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ICES Report on Ocean Climate 2012

Prepared by the Working Group on Oceanic Hydrography

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Rapport des Recherches Collectives

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Editors

Agnieszka Beszczynska-Möller and Stephen R. Dye

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

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Cover image.
The Jumeaux rocks in the Bay of Biscay. © Sabrina Jarry

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

CONTENTS

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 2012 as well as observed trends over a minimum of the past decade. In the first section 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/community/groups/Pages/WGOH.aspx. The group has recently made the many of the datasets available through a new web tool at http://ocean.ices.dk/iroc.

1.1 Highlights of the North Atlantic for 2012

- Temperatures and salinities in the Faroe Bank Channel decreased in 2012 and are now as low as in 2002.
- Temperature and salinity were above average in the Norwegian Sea in 2012.
- Annual mean temperature of Atlantic waters in the Kola Section (Barents Sea) set a new record high in 2012.
- Dry weather and inflow from the south led to a repeat of the high salinities on the shelf and slope in the Bay of Biscay seen in 2011.
- Upper layers of the northwestern North Atlantic were particularly warm in summer 2012.
- Near-surface salinity in the Greenland Sea and along the pathway of the East Greenland Current between Fram Strait and Cape Farewell were high in 2012.
- Surface water of the central Subpolar Gyre appears to be freshening.

1.2 Highlights of the North Atlantic atmosphere in winter 2011/2012

- The NAO index in winter 2011/2012 was the strongest positive value since 1994/1995.
- Surface air temperatures were near average throughout most of the region and were above average over the Greenland, Norwegian, and Barents seas and also over the northeast US and Canadian shelf south of Newfoundland. Air temperature over the central Labrador Sea was only slightly colder than average despite a strong NAO positive.
- Mean winds were weaker than normal across most of the North Atlantic south of Newfoundland and Ireland and also over the Denmark Strait and Iceland. They were particularly weak between the Azores and northern Spain. There was a band of higher-than-average windspeeds between the Faroes and the Labrador Sea.

1.3 Outlook for the North Atlantic atmosphere in winter 2012/2013

We include, for the first time, an initial assessment of the North Atlantic atmosphere at the end of the IROC year. Winter 2012/2013 had conditions indicating a NAO negative index with weakened windspeed across the Nordic seas, Rockall Trough, North Sea, and the central Subpolar Gyre, and strengthened winds at the latitude of the Azores. Air temperatures were cold over much of northwestern Europe and warm over the Labrador Sea.

NORTH ATLANTIC UPPER OCEAN TEMPERATURE: OVERVIEW

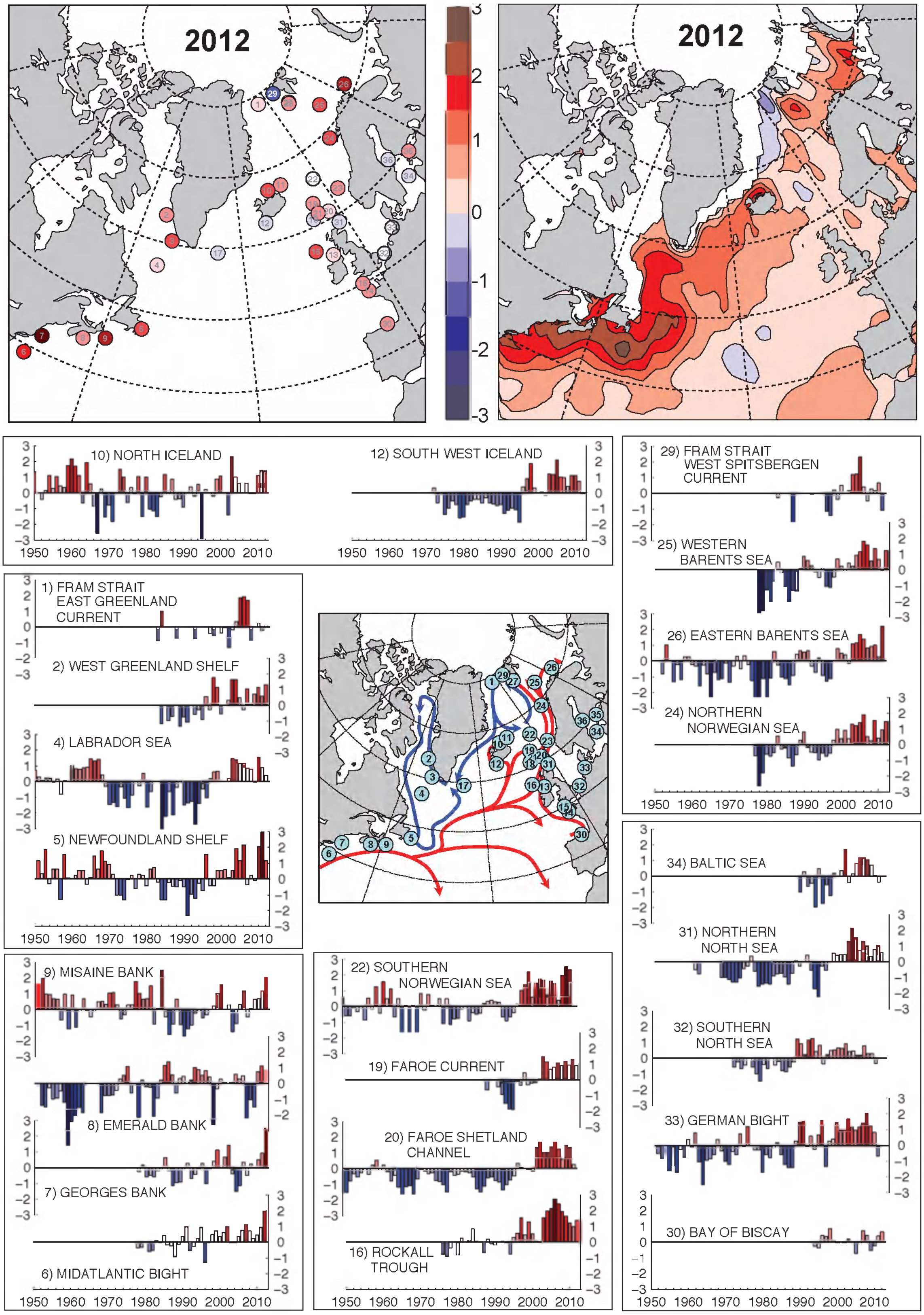


Figure 1.

Upper ocean temperature anomalies at selected locations across the North Atlantic. The anomalies are normalized with respect to the standard deviation (s.d.) (s.d., i.e. a value of +2 indicates 2 s.d. above normal). Upper panels: maps of conditions in 2012; (left) data from in situ *observations; (right) 2012 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

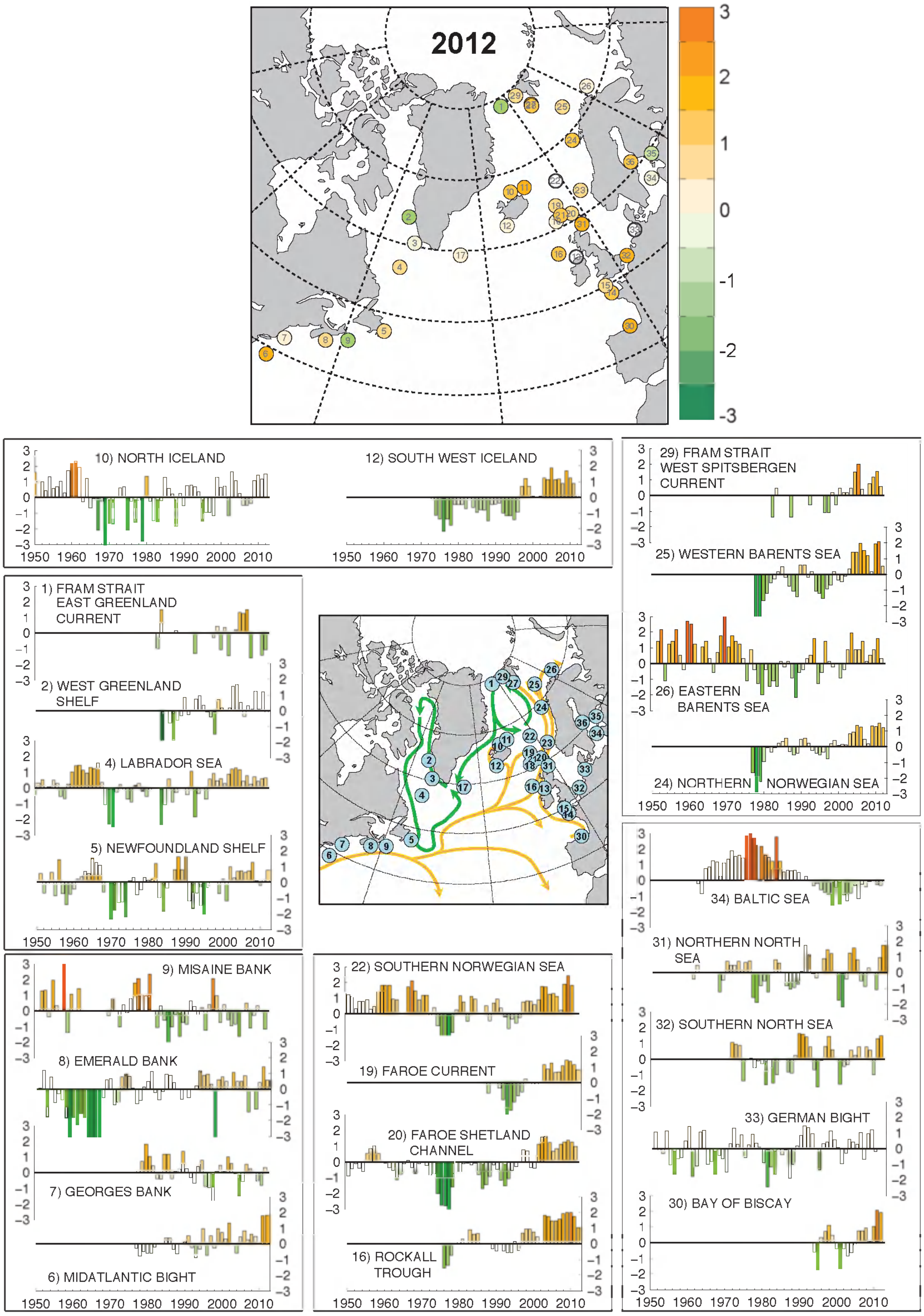


Figure 2.

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 s.d. (e.g. a value of +2 indicates 2 s.d. above normal). Upper panel: map of conditions in 2012. 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 2012

In this section we summarize the conditions in the upper layers of the North Atlantic during 2012, 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 s.d. of the data during 1981–2010 (or the closest time period available). A value of +2 thus represents data (temperature or salinity) at 2 s.d. higher than normal.

"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 variables at each location. Positive anomalies in temperature and salinity mean warm or saline conditions; negative anomalies mean cool or fresh conditions.

"Seasonal cycle" describes the short-term changes at the surface of the ocean brought about by the passing of the seasons; the ocean surface is cold in winter and warms through spring and summer. Temperature and salinity changes caused by the seasonal cycle are usually much greater than the prolonged year-to-year changes we describe here.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1 (12)	-0.21	0.33	1.85	1.93	1.70	-0.85		0.21	-0.23	0.13
2 (1)	1.54	0.32	0.56	0.57	0.18	-0.46	-0.25	2.22	-0.81	0.50
3 (1)	1.63	1.63	0.49	-0.29	1.04	0.06	0.70	1.15	0.57	1.28
4 (2b)	1.46	1.39	1.16	1.13	0.85	0.78	-0.01	1.53	0.90	0.41
5 (2)	0.51	1.93	1.17	2.16	-0.37	0.23	-0.09	2.02	2.96	1.17
6 (2c)	-0.03	-0.08	0.35	0.76	1.11	0.71	0.22	0.46	0.96	1.97
7 (2c)	-0.37	-1.52	-1.14	0.34	-0.48	0.23	-0.01	0.51	0.90	2.53
8 (2)	0.07	0.57	0.29	0.49	-2.20	-1.04	-1.50	0.76	1.12	0.87
9 (2)	-1.43	-0.90	0.34	1.16	-0.49	0.06	0.65	0.69	1.20	2.05
10 (3)	2.29	0.98	0.60	-0.02	0.61	-0.09	-0.10	1.10	1.43	1.38
11 (3)	2.41	0.64	-0.21	0.25	-0.65	0.64	0.46	0.30	1.03	0.64
12 (3)	1.22	1.17	2.10	1.01	0.96	0.40	1.12	1.11	0.73	-0.07
13 (4b)	0.73	0.76	0.04	0.71	1.16	1.67	1.53	0.70	1.21	0.15
14 (4b)	0.14	0.22	-0.03	-1.22	1.88	0.20	-0.65	-2.04	0.20	0.54
15 (4b)	0.39	1.39	-0.31	-0.51	2.02	-0.10	0.16	-1.01	0.23	0.57
16 (5)	1.54	1.98	2.12	2.75	2.42	1.96	1.66	1.21	0.99	1.38
17 (5b)	0.49	2.15	0.98	0.60	1.15	-0.57	-0.74	0.53	0.68	-0.27
18 (6)	1.58	1.08	0.02	1.01	1.12	1.32	1.42	0.73	1.30	-0.03
19 (6)	1.47	1.14	0.68	0.81	1.06	0.89	1.16	0.94	1.30	0.89
20 (7)	1.72	1.01	1.01	1.39	1.78	1.26	0.62	1.46	1.35	0.25
21 (7)	1.38	1.17	0.93	1.07	1.21	1.28	1.46	1.93	1.45	0.87
22 (10)	1.75	1.68	0.65	1.63	1.45	0.38	1.97	2.54	2.36	
23 (10)	1.53	0.68	0.51	1.33	1.87	0.35	1.72	0.93	1.18	0.58
24 (10)	1.29	1.20	1.38	1.89	0.51	0.22	1.51	0.40	0.94	1.47
25 (11)	0.22	0.94	1.13	1.83	1.59	0.55	1.33	0.65	-0.02	1.22
26 (11)	-0.14	1.10	1.15	1.66	1.39	0.81	0.90	1.02	0.28	2.20
27 (12)	-0.92	0.37	1.03	2.17	1.08	-0.18	0.57	0.42	1.01	0.90
28 (10)		0.49	1.36	1.57	0.65	0.22	0.53	-0.01		0.60
29 (12)	0.17	1.18	1.21	2.31	0.42	-0.47	0.29	0.17	0.67	-1.08
30 (4)	0.19	-0.02	-0.74	-0.14	0.71	0.41	-0.53	-0.26	0.37	0.63
31 (89)	2.12	1.54	0.70	1.32	1.02	0.36	0.79	1.04	0.57	-0.03
32 (89)	0.44	0.47	0.17	0.20	0.78	0.30	0.30	-0.34		
33 (89)	1.17	0.95	1.15	1.43	2.05	1.21	0.82	-0.68		
34 (9b)	-0.43	0.14	0.80	1.19	1.19	1.04	0.70	0.05	-0.38	-0.03
35 (9b)	0.17	0.47	0.40	1.15	0.54	1.18	1.37	0.43	-0.70	0.53
36 (9b)	-1.23	-1.27	-0.03	-0.03	1.01	1.26	1.33	-0.53	-1.14	-0.16

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1 (12)	0.14	0.22	1.33	1.25	1.53	-1.57		0.16	-1.41	-1.06
2 (1)	0.93	-0.19	1.03	1.35	0.39	-0.40	-0.18	0.17	0.31	-1.12
3 (1)	1.56	1.65	0.51	-0.34	0.30	0.11	1.23	0.07	1.20	-0.15
4 (2b)	1.20	1.26	1.16	0.44	0.79	0.26	0.69	0.40	0.62	0.64
5 (2)	0.26	0.69	0.73	0.64	0.73	1.25	0.09	-0.21	0.21	0.77
6 (2c)	-0.01	-0.57	0.43	0.83	0.28	0.64	0.49	-0.07	1.81	1.81
7 (2c)	0.56	-0.04	-1.52	-0.56	0.52	0.26	0.15	-0.52	-0.81	0.33
8 (2)	1.07	0.48	0.50	0.85	-1.44		-1.28	0.42	1.43	0.56
9 (2)	-0.96	-0.84	-1.61	-0.05	0.52	-1.11	-0.28	0.29	-0.13	-1.16
10 (3)	1.63	1.05	0.27	-0.49	-0.48	-0.39	1.07	1.43	1.16	1.49
11 (3)	0.12	0.26	-0.10	0.96	0.95	1.07	0.66	0.99	1.13	1.55
12 (3)	1.22	1.10	1.88	1.10	1.16	0.90	1.69	1.24	0.85	0.16
13 (4b)										
14 (4b)	-0.97	-0.07	1.07	0.54	1.19		-0.02	-0.18	0.85	1.42
15 (4b)	-0.68	0.25	1.14	0.24	1.13	0.41	0.58	0.44	1.27	0.73
16 (5)	1.79	1.75	1.47	1.44	1.58	1.91	1.99	2.00	1.73	1.04
17 (5b)	-0.23	1.72	1.10	0.78	0.97	-0.00	0.13	1.39	0.84	0.46
18 (6)	1.39	1.18	0.89	0.49	0.51	1.22	1.61	1.53	1.41	0.31
19 (6)	1.13	0.85	1.24	0.63	0.68	1.06	1.41	1.37	1.15	0.81
20 (7)	1.57	1.63	1.22	0.66	0.83	1.13	1.27	1.36	1.27	0.98
21 (7)	1.23	1.07	1.01	0.85	0.59	1.07	1.78	1.91	1.30	1.44
22 (10)	1.74	1.72	1.25	1.27	1.11	0.22	1.90	2.41	1.79	
23 (10)	0.93	0.91	0.77	0.74	0.92	0.61	1.65	1.52	1.35	0.79
24 (10)	0.83	0.95	1.36	1.27	0.48	0.18	1.31	1.29	1.48	1.22
25 (11)	0.35	1.41	1.38	1.98	1.52	1.18	0.18	1.95	2.07	0.52
26 (11)	0.88	1.96	0.88	0.88	1.42	0.16	0.52	0.88	1.60	0.34
27 (12)	-0.47	0.21	1.12	1.61	1.26	0.39	0.65	0.91	1.70	1.68
28 (10)		0.63	1.61	1.89	1.45	0.92	0.71	0.82		1.45
29 (12)	0.18	0.44	1.49	2.01	0.39	-0.05	0.73	1.18	1.51	0.55
30 (4)	-0.85	-0.63	-0.14	0.73	0.75	0.90	0.08	1.03	2.04	1.92
31 (89)	1.25	1.56	0.80	-0.52	-0.89	0.29	0.06	-1.08	0.96	1.75
32 (89)	-0.35	0.56	0.23	0.76	0.01	0.77	0.56	-1.00	1.30	1.50
33 (89)	0.60	0.44	0.27	1.01	-0.68	0.94	1.20	-0.19		
34 (9b)	-1.29	-0.81	-0.30	-1.18	-0.24	-0.40	-0.08	0.08	-0.29	-0.30
35 (9b)	1.33	0.20	0.24	1.92	0.22	0.12	0.62	0.85	0.46	-1.00
36 (9b)	-0.02	1.00	1.06	0.57	1.00	0.32	0.62	2.13	2.14	1.01

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, 2003–2012. 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 s.d. (e.g. a value of +2 indicates that the data—temperature or salinity—for that year were 2 s.d. above normal). Blank boxes indicate that data were unavailable for a particular year at the time of publication. Note that no salinity data are available for station 13. Colour intervals 0.5 s.d.; red = warm; blue = cold; orange = saline; green = fresh.

Index	Description	Area	Measurement depth	Long-term average	Lat	Lon	Mean T °C	Standard deviation T	Mean S	Standard deviation S
1	Fram Strait – East Greenland Current	12	50–500 m	1980–2010	78.83	6.00	0.84	0.64	34.702	0.126
2	Station 4 – Fylla Section – Greenland Shelf	1	0–50 m	1983–2010	63.88	−53.37	2.64	1.10	33.162	0.392
3	Cape Desolation Station 3	1	75–200 m	1983–2010	60.47	−50.00	5.72	0.66	34.923	0.062
4	Area2b – west – central 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	1981–2010	47.55	−52.59		0.35		0.233
6	Oleander Section (inshore of the 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	1981–2010	42.00	−70.00	9.98	0.79	32.600	0.28
8	Emerald Bank– Central Scotian Shelf– Canada	2	Near bottom	1981–2010	44.00	−63.00		0.83		0.151
9	Misaine Bank – Northeast Scotian Shelf – Canada	2	Near bottom	1981–2010	45.00	−59.00		0.63		0.134
10	Siglunes Station 2–4 – North Iceland – Irminger Current	3	50–150 m	1981–2010	67.00	−18.00	3.41	0.98	34.859	0.108
11	Langanes Station 2–6 – Northeast Iceland – East Icelandic Current	3	0–50 m	1981–2010	67.50	−13.50	1.22	0.61	34.729	0.067
12	Selvogsbanki Station 5 – Southwest Iceland – Irminger Current	3	0–200 m	1981–2010	63.00	−22.00	7.88	0.47	35.187	0.049
13	Malin Head Weather Station	4b	Surface	1981–2010	55.37	−7.34	10.18	0.55		
14	Point 33 – Astan	4b	5 m	1998–2010	48.78	−3.94	12.79	0.34	35.206	0.112
15	Western Channel Observatory (WCO) – E1 – UK	4b	Depth average 0–40 m	1981–2010	50.03	−4.37	12.26	0.41	35.212	0.094
16	Ellett Line – Rockall Trough – UK (Section average)	5	30–800 m	1981–2010	56.75	−11.00	9.44	0.33	35.351	0.040
17	Central Irminger Sea – Subpolar Mode Water	5b	200–400 m	1991–2010	59.40	−36.80	4.34	0.53	34.900	0.031
18	Faroe Bank Channel – West Faroe Islands	6	Upper layer, high salinity core	1988–2010	61.00	−8.00	8.80	0.36	35.302	0.043
19	Faroe Current – North Faroe Islands (Modified North Atlantic Water)	6	Upper layer, high salinity core	1988–2010	63.00	−6.00	8.13	0.40	35.250	0.042
20	Faroe Shetland Channel – Shetland Shelf (North Atlantic Water)	7	Upper layer, high salinity core	1981–2010	61.00	−3.00	9.68	0.31	35.382	0.034
21	Faroe Shetland Channel – Faroe Shelf (Modified North Atlantic Water)	7	Upper layer, high salinity core	1981–2010	61.50	−6.00	7.99	0.49	35.252	0.038
22	Ocean Weather Station Mike – 50m	10	50 m	1981–2010	66.00	−2.00	7.71	0.44	35.176	0.036
23	Southern Norwegian Sea – Svinøy section – Atlantic Water	10	50–200 m	1981–2010	63.00	3.00	8.10	0.39	35.245	0.039
24	Central Norwegian Sea – Gimsøy section – Atlantic Water	10	50–200 m	1981–2010	69.00	12.00	6.91	0.34	35.168	0.030
25	Fugløya – Bear Island section – Western Barents Sea – Atlantic Inflow	11	50–200 m	1981–2010	73.00	20.00	5.55	0.46	35.078	0.035
26	Kola section – Eastern Barents Sea	11	0–200 m	1981–2010	71.50	33.50	4.22	0.52	34.771	0.056
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	1981–2010	76.33	10.00	4.08	0.60	35.073	0.038
29	Fram Strait – West Spitsbergen Current	12	50–500 m	1980–2010	78.83	7.00	3.08	0.72	35.023	0.038
30	Santander Station 6 (shelf break) – Bay of Biscay – Spain	4	5–200 m	1993–2010	43.70	−3.78	12.67	0.45	35.608	0.06
31	Fair Isle Current Water (waters entering North Sea from Atlantic)	8&9	0–100 m	1981–2010	59.00	−2.00	10.01	0.46	34.844	0.064
32	Section average – Felixstowe – Rotterdam	8&9	Surface	1981–2010	52.00	3.00		0.72		0.212
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	1981–2010	57.50	19.50	9.27	1.03	7.172	0.196
35	Baltic – LL7 – Baltic Sea	9b	70 m	1991–2010	59.51	24.50	3.97	0.72	7.961	0.667
36	Baltic – SR5 – Baltic Sea	9b	110 m	1991–2010	61.05	19.35	3.27	0.58	6.428	0.141

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 = temperature, S = 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 midporint along that section.

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 2012 (relative to 1971–2000), extracted from the Optimum Interpolation SST dataset (OISST.v2) provided by the NOAA–CIRES Climate Diagnostics Center in the USA. At high latitudes, where *in situ* data are sparse and satellite data are hindered by cloud cover, the data may be less reliable. Regions with ice cover for >50% of the averaging period appear blank.

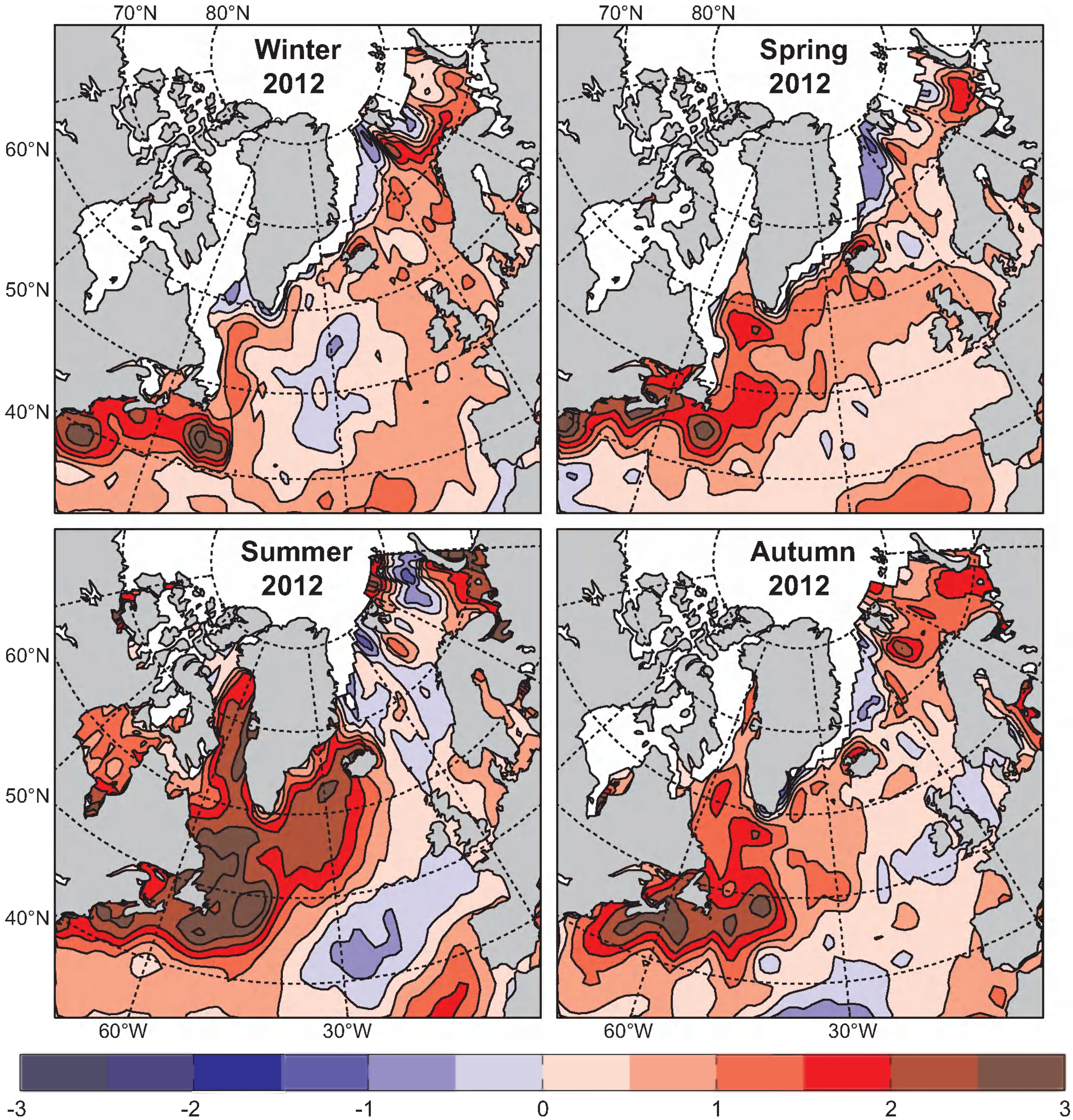


Figure 3.
Maps of seasonal sea surface temperature anomalies (°C) over the North Atlantic for 2012 from the NOAA Optimum Interpolation SSTv2 dataset provided by the NOAA–CIRES Climate Diagnostics Center, USA. The colour-coded temperature scale is the same in all panels. In this case, the anomaly is calculated 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 for >50% of the averaging period are left blank.*

2.3 Gridded temperature and salinity fields

"Argo and the *In Situ* Analysis System"

The Argo network of profiling floats has been set up to monitor large-scale global ocean variability (http://www.argo.ucsd.edu/). Argo data are transmitted in real-time and quickly made available by the two Global Data Assembly Centres (Argo-GDAC). Delayed-mode data undergo expert calibration processes and are delivered later. In the North Atlantic, temperature and salinity conditions of the upper 2000 m are adequately described since 2002. This dataset is thus suitable for an overview of the oceanographic conditions in this basin, giving the general context for the repeat stations and sections collected mainly at the periphery of the basin by the partners of the ICES Working Group on Ocean Hydrography (WGOH).

Temperature and salinity fields are estimated on a regular half-degree (Mercator scale) grid using the *In Situ* Analysis System (ISAS) (Gaillard *et al.*, 2009). The dataset is downloaded from the Coriolis Argo GDAC (http://www.coriolis.eu.org/). It should be noted that Coriolis assembles many types of data transmitted in real-time, merging the ARGO dataset with data collected by the Global Telecommunications System (GTS) relating to mooring, marine animals, gliders, and Conductivity Temperature Depth profilers (CTDs). However, the ARGO dataset remains the main contributor in the open ocean. The last year of the analyzed series uses the Near Real-Time dataset prepared by Coriolis at the end of each month from real-time data. Delayed-mode data are progressively taken into account for the previous years, replacing the NRT data. The results presented here were produced with version 6 of ISAS (Gaillard, 2012). 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. The period 2002–2012 was fully reprocessed to take account of new delayed-mode data and flags.

During winter 2012 (Figures 4 and 5), near-surface waters were anomalously cold and fresh in the northwestern Labrador Sea and over a large area south of Greenland. The cold temperatures in the Labrador Sea were associated with a strengthening of northeasterly winds. Farther south, waters were extremely warm and salty in the western basin along 40°N, indicating a northward shift of the Gulf Stream. The rest of the basin was still slightly warmer and saltier than normal.

Summer 2012 was very warm over most of the basin, west of a line joining Spitsbergen to 40°N–40°W. It was only moderately warm southeast of the Iberian Peninsula and slightly colder than normal in the central Atlantic and off Ireland. Unlike winter, summer salinity anomalies were not correlated with temperature anomalies. Waters were very salty in the Greenland Sea, Norwegian Sea, and along the east coast of Greenland coast. They were fresh along the western boundary starting from the west coast of Greenland, following the Canadian and North American coastlines and extending west.

The year 2012 appears to be an extreme within the 2002–2012 decade, with the cold waters observed in the Labrador Sea and the Irminger Sea in winter and the warm temperatures in the southwestern part of the basin in all seasons. The warm summer that extended over most of the basin, except around the Azores, is clearly seen in the surface temperature, but remains within the variability of this period.

The notable features of the 2012 annual mean temperature was an intense warm anomaly over the western basin from the tip of Greenland to 40°N and the persistence of a moderately warm anomaly over the Greenland Sea and along the east coast of Greenland (Figure 6). The structure of the annual salinity anomaly is not correlated with the temperature anomalies. While surface waters of the Greenland Sea were both saltier and warmer, the warmer-than-usual waters west of 20°W were fresher. The fresh anomaly began in 2009 in the centre of the basin (50°N–30°W) and has gradually increased in both size and intensity. In 2012, a large fresh anomaly (–0.5) vs. WOA05 conditions was observed.

Annual mean anomalies for the ocean interior at a depth of 1000 m are shown in Figure 7. At this depth, the Greenland, Labrador, and Irminger seas were warmer than normal, and have been getting progressively warmer since 2002. Mediterranean Outflow water was warmer and saltier west of the Iberian Peninsula and along the eastern boundary. Salinity appears to be generally increasing out into the basin. A cold and fresh anomaly extends southeast of the Reykjanes Ridge in the Iceland Basin and Rockall Trough. A cold and fresh anomaly is observed south of the Gulf Stream and Azores Current (Subtropical Gyre).

