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ICES COOPERATIVE RESEARCH REPORT
RAPPORT DES RECHERCHES COLLECTIVES

NO. 314 SPECIAL ISSUE
AUGUST 2012

ICES Report on Ocean Climate 2011

Prepared by the Working Group on Oceanic Hydrography

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Editors
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1. INTRODUCTION

The North Atlantic region is unusual in having a relatively large number of locations at which oceanographic data have been collected repeatedly for many years or decades; the longest records go back more than a century. In this report, we provide the very latest information from the ICES Area of the North Atlantic and Nordic seas, where the ocean is currently measured regularly. We describe the status of sea temperature and salinity during 2011, as well as the observed trends over the past decade or longer. In the first part of the report, we draw together the information from the longest time-series in order to give the best possible overview of changes in the ICES Area. Throughout the report, additional complementary datasets are provided, such as sea level pressure, air temperature, and ice cover.

The main focus of the annual *ICES Report on Ocean Climate* (IROC) is the observed variability in the upper ocean (the upper 1000 m). The introductory section includes gridded fields constructed by optimal analysis of the Argo float data distributed by the Coriolis data centre in France. Later in the report, a short section summarizes the variability of the intermediate and deep waters of the North Atlantic.

The data presented here represent an accumulation of knowledge collected by many 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.

More detailed analysis of the datasets that form the time-series presented in this report can be found in the annual meeting reports of the ICES Working Group on Oceanic Hydrography at http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=146.

1.1 Highlights of the North Atlantic for 2011

- The upper layers of the northern North Atlantic and the Nordic seas were warm and saline in 2011 compared with the long-term average.

- In the northwestern North Atlantic, the warm winter led to high ocean temperatures. Low sea ice extent and a low number of icebergs were observed in the Labrador Sea.

- The Nordic seas along the pathway of the North Atlantic Current (NAC) were very saline in 2011, while the interior of the Norwegian Sea continued to freshen at the surface.

- Strong inflow of Atlantic Water entering the Arctic via the West Spitsbergen Current occurred in spring 2011, following very weak inflow in winter 2010/2011.

- Deep water in the Norwegian Sea is at its warmest and most saline, matching the properties of deep waters exiting the Arctic.

- Severe ice winter conditions occurred for a second year in the Baltic.

- Dry weather and flow from the south led to record-high salinities on the shelf and slope in the Bay of Biscay.

1.2 Highlights of the North Atlantic atmosphere in winter 2010/2011

- The North Atlantic Oscillation (NAO) index in winter 2010/2011 was negative, but not as strong as the previous winter, generating less extreme conditions. This was the third winter in succession that showed a negative index, which has not happened since the winters 1968/69 through 1970/71.

- Surface air temperatures were near average over the northeast Atlantic, North Sea, and Nordic seas, and above average over Greenland and the Labrador Sea. The Baltic and northeastern Europe experienced cold winter conditions.

- Mean winds were weaker than normal across the Rockall Trough and into the North Sea. Winds were slightly stronger than average west of Spain and Portugal.

- The winter atmospheric low over the eastern Nordic seas was weaker than average.

NORTH ATLANTIC UPPER OCEAN TEMPERATURE: OVERVIEW

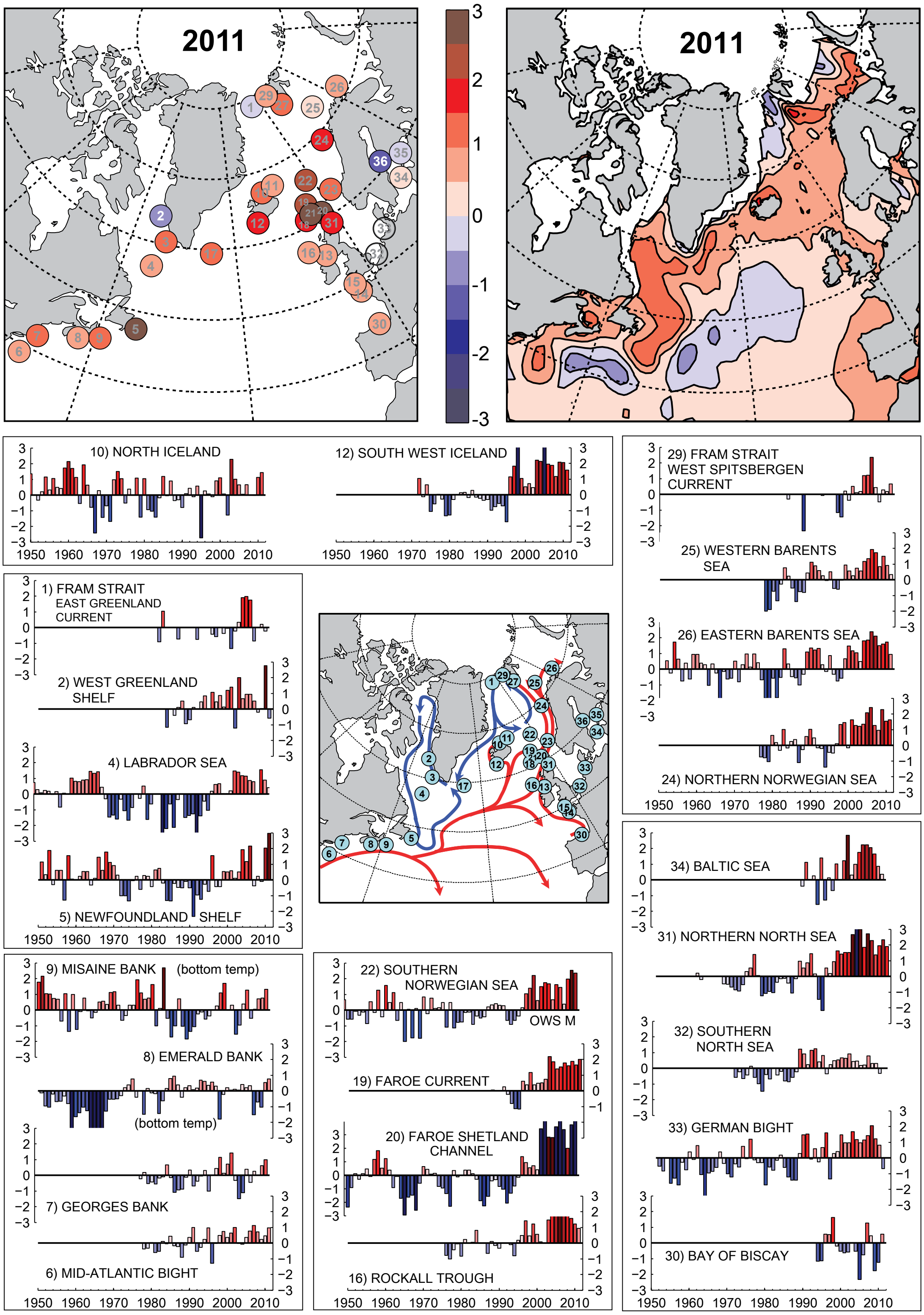
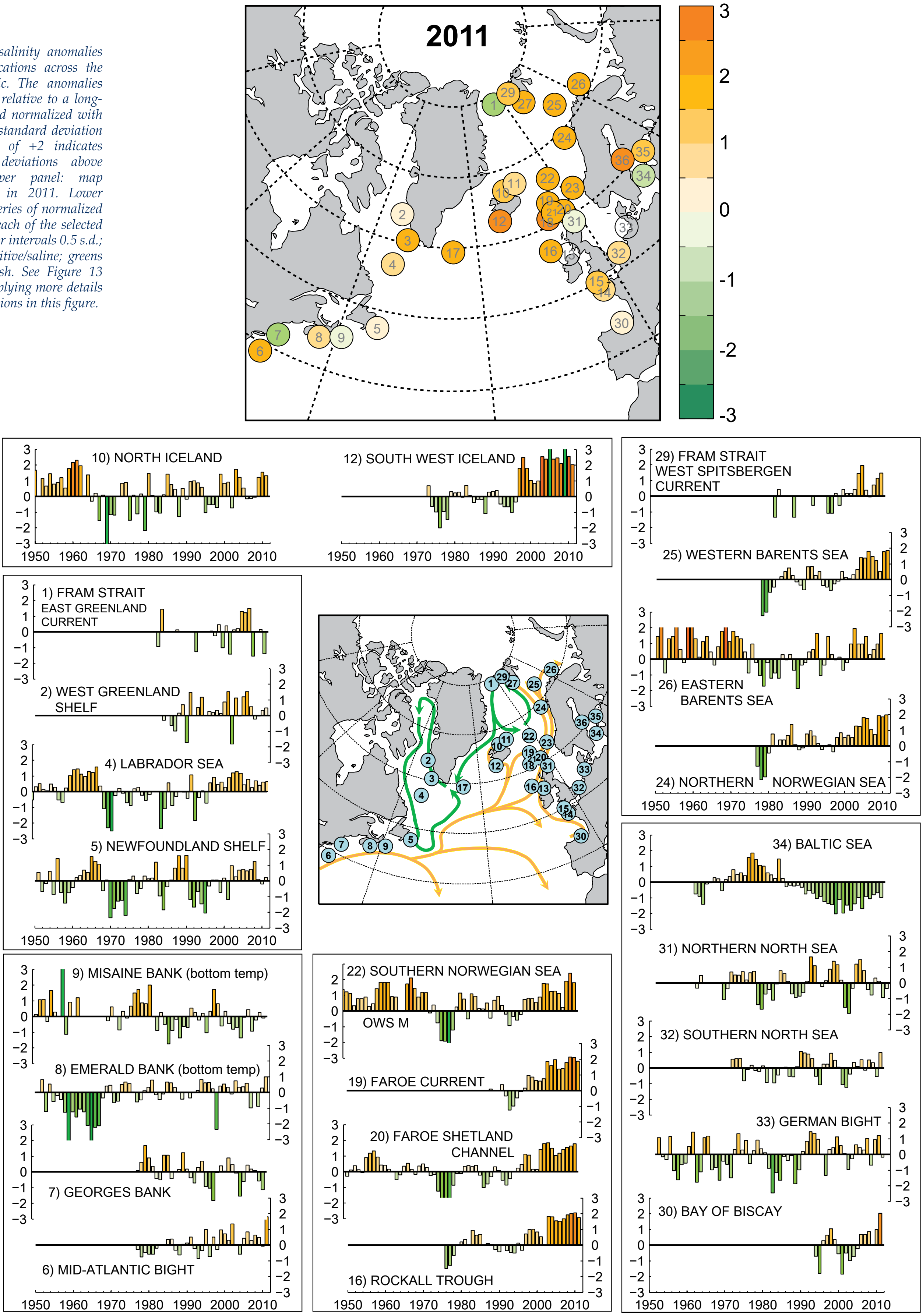


Figure 1.
Upper ocean temperature anomalies at selected locations across the North Atlantic. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations, s.d., above normal). Upper panels: maps of conditions in 2011; (left) data from in situ *observations; (right) 2011 anomalies calculated from OISST.v2 data (see Figure 3). Lower panels: time-series of normalized anomalies at each of the selected stations. Colour intervals 0.5 s.d.; reds = positive/warm; blues = negative/cool. See Figure 13 for a map supplying more details about the locations in this figure.*

NORTH ATLANTIC UPPER OCEAN SALINITY: OVERVIEW

Figure 2.
Upper ocean salinity anomalies at selected locations across the North Atlantic. The anomalies are calculated relative to a long-term mean and normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations above normal). Upper panel: map of conditions in 2011. Lower panels: time-series of normalized anomalies at each of the selected stations. Colour intervals 0.5 s.d.; oranges = positive/saline; greens = negative/fresh. See Figure 13 for a map supplying more details about the locations in this figure.



2. SUMMARY OF UPPER OCEAN CONDITIONS IN 2011

In this section, we summarize the conditions in the upper layers of the North Atlantic during 2011, using data from (i) a selected set of sustained observations, (ii) gridded sea surface temperature (SST) data, and (iii) gridded vertical profiles of temperature and salinity from Argo floats.

2.1 *In situ* stations and sections

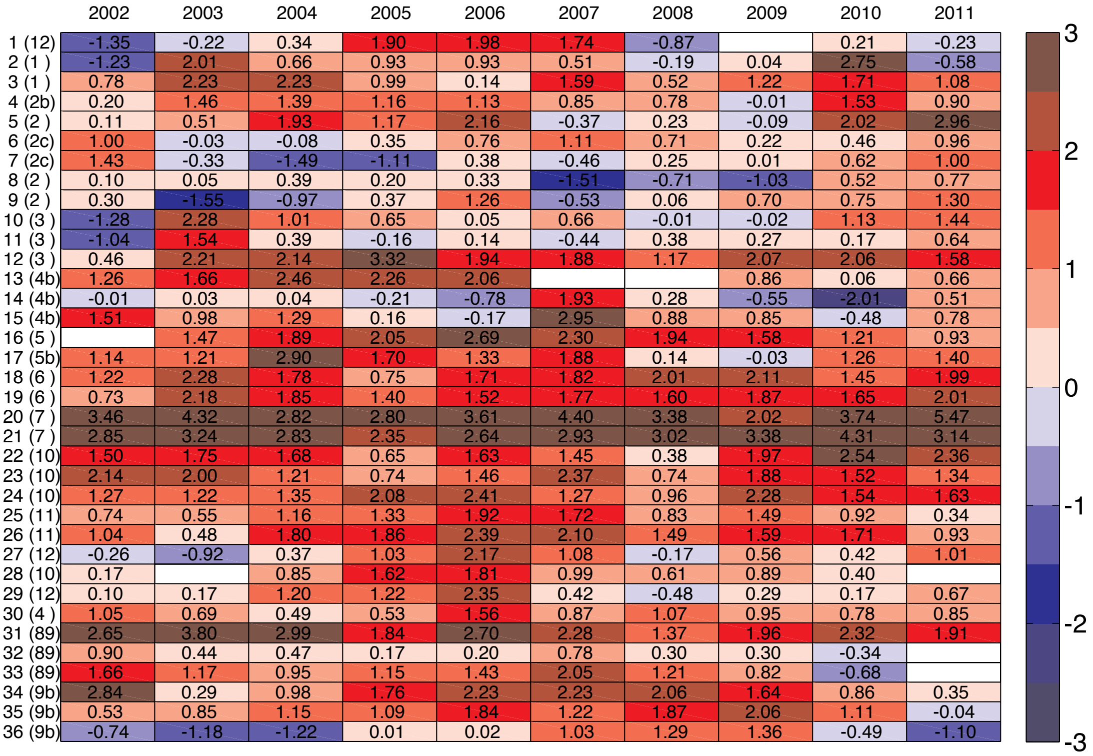
Where *in situ* section and station data are presented in the summary tables and figures, normalized anomalies have been provided to allow better comparison of trends in the data from different regions (Figures 1–3; Tables 1 and 2). The anomalies have been normalized by dividing the values by the standard deviation of the data during 1971–2000. A value of +2 thus represents data (temperature or salinity) at 2 standard deviations (s.d.) greater than normal.

OUR "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 1–4 TIMES A YEAR, BUT SOME ARE MADE MORE FREQUENTLY.

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

THE "SEASONAL CYCLE" DESCRIBES THE ANNUAL 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 GREATER THAN THE PROLONGED YEAR-TO-YEAR CHANGES WE DESCRIBE HERE.

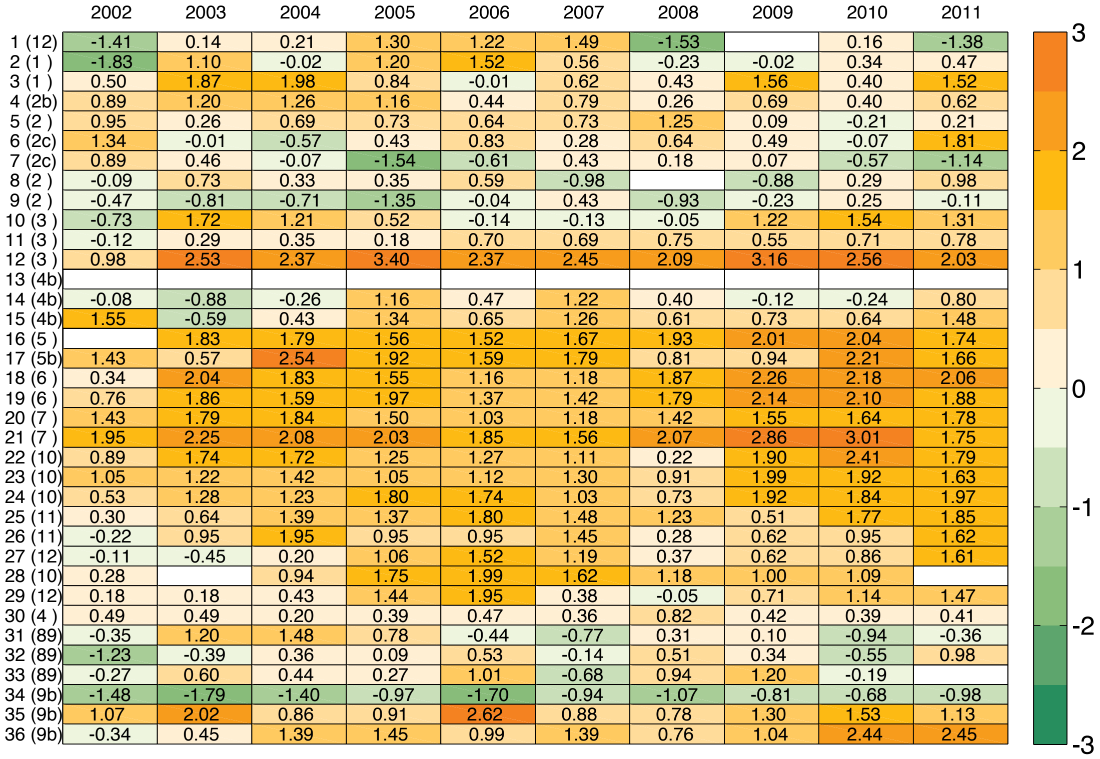
Image courtesy of A. Beszczynska-Möller, AWI, Germany.



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1 (12)	-1.35	-0.22	0.34	1.90	1.98	1.74	-0.87		0.21	-0.23
2 (1)	-1.23	2.01	0.66	0.93	0.93	0.51	-0.19	0.04	2.75	-0.58
3 (1)	0.78	2.23	2.23	0.99	0.14	1.59	0.52	1.22	1.71	1.08
4 (2b)	0.20	1.46	1.39	1.16	1.13	0.85	0.78	-0.01	1.53	0.90
5 (2)	0.11	0.51	1.93	1.17	2.16	-0.37	0.23	-0.09	2.02	2.96
6 (2c)	1.00	-0.03	-0.08	0.35	0.76	1.11	0.71	0.22	0.46	0.96
7 (2c)	1.43	-0.33	-1.49	-1.11	0.38	-0.46	0.25	0.01	0.62	1.00
8 (2)	0.10	0.05	0.39	0.20	0.33	-1.51	-0.71	-1.03	0.52	0.77
9 (2)	0.30	-1.55	-0.97	0.37	1.26	-0.53	0.06	0.70	0.75	1.30
10 (3)	-1.28	2.28	1.01	0.65	0.05	0.66	-0.01	-0.02	1.13	1.44
11 (3)	-1.04	1.54	0.39	-0.16	0.14	-0.44	0.38	0.27	0.17	0.64
12 (3)	0.46	2.21	2.14	3.32	1.94	1.88	1.17	2.07	2.06	1.58
13 (4b)	1.26	1.66	2.46	2.26	2.06			0.86	0.06	0.66
14 (4b)	-0.01	0.03	0.04	-0.21	-0.78	1.93	0.28	-0.55	-2.01	0.51
15 (4b)	1.51	0.98	1.29	0.16	-0.17	2.95	0.88	0.85	-0.48	0.78
16 (5)		1.47	1.89	2.05	2.69	2.30	1.94	1.58	1.21	0.93
17 (5b)	1.14	1.21	2.90	1.70	1.33	1.88	0.14	-0.03	1.26	1.40
18 (6)	1.22	2.28	1.78	0.75	1.71	1.82	2.01	2.11	1.45	1.99
19 (6)	0.73	2.18	1.85	1.40	1.52	1.77	1.60	1.87	1.65	2.01
20 (7)	3.46	4.32	2.82	2.80	3.61	4.40	3.38	2.02	3.74	5.47
21 (7)	2.85	3.24	2.83	2.35	2.64	2.93	3.02	3.38	4.31	3.14
22 (10)	1.50	1.75	1.68	0.65	1.63	1.45	0.38	1.97	2.54	2.36
23 (10)	2.14	2.00	1.21	0.74	1.46	2.37	0.74	1.88	1.52	1.34
24 (10)	1.27	1.22	1.35	2.08	2.41	1.27	0.96	2.28	1.54	1.63
25 (11)	0.74	0.55	1.16	1.33	1.92	1.72	0.83	1.49	0.92	0.34
26 (11)	1.04	0.48	1.80	1.86	2.39	2.10	1.49	1.59	1.71	0.93
27 (12)	-0.26	-0.92	0.37	1.03	2.17	1.08	-0.17	0.56	0.42	1.01
28 (10)	0.17		0.85	1.62	1.81	0.99	0.61	0.89	0.40	
29 (12)	0.10	0.17	1.20	1.22	2.35	0.42	-0.48	0.29	0.17	0.67
30 (4)	1.05	0.69	0.49	0.53	1.56	0.87	1.07	0.95	0.78	0.85
31 (89)	2.65	3.80	2.99	1.84	2.70	2.28	1.37	1.96	2.32	1.91
32 (89)	0.90	0.44	0.47	0.17	0.20	0.78	0.30	0.30	-0.34	
33 (89)	1.66	1.17	0.95	1.15	1.43	2.05	1.21	0.82	-0.68	
34 (9b)	2.84	0.29	0.98	1.76	2.23	2.23	2.06	1.64	0.86	0.35
35 (9b)	0.53	0.85	1.15	1.09	1.84	1.22	1.87	2.06	1.11	-0.04
36 (9b)	-0.74	-1.18	-1.22	0.01	0.02	1.03	1.29	1.36	-0.49	-1.10

Tables 1 and 2.

Changes in temperature (Table 1, top) and salinity (Table 2, bottom) at selected stations in the North Atlantic region during the past decade, 2002–2011. The index numbers on the left can be used to cross-reference each point with information in Figures 1 and 2 and in Table 3. The numbers in brackets refer to detailed area descriptions featured 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 for that year were 2 standard deviations, s.d., above normal). Blank boxes indicate that data were unavailable for a particular year at the time of publication. Colour intervals 0.5 s.d.; red = warm; blue= cold; orange = saline; green =fresh.



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1 (12)	-1.41	0.14	0.21	1.30	1.22	1.49	-1.53		0.16	-1.38
2 (1)	-1.83	1.10	-0.02	1.20	1.52	0.56	-0.23	-0.02	0.34	0.47
3 (1)	0.50	1.87	1.98	0.84	-0.01	0.62	0.43	1.56	0.40	1.52
4 (2b)	0.89	1.20	1.26	1.16	0.44	0.79	0.26	0.69	0.40	0.62
5 (2)	0.95	0.26	0.69	0.73	0.64	0.73	1.25	0.09	-0.21	0.21
6 (2c)	1.34	-0.01	-0.57	0.43	0.83	0.28	0.64	0.49	-0.07	1.81
7 (2c)	0.89	0.46	-0.07	-1.54	-0.61	0.43	0.18	0.07	-0.57	-1.14
8 (2)	-0.09	0.73	0.33	0.35	0.59	-0.98		-0.88	0.29	0.98
9 (2)	-0.47	-0.81	-0.71	-1.35	-0.04	0.43	-0.93	-0.23	0.25	-0.11
10 (3)	-0.73	1.72	1.21	0.52	-0.14	-0.13	-0.05	1.22	1.54	1.31
11 (3)	-0.12	0.29	0.35	0.18	0.70	0.69	0.75	0.55	0.71	0.78
12 (3)	0.98	2.53	2.37	3.40	2.37	2.45	2.09	3.16	2.56	2.03
13 (4b)										
14 (4b)	-0.08	-0.88	-0.26	1.16	0.47	1.22	0.40	-0.12	-0.24	0.80
15 (4b)	1.55	-0.59	0.43	1.34	0.65	1.26	0.61	0.73	0.64	1.48
16 (5)		1.83	1.79	1.56	1.52	1.67	1.93	2.01	2.04	1.74
17 (5b)	1.43	0.57	2.54	1.92	1.59	1.79	0.81	0.94	2.21	1.66
18 (6)	0.34	2.04	1.83	1.55	1.16	1.18	1.87	2.26	2.18	2.06
19 (6)	0.76	1.86	1.59	1.97	1.37	1.42	1.79	2.14	2.10	1.88
20 (7)	1.43	1.79	1.84	1.50	1.03	1.18	1.42	1.55	1.64	1.78
21 (7)	1.95	2.25	2.08	2.03	1.85	1.56	2.07	2.86	3.01	1.75
22 (10)	0.89	1.74	1.72	1.25	1.27	1.11	0.22	1.90	2.41	1.79
23 (10)	1.05	1.22	1.42	1.05	1.12	1.30	0.91	1.99	1.92	1.63
24 (10)	0.53	1.28	1.23	1.80	1.74	1.03	0.73	1.92	1.84	1.97
25 (11)	0.30	0.64	1.39	1.37	1.80	1.48	1.23	0.51	1.77	1.85
26 (11)	-0.22	0.95	1.95	0.95	0.95	1.45	0.28	0.62	0.95	1.62
27 (12)	-0.11	-0.45	0.20	1.06	1.52	1.19	0.37	0.62	0.86	1.61
28 (10)	0.28		0.94	1.75	1.99	1.62	1.18	1.00	1.09	
29 (12)	0.18	0.18	0.43	1.44	1.95	0.38	-0.05	0.71	1.14	1.47
30 (4)	0.49	0.49	0.20	0.39	0.47	0.36	0.82	0.42	0.39	0.41
31 (89)	-0.35	1.20	1.48	0.78	-0.44	-0.77	0.31	0.10	-0.94	-0.36
32 (89)	-1.23	-0.39	0.36	0.09	0.53	-0.14	0.51	0.34	-0.55	0.98
33 (89)	-0.27	0.60	0.44	0.27	1.01	-0.68	0.94	1.20	-0.19	
34 (9b)	-1.48	-1.79	-1.40	-0.97	-1.70	-0.94	-1.07	-0.81	-0.68	-0.98
35 (9b)	1.07	2.02	0.86	0.91	2.62	0.88	0.78	1.30	1.53	1.13
36 (9b)	-0.34	0.45	1.39	1.45	0.99	1.39	0.76	1.04	2.44	2.45

Table 3. *Details of the datasets included in Figures 1 and 2 and in Tables 1 and 2. Blank boxes indicate that no information was available for the area at the time of publication. T stands for temperature, S for salinity. Some data are calculated from an average of more than one station; in such cases, the latitudes and longitudes presented here represent a nominal midpoint along that section.*

Index	Description	Area	Measurement depth	Long-term average	Lat	Lon	Mean T, °C	S.d. T, °C	Mean S	S.d. S
1	Fram Strait – East Greenland Current	12	50–500 m	1980–2010	78.83	-6.00	0.84	0.63	34.702	0.129
2	Station 4 – Fylla Station – Greenland Shelf	1	0–50 m	1983–2000	63.88	-53.37			2.329	1.003
3	Cape Desolation Station 3	1	75–200 m	1983–2000	60.47	-50.00	5.44	0.61	34.903	0.062
4	Area 2b – west-central Labrador Sea – AR7W stations	2b	0–150 m	1971–2000	56.70	-52.50	3.73	0.38	34.710	0.088
5	Station 27 – Newfoundland Shelf (temperature) – Canada	2	0–175 m	1971–2000	47.55	-52.59		0.35		0.233
6	Oleander Section (inshore of 100 m isobath) – Mid-Atlantic Bight – USA	2c	Surface	1980–2010	39.00	-71.50				
7	Northwest Georges Bank – Mid-Atlantic Bight – USA	2c	1–30 m	1980–2010	42.00	-70.00	9.98	0.79	32.600	0.280
8	Emerald Bank – Central Scotian Shelf – Canada	2	Near Bottom	1981–2010	44.00	-63.00		1.21		0.221
9	Misaine Bank – Northeastern Scotian Shelf – Canada	2	Near bottom	1981–2010	45.00	-59.00		0.58		0.159
10	Siglunes Station 2–4 – North Iceland Irminger current	3	50–150 m	1971–2000	67.00	-18.00	3.34	1.01	34.823	0.124
11	Langanes Station 2–6 – Northeast Iceland – East Icelandic Current	3	0–50 m	1971–2000	67.50	-13.50	1.24	0.95	34.698	0.137
12	Selvogsbanki Station 5 – Southwest Iceland – Irminger Current	3	0–200 m	1971–2000	63.00	-22.00	7.64	0.37	35.154	0.037
13	Malin Head Weather Station	4b	Surface	1971–2000	55.37	-7.34	10.57	0.50		
14	Point 33 – Astan	4b	5 m	1998–2010	48.78	-3.94	12.69	0.35	35.212	0.111
15	Western Channel Observatory (WCO) – E1 – UK	4b	Depth average 0–40 m	1971–2000	50.03	-4.37	12.00	0.39	35.186	0.095
16	Ellet Line – Rockall Trough – UK (Section average)	5	0–800 m	1975–2000	56.75	-11.00	9.26	0.33	35.328	0.040
17	Central Irminger Sea – Subpolar Mode Water	5b	200–400 m	1991–2000	59.40	-36.80	3.97	0.52	34.876	0.030
18	Faroe Bank Channel – West Faroe Islands	6	Upper-layer, high-salinity core	1988–2000	61.00	-8.00	8.53	0.37	35.272	0.044
19	Faroe Current – North Faroe Islands (Modified North Atlantic Water)	6	Upper layer, high salinity core	1988–2000	63.00	-6.00	7.84	0.40	35.218	0.043
20	Faroe Shetland Channel – Shetland Sheld (North Atlantic Water)	7	Upper layer, high salinity core	1971–2000	61.00	-3.00	9.57	0.15	35.363	0.040
21	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	35.219	0.035
22	Ocean Weather Station Mike – 50m	10	50 m	1971–2000	66.00	-2.00	7.49	0.44	35.148	0.045
23	Southern Norwegian Sea – Svinøy Section – Atlantic Water	10	50–200 m	1971–2000	63.00	3.00	7.68	0.50	35.210	0.056
24	Central Norwegian Sea – Gimsøy Section – Atlantic Water	10	50–200 m	1971–2000	69.00	12.00	6.45	0.44	35.129	0.053
25	Fugløya – Bear Island Section – Western Barents Sea – Atlantic inflow	11	50–200 m	1977–2006	73.00	20.00	5.35	0.54	35.059	0.049
26	Kola Section – East Barents Sea	11	0–200 m	1971–2000	71.50	33.50	3.92	0.49	34.763	0.060
27	Greenland Sea Section – West of Spitsbergen	12	200 m	1996–2010	76.50	10.50	3.19	0.61	35.058	0.045
28	Northern Norwegian Sea – Sørkapp Section – Atlantic Water	10	50–200 m	1971–2000	76.33	10.00	3.80	0.68	35.054	0.046
29	Fram Strait – West Spitsbergen Current	12	50–500 m	1980–2010	78.83.00	7.00	3.08	0.71	35.023	0.039
30	Santander Station 6 (shelf break) – Bay of Biscay – Spain	4	5–200 m	1993–2000	43.70	-3.78	12.69	0.32	35.617	0.064
31	Fair Isle Current Water (waters entering North Sea from Atlantic)	8 & 9	0–100 m	1971–2000	59.00	-2.00	9.71	0.34	34.841	0.070
32	Section average – Felixstowe – Rotterdam	8 & 9	Surface	1971–2000	52.00	3.00	12.24	1.20	34.650	0.330
33	Helgoland Roads – Coastal waters – German Bight North Sea	8 & 9	Surface	1971–2000	54.19	7.90	10.10	0.72	32.110	0.544
34	Baltic Proper – East of Gotland – Baltic Sea	9b	Surface	1971–2000	57.50	19.50	8.57	0.86	7.352	0.242
35	Baltic Proper – LL7 – Baltic Sea	9b	70 m	1991–2000	59.51	24.50	3.49	0.71	7.531	0.653
36	Baltic Proper – SR5 – Baltic Sea	9b	110 m	1991–2000	61.05	19.35	3.25	0.58	6.357	0.153

2.2 Sea surface temperature

Sea surface temperatures across the entire North Atlantic have also been obtained from a combined satellite and *in situ* gridded dataset. Figure 3 shows the seasonal SST anomalies for 2011, extracted from the Optimum Interpolation SST dataset (OISST.v2) 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 >50% of the averaging period appear blank.

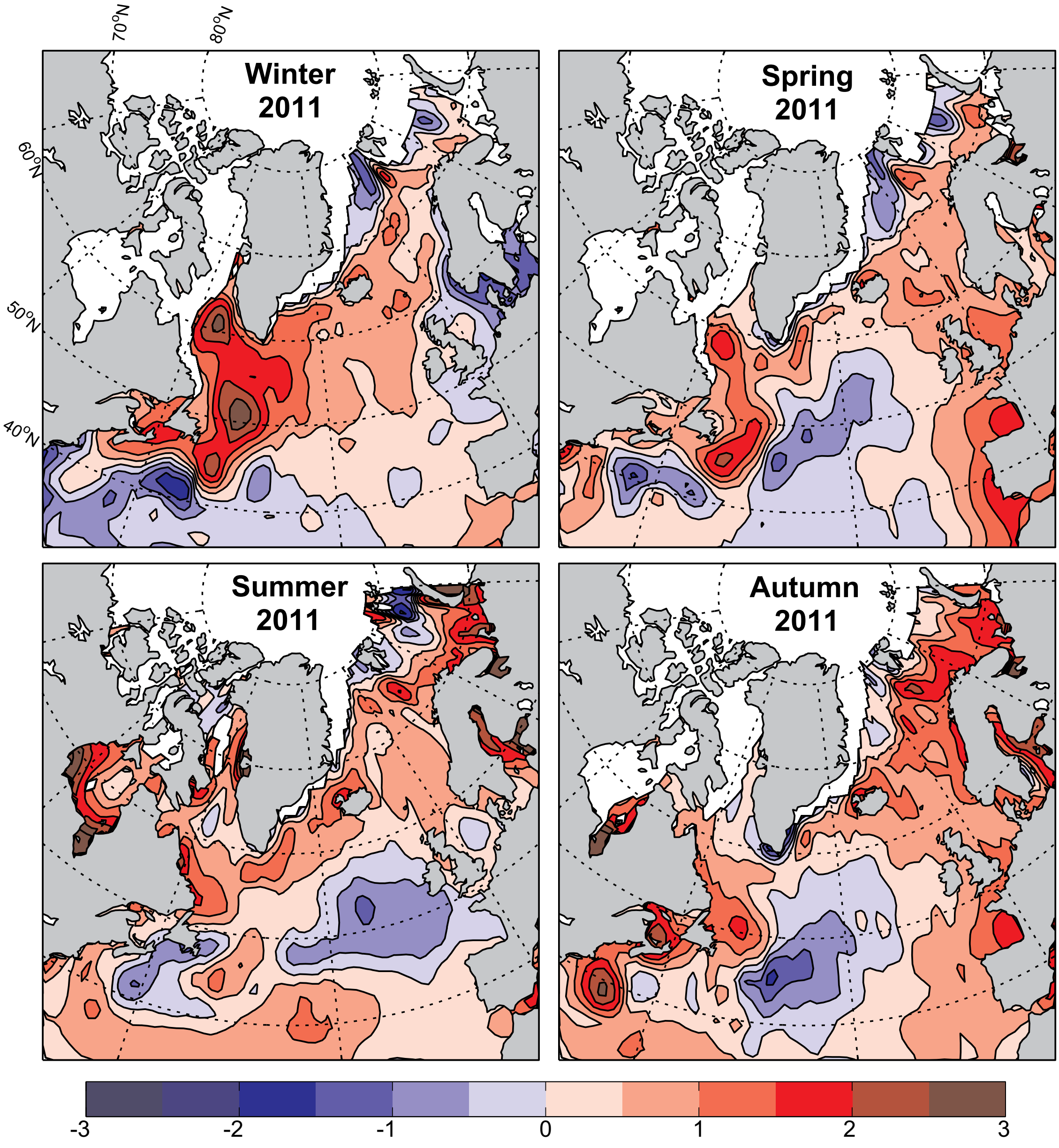


Figure 3.
Maps of seasonal sea surface temperature anomalies (°C) over the North Atlantic for 2011 from the NOAA Optimum Interpolation SSTv2 dataset provided by the NOAA–CIRES Climate Diagnostics Center, USA. The colour-coded temperature scale is the same in all panels. The anomaly is calculated with respect to normal conditions for 1971–2000. The data are produced on a 1° grid from a combination of satellite and in situ *temperature data. Regions with ice cover >50% of the averaging period are left blank.*

2.3 Gridded temperature and salinity fields

A summary of the conditions in the North Atlantic over the last decade can be established using the Argo global observing system based on profiling floats. Temperature and salinity fields are estimated on a regular half degree (Mercator scale) grid using ISAS (*In Situ* Analysis System; Gaillard *et al*., 2009) a tool developed and maintained at LPO (Laboratoire de Physique des Océans) within the SO-Argo (Système d'Observation-Argo, http://wwz.ifremer.fr/lpo/SO-Argo-France).

The year 2011 was processed in near real-time. Around the 8th of each month, the Coriolis data centre prepares files with all data collected for the previous calendar month. The files contain mostly Argo profiles, but some CTD, buoy, and mooring data transmitted in real-time are also included. Preprocessing is performed as follows: a climatological test is first applied to detect outliers, and then the profiles are vertically interpolated on 152 standard depths from 0 to 2000 m. The analysis to produce gridded fields is then performed on the preprocessed data at each standard depth independently. The method is based on optimal estimation principles and includes a horizontal smoothing through specified covariance scales. The results presented in this report were produced with ISAS version 6. The reference state was computed as the mean of a 2004–2010 analysis (D2CA1S2), and the *a priori* variances were computed from the same dataset. To compare the year 2011 with the previous years sampled by Argo, a homogeneous analyzed field was produced over the period 2002–2011 (analysis named D2CA2S0). The data for the period 2002–2010 were obtained in delayed mode for 2002 to mid-2009 and in near real-time for the second half of 2009 and 2010.

The near-surface layer of the ocean (Figures 4 and 5) is directly influenced by the atmospheric conditions. In winter 2011, this layer was more than 1°C warmer than normal throughout the Labrador Sea. It was at least 1°C colder than normal south of Newfoundland along 42°N from the American coast to the centre of the North Atlantic. This cold anomaly was also associated with fresher-than-normal water. In spring, the North Atlantic was warmer than normal east of 20°W and colder west of this longitude. In summer, waters situated east of Greenland and east of America from 60°N to 40°N were warm (1–2°C above normal) and saline. The central North Atlantic was colder and fresher than normal. The cold anomaly continued to develop during autumn, but was limited to the area west of 20°W.

The resulting near-surface annual mean anomaly shows (Figure 6) warm and saline waters in the Greenland Sea and along the path of the East Greenland Current. Warm and saline water was also present along the path of the Labrador Current, with an intrusion of cold/fresh waters on the north flank of the Gulf Stream/North Atlantic Current. At the eastern boundary (Iberian Peninsula, Bay of Biscay, North Scotland, and Norway), waters were slightly warmer and saltier than normal. In the central North Atlantic (50°N) west of 20°W, a pool of cold and fresh water is apparent.

The annual mean anomalies for the ocean interior at a depth of 1000 m are shown in Figure 7. Here, a cold and fresh anomaly is observed south of the Gulf Stream and Azores Current (subtropical gyre). The Greenland and Labrador seas are warmer than normal, and this is a clear tendency since 2002. Mediterranean outflow water seems warmer and saltier west of the Iberian Peninsula and along the eastern boundary than is typical. The cold anomaly along 20°W that started to develop in 2006 was weakening in 2011.

Variations in the February mixed-layer depth (defined as the depth where temperature differs by more than 0.5°C from the 10 m value) are shown in Figure 8. As in 2011, the mixed layer was deep along the eastern boundary, particularly north of the Bay of Biscay. In 2011, this did not extend zonally westwards into the basin as strongly as it had in 2010, and a sharp southern limit was found at 42°N.

Figure 4.
Maps of 2011 seasonal temperature anomalies at 10 m depth in the North Atlantic. Anomalies are the differences between the ISAS monthly mean values and the reference climatology, WOA-05. The colour-coded temperature scale is the same in all panels. From the ISAS monthly analysis of Argo data.

