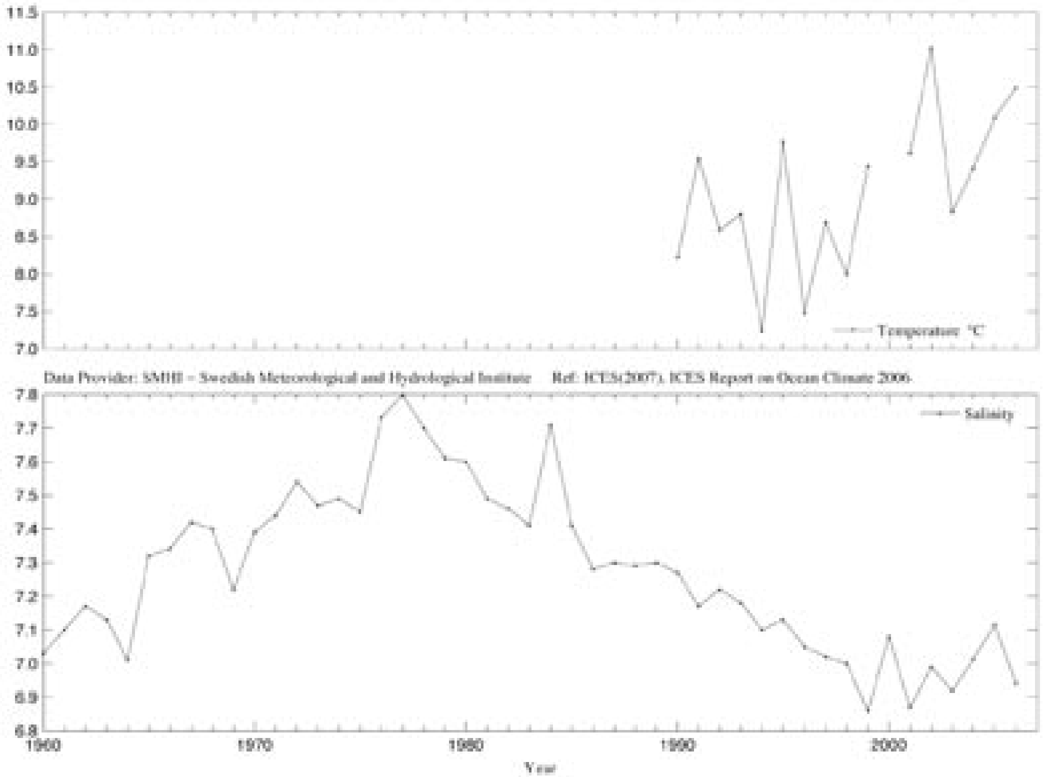


Figure 52. Area 9b – Skagerrak, Kattegat, and the Baltic. The surface temperature (upper panel) and surface salinity (lower panel) at Station BY15 (east of Gotland) in the Baltic proper.

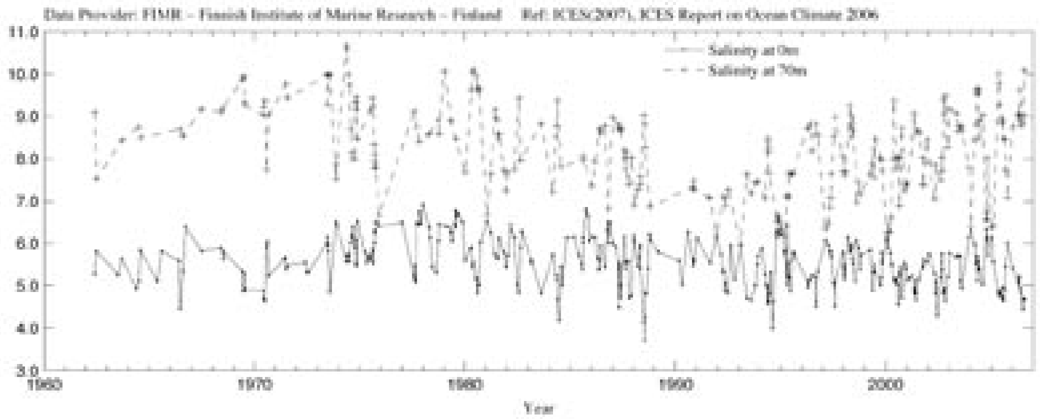


Figure 54. Area 9b – Skagerrak, Kattegat, and the Baltic. Salinity at Station LL7 in the Gulf of Finland.

UNUSUALLY WARM SECOND HALF OF THE YEAR

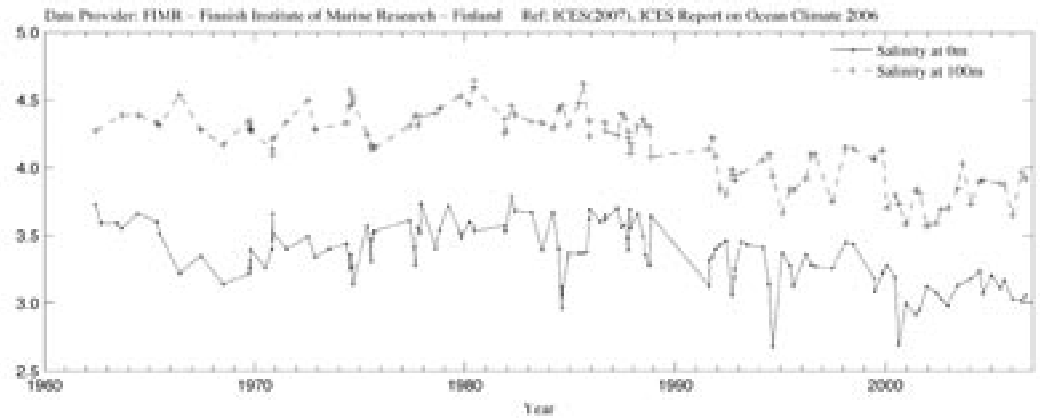


Figure 55. Area 9b – Skagerrak, Kattegat, and the Baltic. Salinity at Station BO3 in the Bothnian Bay.

