ICES WGOH REPORT 2011

SCICOM Steering Group on Ecosystem Functions

ICES CM 2011/SSGEF:05

Ref. SCICOM
ACOM

Report of the Working Group on Oceanic Hydrography (WGOH)

23–25 March 2011

Helsinki, Finland

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

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Recommended format for purposes of citation:

ICES. 2011. Report of the Working Group on Oceanic Hydrography (WGOH), 23–25 March 2011, Helsinki, Finland. ICES CM 2011/SSGEF:05. 138 pp.

Contents

Executive summary

The WGOH meets yearly to review oceanographic conditions in the ICES region and to report on these in the ICES Report on Ocean Climate.

IROC Highlights for 2010

Highlights of the North Atlantic Ocean for 2010

- The upper layers of the northern North Atlantic and the Nordic seas were warm and saline in 2010 compared with the long-term average.
- In the north-east North Atlantic the severe winter 2009/2010 led to cooler ocean conditions compared to previous years, but the annual mean remained above the long term average. Severe ice winter conditions occurred in the Baltic.
- In the north-west North Atlantic the record warm air temperature in winter led to very high ocean temperatures. Record low sea ice and low number of icebergs were observed in the Labrador sea.
- The Nordic seas and the outer regions of the subpolar gyre and were very saline in 2010, while the interior region was fresher at the surface than recent years.
- Warming and salinification of deep waters continues

Highlights of the North Atlantic atmosphere in winter 2009/2010

- The NAO index in winter 2009/2010 was strongly negative, generating more extreme conditions than the record low index observed in winter 1969/1970.
- Surface air temperatures were at record high levels over Greenland and the Labrador Sea. In contrast Northern Europe experienced unusually cold winter conditions.
- Mean winds were weaker than normal across most of the North Atlantic. The dominant easterly winds replaced the more usual westerly storm track.

The WGOH also fulfils the Terms of Reference for the group including strengthening the role of WGOH and physical oceanography within ICES, exploring areas of mutual interest with international climate monitoring programmes and providing expert knowledge and guidance to ICES Data Centre. WGOH is contributing to the ICES Climate Change position paper by writing a chapter on hydrographic variability in the ICES region and by contributing material on atmospheric indices to the annexes of the position paper.

Approach taken at the meeting

A structured agenda was used for this WGOH meeting (see Annex 2). A mini-symposium was held on the second day of the meeting which included a combination of talks from the host institution and invited WGOH members. Half of the meeting was spent reporting findings from the different ICES areas . The combined area reports are included as Annexes 6–16 to this report. The remainder of the meeting was spent working through the other ToRs for the WGOH.

Description of the structure of the report

This report describes the discussion and outcomes relating to the individual terms of reference of the WGOH. The bulk of the report is contained in the area reports (included as Annexes 6–16 to the report), which in turn forms the major contribution to the ICES Report on Ocean Climate.

Solid progress towards the WGOH Terms of Reference were made during this meeting. The ICES Report on Ocean Climate 2010 will be submitted to ICES shortly where many of the Expert Group's key findings are presented.

Key recommendations

WGOH recommends that a specific ToR on responding to the Integrated Framework for Sustained Ocean Observing paper is added for WGOH in 2012.

WGOH recommends that a specific ToR on the Marine Strategy Framework Directive is added for WGOH in 2012 along the lines proposed by the SCICOM Chair:

- Identify elements of the EGs work that may help determine status for the 11 Descriptors set out in the Commission Decision (available at http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:232:0014:0024:EN:PDF;
- Provide views on what good environmental status (GES) might be for those descriptors, including methods that could be used to determine status.

ICES should make more hard copies of the IROC report available to WGOH members (10–15 per member) so that such reports can be distributed for lobbying purposes at the national level and to enhance the profile of the IROC report.

1 Opening of the meeting

The Working Group on Oceanic Hydrography met in FMI, Helsinki, Finland on 23–25 March 2011.

Chairs: Glenn Nolan (Ireland) and Hedinn Valdimarsson (Iceland)

21 WGOH members attended (Annex 1) representing 13 ICES nations.

Local host Bert Rudels welcomed all WGOH participants to the meeting and provided all relevant logistical information to those present.

2 Key discussion points

2.1 Membership and Introductions

Member introductions took place and the agenda was formally adopted. The group welcomed a new member, Paula Fratantoni (NOAA, NMFS) who replaces Bob Pickart of WHOI. Igor Yashayaev of DFO, Canada also attended the WGOH. Ilona Goszczko of IOPAN, Poland was also welcomed to the meeting. Cesar Gonzales Pola (IEO, Spain) replaces Alicia Lavin on WGOH.

2.2 Area reports (latest results from standard sections and stations)

The following members of the WGOH presented their respective area reports:

Eugene Colbourne, Holger Klein, Kjell Arne Mork, Alexander Trofimov, Ilona Goszczko, , Agnieszka Beszczynska-Möller, Fabienne Gaillard, Karen Borenas, Hedinn Valdimarsson, Glenn Nolan, Sarah Hughes, Toby Sherwin , Anna Akimova, Igor Yashayaev and Paula Fratantoni.

Area reports are included as Annexes 6–16 to this report.

2.3 Update on 2011 Decadal Symposium on Hydrobiological Variability in the 2000s: Discussion led by Cesar Gonzales Pola

To build on the previous 2 symposia, Alicia Lavin of IEO hosted this in Santander in May 2011 (after WGOH but before report submission). A motion to host this was approved in late 2008 and €10k given in support.

The symposium took place in Santander between 10 and 12 May 2011 and was attended by 116 participants including the keynote speakers and honorees. The total number of presentations was 5 keynote speakers and 39 presentations. The symposium was organised in six sessions of half day and the inauguration and closure. There was a Symposium dinner where five WGOH scientists were honoured for their contribution to our understanding of the oceanography of the ICES region. See note in Annex 5 from NAFO co-convenor Steve Cadrin.

WGOH records its gratitude to the Symposium Organiser, Alicia Lavin, IEO and her local organising committee for an excellent conference.

2.4 Update on WGOH inputs to Steering Group on Climate Change

WGOH is contributing to the ICES Climate Change position paper by writing a chapter on hydrographic variability in the ICES region and by contributing material on atmospheric indices to the annexes of the position paper. The Cooperative Research Report is now almost complete.

2.5 Discussion of ICES SSGEF workplan (developments at 2010 ASC)

Consideration was given to the group of tables circulated to WGOH by SSGEF where the ToRs for the WGOH are now coded to complement the ICES Science Plan.

2.6 ICES Data Centre (Hjalte Parner)

No overview of recent and planned activities within the ICES data centre was given as the data centre was not represented at the meeting. WGOH felt that there is merit in exploring a means by which data contained in the IROC could be held in the ICES data centre. Sarah Hughes will investigate this in the first instance.

2.7 Strengthening the role of WGOH and physical oceanography within ICES; such as IGSG and WGOOFE

WGOH gave an invited talk at the PICES Conference in Portland, Oregon in October 2010, thereby strengthening interactions with the Pacific community. Within ICES, Holger Klein maintains a link between WGOH and WGOOFE. Holger will attend the WGOOFE meeting in November 2011 and give a talk at the next WGOH in 2012.

The Integrated Framework for Sustained Ocean Observing originating from the OceanObs conference in Venice was considered by WGOH. As this is a complex and far-reaching initiative requiring a detailed response from ICES, WGOH recommends that IFSOO is added as a specific ToR for WGOH in 2012.

WGOH also discussed the new strategic initiatives from ICES, primarily addressing the Marine Strategy Framework Directive Steering Group (MSFDSG). The WGOH believes that MSFD activity should be added to our ToRs.

2.8 Relations with international climate monitoring programmes

WGOH attended the PICES science meeting in Oregon to present on the activities of WGOH.

Several WGOH members are participating in the OSNAP initiative where the thermohaline circulation of the North Atlantic and the sub-polar gyre will be researched in the coming years.

2.9 ASC theme sessions

Given the heavy workload involved in the preparation of the ICES/NAFO Decadal Symposium in Santander (May 2011), no theme sessions are proposed at present as this symposium represents the culmination of a decade of ICES hydrobiological research.

2.10 Election of new chair(s)

Stephen Dye (CEFAS, UK) and Kjell Arne Mork (IMR, NO) were elected co-chairs of the WGOH to commence after the 2011 ASC in Gdansk.

2.11 WGOH website

The WGOH website will continue to be maintained and updated at NOC, Southampton.

2.12 Next Meeting

20–22 March 2012, ICES HQ, Denmark, Copenhagen

WGOH thanked Bert Rudels for hosting the meeting and excellent preparations.

Annex 1: List of participants

Name	Email address	Country
Anna Akimova	anna.akimova@vti.bund.de	DE
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Igor Yashayaev	Igor.Yashayaev@dfo-mpo.gc.ca	CA

Annex 2: Agenda

Day 1, Wednesday 23 March

0900 Start

1. Membership and Introductions

2. IROC (15–25 minutes update from Sarah Hughes)

   Review of 2010 Atmospheric conditions. **Stephen Dye**

   Initial overview of contents and contributions received so far

   Suggestions for improvements and any new time-series or products

3. Area reports (latest results from standard sections and stations)

Day 2, Thursday 24 March

0900 Start

3. Continue area reports

1300–1700: Mini-symposium Programme for the Mini-symposium

13:00	Kimmo Kahma	Surface waves in the Baltic
13:20	Byoung Woong An	Baltic Sea ensemble forecast and process studies
13:40	Milla Johansson	Sea level scenarios for the Finnish coast
14:00	Petra Roihe	(TTBA)
14:20	Aleksi Nummelin	(ARGO floats in the Baltic (tentative title))
14:40	Heidi Pettersson	Carbon dioxide exchange at the air-sea interface
15:00 – 15:30	Coffee break	
15:30	Bin Cheng	Modelling snow and ice thermodynamics in the Northern Oceans
15:50	Jari Haapala	Breaking of pack ice due to the impact of low pressures
16:10	Meri Korhonen	Heat and freshwater distributions in the Arctic Ocean
16:30	Marika Marnela	(Fram Strait exchanges (tentative title))
16:50	Igor Yashayev	(Labrador Sea hydrography (tentative title))
17:10	Bert Rudels	Transports through the Canadian Arctic Archiplago - Baffin Bay system
17:30	Discussions	

Day 3 (morning only), Friday 25 March

0900 Start

4. Update on 2011 Decadal Symposium on Hydrobiological Variability in the 2000s: Discussion led by Alicia Lavin

5. ICES Matters: Improving interaction between WGOH and other EGs

Suggestions here (GOOS SG has been disbanded by ICES)

6. Update on WGOH inputs to **Steering Group on Climate Change.**

7. Discussion of ICES SSGEF workplan (developments at 2010 ASC).

8. ICES Data Centre. Hjalte Parner.

   Review of recent activities and future plans

9. Relations with international climate monitoring programmes

   CLIVAR

   Others?

10. ASC theme sessions

    Proposed sessions for 2012

11. Election of new chair(s)

12. IROC Final review

13. WGOH website

14. Next Meeting

15. AOB

Annex 3: WGOH 2010 Terms of Reference

2010/2/SSGEF04 The **Working Group on Oceanic Hydrography** (WGOH), chaired by Glenn Nolan, Ireland, and Hedinn Valdimarsson, Iceland, will meet in Helsinki, Finland, 23–25 March 2011 to:

a) Update and review results from Standard Sections and Stations;

b) Consolidate inputs from Member Countries to, and continue development of, the ICES Report on Ocean Climate (IROC), and align data source acknowledgements in IROC with ICES policy; archive data used to compile report;

c) Provide support to other Expert Groups requiring information on oceanic hydrography;

d) Take action for strengthening the role of WGOH and physical oceanography within ICES; such as IGSG and WGOOFE and explore areas of mutual interest with international climate monitoring programmes;

e) Provide expert knowledge and guidance to ICES Data Centre (possibly via subgroup) on a continuous basis;

f) Review and refine the WGOH input to the ICES Climate Change position paper (as required by editors);

g) Prepare contributions for the 2011 SSGEF session during the ASC on the topic areas of the Science Plan;

h) Organise and run the ICES/NAFO Symposium on hydrobiological variability in Santander in May 2011.

WGOH will report by 30 April 2011 (via SSGEF) for the attention of SCICOM and ACOM.

Supporting Information

Priority	The activities of this Group are fundamental to the work of the SSGEF.
Scientific Justification	This is a repeating task established by the Working Group to closely monitor the ocean conditions in the ICES area. The materials presented under this item will be utilised to prepare an overview of the state-of-the-environment in the North Atlantic for 2010. The Working Group recognises the need for disseminating climate information in a timely and appropriate manner. This agenda item will allow WGOH members to prepare the document during the meeting, thus avoiding delays in the dissemination of the information. We will review proposed new developments in IROC content. Links have been made with the CLIVAR programme; it would be of benefit both to ICES and the international programmes to enhance internal information exchange. To follow up on the ICES General Secretary's suggestions for increasing the visibility of WGOH within ICES. To improve communications between working groups under the ICES system. This is in compliance with a request from the ICES Data Centre The work of the proposed Expert Group will be relevant for WGOH. ToR g) This is in response to a request from SSGEF.
Resource Requirements	No extraordinary additional resources
Participants	WGOH members; Chair of SSGEF
Secretariat Facilities	N/A
Financial	

Linkages to Advisory Committees	ACOM
Linkages to Other Committees or Groups	Publications Committee; Consultative Committee; IGSG
Linkages to Other Organisations:	IOC, JCOMM, CLIVAR

Annex 4: Recommendations

Recommendation	For follow up by:
1. ICES should make more hard copies of the IROC report available to WGOH members (10-15 per member) so that such reports can be distributed for lobbying purposes at the national level and to enhance the profile of the IROC report.	Reiterated recommendation that is still the contention of WGOH
2. WGOH recommends that a specific ToR on responding to the Integrated Framework for Sustained Ocean Observing paper is added for WGOH in 2012.	SSGEF and SCICOM (Kellerman)
3. WGOH recommends that a specific ToR on the Marine Strategy Framework Directive is added for WGOH in 2012 along the lines proposed by the SCICOM Chair: Identify elements of the EGs work that may help determine status for the 11 Descriptors set out in the Commission Decision (available at http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:232:0014:0024:EN:PDF; Provide views on what good environmental status (GES) might be for those descriptors, including methods that could be used to determine status.	SSGEF and SCICOM

Annex 5: Note on ICES/NAFO Decadal Symposium

Ecosystem Approaches to Marine Science and Advice: looking back before we leap forward.

Steve Cadrin, University of Massachusetts School for Marine Science & Technology

The recent Symposium on "Variability of the North Atlantic and its Marine Ecosystems during 2000–2009" (10–12 May, Santander, Spain) provided a relatively comprehensive status report on the North Atlantic Ecosystem, and served as a firm basis to proceed with advances in ecosystem approaches to ICES science and advice. Since their formations, ICES and NAFO[1] have approached questions in marine science and resource management from an ecosystem perspective. This approach has been reflected in a decadal series of symposia focused on describing variability in the North Atlantic ecosystem in the 1950s. The first symposium was held in Rome in 1964, and was followed by three decadal symposia in Dartmouth, Canada (1971, 1981 and 1994) and an ICES/NAFO co-sponsored symposium in Edinburgh, Scotland in 2001. All of the symposia provided a venue for a diversity of marine scientists to meet, present perspectives from their disciplines and across disciplines to consider decadal scale variability in all ecosystem components. The cross-pollination of ideas at the recent symposium was enhanced by the beautiful venue and warm hospitality of the local hosts.

It's no surprise that the overwhelming observation across all regions of the North Atlantic was a general warming trend. Warming was associated with freshening of seawater in most regions. As the principal drivers of seawater density, changes in temperature and salinity produced distinct changes in ocean circulation patterns such as position of major currents, strength of gyres, and depth of mixed layers. Biological responses to oceanographic changes varied among regions, but common observations were changes in timing of plankton blooms or fish migrations, shifts in latitudinal or depth distributions of fish populations, and a variety of changes in system productivity. One common theme in the symposium is that system changes have been so pronounced in the last decade that some common metrics used to monitor atmospheric or oceanic patterns are no longer tracking the processes as originally intended. Many advances in understanding ecosystem processes were presented that involved the formation of conceptual linkages between physical processes and biological responses. These case studies should inspire conference participants and readers of the ICES Journal proceedings for designing future research.

The advantages of developing conceptual understandings of ecosystem variability were best illustrated by the accomplishments of several honourees at the symposium. Several pioneers in marine science were honoured for their contributions to our understanding of the North Atlantic ecosystem: R. Allyn Clarke (Canada), R.R. (Bob) Dickson (UK), Catherine Maillard (France), Jens Meincke (Germany), Tom Rossby (USA) and Manfred Stein (Germany). Pentti Mälkki (Finland) offered a particularly inspiring history of the decadal symposium at the symposium dinner. The honourees challenged the rest of us to rise to the challenges of ecosystem science and continue to advance our understanding.