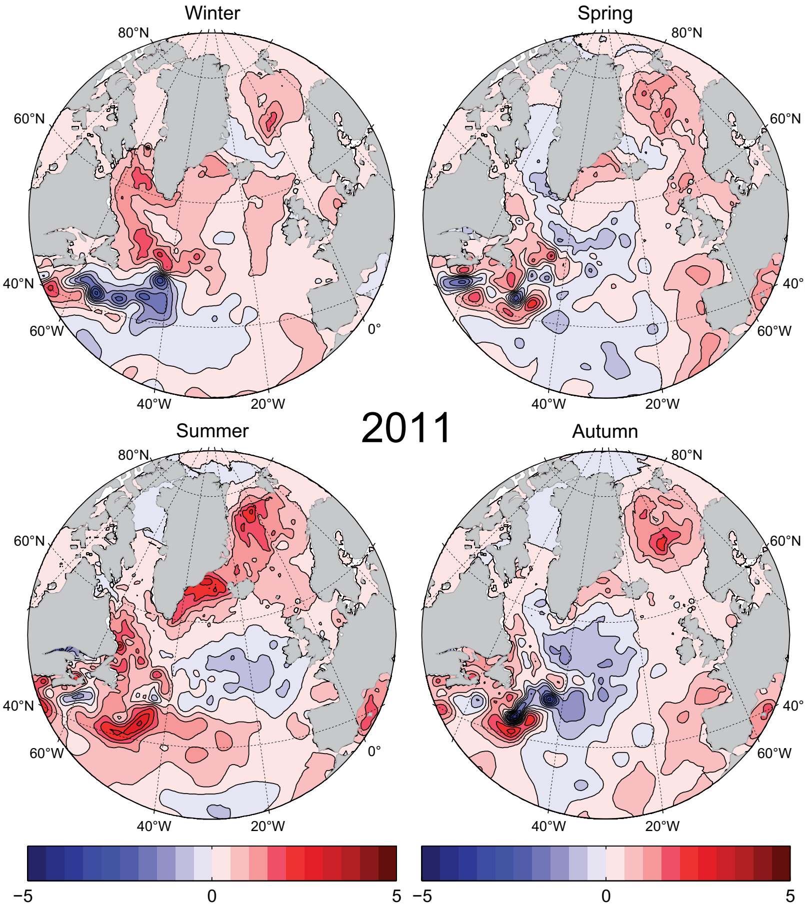
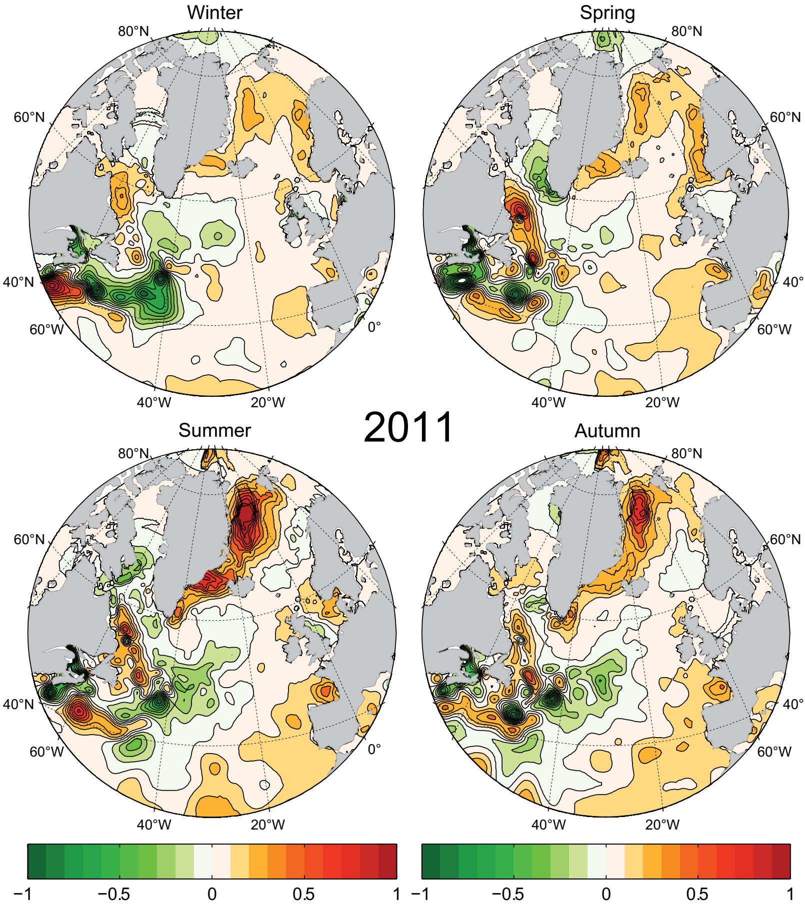


Figure 5.
Maps of 2011 seasonal salinity anomalies at 10 m depth in the North Atlantic. Anomalies are the differences between the ISAS monthly mean values and the reference climatology, WOA-05. The colour-coded salinity scale is the same in all panels. From the ISAS monthly analysis of Argo data.



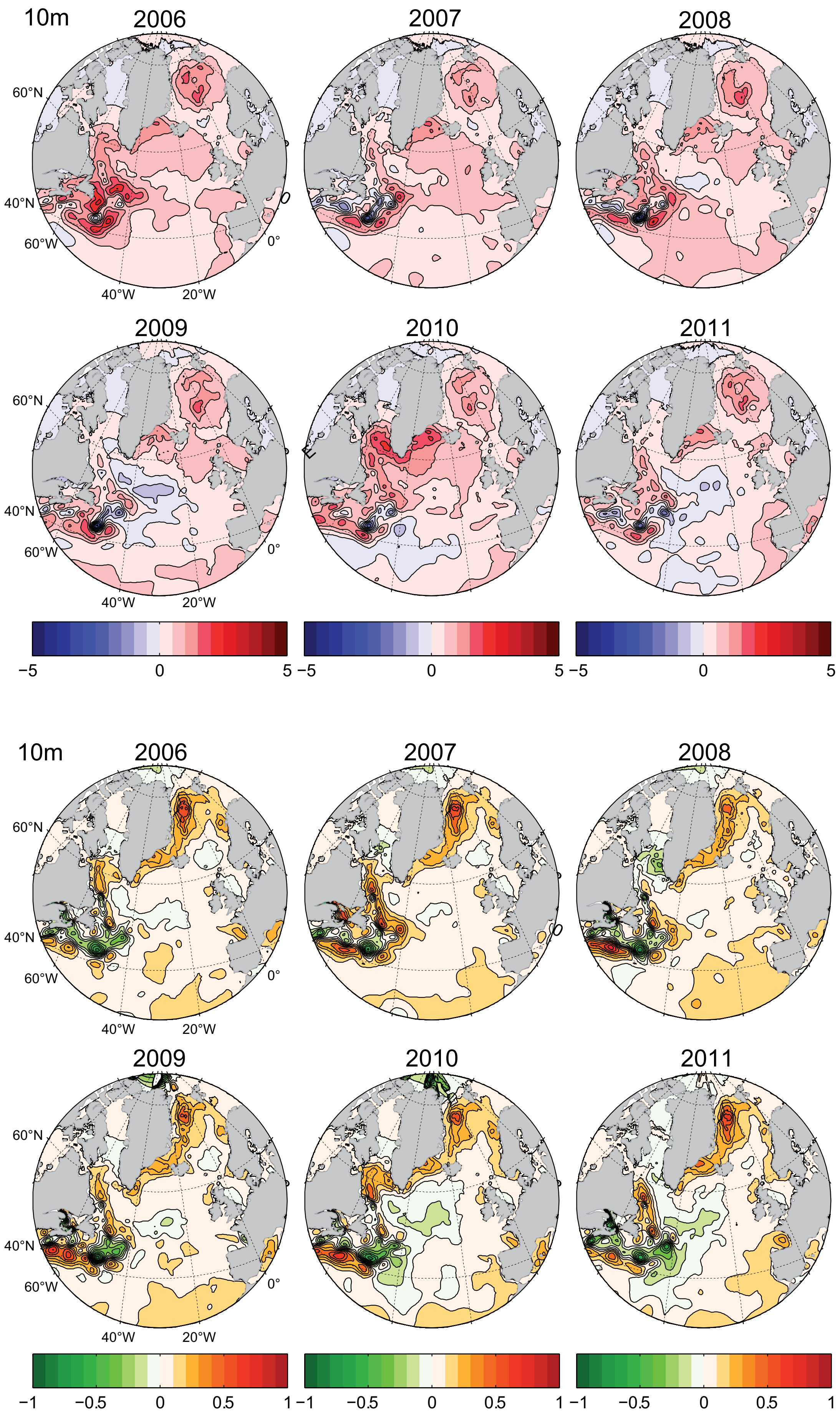
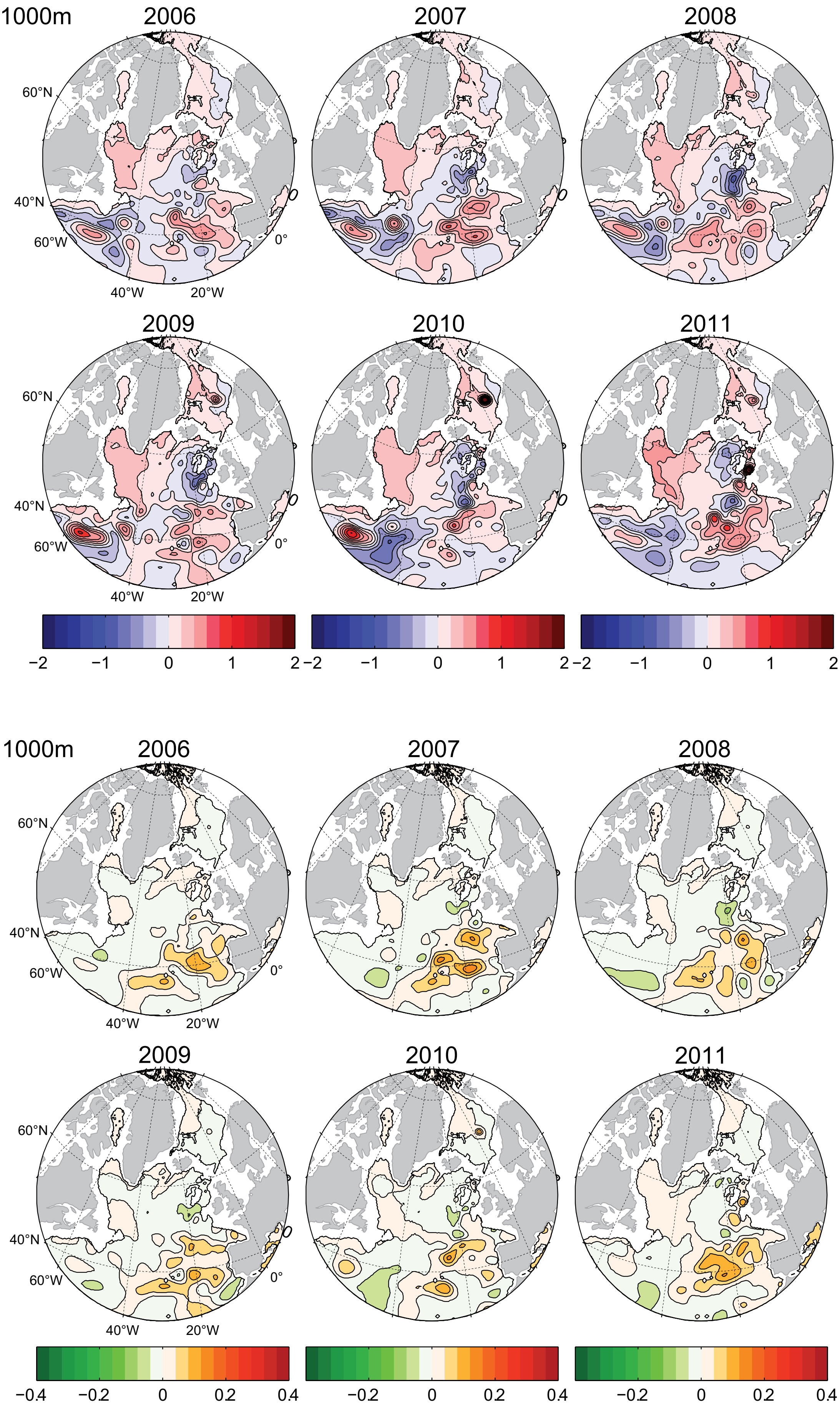


Figure 6.
Maps of annual temperature (upper) and salinity (lower) anomalies at 10 m for 2006–2011. From the ISAS monthly analysis of Argo data.

Figure 7.
Maps of annual temperature (upper) and salinity (lower) anomalies at 1000 m for 2006–2011. From the ISAS monthly analysis of Argo data.



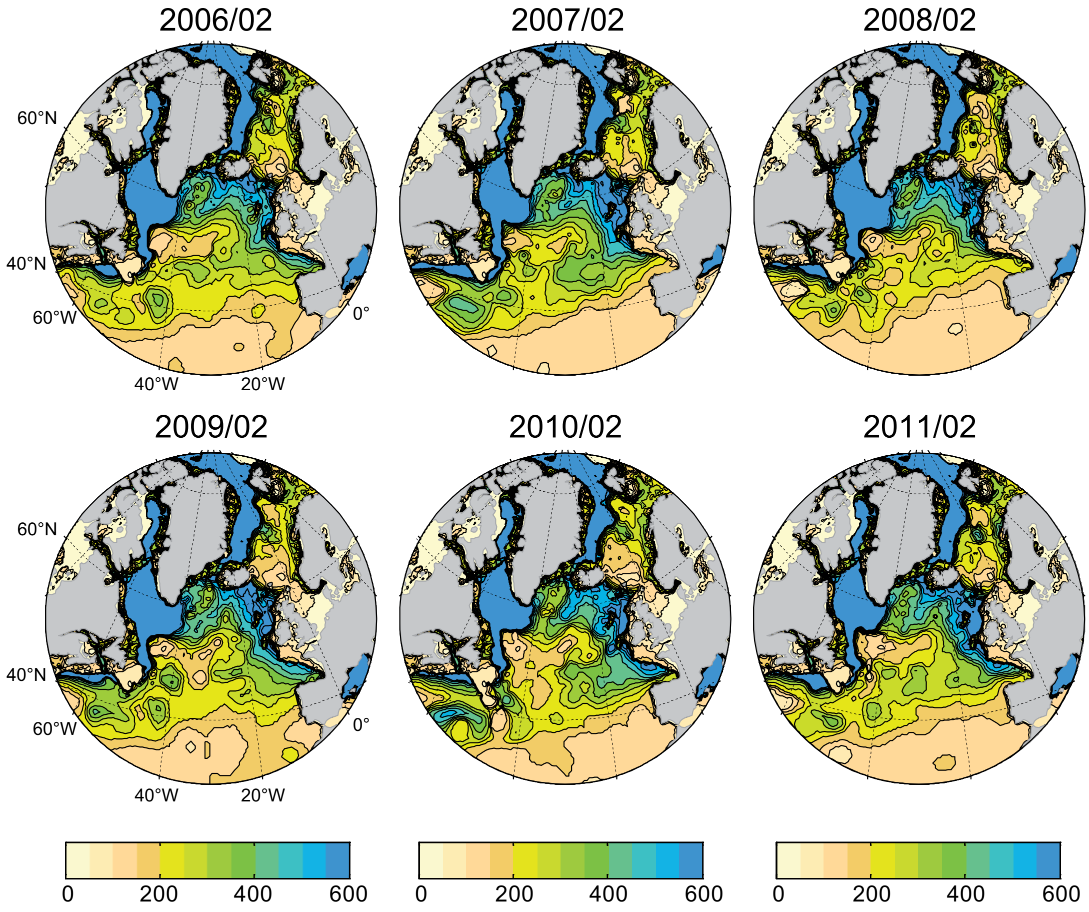


Figure 8.
Maps of North Atlantic winter (February) mixed-layer depths for 2006–2011. From the ISAS monthly analysis of Argo data. Note that the mixed-layer depth is defined as the depth at which the temperature has decreased by more than 0.5°C from the temperature at 10 m depth. This criterion is not suitable for areas where effects of salinity are important (ice melting) or where the basic stratification is weak. Therefore, results in the Labrador Sea, around Greenland, and in the Gulf of Lion are not significant.

3. THE NORTH ATLANTIC ATMOSPHERE

3.1 Sea level pressure

The North Atlantic Oscillation (NAO) is a pattern of atmospheric variability that has a significant impact on oceanic conditions. It affects wind speed, precipitation, evaporation, and the exchange of heat between 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 Lisbon, Portugal. 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.

When the NAO is weak, two additional dominant atmospheric regimes have been recognized as useful descriptors: (i) the Atlantic Ridge mode, when a strong anticyclonic ridge develops off western Europe (similar to the East Atlantic pattern); and (ii) the Blocking regime, when the anticyclonic ridge develops over Scandinavia. The four regimes (positive NAO, negative NAO, Atlantic Ridge, and Blocking) have all been occurring at around the same frequency (20–30% of all winter days) since 1950. These modes of variability are revealed through cluster analysis of sea level pressure (SLP) rather than examining point-to-point SLP gradients.

There are several slightly different versions of the NAO index calculated by climate scientists. The Hurrell winter (December, January, February, and March, or DJFM) NAO index is the one most commonly used and is particularly relevant 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 winter 1995/1996.

Between 1996 and 2009, the Hurrell NAO index was fairly weak in most years and a less useful descriptor of atmospheric conditions. In winter 2010, the index was strongly negative (Figure 9), and its anomaly pattern exerted a dominant influence on atmospheric conditions. This was the strongest negative anomaly since 1969 and the second strongest negative value for the Hurrell winter NAO index on record (which began in 1864).

In winter 2010/2011, the Hurrell NAO winter index remained negative (–1.57; Figure 9), but was not as strong as the previous winter, generating less extreme conditions. It was the third winter in succession that the index was negative, which has not happened since the winters 1968/1969 through 1970/1971. The atmospheric conditions indicated by this negative NAO index are more clearly understandable when the anomaly fields are mapped. Ocean properties are particularly dominated by winter conditions, hence the inclusion of maps of SLP for winter (DJFM; Figure 10). The top panel of Figure 10 shows the winter SLP averaged over 30 years (1971–2000). 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).

The middle panel of Figure 10 shows the mean SLP for winter 2011 (December 2010, January–March 2011), and the bottom panel shows the 2011 winter SLP anomaly (i.e. the difference between the top and middle panels). In winter 2011, the average SLP field had a fairly typical pattern compared to the 1971–2000 average. Both the Iceland Low and the Azores High were evident, but they were weaker than in the mean pattern. The resulting SLP anomaly shows a negative NAO character, being negative in the south and positive in the north.

The figures show contours of constant SLP (isobars). The geostrophic (or“gradient”) wind blows parallel with the isobars, with lower pressure to the left; the closer the isobars, the stronger the wind. The strength of the winter mean surface wind averaged over the 30-year period (1971–2000) is shown in the upper panel of Figure 11, while the lower panel shows the anomaly in winter 2011. These reanalyses demonstrate that the mean winds were stronger than normal across the ocean in the southern part of the region, over the Azores, Newfoundland, and in regions west and east of Iceland. Winds were weaker than normal north and east of the Azores in a broad band centred over Rockall and Ireland and extending across the North Sea.

IN WINTER 2010/2011, THE HURRELL NAO WINTER INDEX WAS NEGATIVE FOR THE THIRD SUCCESSIVE YEAR.

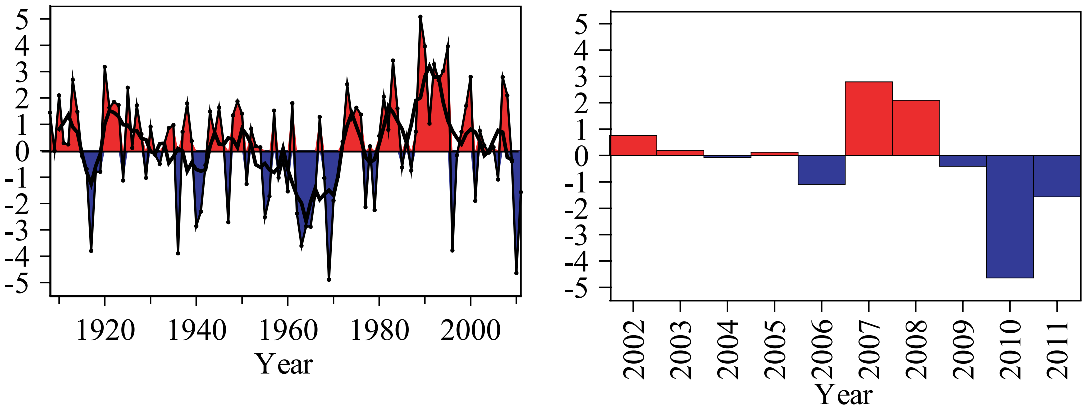
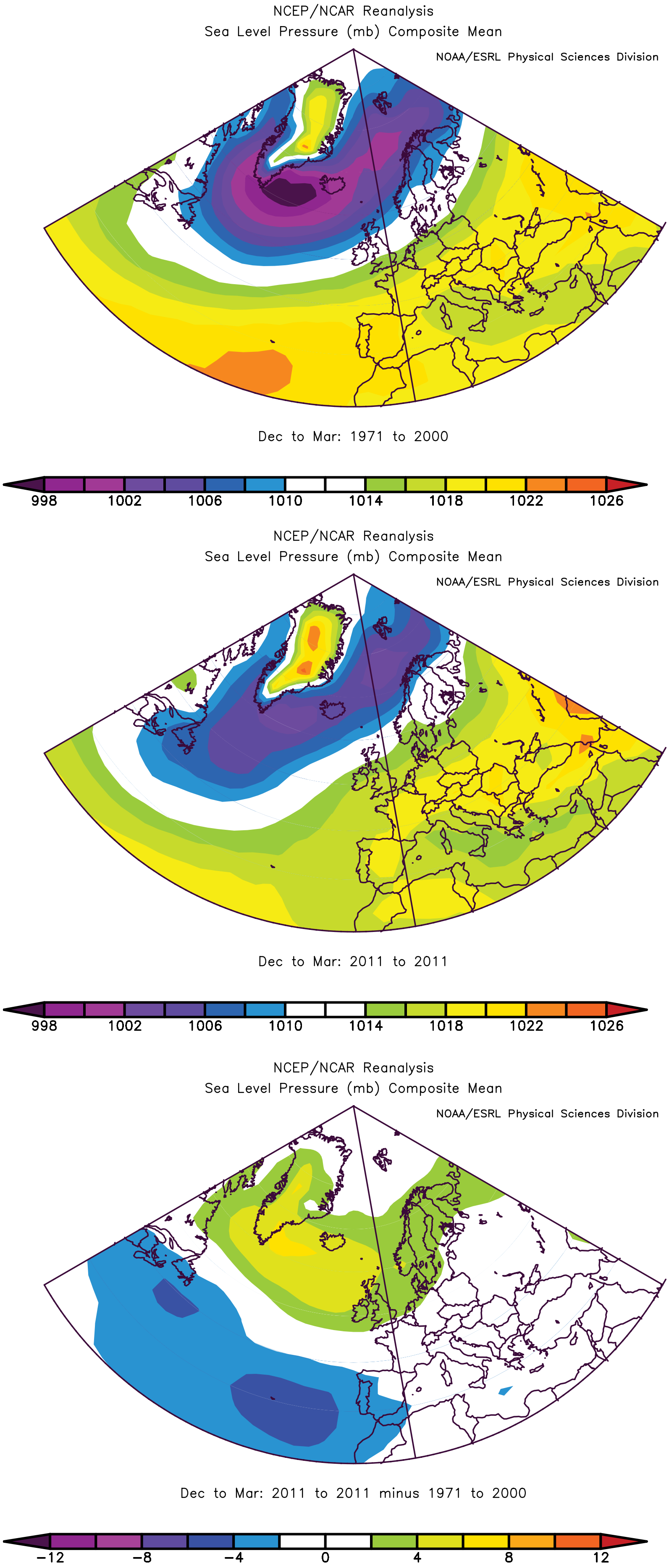


Figure 9.
The Hurrell winter (DJFM) NAO index for the past 100 years, with a 2-year running mean applied (left panel) and for the current decade (right panel). Data source: http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html.

Figure 10.
Winter (DJFM) sea level pressure (SLP) fields. Top panel: SLP averaged over 30 years (1971–2000). Middle panel: mean SLP in winter 2011 (December 2010, January–March 2011). Bottom panel: winter 2011 SLP anomaly – the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO (available online at http://www.cdc.noaa.gov/).



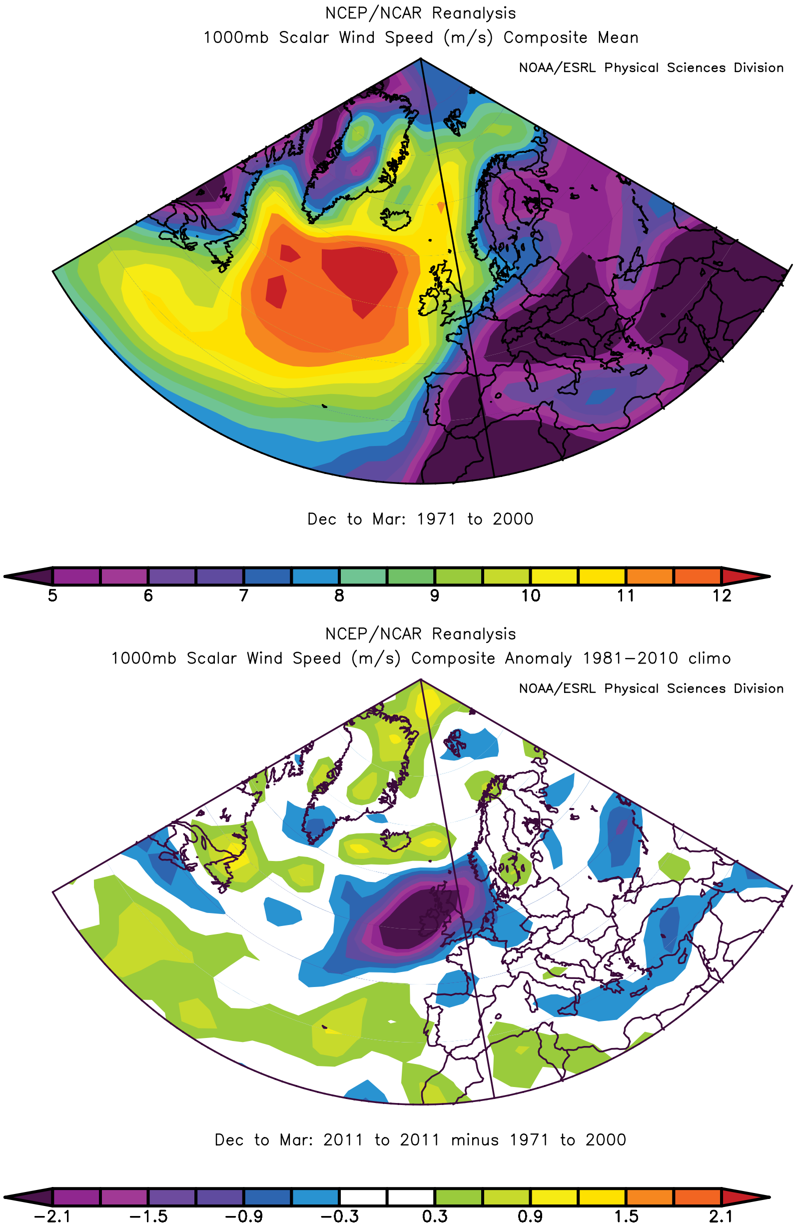


Figure 11.
Winter (DJFM) surface wind speed. Upper panel: surface wind speed averaged over 30 years (1971–2000). Lower panel: winter 2011 anomaly in surface wind speed. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO (available online at http://www.cdc.noaa.gov/).

3.2 Surface air temperature

North Atlantic winter mean surface air temperatures are shown in Figure 12. The 1971–2000 mean conditions (Figure 12, top panel) show high temperatures penetrating far to the north on the eastern side of the North Atlantic and the Nordic seas, caused by the northward movement of warm oceanic water. The middle panel of Figure 12 shows the conditions in winter (DJFM) 2010/2011, and the bottom panel shows the difference between the two.

In winter 2010/2011, the central North Atlantic and Norwegian Sea surface air temperatures were near normal, as were most of the seas off the European continental margin. The Baltic, eastern North Sea, and northeastern Europe experienced cold winter conditions at least 1°C cooler than normal. In contrast, the surface air temperature over the Greenland and southern Irminger seas was more than 1°C higher than normal.

Temperature over the Labrador Sea was again high; much of the area was more than 3°C warmer than the 1971–2000 average.

WINTER SURFACE AIR TEMPERATURES WERE LOW OVER NORTHEASTERN EUROPE AND HIGH OVER GREENLAND, THE IRMINGER SEA, AND THE LABRADOR SEA.

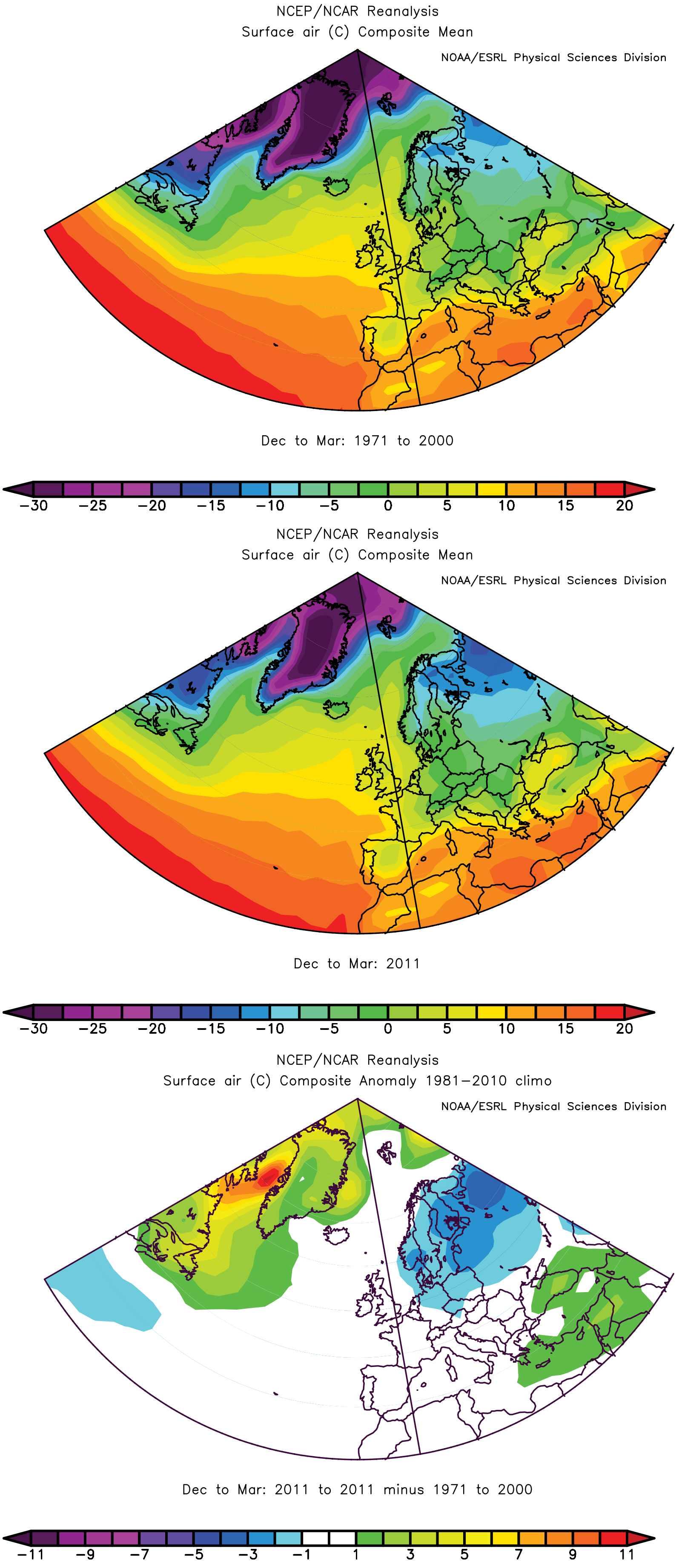


Figure 12.
Winter (DJFM) surface air temperature fields. Top panel: surface air temperature averaged over 30 years (1971–2000). Middle panel: temperatures in winter 2011 (December 2010, January to March 2011). Bottom panel: winter 2011 surface air temperature anomaly – the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO (available online at http://www.cdc.noaa.gov/).

4. DETAILED AREA DESCRIPTIONS, PART I: THE UPPER OCEAN

4.1 Introduction

In this section, we present time-series from many sustained observations in each of the ICES Areas. The general pattern of oceanic circulation in the upper layers of the North Atlantic, in relation to the areas described here, is given in Figure 13. In addition to temperature and salinity, we present other indices where they are available, such as air-temperature and sea-ice indices. The text summarizes the regional context of the sections and stations, noting any significant recent events.

Most standard sections or stations are sampled annually or more frequently. Often, the time-series presented here have been extracted from larger datasets and chosen as indicators of the conditions in a particular area. 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 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 1971–2000 or by drawing on other sources, such as regional climatology datasets. Smoothed versions of most time-series are included using a low-pass filter with a 2-, 5-, or 10-year window, depending on the length of the series.

In some areas, data are sampled regularly enough to allow a good description of the seasonal cycle. Where possible, monthly data from 2011 are presented and compared with the average seasonal conditions and statistics.

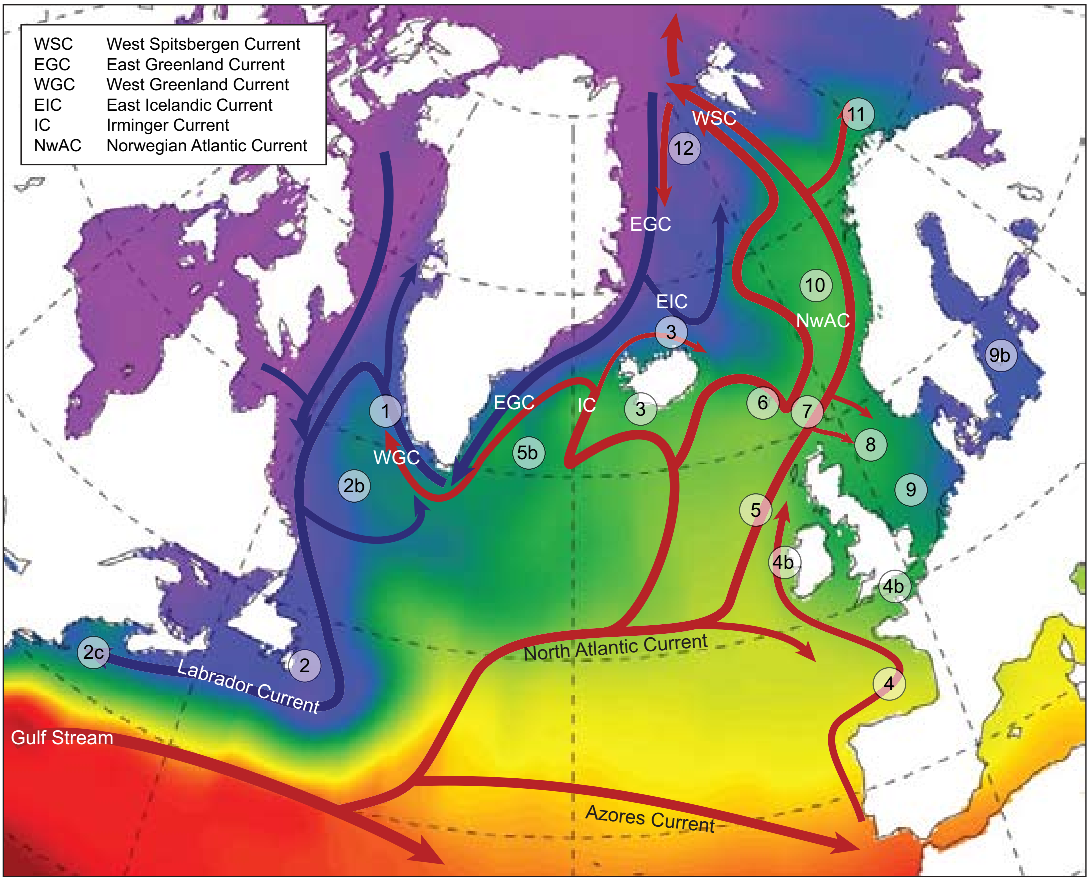


Figure 13.
Schematic of the general circulation of the upper ocean (approximately 0–1000 m) in the North Atlantic in relation to the numbered areas presented below. Blue arrows = movement of cooler waters of polar and subpolar influence; red arrows = movement of warmer waters of Atlantic influence.

4.2 Area 1 – West Greenland

THE WEST GREENLAND CURRENT CARRIES WATER NORTHWARD ALONG THE WEST COAST OF GREENLAND AND CONSISTS OF TWO COMPONENTS: A COLD AND FRESH INSHORE COMPONENT, WHICH IS A MIXTURE OF THE POLAR WATER AND MELT WATER, AND A SALTIER AND WARMER IRMINGER SEA WATER OFFSHORE COMPONENT. THE WEST GREENLAND CURRENT IS PART OF THE CYCLONIC SUBPOLAR GYRE AND THUS IS SUBJECT TO HYDROGRAPHIC VARIATIONS AT THE DIFFERENT TIME-SCALES ASSOCIATED WITH VARIABILITY IN THE GYRE. HYDROGRAPHIC CONDITIONS ARE MONITORED ANNUALLY AT TWO OCEANOGRAPHIC SECTIONS ACROSS THE CONTINENTAL SLOPE OF WEST GREENLAND. TWO OFFSHORE STATIONS AT EACH SECTION HAVE BEEN CHOSEN TO DOCUMENT CHANGES IN HYDROGRAPHIC CONDITIONS OFF WEST GREENLAND.

West Greenland usually experiences warmer-than-normal conditions when the NAO index is negative, and the highest ever reported temperature occurred in 2010. In 2011, following this record year, the annual mean air temperature at Nuuk Weather Station in West Greenland decreased to −1.13°C, a level closer to that of 2009, but still higher than average.

The water properties between 0 and 50 m depth at Fyllas Bank Station 4 are used to monitor the variability of the fresh Polar Water component of the West Greenland Current. In 2010, the temperature of this water was 2.8°C higher than the long-term mean (1983–2000) due to the heat flux from the warm atmosphere. However, in 2011, the temperature of this water was 0.6°C lower than the long-term mean (1983–2000). The salinity anomaly of the Polar Water reveals a short-term increasing trend since 2008. In 2011, the salinity was 0.18°C higher than the long-term mean.

The temperature, salinity, and volume of the Irminger Sea Water component of the West Greenland Current started to increase towards the end of the 1990s, coinciding with a documented slow-down of the Subpolar Gyre. In 2011, the water temperature in the 75–200 m layer at Cape Desolation Station 3 was 6.1°C, which is 0.4°C lower than observed in 2010, but 0.7°C higher than the long-term mean. In 2011, the salinity in the 75–200 m layer at Cape Desolation Station 3 was 35.0, which is 0.07°C higher than observed in 2010 and 0.1°C above the long-term mean.

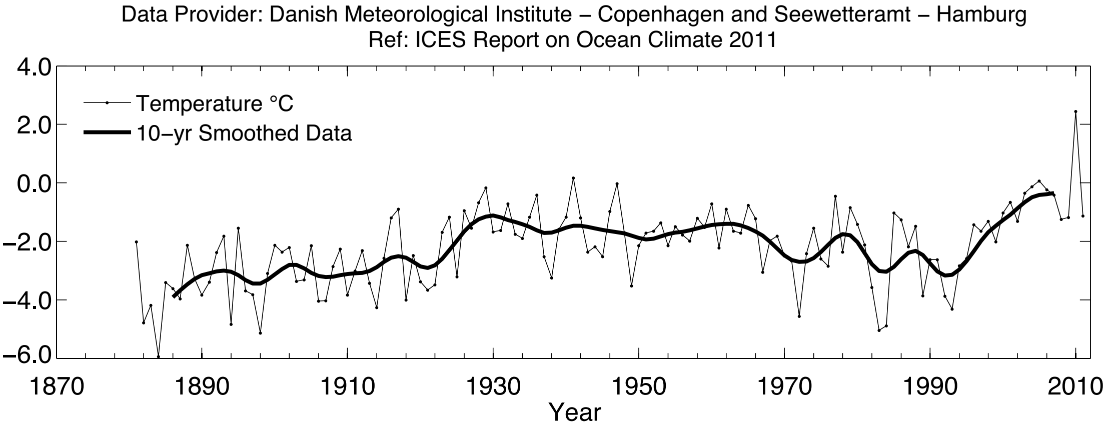


Figure 14. Area 1 – West Greenland. Annual mean air temperature at Nuuk weather station (64.16°N 51.75°W).