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. During 2012, the area experiencing a deep mixed layer (deeper than 600 m) was more extended than usual in the northern part of the basin (more so than during winter 2008) starting from the Labrador Sea, including nearly all of the Irminger Sea, and progressing southward along the coast of North America (Figure 8). In the southeast part of the basin, the deep mixed-layer extension ends around 48/50°N, with only moderate mixed-layer depths observed along the shelf in the Bay of Biscay, contrary to the 2009, 2010, and 2011 winters.

Figure 4.
Maps of 2012 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, WOA05. The colour-coded temperature scale is the same in all panels. From the ISAS monthly analysis of Argo data.

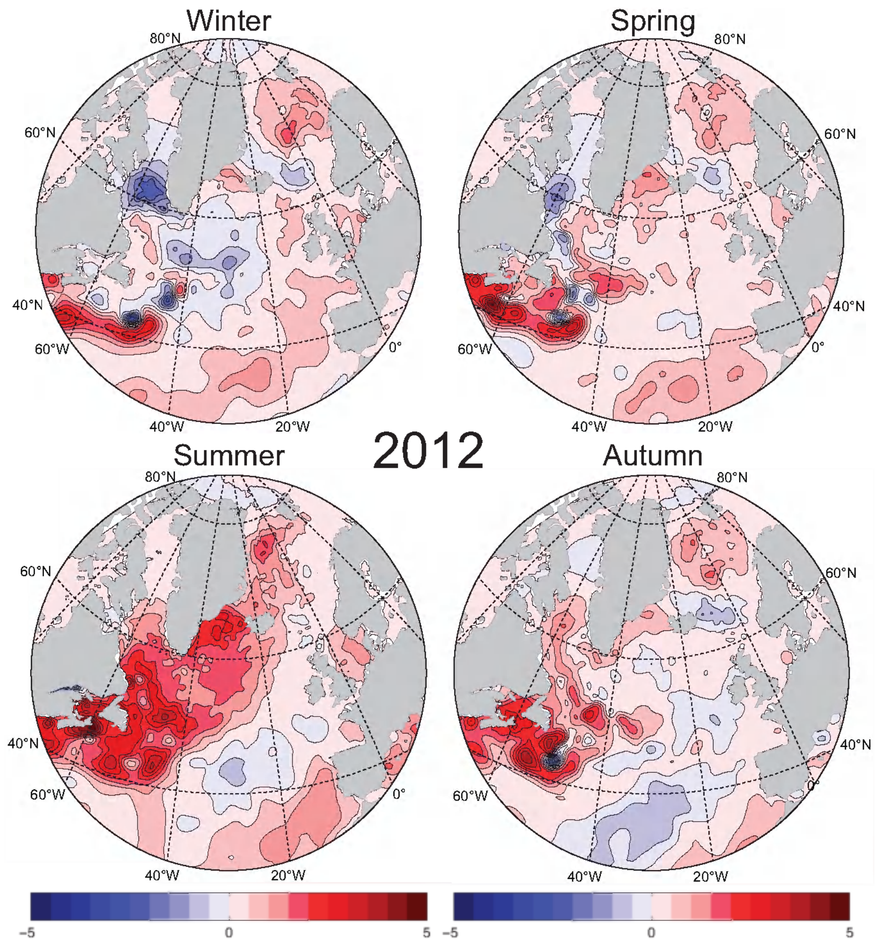
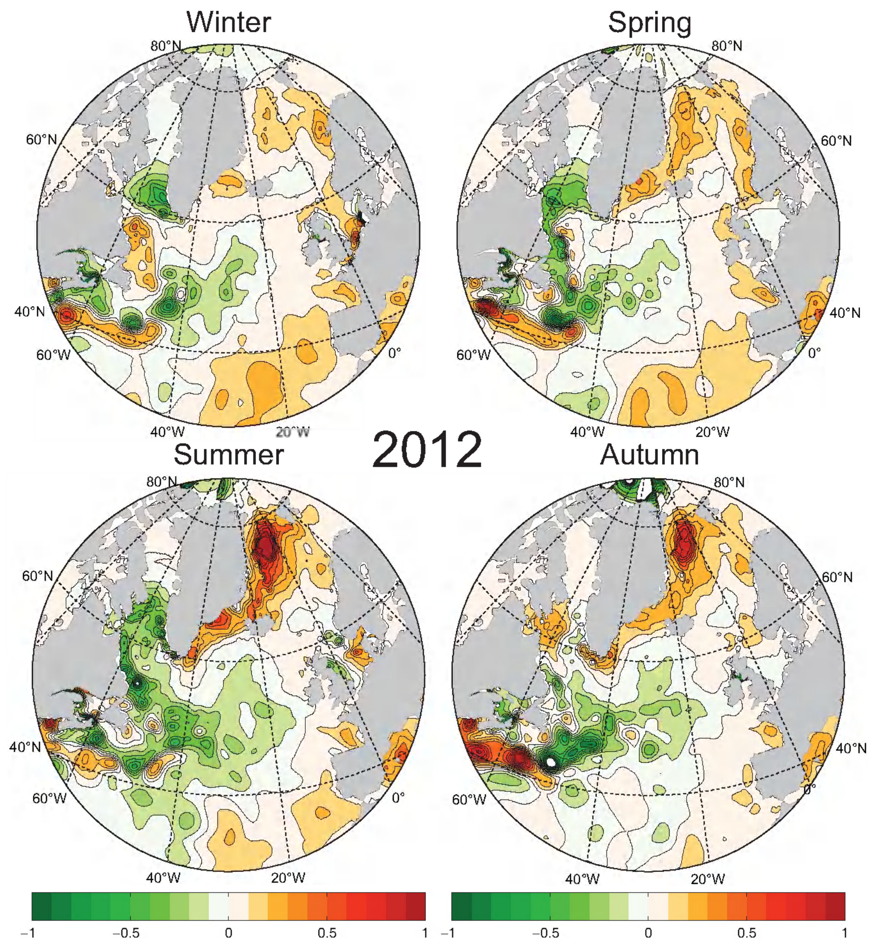


Figure 5.
Maps of 2012 seasonal salinity anomalies at 10 m depth in the North Atlantic. Anomalies are the differences between the ISAS monthly mean values and the reference climatology, WOA05. The colour-coded salinity scale is the same in all panels. From the ISAS monthly analysis of Argo data.



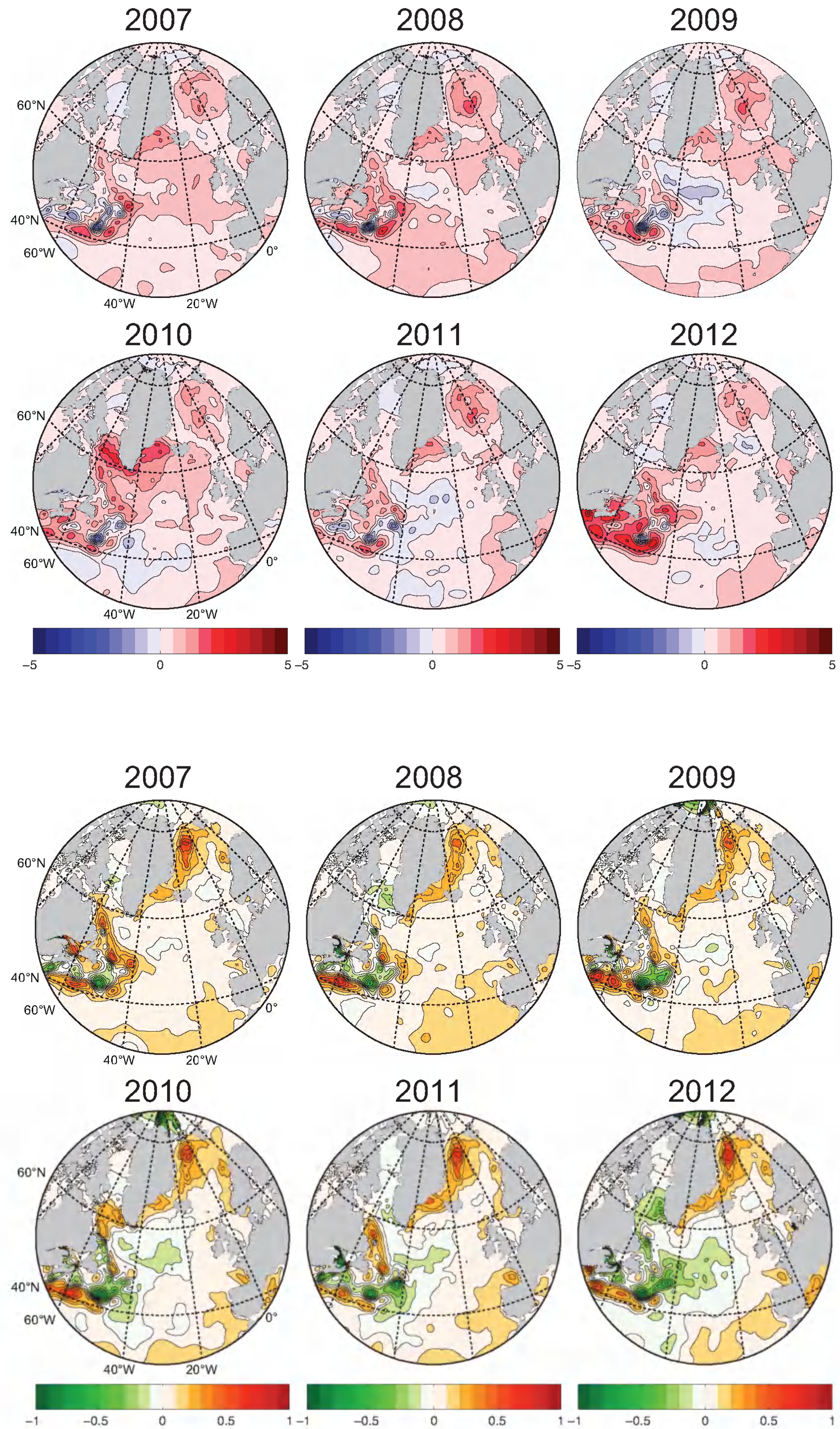
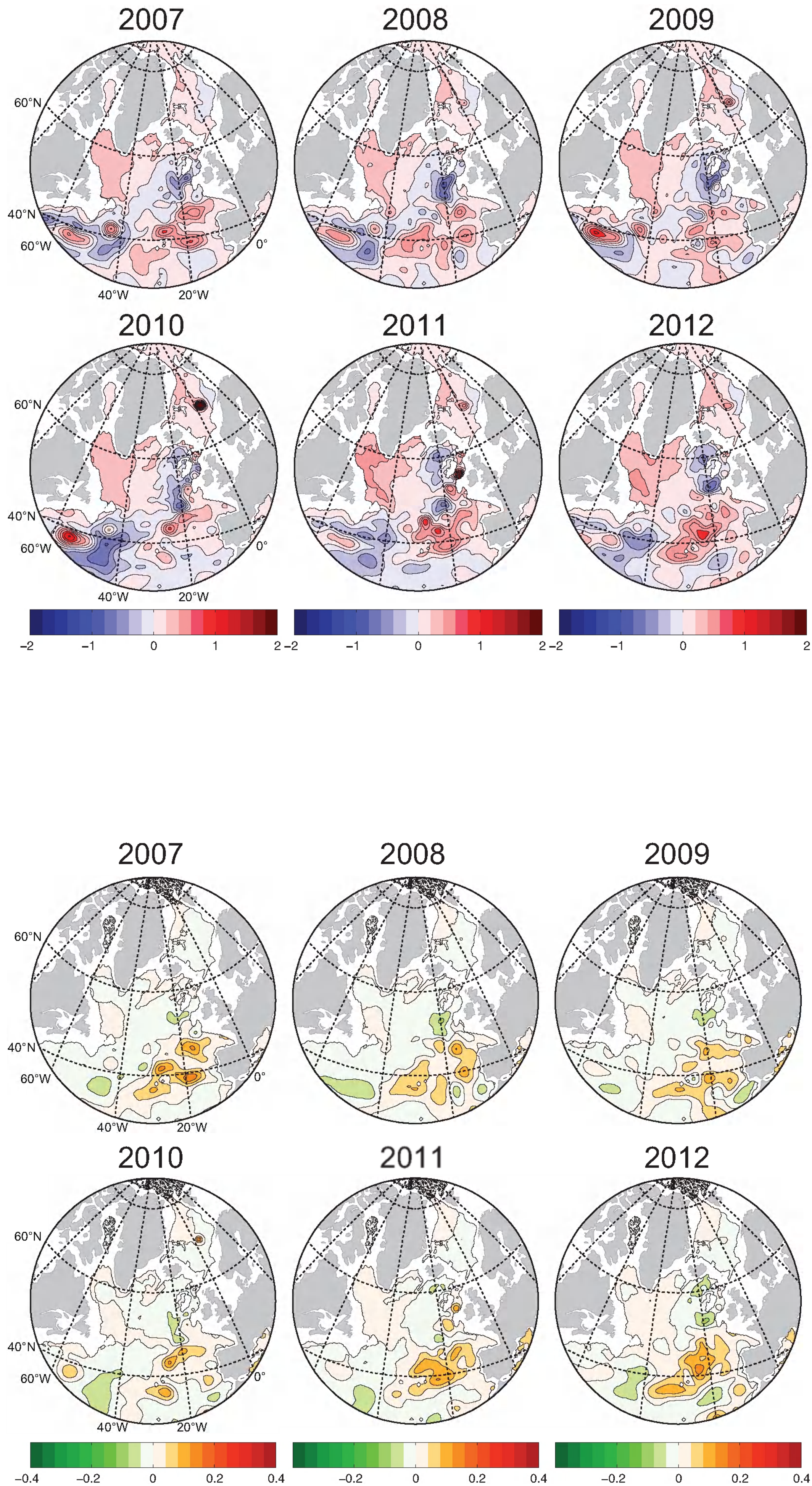


Figure 6.
Maps of annual temperature (upper) and salinity (lower) anomalies at 10 m for 2007–2012. From the ISAS monthly analysis of Argo data..

Figure 7.
Maps of annual temperature (upper) and salinity (lower) anomalies at 1000 m for 2007–2012. From the ISAS monthly analysis of Argo data.



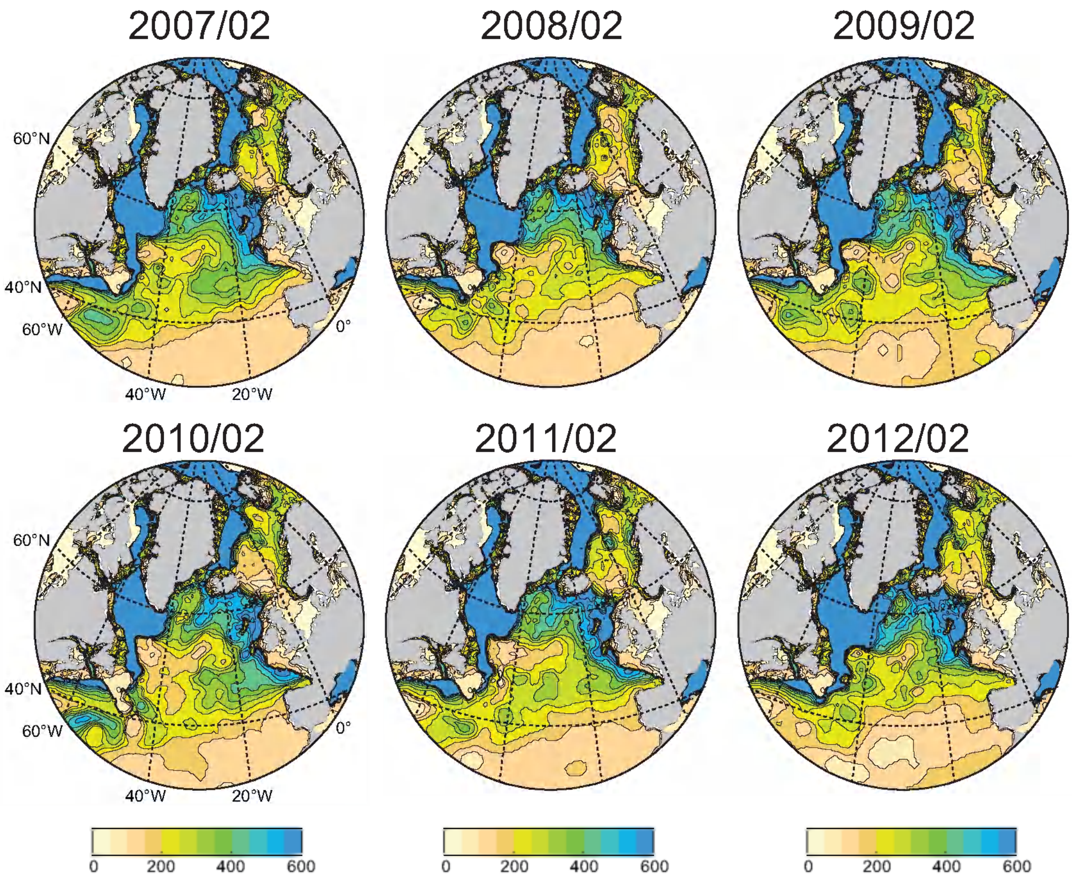


Figure 8.
Maps of North Atlantic winter (February) mixed-layer depths for 2007–2012. From the ISAS monthly analysis of Argo data. Note that the mixed-layer depth is defined as the depth at which the temperature has decreased by more than 0.5°C from the temperature at 10 m depth. This criterion is not 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 windspeed, 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/March, or DJFM) NAO index is 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.

In many of the years between 1996 and 2009, the Hurrell winter NAO index was both fairly weak 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 (starting in 1864). In winter 2011, it remained negative and was the third negative index winter in succession, which had not happened since winters 1968/1969–1970/1971.

In winter 2011/2012, the Hurrell winter NAO index reverted to a strong positive (+3.17), the strongest positive value for this index since winter 1994/1995. 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 (1981–2010). 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 2012 (December 2011, January–March 2012), and the bottom panel shows the 2012 winter SLP anomaly (i.e. the difference between the top and middle panels). In winter 2012, the average SLP pattern appears clearly different to the 1981–2010 average. Both the Iceland Low and the Azores High were evident, but they were stronger than in the mean pattern and with a more eastern emphasis in the south. The SLP anomaly that results has the character of a strong NAO positive being negative in the south and positive in the north, but focused more in the eastern Atlantic.

The figures show contours of constant SLP (isobars). The geostrophic (or "gradient") wind blows parallel to the isobars, with lower pressure to the left, and the closer the isobars, the stronger the wind. The strength of the winter mean surface wind averaged over the 30-year period (1981–2010) is shown in the upper panel of Figure 11, while the lower panel shows the anomaly in winter 2011/2012. These reanalyses demonstrate that the mean winds were weaker than normal across most of the North Atlantic south of Newfoundland and Ireland and also over the Denmark Strait and Iceland. They were particularly weak between the Azores and northern Spain. There was a band of higher-than-average windspeeds between the Faroes and the Labrador Sea.

We include, for the first time, an initial assessment of the North Atlantic atmosphere at the end of the IROC year. Winter 2012/2013 had conditions indicating a NAO negative index with weakened windspeed across the Nordic seas, Rockall Trough, North Sea, and central Subpolar Gyre and strengthened winds at the latitude of the Azores. Air temperatures were cold over much of northwestern Europe and warm over the Labrador Sea.

THE NAO INDEX IN WINTER 2011/2012 WAS THE STRONGEST POSITIVE VALUE SINCE 1994/1995

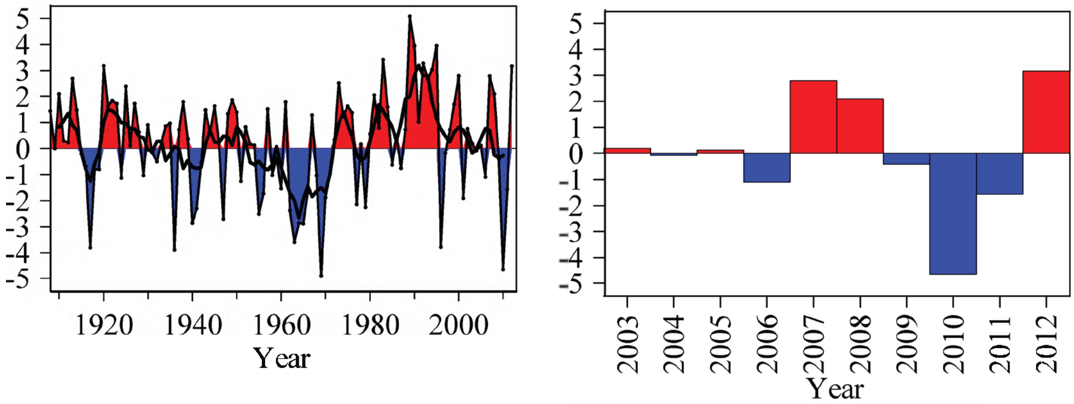


Figure 9. *The Hurrell winter (DJFM) NAO index for the past 100 years with a two-year running mean applied (left panel) and for the current decade (right panel). Data source: http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html.*

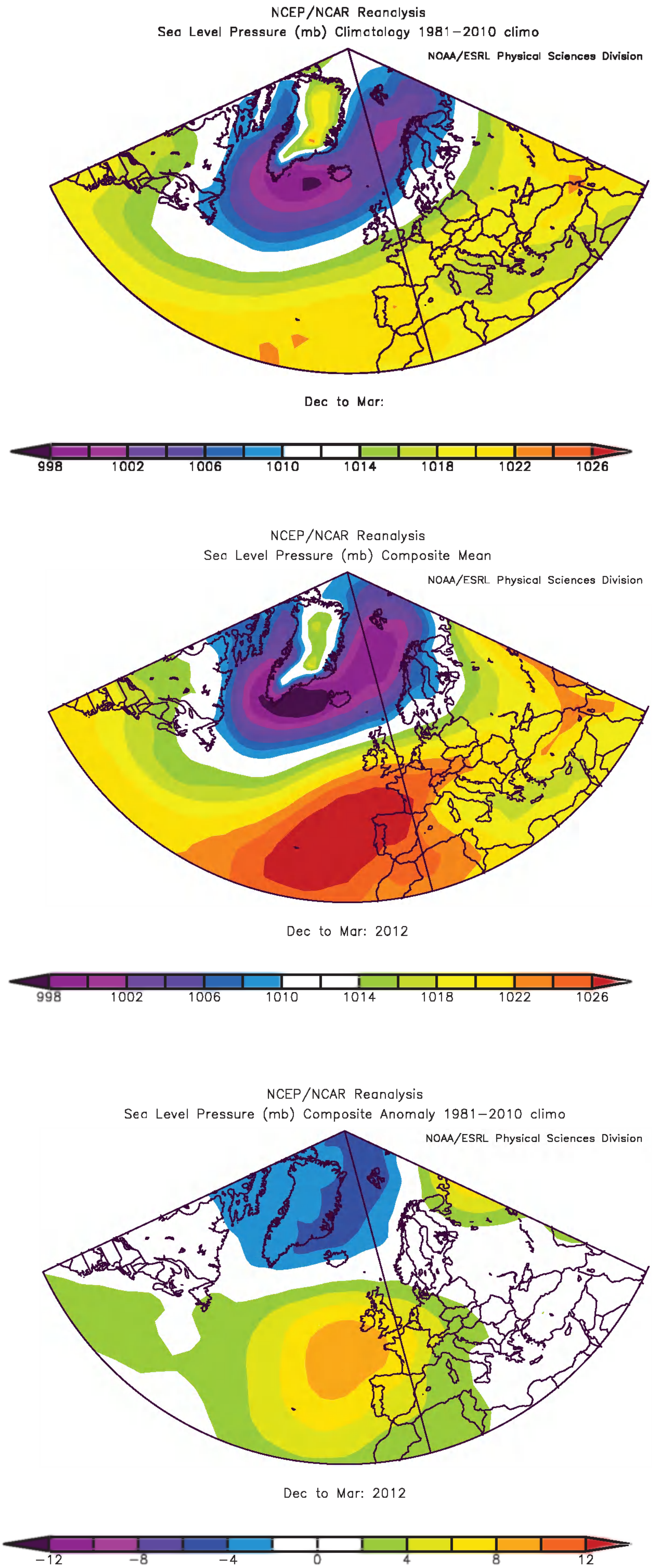


Figure 10.
Winter (DJFM) sea level pressure (SLP) fields. Top panel: SLP averaged over 30 years (1981–2010). Middle panel: mean SLP in winter 2012 (December 2011, January–March 2012). Bottom panel: winter 2012 SLP anomaly—the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO (available online at http://www.cdc.noaa.gov/).

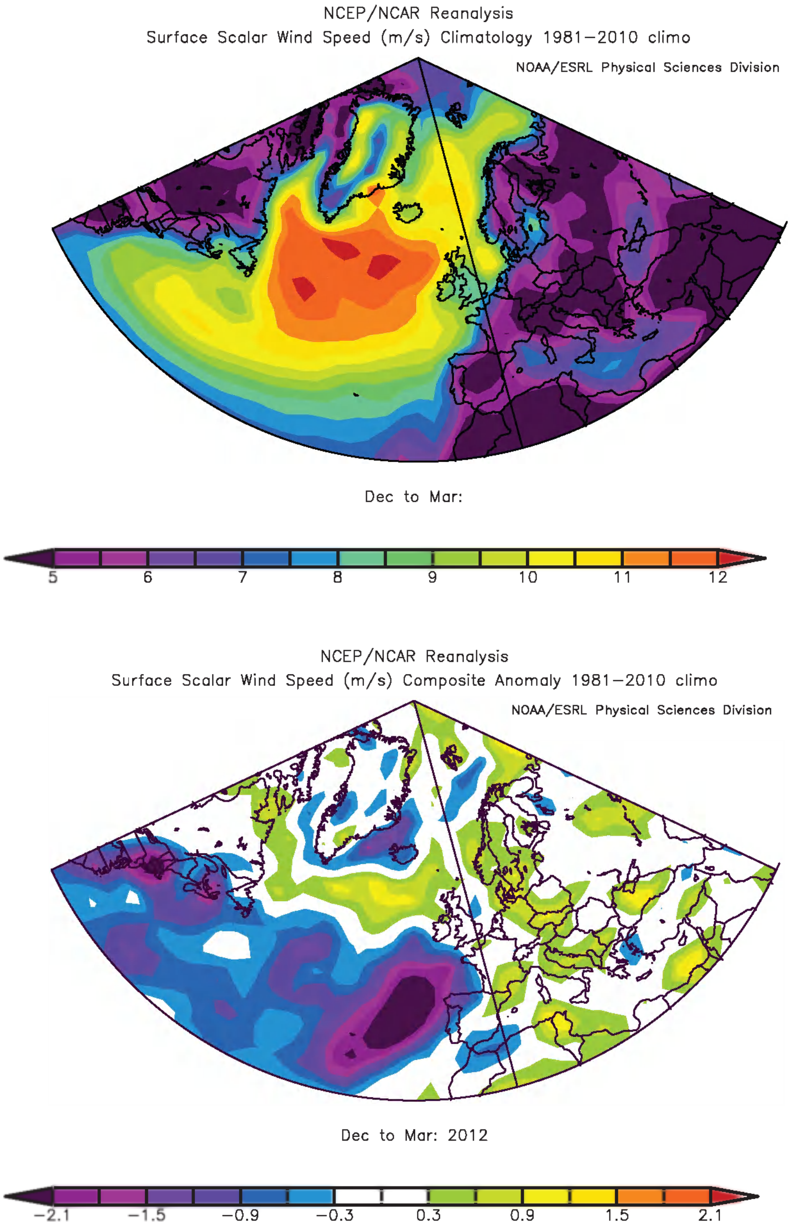


Figure 11.
Winter (DJFM) surface windspeed. Upper panel: surface windspeed averaged over 30 years (1981–2010). Lower panel: winter 2012 anomaly in surface windspeed. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO (available online at http://www.cdc.noaa.gov/).

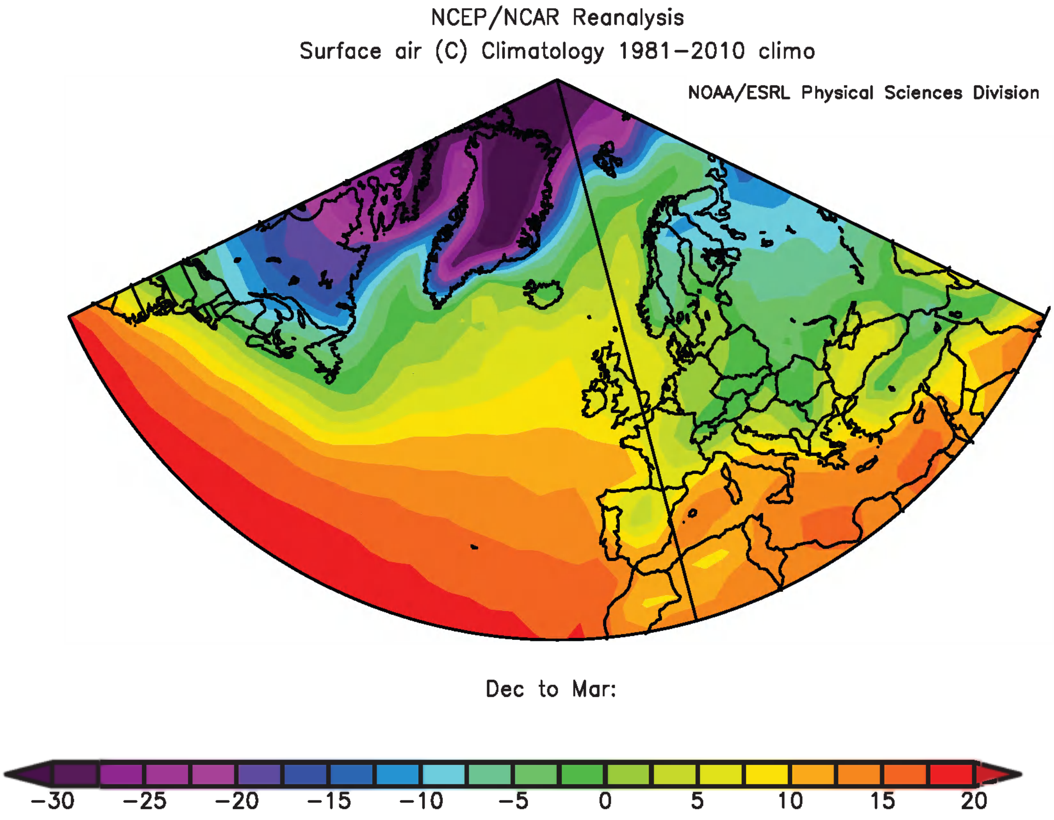
3.2 Surface air temperature

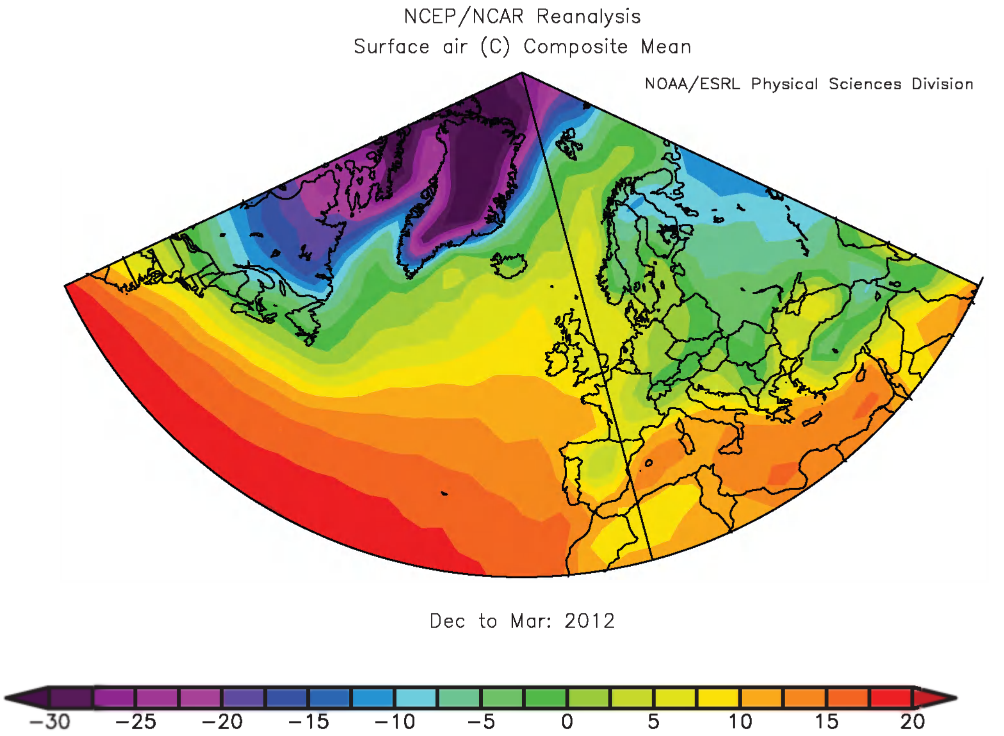
North Atlantic winter mean surface air temperatures are shown in Figure 12. The 1981–2010 mean conditions (Figure 12, top panel) show warm temperatures penetrating far to the north on the eastern side of the North Atlantic and the Nordic seas, caused by the northward movement of warm oceanic water. The middle panel of Figure 12 shows the conditions in winter (DJFM) 2011/2012, and the bottom panel shows the difference between the two.