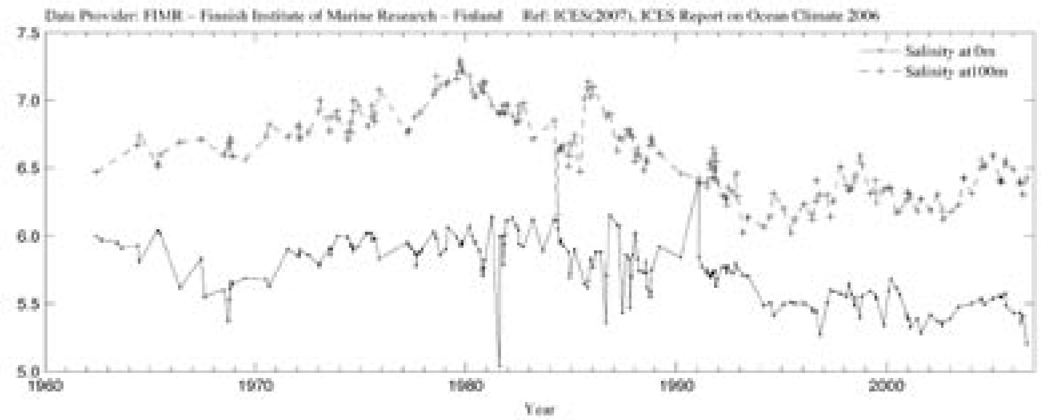


Figure 56. Area 9b – Skagerrak, Kattegat, and the Baltic. Salinity at Station SR5 in the Bothnian Sea.

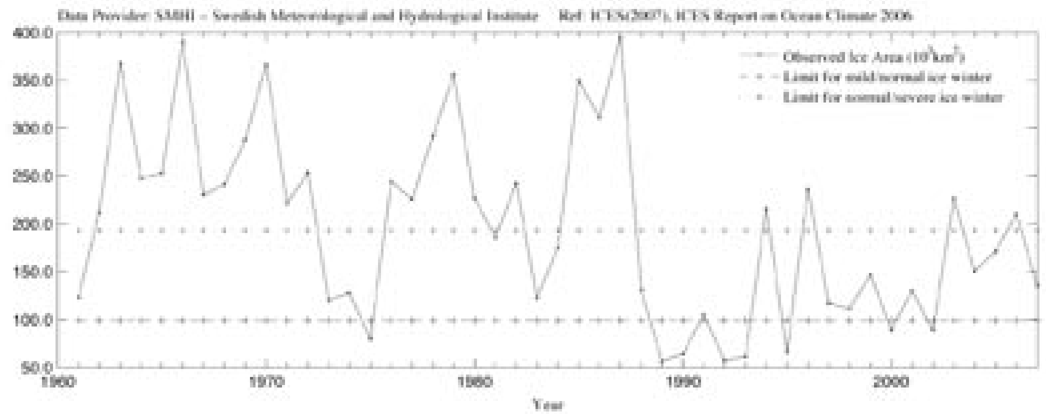


Figure 57. *Area 9b – Skagerrak, Kattegat, and the Baltic. The ice extent in the Baltic starting from 1961. The last value is from 21 March 2007.*

6.14 Area 10 – Norwegian Sea

THE NORWEGIAN SEA IS CHARACTERIZED BY WARM ATLANTIC WATER ON THE EASTERN SIDE AND COLD ARCTIC WATER ON THE WESTERN SIDE, SEPARATED BY THE ARCTIC FRONT. ATLANTIC WATER ENTERS THE NORWEGIAN SEA THROUGH THE FAROE SHETLAND CHANNEL AND BETWEEN THE FAROES AND ICELAND VIA THE FAROE FRONT. A SMALLER BRANCH, THE NORTH ICELANDIC IRMINGER CURRENT, ENTERS THE NORDIC SEAS ON THE WESTERN SIDE OF ICELAND. THE ATLANTIC WATER FLOWS NORTHWARDS AS THE NORWEGIAN ATLANTIC CURRENT, WHICH SPLITS WHEN IT REACHES NORTHERN NORWAY; SOME ENTERS THE BARENTS SEA, WHILE THE REST CONTINUES NORTHWARDS INTO THE ARCTIC OCEAN AS THE WEST SPITSBERGEN CURRENT.

Three sections from south to north in the eastern Norwegian Sea show the development of temperature and salinity in the core of the Atlantic Water (Svinøy, Gimsøy, and Sørkapp). In general, there has been an increase in temperature and salinity in all three sections from the mid-1990s to the present. In 2002–2004 and 2006, the temperatures in the Svinøy Section were highest in the time-series.

The temperature increase can also be observed in the other two sections. In 2006, the temperature and salinities were 0.8°C, 1.0°C, and 1.1°C and 0.08, 0.09, and 0.09 above the long-term mean for the time-series in the Svinøy, Gimsøy, and Sørkapp Sections, respectively. The high salinity values reflect saltier Atlantic Water in the Faroe Shetland Channel.

Ocean Weather Station "Mike" located at 66°N 2°E revealed the 2005 temperature and salinity at 50 m to be above the long-term mean, although there was a slight decrease in both from 2004 values.

HIGH SALINITY VALUES REFLECT SALTIER ATLANTIC WATER

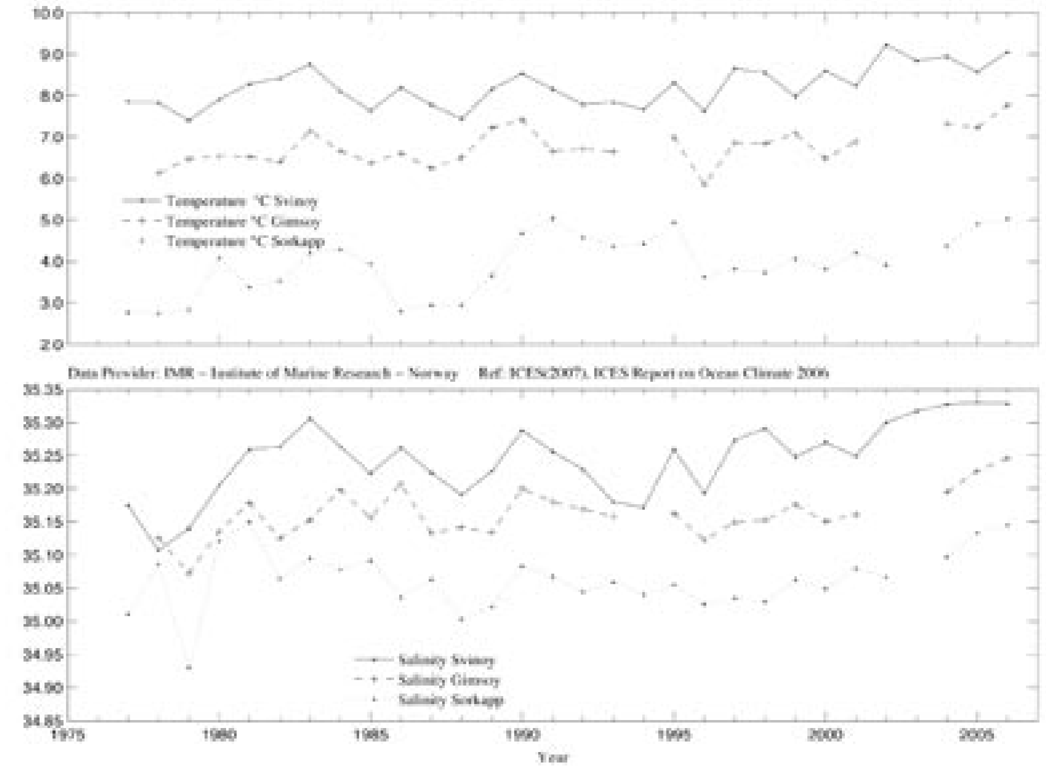


Figure 58. *Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at three sections, Svinøy (63°N), Gimsøy (69°N), and Sørkapp (76°N).*