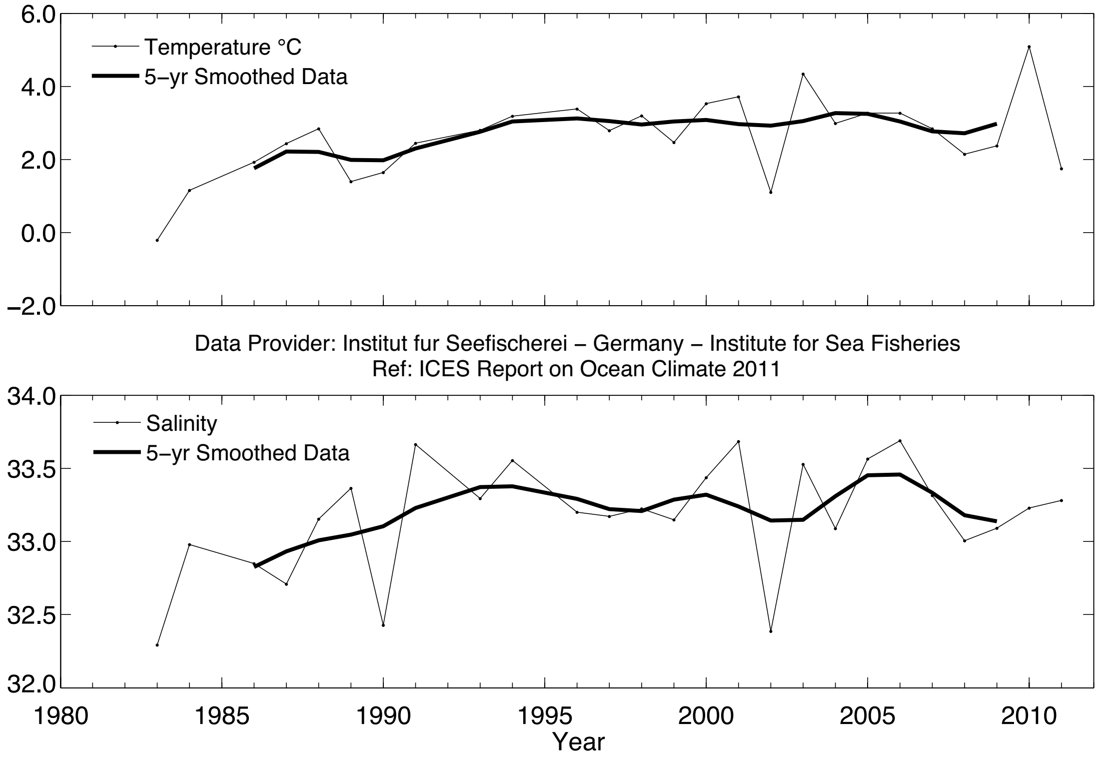


Figure 15.
Area 1 – West Greenland. Mean temperature (upper panel) and salinity (lower panel) in the 0–50 m water layer at Fyllas Bank Station 4 (63.88°N 53.37°W).

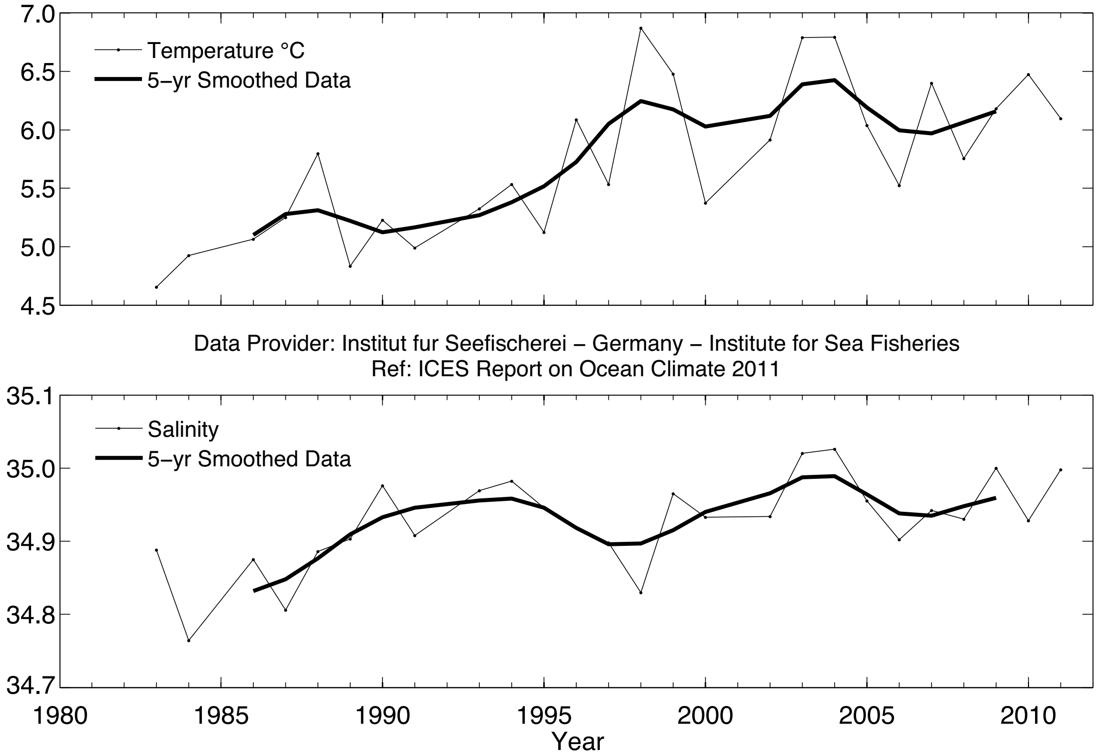


Figure 16.
Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 75–200 m at Cape Desolation Station 3 (60.45°N 50°W).

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

Scotian Shelf

THE CONTINENTAL SHELF OFF THE COAST OF NOVA SCOTIA IS CHARACTERIZED BY COMPLEX TOPOGRAPHY CONSISTING OF MANY OFFSHORE SHALLOW BANKS AND DEEP MID-SHELF BASINS. IT IS SEPARATED FROM THE SOUTHERN NEWFOUNDLAND SHELF BY THE LAURENTIAN CHANNEL AND BORDERS THE GULF OF MAINE TO THE SOUTHWEST. 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.

HYDROGRAPHIC CONDITIONS ON THE SCOTIAN SHELF ARE DETERMINED BY HEAT TRANSFER BETWEEN THE OCEAN AND ATMOSPHERE, INFLOW FROM THE GULF OF ST LAWRENCE AND THE NEWFOUNDLAND SHELF, AND EXCHANGE WITH OFFSHORE SLOPE WATERS. WATER PROPERTIES HAVE LARGE SEASONAL CYCLES AND ARE MODIFIED BY FRESHWATER RUNOFF, PRECIPITATION, AND MELTING OF SEA ICE. TEMPERATURE AND SALINITY EXHIBIT STRONG HORIZONTAL AND VERTICAL GRADIENTS THAT ARE MODIFIED BY DIFFUSION, MIXING, CURRENTS, AND SHELF TOPOGRAPHY.

In 2011, annual mean air temperatures over the Scotian Shelf, represented by Sable Island observations, were 0.8°C, corresponding to +1.1 s.d. above the long-term mean (based on 1981–2010). The amount of sea ice on the Scotian Shelf in 2011, as measured by the total area of ice seaward of Cabot Strait between Nova Scotia and Newfoundland from January to April, was 310 km^2, well below the long-term mean coverage of 32 000 km^2. This is the third lowest coverage in the 43-year time-series. Only 1969 and 2010 had less ice; the differences between these three years are within the uncertainty of the observations.

Topography separates the northeastern Scotian Shelf from the rest of the shelf. In the northeast, the bottom tends to be covered by relatively cold waters (1–4°C), whereas the basins in the central and southwestern regions typically have bottom 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 revealed 2011 average conditions of temperature above normal (by 0.75°C, +1.2 s.d.) and salinity slightly low, but close to normal (−0.02°C, −0.1 s.d.). The deep Emerald Basin anomalies represent the slope water intrusions onto the shelf that are subsequently trapped in the inner basins. In 2011, the 250 m temperature and salinity anomalies were well above normal (+0.92°C, +1.1 s.d.; +0.22°C, +1.5 s.d.) despite the expectation that after two low NAO years, the colder, fresher Labrador Sea Water should have appeared in Emerald Basin by 2011.

VERY LOW SEA ICE EXTENT ON THE SCOTIAN SHELF, 1% OF THE LONG-TERM AVERAGE.

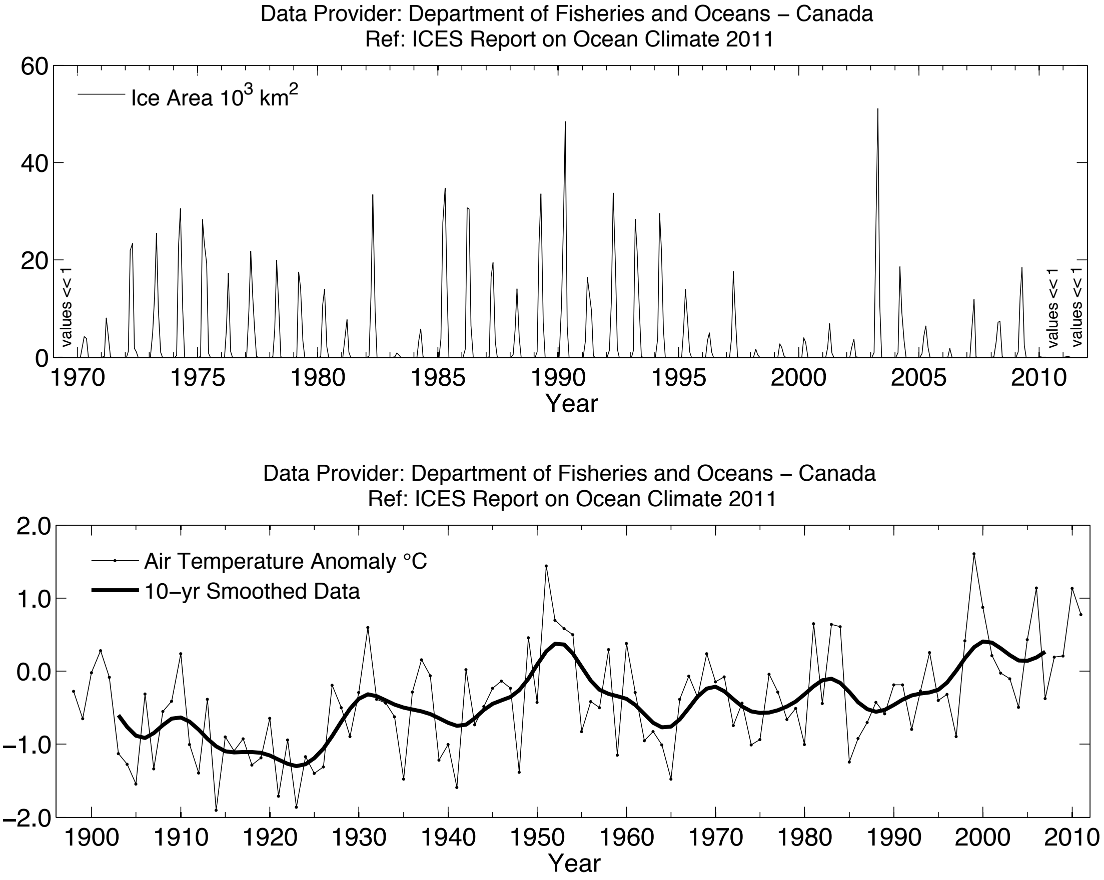


Figure 17.
Area 2 – Northwest Atlantic: Scotian Shelf. Monthly means of ice area seawards of Cabot Strait (upper panel) and air temperature anomalies at Sable Island on the Scotian Shelf (lower panel).

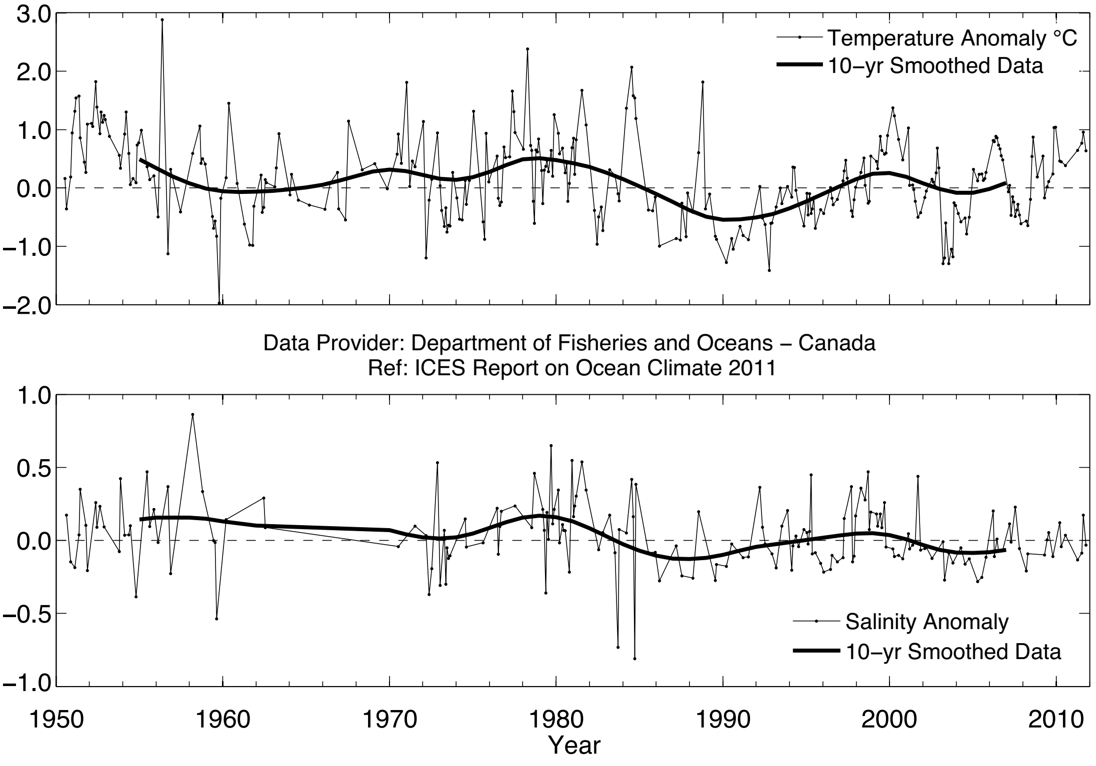


Figure 18.
Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature anomalies (upper panel) and salinity anomalies (lower panel) at Misaine Bank (100 m).

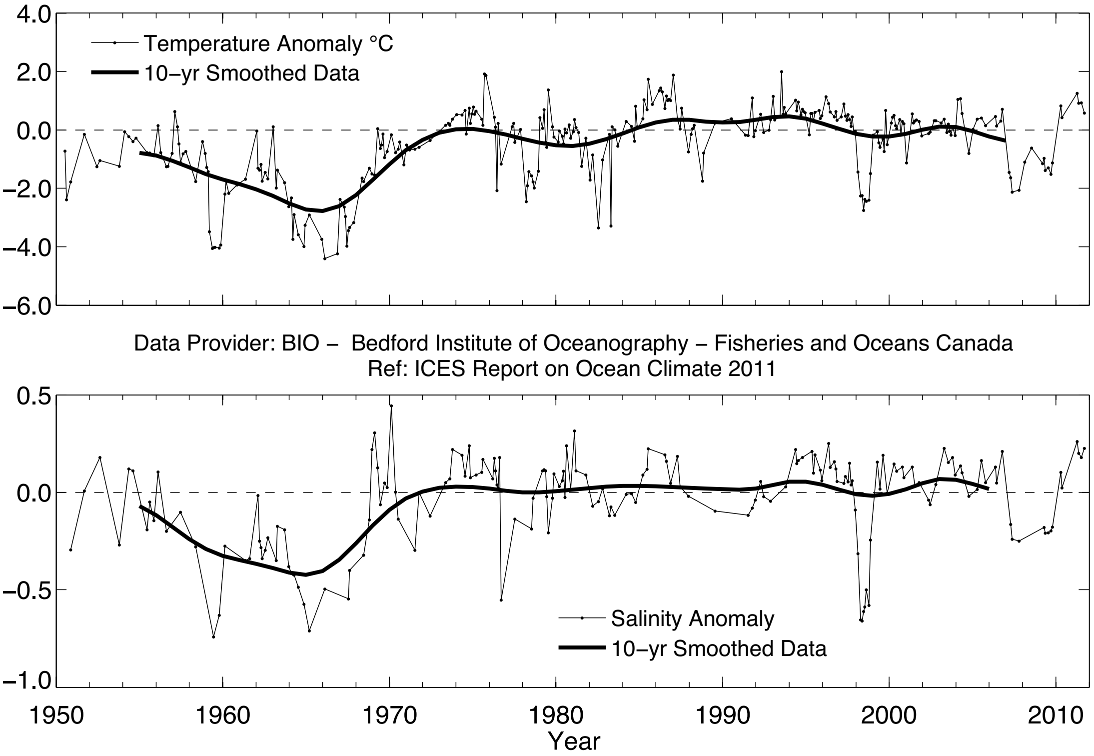


Figure 19.
Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature anomalies (upper panel) and salinity anomalies (lower panel) in the central Scotian Shelf (Emerald Basin, 250 m).

Newfoundland–Labrador Shelf

THIS REGION IS SITUATED ON THE WESTERN SIDE OF THE LABRADOR SEA, STRETCHING FROM HUDSON STRAIT TO THE SOUTHERN GRAND BANK AND DOMINATED BY SHALLOW BANKS, CROSS-SHELF CHANNELS OR SADDLES, AND DEEP MARGINAL TROUGHS NEAR THE COAST. CIRCULATION IS DOMINATED BY THE SOUTH-FLOWING LABRADOR CURRENT BRINGING COLD, FRESH WATERS FROM THE NORTH, TOGETHER WITH SEA ICE AND ICEBERGS, TO SOUTHERN AREAS OF THE GRAND BANKS.

HYDROGRAPHIC CONDITIONS ARE DETERMINED BY THE STRENGTH OF THE WINTER ATMOSPHERIC CIRCULATION OVER THE NORTHWEST ATLANTIC (NAO), ADVECTION BY THE LABRADOR CURRENT, CROSS-SHELF EXCHANGE WITH WARMER CONTINENTAL SLOPE WATER, AND BOTTOM TOPOGRAPHY. SUPERIMPOSED ARE LARGE SEASONAL AND INTERANNUAL VARIATIONS IN SOLAR HEAT INPUT, SEA ICE COVER, AND STORM-FORCED MIXING. THE RESULTING WATER MASS ON THE SHELF EXHIBITS A LARGE ANNUAL CYCLE WITH STRONG HORIZONTAL AND VERTICAL TEMPERATURE AND SALINITY GRADIENTS.

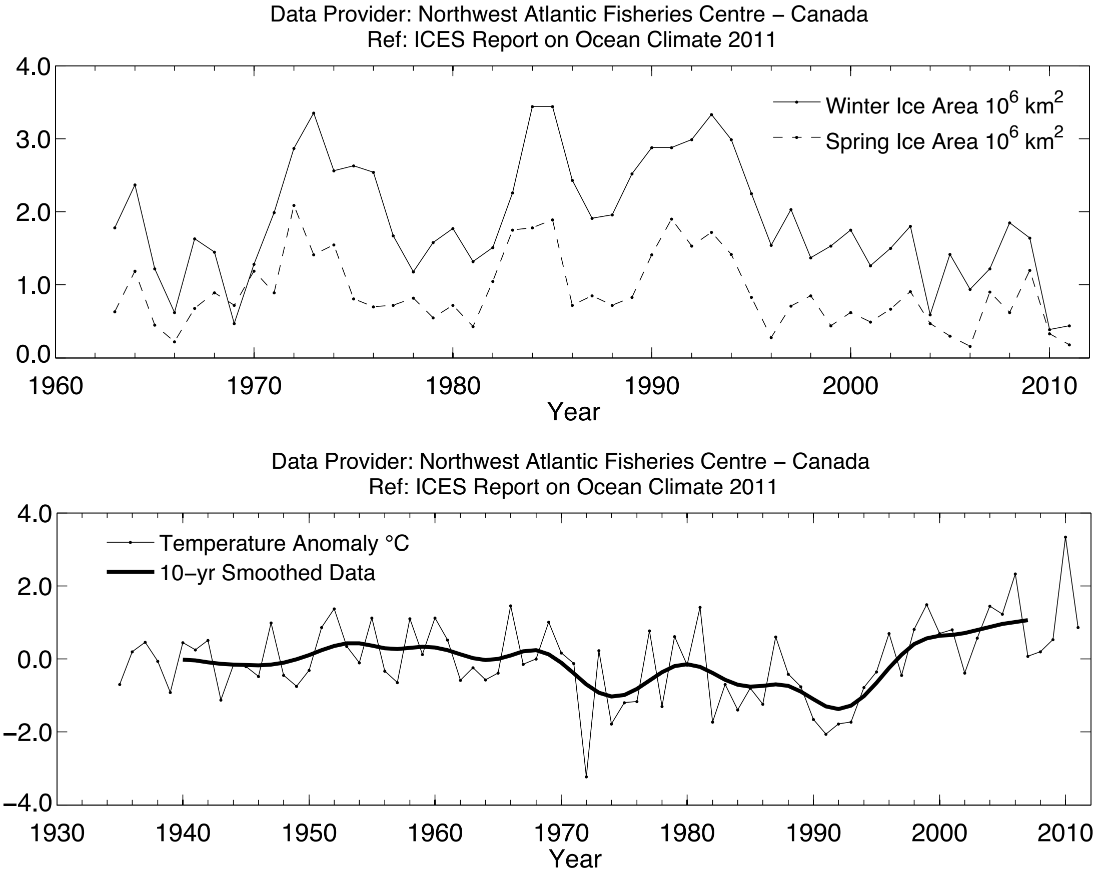
After reaching a record low in 2010, the North Atlantic Oscillation index (Iceland–Azores), a key indicator of climate conditions in the Northwest Atlantic, remained in the negative phase at −1.2 s.d. below normal. As a result, the Arctic outflow to the Northwest Atlantic remained weak in most areas in 2011.

Annual air temperatures remained above normal (based upon 1981–2010) at Labrador +0.9°C (+0.7 s.d. at Cartwright) and Newfoundland +0.5°C (+0.6 s.d. at St. John's), but a strong decrease followed the record highs of 2010. The annual sea ice extent on the Newfoundland–Labrador Shelf remained below normal for the sixteenth consecutive year, reaching a record low in 2011. As a result of these and other factors, local water temperatures on the Newfoundland–Labrador Shelf remained above normal, setting new record highs in some areas.

At the standard monitoring site off eastern Newfoundland (Station 27), the depth-averaged annual water temperature increased to a record high in 2011 at +3 s.d. above the long-term mean. Annual surface temperatures at Station 27 were above normal by 0.4°C (+0.6 s.d.), while bottom temperatures (176 m) were at a record high at +1.3°C (+3.4 s.d.). The annual depth-averaged salinities at Station 27 were below normal for the third consecutive year.

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 isolated between the seasonally heated upper layer and the warmer shelf-slope water throughout the summer and early 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. The area of the CIL water mass on the Newfoundland Shelf during 2011 was at a record low value at −2 s.d. below normal, implying warm conditions, while off southern Labrador, it was the fourth lowest at −1.5 s.d. below normal. In summary, ocean temperatures on the Newfoundland–Labrador Shelf continued to increase, setting new record highs in 2011, while salinities remained lower than normal.

Figure 20.
Area 2 – Northwest Atlantic: Newfoundland–Labrador Shelf. Winter and spring sea ice area off Newfoundland–Labrador between 45° and 55°N (upper panel). Annual air temperature anomalies at Cartwright on the Labrador Coast (lower panel).



OCEAN TEMPERATURES ON THE NEWFOUNDLAND–LABRADOR SHELF CONTINUED TO INCREASE, SETTING NEW RECORD HIGHS IN 2011.

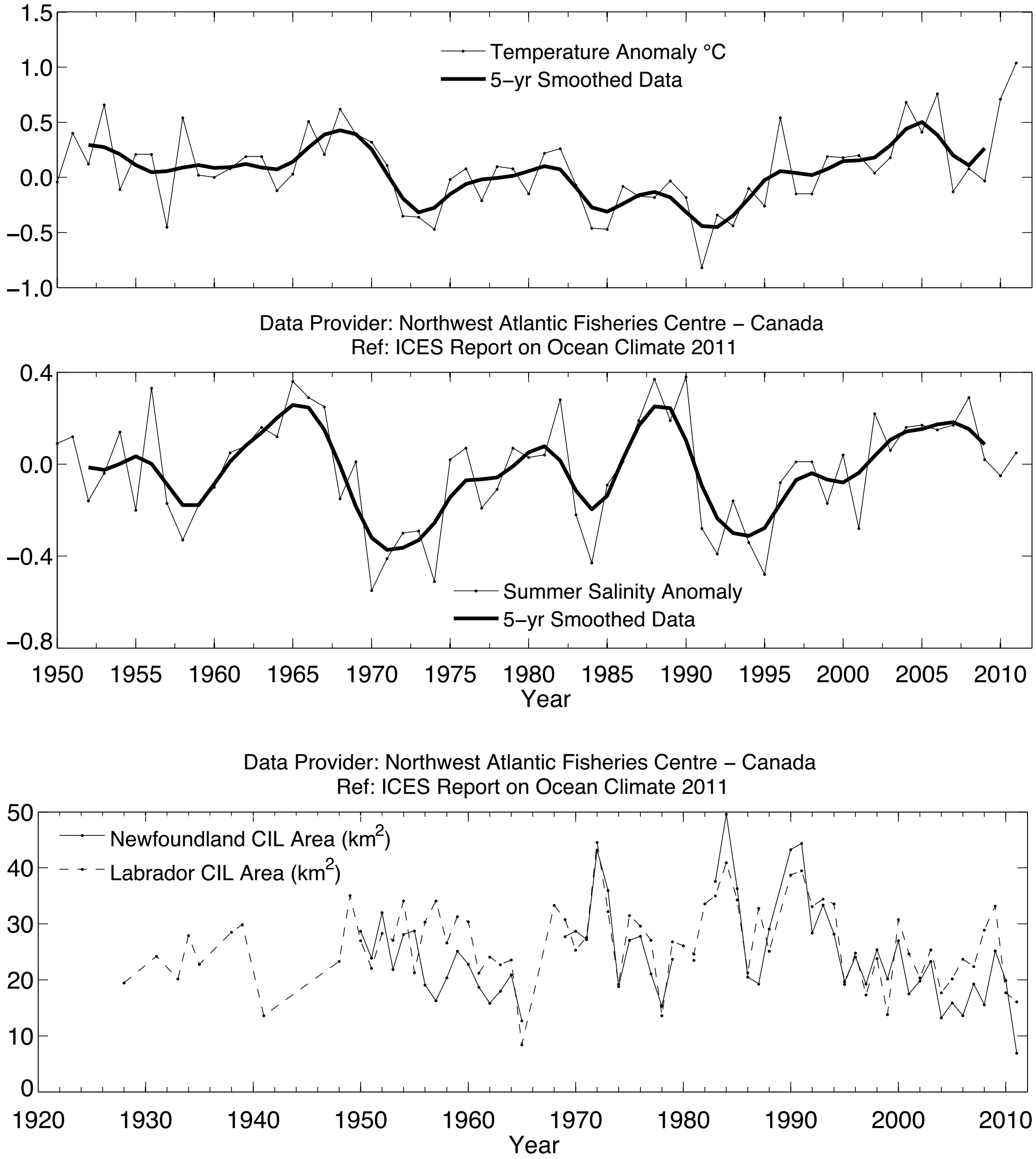


Figure 21.
Area 2 – Northwest Atlantic: Newfoundland–Labrador Shelf. Annual depth-averaged Newfoundland Shelf temperature anomalies (top panel) and salinity anomalies (middle panel) at Station 27 (47.55°N 52.59°W), and spatial extent of cold intermediate layer (CIL; bottom panel).

ANNUAL SEA ICE EXTENT ON THE NEWFOUNDLAND—LABRADOR SHELF REMAINED BELOW NORMAL FOR THE SIXTEENTH CONSECUTIVE YEAR, REACHING A RECORD LOW IN 2011.

4.4 Area 2b – Labrador Sea

The Labrador Sea is located between Greenland and the Labrador coast of eastern Canada. Cold, low-salinity waters of polar origin circle the Labrador Sea in 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 Atlantic waters, originating in the North Atlantic Current, flow north into the Labrador Sea on the Greenland side and become colder and fresher as they circulate around the basin.

Changes in Labrador Sea hydrographic conditions on interannual time-scales depend on the variable influences of heat loss to the atmosphere, heat and salt gain from Atlantic waters, and freshwater gain from Arctic outflow, melting sea ice, precipitation, and run-off. A sequence of severe winters in the early 1990s led to deep convection, peaking in 1993–1994, that filled the upper 2 km of the water column with cold, fresh water. Conditions have generally been milder since the mid-1990s. The upper levels of the Labrador Sea have become warmer and more saline as heat losses to the atmosphere have decreased and Atlantic waters have become increasingly dominant.

The upper 150 m of the west-central Labrador Sea warmed by more than 1°C over the past 15 years, but demonstrated no significant trend in salinity. However, on shorter time-scales, salinity of the same layer increased during 1994–2005 by about 0.3 and decreased over the following years by more than 0.1. Temperature decreased between 2004 and 2009 and started to increase in summer 2009, reaching a record high in 2010. In 2011, temperature dropped slightly again, while salinity remained stable.

The 2011 annual mean SST in the west-central Labrador Sea decreased following its record high in 2010 and exceeded the long-term 1971–2000 mean by 0.8°C, making it the third coolest year of the recent 2003–2011 warm period. Conditions were generally warm throughout the year with record-high January values.

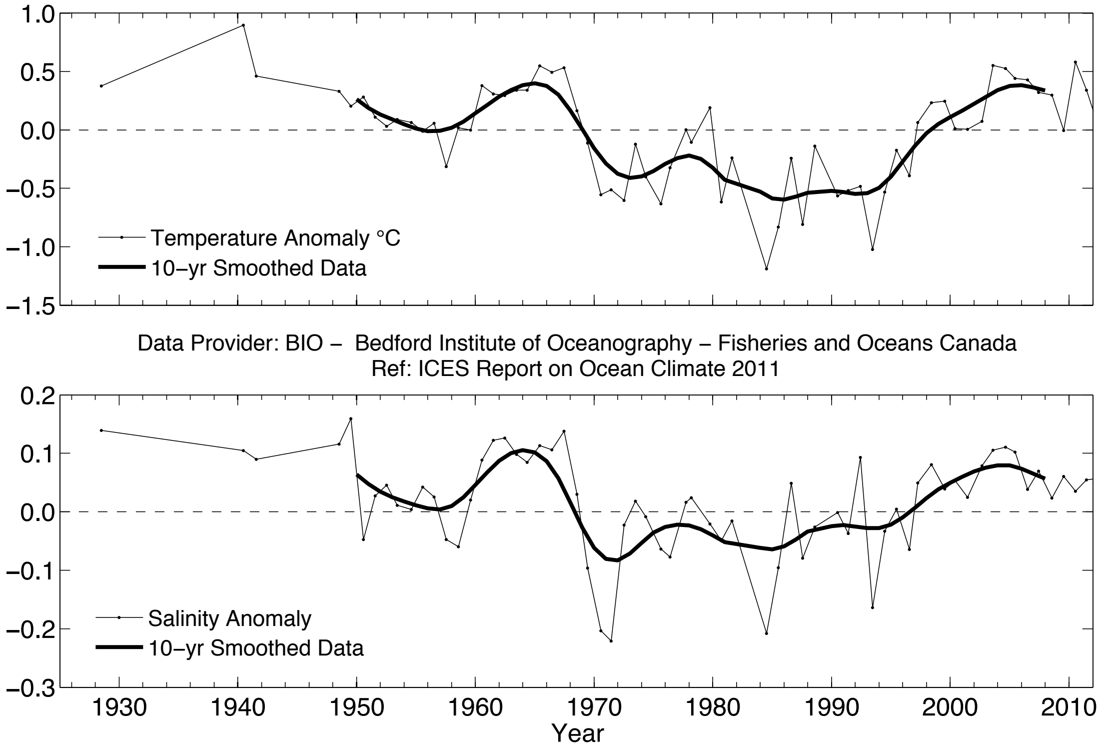


Figure 22.
Area 2b – Labrador Sea. Potential temperature anomaly (upper panel) and salinity anomaly (lower panel) at 16–150 m, from CTD and Argo data in the west-central Labrador Sea (centred at 56.7°N 52.5°W). Estimates of seasonal cycle (derived from all data in the time-series) have been removed from the observations.

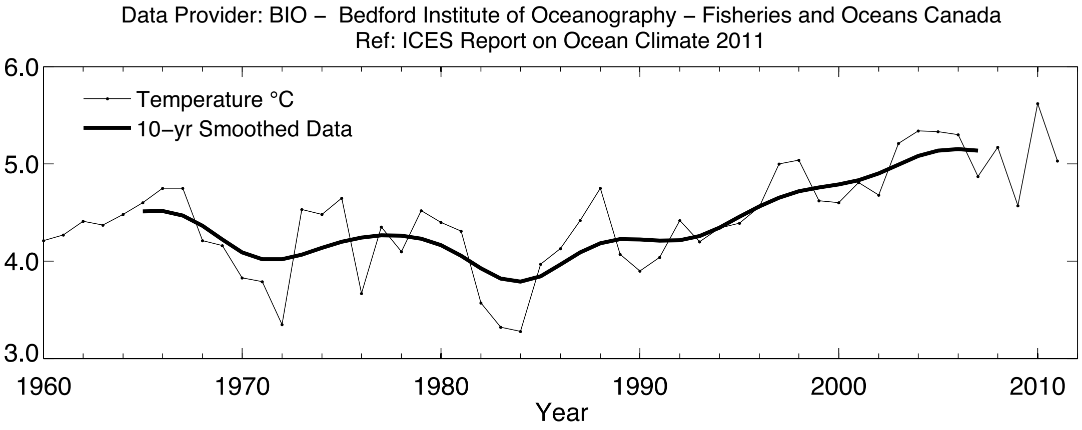


Figure 23.
Area 2b – Labrador Sea. Annual mean sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 sea ice and sea surface temperature dataset, UK Meteorological Office, Hadley Centre.

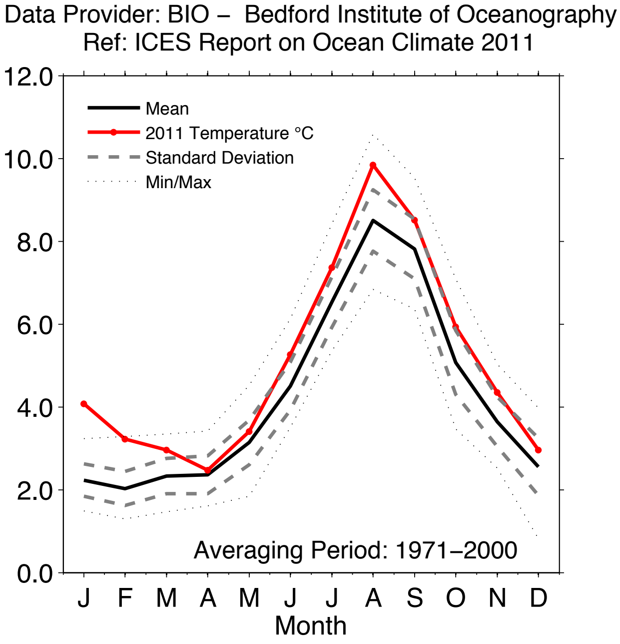


Figure 24.
Area 2b – Labrador Sea. 2011 monthly sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 sea ice and sea surface temperature dataset, UK Meteorological Office, Hadley Centre.

4.5 Area 2c – Mid-Atlantic Bight

HYDROGRAPHIC CONDITIONS IN THE WESTERN NORTH ATLANTIC SLOPE SEA, THE MID-ATLANTIC BIGHT, AND THE GULF OF MAINE DEPEND ON THE SUPPLY OF WATERS FROM THE LABRADOR SEA, ALONG THE SHELF AND CONTINENTAL SLOPE, AS WELL AS THE GULF STREAM OFFSHORE. SHELF-WIDE, HYDROGRAPHIC CONDITIONS HAVE BEEN MONITORED ANNUALLY SINCE 1977 AS PART OF QUARTERLY ECOSYSTEM MONITORING AND TWICE-YEARLY BOTTOM-TRAWL SURVEYS CONDUCTED BY THE U.S. NATIONAL MARINE FISHERIES SERVICE, NORTHEAST FISHERIES SCIENCE CENTER. THE SURVEYS EXTEND FROM CAPE HATTERAS INTO THE GULF OF MAINE, INCLUDING GEORGES BANK AND THE NORTHEAST CHANNEL (GOM – FIGURE 25). IN ADDITION, COMMERCIAL VESSELS HAVE BEEN INSTRUMENTED AND USED TO REGULARLY MONITOR THE TEMPERATURE AND SURFACE SALINITY ALONG SEVERAL REPEAT CROSS-SHELF TRANSECTS SINCE 1961. ONE REGULARLY OCCUPIED SECTION EXTENDS FROM AMBROSE LIGHT OFF NEW YORK CITY TO BERMUDA FOR A DISTANCE OF APPROXIMATELY 450 KM, CROSSING THE CONTINENTAL SHELF AND SLOPE AND EXTENDING INTO GULF STREAM WATER (MAB – FIGURE 25). THE OTHER SECTION TRAVERSES THE GULF OF MAINE, EXTENDING EAST FROM BOSTON TO CAPE SABLE, NOVA SCOTIA, A DISTANCE OF APPROXIMATELY 450 KM. THIS SECTION CROSSES MASSACHUSETTS BAY, WILKINSON BASIN, LEDGES IN THE CENTRAL GULF OF MAINE, CROWELL BASIN, AND THE WESTERN SCOTIAN SHELF.

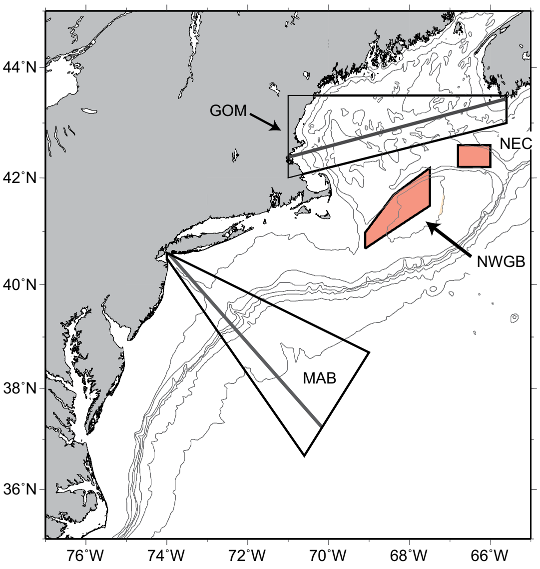


Figure 25.
Area 2c – Mid-Atlantic Bight. The four regions of ongoing time-series: GOM = Gulf of Maine (XBT measurements and surface samples); MAB = central Mid-Atlantic Bight (XBT measurements and surface samples); NEC = Northeast Channel (CTD stations); NWGB = Northwest Georges Bank (CTD stations).The 50, 100, 500, 1000, 2000, and 3000 m isobaths are also shown.

Figure 26 shows annual average surface and bottom temperature anomalies, calculated relative to a 30-year mean along the XBT line southeast of New York City (MAB). The anomalies represent the average anomaly for waters inshore of the 100 m isobath. Interannual temperature fluctuations are vertically coherent inshore of the shelfbreak across the Mid-Atlantic Bight. In 2011, waters were warmer than the long-term mean at both the surface and bottom. Warming was enhanced at the bottom, where waters were nearly 2°C warmer than the long-term mean, the warmest on record. Enhanced warming was also observed upstream in the bottom waters of the western Gulf of Maine during 2010 (Figure 27). Sampling was sparse in 2011 along the Gulf of Maine transect (less than 6 months contributing to the annual mean), precluding the estimation of regional anomalies.

Figure 28 shows a time-series of temperature and salinity anomalies derived from hydrographic observations collected within the upper 30 m over a region encompassing the northwestern portion of Georges Bank (NWGB – Figure 25). Given the known circulation pathways through the Gulf of Maine, the properties observed within this region represent the initial conditions for shelf water exported to the New England Shelf. The anomalies are in original units relative to the mean for 1980–2010. The surface time-series corroborates the trends exhibited in the shipboard XBT records, showing enhanced warming within the upper water column in recent years. Relative to the seasonal mean, warming was particularly strong during spring when observed temperatures exceeded the maximum temperatures observed during the reference period (Figure 29). During this same period, the upper water column was significantly fresher, exceeding the minimum salinities observed in the long-term climatology.

Figure 30 shows a time-series of temperature and salinity anomalies derived from hydrographic observations collected within the deep layer (150–200 m) in the Northeast Channel (location, Figure 25). These deep waters are uninfluenced by seasonal atmospheric forcing and represent deep inflow conditions for one of the dominant water mass sources to the Gulf of Maine (the slope waters). As in Figure 28, the anomalies here are presented in original units, relative to the mean for 1980–2010. The time-series indicates that deep inflow to the Gulf of Maine remained warmer and saltier in 2011 compared with the long-term mean.