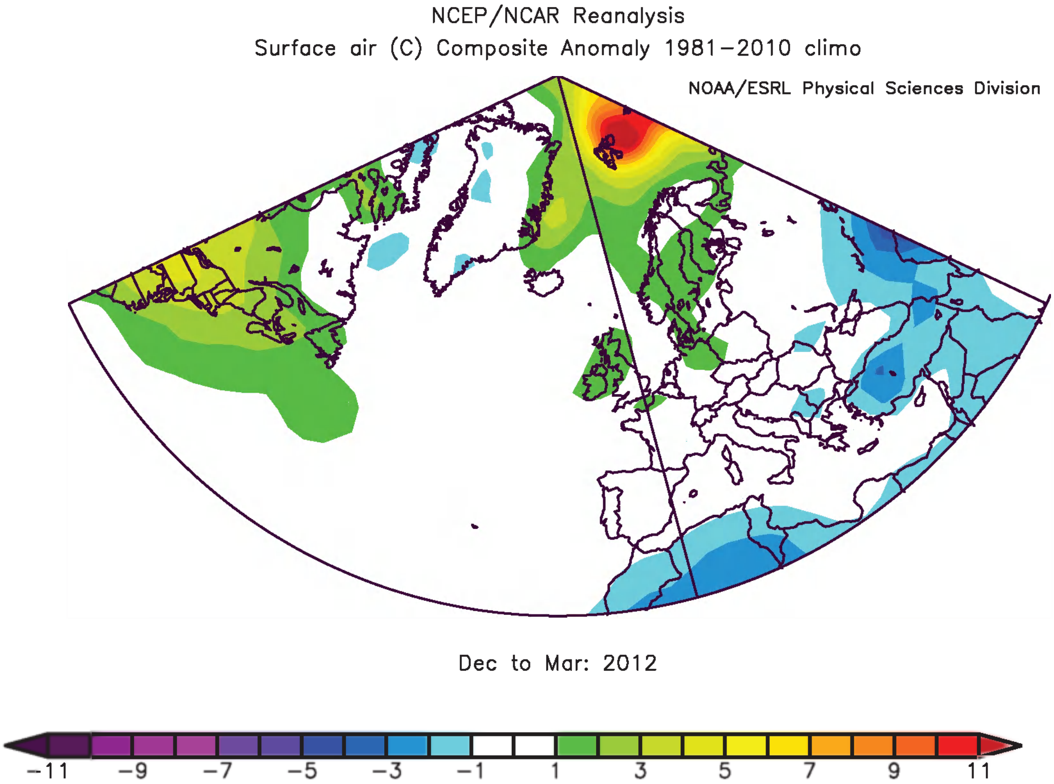
Winter 2011/2012 was notably warm along the northeast US and Canadian shelf south of Newfoundland, while the central North Atlantic experienced near-average air temperature as did most of the seas off the European continental margin. Surface air temperatures were more than 1°C above average over most of the Greenland, Norwegian, and Barents seas. In contrast, although air temperature over the Labrador Sea was near normal during winter, a small area was >1°C lower than the 1981–2010 average.

WINTER SURFACE AIR TEMPERATURES WERE ABOVE AVERAGE OVER THE GREENLAND, NORWEGIAN, AND BARENTS SEAS AND ALSO OVER THE NORTHEAST US AND CANADIAN SHELF SOUTH OF NEWFOUNDLAND.

Figure 12.
Winter (DJFM) surface air temperature fields. Top panel: surface air temperature averaged over 30 years (1981–2010). Middle panel: temperatures in winter 2012 (December 2011, January–March 2012). Bottom panel: winter 2012 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/).




NCEP/NCAR Reanalysis
Surface air (C) Composite Mean
NOAA/ESRL Physical Sciences Division
Dec to Mar: 2012
−30 −25 −20 −15 −10 −5 0 5 10 15 20


NCEP/NCAR Reanalysis
Surface air (C) Composite Anomaly 1981−2010 climo
NOAA/ESRL Physical Sciences Division
Dec to Mar: 2012
−11 −9 −7 −5 −3 −1 1 3 5 7 9 11

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 1981–2010). For datasets that do not extend as far back as 1981, the average conditions have been calculated from the start of the dataset up to 2010.

In places, the seasonal cycle has been removed from a dataset, either by calculating the average seasonal cycle during 1981–2010 or by drawing on other sources, such as regional climatology datasets. Smoothed versions of most time-series are included using a "Loess smoother", a locally weighted regression with a two- or five-year window.

In some areas, data are sampled regularly enough to allow a good description of the seasonal cycle. Where possible, monthly data from 2012 are presented and compared with the average seasonal conditions and statistics.

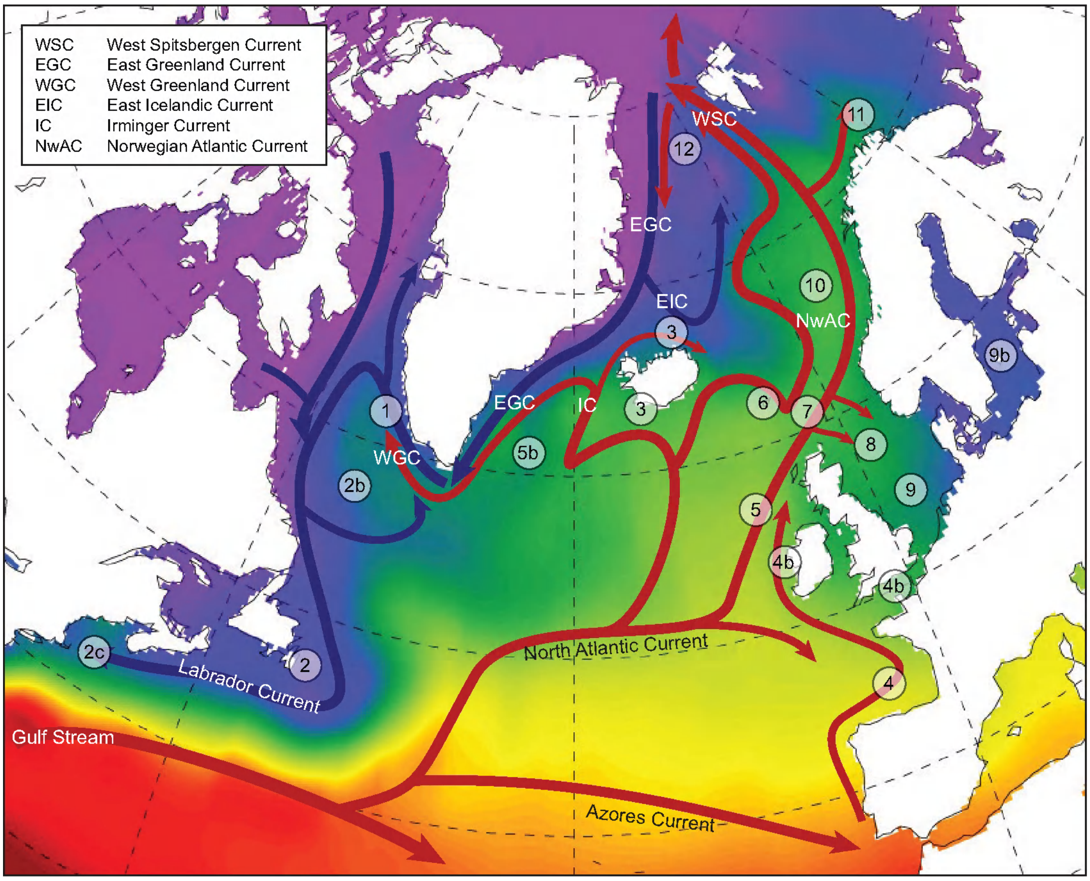


Figure 13. Schematic of the general circulation of the upper ocean (0–1000 m) in the North Atlantic in relation to the numbered areas presented below. Blue arrows = movement of cooler waters of the Subpolar Gyre; red arrows = movement of warmer waters of the Subtropical Gyre.

4.2 Area 1 – West Greenland

The West Greenland Current carries the 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 subject to hydrographic variations at the different time-scales associated with variability of the gyre. Hydrographic conditions are monitored 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-typical conditions when the North Atlantic Oscillation (NAO) index is negative, and the highest temperature ever reported occurred in 2010. In 2011, following this record year, when the winter NAO was weaker but its index remained negative, the annual mean air temperature at Nuuk weather station in West Greenland decreased to a level closer to that of 2009. In 2012, the winter NAO index was strongly positive, yet the annual mean air temperature at Nuuk weather station was 1.4°C in 2012, the second highest temperature reported since observations began in 1881.

Water properties between a depth of 0 and 50 m at Fyllas Bank Station 4 are used to monitor the variability of the fresh Polar Water component of the West Greenland Current. In 2012, the temperature of this water was 0.55°C higher than the long-term mean (1983–2010). The salinity anomaly of the Polar Water reveals a positive trend between 2008 and 2011. However, in 2012, salinity decreased and was 0.44 below its long-term mean.

Temperature and salinity of the Irminger Sea component of the West Greenland Current started to increase towards the end of the 1990s, coinciding with a slowing down of the Subpolar Gyre. In 2012, water temperature in the 75–200 m layer at Cape Desolation Station 3 was 6.56°C, which was 0.84°C above the long-term mean (1983–2010). In 2012, salinity in the 75–200 m layer at Cape Desolation Station 3 was 34.91, which was 0.01 below the long-term mean.

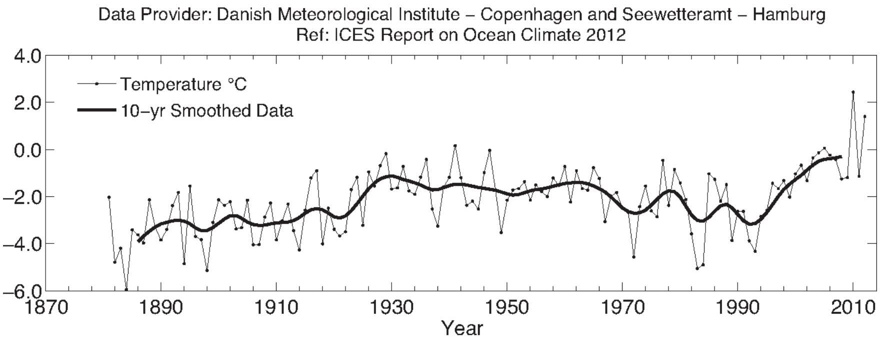


Figure 14.
Area 1 – West Greenland. Annual mean air temperature at Nuuk weather station (64.16°N 51.75°W).

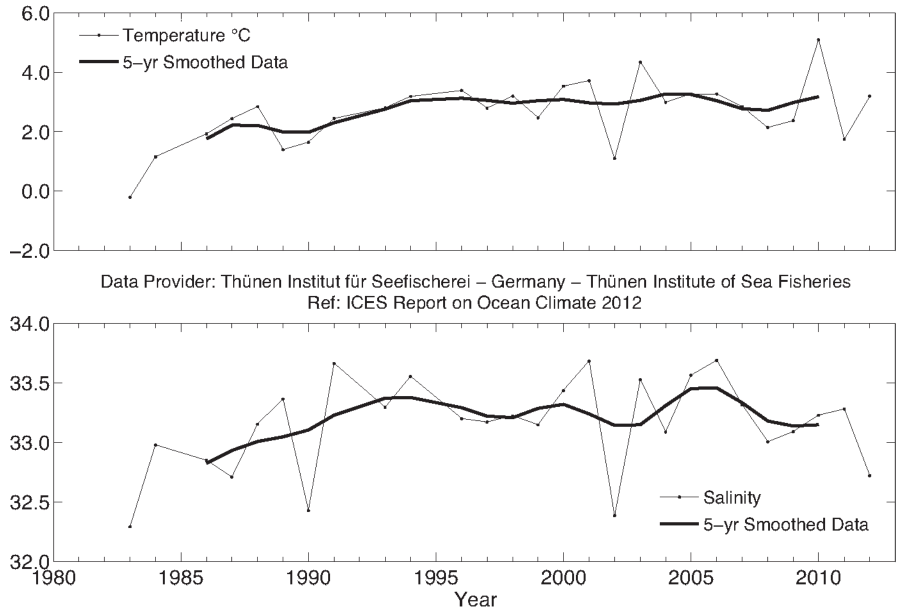


Figure 15.
Area 1 – West Greenland. Mean temperature (upper panel) and salinity (lower panel) in the 0–50 m water layer at Fyllas Bank Station 4 (63.88°N 53.37°W).

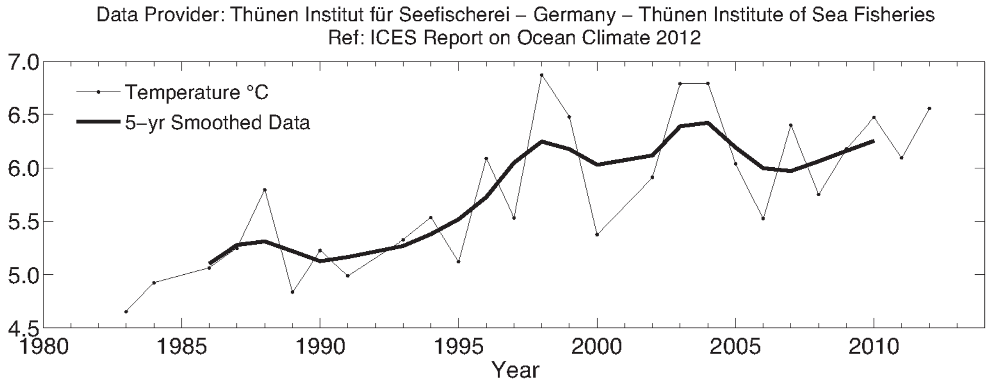


Figure 16.
Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 75–200 m at Cape Desolation Station 3 (60.45°N 50°W).

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 2012, annual mean air temperatures over the Scotian Shelf, represented by Sable Island observations, were 1.7°C, corresponding to 2.4 s.d. above the long-term mean (1981–2010). The amount of sea ice on the Scotian Shelf in 2012, as measured by the total area of ice seaward of Cabot Strait between Nova Scotia and Newfoundland from January to April, was 1200 km^2, well below the long-term mean coverage of 32 000 km^2. This is the fourth lowest coverage in the 51-year time-series. Only 1969, 2010, and 2011 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 average conditions in 2012, with temperature well above normal at +1.3°C (+2.0 s.d.) and salinity –0.15 (–1.1 s.d.) below normal. The deep Emerald Basin anomalies represent the slope water intrusions onto the shelf that are subsequently trapped in the inner basins. In 2012, the 250 m temperature and salinity anomalies were above normal by +0.7°C (+0.9 s.d.) and +0.08 (+0.6 s.d.), respectively. These observations run contrary to the expectation that after two low NAO years in 2010 and 2011, the colder, fresher Labrador Sea Water should have appeared in Emerald Basin.

EXTREMELY WARM WATER AND CONTINUED LOW SEA ICE ON THE SCOTIAN SHELF.

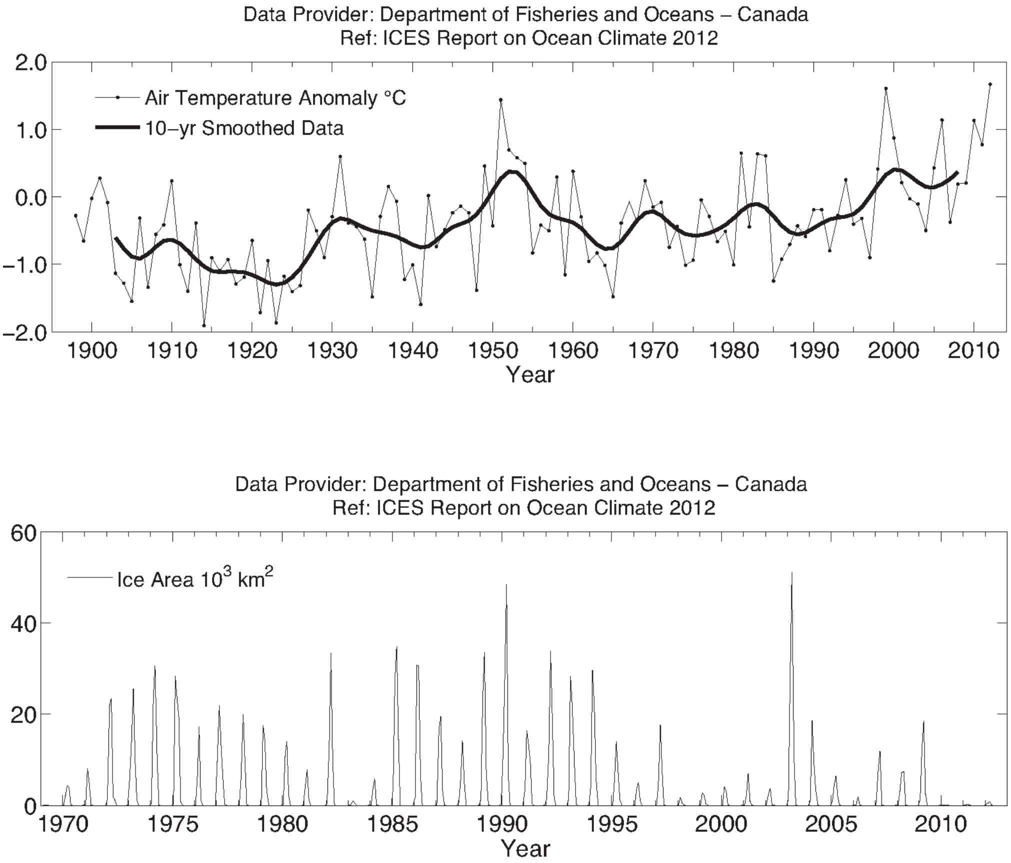


Figure 17.
Area 2 – Northwest Atlantic: Scotian Shelf. Monthly means of ice area seawards of Cabot Strait (upper panel) and air temperature anomalies at Sable Island on the Scotian Shelf (lower panel).

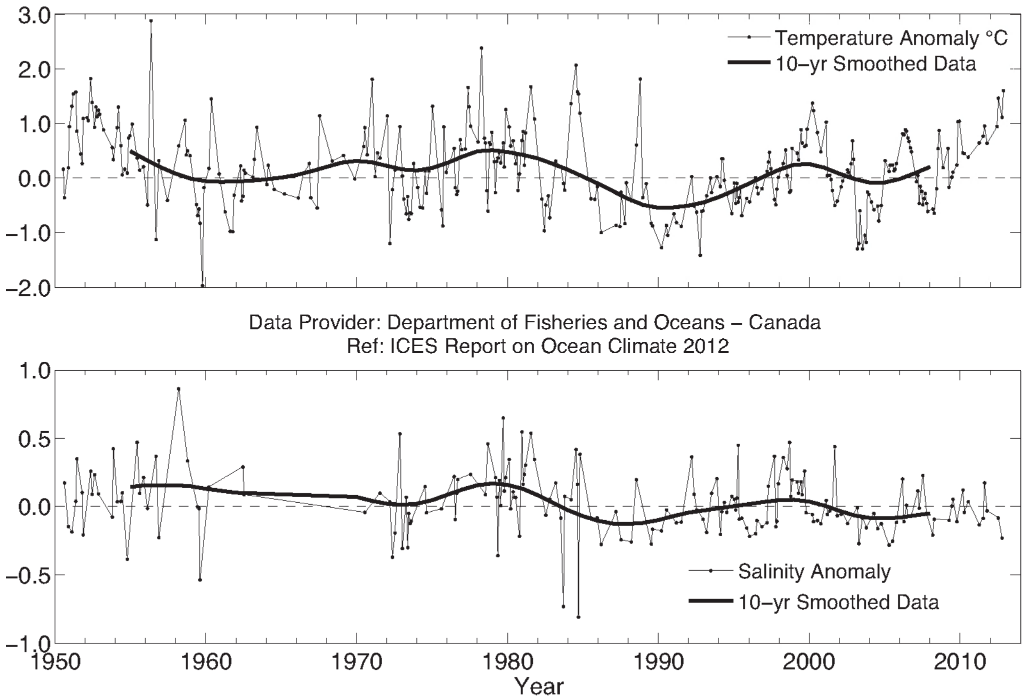
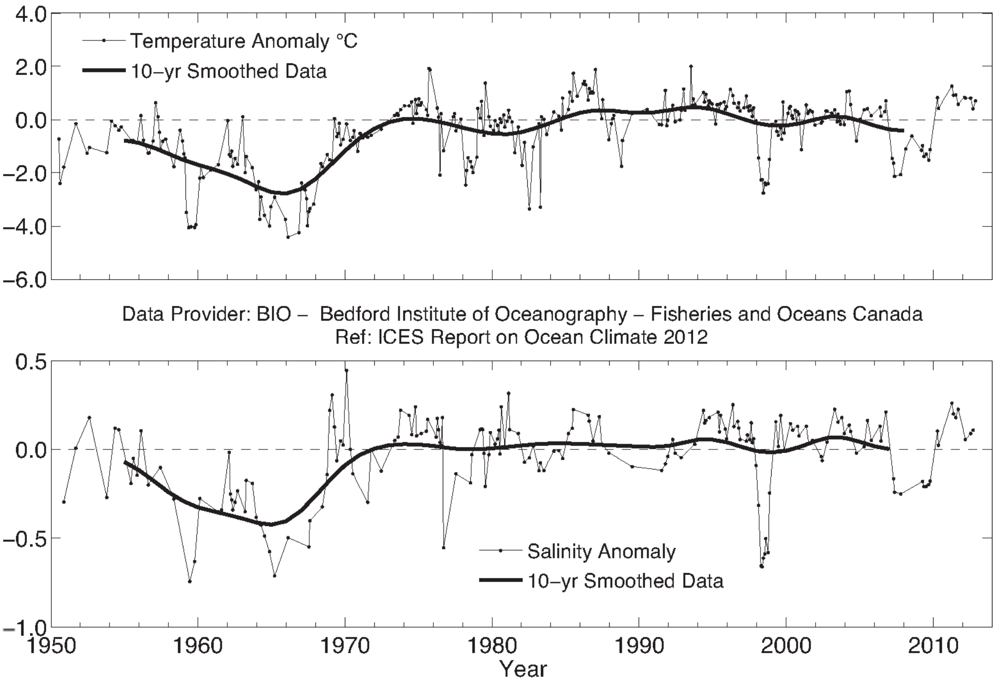


Figure 18.
Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature (upper panel) and salinity (lower panel) anomalies at Misaine Bank (100 m).

Figure 19.
Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature (upper panel) and salinity (lower panel) anomalies 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 the 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, which brings cold freshwater from the north as well as 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 large annual cycles with strong horizontal and vertical temperature and salinity gradients.

The annual NAO index (Iceland–Azores), a key indicator of climate conditions in the Northwest Atlantic, after being in the negative phase for two consecutive years, increased to 1.3 s.d. above normal in 2012, the highest since 1989. As a result, Arctic air outflow to the Northwest Atlantic increased in most areas during winter 2012.

Annual air temperatures, however, remained above normal at Labrador +1.4 s.d. (+1.8°C at Cartwright) and Newfoundland +2.3 s.d. (+1.9°C at St. John's), an increase over 2011 values. The annual sea-ice extent on the Newfoundland–Labrador Shelf remained below normal (0.7 s.d.) for the 17th consecutive year, but increased by 1 s.d. over the record low in 2011. As a result of these and other factors, local water temperatures on the Newfoundland–Labrador Shelf remained above normal in most areas, but decreased significantly over 2011 values.

At the standard monitoring site off eastern Newfoundland (Station 27), the depth-averaged annual water temperature decreased to +1 s.d. (+0.4°C) above normal from the record high of +3 s.d. (+1°C) in 2011. Annual surface temperatures at Station 27 increased to +1.5 s.d. (+1°C) above normal while bottom temperatures (176 m) decreased to +1.1 s.d. (+0.4°C), down from the record high of +3.4 s.d. (+1.3°C) in 2011.

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 the 20th century, the volume of CIL water was at a minimum (warmer-than-normal conditions), and during the high NAO years of the early 1990s, the CIL volume reached near-record high values (colder-than-normal conditions). The area of the CIL water mass on the Newfoundland–Labrador Shelf during 2012 increased to –0.5 s.d. below normal from the record low value at –2 s.d. below normal in 2011.

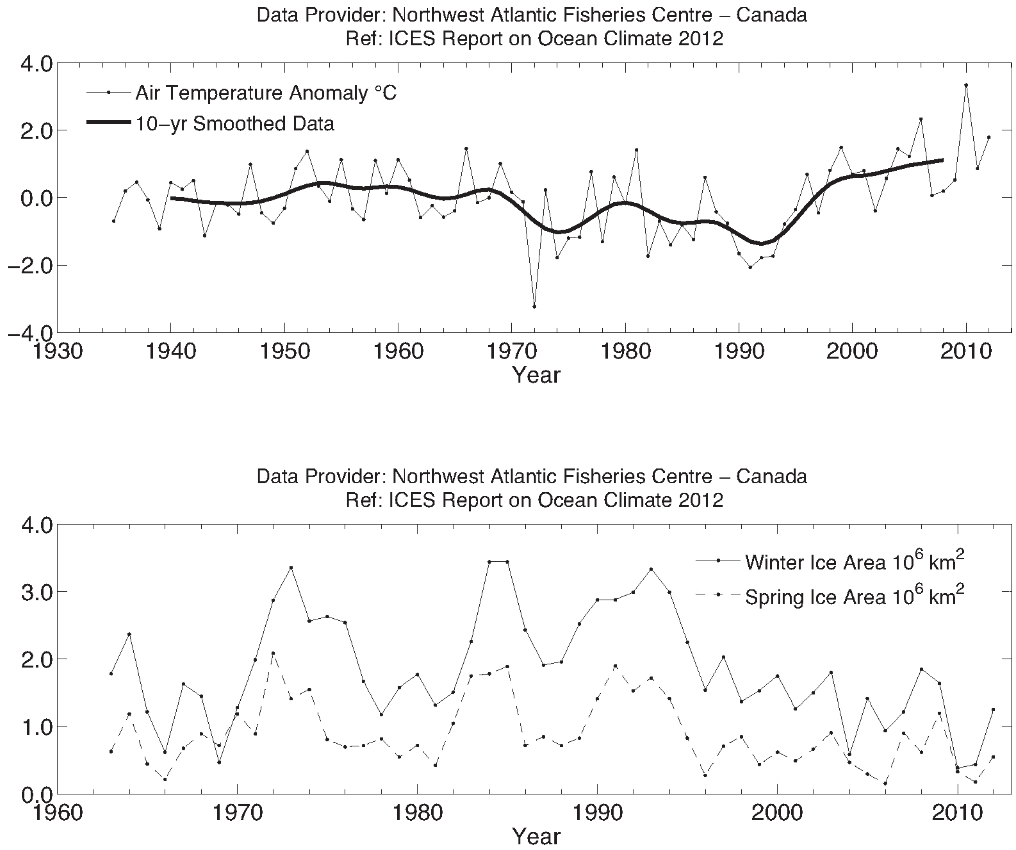
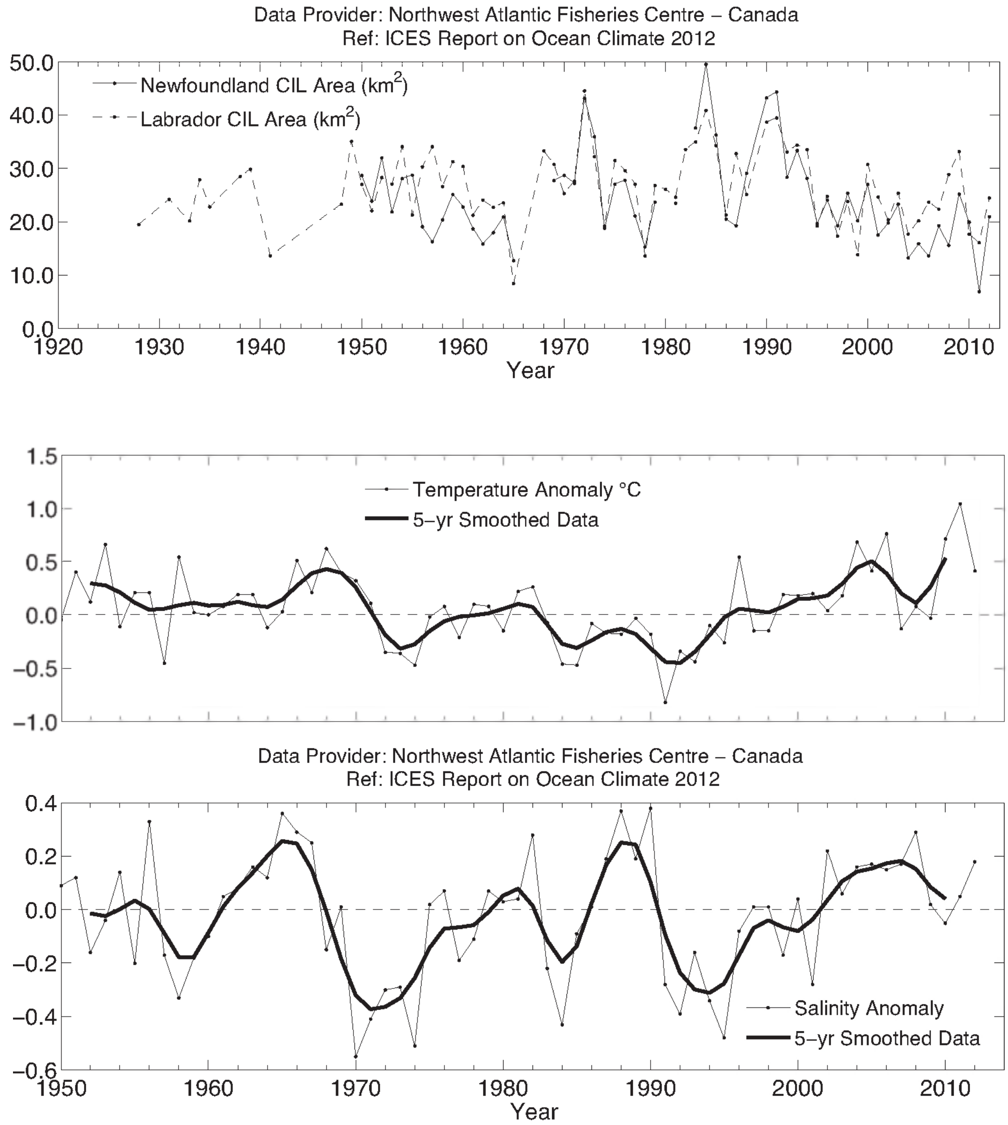


Figure 20.
Area 2 – Northwest Atlantic: Newfoundland–Labrador Shelf. Winter and spring sea-ice areas off Newfoundland–Labrador between 45° and 55°N (upper panel). Annual air temperature anomalies at Cartwright on the Labrador Coast (lower panel).

ANNUAL SEA-ICE EXTENT ON THE NEWFOUNDLAND–LABRADOR SHELF REMAINED BELOW NORMAL FOR THE 17TH CONSECUTIVE YEAR.

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



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 subtropics flow north into the Labrador Sea on the Greenland side and become colder and fresher as they circulate.

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 freshwater. 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.

The 2012 annual mean SST in the west-central Labrador Sea exceeded the long-term (1971–2000) mean by 1.1°C, making it the second warmest year of the recent warm period since 2003. Conditions were generally warm throughout the year, with record-high values through July–September.