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[1] NAFO is the Northwest Atlantic Fisheries Organization; and its predecessor is ICNAF, International Convention for the Northwest Atlantic Fisheries.

Technological advances have greatly improved our ability to sample and monitor the North Atlantic, and many scientists are helping us to understand all of the information. The next stage of marine ecosystem science is to apply our knowledge to wise management of human activities that depend on the North Atlantic ecosystem. Both ICES and NAFO have several strong initiatives that apply ecosystem approaches in their resource management advice. As a recent example, the ICES Working Group for the Northwest Atlantic Regional Sea recognized that the development of an Integrated Ecosystem Assessment involves a transition from science and monitoring to action, quoting Warren Bennis's guidance on leadership:

"We have more information now than we can use, and less knowledge and understanding than we need…The true measure of any society is not what it knows but what it does with what it knows."

The ICES/NAFO decadal symposium on the North Atlantic ecosystem helped to summarize and synthesize the information we have. It also promoted knowledge and understanding of ecosystem linkages. Hopefully this knowledge base will support ecosystem approaches to advice and resource management.

Annex 6: Regional report – West Greenland 2010–2011 (area 1)

Anna Akimova, Institute of Sea Fisheries (vTI), Germany

The West Greenland and East Greenland currents are the boundary currents in the northern part of the North Atlantic sub-polar gyre. The East Greenland current transports the fresh and cold Surface Polar Water (SPW) to the south along the eastern coast of Greenland. The West Greenland Current (WGC) carries the water northward and consists of two components: a cold and fresh inshore component, which is a mixture of the SPW and melt water, and saltier and warmer Irminger Sea Water (ISW) offshore component. The WGC transports water into the Labrador Sea, and hence is important for Labrador Sea Water formation, which is an essential element of the Meridional Overturning Circulation (MOC). The dynamics of the current is monitored yearly in autumn at two standard ICES/NAFO oceanographic sections across the slope off West Greenland. The monitoring is carried out since 1983 by Institute of Sea Fisheries from board of RV 'Walter Herwig III' and reveals significant interannually and long-term variability of both components of the WGC.

Atmospheric conditions in 2010

The variability of the atmospheric conditions over Greenland and the Labrador Sea is driven by the large scale atmospheric circulation over the North Atlantic, which is normally described in terms of the North Atlantic Oscillation (NAO). During a positive NAO strong northwest winds bring cold air from the North American continent and cause negative anomalies of the air temperatures over Greenland, Labrador Sea, Baffin Bay (Hurrell and Deser, 2010). During a negative NAO the westerlies slacken and the weather is normally milder over the whole region. According to ICES standards, we use in this study the Hurrell winter (DJFM) NAO index, which is available at *http://www.cgd.ucar.edu/cas/jhurrell/indices.html*. The correlation between annual air temperature time-series and winter NAO index time-series is -0.51 for the period from 1876 to 2009 and slightly varies between decades (Table 4). However, the NAO index gives us only the information about the strength of Icelandic Low and Azores High and gives no information about their spatial location, which also affects the direction of winds and regional weather. That might explain the low correlation between two parameters.

In 2010 the NAO index was negative (-2.57) and was the third strongest negative NAO since winter 1995/1996 (Figure 1). The circulation cell was strongly shifted to the south-west in comparison with its long-term mean location (Figure 2).

The mean air temperature at Nuuk Weather Station in West Greenland was +2.6°C in 2010, which is the highest ever reported temperature since the beginning of the observations in 1876 (Figure 3). This value reflected extremely warm air condition in 2010 over the whole western North Atlantic (Figure 4). The monthly temperatures were higher than the corresponding long-term means during the whole 2010, especially in the winter months (Figure 5).

Hydrographic Conditions

Here a short overview of the hydrographical condition west off Greenland during autumn 2010 is presented. The core properties of the water masses of the WGC are formed in the western Irminger Basin where the East Greenland current and Irminger current (IC) meet. The East Greenland current transports southwards fresh and cold PSW of Arctic origin. The IC is a northern branch of the Gulf Stream, which makes a cyclonic loop in the Irminger Sea and carries warm and saline ISW. After the currents converge, they turn around the southern tip of Greenland, form the WGC and propagate northward along the western coast of Greenland. During this propagation considerable mixing between two water masses takes place and ISW gradually increases its depth (Clarke and Gascard, 1983; Myers *et al.*, 2009).

There is more than one definition of the water masses carried by the WGC (Clarke and Gascard, 1983; Stein, 2005; Schmidt and Send, 2007; Myers *et al.*, 2009). Here we consider the upper layer down to 700 m water depth and define SPW and ISW following the study of Myers *et al.*, 2009 (Table 5). Deeper Labrador Sea Water and North East Atlantic Deep Water stay beyond the scope of this report.

In 2010, oceanographic observations during the survey were carried out at each fishery station and two standard ICES/NAFO sections (Figure 6). SeaBird 911+ CTD with an accuracy given by a manufacture (www.seabird.com) was used. The collected data was interpolated to a 1 m grid in the vertical. If data was missing at the top of a profile, we assumed constant properties from the first measurement (normally 2–15 m) up to the surface.

Standard Cape Desolation and Fyllas Bank sections span across the shelf and the continental slope off West Greenland (Figure 6). The Cape Desolation section is situated 300 km northwest from the southern tip of Greenland. At this section the strong surface front separates PSW on the shelf from ISW offshore (Figure 7). In autumn, the temperature of the upper layer is well above zero due to the summer heat accumulation, and hence only the salinity can be used as a tracer of the SPW. The salinity of less than 33 was observed at the shallowest station (Figure 7). The most offshore station occupied in 2011 (Station 1111 on Figure 7) corresponds to the standard Cape Desolation Station 3, which was reported in ICES WGOH since 2001 (Stein, 2010). In 2010 as well as in 2009 no SPW was observed in the upper layer at this station in contrast to the previous two years (Figure 8). Upper 100 m of the water was very warm due to a strong heat flux from the warm atmosphere. The temperature of water between 100 and 700, where ISW flows, was warmer than its long-tem mean and thus continued the series of 'warmer than normal' years started in 1998. The salinity of the water was only slightly above its long-term level. The warming of the ISW layer and the increase of its salinity go along this the slowing down the Subpolar Gyre, which is recently widely discussed (Häkkinen and Rhines, 2004; Hátún *et al.*, 2005; Hátún *et al.*, 2009)

The Fyllas Bank section is situated further to the north over the broad shallow Fyllas Bank that affects strongly the structure of the West Greenland Current (Myers *et al.*, 2009). Fresh PSW was seen in top 100 m over the entire section (Figure 9) and it spread at least 100 km away from the shelf. In 2009, the core of ISW (θ >6 °C, S>35.00) was found between 300 and 450 m water depth at the station 1113 almost 40 km offshore (Figure 9).

The Station 222 at the continental slope at 900 m depth corresponds to standard Fyllas Bank Station 4 (e.g. Stein, 2002; Stein, 2004). Similar to Cape Desolation Station 3, year 2010 can be characterized by a very warm upper layer due to warm air conditions and warm ISW, which at this location was as warm as in 2003 (Figure 10). The salinity of ISW was slightly above its long term mean.

The general conclusions about the atmospheric and oceanic conditions west off Greenland in autumn 2010 are follows. The annual air temperature was extremely high in consistence with the negative NAO index in winter 2009/2010. The upper SPW layer was also warmer than its long-term average condition, but its salinity did not exceed its mean values. The potential temperature the ISW was lower than its maxima in 2003, but continued the warm phase started in the end of 1990s due to weakening of the Subpolar Gyre.

Table 1. Details on the times series, analysed in this study. Lat is used for the latitude, long is used for longitude.

Name	Lat (°N)	Lon (°W)	Type
Nuuk	64.36	-51.75	Weather station
Cape Desolation Station 3	60.45	-50.00	Oceanographic station
Fyllas Bank Station 4	63.88	-53.37	Oceanographic station

Table 5. Water mass characteristics in the area of research.

The water masses in the area	Potential temperature (θ)	Salinity (S)
Surface Polar Water (SPW)	$\theta \leq 0$	$S \leq 34.4$
Irminger Sea water (ISW)	$\theta \geq 4.5$	$S \geq 34.95$

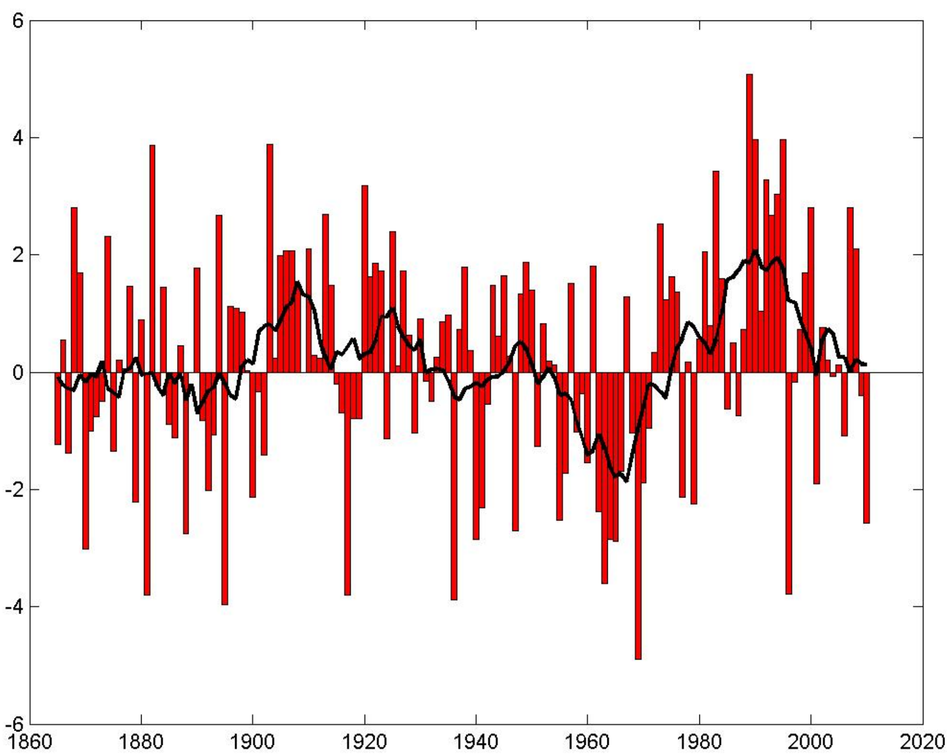

Figure 1. The Hurrell winter (DJFM) NAO index with a 5-year running mean (black curve). Data source: http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html.

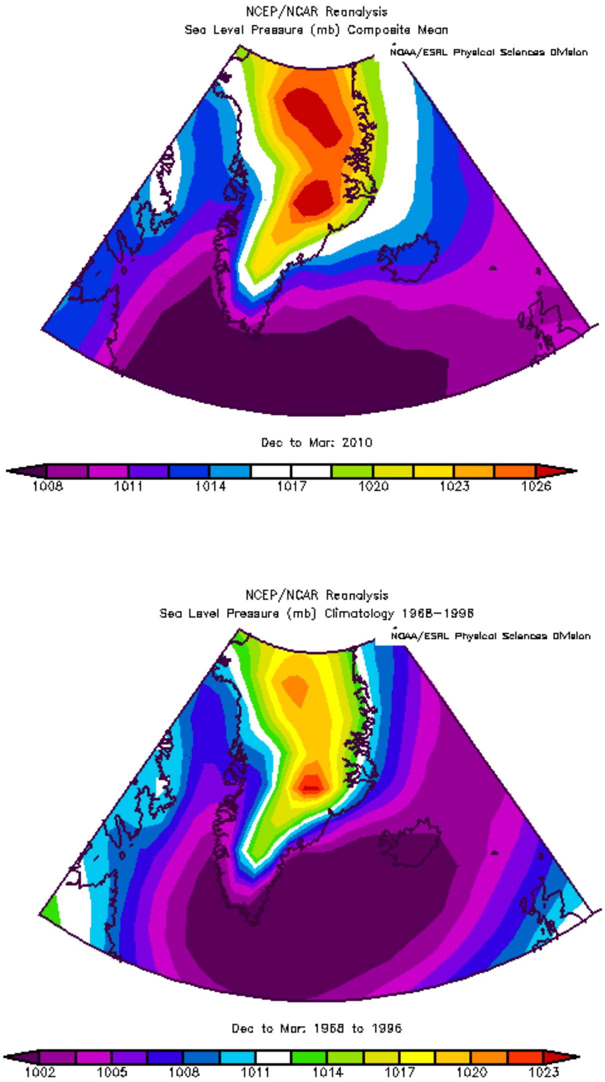

Figure 2. Maps of winter (DJFM) sea level pressure (SLP). Upper panel: mean SLP in winter 2009. Lower panel: mean winter SLP from 1968 to 1996. Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado.

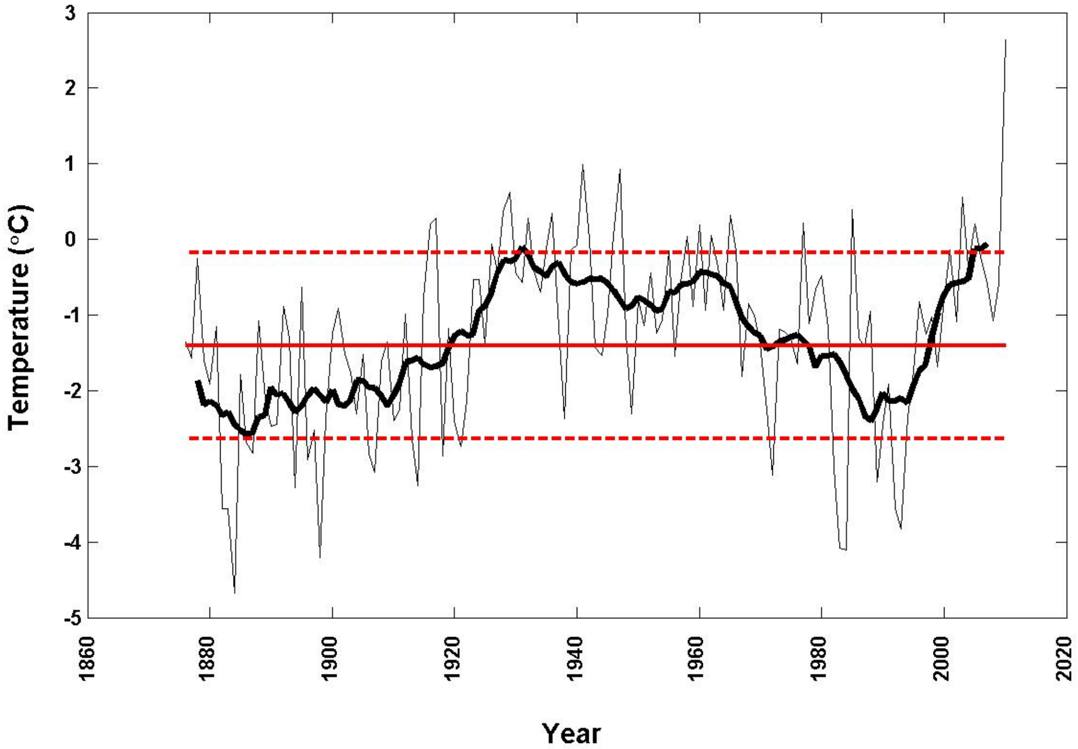

Figure 3. Annual mean air temperature at Nuuk station. Thick black line shows the 5-year smoothed data. Red solid line indicates the long-term mean temperature, referenced to 1971–2000. Dashed red lines mark corresponding standard deviations.

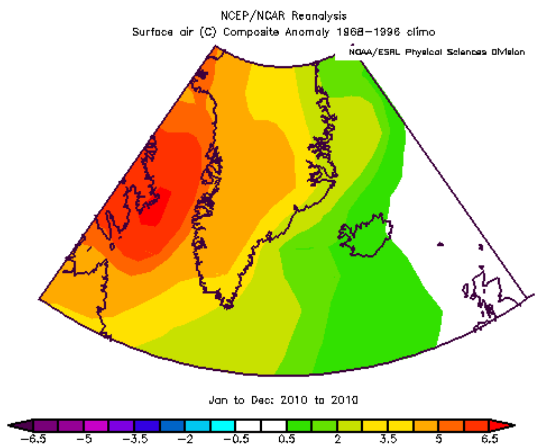

Figure 4. Map of 2010 annual air temperature anomalies in the study region. The long-term mean corresponds to 1968–1996. Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado.