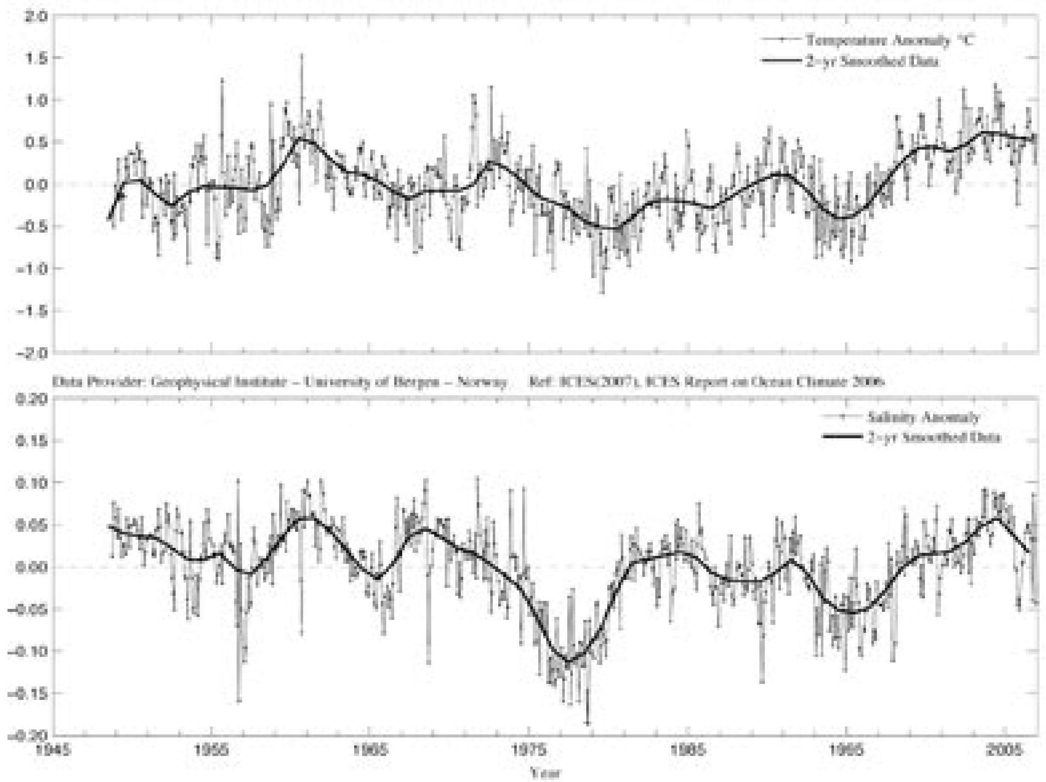


Figure 59. *Area 10 – Norwegian Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) at 50 m at Ocean Weather Station "Mike" (66°N 2°E).*

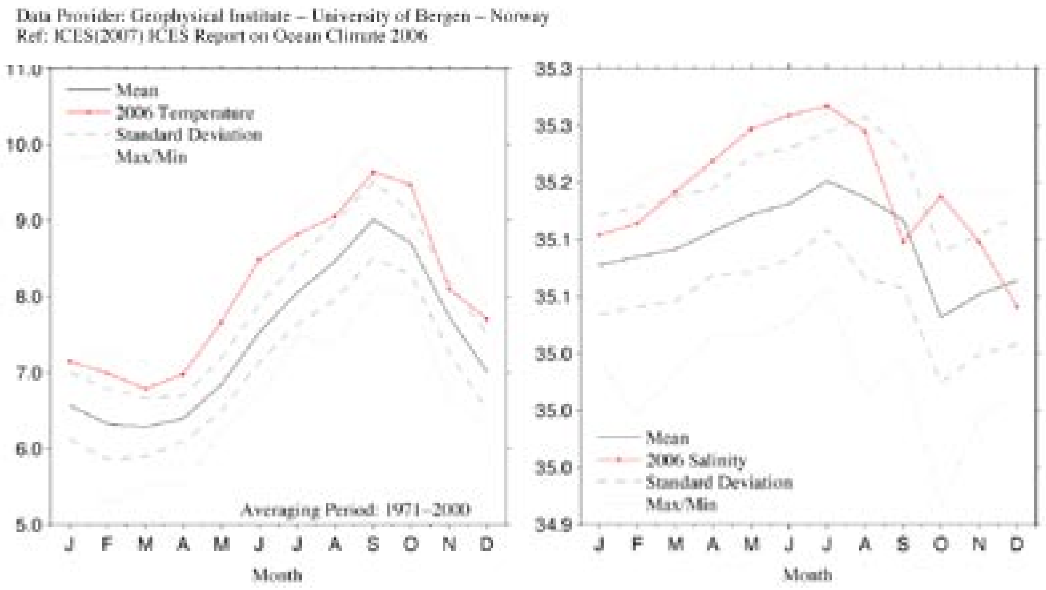


Figure 60. Area 10 – Norwegian Sea. Monthly temperature (left panel) and salinity (right panel) at 50 m at Ocean Weather Station "Mike" (66°N 2°E).

6.15 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.

After a period with high temperatures in the first half of the 1990s, 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, while the temperature in the eastern areas stayed below the average during 1998. 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 the southern Barents Sea, the water temperature anomalies in 2006 were about 1°C above the long-term means. In the coastal waters, the positive anomalies gradually decreased from 1.5°C at the beginning of the year to 0.7°C at the end of the year. The temperature of the Atlantic Water was 0.8–1.7°C higher than the normal throughout the year, depending on time and place. In the Barents Sea, 2006 was the warmest year ever observed. The total ice extent of the sea was much lower than the long-term average throughout the year, and during winter, sea ice was not observed south of 76°N.

Current measurements revealed a strong inflow of Atlantic Water in January and February 2005, and after a short period with low inflow, the inflow during summer and early autumn 2005 was above average.

2006 is the warmest year ever observed

The water temperature in the Barents Sea in 2007 is expected to be higher than the long-term mean, but probably lower than that in 2006.