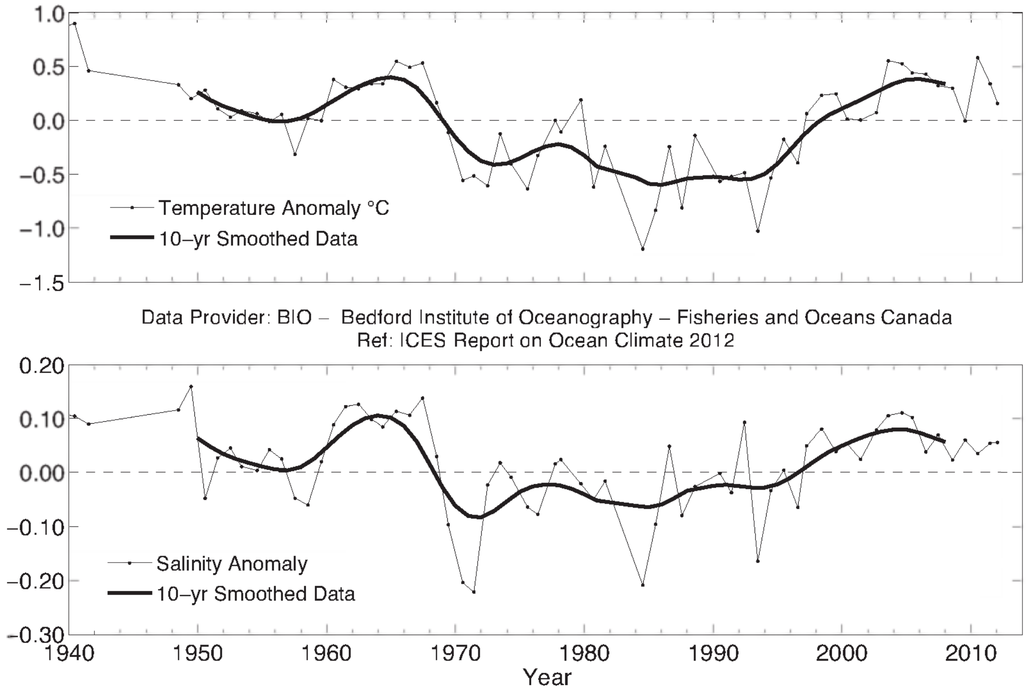


Figure 22.
Area 2b – Labrador Sea. Potential temperature (upper panel) and salinity (lower panel) anomalies at 16–150 m, from CTD and Argo data in the west-central Labrador Sea (centred at 56.7°N 52.5°W). Estimates of seasonal cycle (derived from all data in the time-series) have been removed from the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

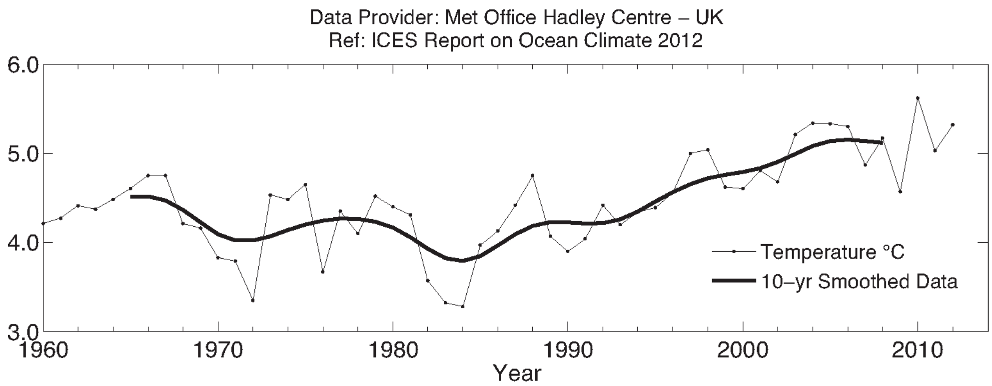


Figure 23.
Area 2b – Labrador Sea. Annual mean sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 sea ice and sea surface temperature dataset, UK Meteorological Office, Hadley Centre.

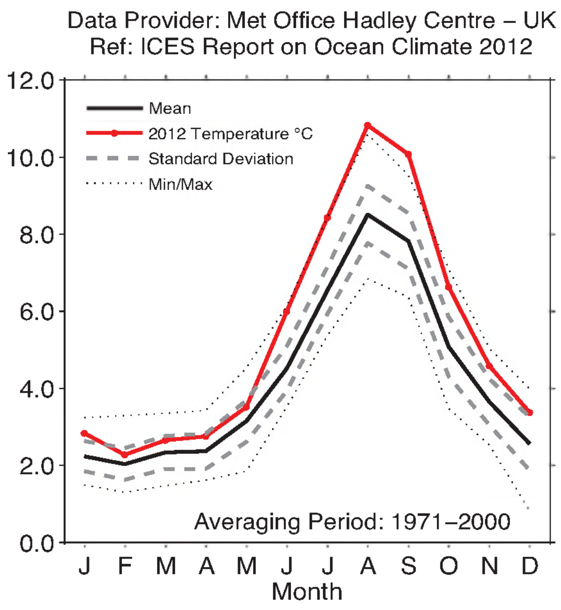


Figure 24.
Area 2b – Labrador Sea. Monthly average (1971–2000) seasonal cycle with 2012 monthly sea surface temperature from the west-central Labrador Sea (3° × 3° area centred on 56.5°N 52.5°W). Data obtained from the HadISST1.1 sea ice and sea surface temperature data-set, UK Meteorological Office, 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 the quarterly ecosystem monitoring and twice-yearly bottom-trawl surveys conducted by the US 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 (Figure 25). In addition, commercial vessels have been instrumented and used to regularly monitor 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 (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 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. The anomalies represent the average anomaly for waters inshore of the 100 m isobath. Interannual temperature fluctuations are vertically coherent inshore of the shelf break across the Mid-Atlantic Bight. In 2012, waters were significantly warmer than the long-term mean at both the surface and bottom, with anomalies approaching +2°C at both the surface and bottom. Enhanced warming was also observed upstream in the Gulf of Maine during 2012, particularly at the bottom where anomalies were nearly 3°C warmer than the long-term average (Figure 27).

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 (0–30 m). Given 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 1981–2010. The surface time-series corroborates the trends exhibited in the shipboard XBT records, showing enhanced warming within the upper water column in recent years where anomalies approached 3°C. Warming occurred throughout the year relative to the seasonal mean, exceeding the maximum temperatures observed the reference period during all seasons (Figure 29). During this same period, the upper water column was only slightly saltier than average over Georges Bank, remaining within the range of the observed variability throughout the year.

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 1981–2010. The time-series indicates that deep inflow to the Gulf of Maine remained warmer and saltier in 2012 compared with the long-term mean.

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.

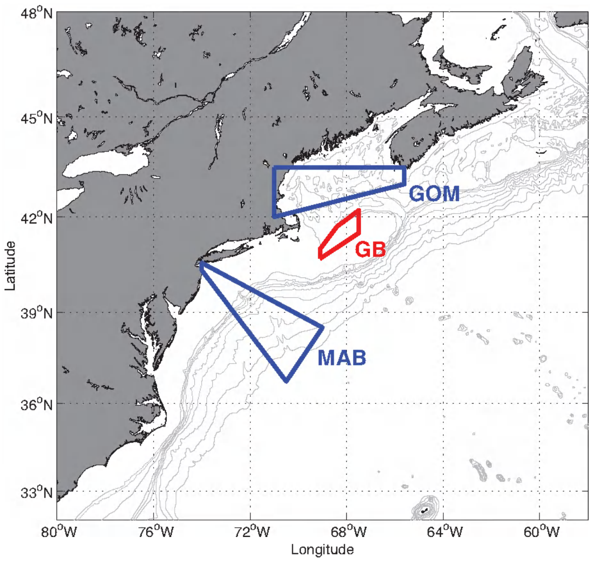


Figure 25.
Area 2c – Mid-Atlantic Bight. The four regions of ongoing time-series: GOM = Gulf of Maine (XBT measurements and surface samples); MAB = central Mid-Atlantic Bight (XBT measurements and surface samples): NEC = Northeast Channel (CTD stations); NWGB = Northwest Georges Bank (CTD stations).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

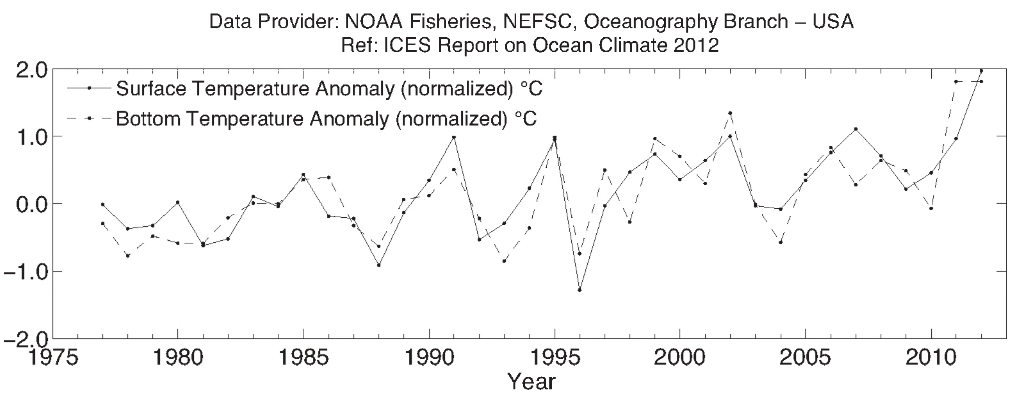


Figure 26.
Area 2c – Mid-Atlantic Bight. Surface and bottom temperature anomalies in the central Mid-Atlantic Bight (relative to the base period of 1981–2010) from XBT measurements; the origin of the line is New York City. The data represent the average conditions at the surface and bottom inshore of the 100 m isobath.

| WATER TEMPERATURES WERE NOTABLY HIGH ACROSS THE REGION |

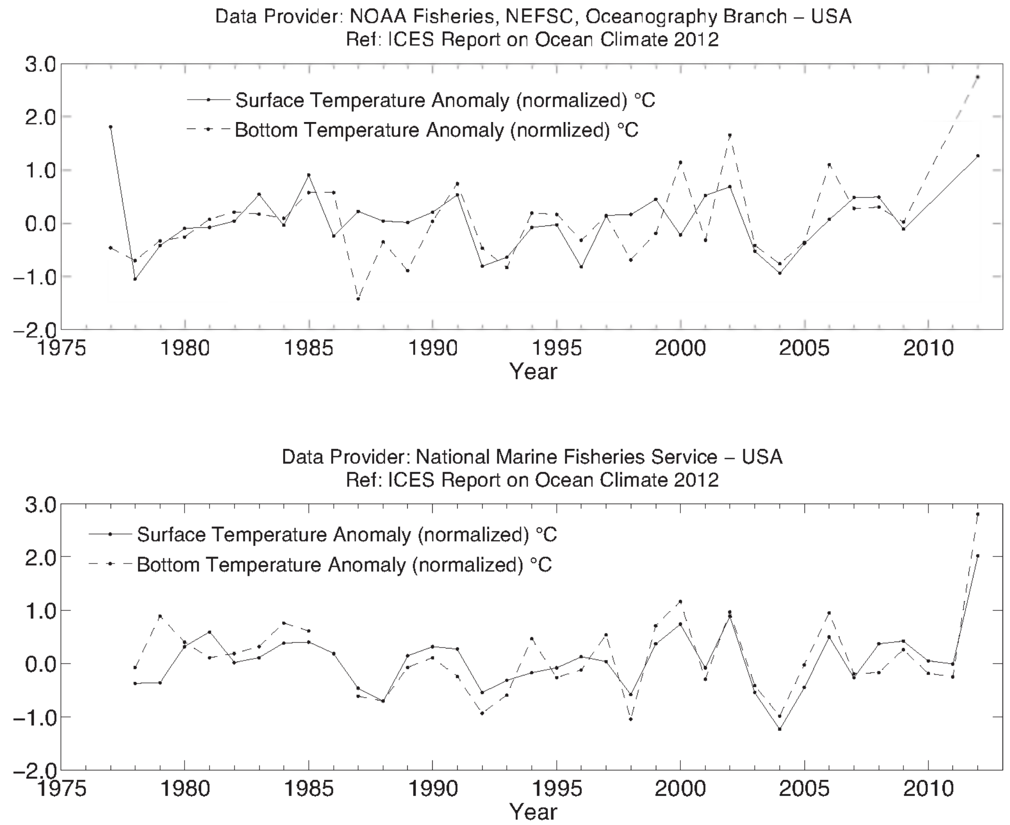


Figure 27.
Area 2c – Mid-Atlantic Bight. Surface and bottom temperature anomalies across the western (top panel) and eastern (bottom panel) Gulf of Maine (relative to the base period of 1981–2010) from XBT measurements. The data represent the average conditions at the surface and bottom to the west (east) of 68°W.

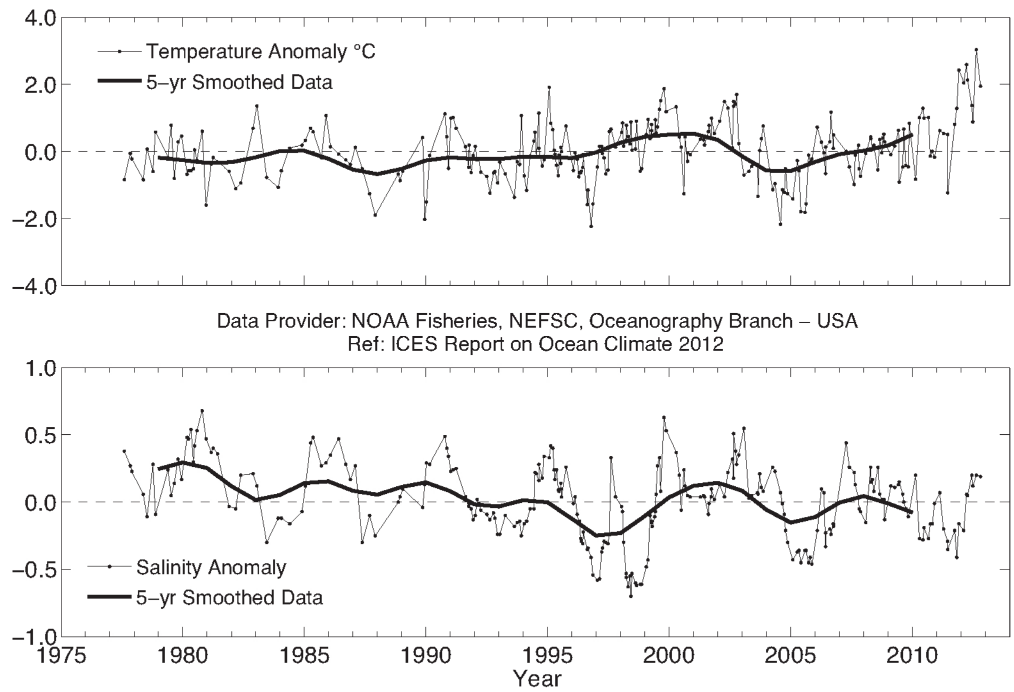


Figure 28.
Area 2c – Mid-Atlantic Bight. Time-series plots of 0–30 m averaged temperature (upper panel) and salinity (lower panel) anomalies on northwest Georges Bank. Anomalies are calculated relative to the period 1981–2010 using hydrographic data from shelf-wide surveys.

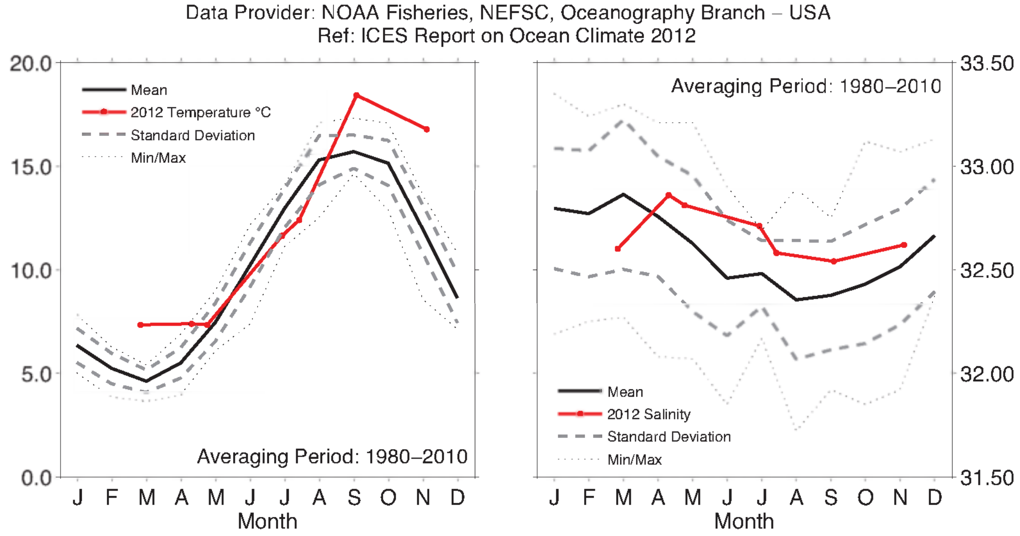


Figure 29.

Area 2c – Mid-Atlantic Bight. 2012 monthly temperatures (0–30 m) at northwest Georges Bank, relative to the annual cycle calculated 1981–2010. The envelope corresponding to the monthly range and one s.d. are shown.

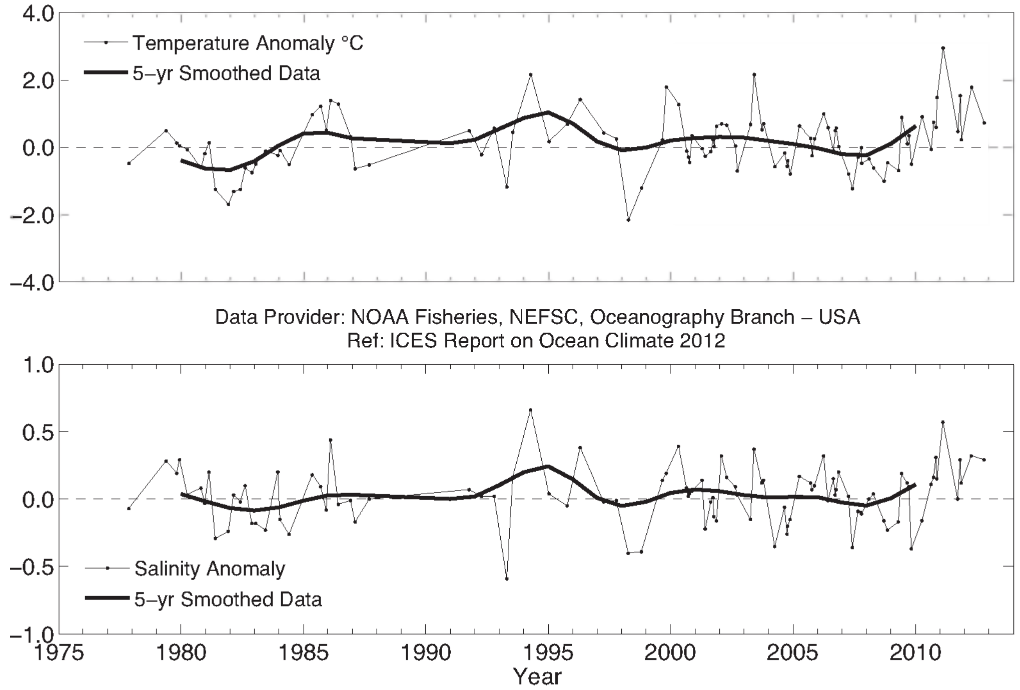


Figure 30.

Area 2c – Mid-Atlantic Bight. Time-series plots of 150–200 m averaged temperature (upper panel) and salinity (lower panel) anomalies in the Northeast Channel. Anomalies are calculated relative to the period 1981–2010 using hydrographic data from shelf-wide surveys.

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 (6–8°C), a branch of the North Atlantic Current, flows from the south, and the cold East Greenland and East Icelandic currents (–1°C to 2°C) flow from the north. Deep and bottom currents in the seas around Iceland are principally the overflow of cold water from the Nordic seas and the Arctic Ocean over the submarine ridges into the North Atlantic.

Hydrographic conditions in Icelandic waters are generally closely related to 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 2012, mean air temperature in the south (Reykjavik) and north (Akureyri) was above the long-term average. The temperature in the Atlantic water from the south remained at high levels similar to previous years; whilst above the long-term mean, the salinity was somewhat lower in 2012 than it had been in 2009–2010. Salinity and temperature in the East Icelandic Current in spring 2011 were both above average. North of Iceland in 2011 and 2012 upper-layer temperatures were near the long-term mean throughout the year, while salinity was below the long-term mean for most of the year, rising above it in winter 2013.

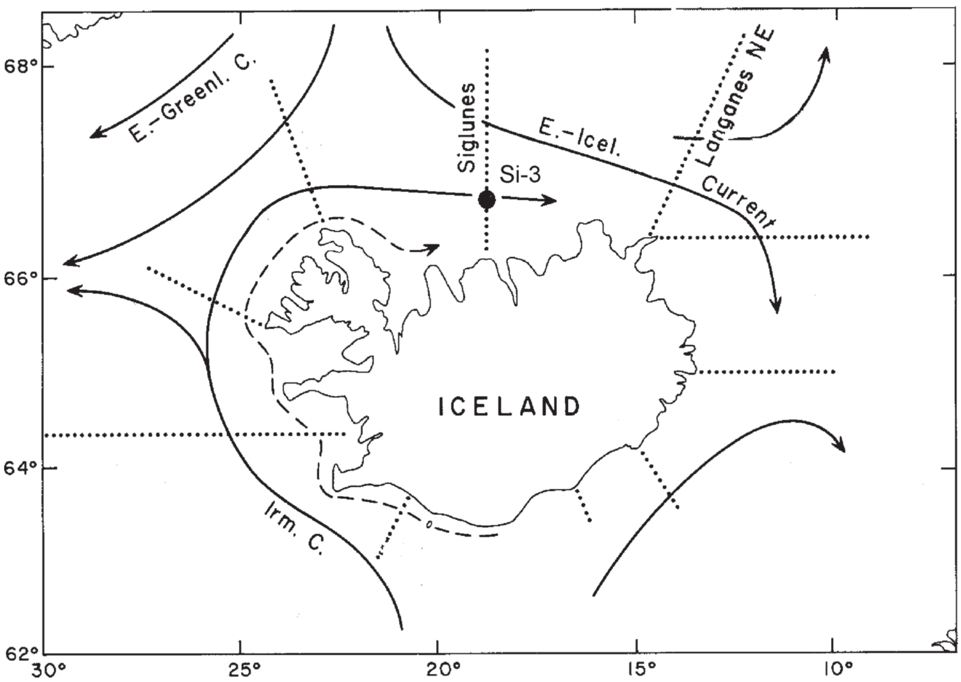


Figure 31.
Area 3 – Icelandic waters. Main currents and location of standard sections in Icelandic waters.

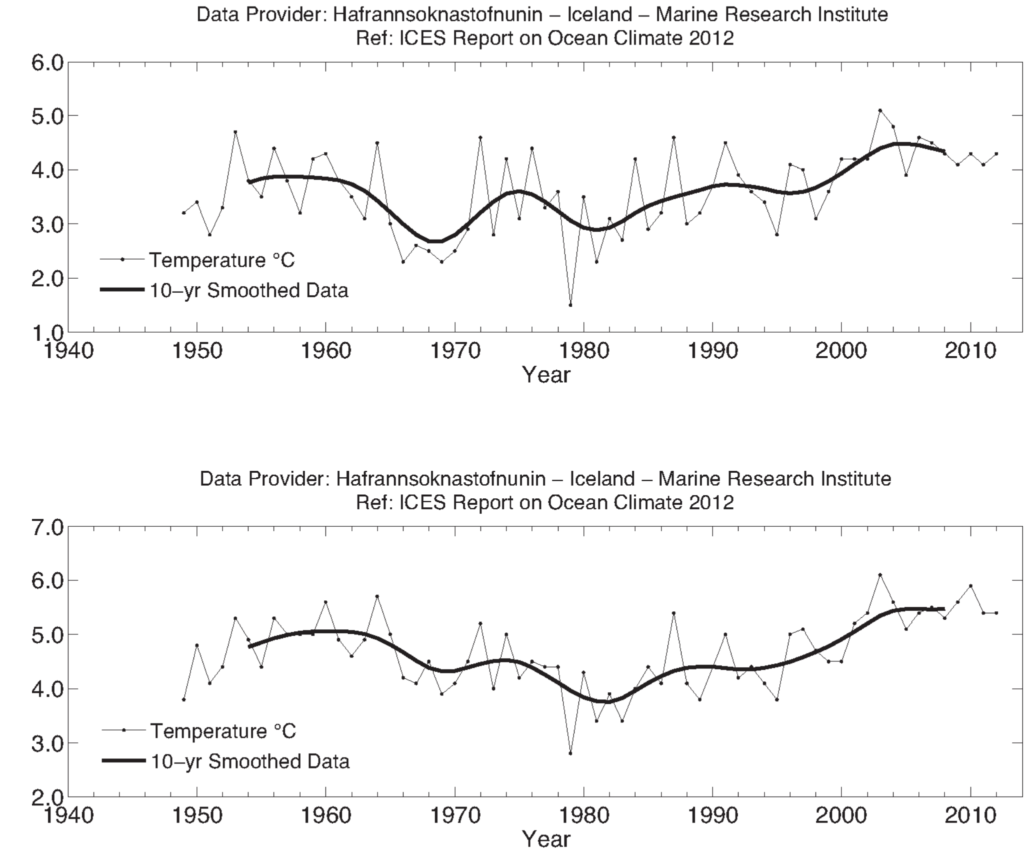


Figure 32.
Area 3 – Icelandic waters. Mean annual air temperature at Reykjavik (upper panel) and Akureyri (lower panel).

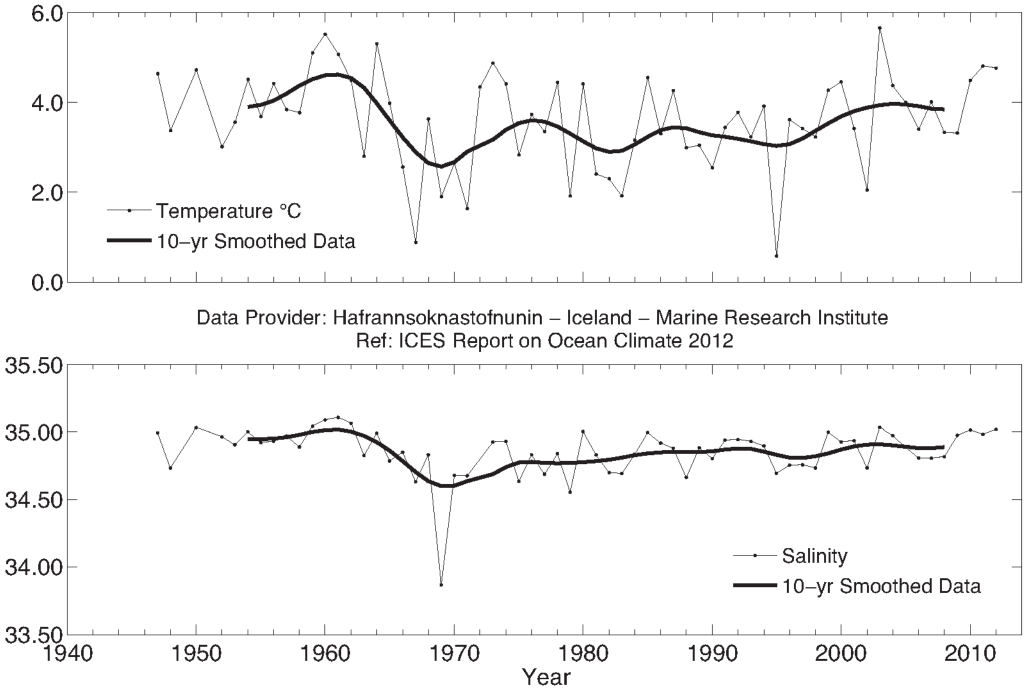


Figure 33.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 50–150 m at Siglunes Stations 2–4 in North Icelandic waters.

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.

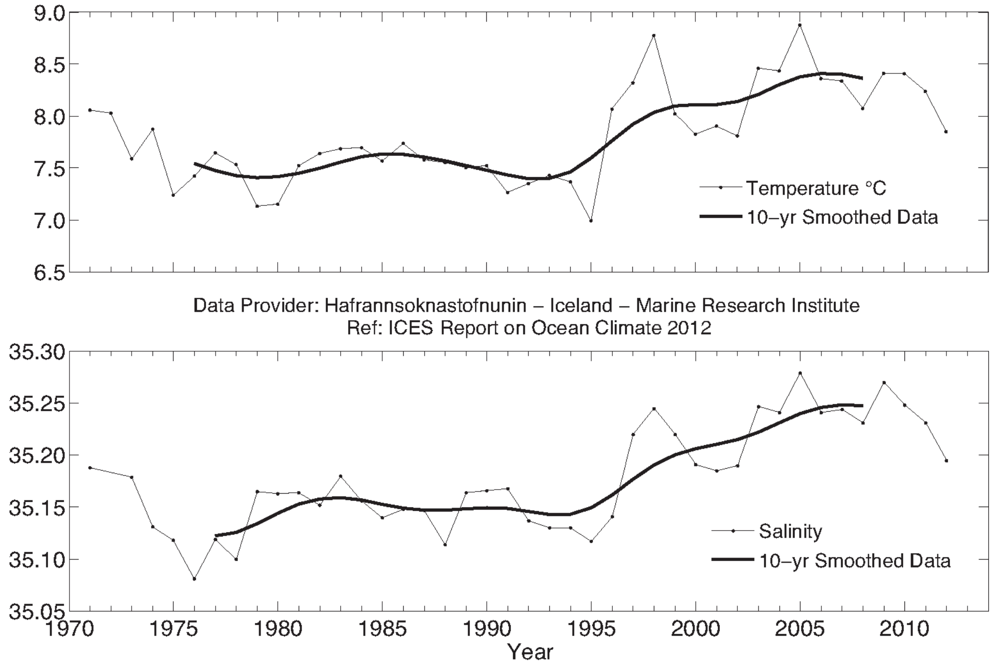
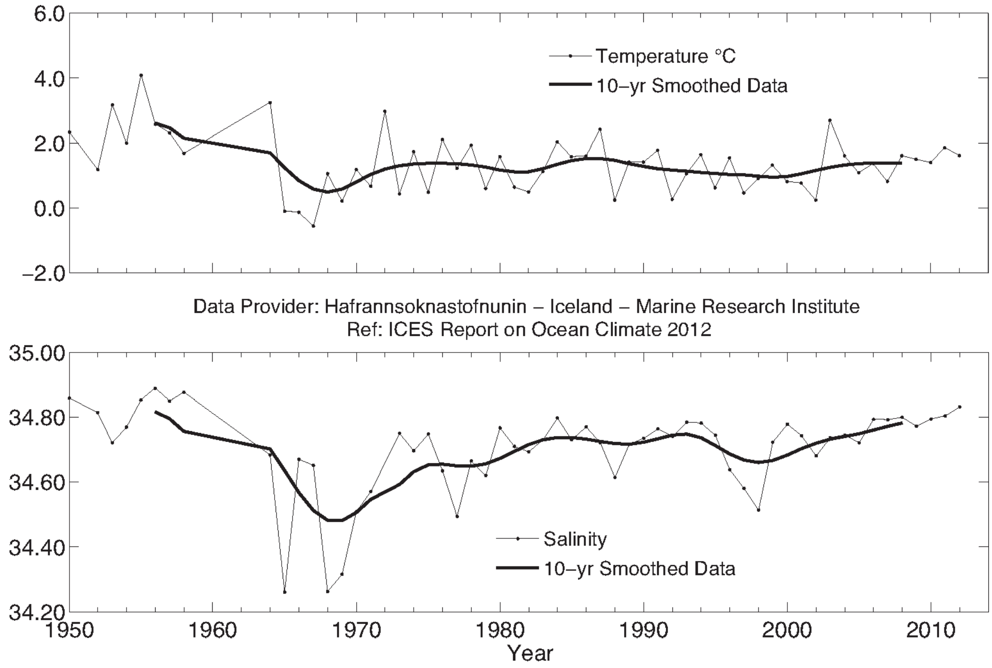


Figure 35.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 0–50 m in the East Icelandic Current (Langanes Stations 2–6).