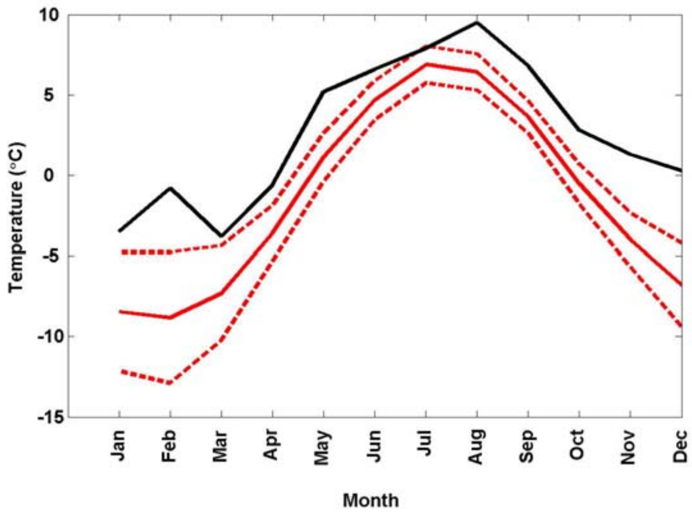

Figure 5. Monthly mean temperature at Nuuk station. Monthly mean temperature in 2009 (black line), long-term monthly mean temperature (red solid line) and one standard deviation (red dashed lines) are shown.

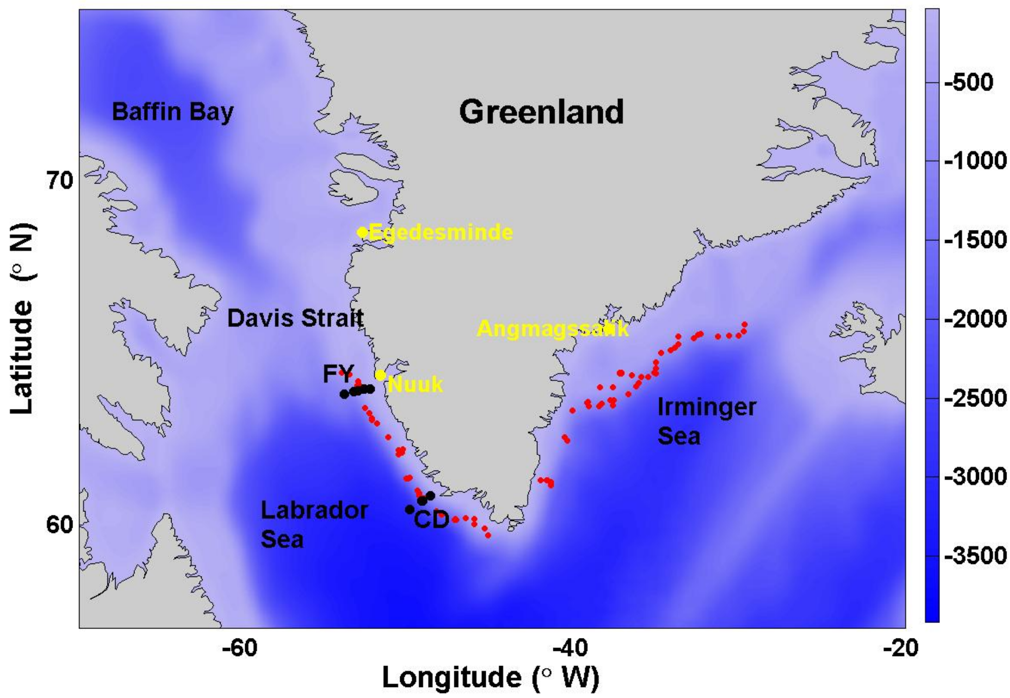

Figure 6. Map and bathymetry of the study region. Meteorological stations location is shown in yellow. Red dots show the location of the fisheries stations, occupied during the survey in 2009. Black dots mark two standard sections (CD – Cape Desolation section, FY – Fyllas Bank Section).

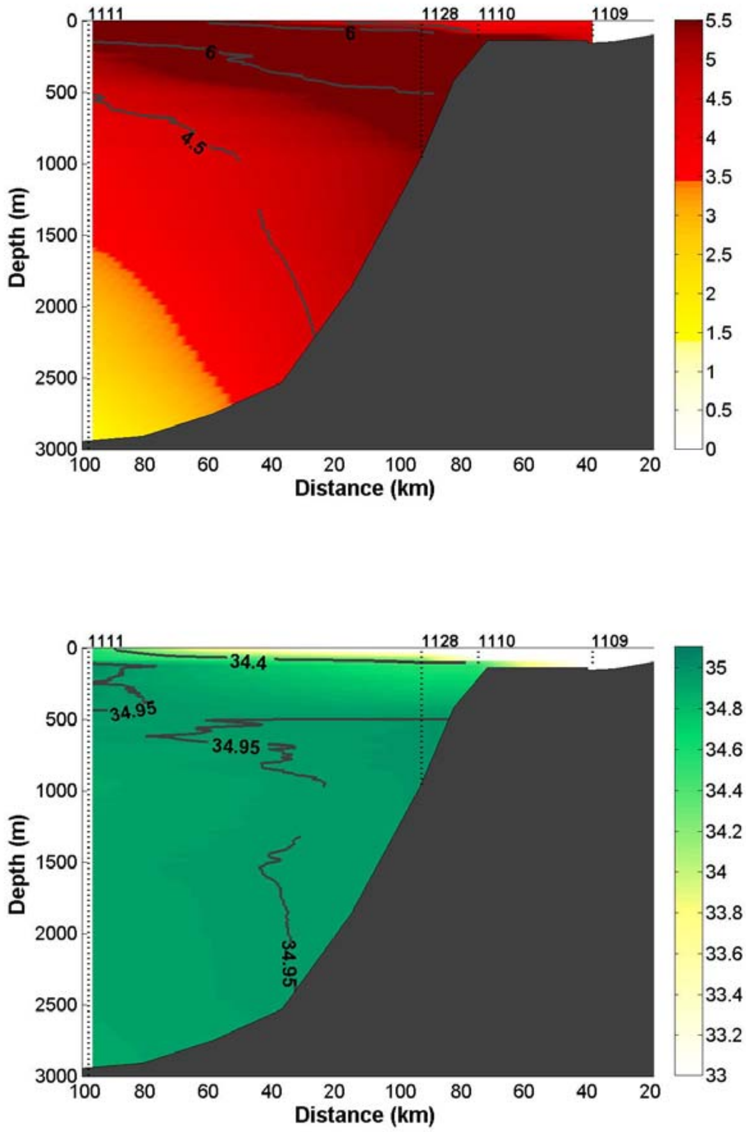

Figure 7. Vertical distribution of potential temperature (upper panel) and salinity (lower panel) along the Cape Desolation section (Figure 1) in 2010. The x-axis shows the distance from the Greenland shore.

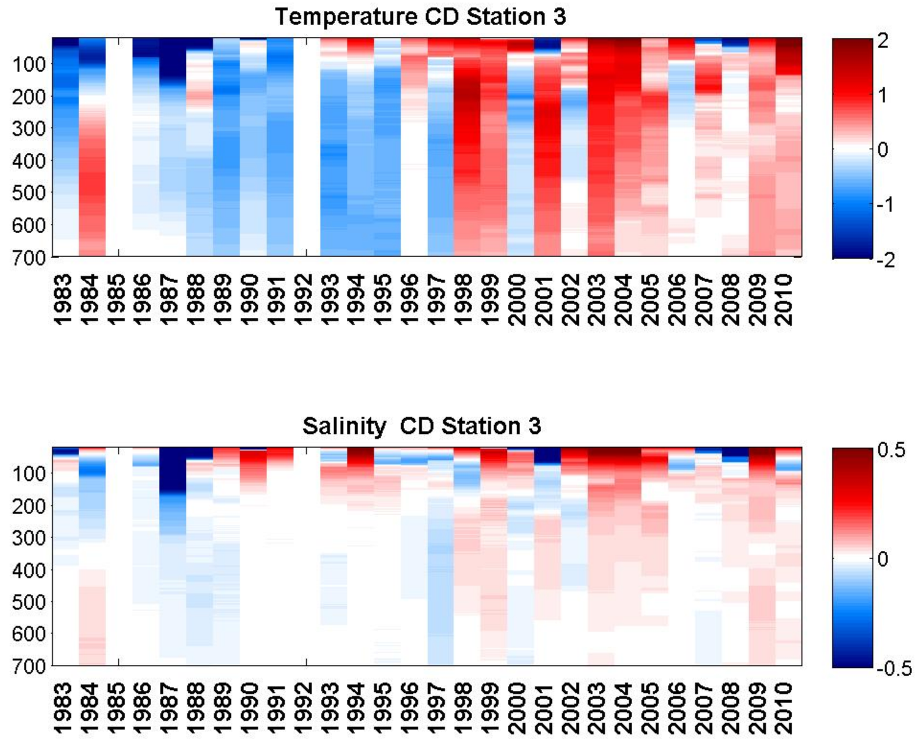

Figure 8. Hovmoeller diagram of the potential temperature anomalies (upper panel) and salinity anomalies (lower panel) in the upper 700 m at Cape Desolation Station 3 (Table 1). Reference period is 1983–2010.

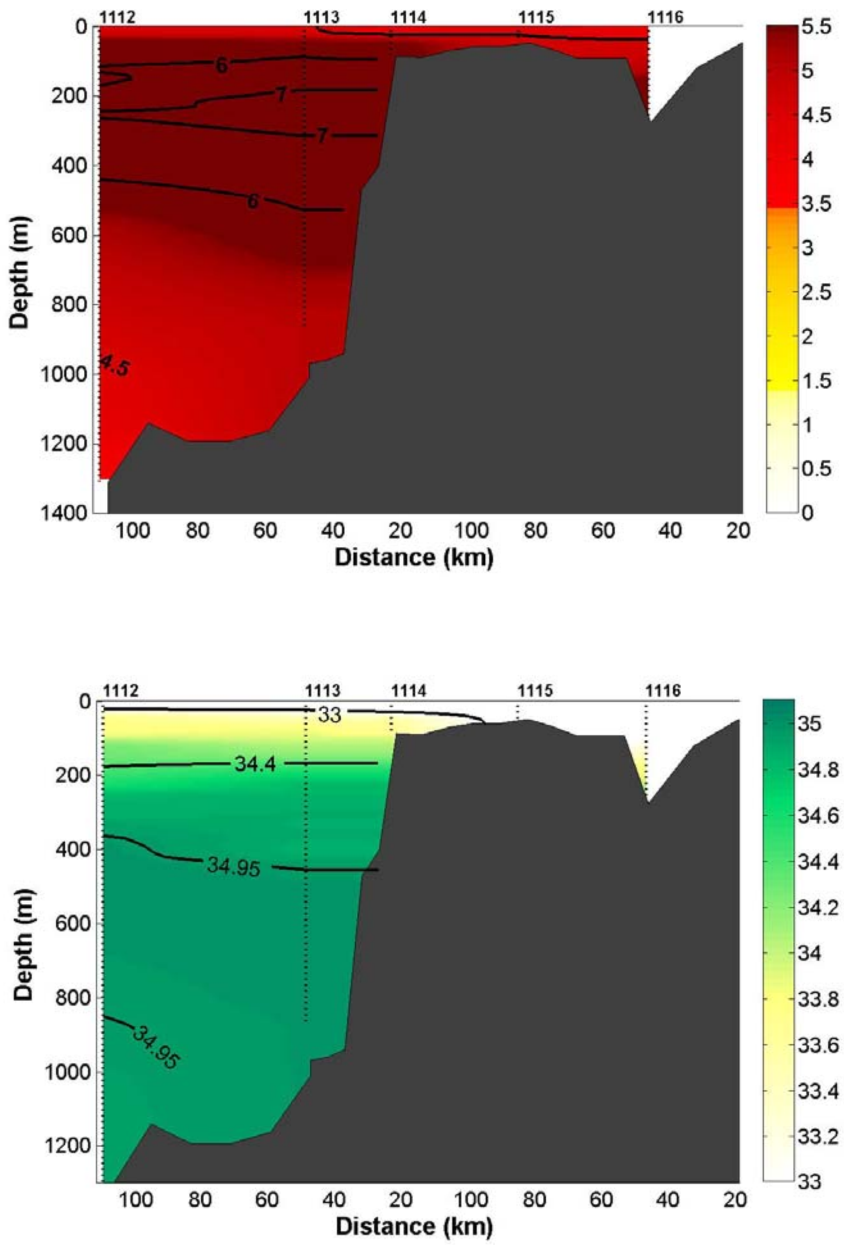

Figure 9. Vertical distribution of potential temperature (upper panel) and salinity (lower panel) along Fyllas Bank section (Figure 1) in 2010. The x-axis shows the distance from the shore.

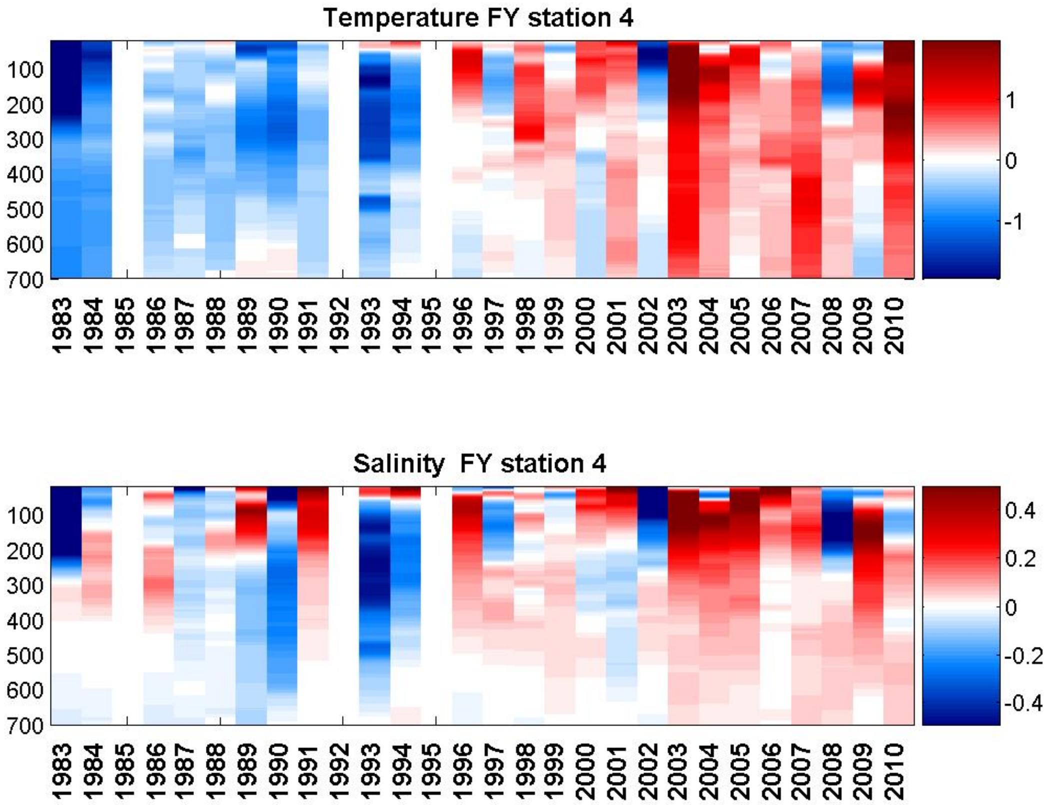

Figure 10. Hovmoeller diagram of the potential temperature anomalies (upper panel) and salinity anomalies (lower panel) in the upper 700 m at Fyllas Bank Station 4 (Table 1). Reference period is 1983–2010.

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Annex 7: Regional report – US National Report

Hydrographic Conditions on the Northeast United States Continental Shelf in 2010

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Background

This report discusses 2010 hydrographic conditions on the Northeast United States (NEUS) Continental Shelf, extending from the southern tip of Nova Scotia, Canada, southwestward through the Gulf of Maine and the Middle Atlantic Bight, to Cape Hatteras, North Carolina. The hydrography in this region is influenced by contrasting water masses from the subtropical and subpolar gyres, as it is here that the major western boundary currents from both gyres converge: the Gulf Stream carrying very warm and salty water from the south meets the Labrador Current carrying very cold, fresh water from the north. The NEUS shelf is located at the downstream end of an extensive interconnected coastal boundary current system, a component of the western boundary current of the subpolar gyre (Figure 1). As such, this region is the direct recipient of the cold/fresh arctic-origin water, accumulated coastal discharge and ice melt that has been advected thousands of kilometres around the boundary of the subpolar North Atlantic. Likewise, subtropical water masses, advected by the Gulf Stream, slope currents and associated eddies, also contribute to the composition of water masses within the NEUS shelf region. Insofar as the western boundary currents of the subpolar and subtropical gyres respond to interannual variations in basin-scale forcing, through variations in transport, water mass properties and/or position (e.g. Joyce *et al.*, 2000; Marsh, 2000, Curry and McCartney, 2001; Häkkinen and Rhines, 2004), these transients will also be communicated to the NEUS shelf region.