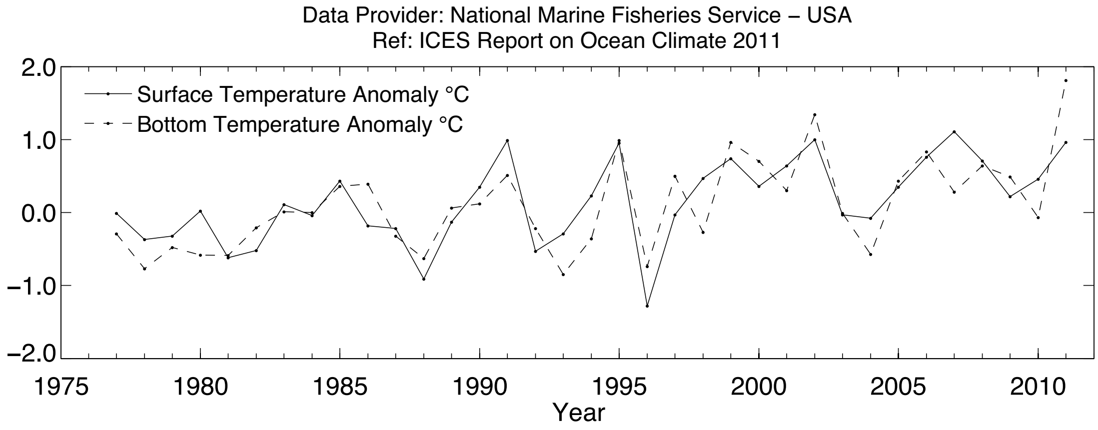


Figure 26.
Area 2c – Mid-Atlantic Bight. Surface and bottom temperature anomalies in the central Mid-Atlantic Bight (relative to the base period of 1980–2010) from XBT measurements; the origin of the line is New York City. The data represent the average conditions at the surface and bottom inshore of the 100 m isobath.

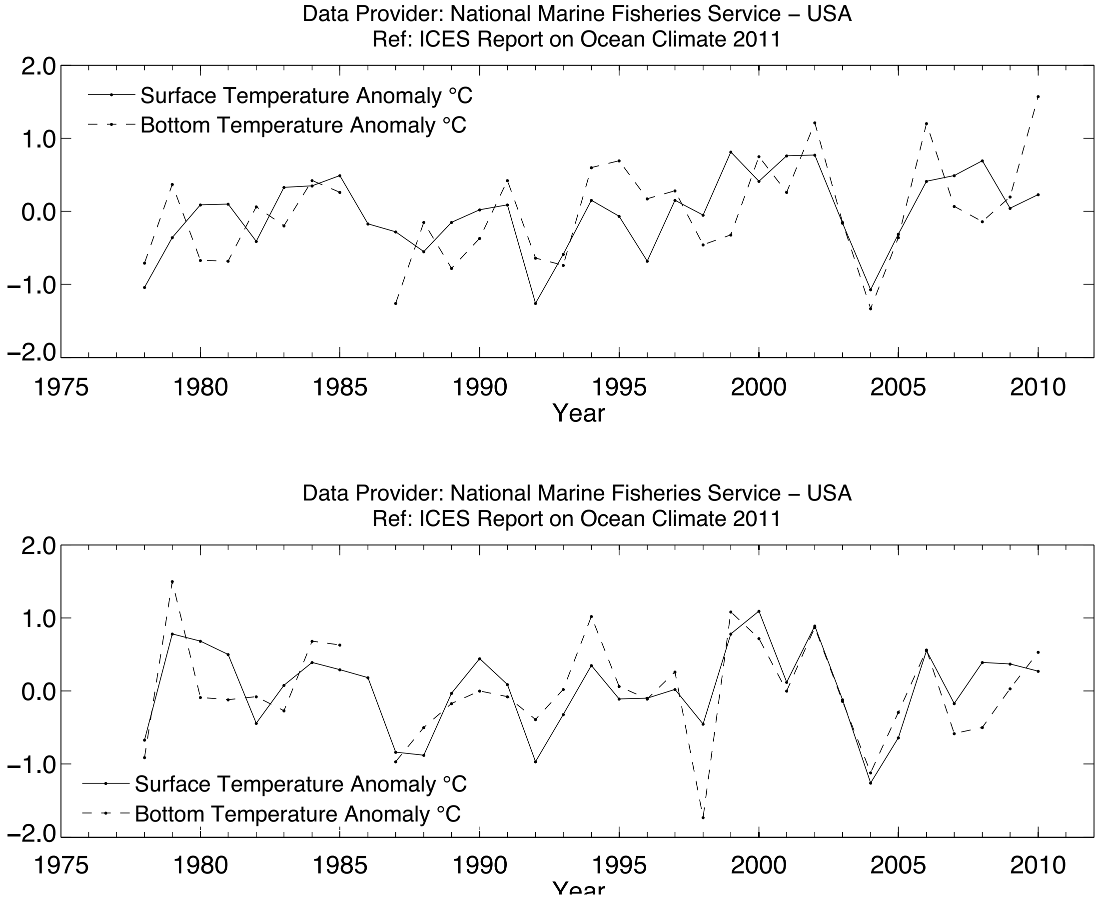


Figure 27.
Area 2c – Mid-Atlantic Bight. Surface and bottom temperature anomalies across the western (upper panel) and eastern (lower panel) Gulf of Maine (relative to the base period of 1980–2010) from XBT measurements. The data represent the average conditions at the surface and bottom west and east of 68°W.

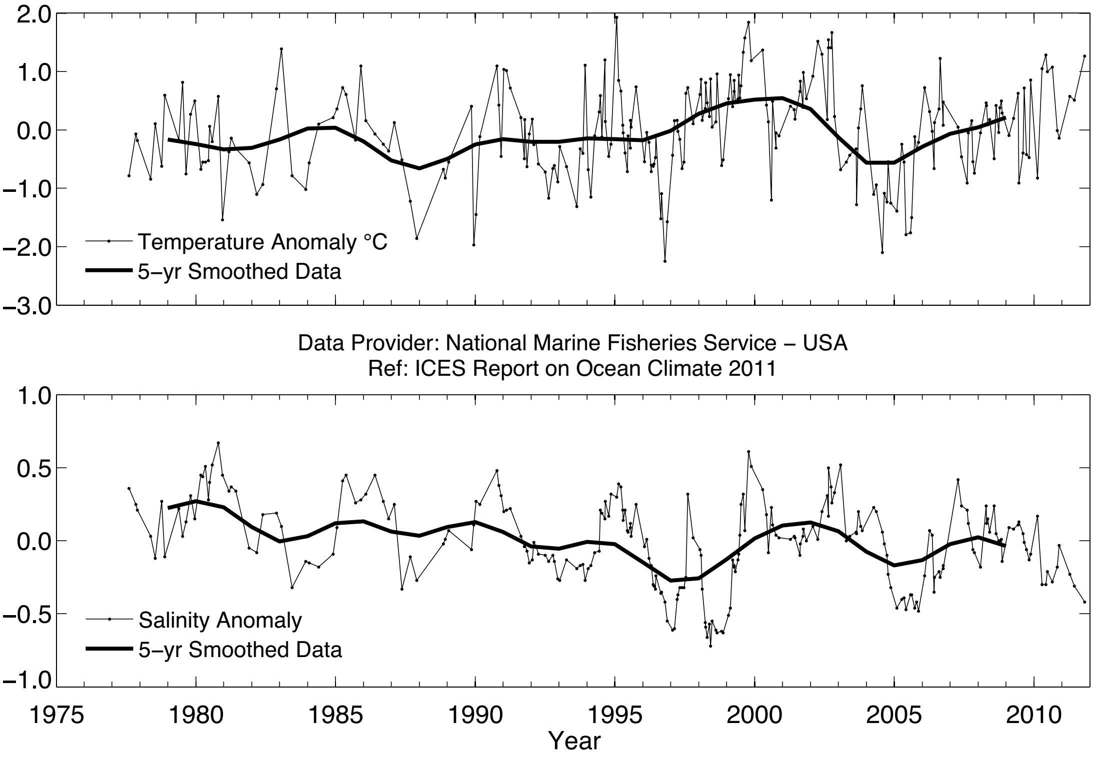


Figure 28.
Area 2c – Mid-Atlantic Bight. Time-series plots of 0–30 m averaged temperature anomaly (upper panel) and salinity anomaly (lower panel) on northwest Georges Bank. Anomalies are calculated relative to the period 1980–2010 using hydrographic data from shelf-wide surveys.

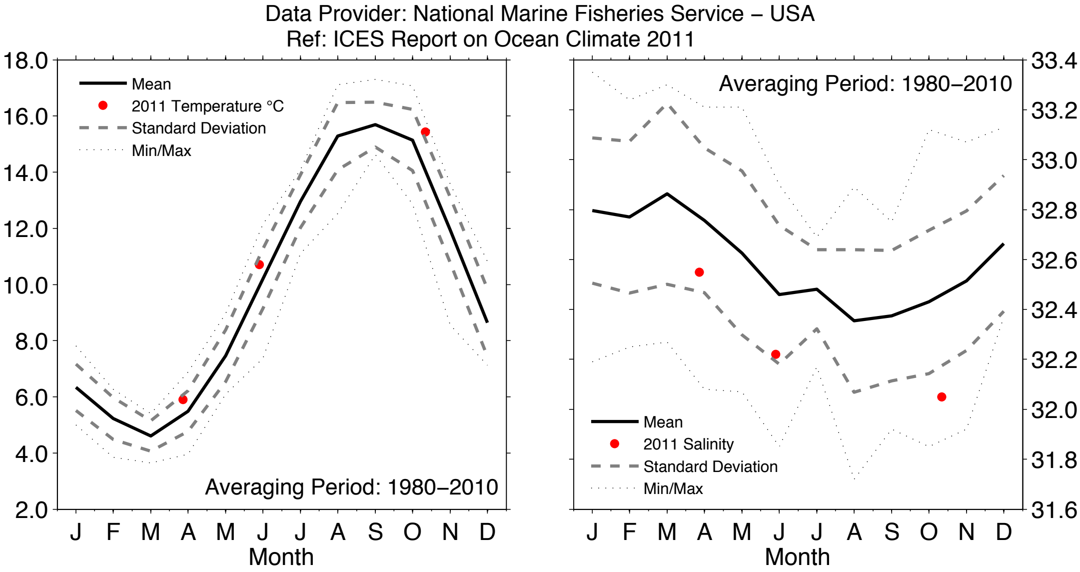


Figure 29.
Area 2c – Mid-Atlantic Bight. 2011 monthly temperatures (0–30 m) at northwest Georges Bank, relative to the annual cycle calculated 1980–2010. The envelope corresponding to the monthly range and one standard deviation are shown.

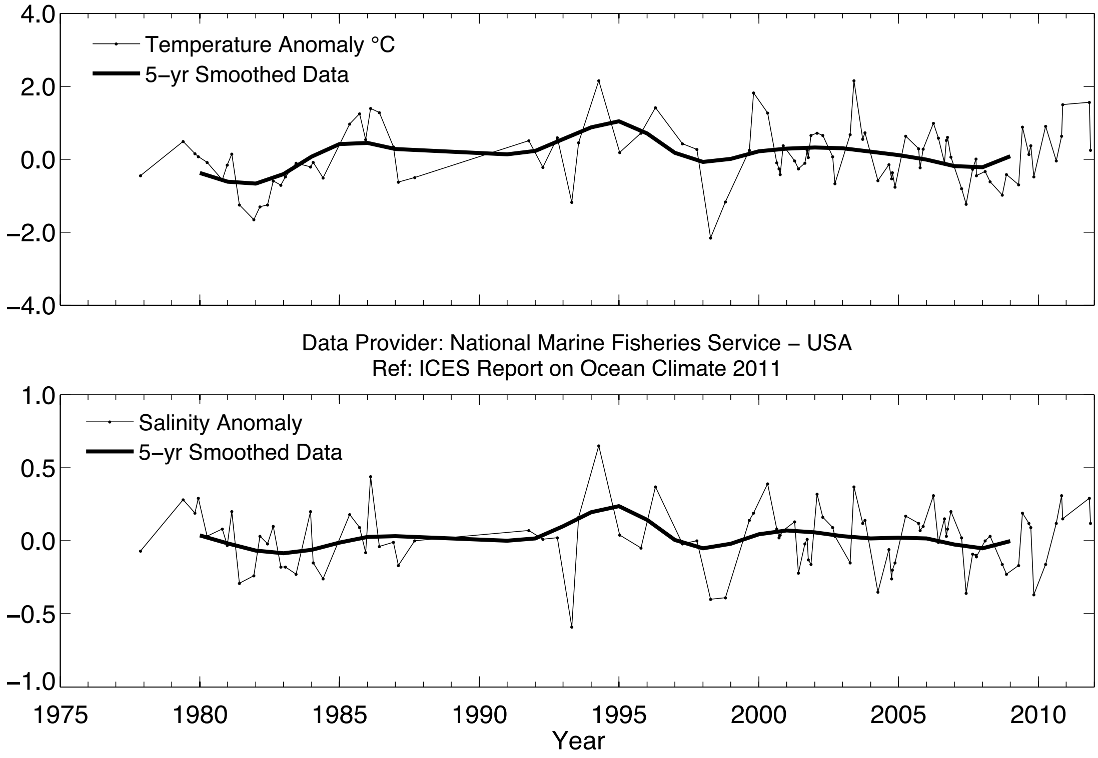


Figure 30.
Area 2c – Mid-Atlantic Bight. Time-series plots of 150-200 m averaged temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Northeast Channel. Anomalies are calculated relative to the period 1980-2010 using hydrographic data from shelf-wide surveys.

Voluntary observing ships

- Many of the data presented here are collected from commercial vessels that voluntarily make ocean measurements along their journeys. The three-decade-long record of monthly sampled surface and bottom temperatures crossing the continental shelf and slope in the Mid-Atlantic Bight and spanning the width of the Gulf of Maine (Figures 26 and 27) reveals the power of repeated systematic sampling from merchant marine vessels. A number of vessels are now operating automated systems to sample surface temperature and salinity while underway. In addition, expandable bathythermographs are deployed from numerous ships. Data from merchant vessels are then sent to the scientific community in real time via satellite uplink. The rapid availability of repeated ocean observations is a key to the programme's success.

The section crossing the shelf from New York, USA, to Bermuda is occupied by the container ship "Oleander", operated by the Bermuda Container Line. The section east of Boston has relied upon observations from various vessels, including those from Hapag Lloyd, Eimskipafelag, Caribou Seafoods, the US Coast Guard, and Hans Speck and Son. Their cooperation is greatly appreciated.

4.6 Area 3 – Icelandic waters

Iceland is at the meeting place of warm and cold currents. These converge in an area of submarine ridges (Greenland–Scotland Ridge, Reykjanes Ridge, Kolbeinsey Ridge) that form natural barriers to the main ocean currents. The warm Irminger Current, a branch of the North Atlantic Current (6–8°C), flows from the south, and the cold East Greenland and East Icelandic currents flow from the north. Deep 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 atmospheric or climatic conditions in and over the country and the surrounding seas, mainly through the Icelandic low-pressure and Greenland high-pressure systems. 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 commercially important fish stocks.

In 2011, mean air temperatures in the south (Reykjavik) and north (Akureyri) were above the long-term averages. During the year, temperature and salinity south and west of Iceland remained high, although both were lower than in preceding years. In the north, temperature in surface layers was slightly above, but close to, average, while salinity in surface layers was just below average. Salinity and temperature in the East Icelandic Current in spring 2011 were both above average.

Temperature and salinity around Iceland were above average in 2011.

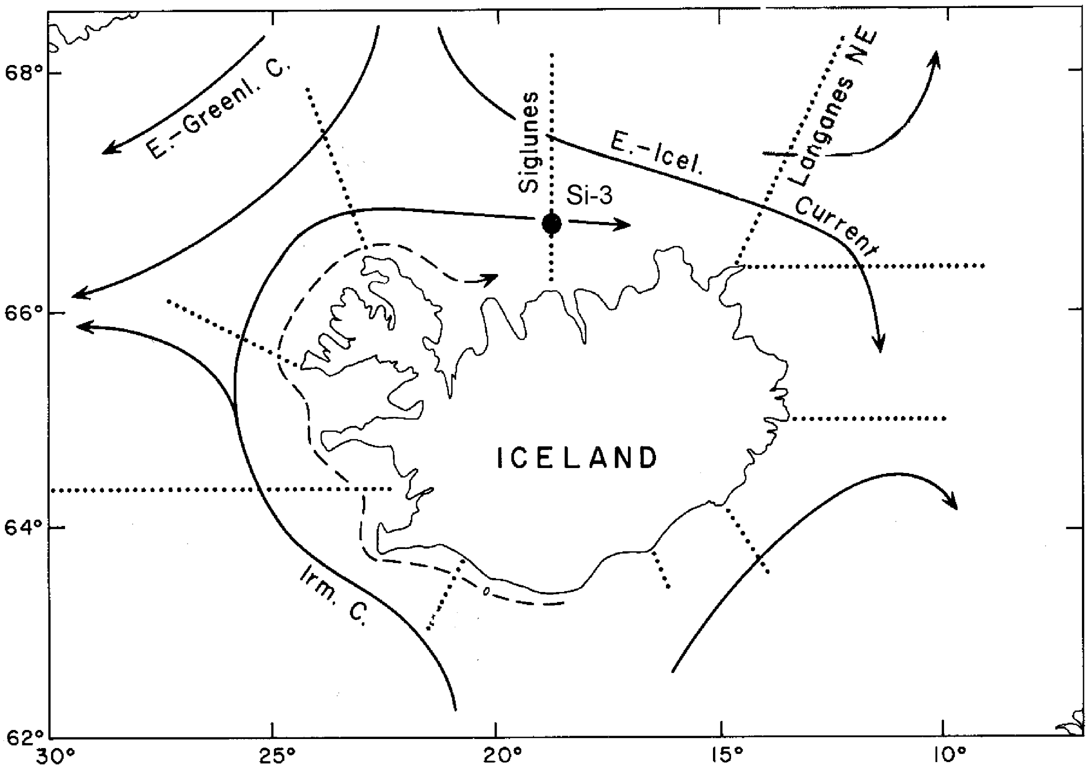


Figure 31.
Area 3 – Icelandic waters. Main currents and location of standard sections in Icelandic waters.

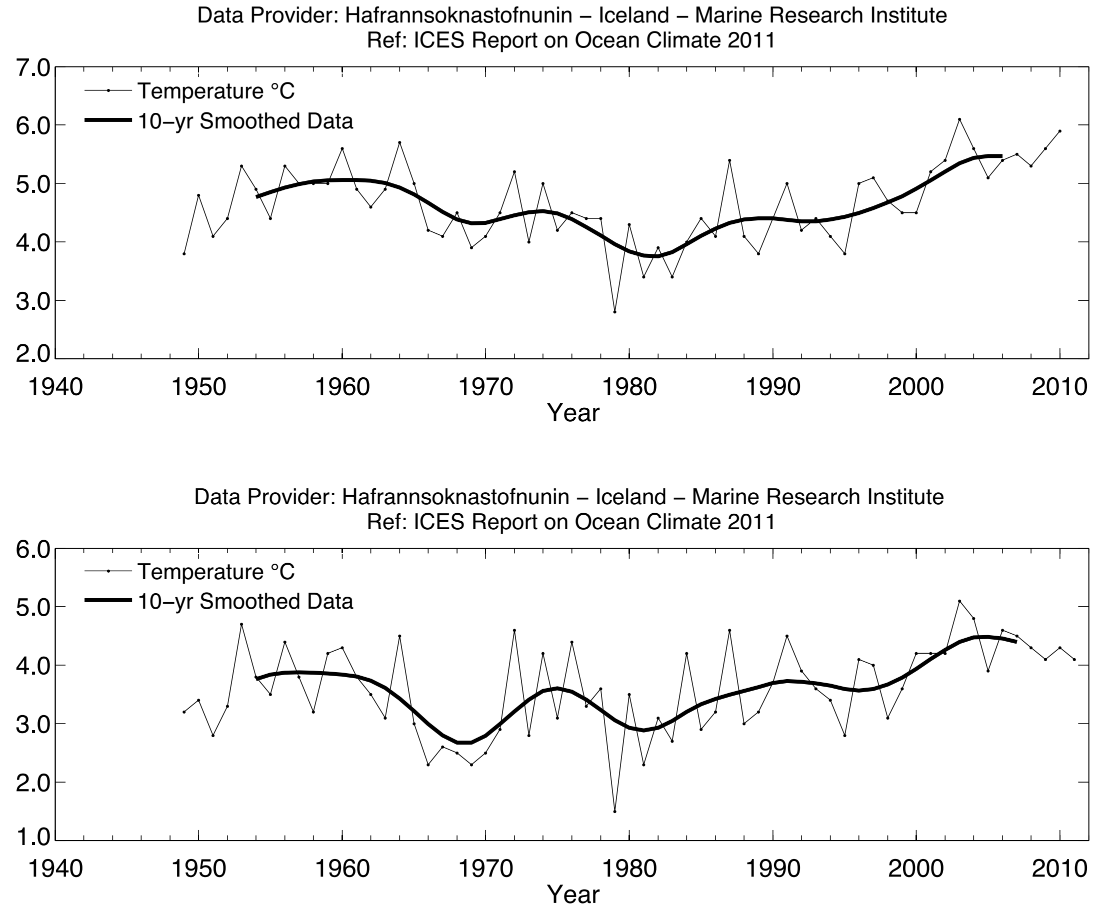


Figure 32.
Area 3 – Icelandic waters. Mean annual air temperature at Reykjavík (upper panel) and Akureyri (lower panel).

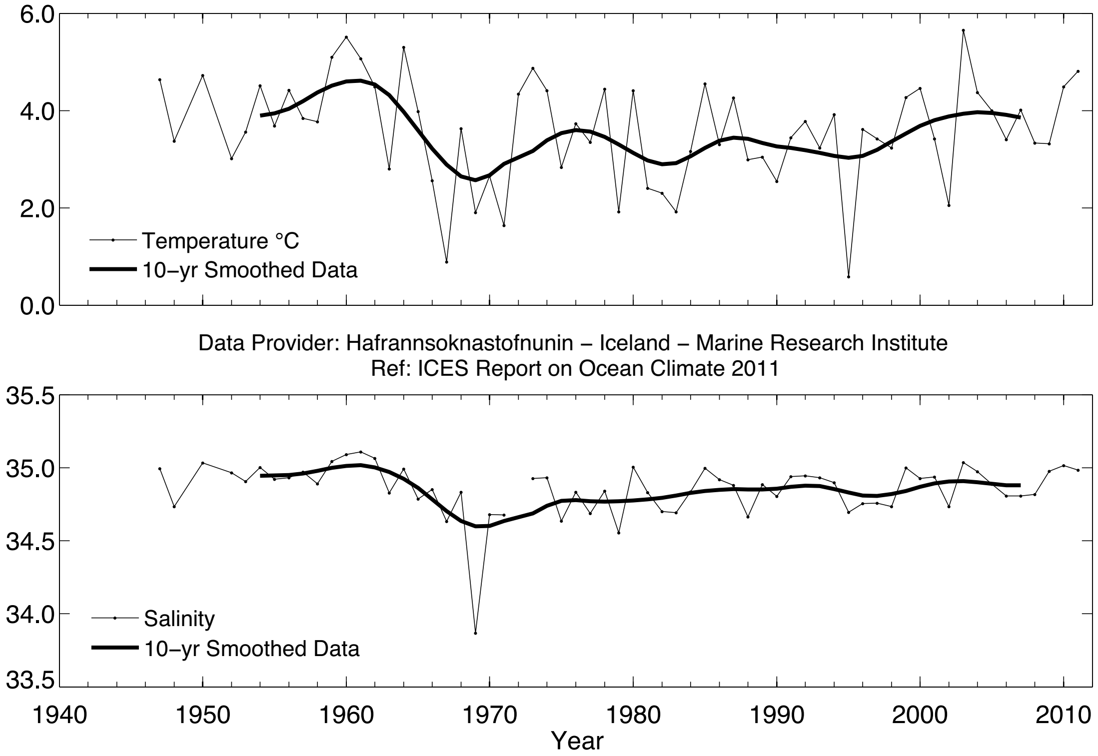


Figure 33.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 50–150 m at Siglunes Stations 2–4 in North Icelandic waters.

Figure 34.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 0–200 m at Selvogsbanki Station 5 in South Icelandic waters.

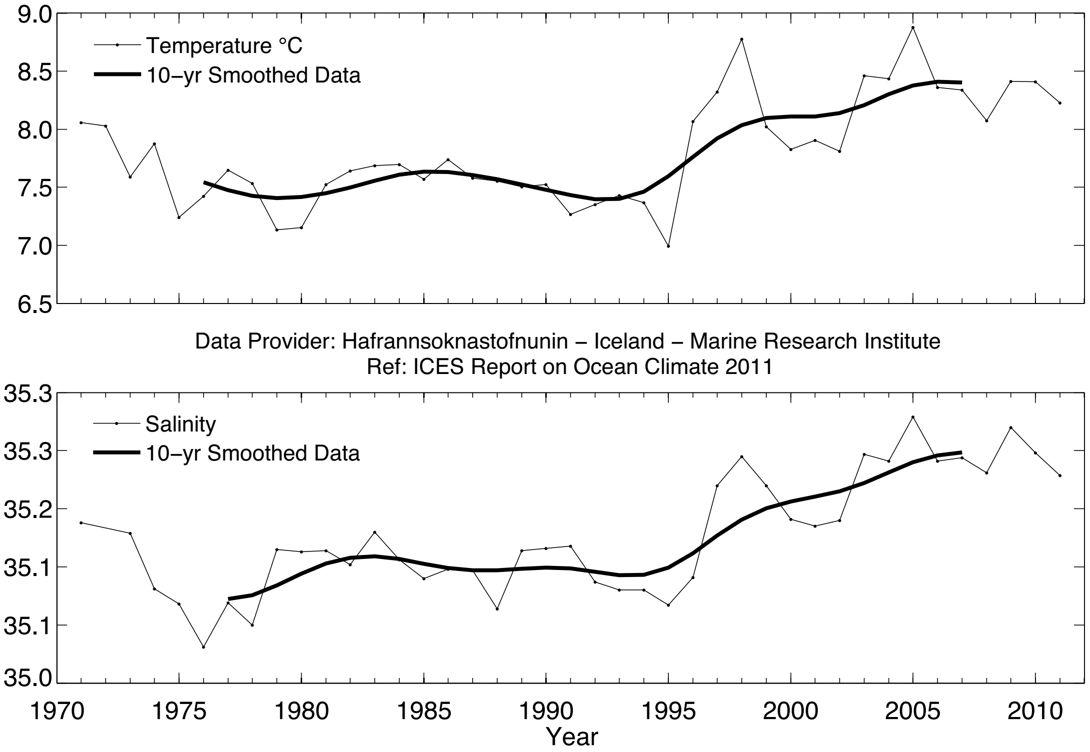
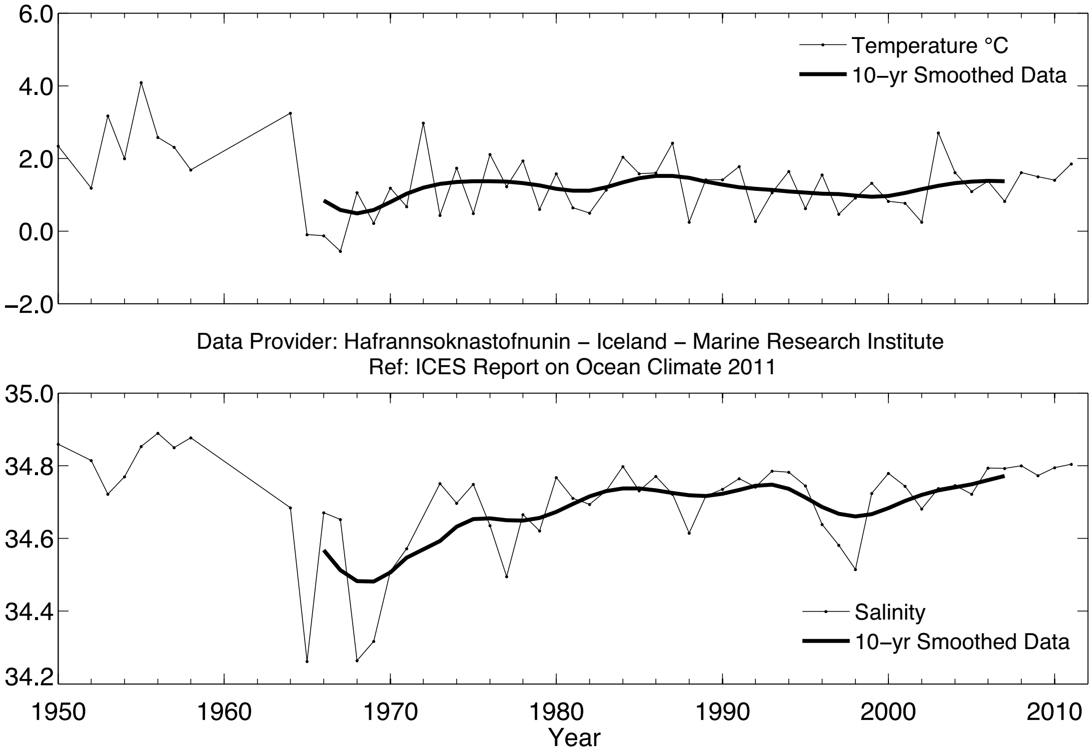


Figure 35.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 0–50 m in the East Icelandic Current (Langanes Stations 2–6).



4.7 Area 4 – Bay of Biscay and eastern North Atlantic

THE BAY OF BISCAY, LOCATED IN THE EASTERN NORTH ATLANTIC AT THE NORTHEASTERN EDGE OF THE SUBTROPICAL ANTI-CYCLONIC GYRE, CAN ALMOST BE CONSIDERED AS A MARGINAL SEA WITH RELATIVELY WEAK ANTI-CYCLONIC CIRCULATION. SHELF AND SLOPE CURRENTS ARE IMPORTANT IN THE SYSTEM, CHARACTERIZED BY COASTAL UPWELLING EVENTS IN SPRING–SUMMER AND THE DOMINANCE OF A GEOSTROPHICALLY BALANCED POLEWARD FLOW (KNOWN AS THE IBERIAN POLEWARD CURRENT) IN AUTUMN AND WINTER.

The atmosphere was very warm with respect to the long-term mean in the Iberian Peninsula and southern Bay of Biscay in 2011. Overall, the average air temperature was in excess of 1.5°C, higher than average (referenced to 1961–1990). 2011 also stands as one of the warmest years of the present century, with positive anomalies comparable to those recorded in 2003. The seasonal cycle showed a strong anomalous character, with very warm spring and autumn seasons and a relatively cold summer. SST responded accordingly, warming rapidly in early spring, stabilizing at lower-than-normal values in summer, and remaining high until late autumn.

Moderate winter cooling determined the development of a normal winter mixed-layer depth. Subsurface structure was conditioned by stronger and more frequent intrusions of southern origin waters than normal, with episodes extending well into spring. A relatively deep summer mixed layer (salty and relatively cold) developed as a consequence of enhanced summer convection and the prevalent downwelling conditions. The combination of these features, together with relatively low precipitation, high evaporation, and reduced river runoff, resulted in very high values of salinity. Thus, the reduced freshwater inputs during 2011 enhanced the increasing salinity trends observed in 2010.

Below the depth of the maximum development of winter mixed layer, central waters continued the long-term warming that has been observed since the early 1990s, with a transitory interruption of the trend in 2009. At the depth of the Mediterranean Water, the water mass has shown a weak freshening for the first time in the overall record from the mid-1990s.

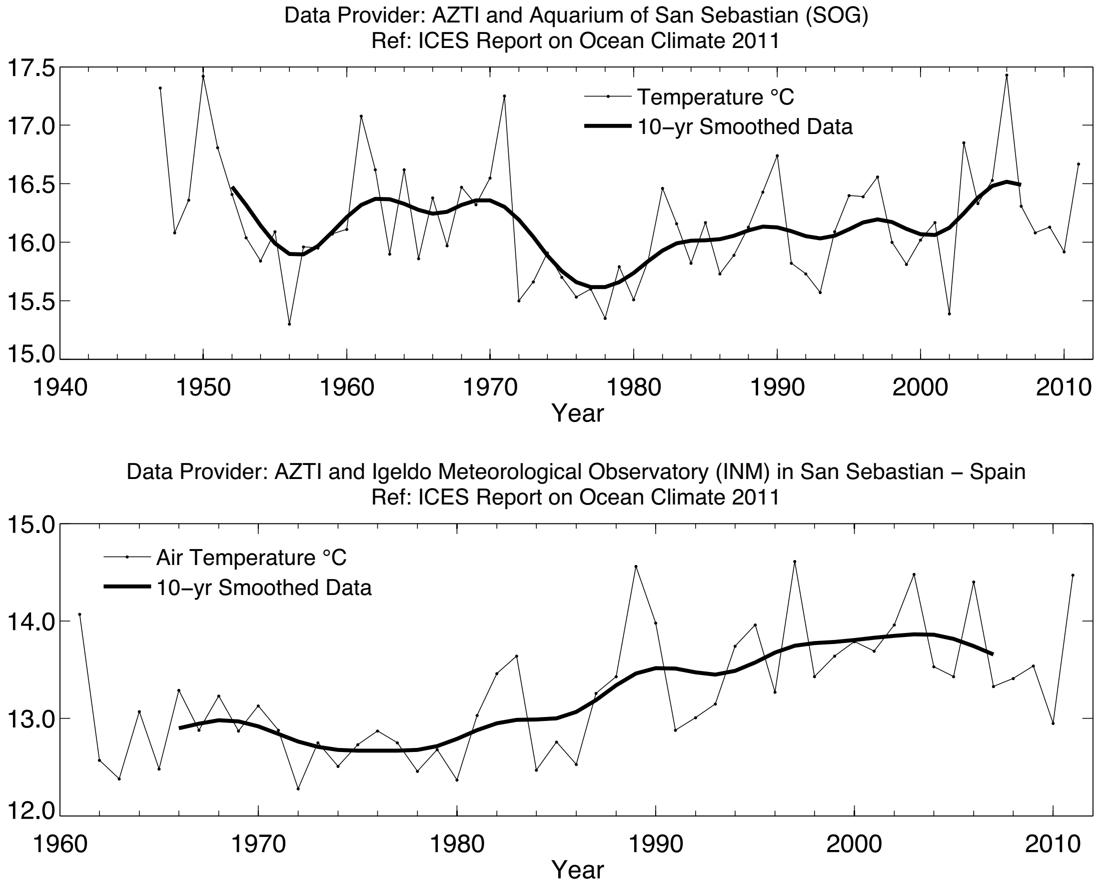


Figure 36.
Area 4 – Bay of Biscay and eastern Atlantic. Sea surface temperature (upper panel) and air temperature (lower panel) at San Sebastian (43°18.5′N 02°2.37′W).

Figure 37.
Area 4 – Bay of Biscay and eastern North Atlantic. Potential temperature (upper panel) and salinity (lower panel) at Santander Station 6 (5–300 m).

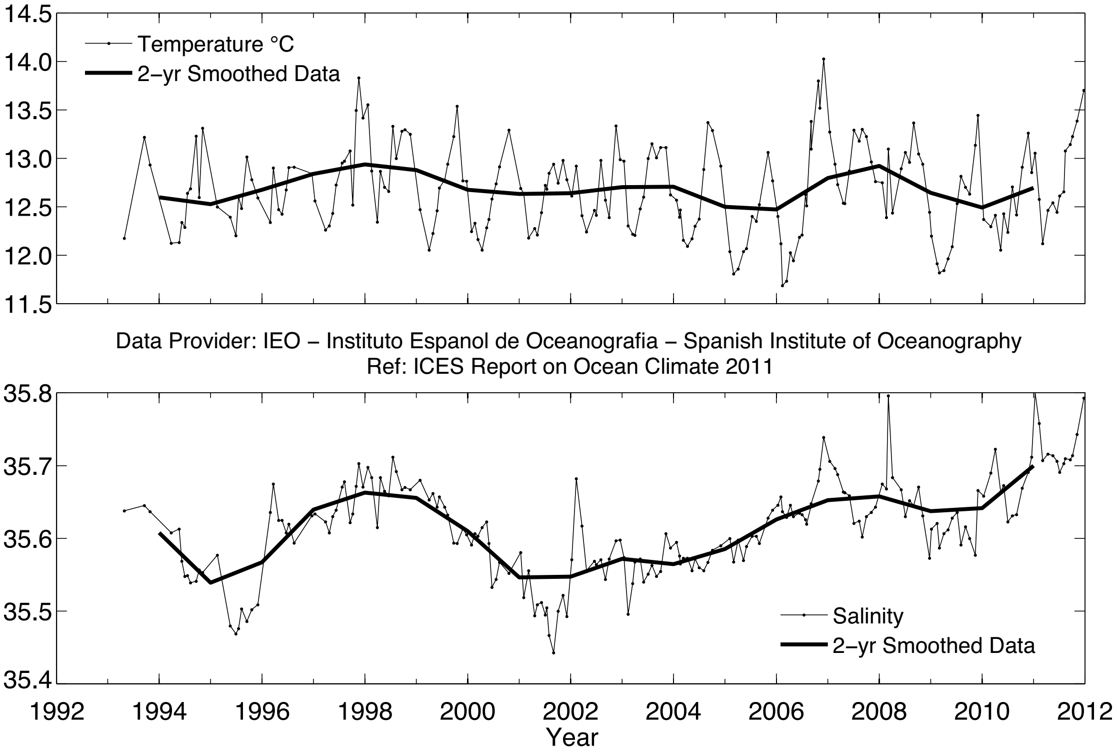
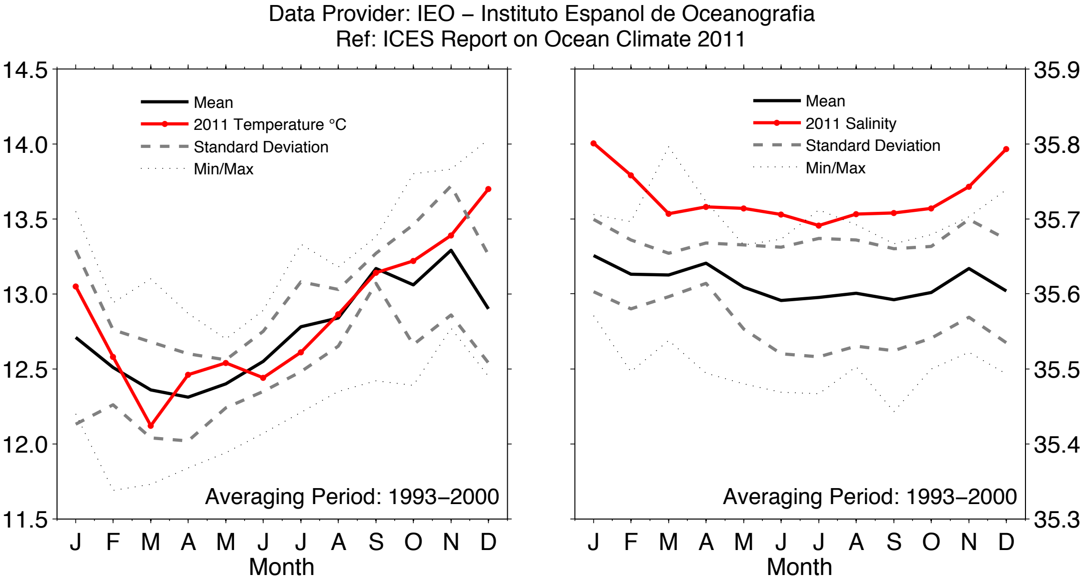


Figure 38.
Area 4 – Bay of Biscay and eastern North Atlantic. 2011 monthly temperature (left panel) and salinity (right panel) at Santander Station 6 (5–300 m).