4.7 Area 4 – Bay of Biscay and eastern North Atlantic

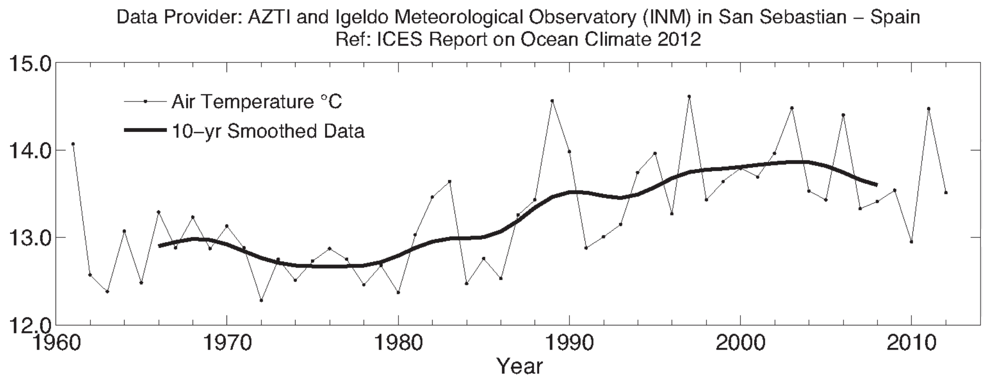
The Bay of Biscay, located in the eastern North Atlantic at the northeastern edge of the subtropical anti-cyclonic gyre, is almost an adjacent sea with relatively weak anti-cyclonic circulation. Shelf and slope currents are important in the system, characterized by coastal upwelling events in spring–summer and the dominance of a geostrophic balanced poleward flow (known as the Iberian Poleward Current) in autumn and winter.

From an atmospheric point of view, the year 2012 can be considered warm with respect to the long-term mean (since the 1960s) across the Iberian Peninsula and southern Bay of Biscay, but average with respect to the three most recent decades (1981–2010). Average temperatures at Santander and San Sebastian meteorological stations were within ±0.1°C of the 1981–2010 average. The seasonal cycle showed warm conditions except during winter. February was the only month that showed notably cold conditions. SST yielded slightly warmer-than-average values year-round despite late winter-early spring values that were near-average. Due to the previous warm ocean state, atmospheric cold spells around February could only cause cold SST anomalies in the southeastern-most portion of Biscay.

Subsurface structure was conditioned by strong intrusions of southern-origin waters along the slope – these being most evident in early winter 2012 – and weak freshwater influence from the discharge of major French rivers. The combination of these features resulted, for the upper ocean (0–300 dbar-influenced by the mixed-layer development), in a year with the highest values of salinity on record (compaired to 2011) and warmer-than-average temperatures.

Below the depth of the maximum development of the winter mixed layer, central waters continued the long-term warming trend and salinity increase after the short-term cooling and freshening observed in 2009. The temperature and salinity of ENACW modal waters were at the highest level of the series. Deeper, at the level of the Mediterranean Water, the water mass properties continued to be generally stable from the mid-2000s, with 2012 showing a slight freshening of its core, (as had already been observed in 2011).

TEMPERATURES REMAINED WARMER THAN AVERAGE, AND A COMBINATION OF SOUTHERN-ORIGIN WATERS AND DRY WEATHER MAINTAINED RECORD-HIGH SALINITY FOR A SECOND YEAR.



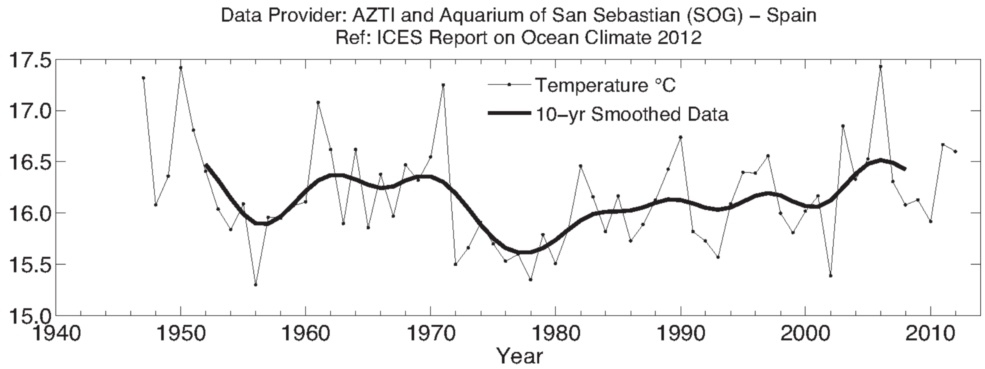


Figure 36.
Area 4 – Bay of Biscay and eastern Atlantic. Sea surface temperature (upper panel) and air temperature (lower panel) at San Sebastian (43°18.5′N 02°2.37′W).

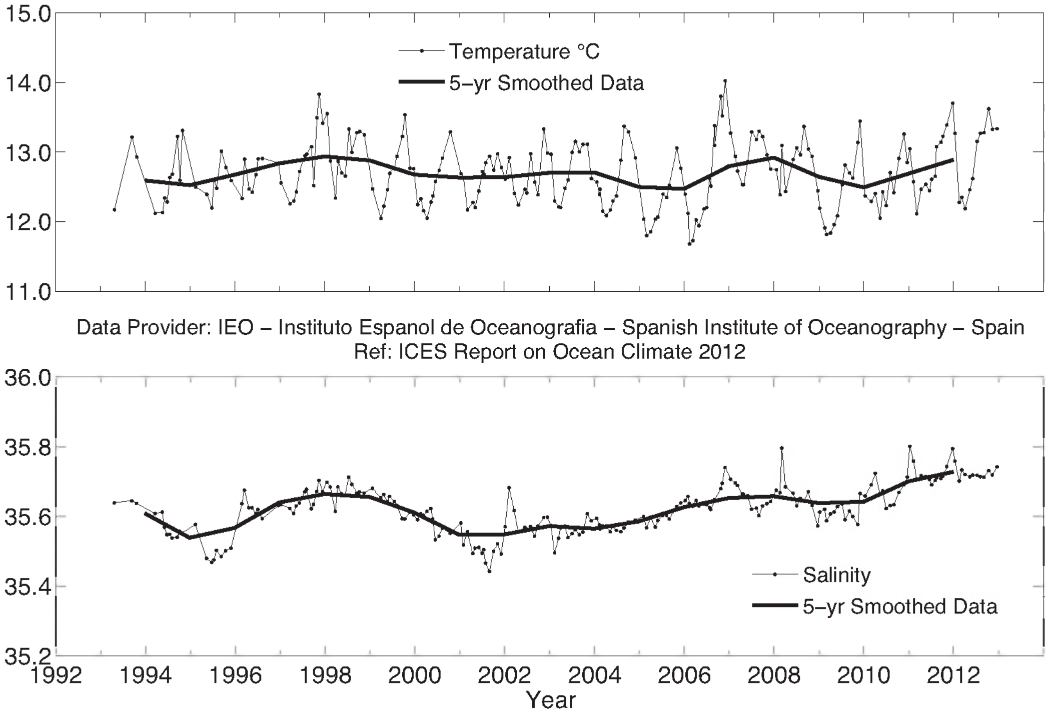


Figure 37.
Area 4 – Bay of Biscay and eastern North Atlantic. Potential temperature (upper panel) and salinity (lower panel) at Santander Station 6 (5–300 m).

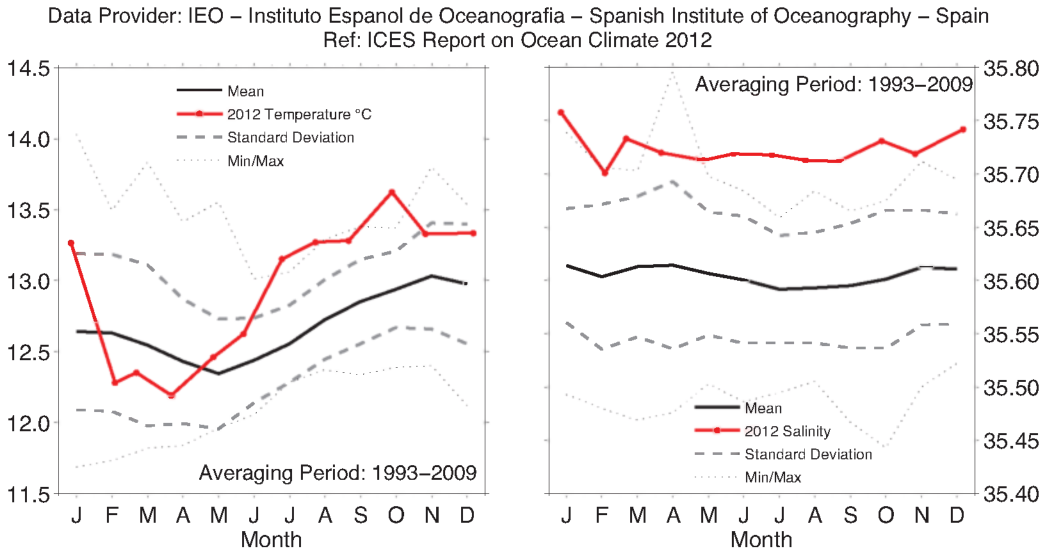


Figure 38.
Area 4 – Bay of Biscay and eastern North Atlantic. 2012 monthly temperature (left panel) and salinity (right panel) at Santander Station 6 (5–300 m).

4.8 Area 4b – Northwest European continental shelf

North coast of Brittany

Measurements are collected twice a month at a coastal station on the north 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 English Channel waters. Bottom depth is ca. 60 m, and the water column is well mixed for most of the surveys.

During winter and early spring, temperatures were higher (from +1.21°C in January to +0.40°C in April) than the average values (1998–2010) observed at the Astan station, and higher than those observed during the previous three winters. During late spring and summer, temperatures were close to the average, becoming lower than average in late autumn (–0.30°C in November). Salinity in 2012 remained relatively constant (>35.3) and was higher than the long-term mean for the first half of the year without the typical minimum usually observed in March (+0.32) and April at Astan due to a dry winter with low precipitation and a resultant reduced influence of the river inputs in the Western Channel. As usually observed in this area, Western Channel waters were well-mixed over the entire water column during the whole year since no temperature or salinity differences between surface and bottom waters were observed.

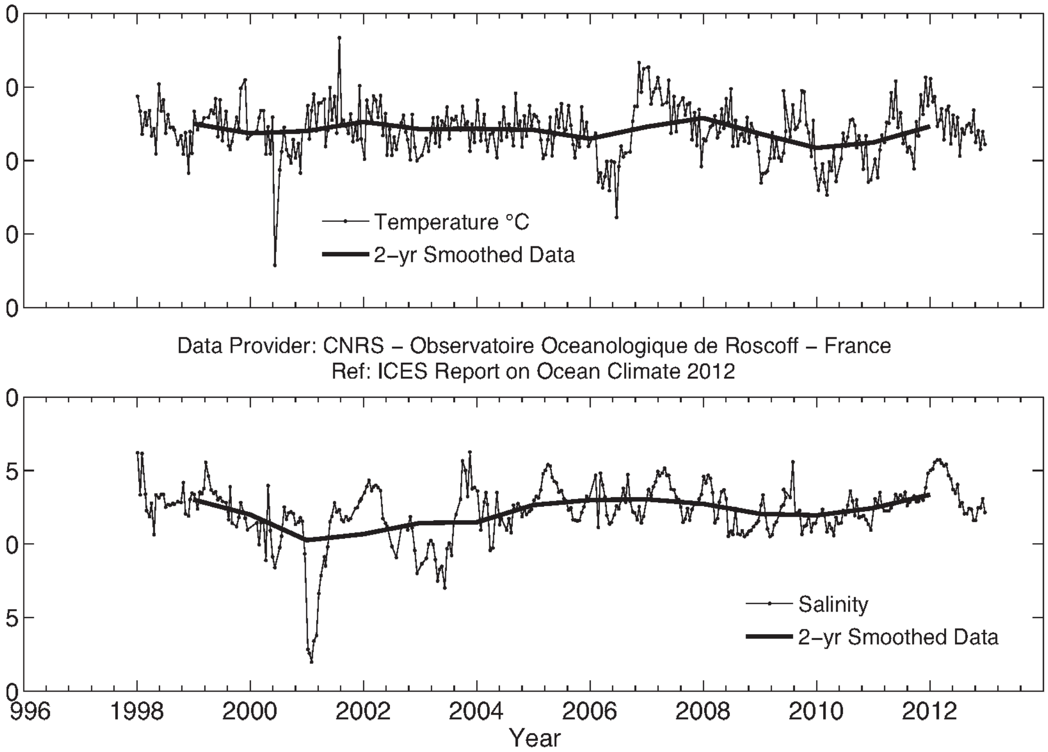
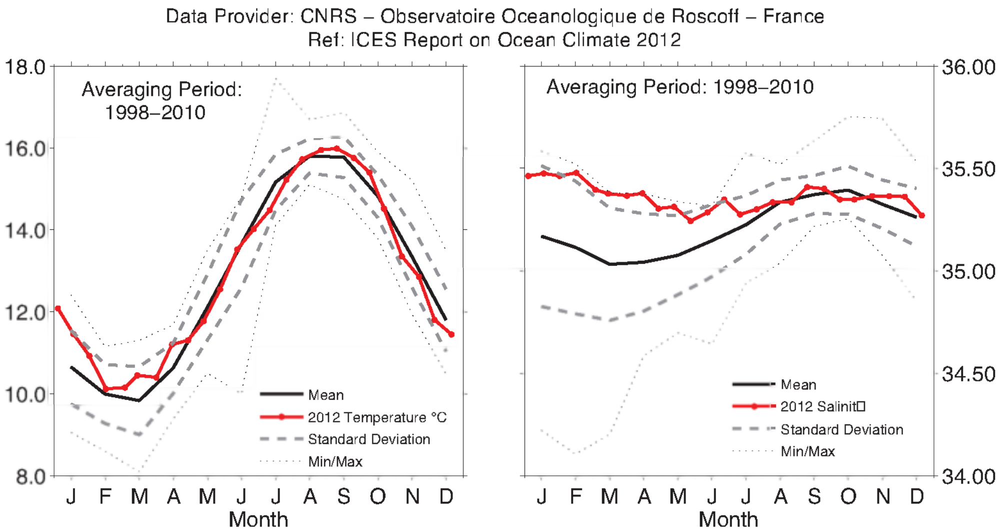


Figure 39.
Area 4b – Northwest European continental shelf. Temperature (upper panel) and salinity (lower panel) anomalies of surface water at the Astan station (48.77°N 3.94°W) base period 1998–2010.

Figure 40.
Area 4b – Northwest European continental shelf. Monthly average seasonal cycle with 2012 temperature (left panel) and salinity (right panel) observations of surface water at the Astan station (48.77°N 3.94°W) (NB: Month markers are placed mid-month).



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 seabed is mainly sand, resulting in a low bottom stress (1–2 ergs cm^{-2} s^{-1}). The station may be described as oceanic with the development of a seasonal thermocline; 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 unbroken, apart from the gaps for the two world wars and a hiatus in funding between 1985 and 2002. The data takes 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 utilized.

The time-series demonstrates considerable interannual variability in temperature. In 2012, Station E1 was sampled on 19 occasions, with at least one sample in each month. The average temperature of the upper 40 m of the water column was relatively warm early in the year, but close to average subsequently. The minimum average temperature (end of February) was 9.94°C when the water column was well mixed. Thermal stratification shallower than 30 m was evident between June and September and was strongest at the end of July when the surface was 4.36°C warmer than water in the bottom mixed layer. The maximum average temperature of the upper 40 m (early September) was 15.67°C, whilst the surface itself peaked at 17.18°C slightly earlier (late August).

The salinity recorded between January and August was generally higher than the long-term mean and particularly so in March and April 2012. The final four months of the year showed fresher conditions close to or below the long-term values.

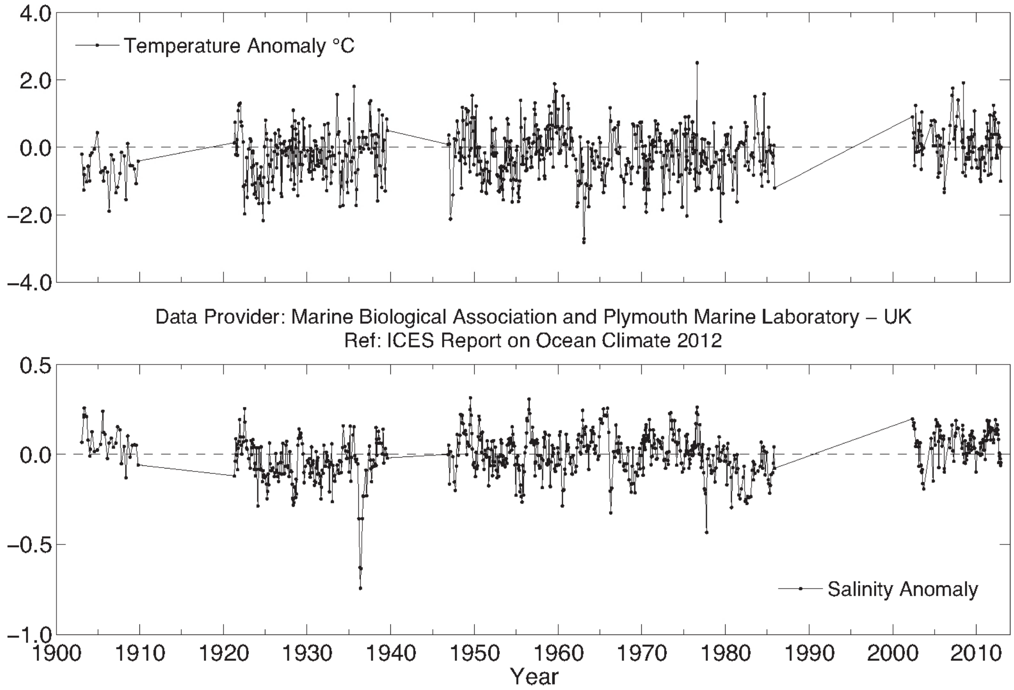


Figure 41.
Area 4b – Northwest European continental shelf. Temperature (upper panel) and salinity (lower panel) anomalies of surface (0–40 m) water at Station E1 in the western English Channel (50.03°N 4.37°W) (NB: Month markers are placed mid-month).

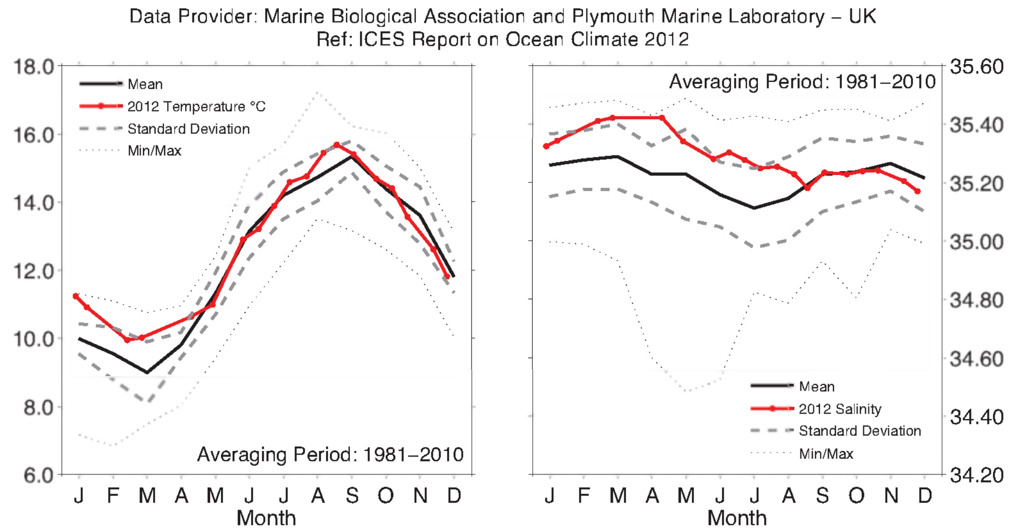


Figure 42.
Area 4b – Northwest European continental shelf. Monthly average seasonal cycle with 2012 temperature (left panel) and salinity (right panel) observations of surface (0–40 m) water at Station E1 in the western English Channel (50.03°N 4.37°W) (NB: Month markers are placed mid-month).

THE SALINITY RECORDED BETWEEN JANUARY AND AUGUST WAS GENERALLY HIGHER THAN THE LONG-TERM MEAN AND PARTICULARLYSO IN MARCH AND APRIL 2012.

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 a SBE 39 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.

The sea surface temperature at Malin Head for 2012 was higher than average until May, but then lower than average until August (with no data after this month). 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 2012, the buoy was out of operation until June. Temperatures were below the time-series mean (2003–2011) from June until the end of the year, with the difference being greater than 1 s.d. from October onwards.

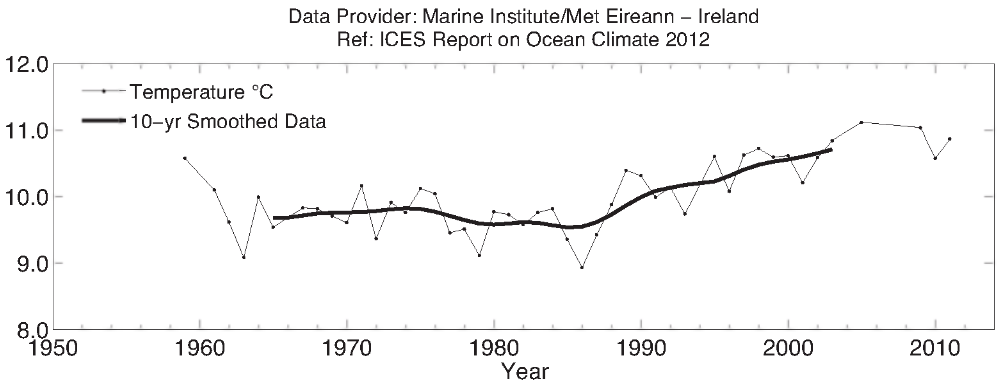


Figure 43.
Area 4b – Northwest European continental shelf. Temperature at the Malin Head coastal station (55.39°N 7.38°W).

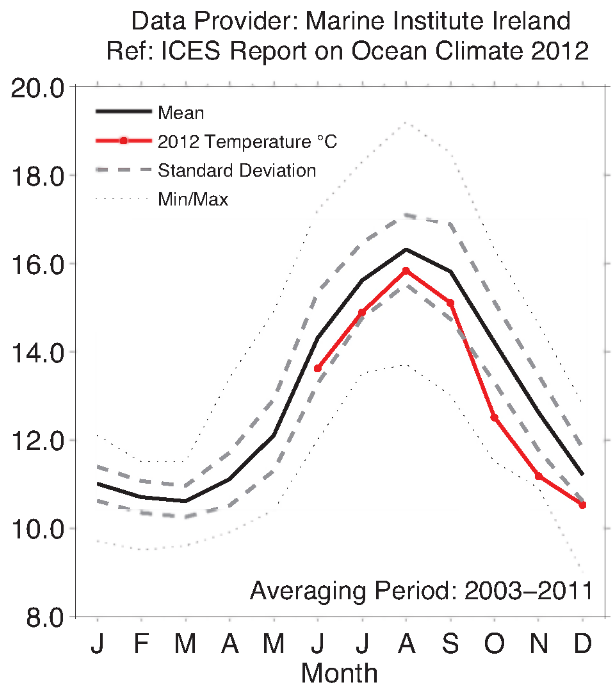


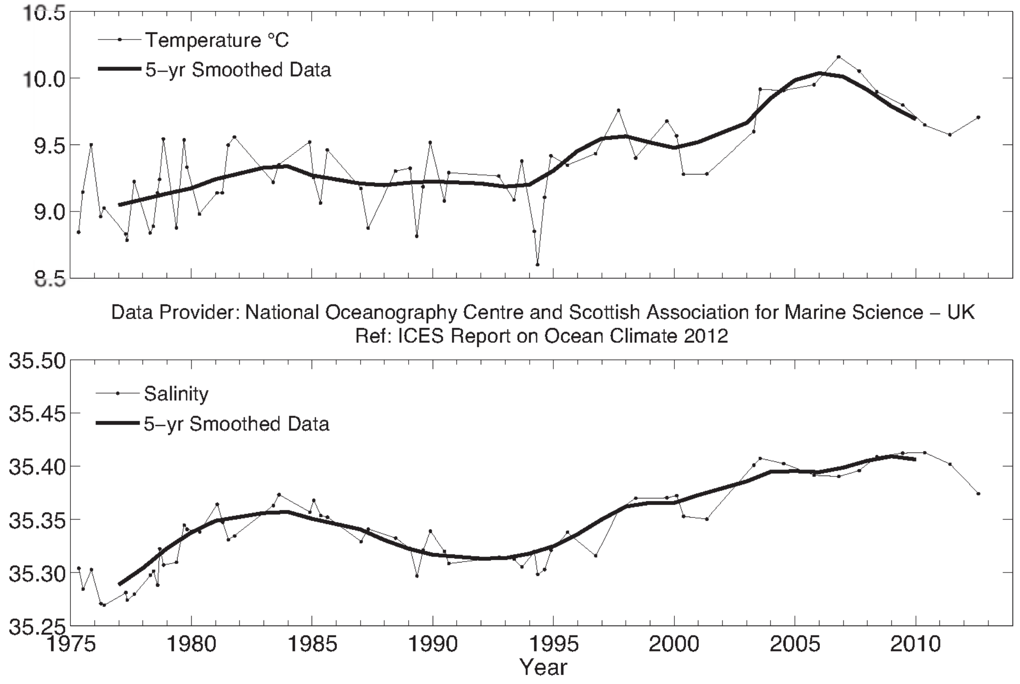
Figure 44.
Area 4b – Northwest European continental shelf. Monthly average seasonal cycle with 2012 monthly temperature at the M3 Weather Buoy southwest of Ireland (51.22°N 10.55°W). No salinity data were collected at this station.

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.

The potential temperature of the upper 800 m remains higher than the long-term mean. The 5-year run of years cooler than the previous year (from the peak of 10.09°C in 2006) ended as the temperature rose from 9.58°C in 2011 to 9.71°C in 2012. The equivalent salinity, though still higher than the long-term mean, was lower than observed at any time in the previous ten years, falling from 35.402 in 2011 to 35.374 in 2012. These observations suggest that the Subpolar Gyre may be expanding in the Northeast Atlantic.

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



IN 2012, THE UPPER 800 M OF THE ROCKALL TROUGH WAS FRESHER THAN AT ANY TIME IN THE PREVIOUS DECADE.

4.10 Area 5b – Irminger Sea

The Irminger Sea is the ocean basin between southern Greenland, the Reykjanes Ridge, and Iceland. This area forms part of the North Atlantic subarctic cyclonic gyre. Due to this gyre, the exchange of water between the Irminger and Labrador seas proceeds relatively fast. In the bottom layers of the Irminger Sea, cold water originating from the (sub)arctic seas flows from Denmark Strait southwards over 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 shows 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.

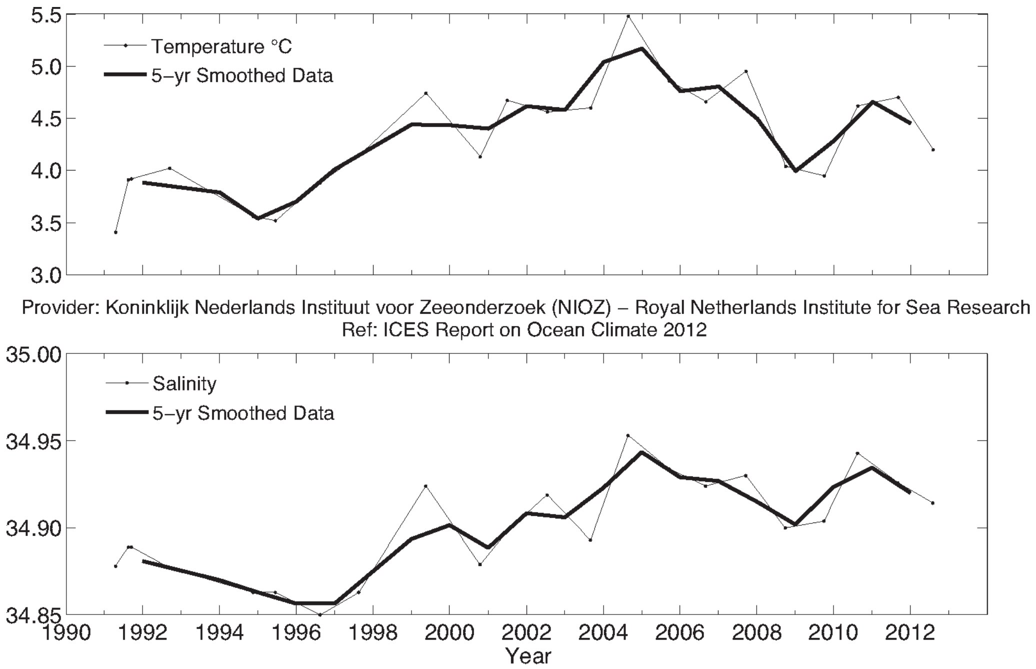


Figure 46.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Subpolar Mode Water in the central Irminger Sea (averaged over 200–400 m).

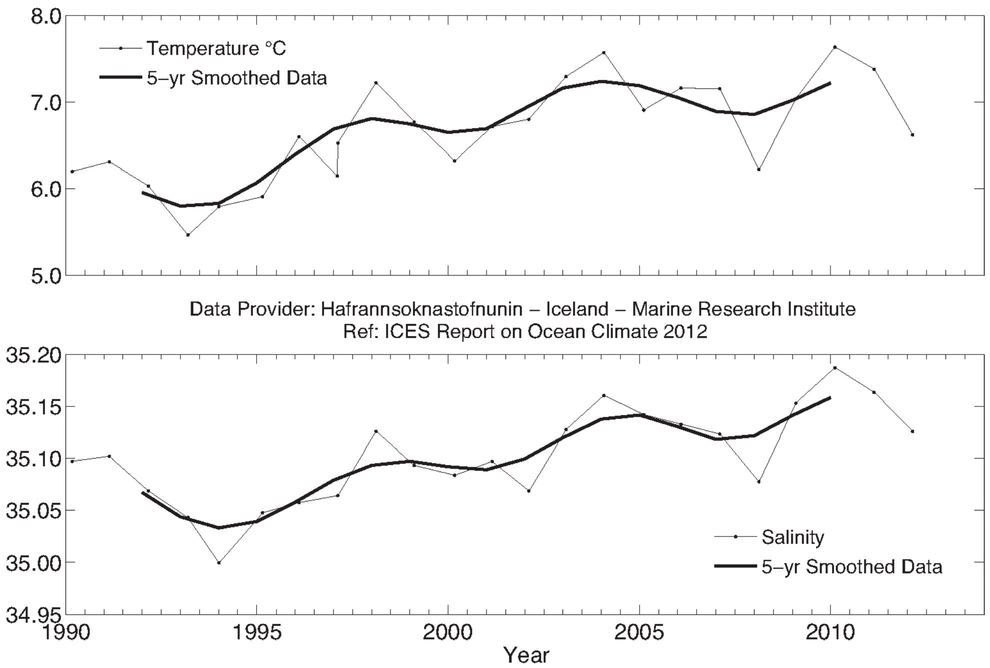


Figure 47.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Subpolar Mode Water in the northern Irminger Sea (Station FX9, 64.33°N 28°W), averaged over 200–500 m).

4.11 Areas 6 and 7 – Faroese waters 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 sampled by 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 sampled within the Faroe–Shetland Channel as modified North Atlantic Water (MNAW).

Farther to the east, the continental slope current flows along the edge of the northwest European continental shelf; originating in the southern Rockall Trough, it carries warm, saline Atlantic Water (AW) into the Faroe–Shetland Channel. A proportion of this Atlantic Water crosses onto the shelf itself and enters the North Sea, where it is diluted with coastal water and eventually leaves in the Norwegian coastal current. The remainder enters the Norwegian Sea 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 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 from 1975–1980.

After the record-high salinities observed in the Faroe Bank Channel and the Faroe Current in November 2009, salinities have been decreasing, and this continued in 2012. This was most pronounced in the Faroe Bank Channel, where both salinities and temperatures were the lowest since 2002. Temperatures in the Faroe Current decreased only slightly in 2012 compared to 2011. On the Faroe Shelf, the annual average temperature decreased in 2012, although spring was particularly warm. Conditions thus still remain 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.

Temperature and salinity of the surface waters of the Faroe–Shetland Channel have generally increased over the past two decades. Water on the western slopes of the Channel, known as modified North Atlantic Water, reached record-high temperature and salinity in 2010. This water is thought to have passed into the Faroe–Shetland Channel from north of the Faroes. On the eastern side of the Faroe–Shetland Channel, both salinity and temperature are generally increasing, although slight decreases were observed in 2012.