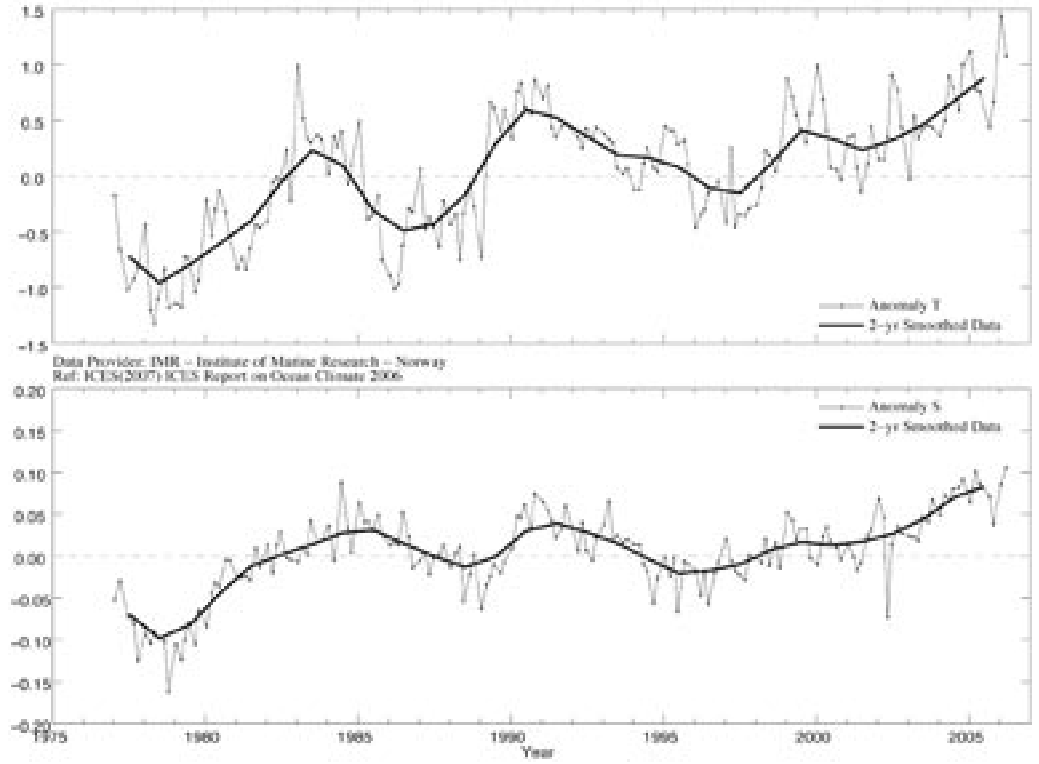


Figure 61. Area 11 – Barents Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Fugløya–Bear Island Section.

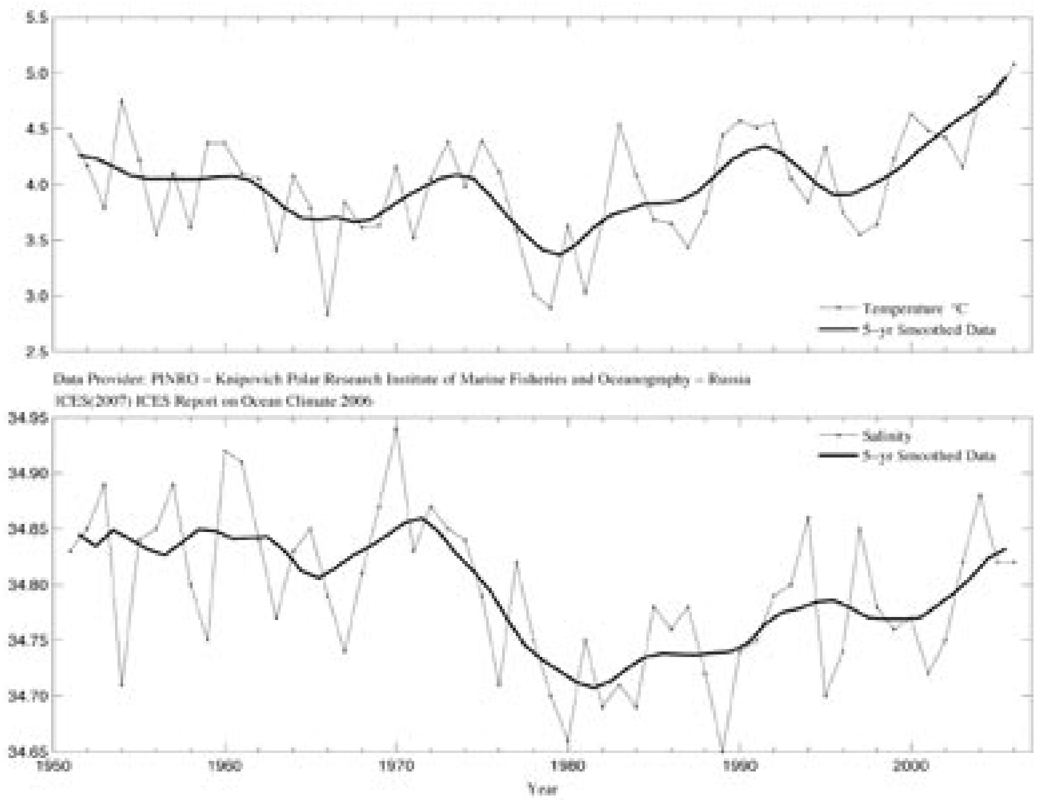


Figure 62. Area 11 – Barents Sea. Temperature (upper panel) and salinity (lower panel) in the Kola Section (0–200 m).

ICES Cooperative Research Report No. 289

6.16 Area 12 – Greenland Sea and Fram Strait

Fram Strait is the northern border of the Nordic Seas. It is the deepest passage connecting the Arctic to the rest of the World Ocean, and one of the main routes whereby Atlantic Water enters the Arctic (the other is the Barents Sea). The Atlantic Water is carried northwards by the West Spitsbergen Current, and volume and heat fluxes demonstrate strong seasonal and interannual variations. A significant part of the Atlantic Water also recirculates within the Fram Strait and returns southwards (Return Atlantic Water). Polar Water from the Arctic Ocean flows southwards in the East Greenland Current and affects water masses in the Nordic Seas.

In 2006, a very strong increase in temperature, and especially in salinity, was observed in the Return Atlantic Water. Although mean properties of the Atlantic Water at the eastern boundary remained similar to those observed in 2005, they were still much higher than their long-term averages. At the western boundary in 2006, the salinity of the Return Atlantic Water reached its maximum value since the beginning of observations (S_{max} = 35.106) and temperature was the second highest. After a few years of colder and less saline conditions, the temperature and salinity of Return Atlantic Water in the last three years have returned to the high values of the mid-1990s, resulting in positive anomalies from the long-term mean.