To first order, hydrographic conditions along the NEUS shelf are determined by the relative proportion of the two main sources of water entering the region: cold/fresh arctic-origin water advected by the coastal boundary current from the north and warm/salty slope waters residing offshore of the shelf break. The source waters first enter the NEUS shelf region through the Gulf of Maine, a semi-enclosed shelf sea that is partially isolated from the open Northwest Atlantic by two shallow banks, Browns and Georges Banks (Figure 2). Below 100 meters, exchange between the Gulf of Maine and the deeper North Atlantic is restricted to a single deep channel, the Northeast Channel, which bisects the shelf between the two banks. This deep channel interrupts the continued flow of cold, fresh arctic-origin water along the coast, redirecting the majority of this flow into the Gulf of Maine. Within the Gulf of Maine, these shelf waters circulate counter-clockwise around the basin before continuing southwestward through the Middle-Atlantic Bight. Within the Gulf of Maine, the shelf water is progressively modified by atmospheric fluxes of heat and salt and through mixing with both deeper slope waters and the discharge of several local rivers. For this reason, the Gulf of Maine represents the gateway to the NEUS shelf region, responsible for setting the initial hydrographic conditions for water masses entering the Middle Atlantic Bight further downstream.

The pronounced seasonal cycle of heating and cooling over the region produces distinct water mass layers within the Gulf of Maine (Figure 3). During fall and winter, intense cooling at the surface removes buoyancy, resulting in overturning and vertical homogenization of the water column to approximately 150 meters (Hopkins and

Garfield, 1979). During spring and summer, surface heating restratifies the surface layer, isolating a remnant of the previous winter's cold/fresh mixed water within an intermediate layer that is sandwiched beneath the relatively warm/fresh surface layer and above the relatively warm/salty deep layer. Variations in the properties and the volume of source waters entering the Gulf of Maine drive interannual variations in water properties relative to this seasonal mean picture. For instance, the slope water that enters the Gulf of Maine is a mixture of two water masses (Figure 4): warm/salty/nutrient-rich Warm Slope Water (WSLW) originating in the subtropics and cold/fresh/nutrient-poor Labrador Slope Water (LSLW), having subpolar origins (Gatien, 1976). Seaward of the Gulf of Maine, the relative proportion of these two water masses varies over time. However, in general, the volume of each decreases with increasing along-slope distance from their respective sources; LSLW (WSLW) volume decreases from north to south (south to north). Several investigators have presented compelling evidence that variations in the composition of the slope water in the Gulf of Maine is correlated with basin-scale atmospheric forcing in the North Atlantic (specifically the North Atlantic Oscillation, NAO.) The conceptual model is that during years characterized by negative NAO anomalies a larger volume of LSLW penetrates southwestward along the continental slope than during positive NAO years (Figure 5; Drinkwater *et al.*, 2002). The apparent consequence is that bottom waters are colder and fresher along the western Scotian Shelf and in the Gulf of Maine during these periods (Petrie, 2007.)

During the 1960–1970s, hydrographic variations in the deep water masses in the Gulf of Maine were directly correlated with shifts in the slope water composition and reasonably correlated with prolonged negative and positive NAO fluctuations in the North Atlantic. However, in more recent years (particularly from the 1990s-present) the correlations between hydrographic conditions in the Gulf of Maine and the shifts in slope water composition have not been as strong. Instead, observations indicate that the inflow to the Gulf of Maine now contains a larger proportion of shelf water than slope water (Smith *et al.*, 2001; Townsend *et al.*, 2010.). One hypothesis is that increased melting in the north has led to fresher conditions on the shelf and slope throughout the western North Atlantic, enhancing baroclinic transport and leading to greater transport of shelf water and LSLW downstream of the Grand Banks of Newfoundland (Greene and Pershing, 2007; Townsend *et al.*, 2010). Indeed, the transport of the Labrador Current along the Newfoundland shelf/slope does appear to be correlated with fluctuations in salinity in the Gulf of Maine. However, this correlation breaks down in more recent years. One possibility is that a larger portion of transport is being diverted away from the shelfbreak into inshore branches of the coastal boundary current in recent years.

Hydrographic Conditions in 2010

The US National Oceanic and Atmospheric Administration's Northeast Fisheries Science Center (NEFSC) conducts multiple shelf-wide surveys every year in support of its mission to monitor the NEUS ecosystem (Figure 6). Monitoring efforts have been ongoing since 1977. In 2010, the NEFSC completed ten surveys on the NEUS shelf. Hydrographic data from five of these surveys have been analyzed for this report (Table 1). Maps of surface and bottom temperature and salinity anomaly, measured relative to the average conditions from the same time of year during 1977–1987, were compared from spring and fall surveys in 2009 and 2010 (Figure 7). In general, significant warming was observed in 2010 at both the surface and bottom, particularly in the Gulf of Maine and northern Middle Atlantic Bight. Some freshening was observed in the surface waters of the Gulf of Maine, particularly in the northwestern region. Relative to 2009, saltier bottom waters were observed within Northeast Channel, extending into the northern Gulf of Maine. A closer examination of deep temperature and salinity observations in the Northeast Channel confirms that deep inflow to the Gulf of Maine was warmer and saltier in 2010, close to the upper limit of the historical range (Figure 8).

In order to examine hydrographic trends throughout the Gulf of Maine, we examine profiles of temperature and salinity at several locations following the general path of the mean circulation: in the eastern and northern Gulf of Maine and on the northwest side of Georges Bank. We choose to restrict our comparisons to stations occupied between early-May and August, as this encompasses the period when the freshest pulse propagates through the Gulf of Maine, according to historical observations (Mountain and Manning, 1994). In the eastern and northern Gulf of Maine, temperature-salinity relations show that the intermediate layer trended colder and fresher from 2008–2010, while the deep layer trended warmer and saltier (Figure 9). The apparent cooling trend in the upper layers during 2010 is due to a seasonal bias introduced by sampling: the 2010 stations were occupied in early-summer before the peak in seasonal heating at the surface, while 2008 stations were occupied in late-summer following the peak in heating. On Georges Bank, just before the water exits the Gulf of Maine, waters were 0.25–0.5 units fresher in 2010 (Figure 9). The temperature trends on Georges Bank are also dominated by the seasonal bias introduced by sampling. Trends in upper-layer temperature were examined by computing the regional average temperature and salinity on the northwestern flank of Georges Bank. Relative to the long-term monthly climatology (1977–2000), the surface layer (0–30 meters) was warmer than it has ever been during spring/summer and colder than it has ever been during fall/winter, 2010 (Figure 10). Similarly, the regional average salinity record corroborates the trends already discussed: upper layer waters were significantly fresher than the climatological mean during spring and summer, 2010 over northwest Georges Bank (Figure 10).

Perturbations in the volume or properties of the various sources feeding into the Gulf of Maine influence the hydrographic conditions within the NEUS shelf ecosystem. While observations and models suggest that basin-scale meteorological forcing (e.g. NAO) alters the composition of slope waters available to enter the Gulf of Maine (Petrie and Drinkwater, 1993; Marsh, 2000; Petrie, 2007), this response may be muted if shelf water dominates the inflow, as we have seen in recent years (Townsend *et al.*, 2010). It remains to be seen whether the record-low NAO, beginning in 2010, will force a lagged shift in the slope water composition. Based on the Drinkwater *et al.* (2002) model, we might expect a shift toward a colder/fresher variety of slope water offshore of the Gulf of Maine as a larger volume of LSLW penetrates equatorward along the Scotian Shelf. In fact, preliminary data collected in February 2011 indicates that the slope waters in the Northeast Channel and the bottom waters in the deep basins of the Gulf of Maine are even warmer and saltier than they were in 2010. This suggests that the linkages between mechanisms and responses in the NEUS shelf region are complicated by the interplay between remote versus local forcing and the competing influence of multiple advective sources (e.g. shelf versus slope).

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Table 1. 2010 Hydrographic cruises included in this report.

Survey	Sampling Dates	Total Stations
Ecosystem monitoring survey	Feb. 2 – 18, 2010	131
Bottom trawl survey	Feb. 22 – May 4,2010	390
Ecosystem monitoring survey	May 26 – June 10, 2010	196
Bottom trawl survey	Sep. 7 – Dec. 2, 2010	356
Ecosystem monitoring survey*	Nov. 4 – Nov. 22, 2010	253

*** based on preliminary data**

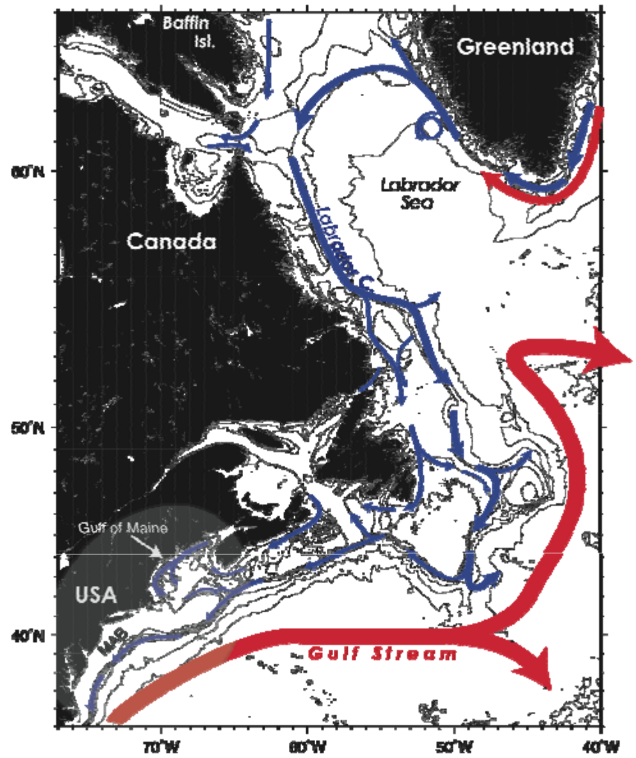

Figure 1. Dominant circulation features in the western North Atlantic Ocean. The Northeast U.S. shelf region is denoted by the gray oval.

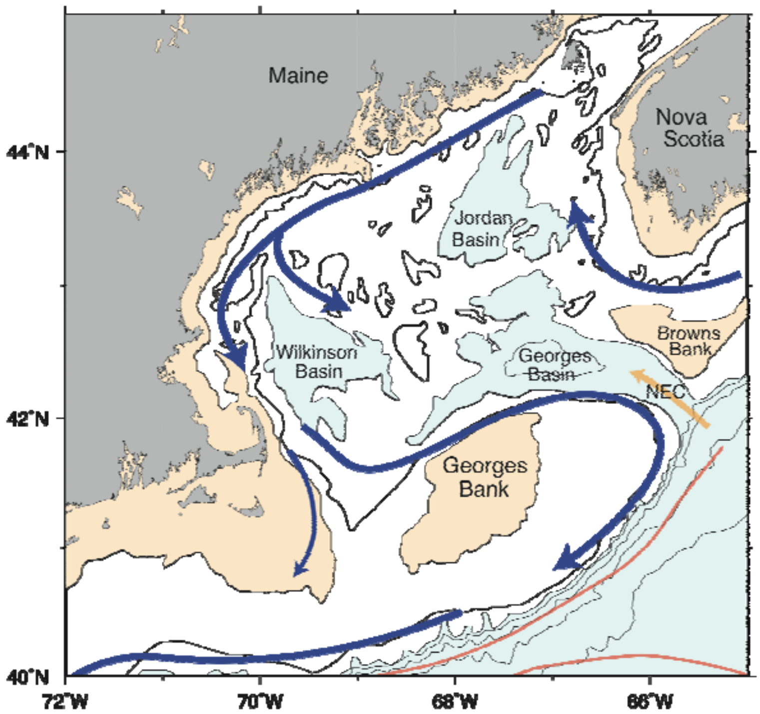

Figure 2. Circulation and topography in the Gulf of Maine. Water depths less than 50 meters are shaded brown. Water depths greater than 200 meters are shaded blue.

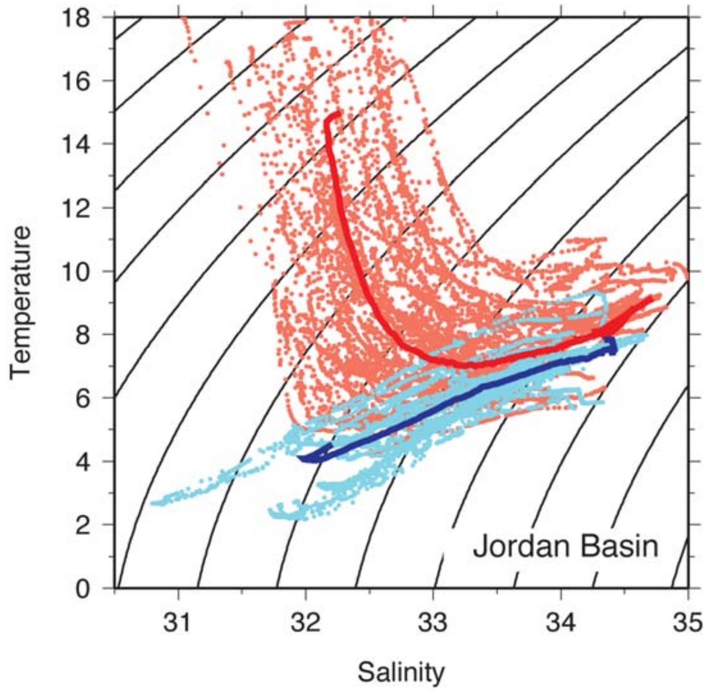

Figure 3. Profiles of temperature and salinity within Jordan Basin (Figure 2) collected during summer (May–Aug, red) and winter (Jan–Apr, blue). The solid lines show the seasonal average profiles.

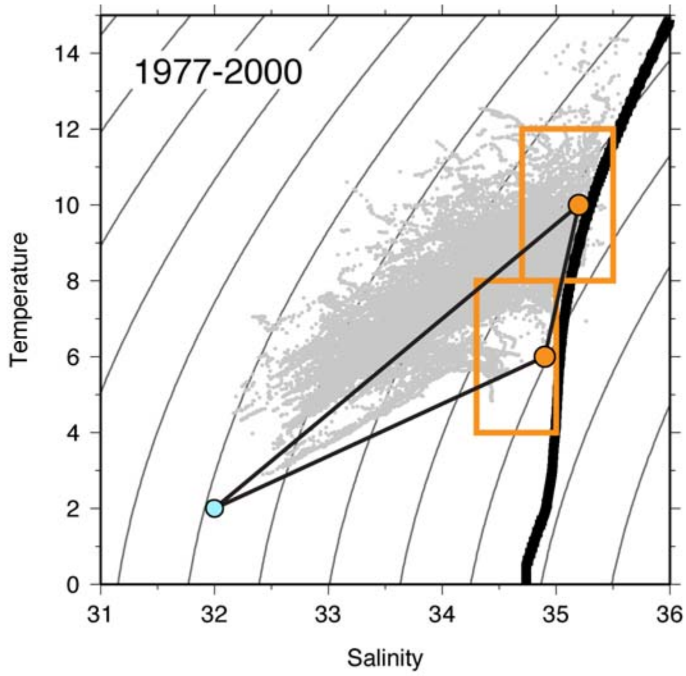

Figure 4. Lower-layer temperature and salinity (>100 meters) within the Northeast Channel for the period 1977–2000 (gray). The solid black line is the standard curve for North Atlantic Central Water, representing "pure" subtropical water. The property range associated with the three sources of water entering the Gulf of Maine is shown by the mixing triangle: Scotian Shelf water (blue), Warm Slope Water (WSLW, upper orange box) and Labrador Slope Water (LSLW, lower orange box).