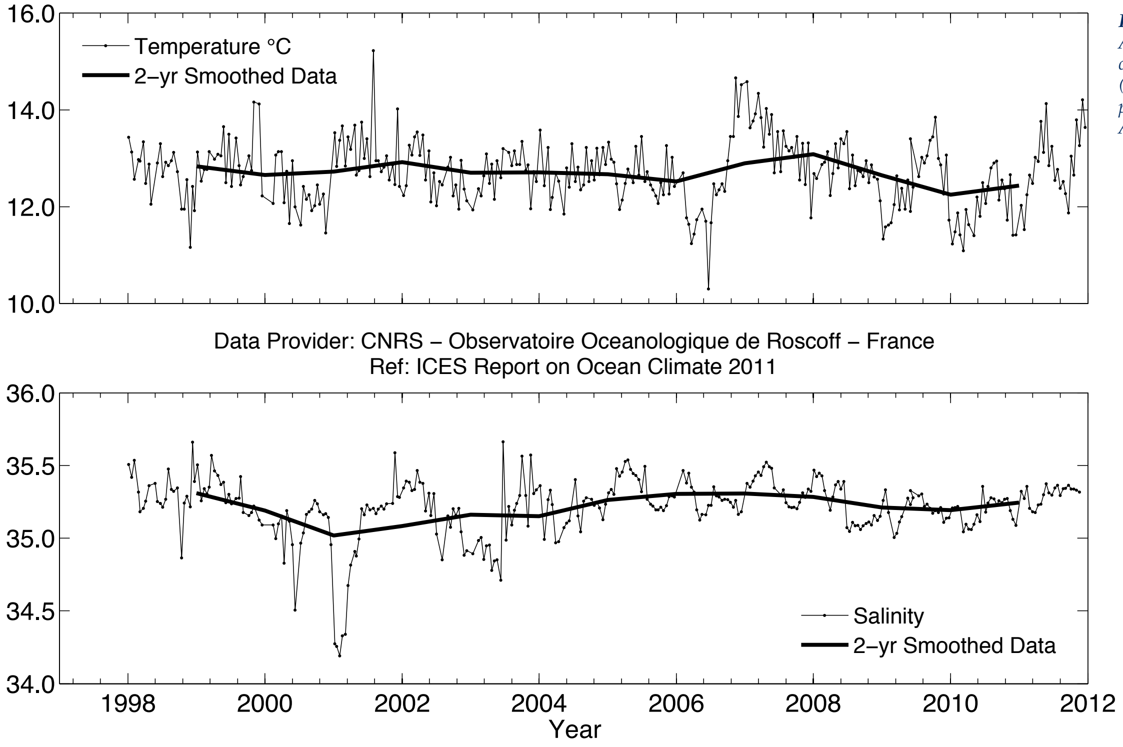


4.8 Area 4b – Northwest European continental shelf

Northern coast of Brittany

MEASUREMENTS ARE COLLECTED TWICE A MONTH AT A COASTAL STATION ON THE NORTHERN COAST OF BRITTANY, FRANCE. THE ASTAN SITE (48.77°N 3.94°W) IS LOCATED 3.5 KM OFFSHORE, AND MEASUREMENTS BEGAN IN 2000. PROPERTIES AT THIS SITE ARE TYPICAL OF WESTERN CHANNEL WATERS. BOTTOM DEPTH IS ABOUT 60 M, AND THE WATER COLUMN IS WELL MIXED MOST OF THE TIME.

In winter 2011, temperatures were lower (by –0.84°C in January and –0.39°C in February) than the average values at the Astan station. During spring and early summer, temperatures higher than average were observed (for example +1.01°C above average in May). During early and mid-summer, temperatures were close to average, becoming lower than average in late summer (–0.64°C below average in September) due to a particularly cloudy summer in 2011. During late autumn and early winter, temperatures became higher again than average due to a mild winter, with a maximum in December (+0.86°C above average). In 2011, the salinity cycle was characterized by values higher than usually observed in this area (2011 annual mean salinity = 35.291). Since 2000, annual mean salinity at Astan was higher only in 2005 (35.324) and 2007 (35.349). The usual late winter–early spring minimum was very weak due to lower influence of river inputs in the southern Western Channel. As usually observed in this area, Western Channel waters were generally well-mixed over the entire water column. Limited thermal stratification (ΔT = 0.4°C) was episodically observed in late summer (late August–early September) during a low wind–neap tide period, favourable to a heating of surface waters.



Data Provider: CNRS – Observatoire Oceanologique de Roscoff – France
Ref: ICES Report on Ocean Climate 2011

Figure 39.
Area 4b – Northwest European continental shelf. Temperature (upper panel) and salinity (lower panel) of surface water at the Astan station (48.77°N 3.94°W).

Figure 40.
Area 4b – Northwest European continental shelf. 2011 monthly temperature (left panel) and salinity (right panel) of surface water at the Astan station (48.77°N 3.94°W).

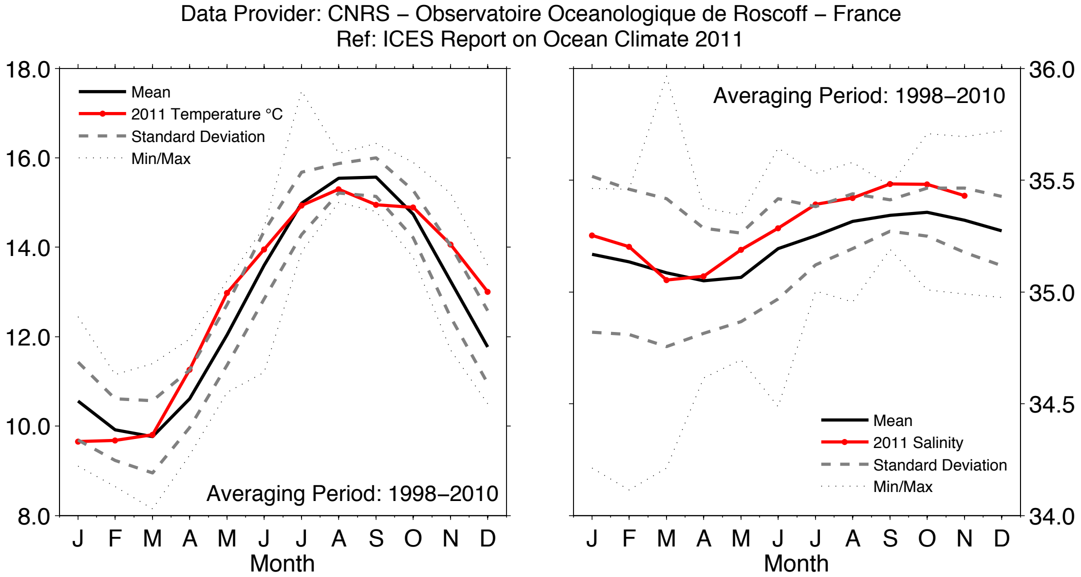


Image courtesy of A. Beszczynska-Möller, AWI, Germany.

Western English Channel

STATION E1 (50.03°N 4.37°W) IS SITUATED IN THE WESTERN ENGLISH CHANNEL AND IS MAINLY INFLUENCED BY NORTH ATLANTIC WATER. THE WATER DEPTH IS 75 M, AND THE STATION IS TIDALLY INFLUENCED BY A 1.1-KNOT MAXIMUM SURFACE STREAM AT MEAN SPRING TIDE. THE WATER COLUMN HERE DEVELOPS A SEASONAL THERMOCLINE, AS STRATIFICATION TYPICALLY STARTS IN EARLY APRIL, PERSISTS THROUGHOUT SUMMER, AND IS ERODED BY THE END OF OCTOBER. THE TYPICAL DEPTH OF THE SUMMER THERMOCLINE IS AROUND 20 M. THE STATION IS GREATLY AFFECTED BY AMBIENT WEATHER. MEASUREMENTS HAVE BEEN TAKEN AT THIS STATION SINCE THE END OF THE 19TH CENTURY, WITH DATA CURRENTLY AVAILABLE SINCE 1903. THE SERIES IS ALMOST UNBROKEN, WITH GAPS FOR THE TWO WORLD WARS AND BETWEEN 1985 AND 2002. THE DATA TAKE THE FORM OF VERTICAL PROFILES OF TEMPERATURE AND SALINITY. EARLY MEASUREMENTS WERE TAKEN WITH REVERSING MERCURY-IN-GLASS THERMOMETERS AND DISCRETE SALINITY BOTTLES. MORE RECENTLY, ELECTRONIC EQUIPMENT (SEABIRD CTD) HAS BEEN USED.

The time-series demonstrates considerable interannual variability in temperature. In 2011, Station E1 was sampled on 15 occasions, with no sampling occurring during February and December. The minimum recorded surface temperature (March) was 9.02°C, and the maximum surface temperature (August) was 17.23°C.

The 50 m temperature series show that water was cooler than the long-term average until March, warmer in April until August, slightly cooler in September and October, but warmer in November. With the exception of the surface salinity record in January 2011, the year showed at both the surface and 50 m that the water column was more saline than average by approximately 0.15. This was particularly marked in autumn.

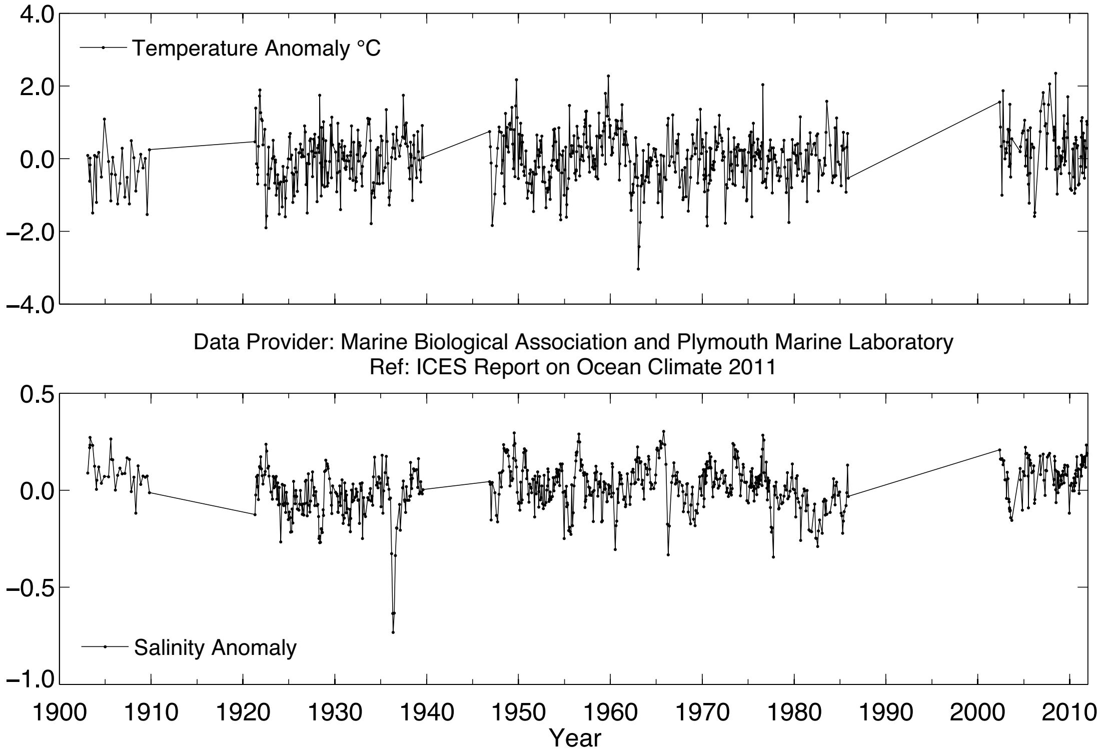


Figure 41.
Area 4b – Northwest European continental shelf. Temperature anomalies (upper panel) and salinity anomalies (lower panel) of surface water at Station E1 in the western English Channel (50.03°N 4.37°W).

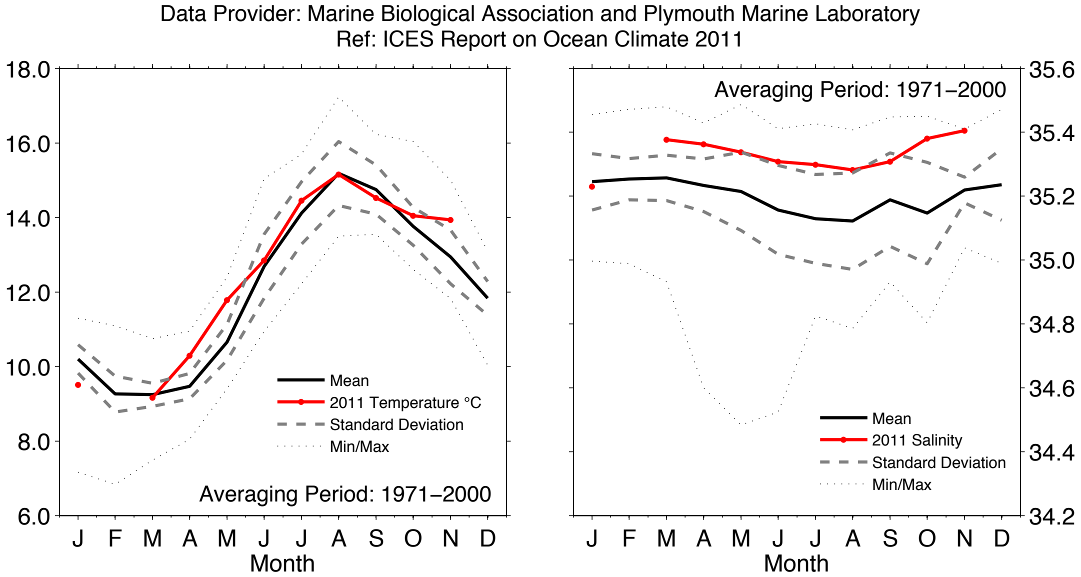


Figure 42.
Area 4b – Northwest European continental shelf. 2011 monthly temperature (left panel) and salinity (right panel) of surface water at Station E1 in the western English Channel (50.03°N 4.37°W).

Image courtesy of I. Yashayaev, BIO, Canada.

North and southwest of Ireland

The time-series of surface observations at the Malin Head coastal station (the most northerly point of Ireland) is inshore of coastal currents and influenced by run-off. The early part of the record between 1959 and 2006 used bucket measurements, while the post-2007 period has used an electronic temperature sensor. An offshore weather buoy has been maintained at 51.22°N 10.55°W off the southwest coast of Ireland since mid-2002, where sea surface temperature data are collected hourly.

At Malin Head, sea surface temperatures have been increasing since the late 1980s, and those for the mid-2000s were the highest since records began in 1960. In 2011, the sea surface temperature anomaly at Malin Head was slightly higher than in 2010 and remains as a positive anomaly in the time-series. At the M3 buoy, there is considerable interannual variability, with the warmest recorded summer temperatures in 2003 and 2005, and the warmest winter temperatures in 2007. In 2011, temperatures started below the time-series mean (2003–2011) until March. Temperatures were above the time-series mean between March and May, and then below the mean values until November.

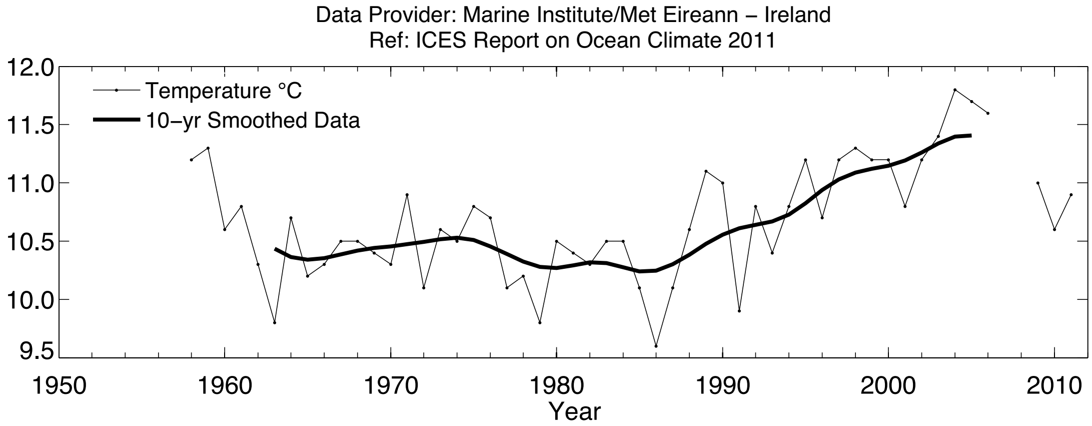


Figure 43.
Area 4b – Northwest European continental shelf. Temperature at the Malin Head coastal station (55.39°N 7.38°W).

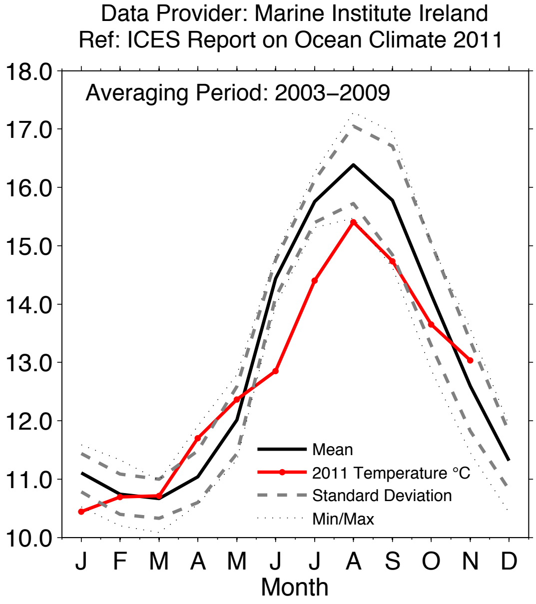
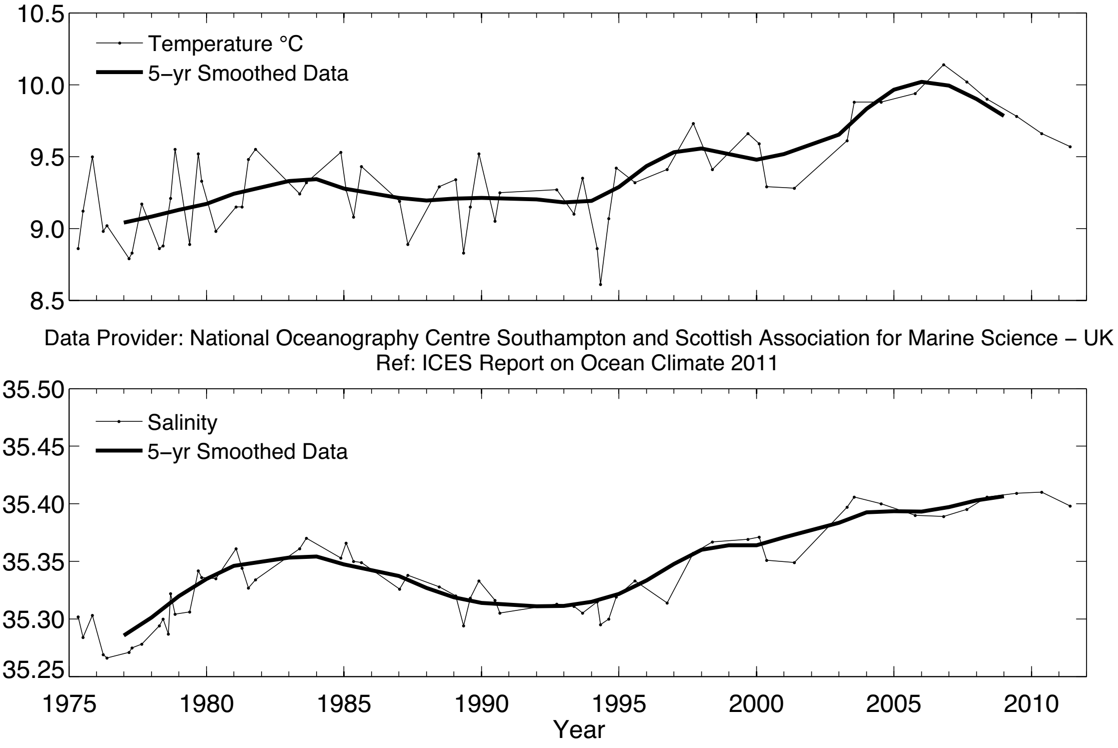


Figure 44.
Area 4b – Northwest European continental shelf. 2011 monthly temperature at the M3 Weather Buoy southwest of Ireland (51.22°N 10.55°W). No salinity data were collected at this station.

4.9 Area 5 – Rockall Trough

The Rockall Trough is situated west of Britain and Ireland and is separated from the Iceland Basin by 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 poleward-moving Eastern North Atlantic Water, which is warmer and more saline than waters of the Iceland Basin, which also contribute to the Nordic Sea inflow.

Although the potential temperature of the upper 800 m remains higher than the long-term mean, the cooling trend that started after the peak of 10.09°C in 2006 continues, with a value of 9.52°C observed in May 2011. More significantly, perhaps, the equivalent salinity, though still high, has fallen slightly for the first time since 2006 from the peak of 35.410 in 2010 to 35.398 in 2011. Whether these observations mean that the Subpolar Gyre is expanding in the NE Atlantic again remains to be seen.



Data Provider: National Oceanography Centre Southampton and Scottish Association for Marine Science – UK
Ref: ICES Report on Ocean Climate 2011

Figure 45.
Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) for the upper ocean (0–800 m).

The post-2006 cooling trend continues in the upper 800 m of the Rockall Trough accompanied by a freshening between 2010 and 2011.

4.10 Area 5b – Irminger Sea

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

The Subpolar Mode Water (SPMW) 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, temperature and salinity show well-correlated interannual variations, without a clear long-term trend, suggesting that variations in the wind-driven circulation are the main cause of this hydrographic variability.

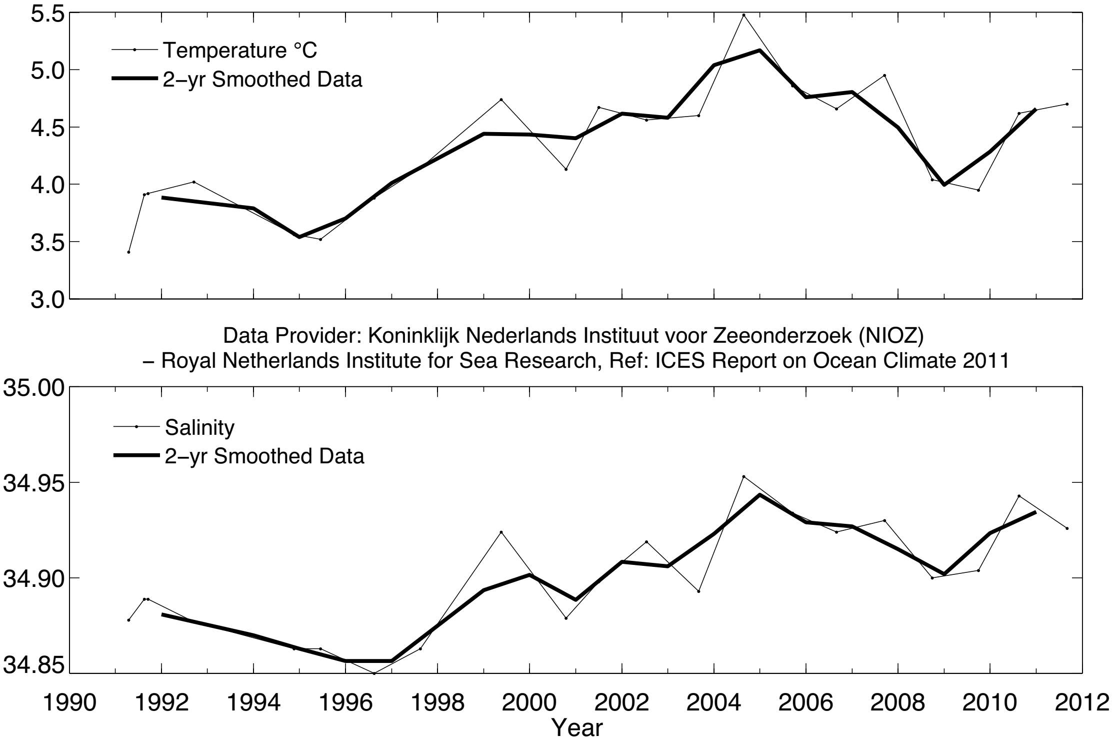
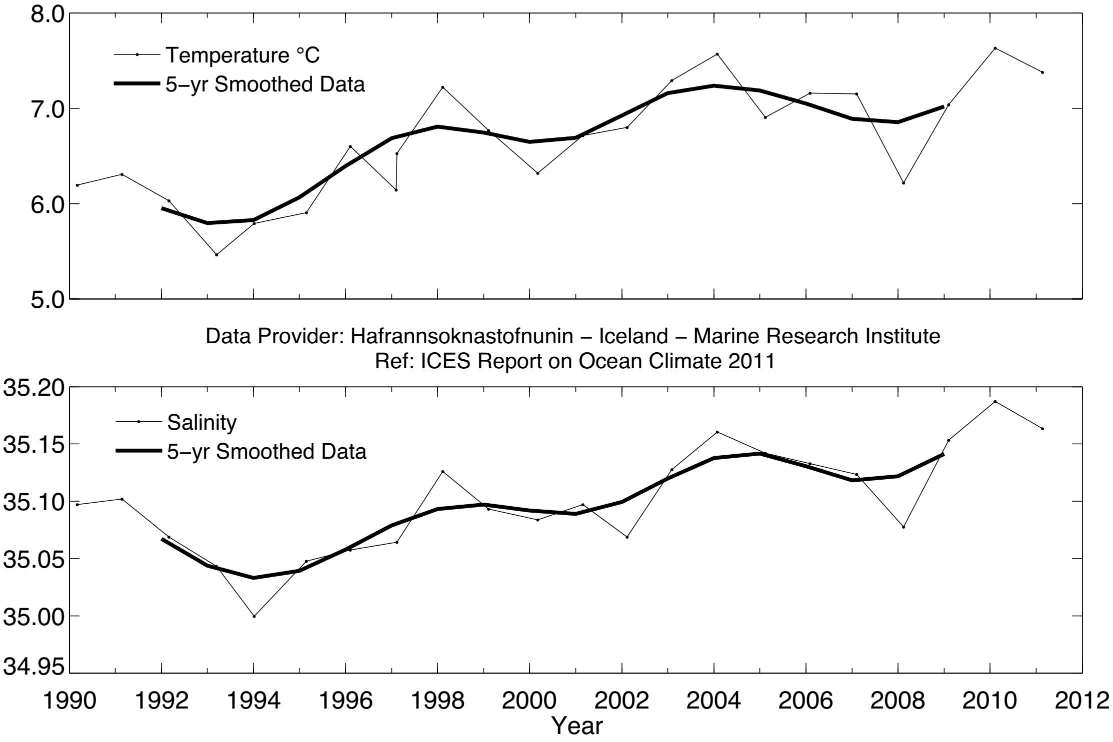


Figure 46.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Subpolar Mode Water in the central Irminger Sea (averaged over 200–400 m).



Data Provider: Hafrannsoknastofnunin – Iceland – Marine Research Institute
Ref: ICES Report on Ocean Climate 2011

Figure 47.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Subpolar Mode Water in the northern Irminger Sea (Station FX9, 64.33°N 28°W), averaged over 200–500 m).

4.11 Areas 6 and 7 – Faroe Bank, Faroe Shelf, and Faroe–Shetland Channel

One branch of the North Atlantic Current crosses the Greenland–Scotland Ridge, flowing on either side of the Faroes. Its properties are observed in the Faroe Bank Channel before it crosses the ridge, and by the Faroe Current after it crosses the ridge. Some of this water recirculates and is seen within the Faroe Shetland Channel as modified North Atlantic Water (MNAW).

Farther to the east, the Continental Slope Current, originating in the southern Rockall Trough, flows along the edge of the northwest European continental shelf. It carries warm, saline Atlantic Water (AW) into the Faroe–Shetland Channel. Part of this AW crosses onto the shelf itself and enters the North Sea, where it is diluted with coastal water and eventually leaves in the Norwegian Coastal Current. The remainder enters the Norwegian Sea directly and joins the water coming from north of the Faroes to become the Norwegian Atlantic Water.

Generally, both temperature and salinity in all upper-layer waters around the Faroes and in the Faroe–Shetland Channel have increased markedly during the 1990s and 2000s. Additionally, the longer time-series of the Faroe–Shetland Channel reveal that salinity has generally increased, following the very low values recorded during 1975–1980.

After the record-high salinities observed in the Faroe Bank Channel and the Faroe Current in November 2009, salinities decreased somewhat in 2010 and 2011, whereas temperatures have been very stable since the early 2000s. On the Faroe Shelf, the annual average temperature increased in 2011 compared to 2010, and the spring was particularly warm, with record-high temperatures in May 2011. Conditions thus still remain exceptionally warm and saline in the century-long perspective given by the Faroe coastal temperature time-series, although, like all coastal and shelf time-series, this is affected by atmospheric and terrestrial effects.

The water on the western slope of the Faroe–Shetland Channel, known as modified North Atlantic Water, reached record-high temperature and salinity in 2010. This water is thought to have passed into the Channel from north of the Faroes. On the eastern side of the Faroe–Shetland Channel, both salinity and temperature are increasing, and record-high temperatures were observed in 2011.

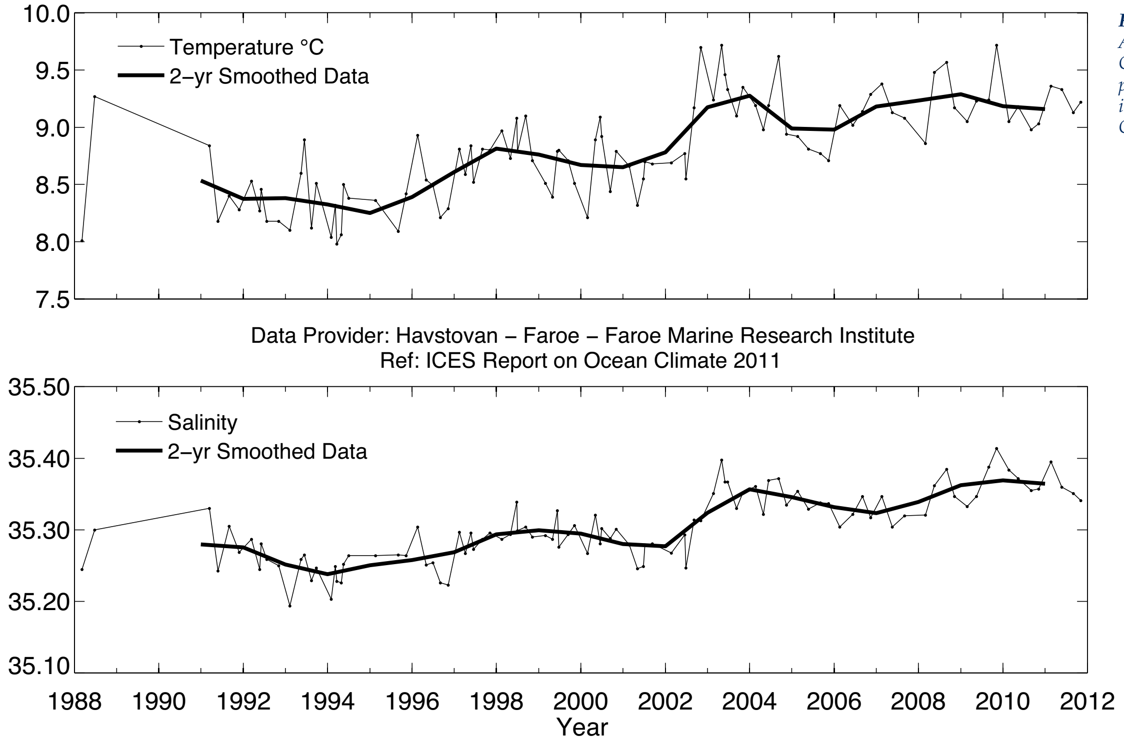


Figure 48.
Areas 6 and 7 – Faroe Bank Channel. Temperature (upper panel) and salinity (lower panel) in the Atlantic Water in the Slope Current.

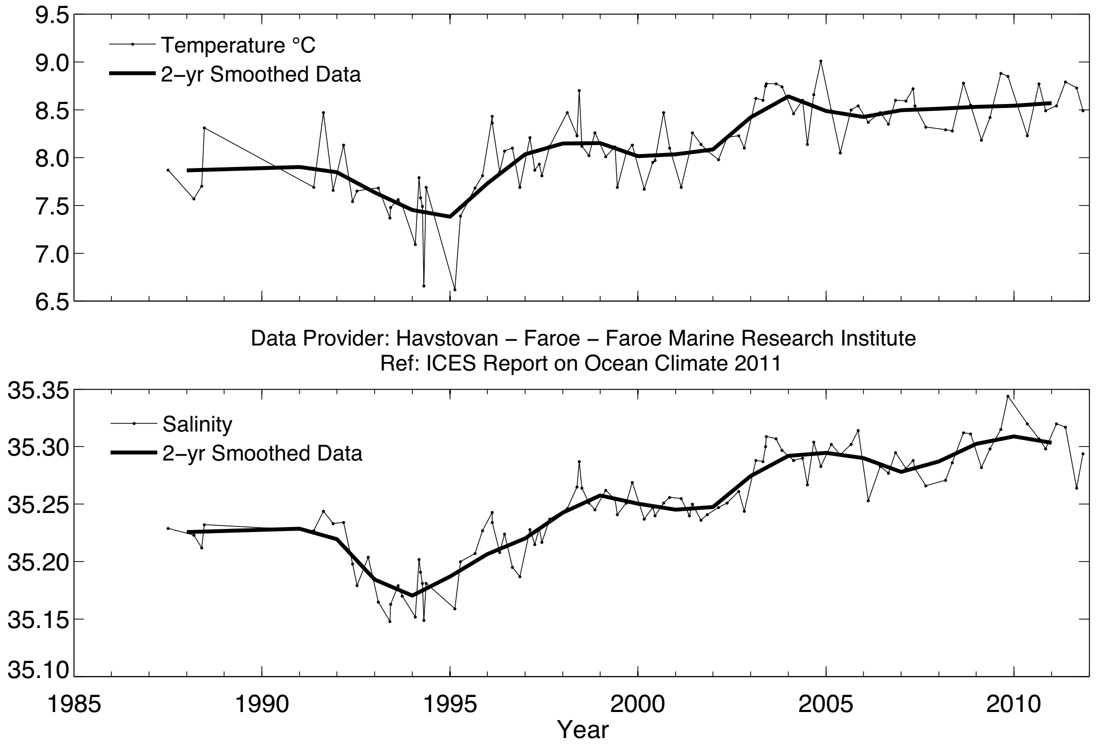


Figure 49.
Areas 6 and 7 – Faroe Current. Temperature (upper panel) and salinity (lower panel) in the high salinity core of the Faroe Current north of the Faroes (maximum salinity averaged over a 50 m deep layer).

IN 2011, RECORD-HIGH TEMPERATURES WERE OBSERVED IN THE EASTERN PART OF THE FAROE–SHETLAND CHANNEL.

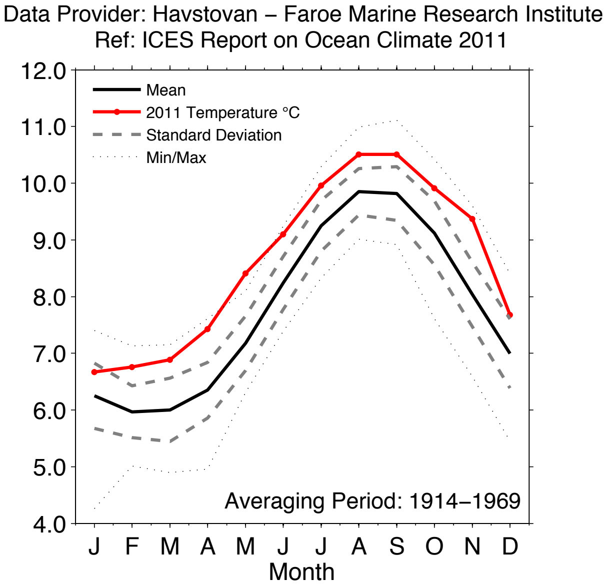


Figure 50.
Areas 6 and 7 – Faroe Shelf. 2011 monthly temperature data from the Faroe coastal station at Oyrargjogv (62.12°N 7.17°W). Note the average values were calculated from the nearby station at Mykines (69.10°N 7.66°W).

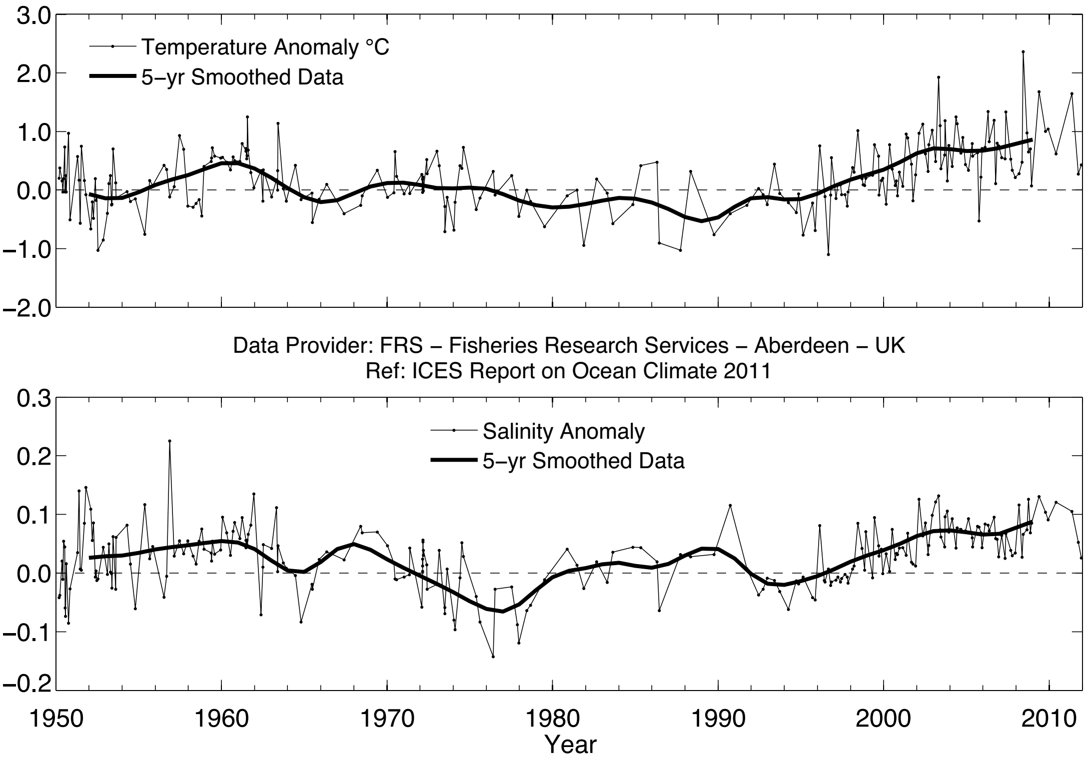


Figure 51.
Areas 6 and 7 – Faroe–Shetland Channel. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Modified Atlantic Water entering the Faroe–Shetland Channel from the north after circulating around the Faroes.