In the Fram Strait at 78°50'N, three characteristic areas can be distinguished in relation to the main flows: the West Spitsbergen Current between the shelf edge and 5°E, the Return Atlantic Current between 3°W and 5°E, and Polar Water in the East Greenland Current between 3°W and the Greenland Shelf. In 2006, the temperatures and salinities recorded in the West Spitsbergen Current were higher than those in 2005, reaching their maxima for the whole time-series (T_{max} = 4.75°C and S_{max} = 35.10). Mean properties in the East Greenland Current remained similar to those recorded in 2005, still significantly exceeding the long-term average. A small decrease in the mean temperature and salinity in the Return Atlantic Current (recirculation domain) resulted from the position of the ice edge, when a transient sea-ice tongue developed towards the middle part of the Fram Strait during the measurement cruise.

The increase of temperature and salinity, which has been observed in the Return Atlantic Current and East Greenland Current since 2003, is related to the westward shift of the boundary between the recirculating Atlantic Water and Polar Waters. In 2006, although ice conditions prevented sampling of the westward limit of the recirculating Atlantic Water, the observed Atlantic Water layer thickness at the western end of the section suggested that it continued even farther west. Mean temperature and salinity values in the 50–500 m layer in three domains were all higher than the long period average and have continued to increase since 2003. The northward flow, and consequently the volume transport, observed in winter 2005/2006 in the West Spitsbergen Current from mooring data, was significantly lower than that the winter before, but, balanced by warmer temperatures, the heat flux in 2005/2006 remained high and similar to that observed in 2004/2005.

Heat flux in 2005/2006 remained high

The hydrographic properties of the Atlantic Water (defined as water mass with T >2°C and S >34.92) reveal a clear trend over the past seven years, with mean temperature and salinity values increasing since 1997. The area of the cross section occupied by Atlantic Water (a proxy for the amount of Atlantic Water in the Fram Strait), which varied strongly in the early years of measurements, has expanded steadily since 2002. The proportion of warm Atlantic Water T >2°C) in the total Atlantic Water (T >0°C) at the section has been also continuously growing since 2002.

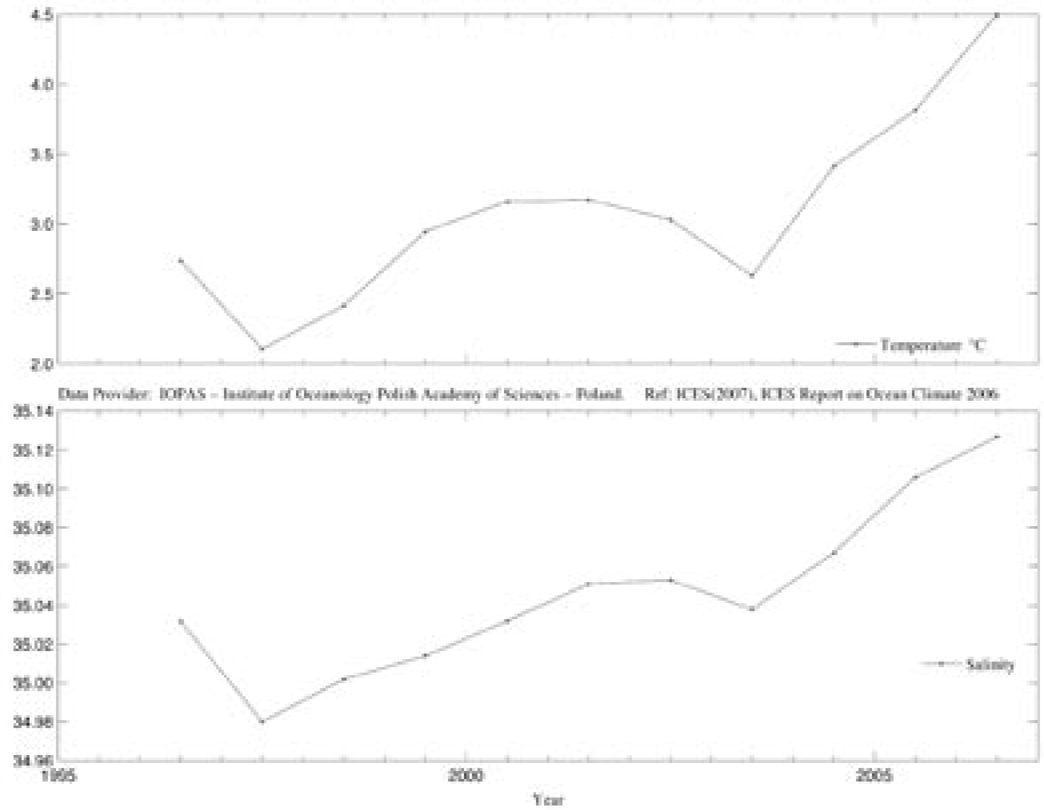


Figure 63. Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) at 200 m in the Spitsbergen Section (76°30'N).