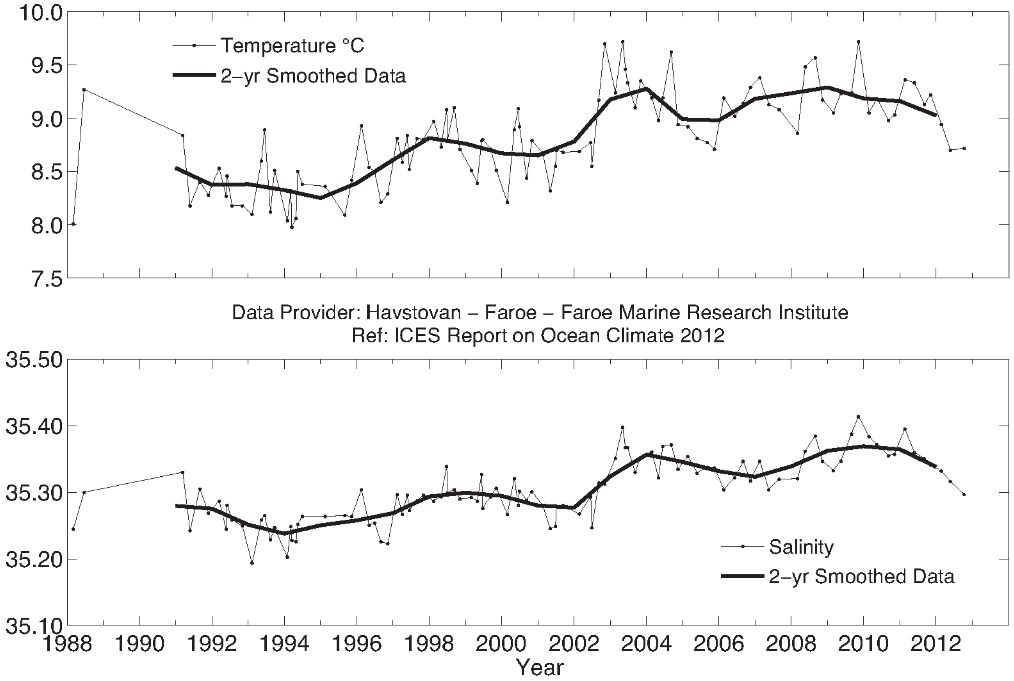


Figure 48. *Areas 6 and 7 – Faroe Bank Channel. Temperature (upper panel) and salinity (lower panel) in the high-salinity core of the Atlantic Water over the Faroe Bank Channel (maximum salinity averaged over a 50 m deep layer).*

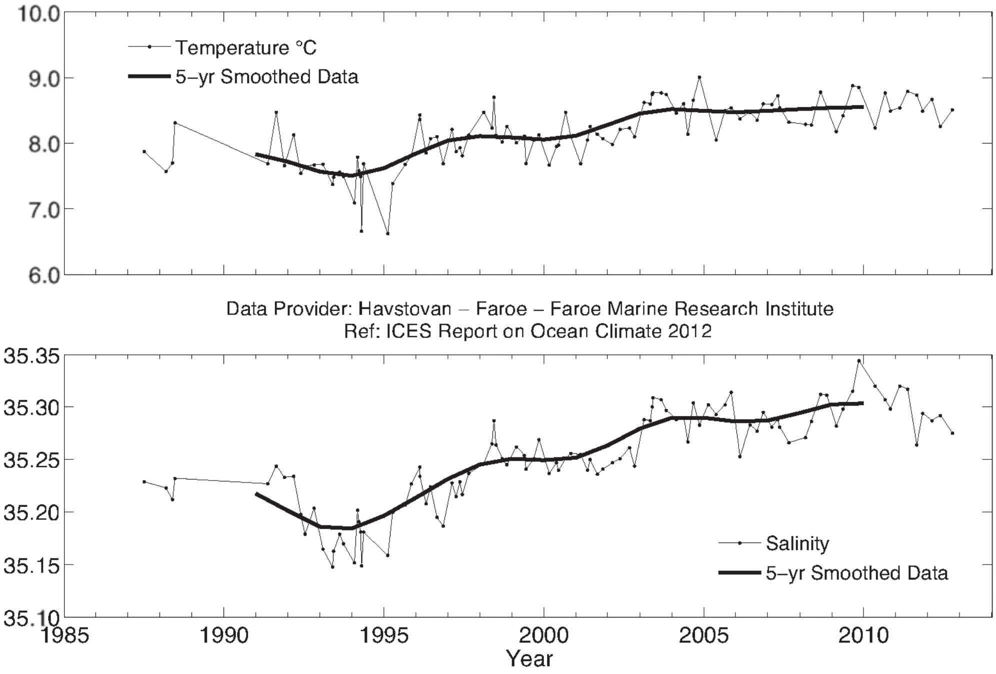


Figure 49. Areas 6 and 7 – Faroe Current. Temperature (upper panel) and salinity (lower panel) in the high-salinity core of the Faroe Current north of the Faroes (maximum salinity averaged over a 50 m deep layer).

TEMPERATURES AND SALINITIES IN THE FAROE BANK CHANNEL DECREASED IN 2012 AND ARE NOW AS LOW AS IN 2002.

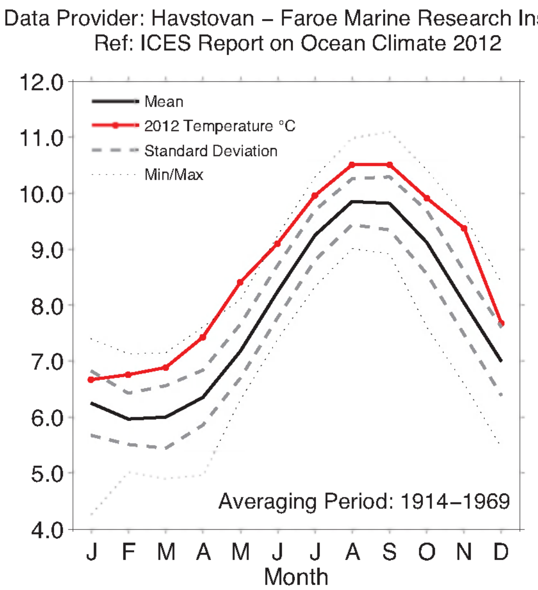


Figure 50. Areas 6 and 7 – Faroe Shelf. 2012 monthly temperature data from the Faroe coastal station at Oyrargjogv (62.12°N 7.17°W). Note the average values were calculated from the nearby station at Mykines (69.10°N 7.66°W).

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

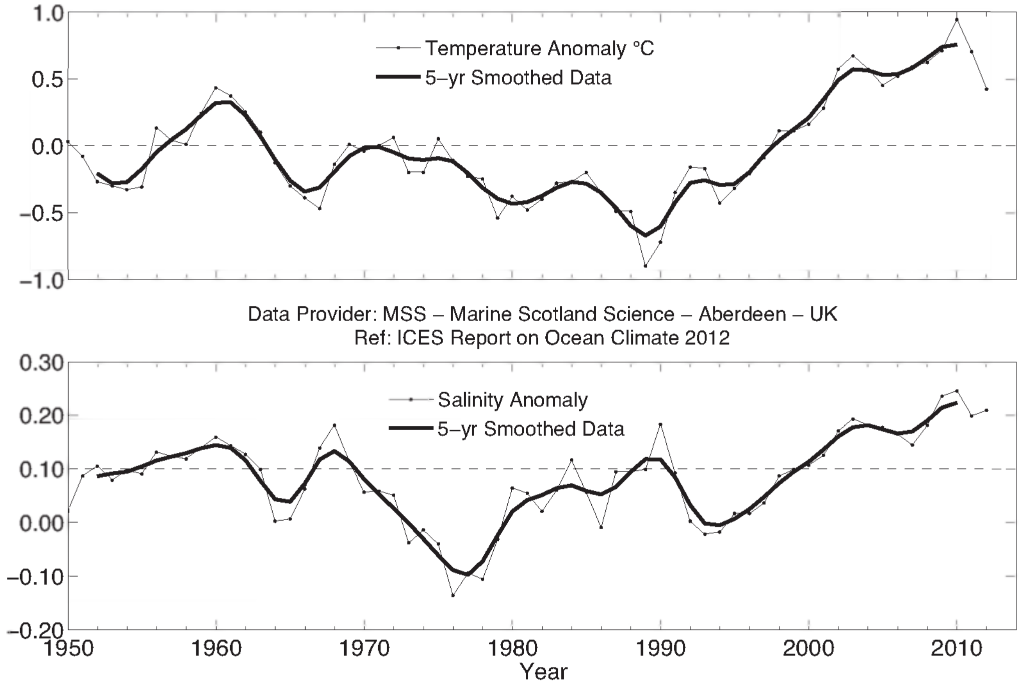
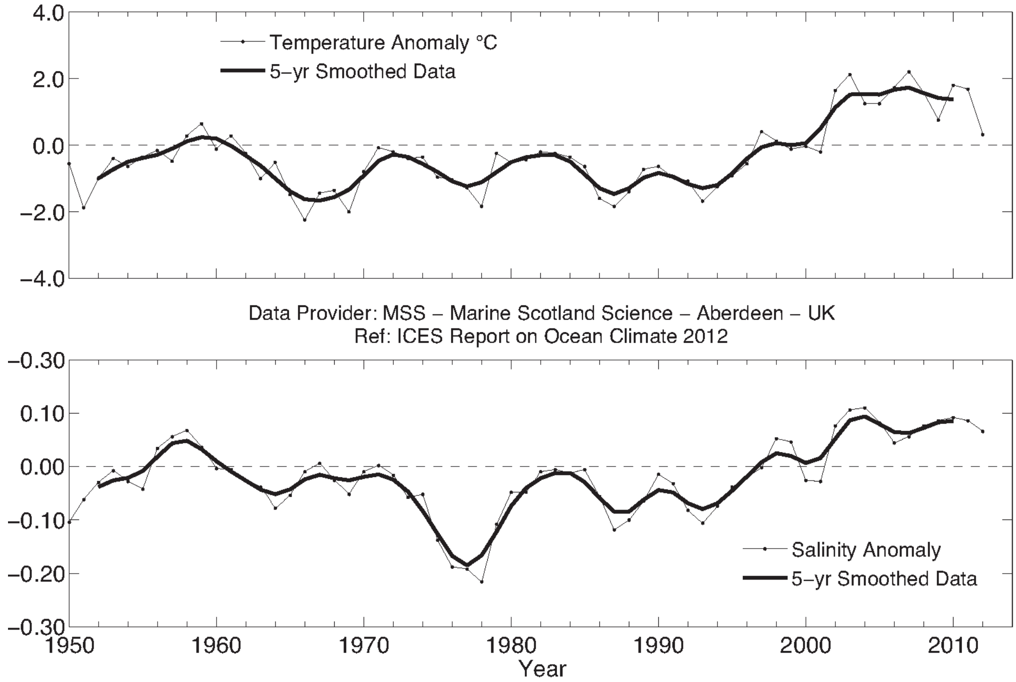


Figure 52.
Area 6 and 7 – Faroe–Shetland Channel. Temperature (upper panel) and salinity (lower panel) anomalies in the Atlantic Water in the Slope Current.



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. Inflow through the northern entrances (and, to a lesser degree, through the English Channel) can be strongly nfluenced by the NAO. Numerical-model simulations also demonstrate strong differences in the North Sea circulation, depending on the state of the NAO. The Atlantic Water mixes with river run-off and lower salinity Baltic outflow along the Norwegian coast. A balance of tidal mixing and local heating forces the development of a seasonal stratification from April/May to September in most parts of the North Sea.

High SST evident during autumn 2011 persisted into winter 2011/2012 and reached anomalies of up to +0.7°C (March). January, March, April, and August were all ≥0.5°C warmer than average (1981–2010). During autumn, cooling started along the southern part of the UK coast. The annually averaged SST anomaly for 2012 (+0.13°C) was close to that in 2011, and most months were close to average temperature.

The large-scale horizontal temperature distribution during summer in 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 Norwegian, Danish, and German coasts was about 1°C warmer than in 2011. Anomalies in the surface layer differ only about ±0.5°C from the reference period for the summer surveys (2000–2010, except 2002) while the bottom temperatures differ by up to ±1.5°C, with a positive anomaly in the eastern central North Sea and negative anomalies along the Danish, North Frisian, and UK coasts. As in 2011, the maximum difference between surface and bottom temperature is about 8°C, but the area with an 8°C difference is much greater than in 2011. The maximum of the vertical temperature gradient varies between 0.5 and 1.7°C m^{-1}, which is a much weaker gradient compared to previous years, when typical values were between 3 and 2.5°C m^{-1}. The maximum depth of the thermocline was about 38 m. Compared to 2011, the total heat content of 1.695×10^{21} J increased slightly and exceeds the reference mean of 1.631×10^{21} J.

The horizontal salinity distribution in 2012 was comparable to 2011, but with slightly higher salinity values in the southern North Sea. Compared to the summer survey reference period, the differences do not exceed ±0.5 in the bottom and surface layers. Along the Norwegian, Danish, and North Frisian coasts, the anomalies exceed –1 at the surface. The area with Atlantic Water (S >35) intruding from the northern boundary at the surface is clearly smaller compared to the two previous years, while the ribbon of low saline water < 34 parallel to the eastern coast is comparable to 2011 in the surface layer. Compared to 2011, the total salt content increased to 1.132×10^{12} t, which is 0.12 s.d. below the mean of the reference period.

Despite enhanced precipitation and snowfall during the 2011/2012 winter, the Elbe river run-off during January and March was slightly above the long-term (1971–2000) mean, though within the range of normal variability. During the rest of the year, the run-off volumes were slightly below the long-term mean. Also, the annual averaged run-off volume of about 20 km^3 $year^{-1}$ was slightly below the mean of the reference period 1971–2000.

Temperature and salinity at two positions in the northern North Sea illustrate conditions in the Atlantic inflow (Figure 54). The first (Location A) is at the near-bottom in the northwest 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 is generally about 1–2°C lower than at Location B, and salinity is slightly lower (0–0.2 fresher). Compared to the long-term mean (1981–2010), 2012 conditions at Location A were the warmest (+0.9°C) on record and fairly saline (+0.1) following cold (–0.27°C) and slightly saline (+0.03) conditions in 2011. At Location B, the temperature was near normal, with salinities high, but at a level typical since 2002. The stronger anomalies at Location A meant that conditions here were more similar to those at Location B than is normally evident.

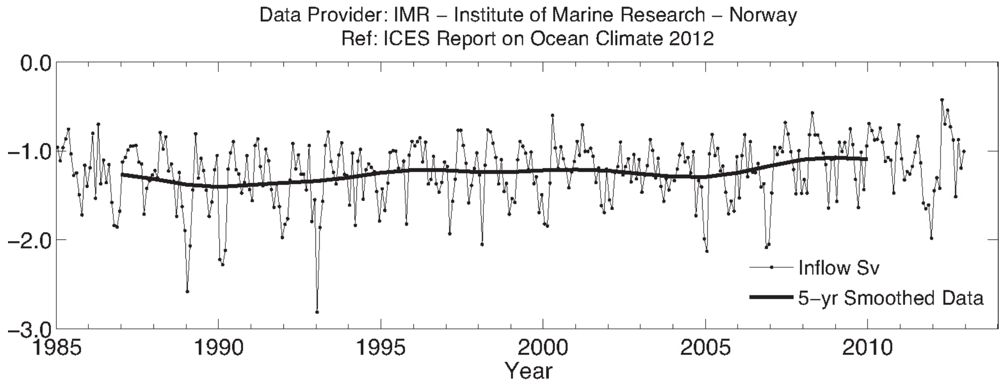


Figure 53.
Area 8 – Northern North Sea. Modelled monthly mean volume transport of AW into the northern and central North Sea southwards between the Orkney Islands and Utsire, Norway.

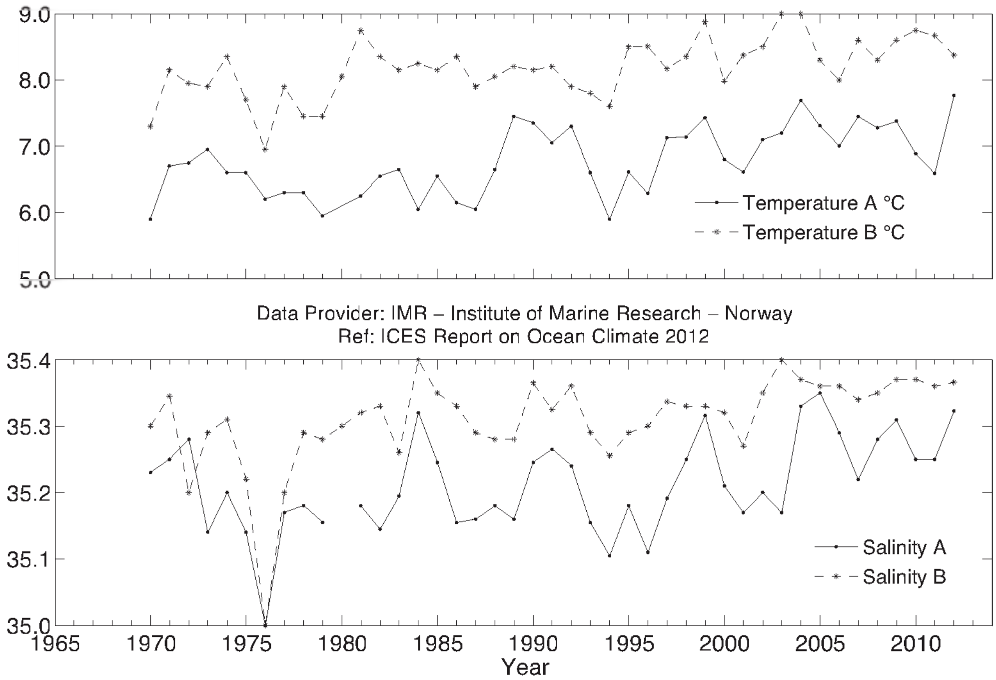


Figure 54.
Area 8 – Northern North Sea. Temperature (upper panel) and salinity (lower panel) near the seabed in the northwestern part of the North Sea (Location A) and in the core of AW at the western shelf edge of the Norwegian Trench (Location B) during summers 1970–2011.

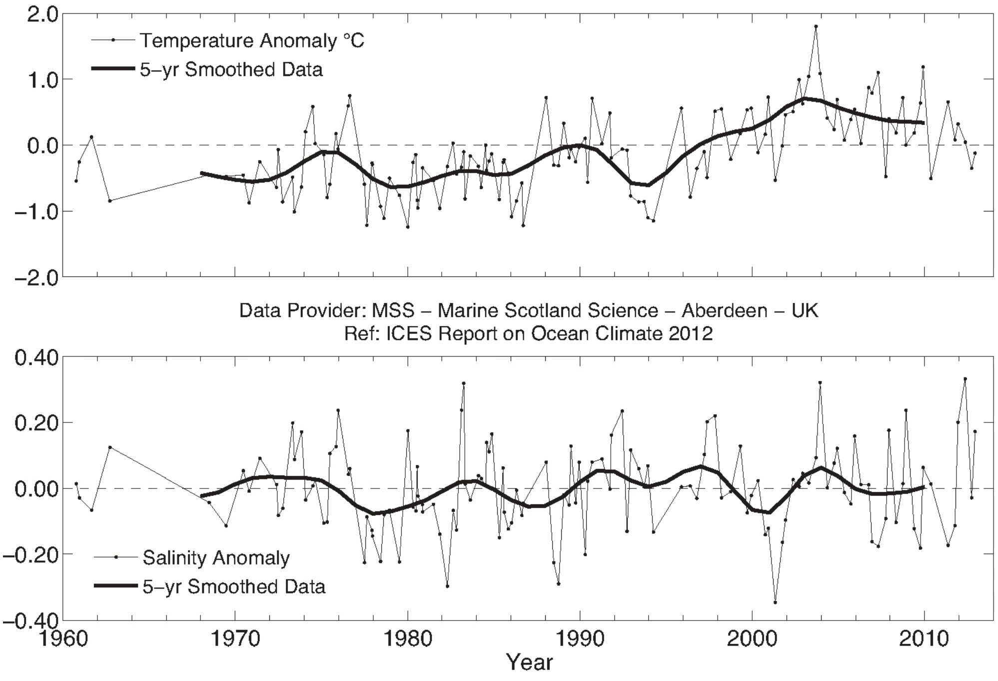


Figure 55.
Area 8 – Northern North Sea. Temperature (upper panel) and salinity (lower panel) anomalies in the Fair Isle Current entering the North Sea from the North Atlantic.

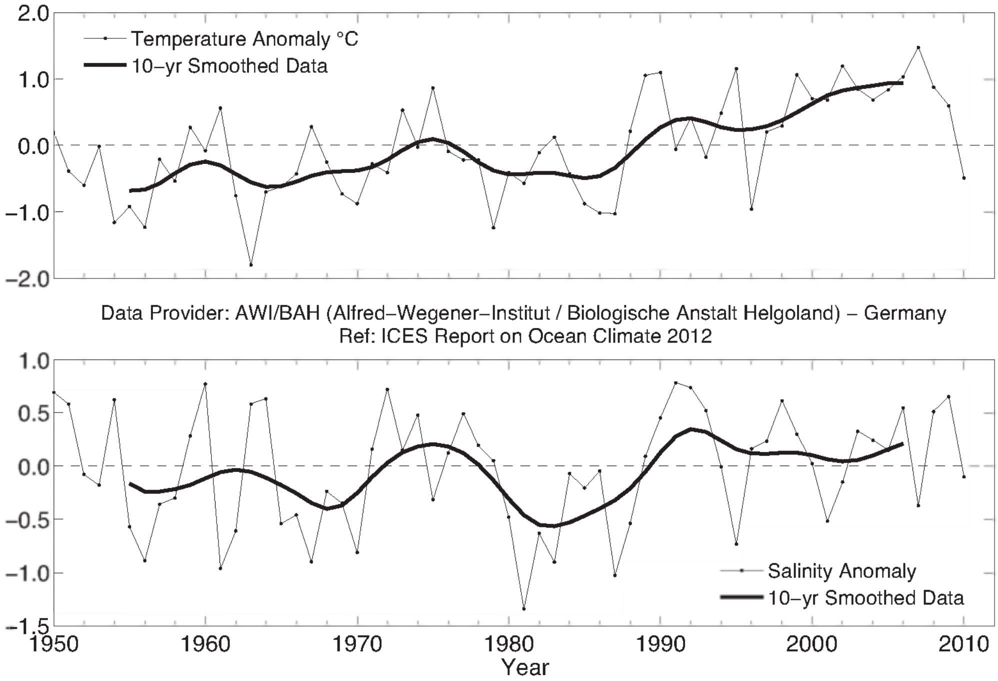


Figure 56.

Area 9 – Southern North Sea. Annual mean surface temperature (upper panel) and salinity (lower panel) anomalies at Station Helgoland Roads (data to 2010).

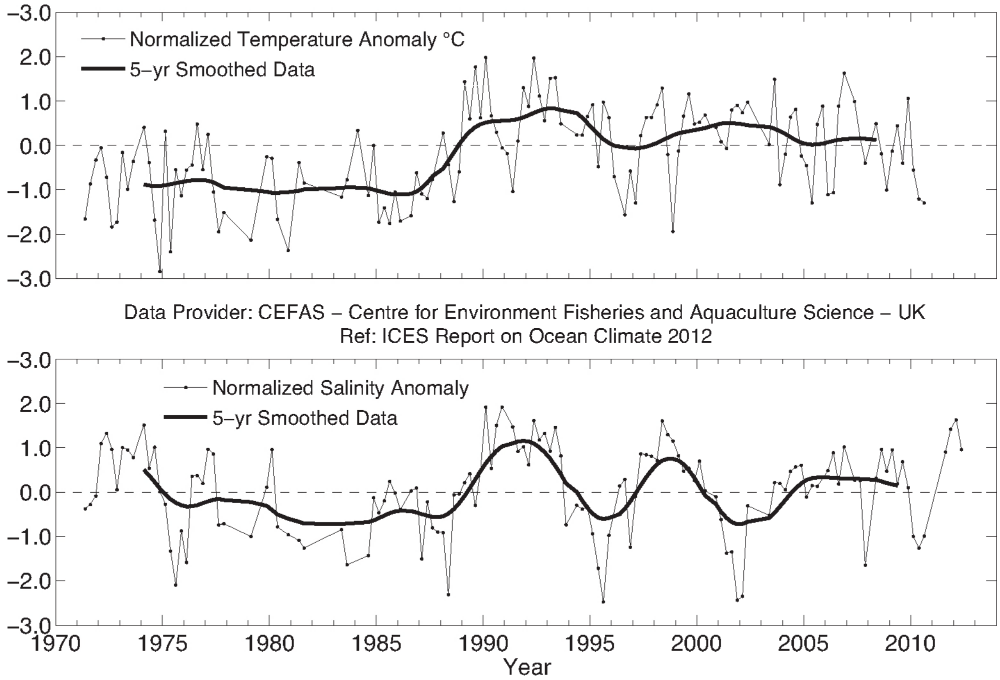
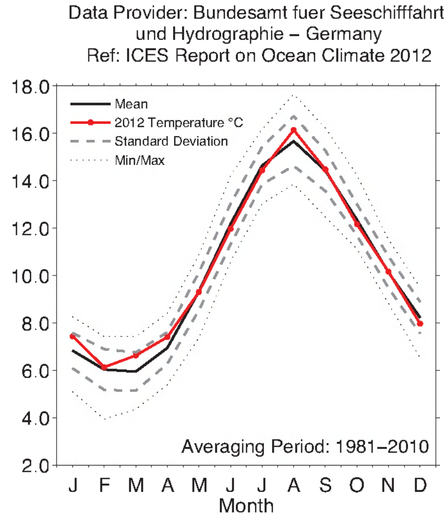


Figure 57.

Area 9 – Southern North Sea. Normalized sea surface temperature (upper panel) and salinity (lower panel) anomalies relative to 1981–2010, measured along 52°N by a regular ferry at six standard stations. The time-series reveals 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; 2012 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.

Owing to its central location relative to the Skagerrak, Kattegat, and Baltic, weather in Sweden can be taken as representative of the area. Weather in 2012 was characterized by wet conditions prevailing from April to the end of the year.

At some locations, precipitation was the highest measured since records began 150 years ago. The number of sun hours was, nevertheless, close to normal in most places, and the yearly mean temperature was 0.5°C above normal (compared to the period 1961–1990). 2012 was the second coldest year since 2000. March was unusually warm, while the coldest period was at the end of January and beginning of February, when most of the country was covered by snow. Storm winds occurred on only a few occasions.

Sea surface temperatures in Skagerrak and Kattegat were normal for most of the year. In the Kattegat, the surface temperature was somewhat above normal in January, but slightly below normal in the Skagerrak in December. In the southern part of the Baltic Proper, the surface water temperature was somewhat above normal at the beginning of the year and slightly below normal in October. For the rest of the year, surface temperatures were close to normal. Due to problems with vessels and permits, some stations in the Bornholm Basin and the Baltic Proper were not monitored at the normal frequency. However, when monitoring did take place, sea surface temperatures were normal. Sea surface salinities were close to normal most of the year in the Skagerrak and Kattegat. Somewhat lower-than-normal values were recorded in July, August, and December. In the Kattegat, lower-than-normal values were also found at some locations in spring. The southern part of the Baltic Proper had values close to normal, except for January and September, when they were above normal. For the Baltic Proper, sea surface salinities were at normal levels during monitoring. Some higher-than-normal values, coupled to upwelling events, were observed in spring at a station close to Öland.

Some minor inflows to the Baltic Sea occurred in February and December, thereby improving oxygen conditions somewhat in the deep water in the Arkona and Bornholm basins.

The ice season started about two weeks later than normal. At the beginning of February, the Bay of Bothnia was completely ice covered. Ice formation continued in the Bothnian Sea, the Gulf of Finland, the archipelagos of the Baltic Sea, and along the Swedish west coast. Maximum ice extent, 168 000 km^2, was reached on 11 February. The area was completely ice free by 20 May, about a week earlier than normal. The ice season was considered mild, with a shorter-than-normal duration. Although the maximum ice extent was about normal, its value was largely affected by the short-lived ice cover in Kattegat.

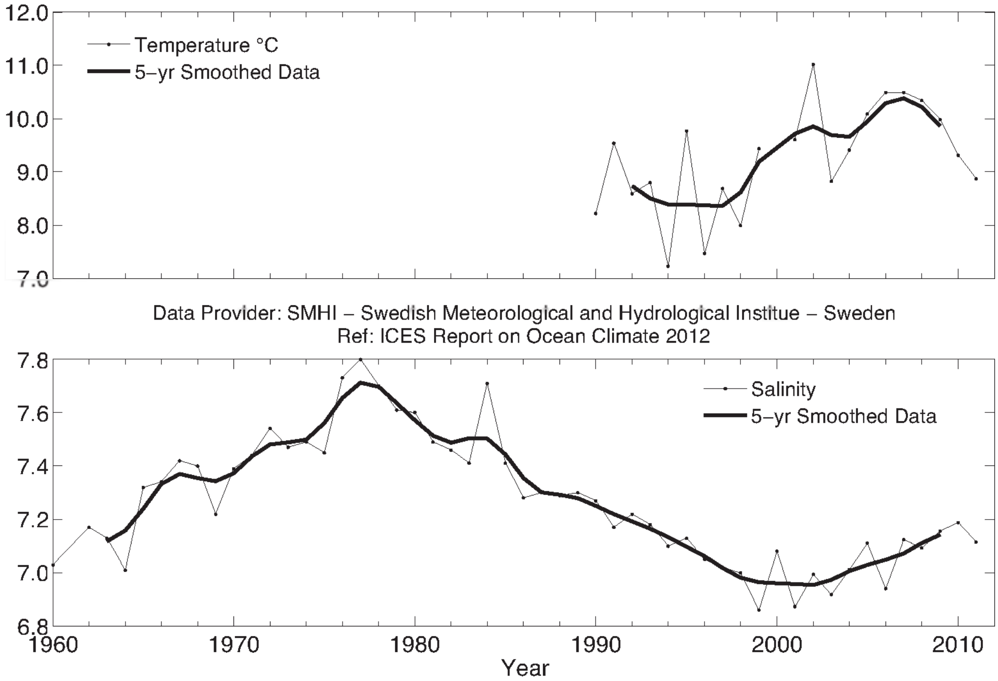


Figure 59.
Area 9b – Skagerrak, Kattegat, and the Baltic. Surface temperature (upper panel) and surface salinity (lower panel) at Station BY15 (east of Gotland) in the Baltic proper (data to 2011).

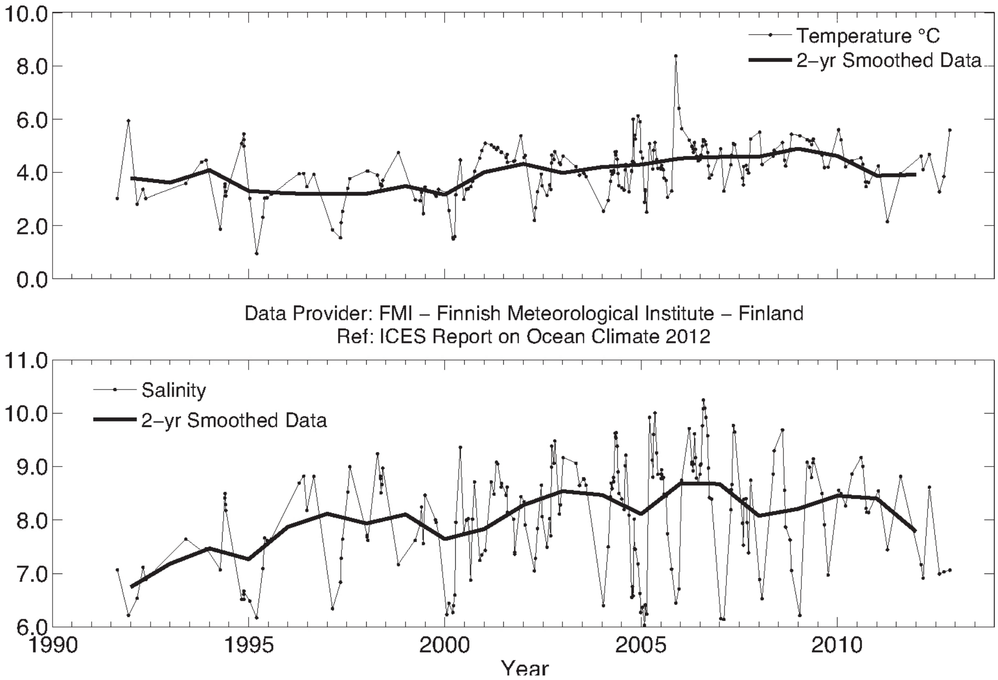


Figure 60.
Area 9b – Skagerrak, Kattegat, and the Baltic. Temperature (upper panel) and salinity (lower panel) at Station LL7 in the Gulf of Finland.

| HIGH PRECIPITATION IN 2012 |

Figure 61.
Area 9b – Skagerrak, Kattegat, and the Baltic. Temperature (upper panel) and salinity (lower panel) at Station SR5 in the Bothnian Sea.