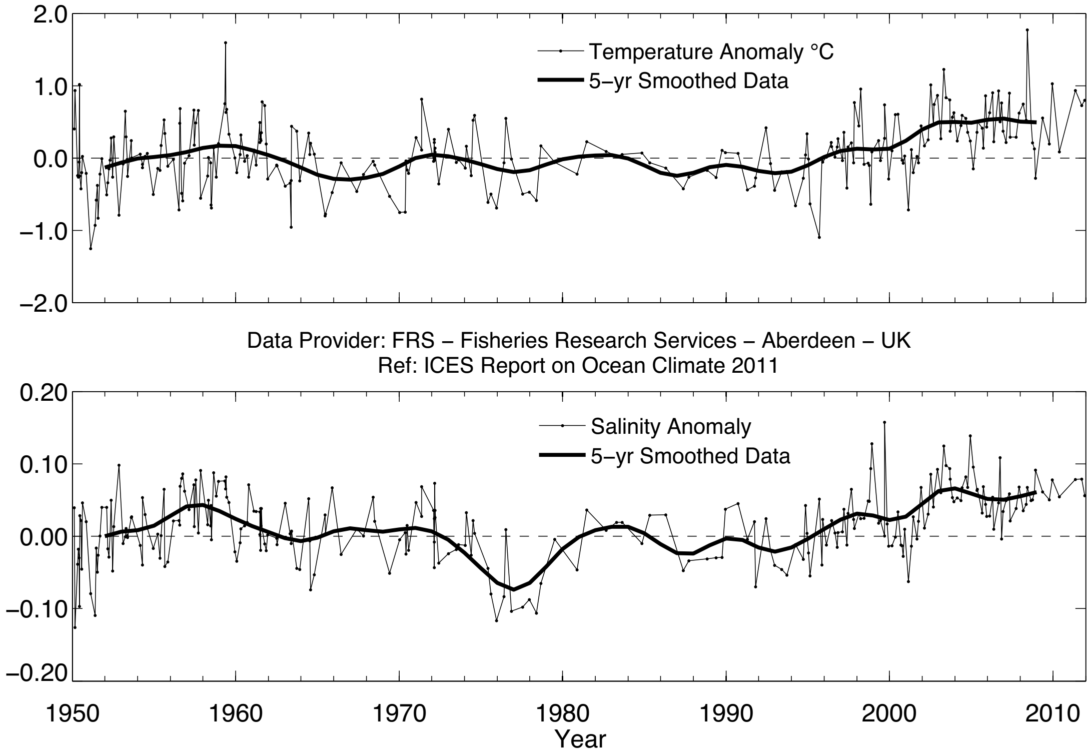
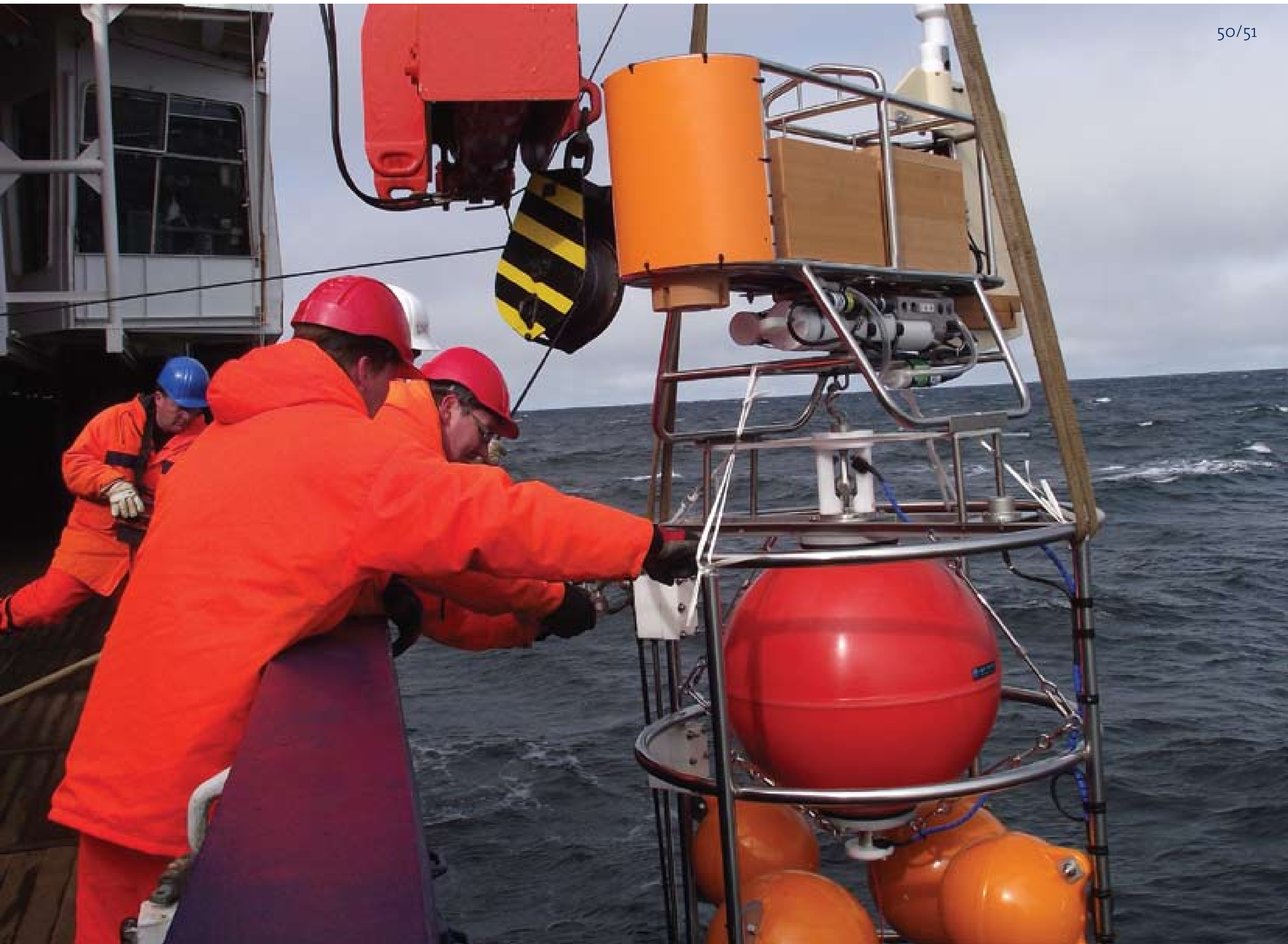


Figure 52.
Areas 6 and 7 – Faroe–Shetland Channel. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Atlantic Water in the Slope Current.

Image courtesy of A. Beszczynska-Möller, AWI, Germany.



4.12 Areas 8 and 9 – Northern and southern North Sea

NORTH SEA OCEANOGRAPHIC CONDITIONS ARE DETERMINED BY THE INFLOW OF SALINE ATLANTIC WATER (AW) 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 AW MIXES WITH 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 MUCH OF THE NORTH SEA.

Due to a strong temperature drop during November 2010, the winter 2010/2011 started with negative monthly SST anomalies up to –0.9°C. The spatial pattern in January exhibited strong negative anomalies along the Norwegian and Danish coasts and weaker negative anomalies all over the central and southern North Sea. In March, the monthly mean returned to the long-term mean, with still some weak negative anomalies along the coasts of Norway and Denmark and positive anomalies along the UK coast. May was very warm, with a monthly SST anomaly of +1.2°C. During autumn, the SSTs exceeded the long-term mean, with positive anomalies over the whole North Sea area and a monthly anomaly of +1.4°C in November. The annually averaged SST anomaly for 2011 was +0.5°C (2010: +0.1°C). Besides the inflow of warmer Atlantic Water at the northern boundary and through the English Channel, much of the SST variability is caused by the local ocean–atmosphere heat flux.

The general late summer horizontal temperature distribution of the surface and bottom layer was comparable to the previous year, with isotherms running approximately from southwest to northeast. The ribbon of warm, vertically mixed water along the continental coast was smaller and about 1°C colder than in 2010. Relative to the reference period (summer surveys 2000–2010 except 2002), the surface layer was up to 1.5°C colder, while the bottom layer showed a heterogeneous pattern, with anomalies between +3.0 and –1.5°C. The difference between surface and bottom temperature decreased by 2°C from 10 to 8°C compared to 2010 in the central North Sea. The vertical temperature gradient varied between 0.5 and 2.5°C m^{-1}. On average, the mixed layer, with a depth of 40 m, is about 5 m deeper and cooler than in 2010. Compared to 2010, the total summer heat content dropped slightly to 1.621×10^{21}J and lies close to the average of the reference period (1.626×10^{21}J).

At the surface, the area with a salinity higher than 35 was smaller compared to 2009 and 2010, while the ribbon of low saline water (salinity below 34), parallel to the Norwegian coast, was much broader than in most of the preceding years, expanding as far as 1°E at 60°N. The low saline water occupied a much larger volume in 2011 compared to other years, causing strong negative anomalies up to –2 relative to the reference period. Southwards of 56°N, the 34-isohaline was located in a position close to the long-term mean. The bottom salinity south of 56°N was generally comparable to 2010, the ribbon of low salinity water (below 34), parallel to the Jutland coast, was slightly smaller. At 58°N, there was a pronounced positive salinity anomaly over the Norwegian Trench. In 2011, the maximum vertical expansion of the Baltic outflow was about 30 m, compared to its maximum depth, exceeding 60 m in many previous years. The total salt content of 1.099×10^{12} t was the lowest since 2001. The difference from the mean of the reference period was equal to 3.3% of the total salt content, mainly caused by the westward extension of the fresher Baltic outflow over the Norwegian Trench and by fresher water in the southern North Sea.

Due to strong precipitation and snowfall in the cold winter 2010/2011, there was an extraordinary high Elbe River run-off in January and February, with daily maxima exceeding 3500 $m^3 s^{-1}$. Also, the annually averaged run-off of more than 25 $km^3 year^{-1}$ exceeded the long-term mean of 21.6 $km^3 year^{-1}$, but this is still within the 95% confidence interval of the long-term mean.

Temperature and salinity at two positions in the northern North Sea illustrate conditions in the Atlantic inflow (Figure 53). 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 AW at the western shelf edge of the Norwegian Trench. Measurements are taken during summer and represent the previous winter's conditions. The average temperature at Location A was 1–2°C lower than at Location B, and salinity was also slightly lower. In both locations, there were above-average temperatures and salinities in 2009, and there has been an increase in both salinities and temperatures from 2008. Temperature at Location A has been decreasing since 2009, while at Location B, it reached a peak in 2010 and decreased in 2011. Salinity at Location A remained similar in 2011 as in 2010, but dropped slightly at Location B.

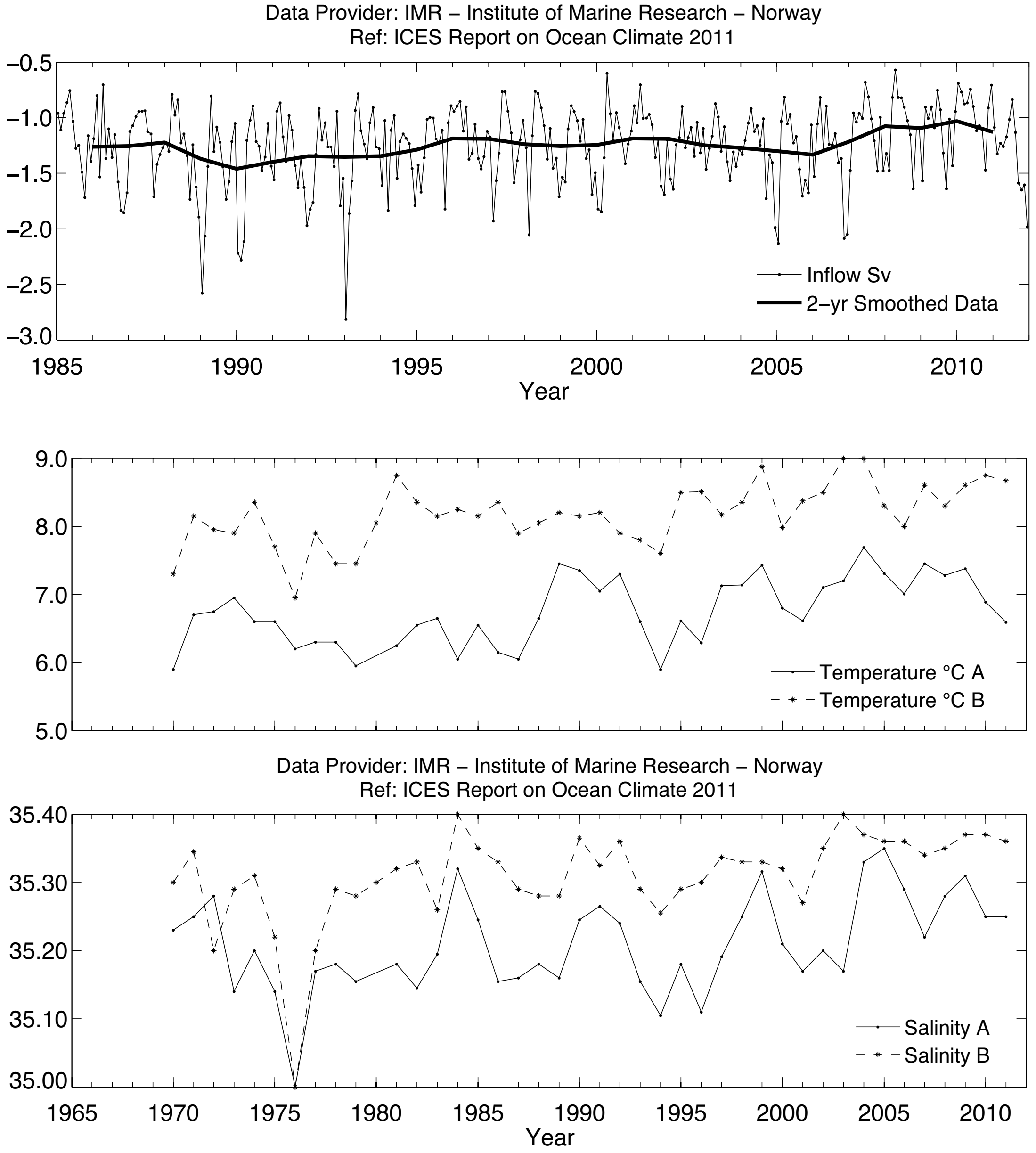


Figure 53.
Area 8 – Northern North Sea. Modelled monthly mean volume transport of Atlantic Water (AW) into the northern and central North Sea southwards between the Orkney Islands and Utsira, Norway (top panel). Observed temperature (middle panel) and salinity (bottom panel) near the seabed in the northwestern part of the North Sea (Location A) and in the core of AW at the western shelf edge of the Norwegian Trench (Location B) during summers 1970–2011.

Figure 54.
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.

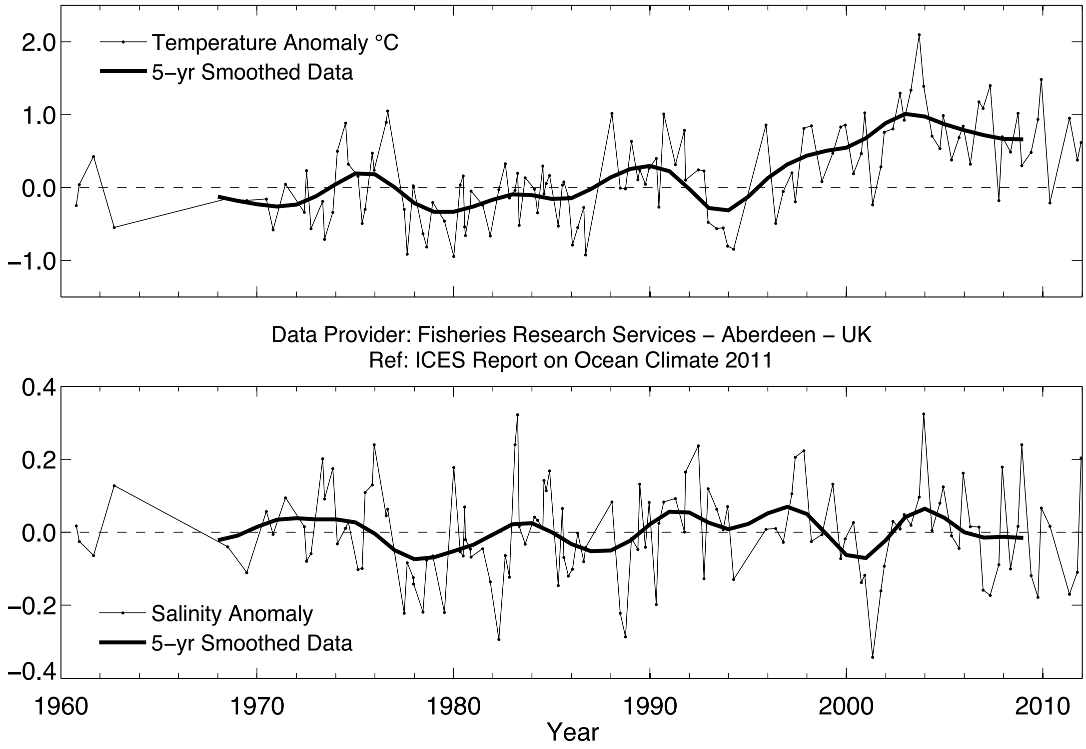
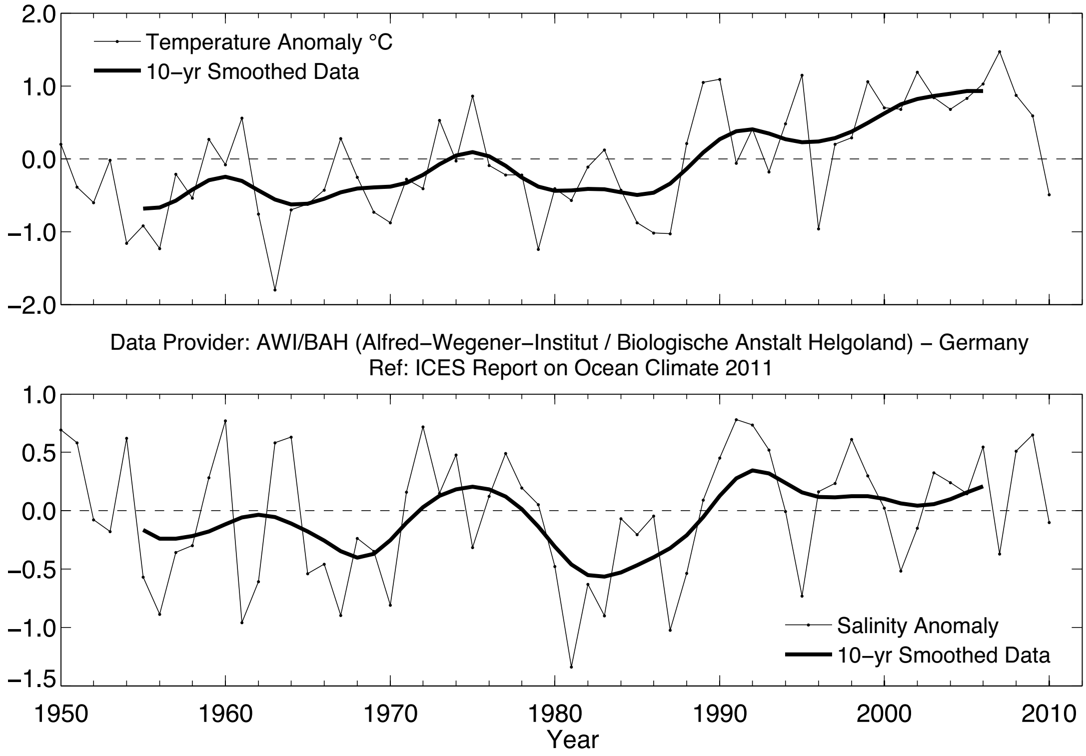


Figure 55.
Area 9 – Southern North Sea. Annual mean surface temperature anomaly (upper panel) and salinity anomaly (lower panel) at Station Helgoland Roads.



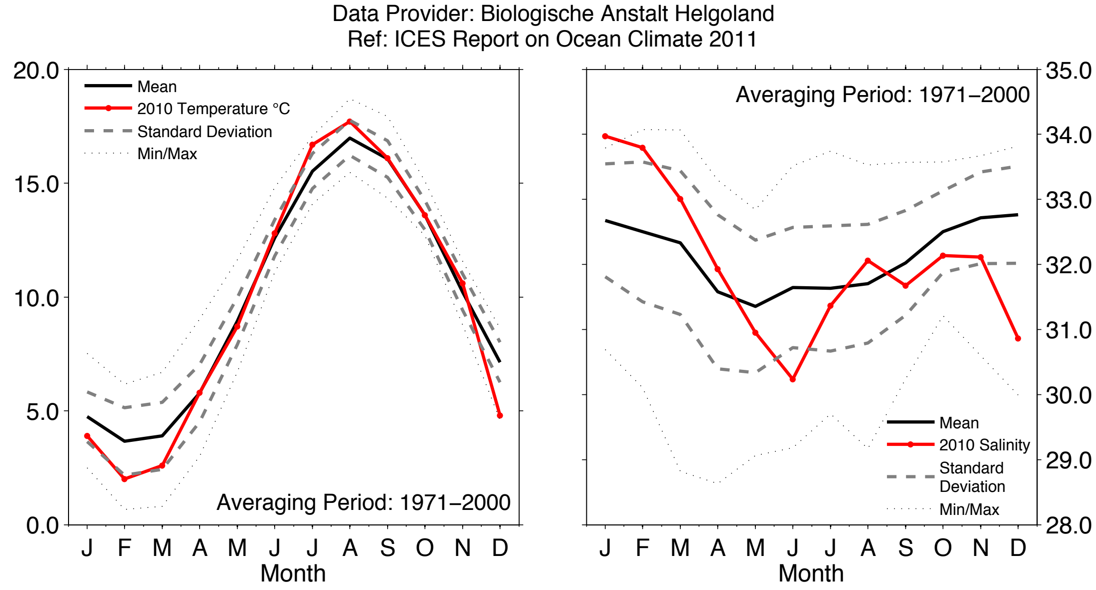


Figure 56.
Area 9 – Southern North Sea. 2010 monthly surface temperature (left panel) and salinity (right panel) at Station Helgoland Roads.

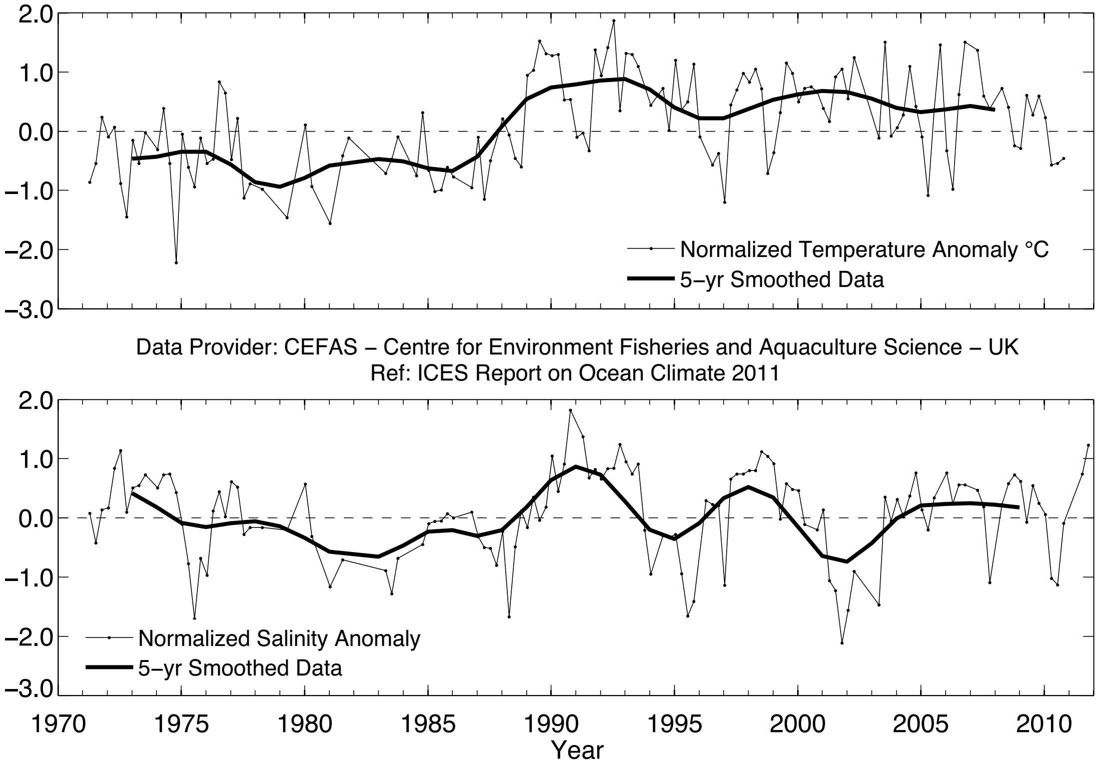


Figure 57.
Area 9 – Southern North Sea. Normalized sea surface temperature anomaly (upper panel) and salinity anomaly (lower panel) relative to 1971–2000, measured along 52°N by a regular ferry at six standard stations. The time-series shows the seasonal section average (DJF, MAM, JJA, SON) of the normalized variable.

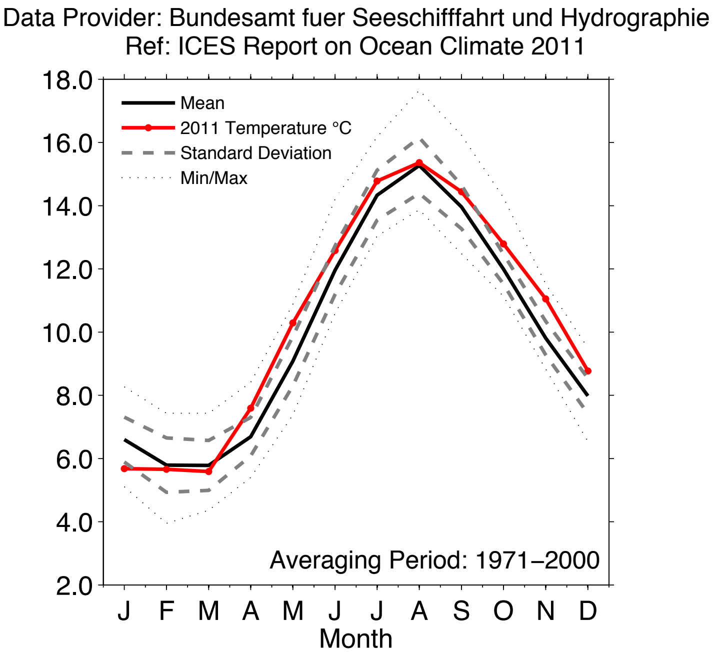


Figure 58.
Areas 8 and 9 – Northern and southern North Sea. North Sea area-averaged sea surface temperature (SST) annual cycle; 2011 monthly means based on operational weekly North Sea SST maps.

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

The seas in area 9b 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 in the southern Baltic, smaller inflows pass relatively quickly, and conditions in the deep water are very variable. Surface salinity is very low in the Baltic Proper and its gulfs. The Gulf of Bothnia and the Gulf of Finland are ice covered during winter.

ANOTHER SEVERE ICE SEASON.

Owing to its central location relative to the Skagerrak, Kattegat, and Baltic, the weather in Sweden can be taken as representative of the area. The weather in 2011 was unusually warm and wet, especially in the northern parts. The mean air temperature for the whole country was around 2°C above normal. Higher mean values have only been recorded twice since 1860. Temperatures were above normal for all months except February, which was colder than normal. April stood out as being one of the warmest ever in most parts of Sweden, and in the north, record-high values were observed in September and November. Several storms passed the region at the end of the year. In most areas, the number of sun hours was above normal.

For the first four months, the sea surface temperatures were generally somewhat lower than normal. In Skagerrak and Kattegat, summer temperatures were slightly higher than normal, while they were close to mean values in the Baltic Proper. Kattegat was warmer than normal at the end of the year; elsewhere, only minor deviations from mean values were observed in the second half of the year. Surface salinity was close to normal most of the year in Skagerrak and in the Baltic Proper. Lower-than-normal values were observed in Kattegat in September and November, but otherwise, surface salinity was close to the mean in this area. In the Gulf of Bothnia and Gulf of Finland, sea surface temperature was higher than average in summer and autumn. In summer, strong upwelling occasionally cooled the sea surface.

The deep waters of the northern Baltic Sea warmed slightly from 2004 to 2008, but subsequently, cooled back to the temperatures observed before 2004. The deep-water salinity has remained more or less at the same level for the last seven years.

The stormy period at the end of 2011 yielded deep-water inflows to the Baltic, thereby improving oxygen conditions in the deepest parts of the Arkona and Bornholm basins.

The ice season 2010/2011 was even more severe than the previous season 2009/2010, which was considered the most severe since 1987. Large areas were already ice covered at the start of the year, owing to the exceptionally cold December 2010. After a mild January, February was cold, and ice cover reached its maximum, 300 000 km^2, on 25 February. Bothnian Bay, Bothnian Sea, Gulf of Finland, and large parts of the Baltic Proper were ice covered at that time. Ice was also found along the Swedish west coast.

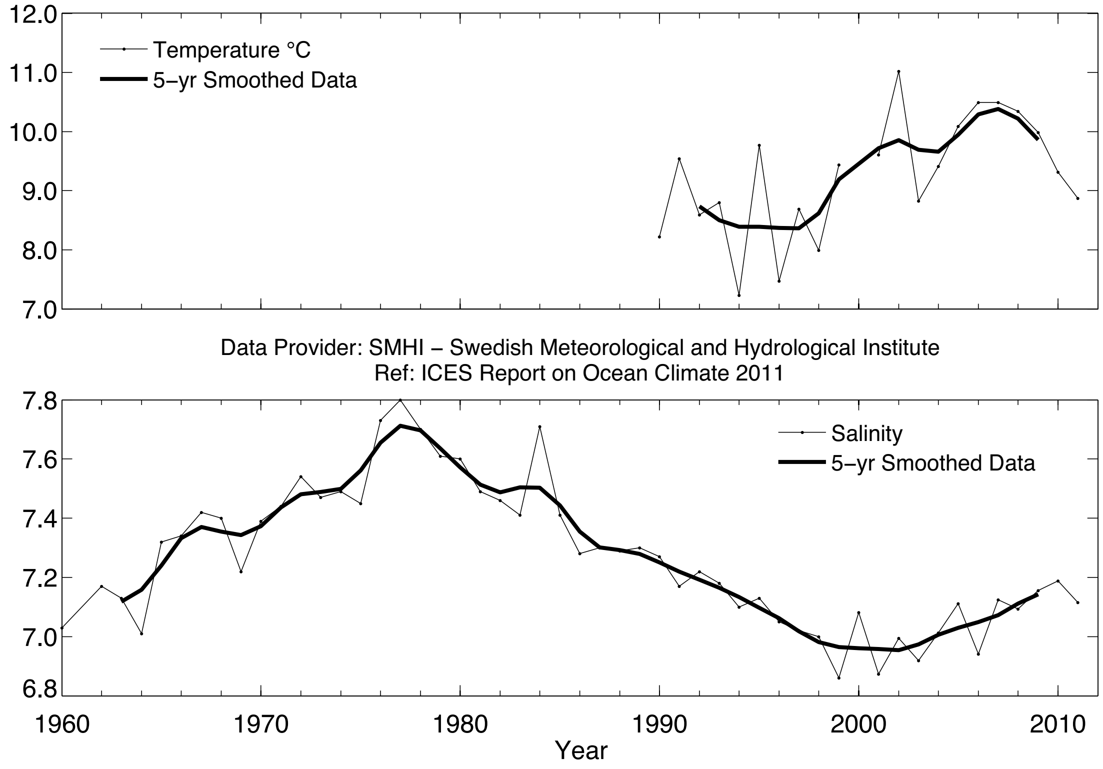


Figure 59.
Area 9b – Skagerrak, Kattegat, and the Baltic. Surface temperature (upper panel) and surface salinity (lower panel) at Station BY15 (east of Gotland) in the Baltic proper.

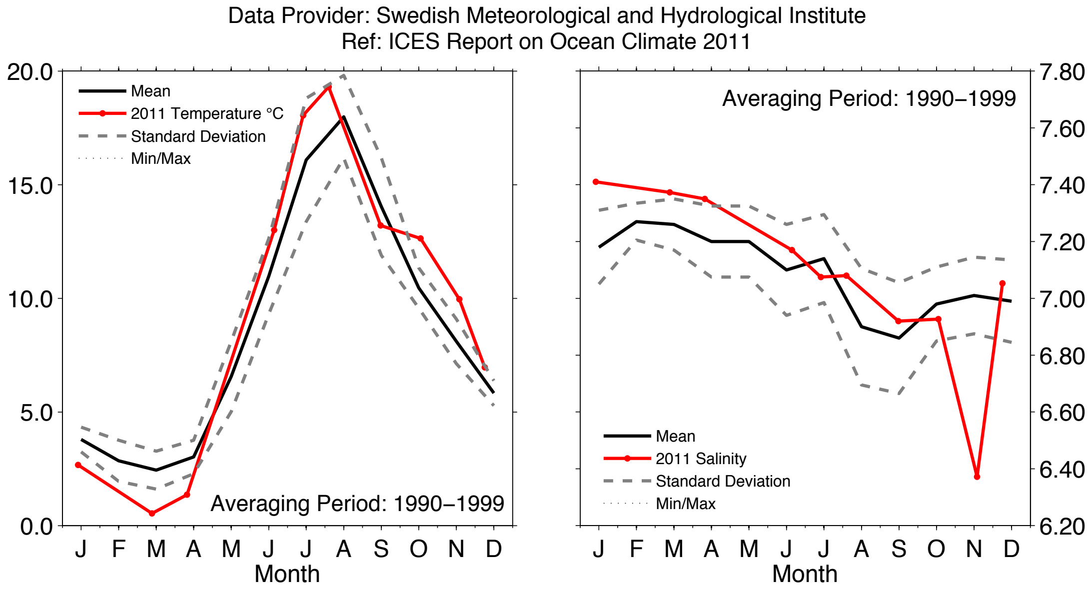
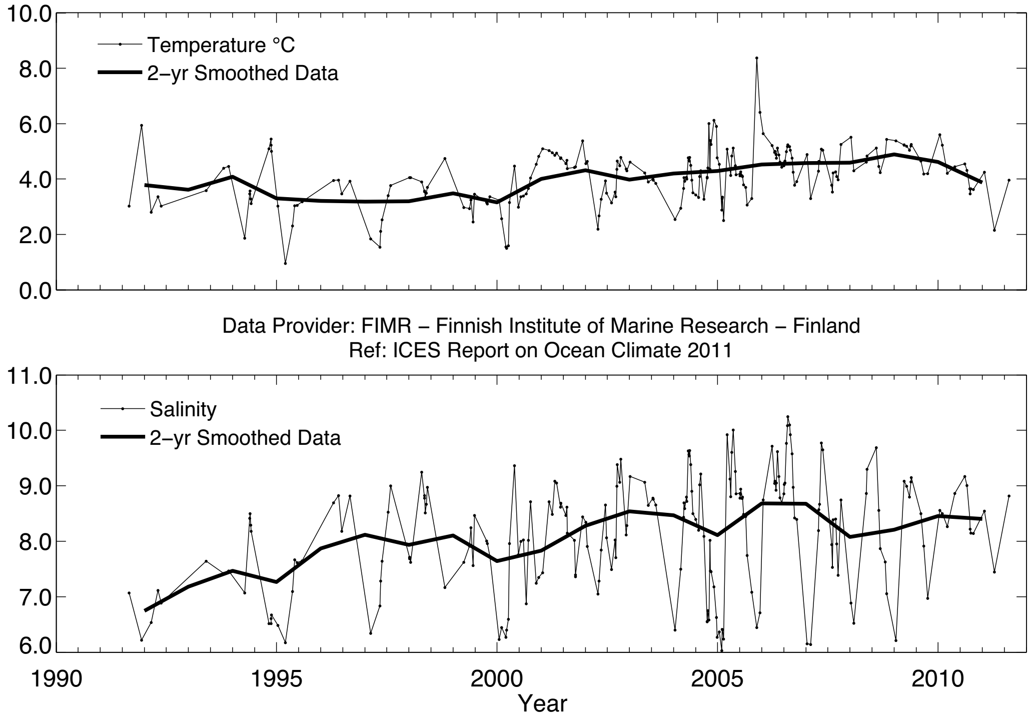


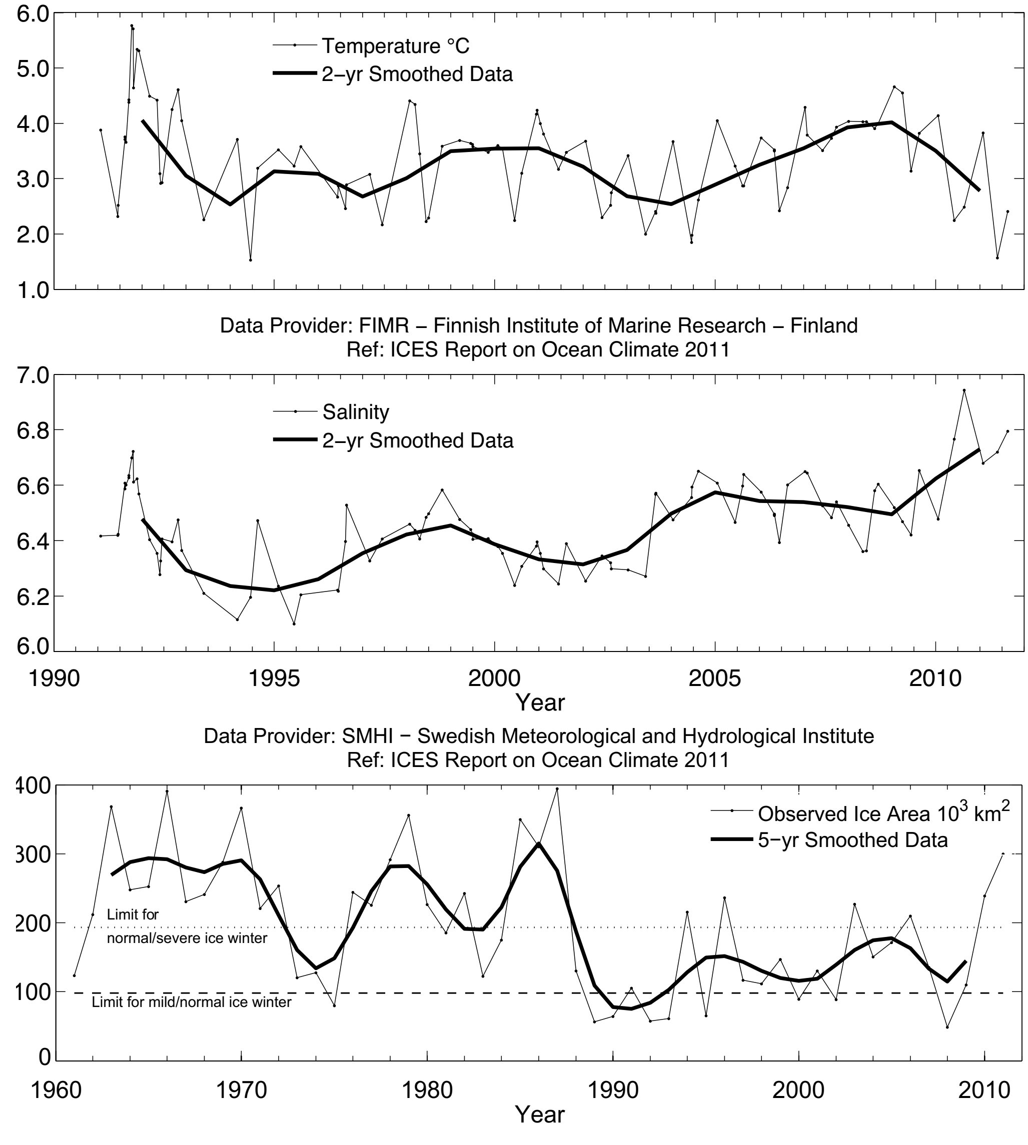
Figure 60.
Area 9b – Skagerrak, Kattegat, and the Baltic. 2011 monthly surface temperature (left panel) and salinity (right panel) at Station BY15 (east of Gotland) in the Baltic Proper.

Figure 61.
Area 9b – Skagerrak, Kattegat, and the Baltic. Temperature (upper panel) and salinity (lower panel) at Station LL7 in the Gulf of Finland.



Data Provider: FIMR – Finnish Institute of Marine Research – Finland
Ref: ICES Report on Ocean Climate 2011

Figure 62.
Area 9b – Skagerrak, Kattegat, and the Baltic. Temperature (upper panel) and salinity (middle panel) at Station SR5 in the Bothnian Sea, and ice extent in the Baltic starting from 1961 (lower panel).



Data Provider: FIMR – Finnish Institute of Marine Research – Finland
Ref: ICES Report on Ocean Climate 2011

Data Provider: SMHI – Swedish Meteorological and Hydrological Institute
Ref: ICES Report on Ocean Climate 2011

4.14 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. ATLANTIC WATER FLOWS NORTH AS THE NORWEGIAN ATLANTIC CURRENT, WHICH SPLITS WHEN IT REACHES NORTHERN NORWAY; SOME ENTERS THE BARENTS SEA, WHEREAS THE REST CONTINUES NORTH INTO THE ARCTIC OCEAN AS THE WEST SPITSBERGEN CURRENT.

Three sections from south to north in the eastern Norwegian Sea demonstrate the development of temperature and salinity in the core of the Atlantic Water (AW) at 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. At the Svinøy and Gimsøy sections, temperature and salinity were above long-term means in 2011 by 0.3°C and 0.06, respectively. The high salinity values reflect more saline AW in the Faroe–Shetland Channel. There were no data from the Sørkapp section in 2011.

Since the late 1990s, Ocean Weather Station "M", located at 66°N 2°E, has revealed strong positive anomalies of temperature and salinity at 50 m. Both parameters reached their record-high values in 2010 and dropped slightly in 2011, still remaining well above their long-term averages. In particular, salinity was significantly above its averaged seasonal cycle through the first eight months of 2011.