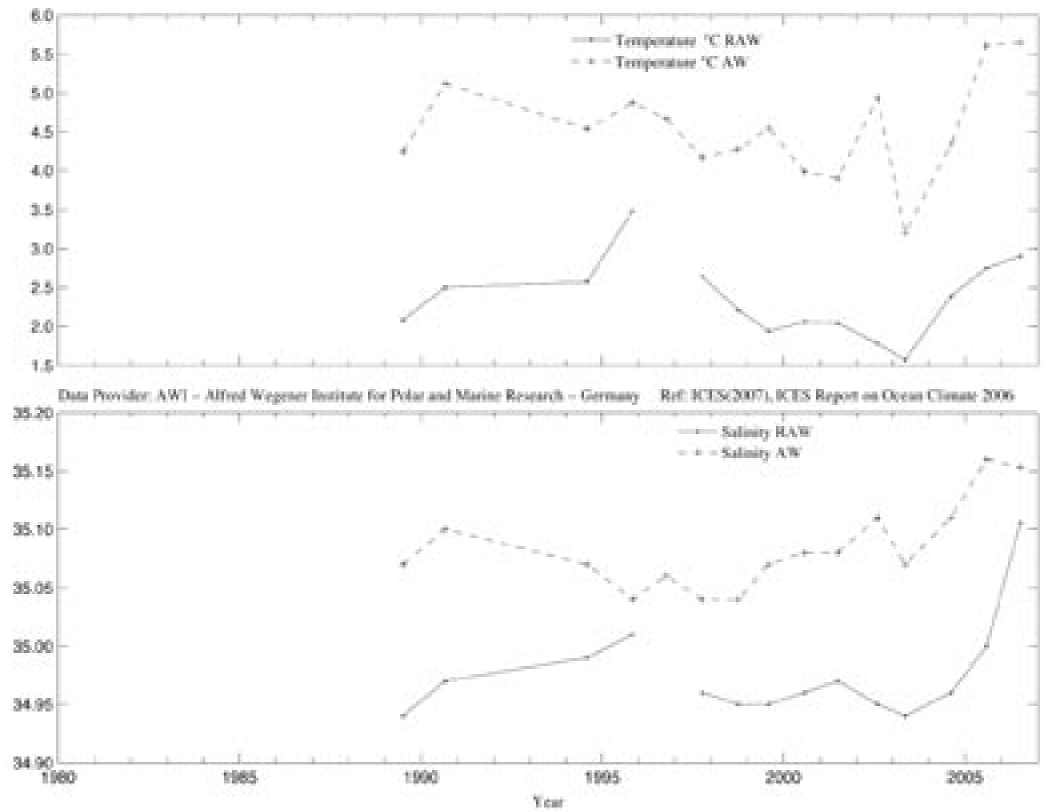
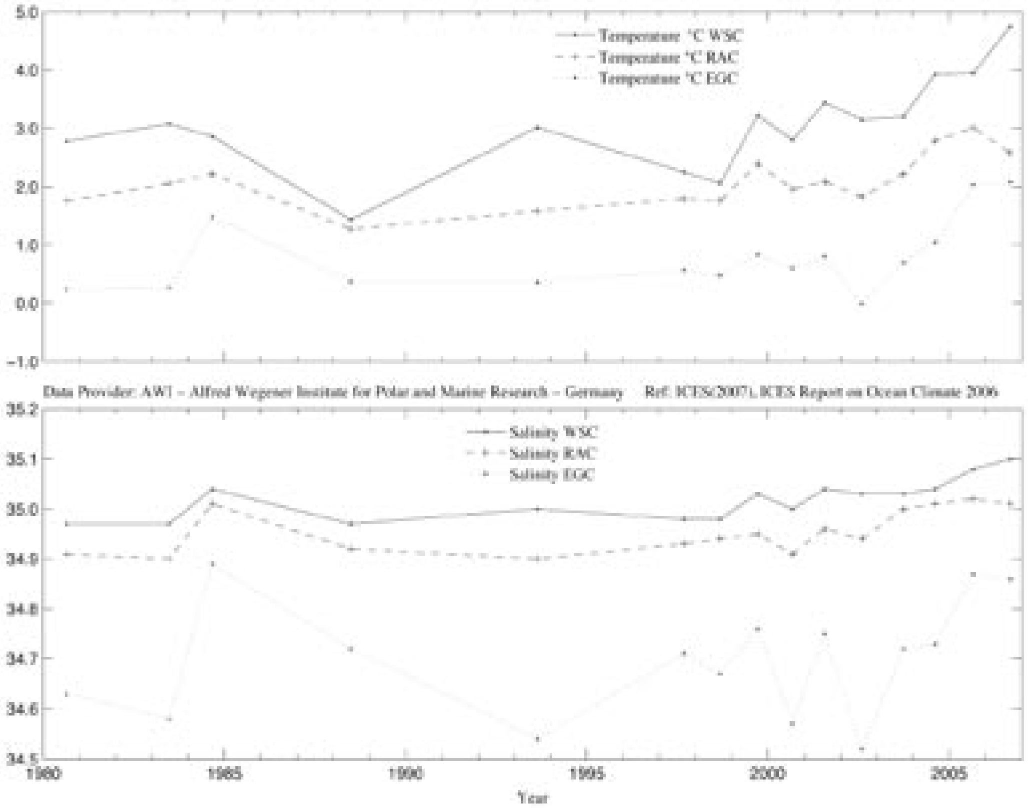


Figure 64. Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) anomalies of the Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea Section at 75°N. AW properties are 50–150 m averages at 10–13°E. The RAW is characterized by the temperature and salinity maximum below 50 m averaged over three stations west of 11.5°W.

***Figure 65.** Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) anomalies in Fram Strait (78°50'N), in the West Spitsbergen Current (WSC) between the shelf edge and 5°E, Return Atlantic Current (RAC) 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.*



6.17 Nordic Seas Deep Waters

The Greenland, Iceland, and Norwegian Sea deep waters are all warming. The longest time-series (the Norwegian Sea) reveals warming from the mid-1980s. The warming rates are 0.12°C per decade (Greenland Sea), 0.06°C per decade (Norwegian Sea), 0.06°C per decade (Iceland Sea). Bottom-water renewal by deep convection used to determine the deep hydrographic conditions in the Greenland Sea. Since the late 1980s, no bottom-water renewal has taken place. The source of the warming is the Arctic Ocean Deep Outflow, a south-going current found on the west side of the Fram Strait, centred at 2000 m depth, which has a temperature of approximately -0.5°C. The Greenland Sea deep water is warming fastest because it is most directly in contact with this Arctic outflow. The Iceland and Norwegian Seas, which are more distant from the Arctic outflow, are warming more slowly because they are products of mixing between their own ambient waters with Greenland Sea deep water and Arctic outflow water.

The cessation of deep convection in the Greenland Sea has led to the doming structure in the Greenland Gyre being replaced by a two-layered water mass arrangement, with a density interface that has descended more than 1000 m since the beginning of measurements in 1993. The winter convection depth varies between 700 and 1600 m, except in small-scale convective eddies, where it has been found to be significantly deeper. In winter 2005/2006, the maximum convection depth was estimated to be 1200 m. At the standard section at 75°N, the deep water properties have changed towards higher temperatures and salinities, changing over 14 years by 0.17°C and 0.0115, respectively.

Greenland Sea deep water used to include a small admixture of surface fresh water through the convective process, and therefore had a lower salinity than the Arctic outflow waters. The observed increase in the salinity of Greenland Sea deep water is likely to be an adjustment to the Arctic outflow in the continued absence of deep convection. It is not clear that there has been any corresponding salinity trend in Norwegian Sea deep water in recent decades. Iceland Sea deep water salinity is not shown.