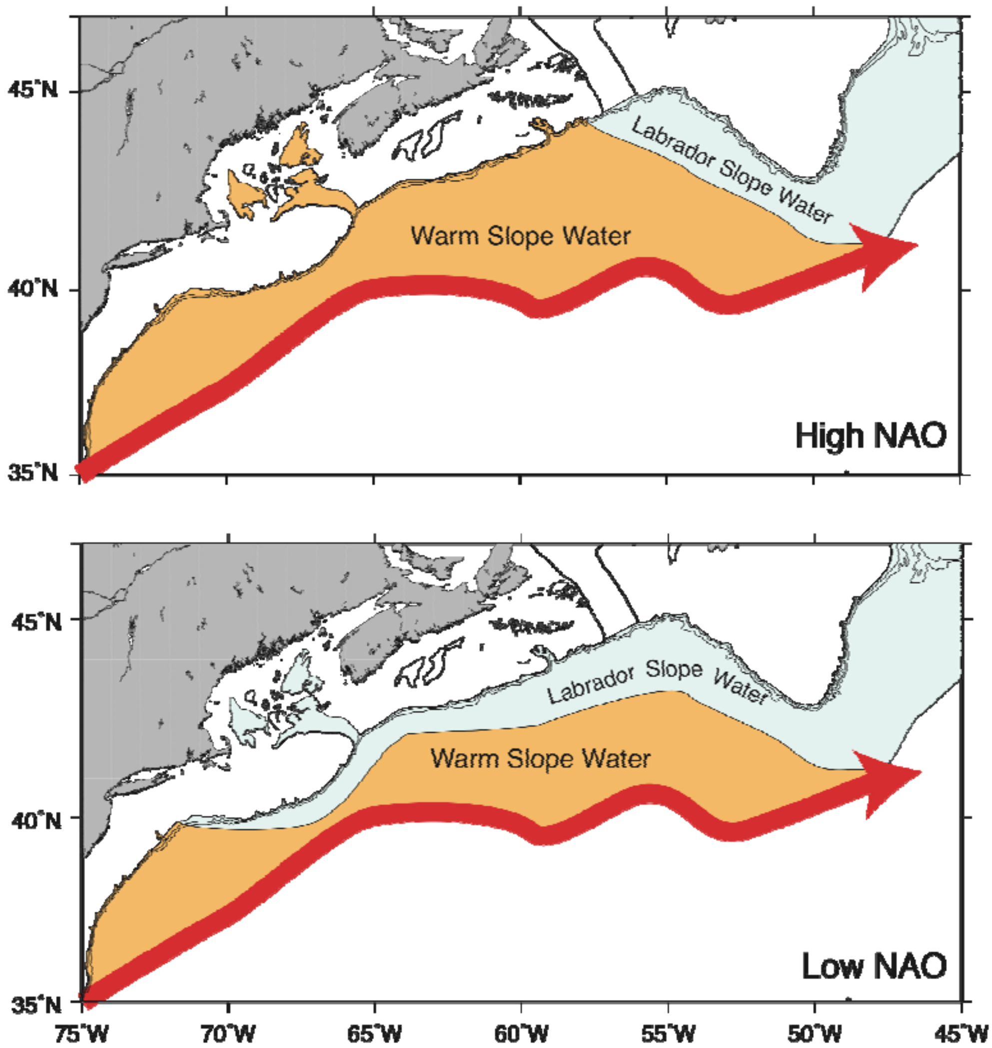

Figure 5. Conceptual model for the configuration of constituent slope water masses offshore of the Gulf of Maine during high and low NAO phases in the North Atlantic (Drinkwater *et al.*, 2002).

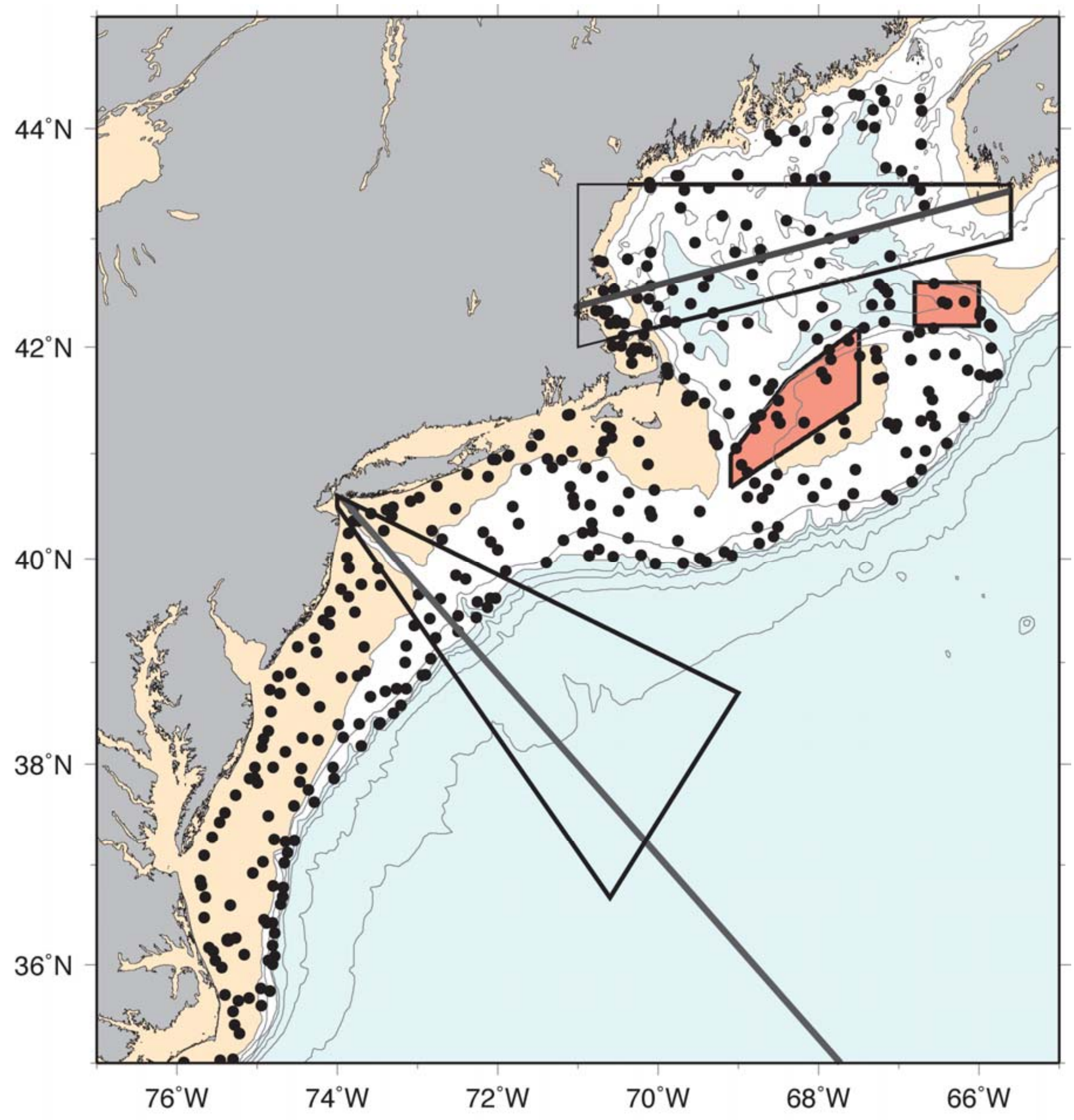

Figure 6. Ongoing monitoring in the NEUS shelf region by the Northeast Fisheries Science Center. The black dots show the typical station distribution for a shelf-wide bottom trawl survey. The gray lines show the ship tracks for two regularly occupied ship of opportunity transects: one extending from New York to Bermuda and the other extending from Boston to Cape Sable, Nova Scotia. The red shaded polygons show the areas within which regional average time-series are updated each year from shipboard temperature and salinity observations.

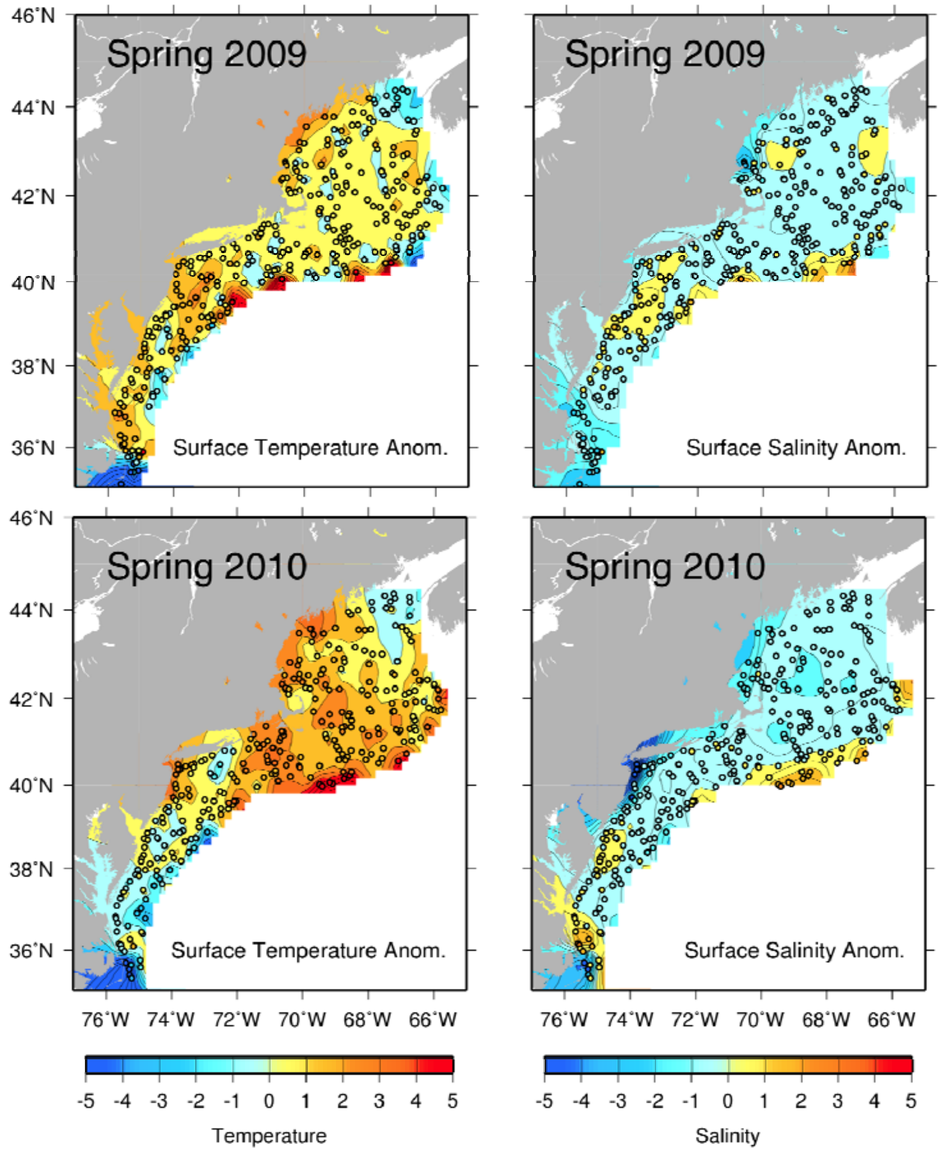

Figure 7a. Surface temperature anomaly (left) and salinity anomaly (right) during spring 2009 (top) and spring 2010 (bottom). The anomaly is calculated relative to the springtime mean for 1977–1987.

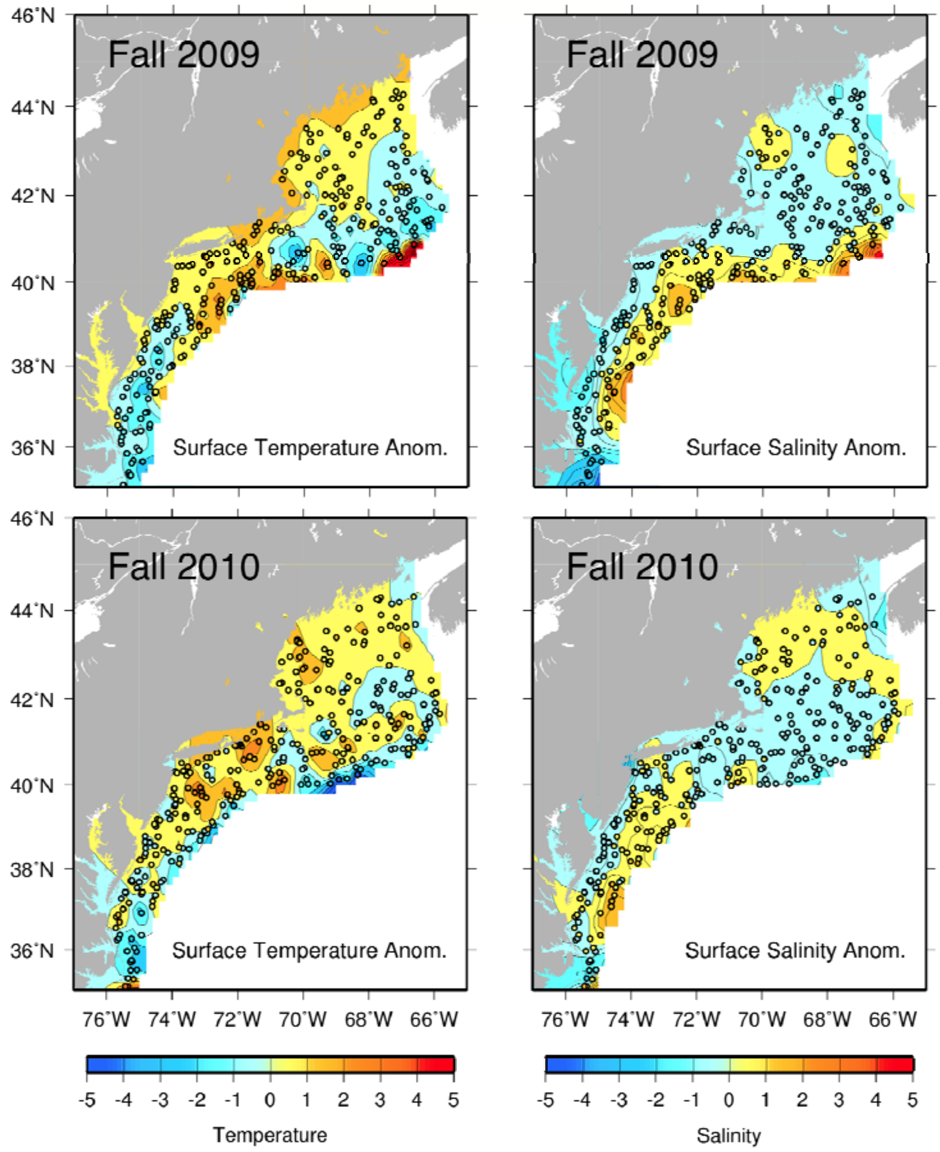

Figure 7b. As in 7(a) but for fall 2009 (top) and fall 2010 (bottom).

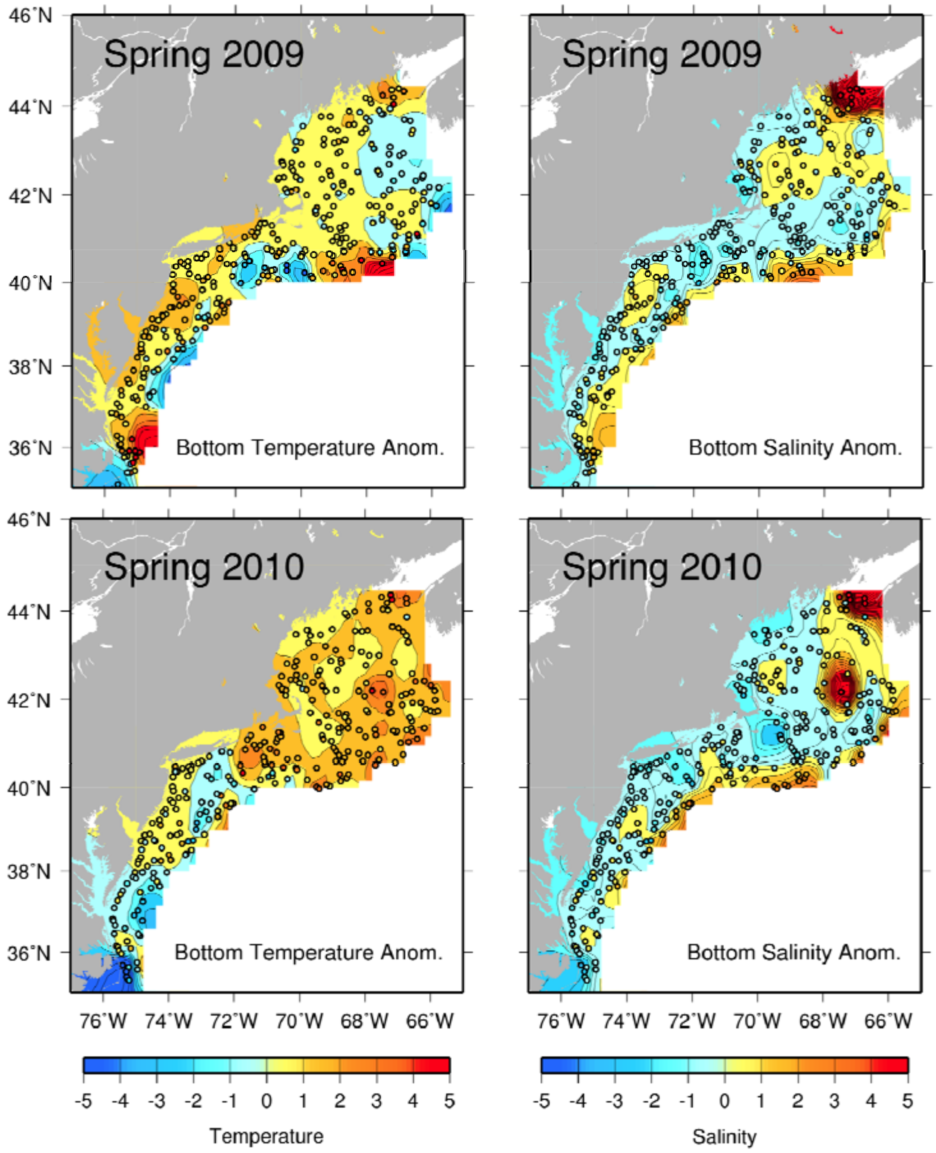

Figure 7c. Bottom temperature anomaly (left) and salinity anomaly (right) during spring 2009 (top) and spring 2010 (bottom). The anomaly is calculated relative to the springtime mean for 1977–1987.