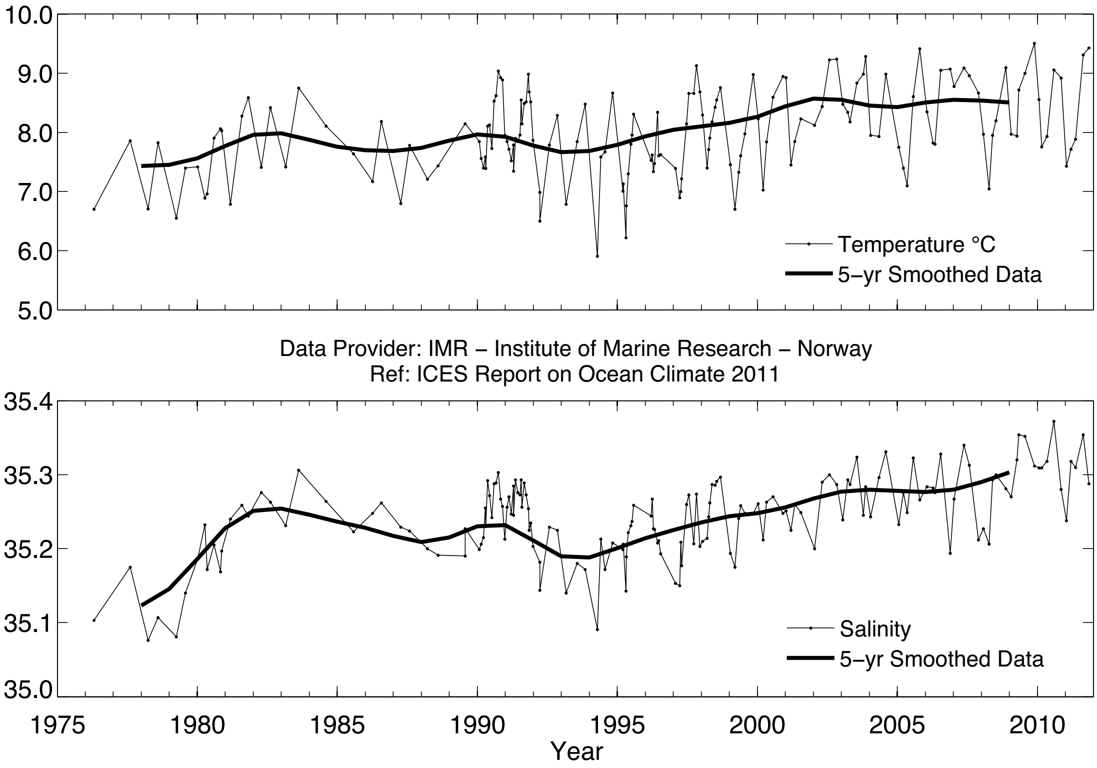
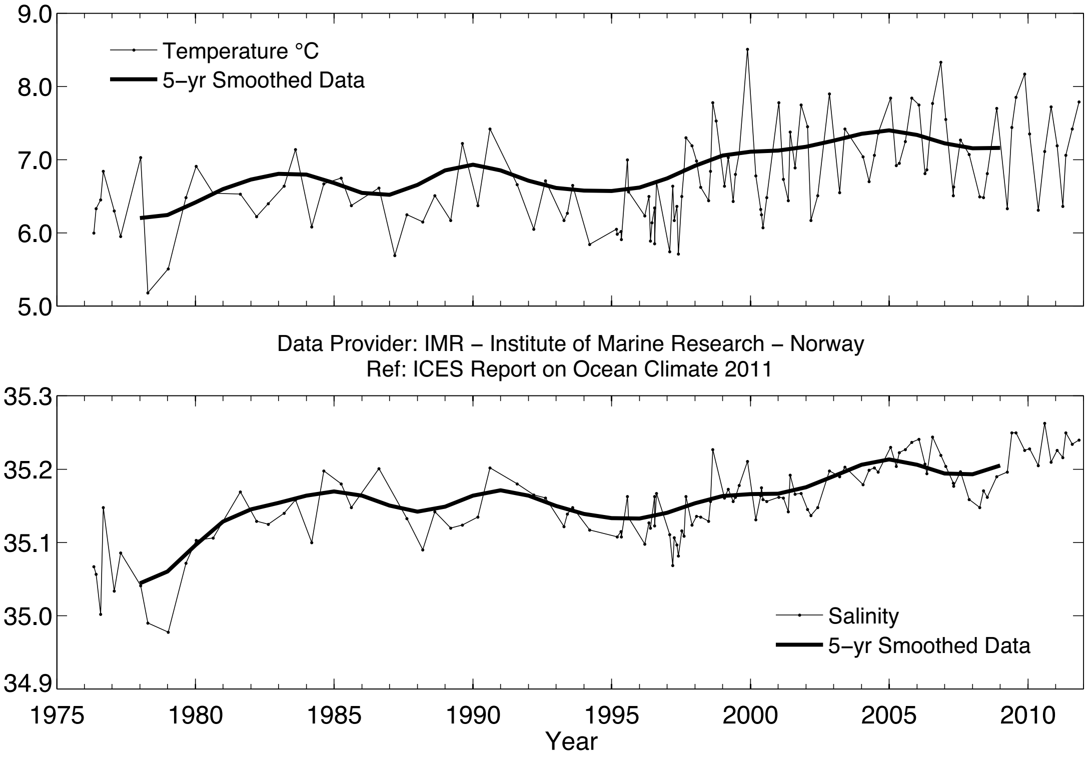


Figure 63.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Svinøy Section (63°N).

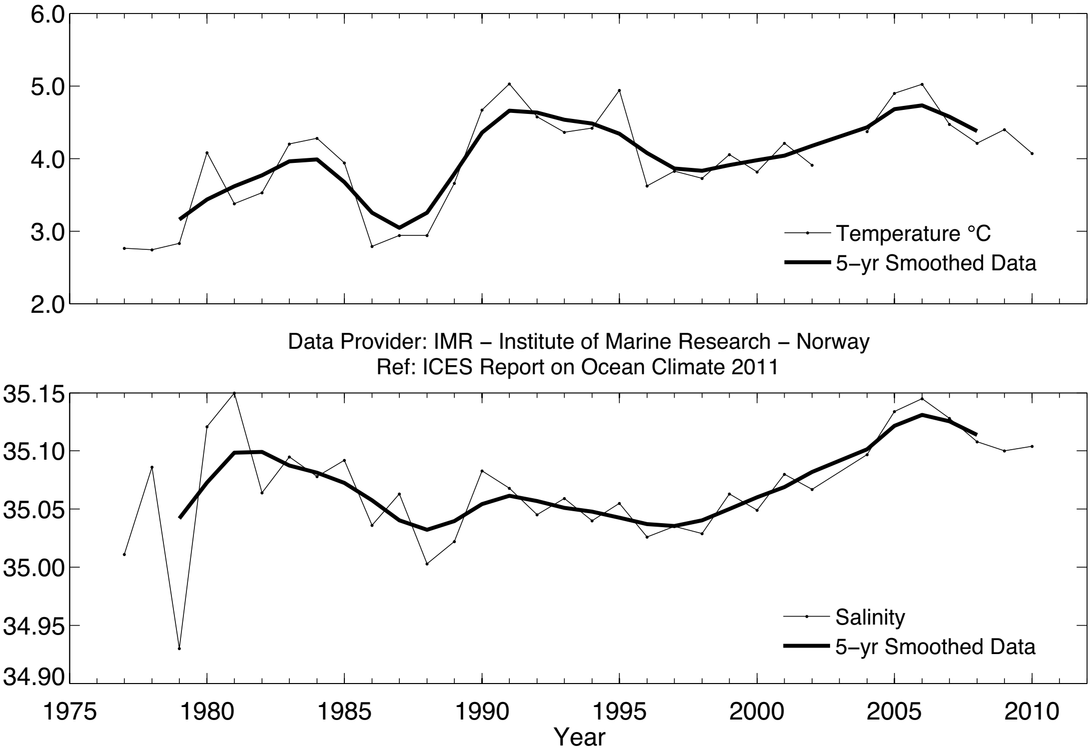
ABOVE-AVERAGE TEMPERATURE AND SALINITY IN THE NORWEGIAN SEA IN 2011.

Figure 64.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Gimsøy Section (69°N).



Data Provider: IMR – Institute of Marine Research – Norway
Ref: ICES Report on Ocean Climate 2011

Figure 65.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Sørkapp Section (76°N, not updated for 2011).



Data Provider: IMR – Institute of Marine Research – Norway
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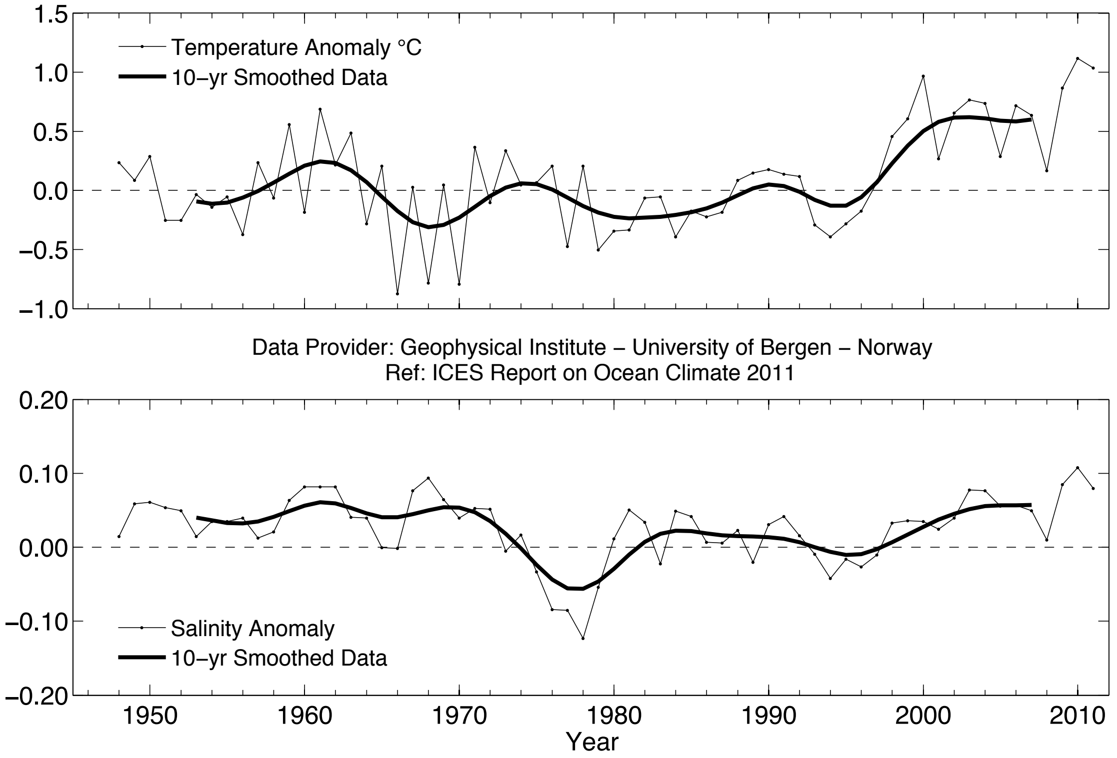


Figure 66.
Area 10 – Norwegian Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) at 50 m at Ocean Weather Station "M" (66°N 2°E).

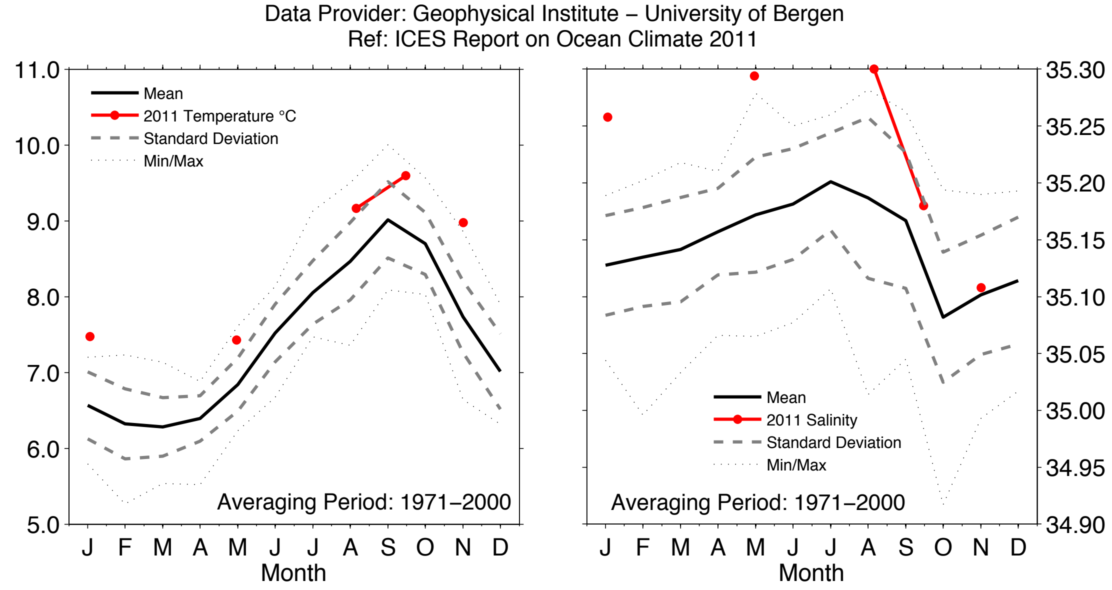


Figure 67.
Area 10 – Norwegian Sea. 2011 monthly temperature (left panel) and salinity (right panel) at 50 m at Ocean Weather Station "M" (66°N 2°E).

4.15 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, CAUSING HIGH VARIABILITY IN HEAT CONTENT AND ICE COVERAGE OF THE REGION.

In 1996 and 1997, 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. From March 1998, temperature in the western Barents Sea increased to just above average, whereas temperature in the eastern part remained below 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. Since then, temperature has remained above average.

The temperature of Atlantic waters in the Barents Sea was generally 0.1–1.1°C higher than average throughout 2011, depending on time and location. Temperature anomalies increased by the end of the year. During most of 2011, salinity at the Kola Section was higher than both the averages of 2011 (by 0.05–0.10) and of 2010. In October–December, salinity anomalies decreased, especially in coastal waters, where negative anomalies (down to –0.06) were evident in November and December. In the Kola Section (0–200 m), the 2011 annual mean temperature was about 0.3°C higher than normal. This is typical of warm years and lower than observed in 2010. Annual mean salinity was higher than both the average and that of 2010.

In August–September 2011, surface waters in most of the Barents Sea were 1.1–1.9°C warmer than usual and 1.7–2.6°C warmer than in 2010. The only area with negative surface temperature anomalies was west of the Spitsbergen Archipelago. Arctic waters were, as usual, most dominant at 50 m north of 76°N. The 50 m temperatures were mainly higher (by 0.1–0.8°C) than normal, but lower (by 0.1–1.3°C) than in 2010. At 100 m depth and close to the bottom, only small areas with temperatures below –1°C were observed. Temperatures below 100 m were, in general, close to those in 2010, and still above the long-term mean (by 0.2–0.7°C) in most of the Barents Sea. Throughout 2011, ice coverage of the Barents Sea was lower than the long-term average. Compared to 2010, it was lower in spring and at the end of 2011 and above or close to that in 2010 for the remainder of 2011.

The volume flux into the Barents Sea varies with periods of several years, and was significantly lower during 1997–2002 than during 2003–2006. In 2006, the volume flux was at a maximum during winter and very low during autumn. After 2006, the inflow has been relatively low, particularly during spring/summer. There has been, however, a weak increasing trend since 2009, and the volume flux during the first half of 2011 was close to the 1997–2011 mean. The dataseries presently stops in summer 2011, thus no information about autumn and early winter 2011 is available. On annual time-scales, the volume flux and temperature in the inflowing Atlantic Water does not vary in syncrony, and temperature has shown a declining trend since 2006, which continued into 2011. Thus, since 2009, temperatures have decreased, while the volume flux has weakly increased.

Water temperature in the Barents Sea in 2012 is expected to be typical of warm years and similar to that in 2011. In 2013, it is expected to decrease from the typical of warm years to the typical of normal years, and will probably average 0.2°C lower than in 2011.

ICE COVERAGE OF THE BARENTS SEA WAS LOWER THAN THE LONG-TERM AVERAGE.

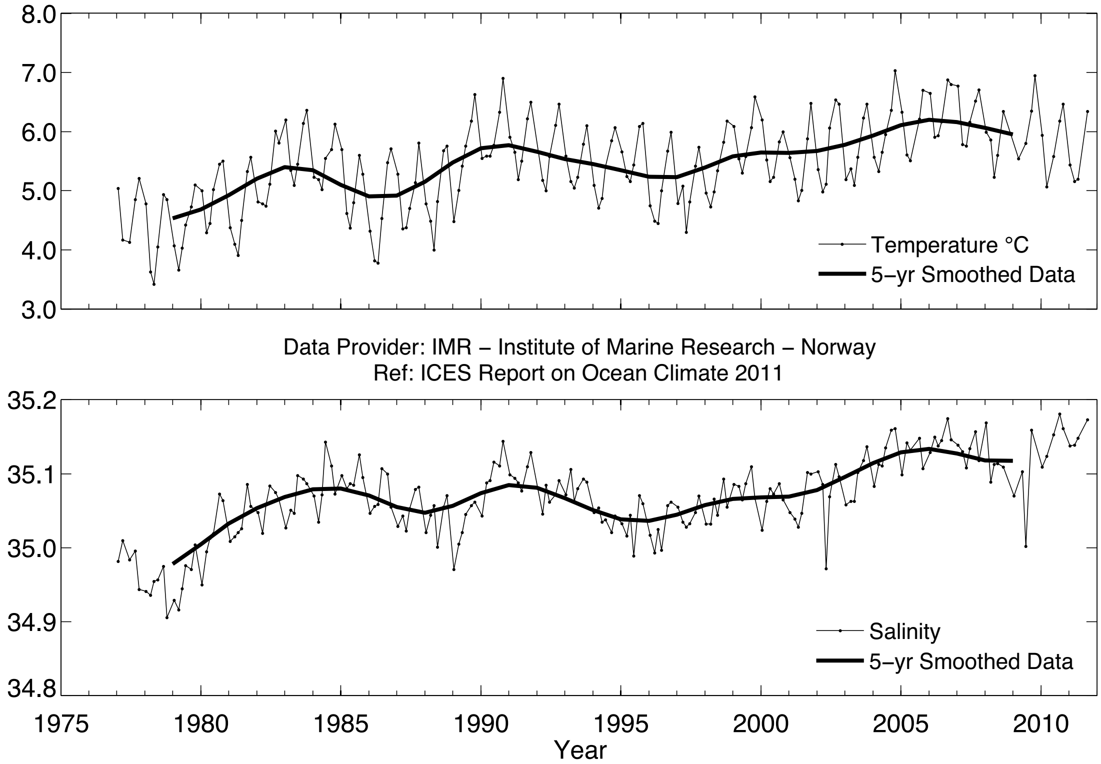


Figure 68.
Area 11 – Barents Sea. Temperature (upper panel) and salinity (lower panel) in the Fugløya–Bear Island Section.

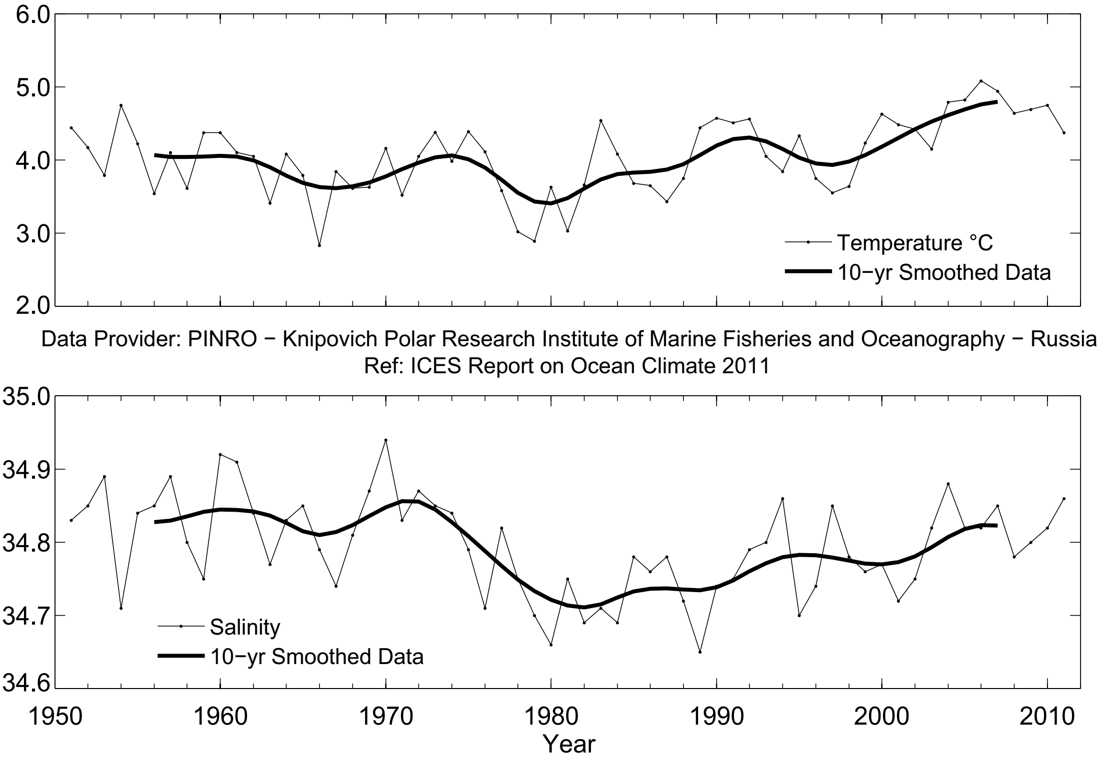


Figure 69.
Area 11 – Barents Sea. Temperature (upper panel) and salinity (lower panel) in the Kola Section (0–200 m).

4.16 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 (AW) ENTERS THE ARCTIC (THE OTHER IS THE BARENTS SEA). THE AW IS CARRIED NORTHWARDS BY THE WEST SPITSBERGEN CURRENT, AND VOLUME AND HEAT FLUXES EXHIBIT STRONG SEASONAL AND INTERANNUAL VARIATIONS. A SIGNIFICANT PART OF THE AW ALSO RECIRCULATES WITHIN FRAM STRAIT AND RETURNS SOUTHWARDS (RETURN ATLANTIC WATER). POLAR WATER FROM THE ARCTIC OCEAN FLOWS SOUTH IN THE EAST GREENLAND CURRENT AND AFFECTS WATER MASSES IN THE NORDIC SEAS AND NORTH ATLANTIC.

Since the Greenland Sea section at 75°N was not measured in 2011, the most recent data originate from 2010. In 2010, the temperature of Atlantic Water (AW) at the eastern rim of the Greenland Sea (along the 75°N section, between 10° and 13°E), was close to the long-term mean. A significant increase in salinity was observed compared with 2008 and, since 2004, the salinity of AW has remained higher than its long-term average. At the western rim of the Greenland Sea, the temperature of Return Atlantic Water (RAW) was slightly lower in 2010 than in 2009, whereas salinity remained similar to the 2009 value. Both values were close to their long-term means. In the Greenland Gyre, the interface with enhanced temperature and salinity gradients has steadily descended (by more than 1000 m) since the beginning of measurements in 1993. In recent years, the hydrographic situation in the Greenland Sea has been characterized by the increasing and overwhelming influence of AW inflow. This trend continued in the western half of the Greenland Gyre during 2009, but was interrupted by a freshwater event in the eastern half. The mean salinity in the central Greenland Sea in summer 2010 suggests that the high-salinity intrusion into the gyre centre had already surpassed its maximum. There was a tendency towards fresher waters in the gyre centre, but salinity was still higher than before 2004.

In southern Fram Strait, record-high summer temperature for AW was observed in 2006, after which both temperature and salinity decreased rapidly in 2007 and 2008, before increasing again in summer 2009. In 2011, both temperature and salinity were above their 16-year means. Salinity exceeded its last maximum in 2006 and was the highest observed since the beginning of the time-series in 1996. Mean temperature at 200 m at the standard section along 76.50°N (spatially averaged between 9° and 12°E) was 3.80°C, thus 0.57°C higher than its long-term mean. Salinity reached 35.13, exceeding its 1996–2011 mean by 0.068. Both temperature and salinity trends for the 1996–2011 period were positive.

In northern Fram Strait, at the standard section along 78.83°N, three characteristic areas can be distinguished in relation to the main flows: the West Spitsbergen Current (WSC) between the shelf edge and 5°E, the Return Atlantic Current (RAC) between 3°W and 5°E, and the Polar Water in the East Greenland Current (EGC) between 3°W and the Greenland Shelf. Only in the WSC were the spatially averaged means of temperature and salinity higher in 2011 than in 2010, while in the RAC and EGC, they were lower than the year before. Decreases in temperature and salinity in the eastern RAC overcame an increase in both properties in the western part, so on average, the entire RAC was colder and less saline in 2011 than in 2010. Temperature in the EGC in 2011 slightly decreased in comparison to 2010, while spatially averaged salinity was significantly lower, mostly due to the thicker upper layer of Polar-origin water.

HIGH SALINITY WAS OBSERVED IN THE ATLANTIC INFLOW TO THE ARCTIC OCEAN AND IN THE ATLANTIC WATER RETURNING TO THE SOUTH.

In 2011, the AW layer in the West Spitsbergen Current above the slope was deeper compared to the previous year. Over the upper continental slope, the isotherm 0°C was deeper, reaching about 1000 m (compared to its average depth of 700 m in 2010). However, the amount of warm AW in the eastern recirculation area (between 1° and 5°E) decreased in 2011. Maximum temperature of the AW inflow in the WSC was higher in 2011 than in 2010, but AW recirculating directly in Fram Strait was colder than the year before. In summer 2011, temperatures of the Atlantic Water in the WSC core and in the offshore WSC branch were similar, rather than the normally warmer core. The offshore branch of WSC was pronounced and reached far into the central part of the strait (ca. 1°30′E). The recirculating Atlantic Water extended farther west than in previous years, and patches of AW warmer than 3°C were observed west of 3°W. The position of the Polar Front between the Arctic-derived Polar Water and Atlantic Water at the surface was slightly shifted eastward (from 3°W in 2010 to around 2°W in 2011). The Polar Water surface layer observed in 2011 was thicker than in the year before.

Salinity of the AW in 2011 was higher than in 2010, particularly in the West Spitsbergen Current and in the western recirculation part of Fram Strait. Salinity in 2011 was characterized by a dipole structure in the AW-derived layer. High salinity patterns in the WSC and in western Fram Strait were separated by the lower salinity in the eastern deep part of the Strait. This situation was significantly different than in 2010 when higher salinity was found in the continuous layer, almost reaching to the East Greenland continental slope. It may indicate that the direct recirculation in Fram Strait weakened in 2011, while the AW, which had entered the short loop around the Nansen Basin in 2006–2007, was now returning through the Strait towards the northern North Atlantic (showing also as the strongest temperature and salinity anomaly in reference to the long-term mean located in the upper 500 m in western Fram Strait). The warm patches of AW observed in western Fram Strait around 4°W were also characterized by high salinity, resulting in a strong halocline between polar- and Atlantic-origin waters over the continental slope east of Greenland.

Due to limited exchange of moorings in Fram Strait in 2011, the time-series of volume transport can only be updated for the West Spitsbergen Current. The winter-centred annual mean of the net volume transport in 2010–2011 was 6.0 Sv, the same as the long-term mean (2002–2009) and slightly higher than in 2009–2010 (5.6 Sv). The winter maximum in volume transport was lower than average, but in late winter/early spring, a strong inflow was observed in the WSC. Early summer volume transport in the WSC was relatively weak.

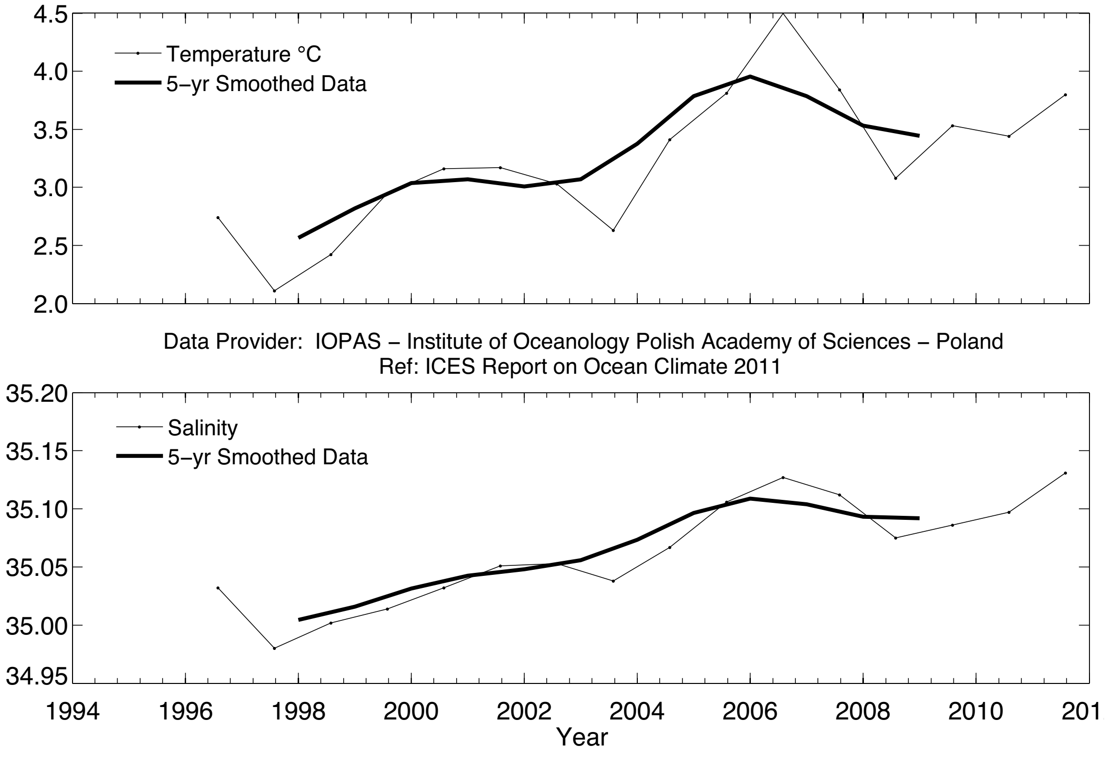
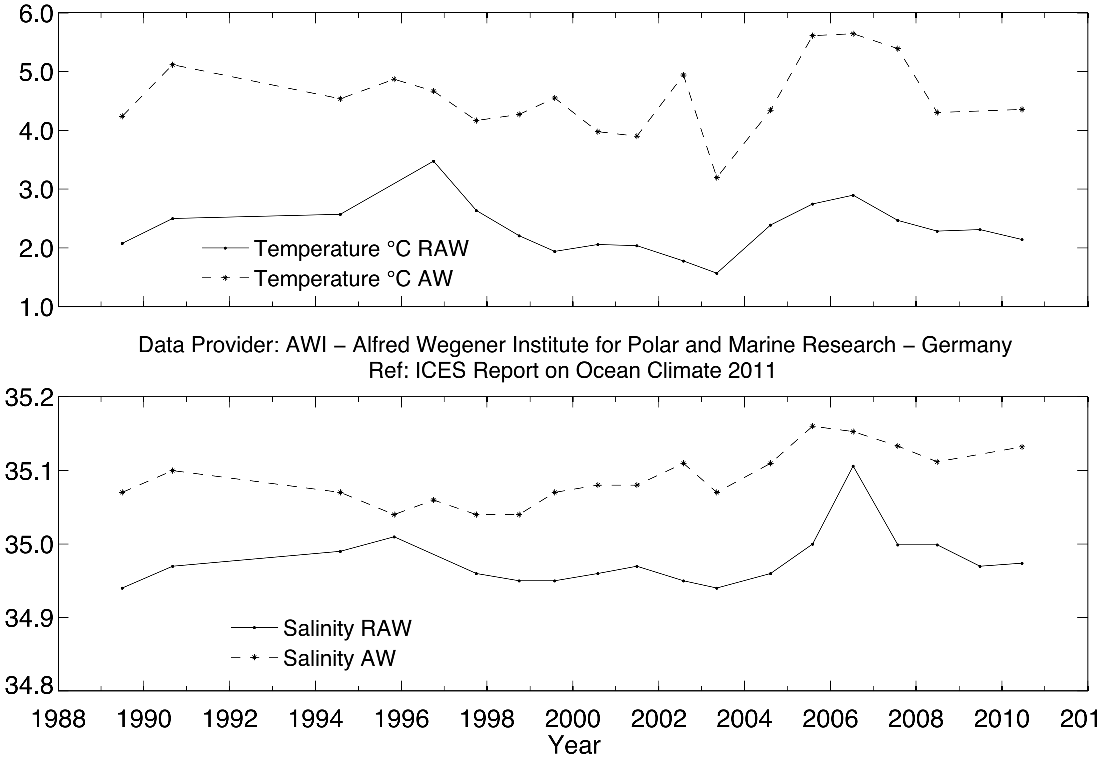
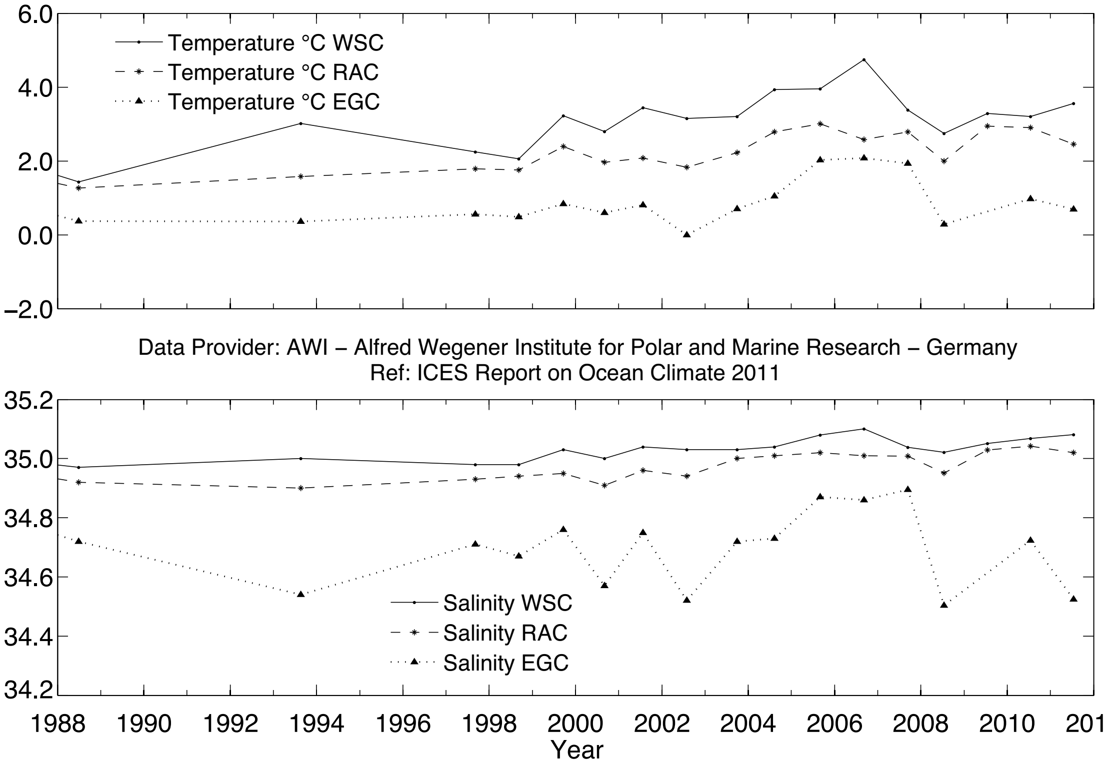


Figure 70.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) at 200 m in the Spitsbergen Section (76.50°N).



Data Provider: AWI – Alfred Wegener Institute for Polar and Marine Research – Germany
Ref: ICES Report on Ocean Climate 2011

Figure 71.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) of Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea Section at 75°N (data to 2010). AW properties are 50–150 m averages at 10–13°E. The RAW is characterized by temperature and salinity maxima below 50 m, averaged over three stations west of 11.5°W.



Data Provider: AWI – Alfred Wegener Institute for Polar and Marine Research – Germany
Ref: ICES Report on Ocean Climate 2011

Figure 72.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) in Fram Strait (78.83°N) at 50–500 m: in the West Spitsbergen Current (WSC; between the shelf edge and 5°E), in the Return Atlantic Current (RAC; between 3°W and 5°E), and in the Polar Water in the East Greenland Current (EGC; between 3°W and the Greenland Shelf).

Image courtesy of J. Wright, Marine Laboratory Scotland, UK.

5. DETAILED AREA DESCRIPTIONS, PART II: THE DEEP OCEAN

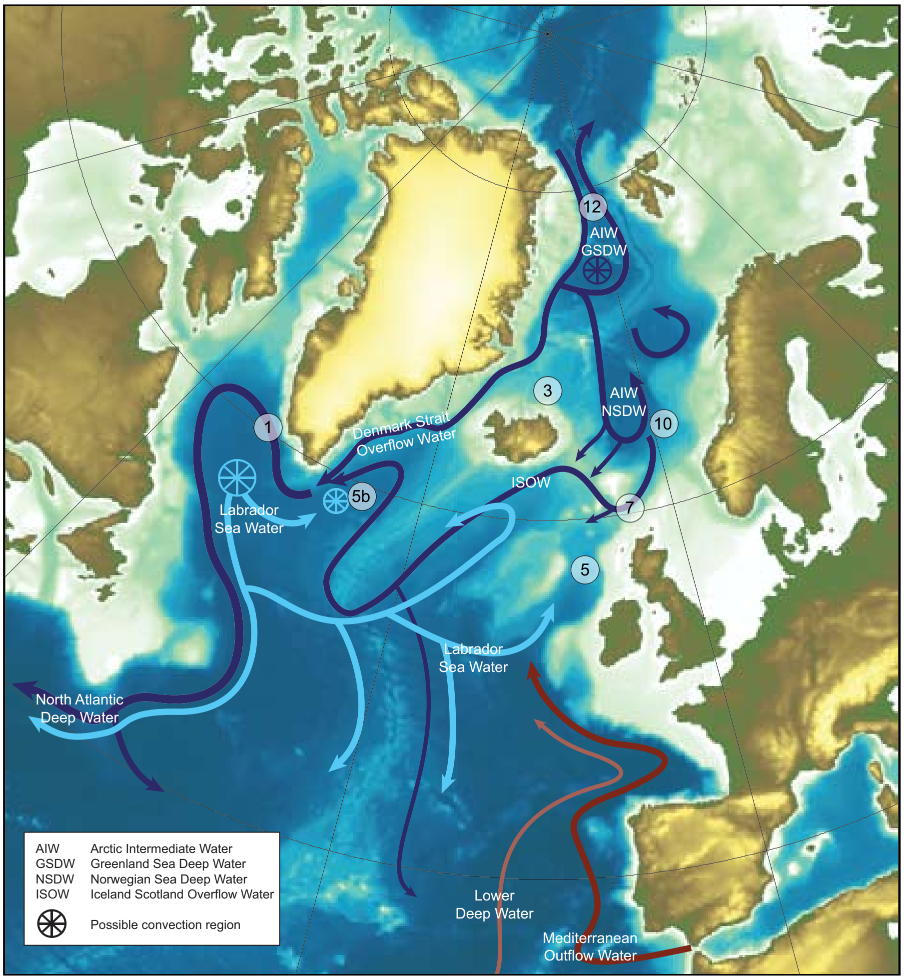
5.1 Introduction

In this section, we focus on the deeper waters of the Nordic seas and the North Atlantic, typically below 1000 m. The general circulation scheme and dominant water masses are given in Figure 73.

AT THE NORTHERN BOUNDARY OF OUR REGION OF INTEREST, THE COLD AND DENSE OUTFLOW FROM THE ARCTIC OCEAN ENTERS FRAM STRAIT AND REACHES THE GREENLAND SEA. THE OUTFLOW IS A MIXTURE OF EURASIAN BASIN AND CANADIAN BASIN DEEP WATERS AND UPPER POLAR DEEP WATER (UPDW). THE EURASIAN DEEP WATER FEEDS THE DENSEST WATER OF ALL NORDIC SEAS: THE GREENLAND SEA BOTTOM WATER. THE CANADIAN BASIN DEEP WATER AND UPDW SUPPLY THE ARCTIC INTERMEDIATE WATER IN THE GREENLAND SEA, AND THE UPDW ALSO INCLUDES PRODUCTS OF THE WINTER CONVECTION.

AT THE SOUTHERN BOUNDARY, OUTFLOW FROM THE NORTH ATLANTIC IN THE DEEP WESTERN BOUNDARY CURRENT IS FED BY COLD AND DENSE OVERFLOW WATERS AS WELL AS BY WATER FORMED IN THE LABRADOR SEA. THE DEEPEST AND DENSEST IS THE DENMARK STRAIT OVERFLOW WATER. THIS WATER MASS ORIGINATES IN THE ARCTIC INTERMEDIATE WATER PRODUCED IN THE GREENLAND AND ICELAND SEAS BY WINTER CONVECTION AND MIXING WITH SURROUNDING WATER MASSES. THE DENMARK STRAIT OVERFLOW WATER SINKS TO THE BOTTOM AS IT PASSES OVER THE DENMARK STRAIT SILL, VIGOROUSLY ENTRAINING AMBIENT WATER. DOWNSTREAM, IT IS OVERLAIN BY AN INTERMEDIATE WATER MASS, THE LABRADOR SEA WATER, FORMED BY DEEP WINTER CONVECTION IN THE LABRADOR SEA. THE MIDDLE LAYER OF THE DEEP, COLD-WATER EXPORT IN THE DEEP WESTERN BOUNDARY CURRENT IS SUPPLIED BY THE ICELAND–SCOTLAND OVERFLOW WATER, ORIGINATING IN WATER MASSES FORMED IN THE NORWEGIAN SEA (ARCTIC INTERMEDIATE WATER AND NORTH ATLANTIC DEEP WATER). PASSING THROUGH THE ICELANDIC BASIN, THE ICELAND–SCOTLAND OVERFLOW WATER ALSO ENTRAINS UPPER OCEAN WATER AND LABRADOR SEA WATER. THE DEEP ANTARCTIC BOTTOM WATER ENTERS THE NORTH ATLANTIC ON THE WESTERN SIDE, AND SOME OF THE LOWER DEEP WATER ACCOMPANIES THE INFLOW OF MEDITERRANEAN WATER ON THE EASTERN SIDE.

Figure 73.
Schematic circulation of the intermediate to deep waters in the Nordic seas and North Atlantic.