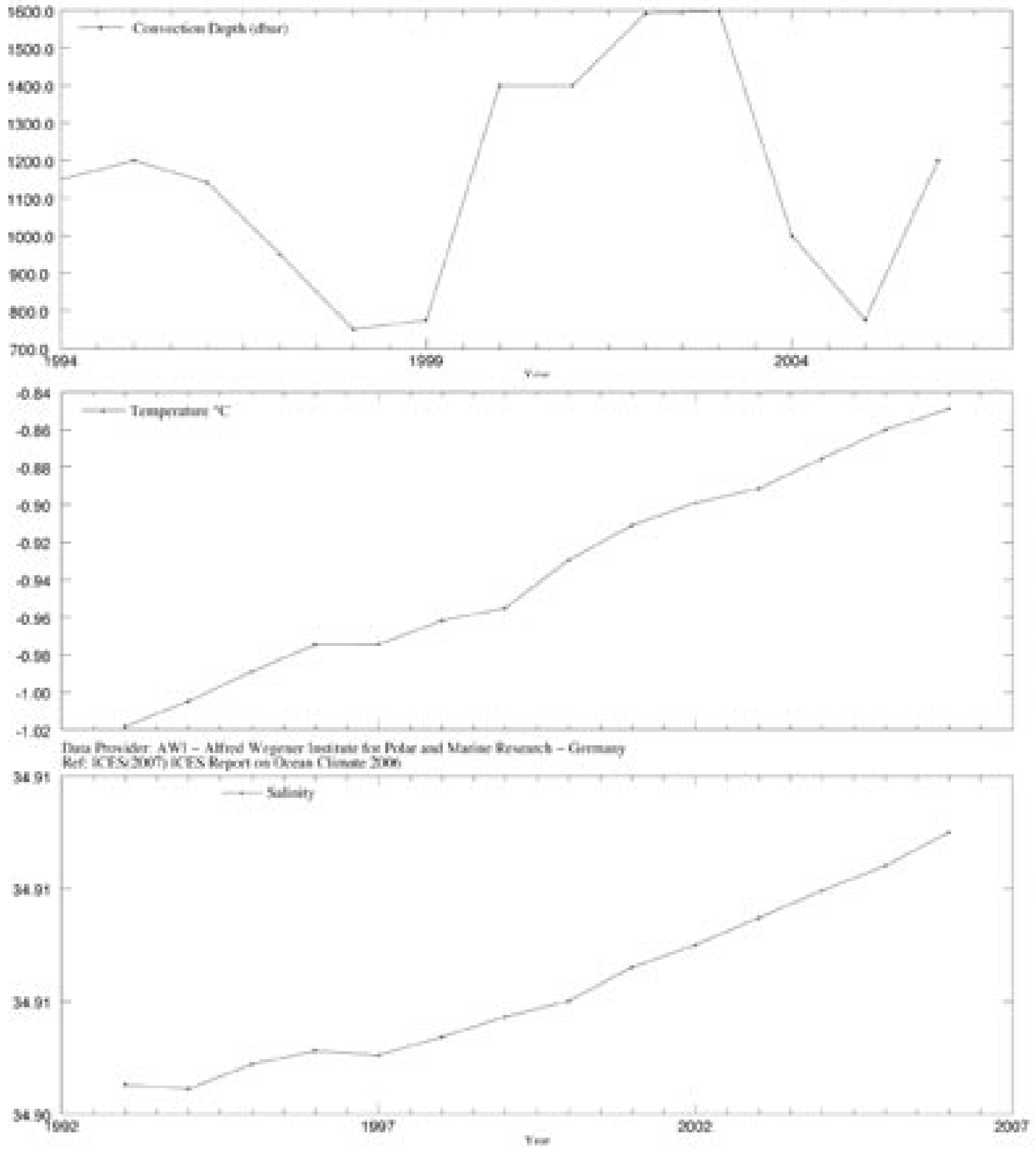


***Figure 66.** Area 12 – Greenland Sea and Fram Strait. Winter convection depths (upper panel) and temperature (middle panel) and salinity (lower panel) at 3000 m in the Greenland Sea Section at 75°N.*

ICES Cooperative Research Report No. 289

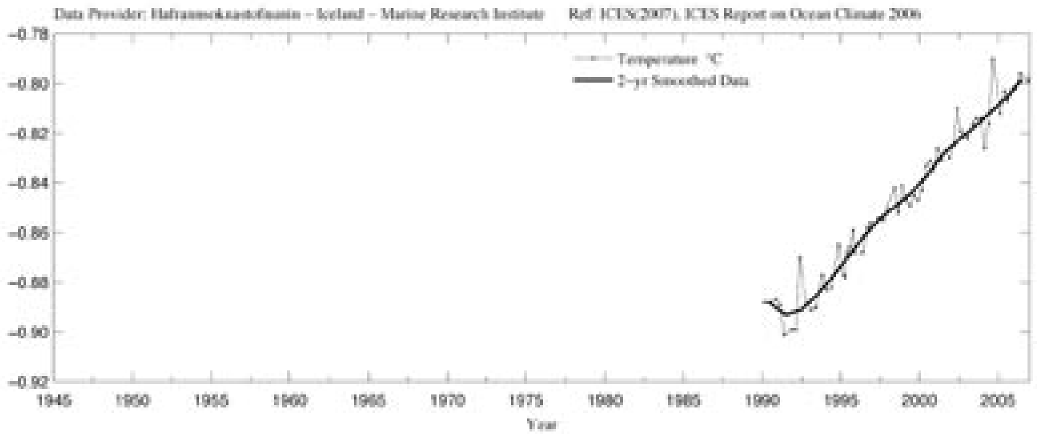


Figure 67. Area 3 – Icelandic Waters. Temperature at 1500–1800 m in the Iceland Sea (68°N 12°40'W).

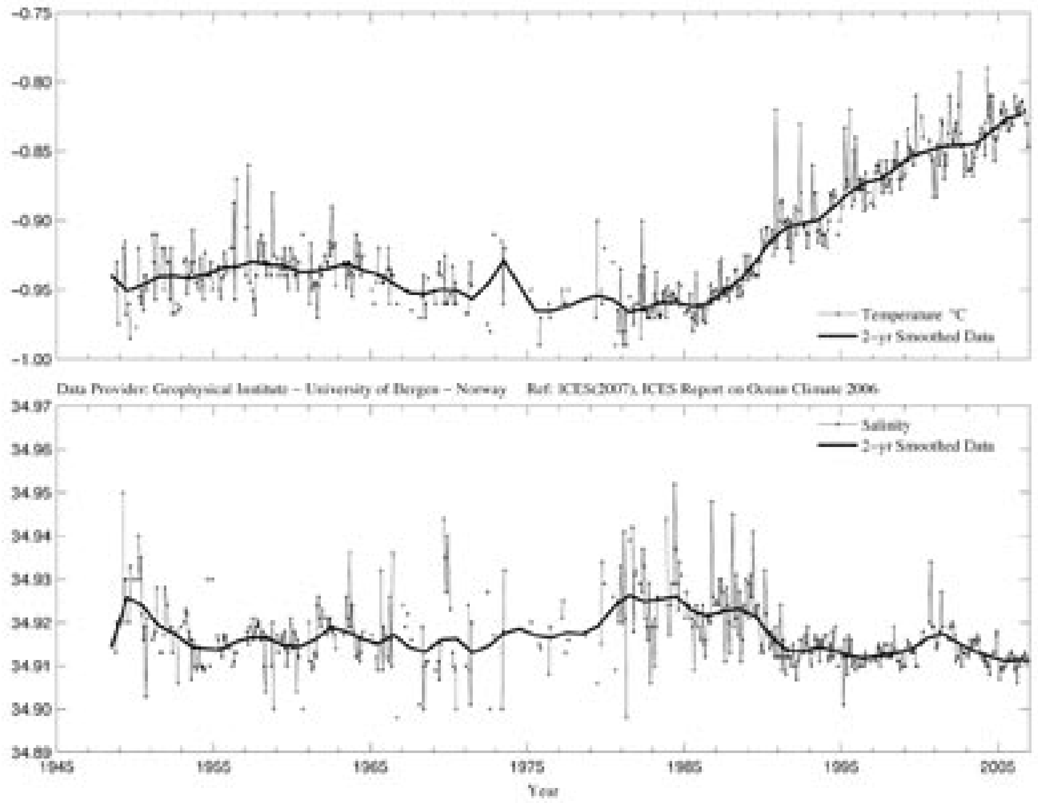


Figure 68. Area 10 – Norwegian Sea. Temperature (upper panel) and salinity (lower panel) at 2000 m at Ocean Weather Station "Mike" (66°N 2°E).