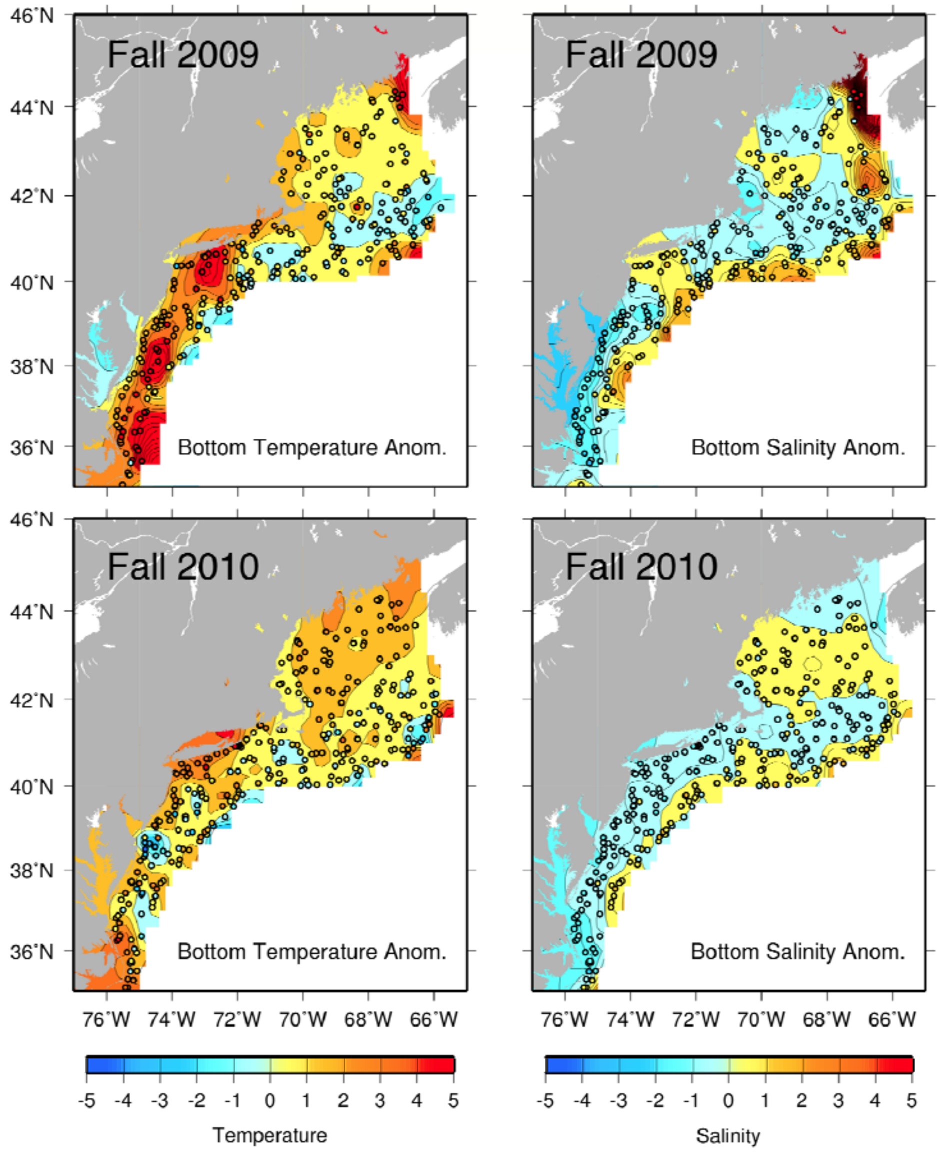

Figure 7d. As in 7 (c) but for fall 2009 (top) and fall 2010 (bottom).

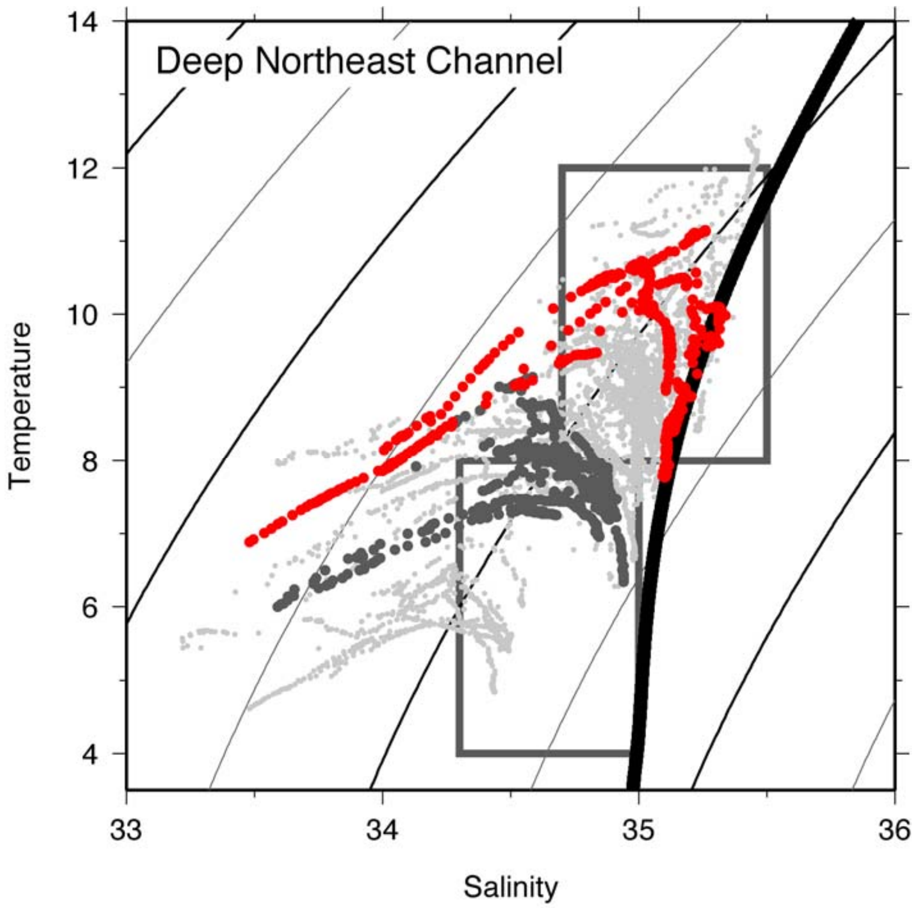

Figure 8. Profiles of temperature and salinity within the Northeast Channel (>100 m). Observations are shown from 2010 (red) and 2008 (dark gray). Light gray dots are the historical observations between 1977-present. The property ranges associated with two slope water sources are shown by the gray boxes: Warm Slope Water (WSLW, upper box) and Labrador Slope Water (LSLW, lower box). The solid black line is the standard curve for North Atlantic Central Water, representative of "pure" subtropical water.

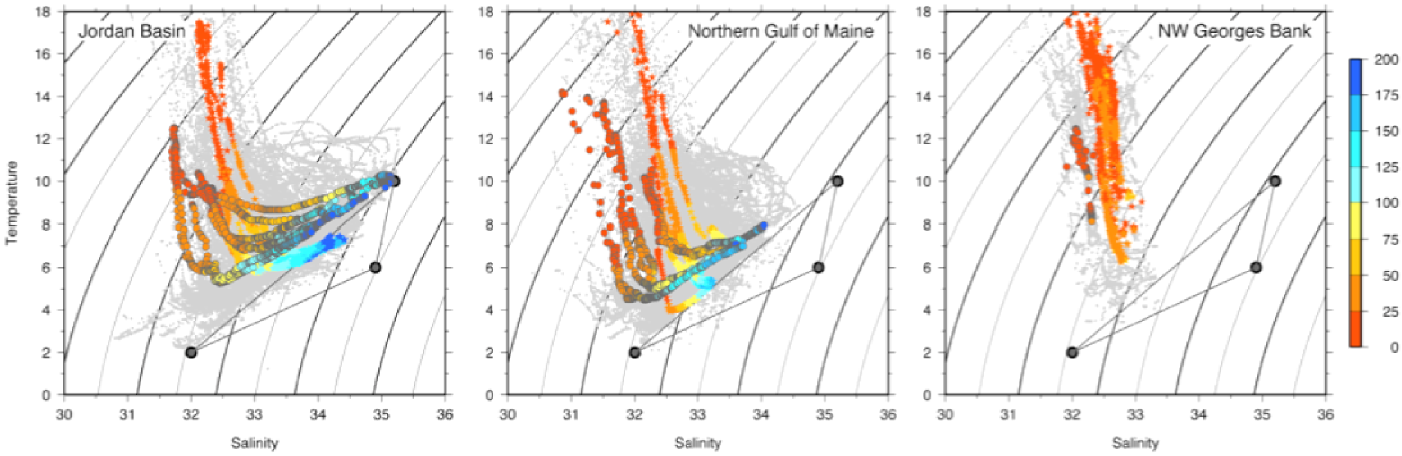

Figure 9. Profiles of temperature and salinity within Jordan Basin (left), in the northern Gulf of Maine (middle) and on the northwest side of Georges Bank (right). Observations are shown from 2010 (circles) and 2008 (stars). Values are colour-coded by observation depth. The mixing triangle for the three dominant inflowing water masses is also shown. Gray dots are the historical observations between 1977-present.

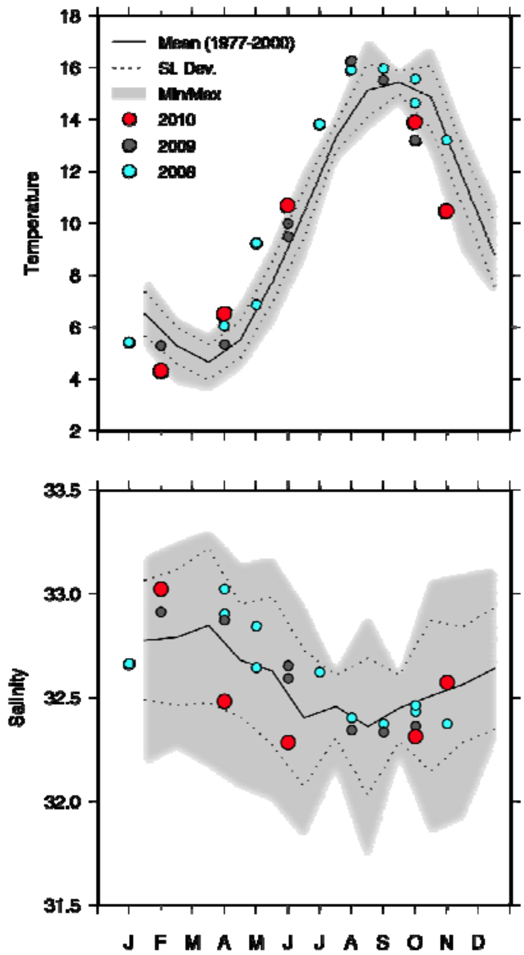

Figure 10. Regional average temperature (top) and salinity (bottom) on the northwest portion of Georges Bank in 2008 (cyan), 2009 (gray) and 2010 (red) relative to the monthly mean for 1977–2000. The historical range is shown by the gray shading, while the dotted line shows the one standard deviation envelope.

Annex 8: Regional report – Iceland (area 3)

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

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.

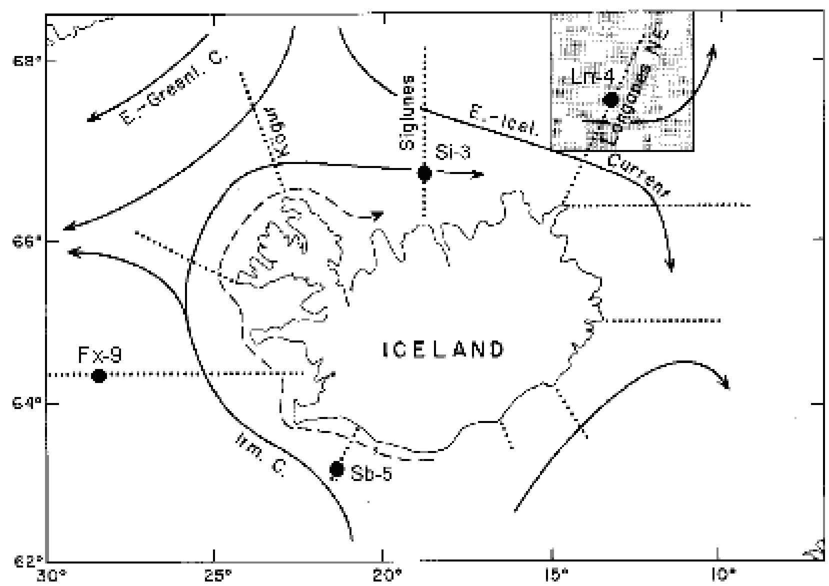

Figure 1. Main currents and location of standard hydrographic sections in Icelandic waters. Selected areas and stations dealt with in this report are indicated.

Hydrographic conditions in Icelandic waters are generally closely related with the atmospheric or climatic conditions in and over the country and the surrounding seas, mainly through the Iceland Low and the high pressure over Greenland. These conditions in the atmosphere and the surrounding seas have impact on biological conditions, expressed through the food chain in the waters including recruitment and abundance of commercial fish stocks.

In 2010 mean air temperature in the south (Reykjavik) and north (Akureyri) were above long time average (Figure 2a).

The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years (Figures 3.b, 5 and 7), with the highest salinity in almost forty years occurring in 2009 and slightly lower in 2010. Temperature record was observed west of Iceland in summer 2010. The salinity in the East Icelandic Current in spring 2010 was well above average and temperature was above long term mean (Figures 3a, 6 and 7).

Extremely cold conditions were observed in the northern area 1995, warming in the years 1996 to 2001. With a slight decrease in first half of 2002 (Figure 2b) and were then followed by the mild conditions for all seasons in 2003 and 2004. Lower temperatures were seen in the north and east areas in 2005 and 2006. However south and west of Iceland temperatures and salinities have remained high since 1997 and this continued in 2010. In 2010 surface layers temperatures and salinities were above long term mean in the north throughout the year.