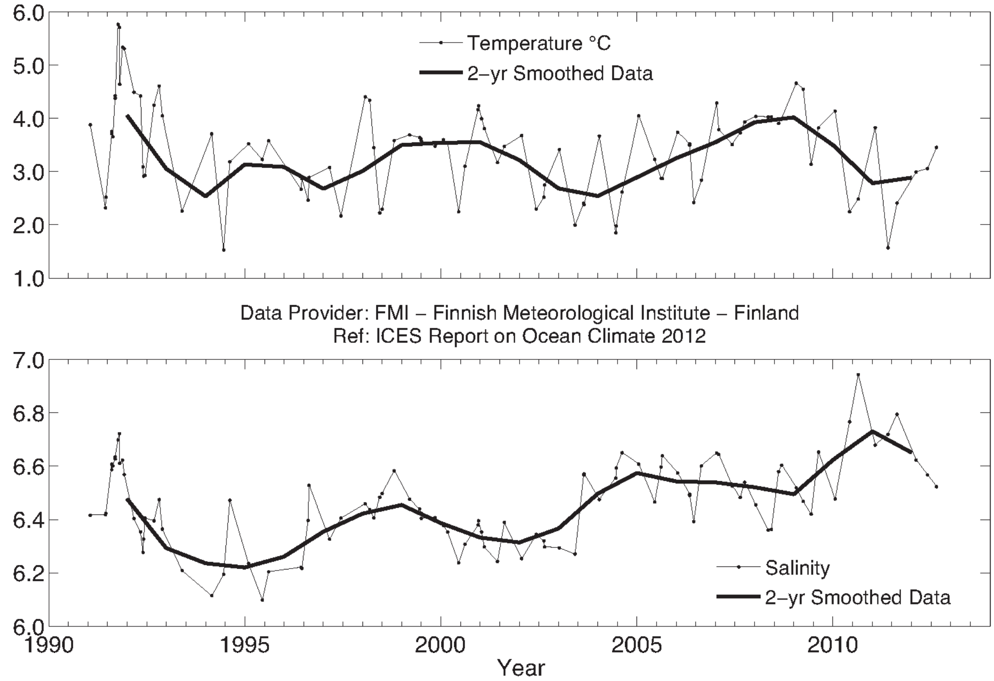
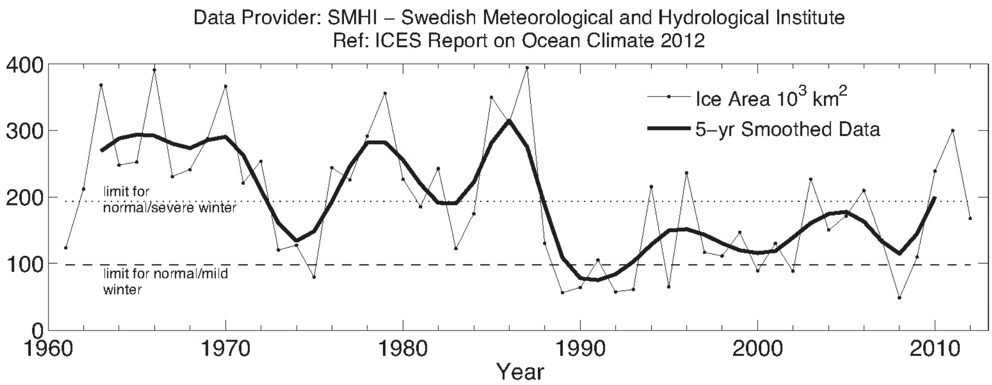


Figure 62.
Area 9b – Skagerrak, Kattegat, and the Baltic. Ice extent in the Baltic since 1961.



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 Iceland–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. In all sections, temperature and salinity were above the long-term means in 2012. In 2012, the annual temperature averages were 0.2°C, 0.6°C, and 0.4°C above the long-term means at Svinøy, Gimsøy, and Sørkapp, respectively. In 2012, salinity values in the sections were also higher than normal: 0.03, 0.05, and 0.06, respectively, above the long-term means. The high salinity values reflect more saline AW in the Faroe–Shetland Channel.

ABOVE-AVERAGE TEMPERATURE AND SALINITY IN THE NORWEGIAN SEA IN 2012.

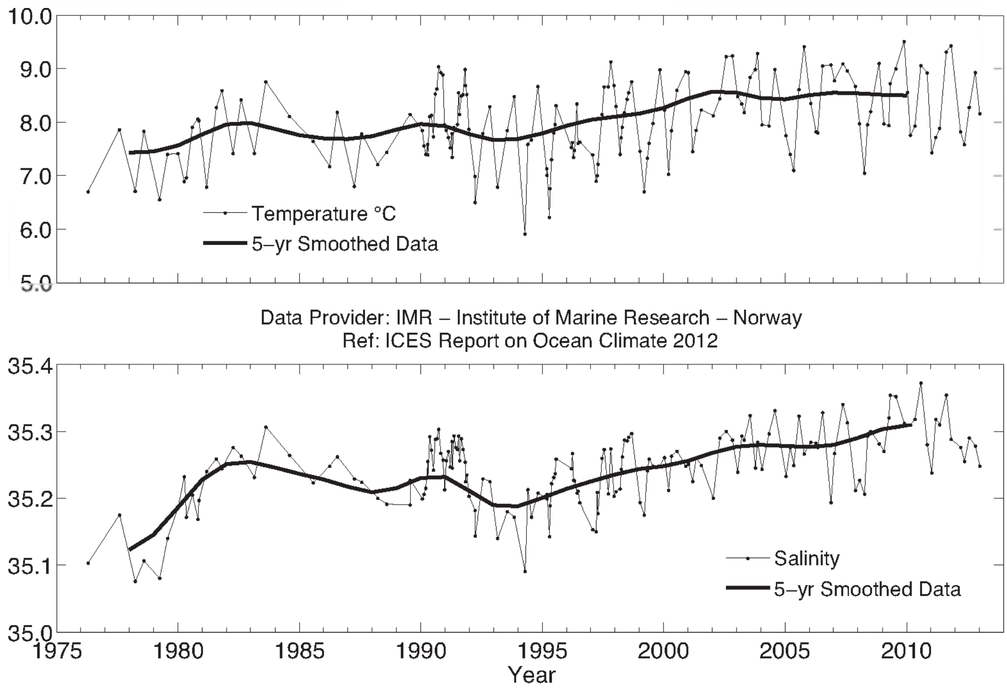


Figure 63.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Svinøy Section (63°N).

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

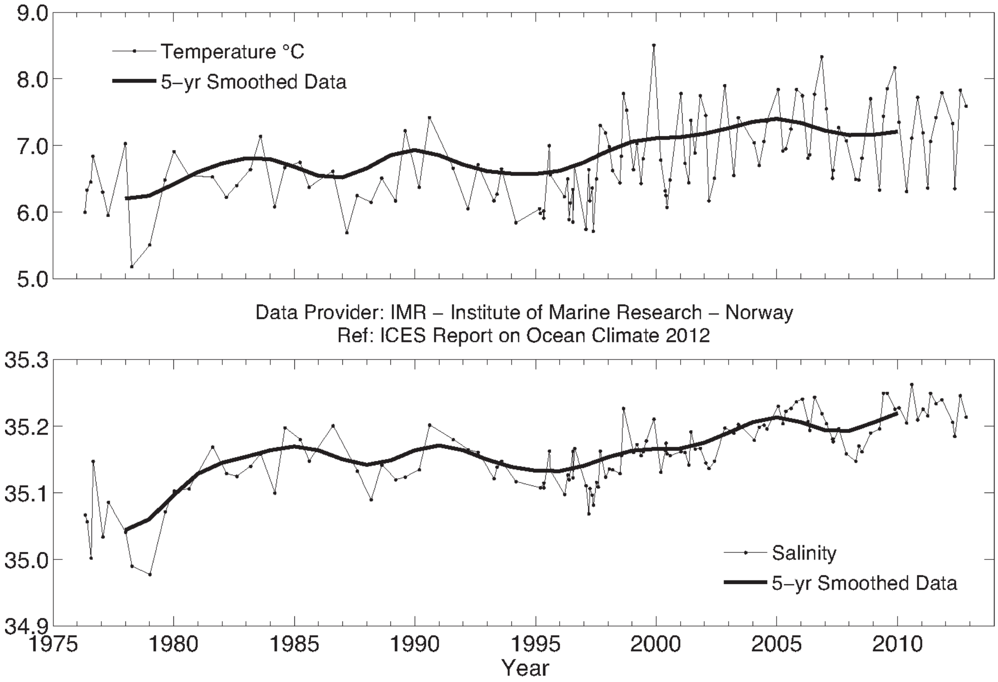
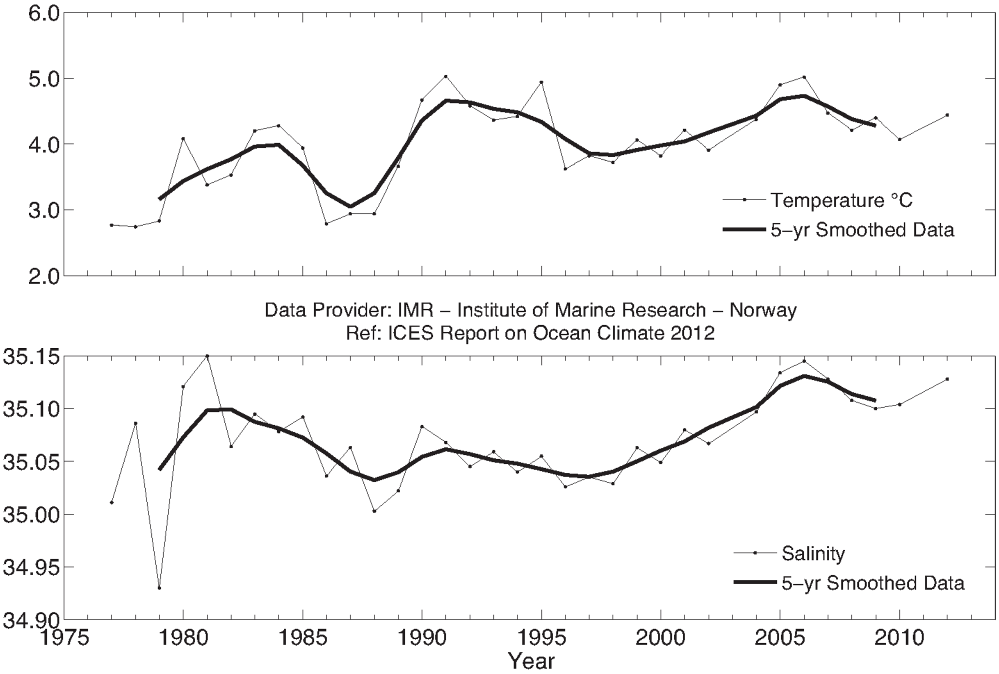


Figure 65.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Sørkapp Section (76°N).



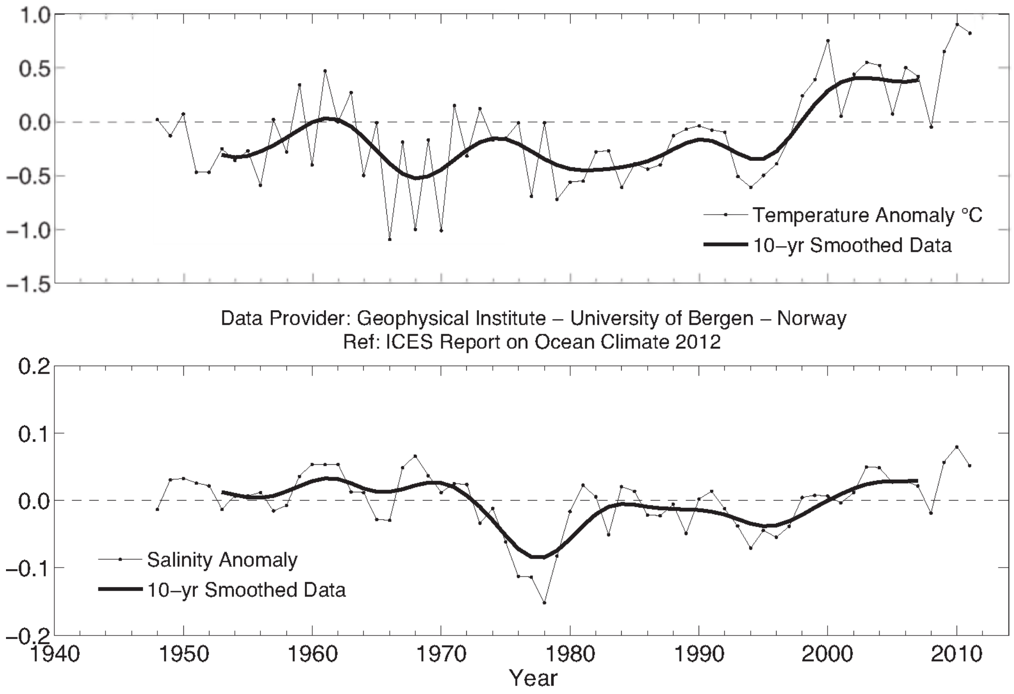


Figure 66.
Area 10 – Norwegian Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) at 50 m at Ocean Weather Station "M" (66°N 2°E).

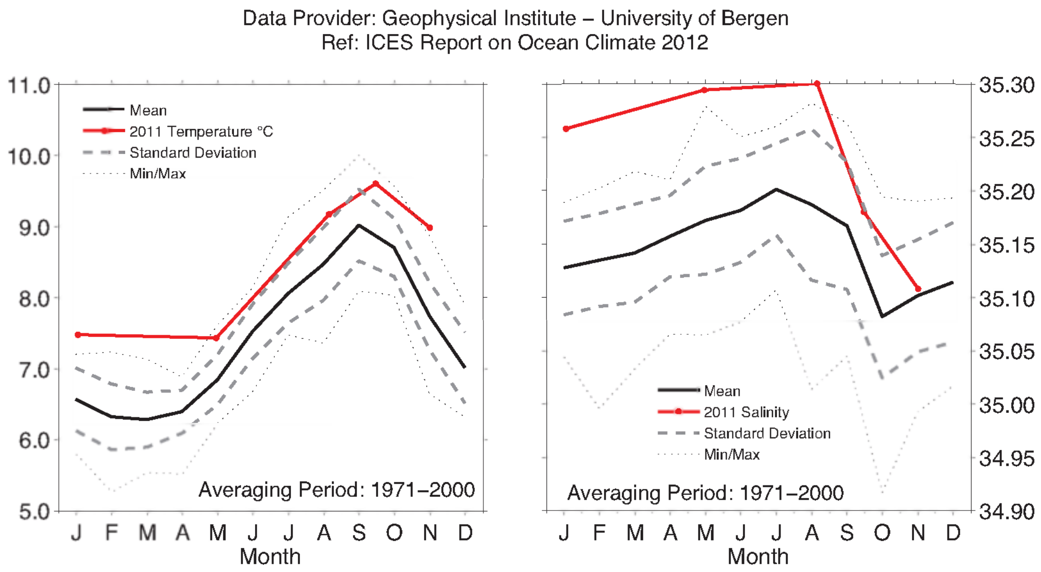


Figure 67.
Norwegian Sea. 2012 monthly temperature (left panel) and salinity (right panel) at 50 m at Ocean Weather Station "M" (66°N 2°E).

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 the average, whereas temperature in the eastern part remained below the average during 1998. From the beginning of 1999, there was a rapid temperature increase in the western Barents Sea that also spread to the eastern part. Since then, temperature has remained above average.

During 2012, the temperature of Atlantic waters in the Barents Sea was 0.7–2.0°C higher than average, with positive anomalies decreasing by the end of the year. Salinity in the coastal waters was much lower than average in the first half of the year, with anomalies increasing during the rest of the year and reaching positive values in December. In the Kola Section (0–200 m), the 2012 annual mean temperature was the highest (5.4°C) since 1900 and set a new record high. The 2012 annual mean salinity was close to average and less than in 2011.

In August–September 2012, surface waters in most of the Barents Sea were 0.5–2.0°C warmer than usual and 0.4–1.3°C colder than in 2011. The highest positive anomalies (>2.0°C) were found north of 76°N. Small negative anomalies (–0.1 to –0.5°C) were present only in the central and southwestern Barents Sea.

Arctic waters were, as usual, most dominant at 50 m in the northern Barents Sea. In 2012, however, they covered a smaller area than in the previous year. The 50 m temperatures were mainly higher than normal (by 0.7–2.4°C) and compared to the previous year (by 0.5–1.9°C). Temperatures at depths < 100 m were also higher than normal (by 0.8–1.9°C; compared to the previous year by 0.4–1.5°C) throughout the Barents Sea. The area occupied by water at temperatures < 0°C was much less in 2012 than in the previous year, and near the bottom it was the smallest since 1965, the year when the annual joint Norwegian–Russian autumn surveys started there. In addition, ice coverage of the Barents Sea throughout 2012 was still less than average compared to the previous year. In August and September, there was no ice in the Barents Sea; the ice edge was located much farther northwards than usual, at a latitude of about 83°N.

The volume flux into the Barents Sea varies with periods of several years, being 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. From autumn 2011 and during winter and spring 2012, there was decreasing volume flux, with values below the 1997–2012 mean. The dataseries presently stops in summer 2012, thus no information about autumn and early winter 2012 is available.

ANNUAL MEAN TEMPERATURE OF ATLANTIC WATERS IN THE KOLA SECTION SET A NEW RECORD HIGH IN 2012.

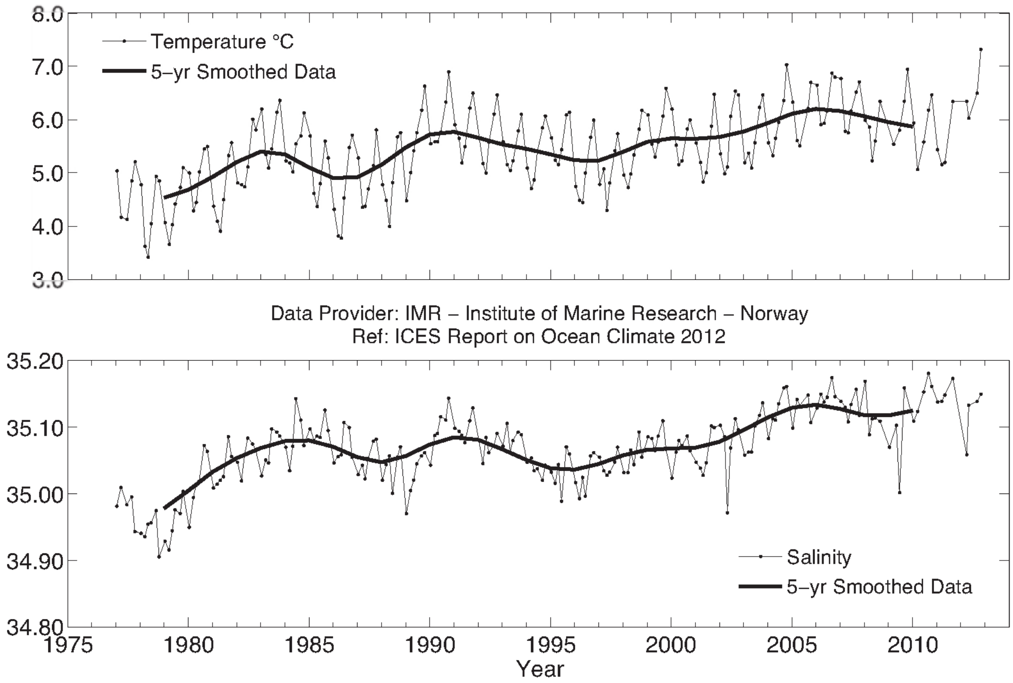


Figure 68.
Area 11 – Barents Sea. Temperature (upper panel) and salinity (lower panel) in the Fugløya–Bear Island Section.

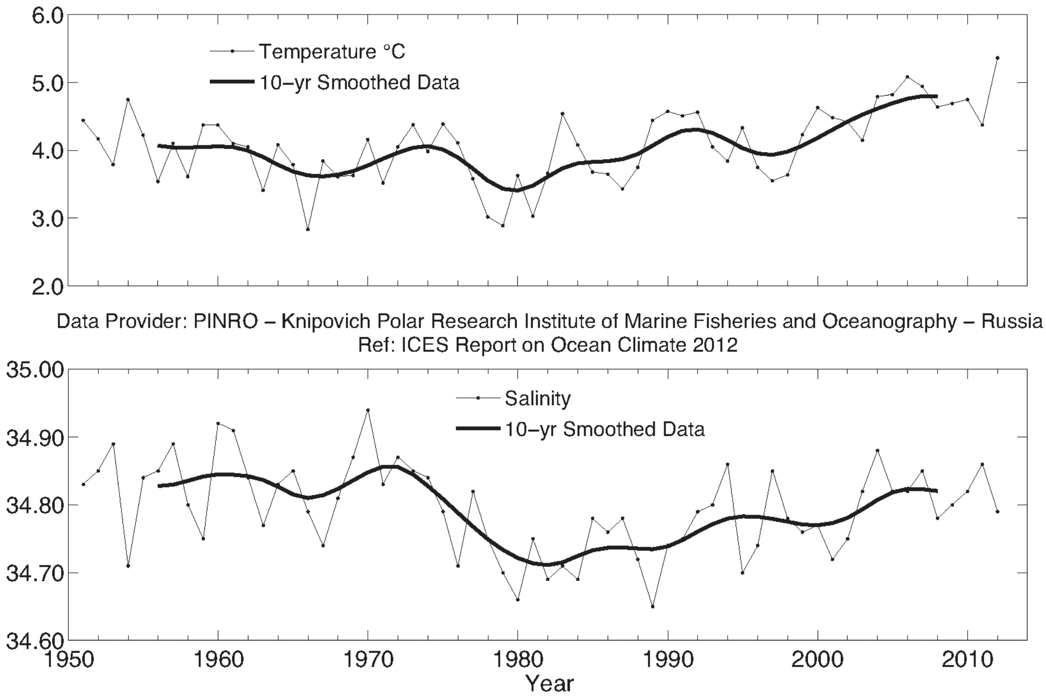


Figure 69.
Area 11 – Barents Sea. Temperature (upper panel) and salinity (lower panel) in the Kola Section (0–200 m).

4.16 Area 12 – Greenland Sea and Fram Strait

The 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 the 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.

In the southern Fram Strait, a 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 summer 2012, the mean temperature at the standard Spitsbergen section along 76.50°N (at the level of 200 dbar, spatially averaged between 9° and 12°E) was 3.73°C, thus 0.07° lower than the previous year. Salinity in the southern Fram Strait in 2012 remained at the same level as in 2011 (35.13), significantly exceeding its long-term mean of 35.06. Both temperature and salinity trends for the 1996–2012 period were positive.

In the northern Fram Strait, at the standard Fram Strait 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. In 2012, the spatially averaged mean temperature of the upper 500 m layer in the WSC was the second lowest in the time-series and similar to the mean temperature in the RAC area, which was close to its long-term average. Mean temperature in the EGC domain increased slightly compared to 211. Salinity in the upper 500 m in the WSC was slightly lower than in 2011, and in the RAC, it remained similar to that in the previous year. A slight increase in salinity of the upper 500 m was observed in the EGC domain.

In 2012, the AW layer in the West Spitsbergen Current was much shallower than in the previous year. Over the upper shelf slope, the 0°C isotherm was shifted up to ca. 600 m (observed at ~1000 m in 2011). AW temperature in the WSC was much lower in summer 2012 than in 2011, with no water warmer than 5°C observed (except a small surface patch around 7°E). In contrast to summer 2011, when very warm water was found in the WSC, but AW directly recirculating westward was much colder than average, temperature of recirculating AW in 2012 in the central Fram Strait was similar to temperature of AW in the WSC. The AW mean temperature in the WSC [defined after Rudels *et al.* (2005) with T >2°C and $27.7 < \sigma\Theta < 27.97$] was 3.41°C in 2012 compared to 3.85°C in 2011 and the maximum of 4.88°C observed in 2006. In the western deep part of the strait in the vicinity of the Polar Front, patches of recirculating AW were found, with maximum temperatures about 3–3.5°C, in contrast to the previous three years when much warmer water (with temperature above 5°C and in 2009, even above 6°C) was carried by the Atlantic Return Current to the west and ultimately south. The position of the Polar Front between the Arctic-derived Polar Water and Atlantic Water at the surface was shifted eastward and located at about the Greenwich meridian (as compared to 3°W in 2010 and around 2°W in 2011). The Polar water surface layer observed in 2011 was thicker than in the previous year. The Polar water spread farther eastward in the East Greenland Current, but on the upper continental slope east of Greenland, higher temperatures were observed in 2012 (maximum of ca. 2°C) than in 2011 (maximum of ca. 1°C).

Salinity of the AW in 2012 was similar to that in 2011, but its vertical distribution confirms that the AW layer in 2012 was much shallower than in 2011. In 2011, water more saline than 35 was observed in the entire upper 800 m layer in the WSC, while in 2012, it occupied, on average, only the 400 m thick upper layer. Opposite to the dipole structure found in 2011, with very saline water in the WSC and low salinity observed in the central part of the strait, in 2012, the AW layer with salinity higher than 35 had a similar thickness in the entire eastern Fram Strait between the upper slope west of Svalbard and the Polar Front. The thickness of low salinity (fresh) water in the western Fram Strait above the continental slope east of Greenland was similar in 2012 and 2011.

In terms of differences of temperature and salinity from their long-term means, in summer 2012, temperature in the entire WSC (in its core and offshore branch) was lower than its long-term mean, with strongest negative anomalies up to 2–2.5°C found in the upper 700 m layer. Salinity values were close to the long-term average except in the near-surface layer of ca. 50 m and in the western Fram Strait, where the strongest (both positive and negative) anomalies were observed. Above the lower continental slope east of Greenland, the Arctic Atlantic Water subducting below the Polar Water was also slightly warmer and more saline than the long-term average, while over the upper continental slope, weakly negative temperature and strongly negative salinity anomalies were found in the whole water column. Temperature in the deep layer below 1000 m was close to average at the entire section.

The continuous measurements at the mooring line along 78°50′N show that temperature in the WSC core and in the offshore WSC branch was extremely high in winter 2011/2012, reaching the 2006 maximum. However, during the following summer, AW temperature decreased significantly, being only slightly higher in the very core and much lower than in summer 2011 in the offshore branch. This warm winter peak was not observed in the recirculating water, where temperatures in 2011–2012 were similar to the previous deployment period (2010–2011).

The winter-centred annual mean of the volume transport in the West Spitsbergen Current was 6.4 Sv in 2011–2012, close to the transport observed in 2010–2011 (6.3 Sv) and slightly higher than the long-term mean of 6 Sv. In 2011–2012, the winter maximum in the WSC volume transport was slightly lower than average, but in the following summer, a strong inflow of Atlantic water was observed. However, in winter 2011–2012, extremely warm Atlantic inflow combined with the relatively low temperature of the Arctic outflow and winter-intensified volume transport resulted in a high oceanic heat flux into the Arctic Ocean.

The Greenland Sea section at 75°N was not measured in 2011 and 2012. The most recent data are from 2010, and we retain the status reported last year. In 2010, the temperature of AW at the eastern rim of the Greenland Sea (along the 75°N section, between 10° and 13°E), was similar to that observed in 2008 (no data for 2009) and close to the long-term mean. A significant increase in salinity was observed compared to 2008; 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. Temperature and salinity in the upper layer of the central Greenland Basin, within the Greenland Gyre, were modified by the advection of AW and winter convection. The interface with enhanced temperature and salinity gradients has steadily descended (by more than 1000 m) since the beginning of measurements in 1993. After winter 2007/2008, a two-layer structure resulted from a mixed-layer type convection that supplied both salt and heat into the intermediate layers. In winter 2008/2009, almost half of the Greenland Sea was shielded from convection because of the unusual western location of the Arctic Front (boundary between Atlantic and Greenland Sea waters).

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. 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 the salinity was still higher than before 2004.

THE TEMPERATURE OF THE ATLANTIC WATER IN FRAM STRAIT WAS HIGH IN WINTER 2011/2012, BUT DECREASED SIGNIFICANTLY BELOW ITS MEAN VALUE DURING SUMMER 2012. SALINITY OF THE ATLANTIC INFLOW TO THE ARCTIC OCEAN RETURNED TO ITS MEAN VALUE AFTER THE STRONG PEAK OBSERVED IN 2011.

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).