CONTACT INFORMATION

Area		Time-series	Contact	Institute
1	West Greenland	Nuuk Air Temperature	Manfred Stein (manfred.stein@ish.bfa-fish.de)	Danish Meteorological Institute, Copenhagen, and Seewetteramt, Hamburg
1	West Greenland	Fylla Section and Cape Desolation Section	Manfred Stein (manfred.stein@ish.bfa-fish.de)	Institut für Seefischerei, (Institute for Sea Fisheries) Germany
2	Northwest Atlantic	Scotian Shelf	Brian Petrie (PetrieB@mar.dfo-mpo.gc.ca)	BIO (Bedford Institute of Oceanography), Fisheries and Oceans Canada
2	Northwest Atlantic	Newfoundland and Labrador Shelf	Eugene Colbourne (colbourn@dfo-mpo.gc.ca)	Northwest Atlantic Fisheries Centre, Canada
2b	Labrador Sea	AR7W	Ross Hendry (hendryr@dfo-mpo.gc.ca)	BIO (Bedford Institute of Oceanography), Fisheries and Oceans Canada
2c	Mid-Atlantic Bight	Oleander Section (east of Boston)	Tom Rossby (trossby@gso.uri.edu)	National Marine Fisheries Service (NOAA), USA
2c	Mid-Atlantic Bight	Georges Bank	David Mountain (dmountain@whsun1.wh.whoi.edu)	Woods Hole Oceanographic Institute, USA
3	Icelandic Waters	Air temperatures and stations	Hedinn Valdimarsson (hv@hafro.is)	Hafrannsoknastofnunin, (Marine Research Institute), Iceland
4	Bay of Biscay	Santander Station 6 and San Sebastian air temperature	Alicia Lavin (alicia.lavin@st.ieo.es)	IEO (Instituto Español de Oceanografía), Spanish Institute of Oceanography
4	Bay of Biscay	San Sebastian temperature	Victor Valencia (vvalencia@pas.azti.es)	AZTI and Aquarium of San Sebastián (SOG)
5	Rockall Trough	Malin Head Weather Station	Glenn Nolan (Glenn.Nolan@marine.ie)	Marine Institute/Met Eireann, Ireland
5	Rockall Trough	$M_{,}$ Marine Weather Buoy	Sheena Fennell (Sheena.Fennell@marine.ie)	Marine Institute, Ireland
5	Rockall Trough	Ellett Line	N. Penny Holliday (nph@noc.soton.ac.uk)	National Oceanography Centre Southampton and Scottish Association for Marine Science, UK
5b	Irminger Sea	All depths	H. M. van Aken (aken@nioz.nl)	Royal NIOZ (Nederlands Institut Voor Onderzoek der Zee), Netherlands Institute for Sea Research
6	Faroe Bank Channel	FBC and Faroe Current	Bogi Hansen (bogihan@frs.fo)	Fiskirannsoknarstovan, (Faroese Fisheries Laboratory), Faroe Islands
6	Faroe Bank Channel	Faroe Coastal Oyrargjogv	Karin Margretha Larsen (KarinL@frs.fo)	Fiskirannsoknarstovan, (Faroese Fisheries Laboratory), Faroe Islands
7	Faroe Shetland Channel	All depths	Sarah Hughes (s.hughes@marlab.ac.uk)	FRS (Fisheries Research Services), Aberdeen, UK
8&9	North Sea	Modelled North Sea Inflow	Morten Skogen (morten@imr.no)	IMR (Institute of Marine Research), Norway
8&9	North Sea	North Sea Utsira A and B	Einar Svendsen (einar.svendsen@imr.no)	IMR (Institute of Marine Research), Norway
8&9	North Sea	Fair Isle Current Water	Sarah Hughes (s.hughes@marlab.ac.uk)	Fisheries Research Services, Aberdeen, UK
8&9	North Sea	Helogoland Roads	Karen Wiltshire (kwiltshire@awi-bremerhaven.de)	AWI/BAH (Alfred-Wegener-Institut/ Biologische Anstalt Helgoland), Germany
8&9	North Sea	Felixstowe to Rotterdam Section	Stephen Dye (stephen.dye@cefas.co.uk)	CEFAS (Centre for Environment Fisheries and Aquaculture Science), UK
8&9	North Sea	Sea Surface Temperature	Peter Lowe (peter.loewe@bsh.de)	Bundesamt für Seeschifffahrt und Hydrographie (BSH), Germany
9b	Baltic Sea	East of Gotland and sea ice	Karin Borenas (karin.borenas@smhi.se)	SMHI (Swedish Meteorological and Hydrological Institute), Sweden
9b	Baltic Sea	Stations LL7, BO3 and SR5	Pekka Alenius (pekka.alenius@fimr.fi)	FIMR (Finnish Institute of Marine Research), Finland
10	Norwegian Sea	Svinøy, Gimsøy, and Sørkapp Sections	Kjell Arne Mork (kjell.arne.mork@imr.no)	IMR (Institute of Marine Research), Norway
10	Norwegian Sea	Ocean Weather Station Mike	Svein Østerhus (Svein.Osterhus@gfi.uib.no)	Geophysical Institute, University of Bergen, Norway
11	Barents Sea	Fugløya–Bear Island Section	Harald Loeng (harald.loeng@imr.no)	IMR (Institute of Marine Research), Norway
11	Barents Sea	Kola Section – Eastern Barents Sea	Dr Oleg V. Titov Research Director (titov@pinro.ru)	PINRO (Knipovich Polar Research Institute of Marine Fisheries and Oceanography), Russia
12	Greenland Sea and Fram Strait	West of Spitsbergen 76.5°N	Waldemar Walczowski (walczows@iopan.gda.pl)	IOPAS (Institute of Oceanology, Polish Academy of Sciences), Poland
12	Greenland Sea and and Fram Strait	Fram Strait	A. Beszczynska-Möller (abeszczynska@awi-bremerhaven.de)	AWI (Alfred Wegener Institute for Polar and Marine Research), Germany
12	Greenland Sea and Fram Strait	Greenland Sea Section at 75°N	G. Budeus (Gereon.Budeus@awi.de)	AWI (Alfred Wegener Institute for Polar and Marine Research), Germany