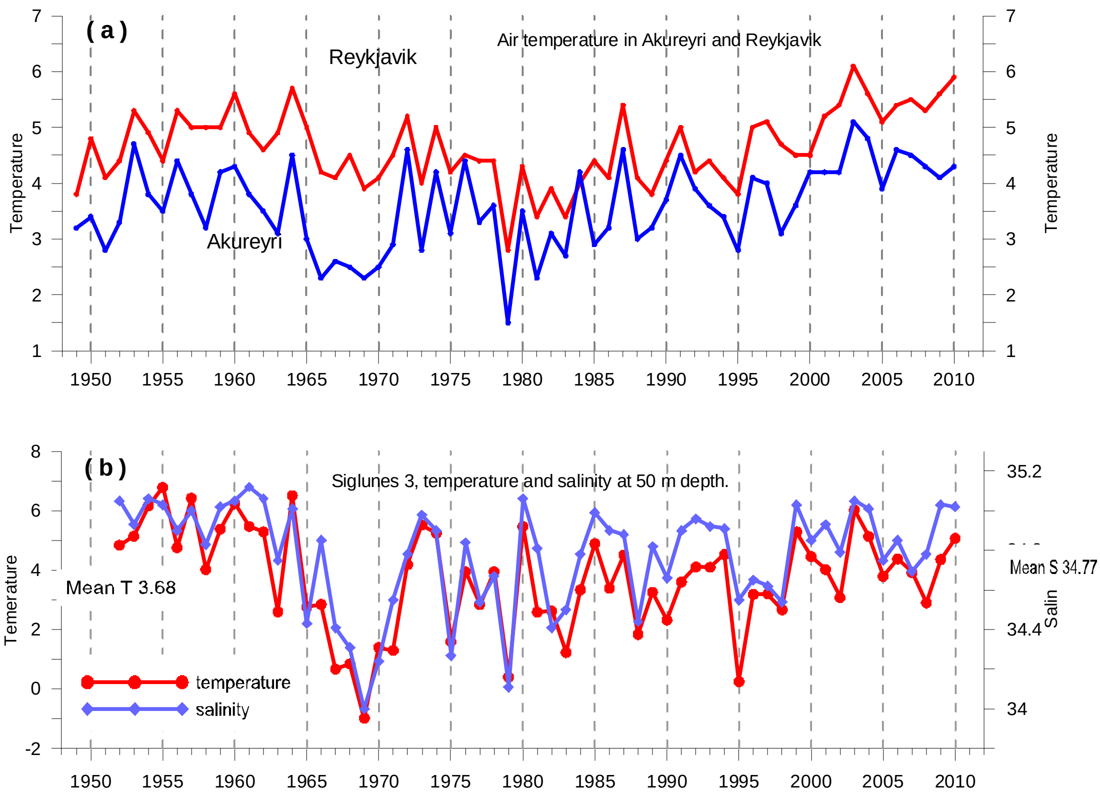

Figure 2. a) Mean annual air-temperatures in Reykjavík and Akureyri 1949–2010; b) Temperature and salinity at 50 m depth in spring at Station Si-3 in North Icelandic waters 1952–2010.

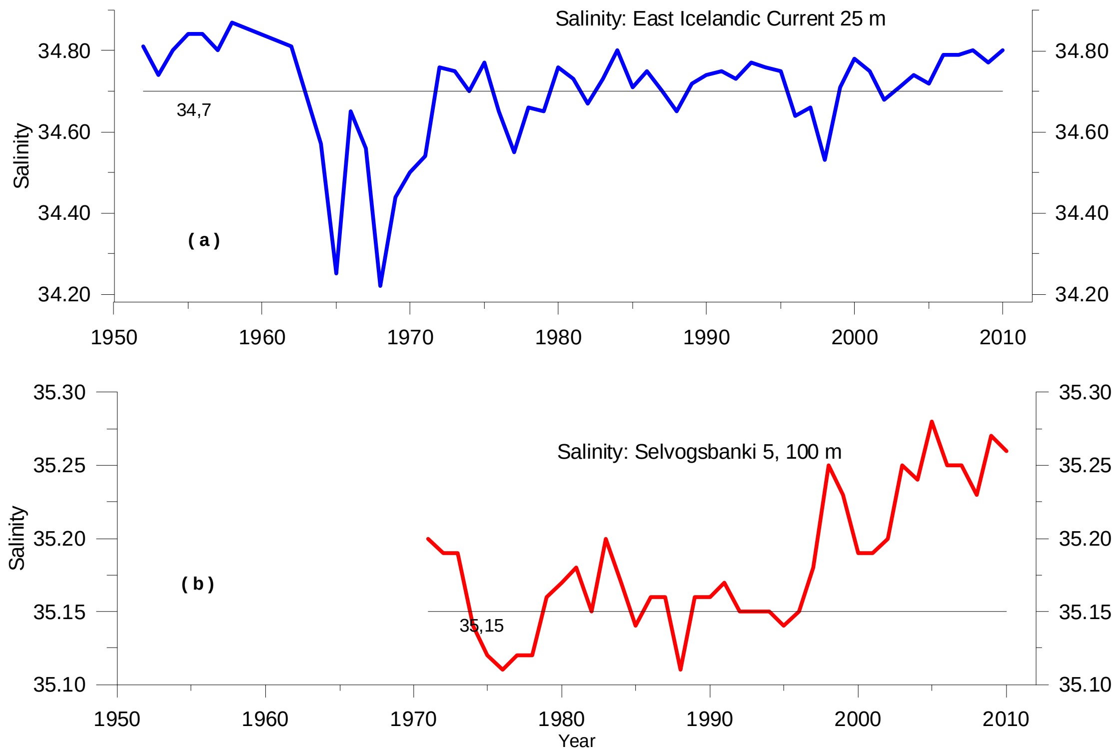

Figure 3. Salinity in spring at: a) 100 m depth in the Irminger Current south of Iceland (Sb-5) 1971–2010; b) 25 m depth in the East Icelandic Current north-east of Iceland 1952–2010, mean from shaded area in Figure 1.

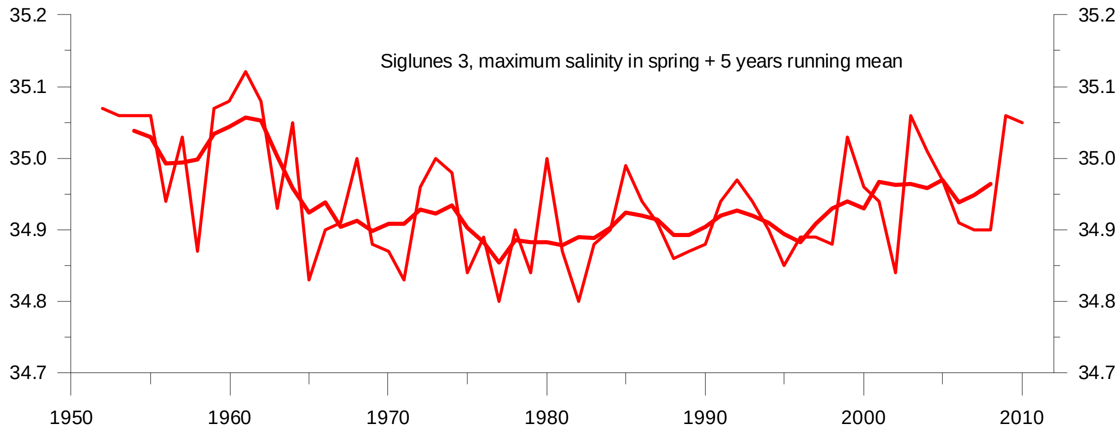

Figure 4. Maximum salinity in the upper 300 m in spring at station Si-3 in North Icelandic waters 1952–2010 and 5 years running mean.

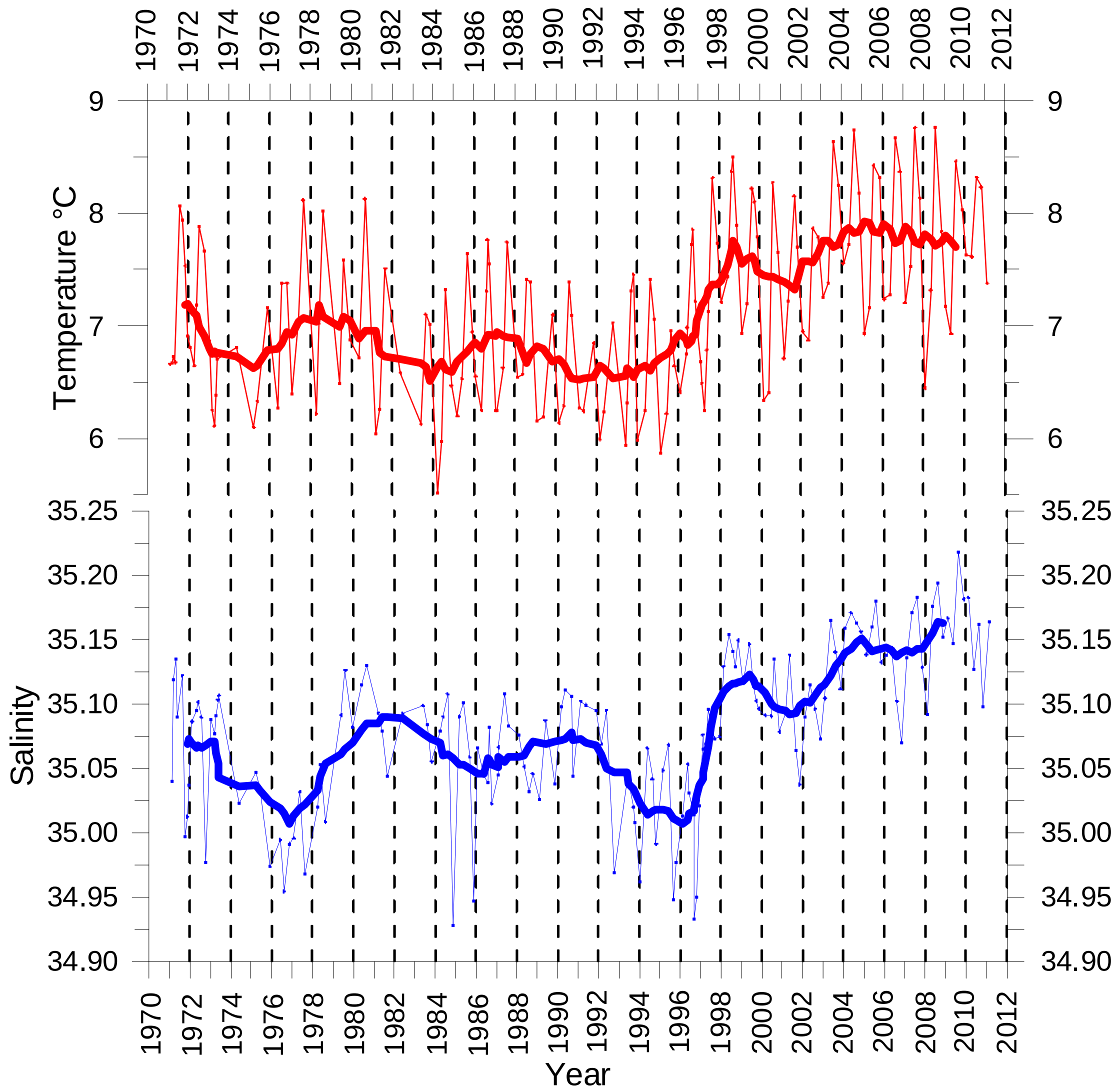

Figure 5. Mean temperature 0–200 m at the shelf brake west of Iceland, 1971–2011. Combined data from stations RE8 (1971–1984) and FX9 (1984–2011), 20 nm apart. Thick line is approx. 3 yrs running mean.

Annex 9: Regional report – Spanish Standard Sections

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The Spanish Standard Sections cover the area of the shelf and shelf-break of the Eastern Atlantic and North Iberian Peninsula. Five sections are sampled monthly by the Instituto Español de Oceanografía, located in Santander (43.5ºN, 3.8ºW), which is the largest, two in Asturias (43.6ºN, 6.2ºW) and from 2001 (43.6ºN, 5.6ºW), A Coruña (43.40ºN, 8.3ºW) and Vigo (42.1ºN, 9.0ºW). Additionally to the area covered by the Instituto Español de Oceanografía, AZTI collected oceanographic data at 43.30ºN, 2ºW (San Sebastián Section) over the continental shelf of the SE Bay of Biscay from 1986 (Figure 1).

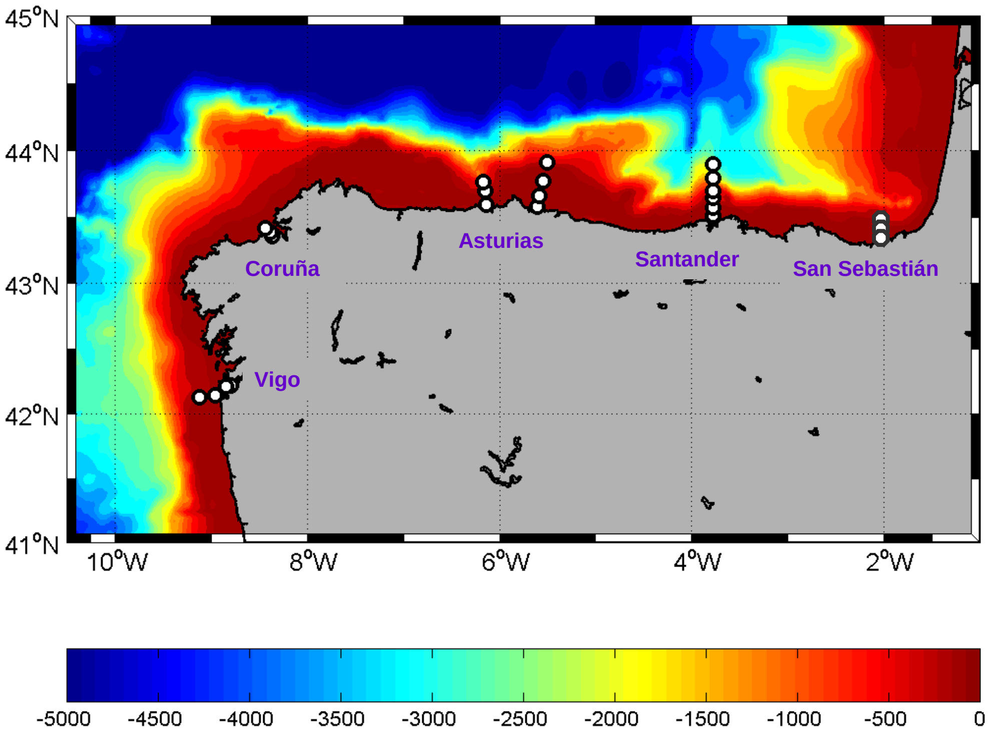


Figure 1. Spanish Standard Sections from the 'Instituto Español de Oceanografía' (Vigo, Coruña, Asturias, Santander) and from AZTI (San Sebastián).

The Bay of Biscay, located in the eastern North Atlantic at the NE edge of the subtropical anticyclonic gyre, is almost an adjacent sea with weak anticyclonic circulation (1–2 cm·s^{-1}). 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 IPC) in autumn and winter.

In the SE corner of the Bay of Biscay, relatively strong continental influence modifies both the temperature and salinity of the shelf waters. Nevertheless, the changes in salt and heat content in the water column, over the continental shelf and slope, cannot be explained fully by the local modification of the water masses (e.g. the increase of the heat content in the shelf waters, from summer to early autumn, as opposed to the atmospheric and sea surface cooling, should be explained by accumulation and downwelling of warm waters into the shelf area).

Meteorological Conditions

Atmospheric temperature

Meteorological conditions in the north of the Iberian Peninsula in 2010 indicate that it was an average year relative to the long-term period reference (1971–2000), but colder that previous years. Annual mean air temperature was 14.10º C in Santander (43º30′N, 3º47′W). The cold character increases to the East, being at the easternmost part of the Bay of Biscay the coldest of the decade. Annual mean air temperature average in 2010 at the Igeldo Meteorological Observatory (San Sebastian, 43°18.5′N, 02°2.37′W) was 12.95º C, 0.65º C below the 1986–2010 record.

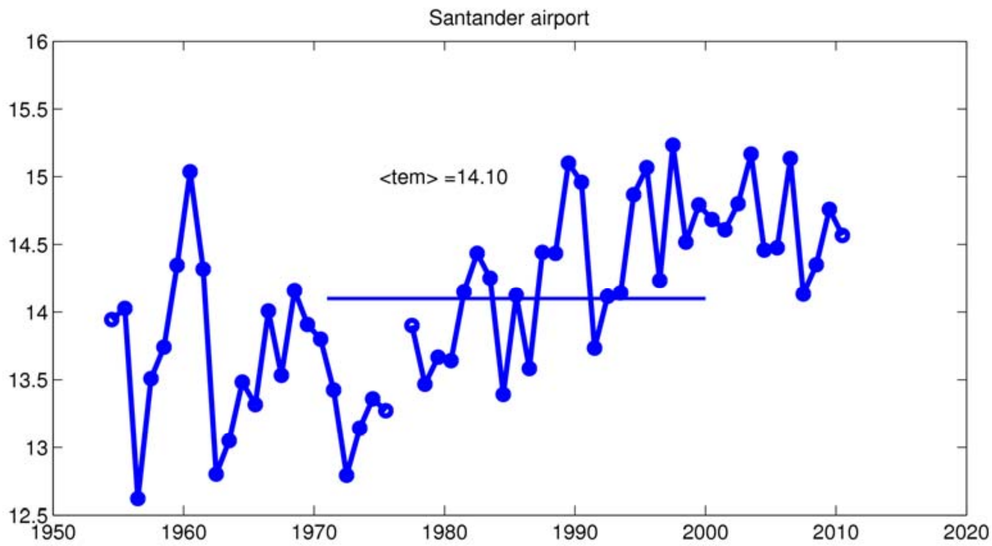


Figure 2. Air temperature in Santander meteorological station.