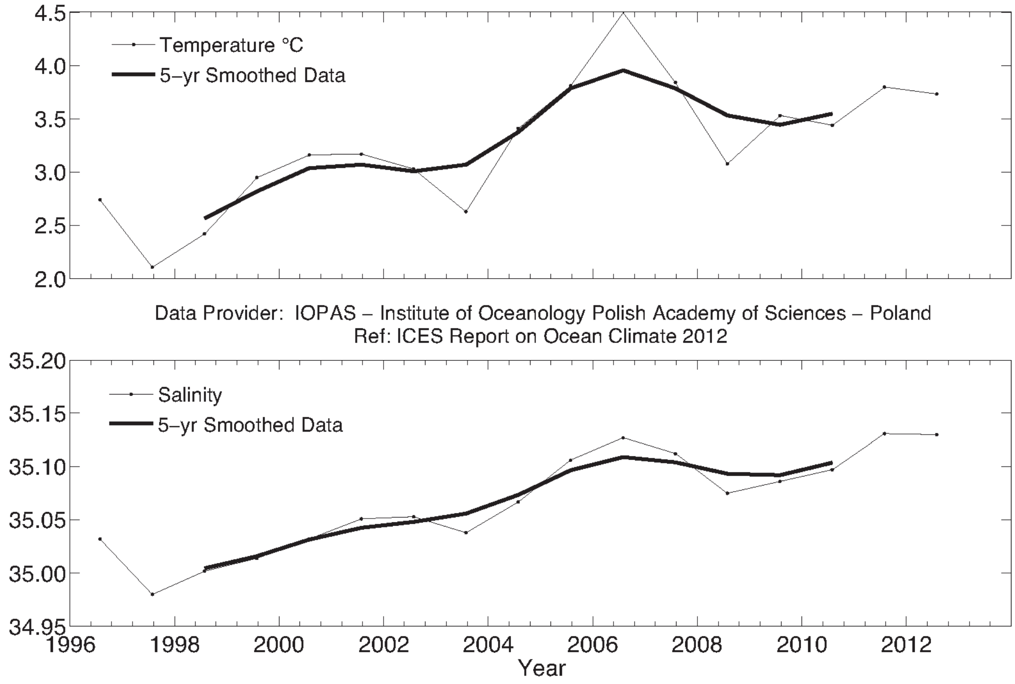
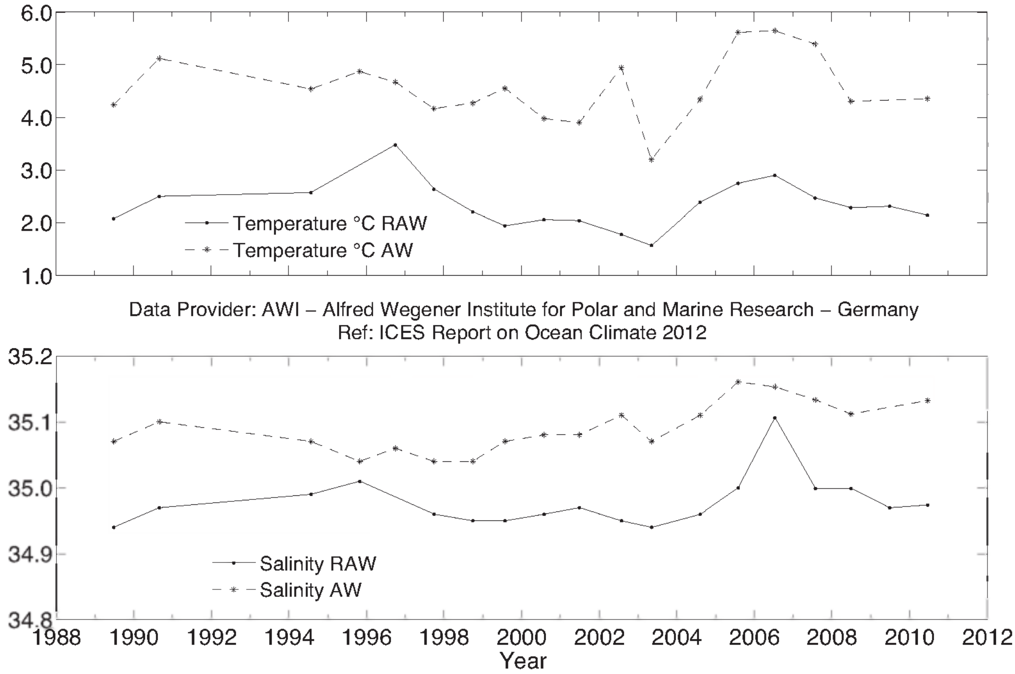


Figure 71.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) of Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea Section at 75°N (data to 2010). AW properties are 50–150 m averages at 10-13°E. The RAW is characterized by temperature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



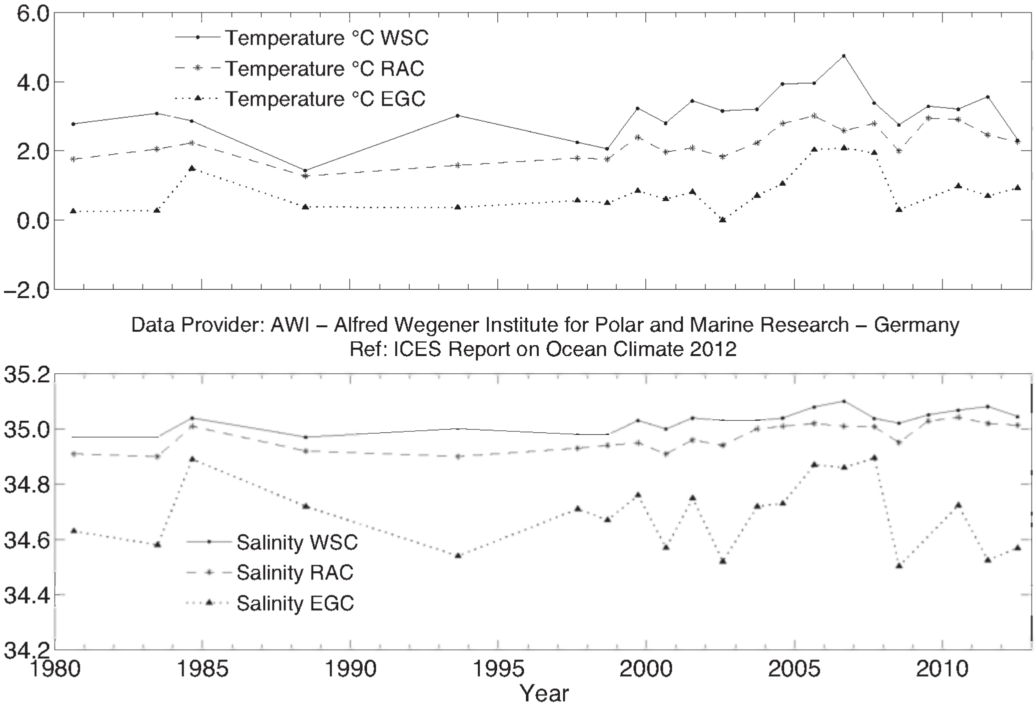


Figure 72.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) in Fram Strait (78.83°N) at 50–500 m: in the West Spitsbergen Current (WSC; between the shelf edge and 5°E), in the Return Atlantic Current (RAC; between 3°W and 5°E), and in the Polar Water in the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

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. The deep southward outflow from the North Atlantic in the deep western boundary current is fed by the cold and dense overflow waters. 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, that of 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.

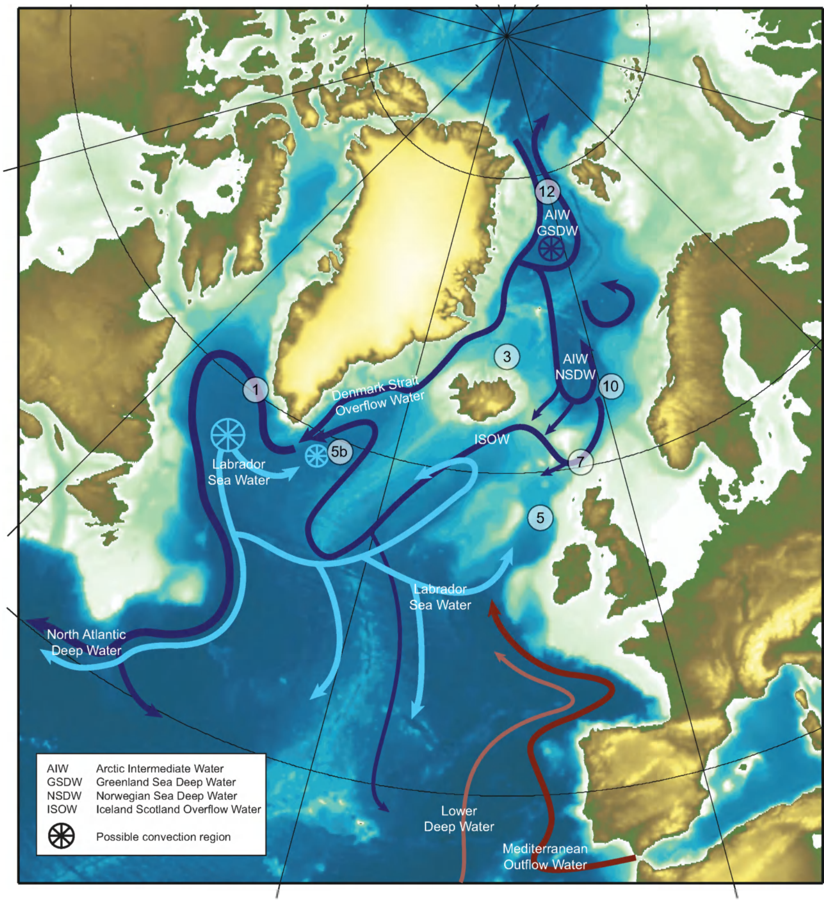


Figure 73. *Schematic circulation of the intermediate to deep waters in the Nordic seas and North Atlantic.*

5.2 Nordic seas deep waters

The deep waters of the Greenland, Iceland, and Norwegian seas are all warming. The longest time-series (the Norwegian Sea, Area 10) reveals warming from the mid-1980s; however, a slight decrease in temperature occurred in 2010–2011. The continuous warming has been observed in the Greenland Sea deep layer at 3000 m (Area 12, no data for 2011–2012), and the temperature increase between 2009 and 2010 was slightly lower (0.01°C) than the 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 until the end of 2012 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). The source of the warming is the deep outflow from the Arctic Ocean, a southward flowing 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 measurements began in 1993, the winter convection depth has varied between 700 and 1600 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 Water from the north. The AW, which dominates changes in the upper ocean, took over the role of former 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 an adjustment to the Arctic outflow in the continued absence of deep convection and an increased presence of AW in the upper layer.

In the Greenland Gyre in summer 2009, the usual relatively homogenous pool, mixed by previous winter convection, was replaced by a bipolar 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 74), depending on a choice of the 2009 mean profile. No data are available for 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 over the past decade. In the Iceland Sea, salinity in the deep layer has also been relatively stable since the end of the 1990s, with some slight decrease evident in salinity observations since 2009 and a notable low value observed in early 2012 compared to the previous 14 years.

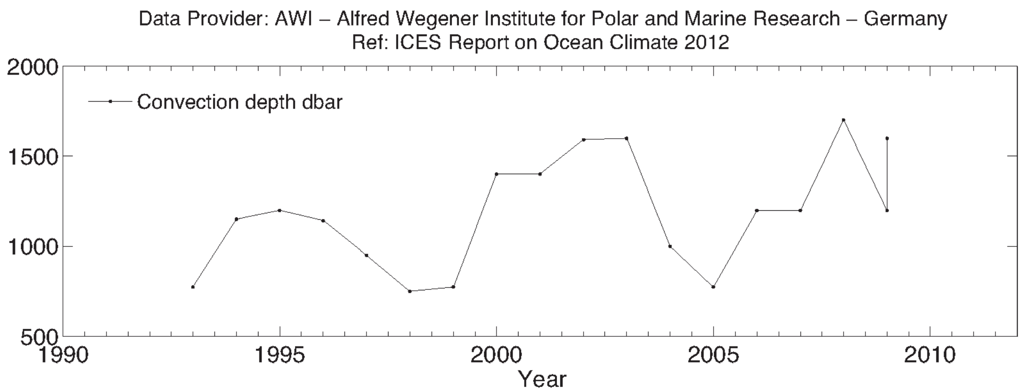


Figure 74.
Area 12 – Greenland Sea and Fram Strait. Winter convection depths in the Greenland Sea Section at 75°N (data to 2009; note that due to the ambiguous convection depth in winter 2009/2010, two values are provided for this period).

Figure 75.
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).

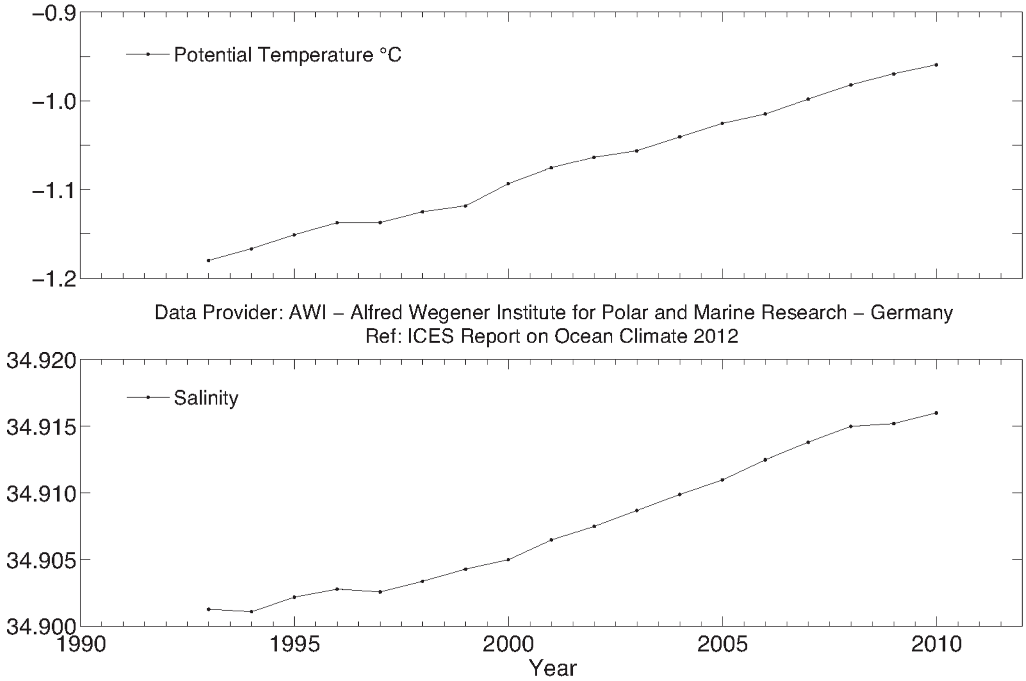
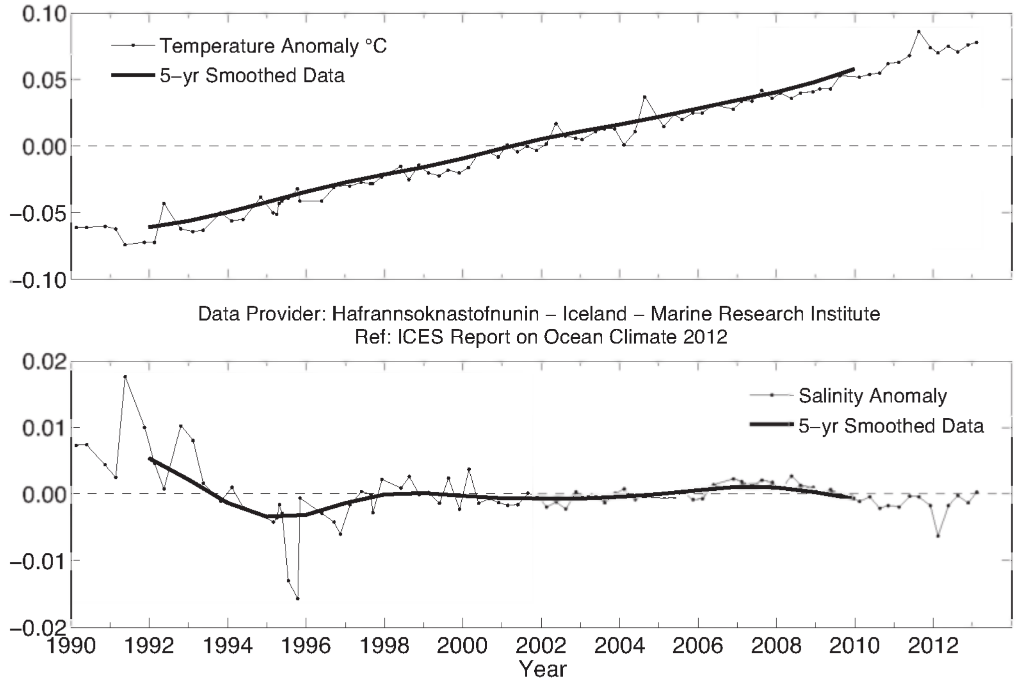


Figure 76.
Area 3 – Icelandic waters. Temperature at 1500–1800 m in the Iceland Sea (68°N 12.67°W).



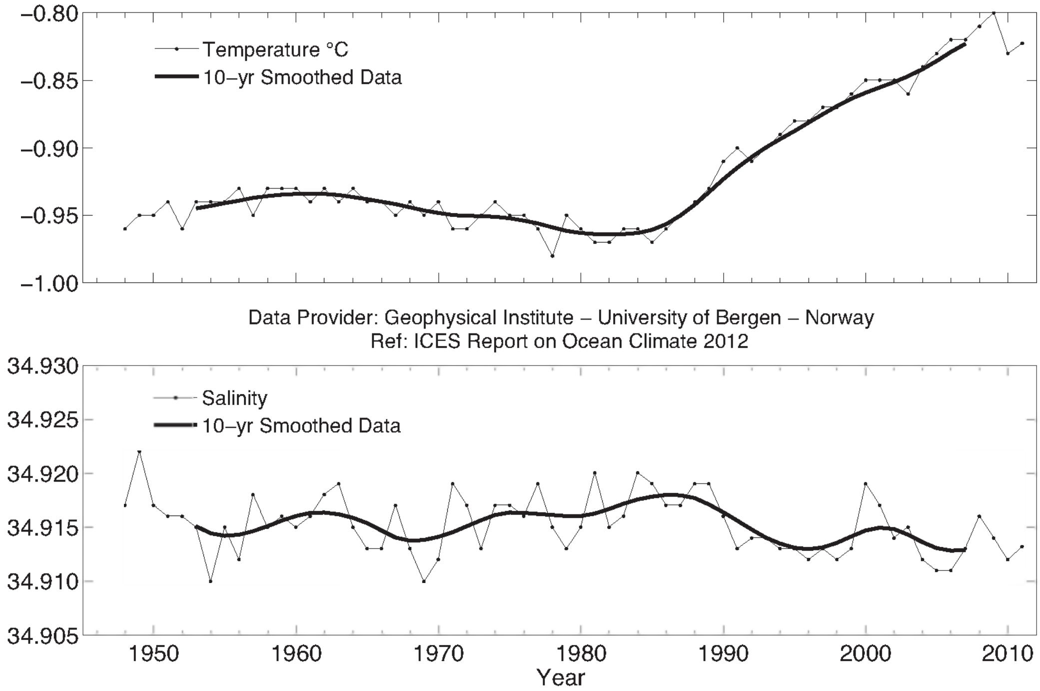


Figure 77.
Area 10 – Norwegian Sea. Temperature (upper panel) and salinity (lower panel) at 2000 m at Ocean Weather Station "M" (66°N 2°E) (data to 2010).

5.3 North Atlantic deep waters

In the deep layers of the Faroe–Shetland Channel (Area 7), the properties at 800 m are the same as those of Norwegian Sea Deep Water as it passes through the Channel back into the North Atlantic. 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 through the subsequent 15 years; since 1992, it has stabilized again.

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, the changes in temperature and salinity of the DSOW broke this rule; the correlation was reduced to about 0.5. This implies that less than 30% of the variance of 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 timescale, possibly forced by wind-driven processes near Denmark Strait.

The properties of the North Atlantic Deep Water in the deep boundary current west of Greenland are monitored at 2000 m depth at Cape Desolation Station 3. Temperature and salinity of this water underwent strong interannual variability during the 1980s. From the beginning of the 1990s, both characteristics were decreasing until reaching their minimum values in 1998 and 1997, respectively. After that, positive trends were observed until 2007. In 2007, the temperature of the North Atlantic Deep Water started to decrease, and its salinity stagnated. This decrease in water temperature continued until 2010. Since then, temperature and salinity have increased again and reached values of 3.09°C and 34.92 in 2012, respectively.

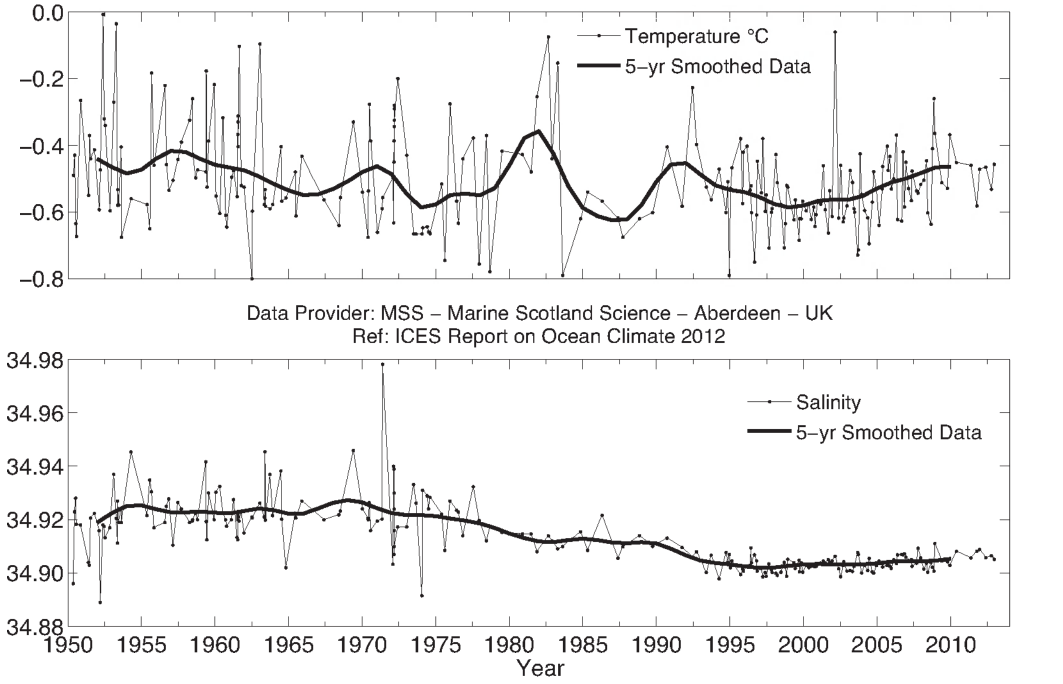


Figure 78.
Area 7 – Faroe–Shetland Channel. Temperature (upper panel) and salinity (lower panel) at 800 m.

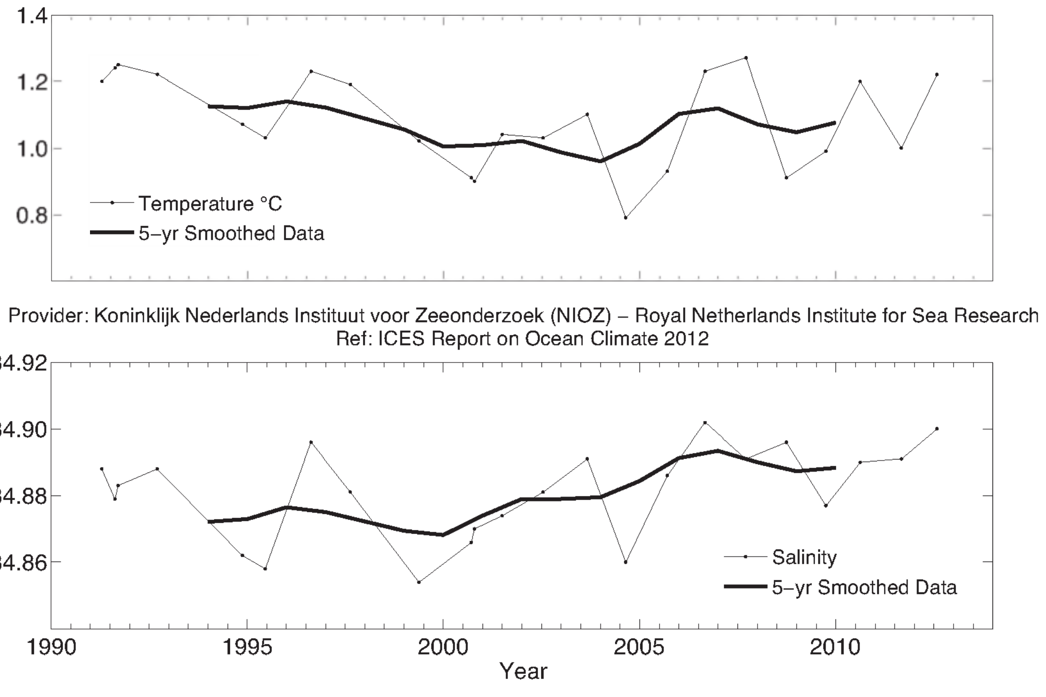


Figure 79.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) in Denmark Strait Overflow Water on the East Greenland Slope.

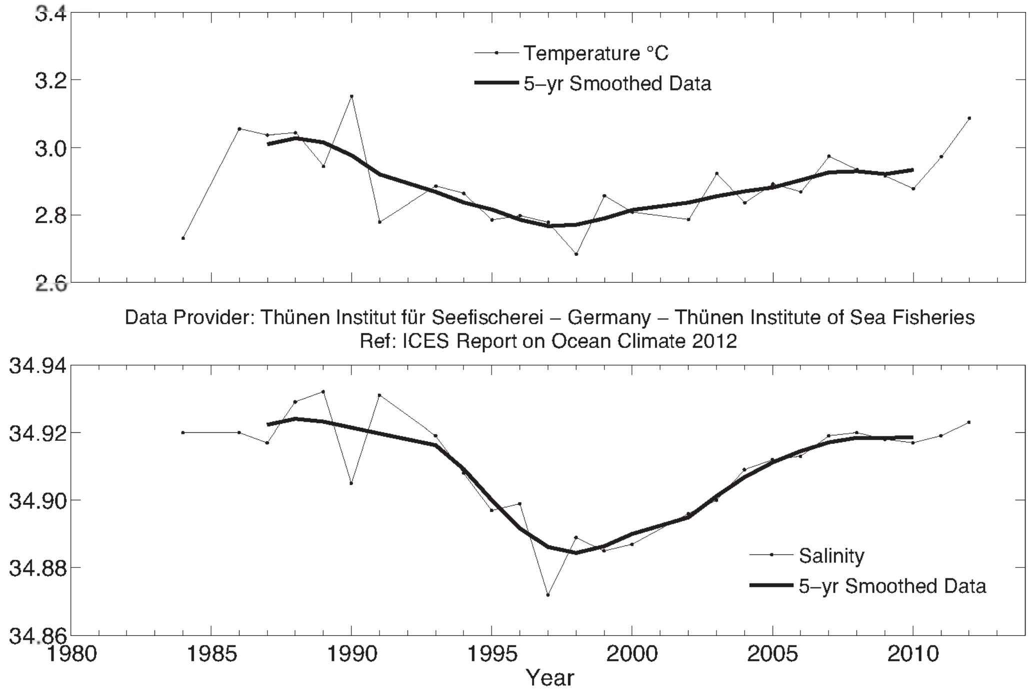


Figure 80.
Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 2000 m water depth at Cape Desolation Station 3 (60.45°N 50°W).

5.4 North Atlantic intermediate waters

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, this LSW core has generally been increasing in temperature and salinity as it mixes with surrounding water masses. In 2012, temperature and salinity were only slightly below the long-term maximum 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 between 1700 and 2000 m. East of the Anton Dohrn Seamount, this 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 (3.28°C) and salinity (34.925) remain cooler and fresher than the long-term mean values. This salinity represents a small change vs. 2010, but temperature decreased by 0.25°C, reaching a similar level to that found between 2000 and 2007, which was the coolest period since records began in 1975.

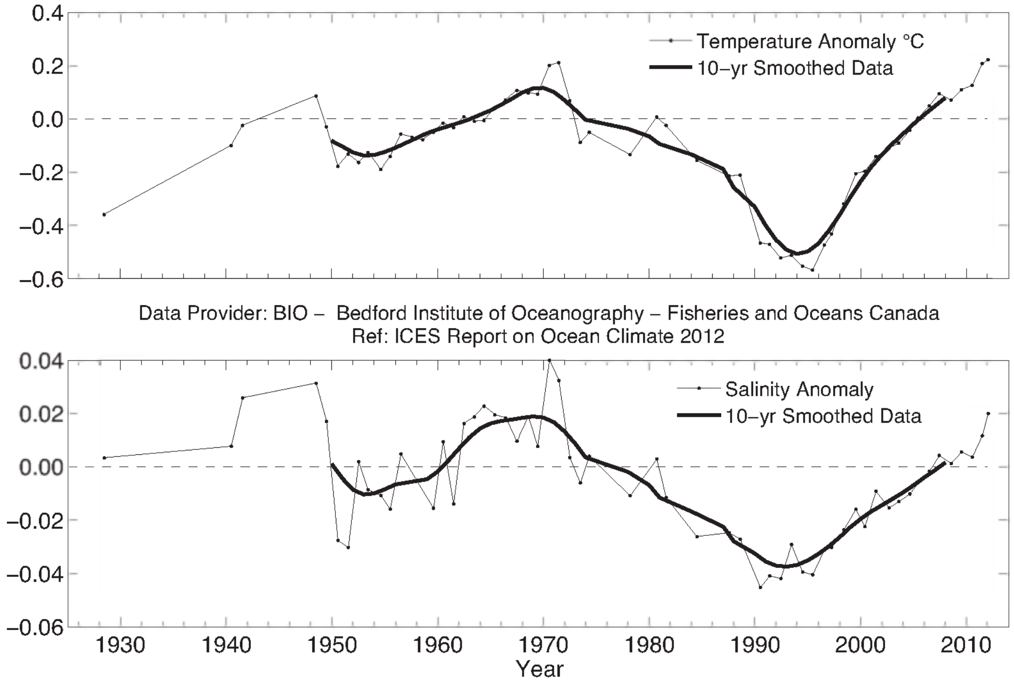


Figure 81.
Area 2b – Labrador Sea. Temperature (upper panel) and salinity (lower panel) anomalies of Labrador Sea Water (averaged over 1000–1800 m).

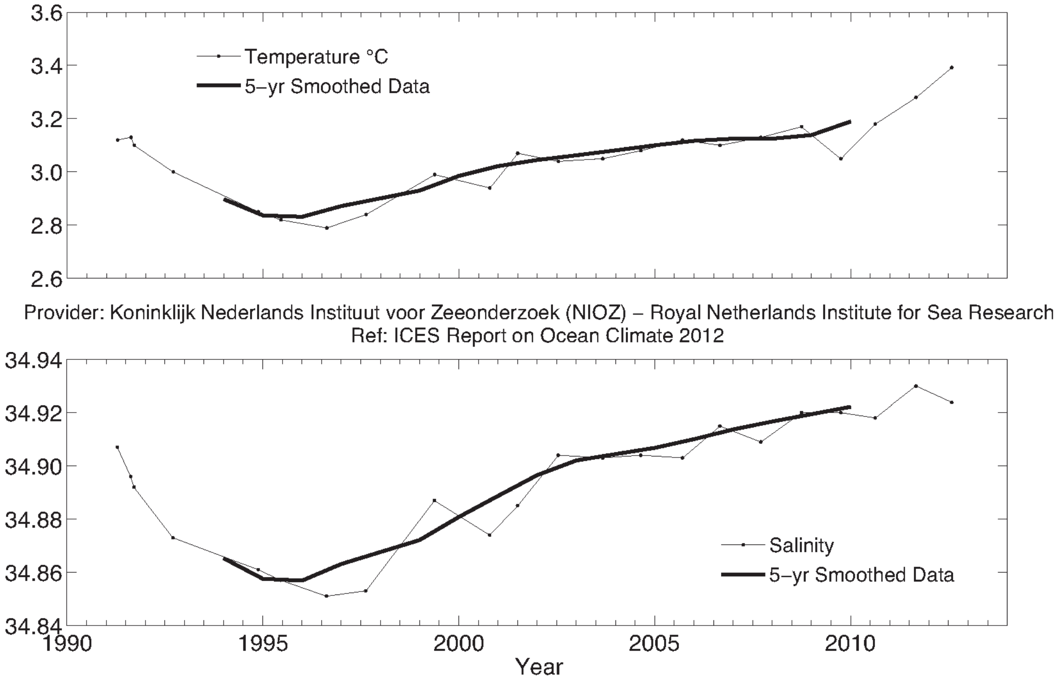


Figure 82.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (averaged over 1600–2000 m).

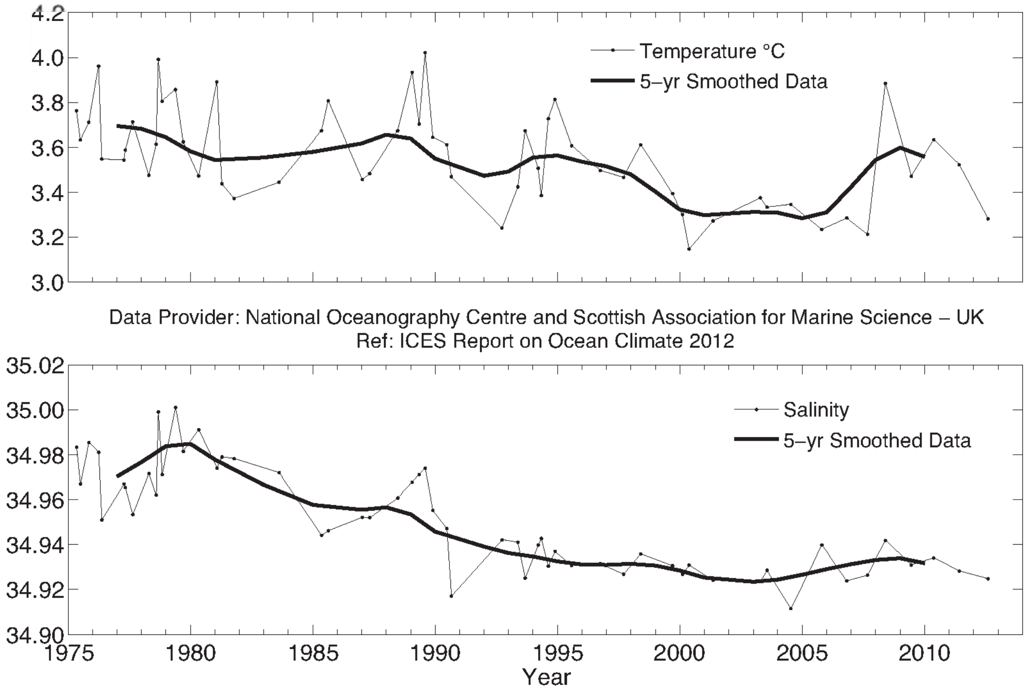


Figure 83.
Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (1800–2000 m).

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 Seewetteramt, Hamburg, Germany
1	West Greenland	15, 16, 80	Fylla Section and Cape Desolation Section	Boris Cisewski (boris.cisewski@vti.bund.de)	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	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)	Hafrannsoknastofnun (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 Continental Shelf	41, 42	Western Channel Observatory, Station E1	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	Faroese waters	48, 49, 50	Faroe Bank Channel – West Faroe Islands, Faroe Coastal Station 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 (solfrids@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	Wilken Jon von Appen (wilken-jon.von.appen@awi.de)	Alfred Wegener Institute for Polar and Marine Research (AWI), Germany

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