5.2 Nordic seas deep waters

The deep waters of the Greenland, Iceland, and Norwegian seas are all warming. The longest time-series (Norwegian Sea, Area 10) reveals warming since the mid-1980s; however, a slight decrease in temperature occurred in 2010–2011. Continuous warming has been observed in the Greenland Sea deep layer at 3000 m (Area 12, no data for 2011), and the temperature increase between 2009 and 2010 was slightly lower (0.01°C) than the average annual increase over the past five years (0.014°C). Warming in the Greenland Sea was accompanied by a year-to-year increase in salinity of 0.001. In the Iceland Sea, an increase in temperature in the depth range 1500–1800 m has been observed since the beginning of the time-series (early 1990s), and the temperature in 2011 continued to rise slowly. The long-term warming rates for the last decade are 0.134°C (Greenland Sea), 0.06°C (Norwegian Sea), and 0.064°C (Iceland Sea) per decade. The source of the warming is the deep outflow from the Arctic Ocean, a southward current of the Eurasian and Canadian Basin Deep Waters and the Upper Polar Deep Water found on the western side of Fram Strait at ca. 2000 m depth. The Greenland Sea Deep Water (GSDW) is warming fastest owing to its direct contact with this Arctic outflow, whereas the Iceland and Norwegian seas are warming more slowly, because they are products of the mixing of their own ambient waters with GSDW and Arctic outflow water.

The doming structure in the Greenland Gyre is being replaced by a two-layered water mass arrangement, after a cessation of deep convection. Since the beginning of measurements in 1993, the winter convection depth has varied between 700 and 1700 m, and has only been significantly deeper in small-scale convective eddies. In winter 2007/2008, the maximum convection depth was estimated to be 1700 m, deeper than the previous year (1200 m) and similar to the maxima observed during 2001/2002 and 2002/2003. The import of warm and saline Atlantic Water (AW) to the Greenland Sea is currently not balanced by an import of cool and fresh Polar Waters from the north. The AW, which dominates changes in the upper ocean, took over the former role of ice production as a source of salt and densification in the context of winter convection. The input of AW tends to prevent ice formation and to vertically homogenize the waters ventilated by convective processes. The GSDW formerly included a small admixture of surface freshwater through the convective process and, therefore, had a lower salinity than the Arctic outflow waters. The observed increase in GSDW salinity may be the result of the continued absence of deep convection and an increased presence of AW in the upper layer.

In summer 2009, in the Greenland Gyre, the usual relatively homogenous pool, mixed by previous winter convection, was replaced by a distribution of water masses with higher salinity in the western part of the gyre and fresher waters in its eastern part. This made it difficult to compose a reliable mean profile for the gyre centre and, consequently, because of the lack of a 2009 mean profile for comparison with the 2010 mean profile, it was not possible to provide an unambiguous estimate of the convection depth in winter 2009/2010. Therefore, two possible convection depths were obtained (see Figure 77), depending on a choice of the 2009 mean profile. No data are available for winter 2010/2011.

It is unclear whether there has been any corresponding salinity trend in either the Norwegian or the Iceland Sea Deep Waters in recent decades. After some decrease in the early 1990s, salinity in Norwegian Sea deep basins has remained relatively stable for the past decade. In the Iceland Sea, salinity in the deep layer has been decreasing slightly since 2009 (after being stable for nearly a decade), but in 2011, there was a slight increase.

Figure 74.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) at 3000 m in the Greenland Sea Section at 75°N (data to 2010).

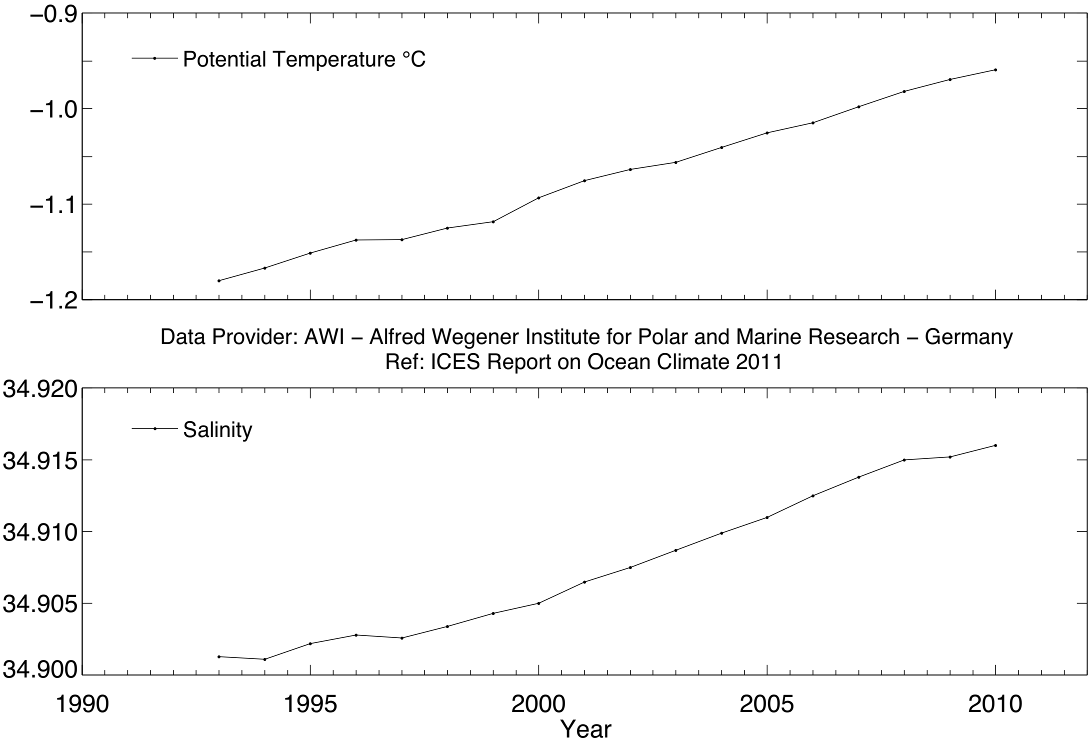
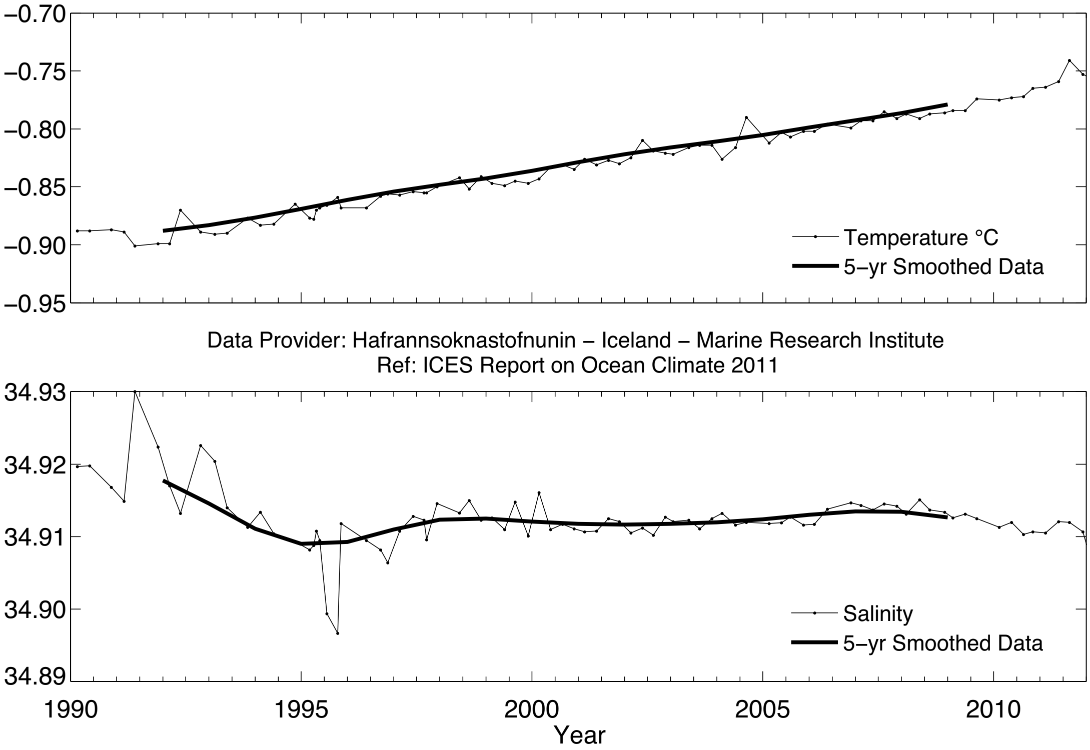


Figure 75.
Area 3 – Icelandic waters. Temperature at 1500–1800 m in the Iceland Sea (68°N 12.67°W).



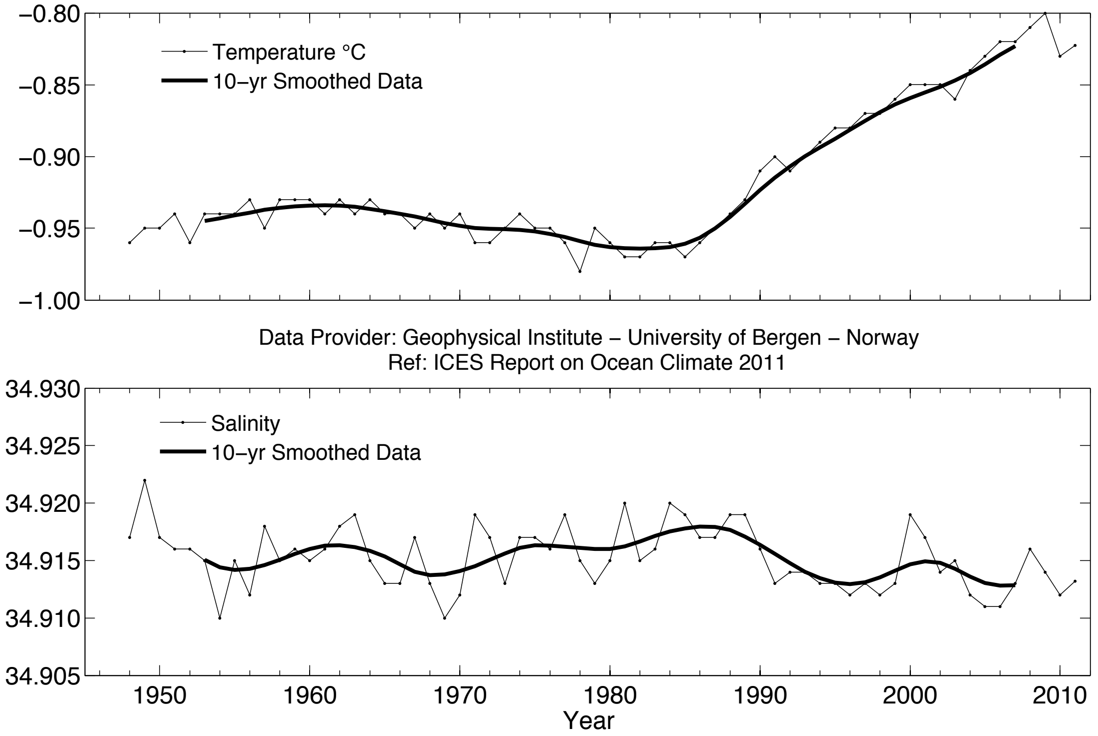


Figure 76.
Area 10 – Norwegian Sea. Temperature (upper panel) and salinity (lower panel) at 2000 m at Ocean Weather Station "M" (66°N 2°E).

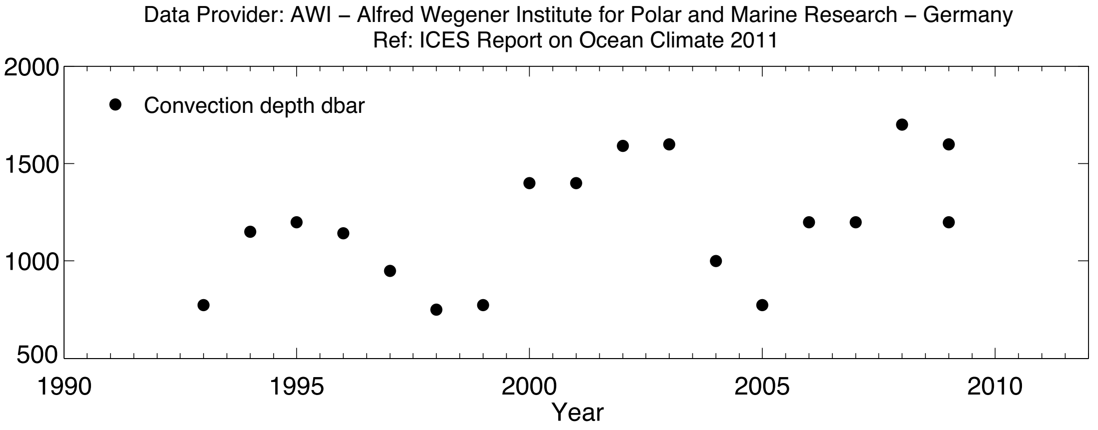


Figure 77.
Area 12 – Greenland Sea and Fram Strait. Winter convection depths in the Greenland Sea Section at 75°N (data to 2009; note that due to the unambiguous convection depth in winter 2009/2010 two values are provided for this period).

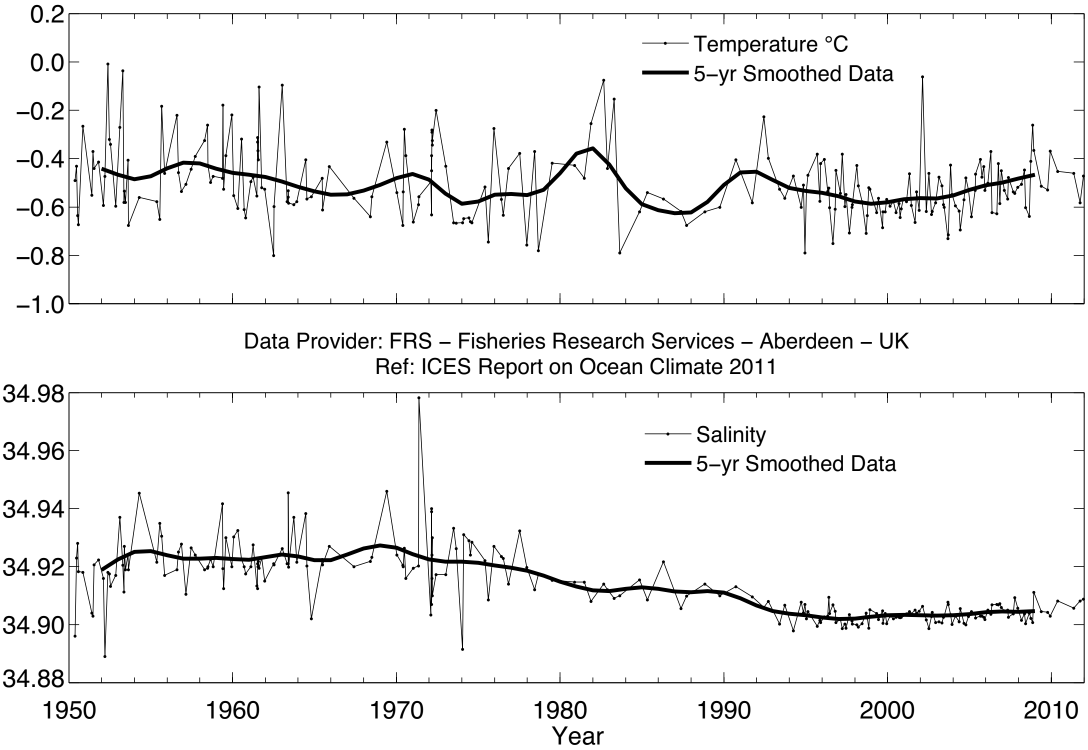
5.3 North Atlantic deep waters

In the deep layers of the Faroe–Shetland Channel (Area 7), the properties at 800 m reflect those of the Norwegian Sea Deep Water as it passes through the Channel back into the North Atlantic. After a period of decline in the 1990s, temperature has increased since 2000, but still remains lower than the highest temperatures observed in the 1950s, 1960s, and early 1980s. The relatively stable salinity in the first period of measurements (1950 to mid-1970s) was followed by a slow decline over the next two decades; since the mid-1990s, it has been more stable.

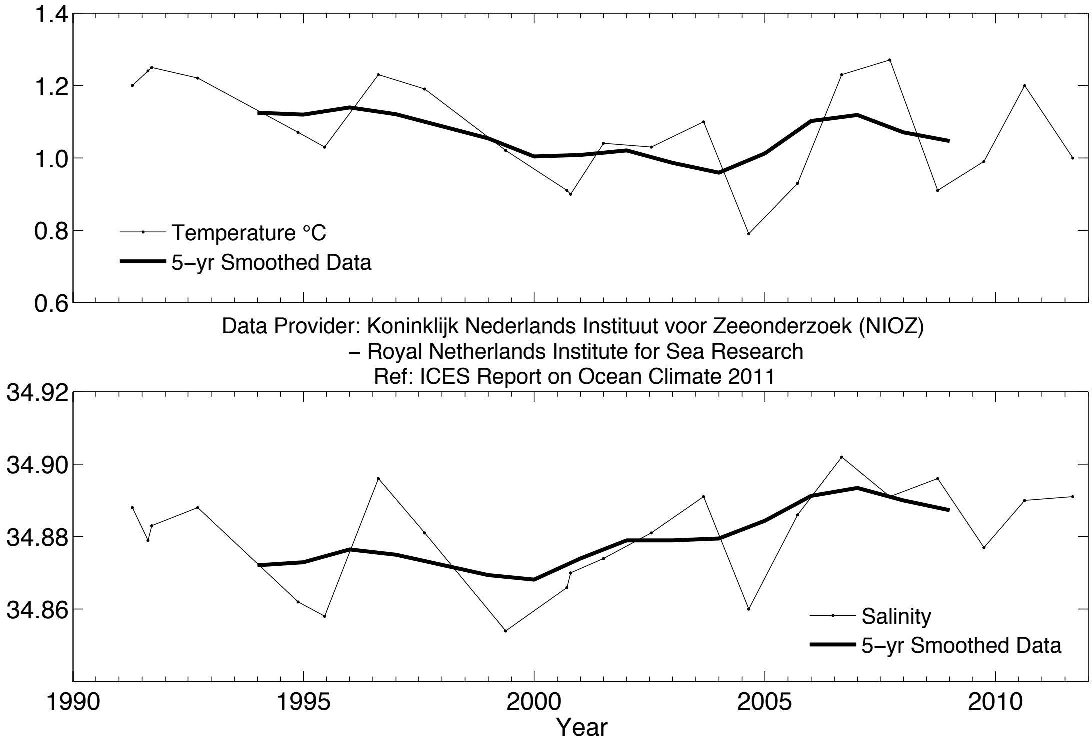
Salinity and potential temperature of the Denmark Strait Overflow Water (DSOW) near Cape Farewell showed correlated interannual variations between 1991 and 2007 (correlation = 0.7). However, after 2007, changes in temperature and salinity of the DSOW broke this rule, and the correlation was reduced to about 0.5. This implies that less than 30% of the variance in the salinity can be explained by the variance of the temperature variability. Density of the DSOW hardly changes on long time-scales. Measurements with moored instrumentation have demonstrated that temperature and density mainly vary at an annual time-scale, possibly forced by wind-driven processes near Denmark Strait.

In the North Atlantic Deep Water (NADW), monitored at Cape Desolation Station 3 (at 2000 m), which represents the West Greenland and Deep Western Boundary currents, an increase in temperature and salinity was observed between 1984 and 1989, followed by a cooling and freshening trend that continued until the late 1990s, when temperature and salinity reached their minima in 1998 and 1997, respectively. Since 1997, an increase in temperature (~0.3°C decade−1) and, since 1998, an increase in salinity (~0.05 decade−1) have been observed again. The positive trends were observed until 2007, after which the temperature of the NADW has been decreasing and salinity has remained relatively stable. This decrease in the NADW temperature continued in 2010, and temperature returned to its long-term mean value. In 2011, temperature increased again and reached the value of 2007. Salinity showed only a tiny decrease since 2008, but was still above average.

Figure 78.
Area 7 – Faroe–Shetland Channel. Temperature (upper panel) and salinity (lower panel) at 800 m.

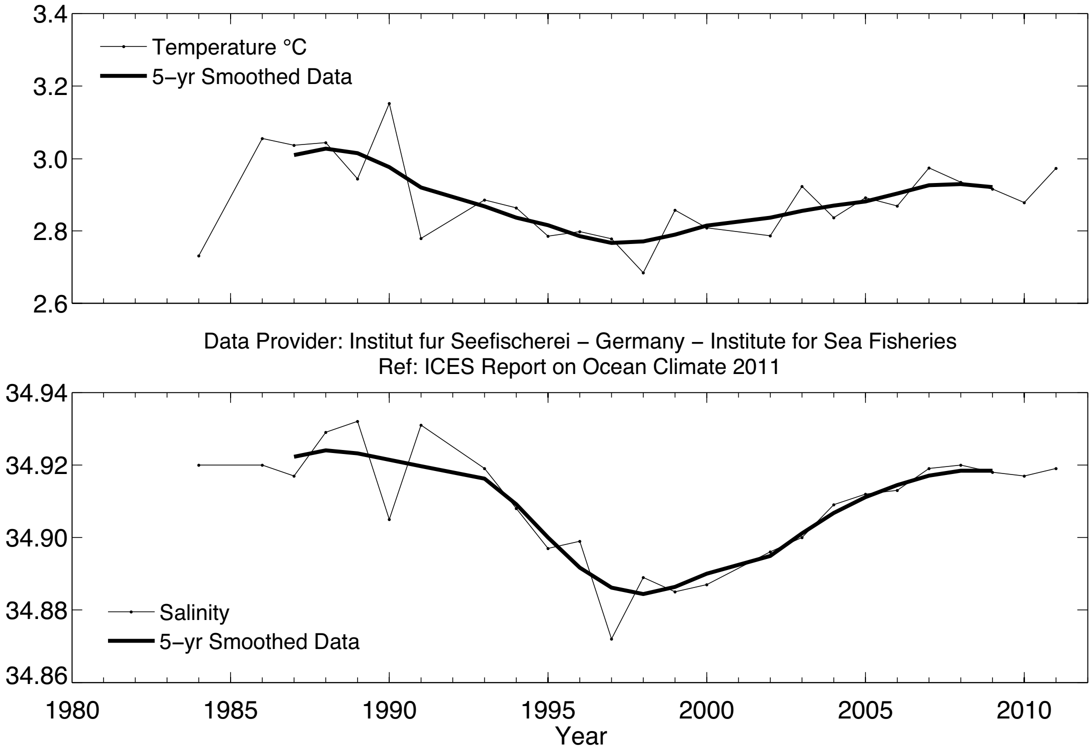


Data Provider: FRS – Fisheries Research Services – Aberdeen – UK
Ref: ICES Report on Ocean Climate 2011



Data Provider: Koninklijk Nederlands Instituut voor Zeeonderzoek (NIOZ)
– Royal Netherlands Institute for Sea Research
Ref: ICES Report on Ocean Climate 2011

Figure 79.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) in Denmark Strait Overflow Water on the East Greenland Slope.



Data Provider: Institut fur Seefischerei – Germany – Institute for Sea Fisheries
Ref: ICES Report on Ocean Climate 2011

Figure 80.
Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 2000 m at Cape Desolation Station 3 in the West Greenland Current.

5.4 North Atlantic intermediate waters

In the Labrador Sea, temperature and salinity, averaged between 1000 and 1800 m, have been continuously increasing since their minima in the early 1990s. In 2011, temperature reached its previous maximum observed in 1970. Salinity was still lower than the record high in 1970, but since 2007, it has remained higher than its long-term average.

A cold and low-salinity core was observed between 1600 and 2000 m in the central Irminger Sea (Area 5b) during the early 1990s. This was the result of the presence of deep Labrador Sea Water (LSW) formed in the period 1988–1995. Since summer 1996, temperature and salinity of this LSW core have been increasing as a result of mixing with surrounding water masses. The increases levelled off in 2001–2002, then slowly began to rise again. In 2009, temperature reached a minimum as a result of the temporary presence of a cold LSW core formed in 2008. The highest temperature and salinity since 1990 were observed in 2011.

In the Rockall Trough (Area 5), the dominant water mass below about 1500 m is Labrador Sea Water (LSW), which usually has its maximum concentration located between 1700 and 2000 m. East of the Anton Dohrn Seamount, this LSW peak tends to be characterized by a minimum in salinity and potential vorticity, although its patchy temporal distribution (possibly due to aliasing of mesoscale eddies) results in a noisy year-on-year signal. Potential temperature (3.47°C) and salinity (34.926) remain cooler and fresher than the long-term mean values. Nevertheless, the temperature of LSW since 2009 is still about 0.2°C warmer than the coolest period since records began in 1975 (from 2001 to 2007).

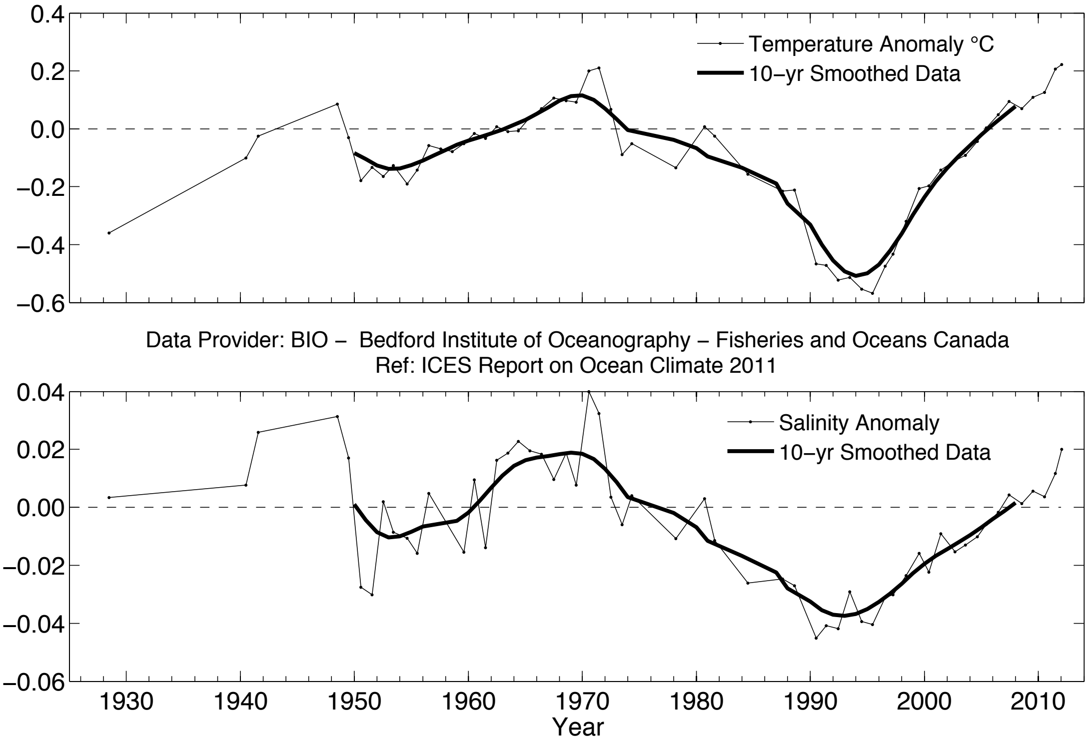
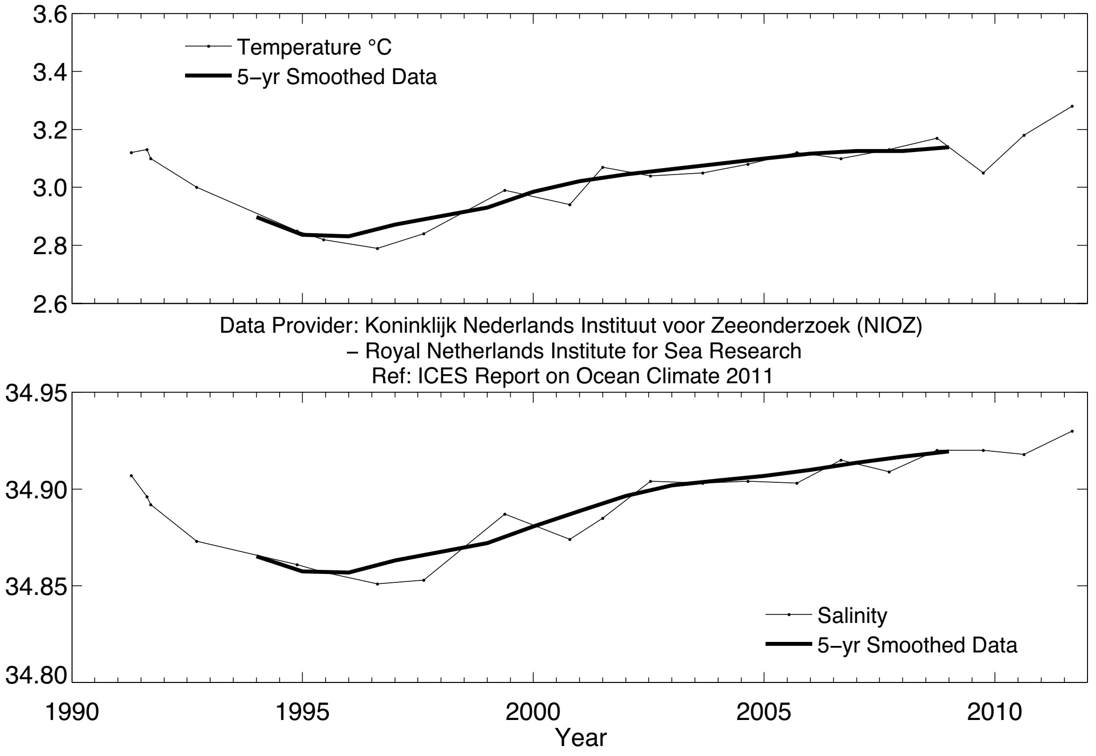


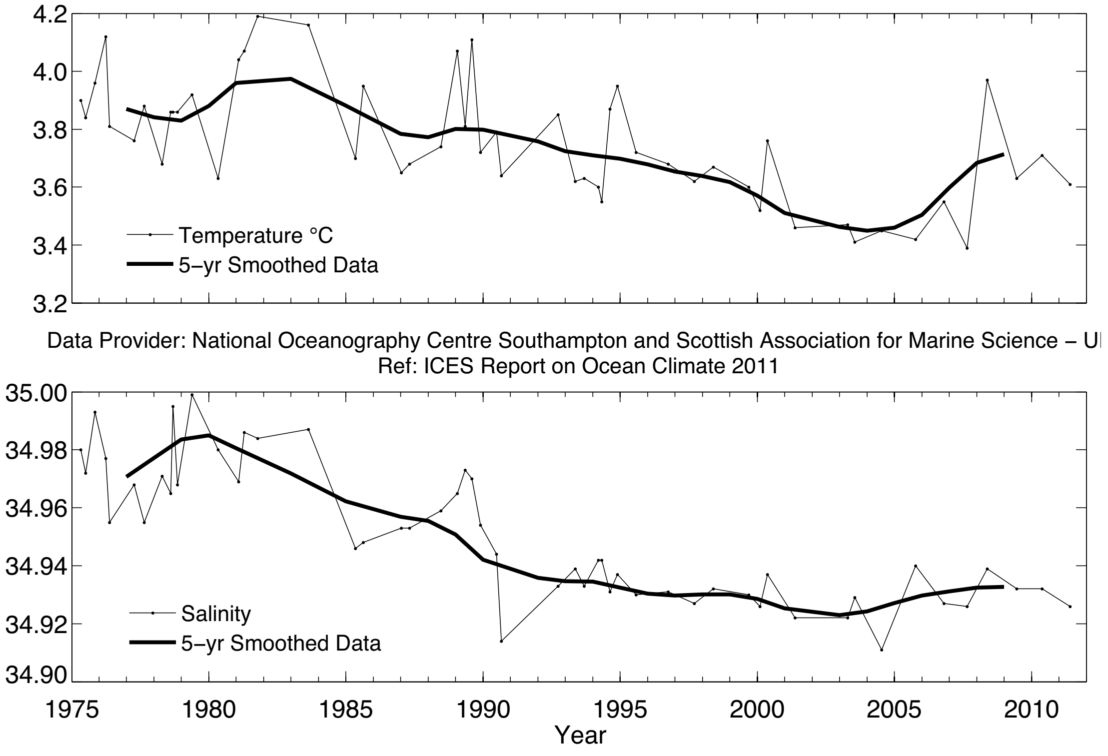
Figure 81.
Area 2b – Labrador Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) of Labrador Sea Water (averaged over 1000–1800 m).



Data Provider: Koninklijk Nederlands Instituut voor Zeeonderzoek (NIOZ)
– Royal Netherlands Institute for Sea Research
Ref: ICES Report on Ocean Climate 2011

Figure 82.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (averaged over 1600–2000 m).

THE TEMPERATURE OF LABRADOR SEA WATER IN THE LABRADOR AND IRMINGER SEAS HAS BEEN INCREASING SINCE THE EARLY 1990S AND, IN 2011, REACHED A LEVEL ONLY PREVIOUSLY OBSERVED IN 1970.



Data Provider: National Oceanography Centre Southampton and Scottish Association for Marine Science – U
Ref: ICES Report on Ocean Climate 2011

Figure 83.
Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (averaged over 1800–2000 m).

Reference

Gaillard, F., Autret, E., Thierry, V., Galaup, P., Coatanoan, C., and Loubrieu, T. 2009. Quality control of large Argo data sets. Journal of Atmospheric and Oceanic Technology, 26: 337–351.

6. CONTACT INFORMATION

Area	Area name	Figures	Time-series	Contact	Institute
1	West Greenland	14	Nuuk – air temperature	Boris Cisewski (boris.cisewski@vti.bund.de)	Danish Meteorological Institute, Copenhagen, Denmark, and Institut für Seefischerei (Institute for Sea Fisheries), Germany
1	West Greenland	15, 16, 80	Fylla Section and Cape Desolation Section	Boris Cisewski (boris.cisewski@vti.bund.de)	Danish Meteorological Institute, Copenhagen, Denmark, and Institut für Seefischerei (Institute for Sea Fisheries), Germany
2	Northwest Atlantic	17, 18, 19	Sable Island air temperature, Cabot Strait sea ice, Misaine Bank, Emerald Bank	David Hebert (David.Hebert@dfo-mpo.gc.ca)	BIO (Bedford Institute of Oceanography), Department of Fisheries and Oceans, Canada
2	Northwest Atlantic	20, 21	Newfoundland and Labrador sea ice, Cartwright air temperature, Station 27 CIL	Eugene Colbourne (eugene.colbourne@dfo-mpo.gc.ca)	Northwest Atlantic Fisheries Centre, Canada
2b	Labrador Sea	22, 23, 24, 81	Section AR7W	Igor Yashayaev (Igor.Yashayaev@dfo-mpo.gc.ca)	BIO (Bedford Institute of Oceanography), Department of Fisheries and Oceans, Canada
2c	Mid-Atlantic Bight	25, 26, 27, 28, 29, 30	Central MAB and Gulf of Maine, Georges Bank	Paula Fratantoni (paula.fratantoni@noaa.gov)	Woods Hole Oceanographic Institution and NOAA Fisheries, NEFSC, Oceanography Branch, USA
3	Icelandic waters	31, 32, 33, 34, 35, 47, 76	Reykjavik and Akureyri air temperature, Siglunes stations 2–4, Selvogsbanki Station 5, Langanes stations 2–6, Faxafloi Station 9, Icelandic Deep Water (1800 m)	Hedinn Valdimarsson (hv@hafro.is)	Hafrannsoknastofnunin (Marine Research Institute), Iceland
4	Bay of Biscay	36	San Sebastian air and water temperature	Victor Valencia (vvalencia@pas.azti.es)	AZTI, Aquarium of San Sebastian (SOG) and Igeldo Meteorological Observatory (INM) in San Sebastian, Spain
4	Bay of Biscay	37, 38	Santander Station 6 (shelf break)	Cesar Pola (cesar.pola@gi.ieo.es)	Instituto Español de Oceanografía (IEO, Spanish Institute of Oceanography), Spain
4b	NW European Continental Shelf	39, 40	Astan Section, Point 33	Pascal Morin (pmorin@sb-roscoff.fr)	CNRS, Observatoire Oceanologique de Roscoff and IFREMER, France
4b	NW European	41, 42	Western Channel Observatory, Station E1 Continental Shelf	Tim J. Smyth (tjsm@pml.ac.uk)	Marine Biological Association and Plymouth Marine Laboratory, UK
4b	NW European Continental Shelf	43	Malin Head Weather Station	Glenn Nolan (Glenn.Nolan@marine.ie)	Marine Institute/Met Eireann, Ireland
4b	NW European Continental Shelf	44	M3 Marine Weather Buoy	Sheena Fennell (Sheena.Fennell@marine.ie)	Marine Institute/Met Eireann, Ireland
5	Rockall Trough	45, 83	Ellett Line	N. Penny Holliday (nph@noc.soton.ac.uk)	National Oceanography Centre, Southampton and Scottish Association for Marine Science, UK
5b	Irminger Sea	46, 79, 82	Central Irminger Sea, East Greenland Slope	Hendrik M. van Aken (aken@nioz.nl)	Koninklijk Nederlands Instituut voor Zeeonderzoek (NIOZ, Royal Netherlands Institute for Sea Research), Netherlands
6	Faroe Bank Channel	48, 49, 50	Faroe Bank Channel – West Faroe Islands, Faroe Coastal Oyrargjog, Faroe Current – North Faroe Islands	Karin Margretha H. Larsen (KarinL@hav.fo)	Havstovan (Faroe Marine Research Institute), Faroe Islands

Area	Area name	Figures	Time-series	Contact	Institute
7	Faroe Shetland Channel	51, 52, 78	Faroe Shetland Channel – Faroe Shelf and Shetland Shelf, deep waters (800 m)	Sarah Hughes (s.hughes@marlab.ac.uk)	Fisheries Research Services (FRS, Aberdeen), UK
8&9	North Sea	53	North Sea Utsire, Modelled North Sea Inflow	Jon Albretsen (jon.albretsen@imr.no) Solfrid Hjollo (solfrid.hjollo@imr.no)	Institute of Marine Research (IMR), Norway
8&9	North Sea	54	Fair Isle Current Water	Sarah Hughes (s.hughes@marlab.ac.uk)	Fisheries Research Services (FRS, Aberdeen), UK
8&9	North Sea	55, 56	Helgoland Roads – coastal waters – German Bight, North Sea	Karen Wiltshire (Karen.Wiltshire@awi.de)	Alfred Wegener Institute for Polar and Marine Research (AWI)/Biologische Anstalt Helgoland (BAH), Germany
8&9	North Sea	57	Felixstowe – Rotterdam Section average (52°N)	Stephen Dye (stephen.dye@cefas.co.uk)	Centre for Environment, Fisheries and Aquaculture Science (CEFAS), UK
8&9	North Sea	58	Sea surface temperature – North Sea average	Peter Loewe (peter.loewe@bsh.de)	Bundesamt für Seeschifffahrt und Hydrographie (BSH), Germany
9b	Baltic Sea	59, 60, 62	Station BY5, Baltic Proper, east of Gotland, and observed ice extent	Karin Borenas (karin.borenas@smhi.se)	Swedish Meteorological and Hydrological Institute (SMHI), Sweden
9b	Baltic Sea	61, 62	Stations SR5 and LL7	Pekka Alenius (pekka.alenius@fimr.fi)	Finnish Institute of Marine Research (FIMR), Finland
10	Norwegian Sea	63, 64, 65	Svinøy, Gimsøy, and Sørkapp sections	Kjell Arne Mork (kjell.arne.mork@imr.no)	Institute of Marine Research (IMR), Norway
10	Norwegian Sea	66, 67, 77	Ocean Weather Station Mike	Svein Østerhus (Svein.Osterhus@gfi.uib.no)	Geophysical Institute, University of Bergen, Norway
11	Barents Sea	68	Fugløya – Bear Island Section, Western Barents Sea	Randi Ingvaldsen (randi.ingvaldsen@imr.no)	Institute of Marine Research (IMR), Norway
11	Barents Sea	69	Kola Section, Eastern Barents Sea	Oleg V. Titov (titov@pinro.ru)	Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Russia
12	Greenland Sea and Fram Strait	70	Greenland Sea Section N, west of Spitsbergen (76.5°N)	Waldemar Walczowski (walczows@iopan.gda.pl)	Institute of Oceanology, Polish Academy of Sciences (IOPAS), Poland
12	Greenland Sea and Fram Strait	71, 74, 75	Greenland Sea Section 75°N, Greenland Gyre convection depth and deep waters (3000 m)	Gereon Budeus (Gereon.Budeus@awi.de)	Alfred Wegener Institute for Polar and Marine Research (AWI), Germany
12	Greenland Sea and Fram Strait	72	Fram Strait: West Spitsbergen Current, Return Atlantic Current, and East Greenland Current	Agnieszka Beszczynska-Möller (Agnieszka.Beszczynska-Moeller@awi.de)	Alfred Wegener Institute for Polar and Marine Research (AWI), Germany

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