The seasonal cycle was characterized by average values or slightly negative anomalies in winter and late autumn (January–February, November/December), and positive anomalies for the rest of the year. Again this character is enhanced at the easternmost part with were winter and spring can be considered cold (around the mean minus standard deviation for 1986–2010), with the exception of April; and summer and autumn seasons excluding July were also cold (Figure 3b).

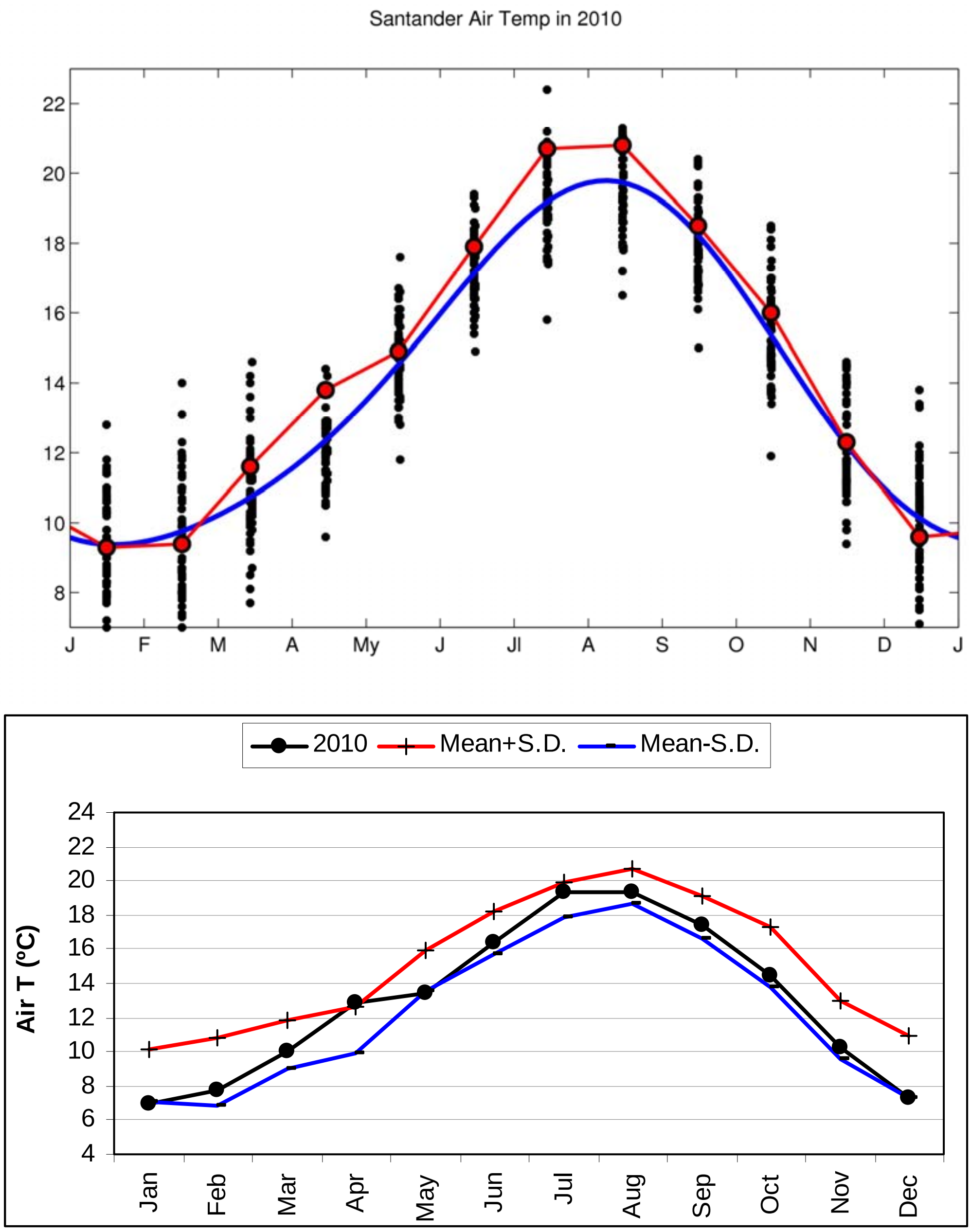


Figure 3. Monthly mean air temperature (°C) in Santander (43º30′N, 03º47′W,upper) and San Sebastián (43°18.5′N, 02°2.37′W, lower) in 2010 compared with the mean ± standard deviation for the period 1986–2010. Courtesy of the 'Agencia Estatal de Meteorología'.

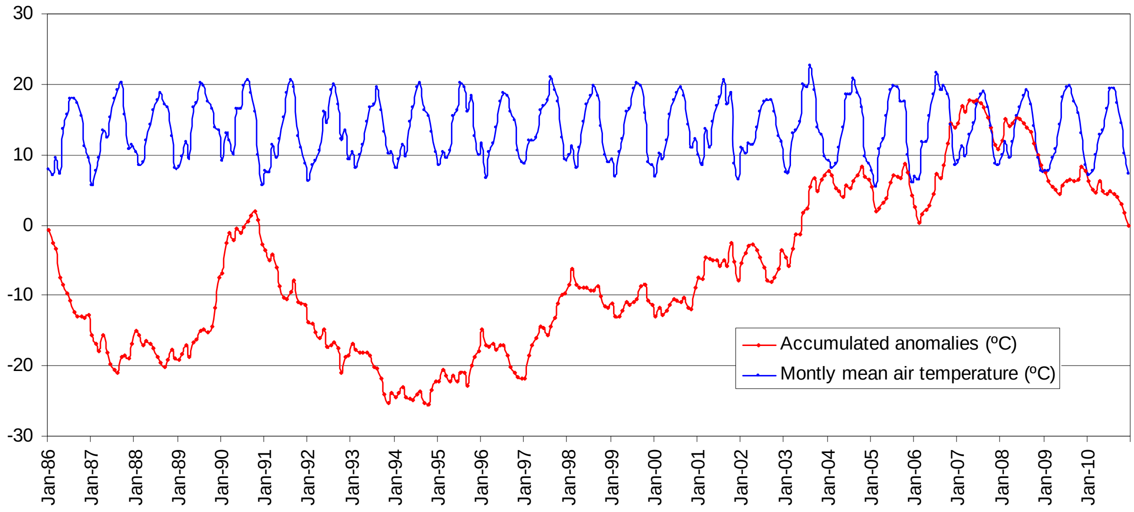


Figure 4. Monthly mean temperatures in San Sebastián (43°18.5′N, 02°2.37′W) in 1986–2010 and accumulated anomalies. Data Courtesy of the 'Agencia Estatal de Meteorología'.

Precipitation and evaporation

2010 can be characterised as an average year concerning the precipitation regime. Thus, March, April and September were around the mean minus standard deviation for the period 1986–2010; conversely, January and June were around the mean plus standard deviation for the period 1986–2010; November was over the mean+standard deviation (1986–2010) (Figure 5). The annual mean precipitation was 123 mm, around the 1986–2010 average.

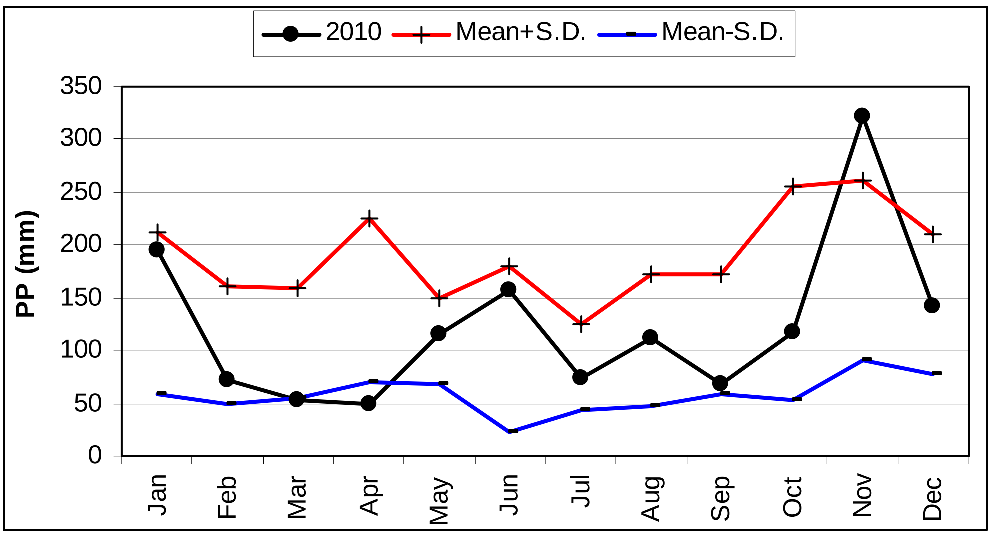


Figure 5. Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 2010 compared with the mean ± standard deviation for the period 1986–2010. Data Courtesy of the 'Agencia Estatal de Meteorología'.

With regard to water balance, the year 2010, within the context of the previous years, shows an increase in the precipitation, in terms of accumulated anomalies (Figure 6). In addition, the precipitation minus evaporation balance shows an increasing trend, in terms of water balance (Figure 7).

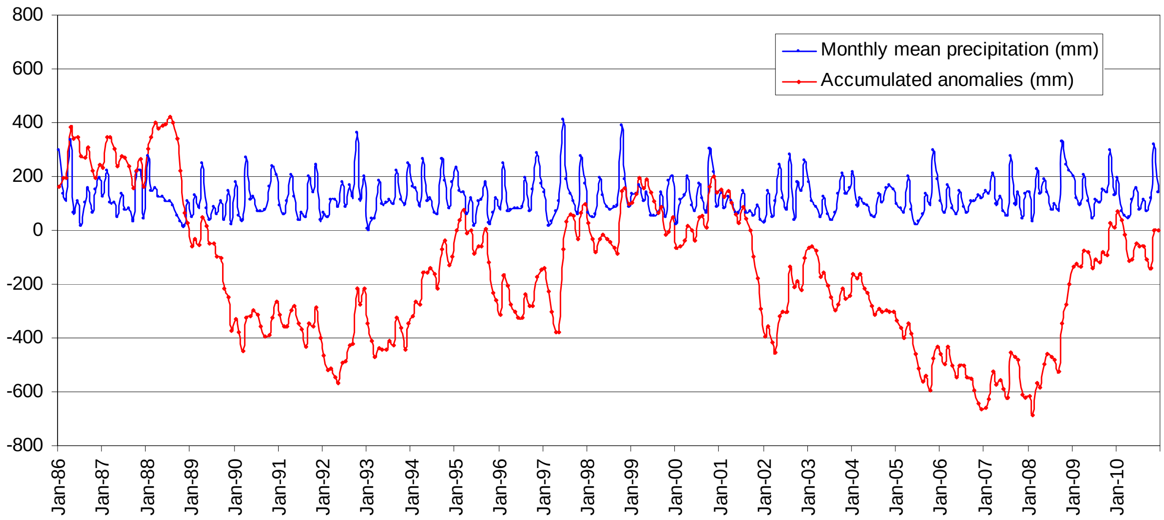


Figure 6. Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 1986–2010 and accumulated anomalies. Data Courtesy of the 'Agencia Estatal de Meteorología'.

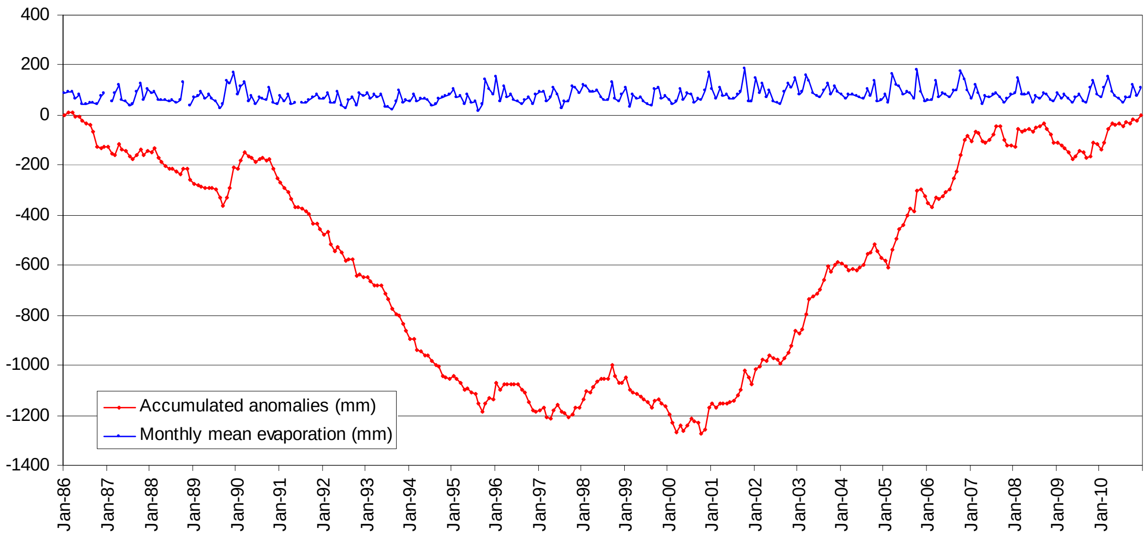


Figure 7. Monthly precipitation minus evaporation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 1986–2010 and accumulated anomalies. Data Courtesy of the 'Agencia Estatal de Meteorología'.

Continental runoff

The Gironde river runoff values represent well the water inputs of continental origin into the SE Bay of Biscay. In a quarterly basis, the Gironde River flow correlates significantly with the precipitation in San Sebastián as well as with the flow of the Adour River and the other small Cantabrian rivers incoming into the SE Bay of Biscay (Table 1).

Table 1. Correlation matrix for the Gironde river flow, precipitation in San Sebastián (PP) and precipitation minus evaporation balance in San Sebastián (PP-EV) in a quarterly basis, for the period 1986–2010. NS: not significant; *P=0.01; **P=0.005 ***P=0.001.

	FLOW WINTER	FLOW SPRING	FLOW SUMMER	FLOW AUTUMN
PP WINTER	0.68***			
PP-EV WINTER	0.68***			
PP SPRING		NS		
PP-EV SPRING		NS		
PP SUMMER			0.57**	
PP-EV SUMMER			0.56**	
PP AUTUMN				0.53*
PP-EV AUTUMN				0.57**

The Gironde River flow in 2010 was around the 1986–2010 average; the annual mean river flow was 778 $m^3 \cdot s^{-1}$, only 55 $m^3 \cdot s^{-1}$ below the 1986–2010 average. On a monthly basis, the flow was around the monthly average for the period 1986–2010, excluding June in response to the increase of precipitations. In this context, the Gironde River flow is in agreement with the precipitation in San Sebastián except for the local precipitation events (January and November) and spring thaw (Figures 5 and 8).

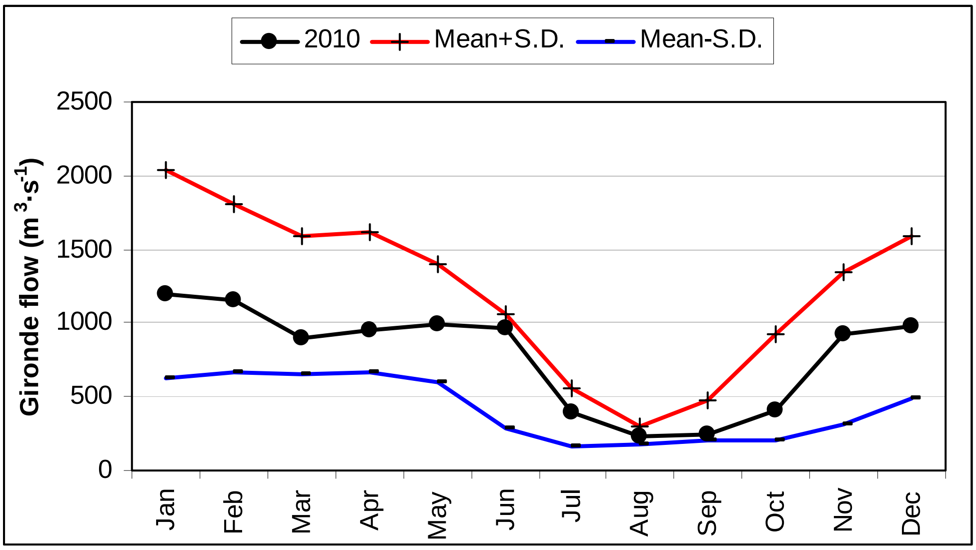


Figure 8. Monthly mean flow (m^3 s^{-1}) of the Gironde River in 2010 compared with the mean ± standard deviation for the period 1986–2010. Data Courtesy of the 'Bordeaux Harbour Authority'.

The peculiarities of the Gironde river flow in 2010 can be observed in the context of the monthly mean values of the reference period (1986–2010) and the evolution of the accumulated anomalies (Figure 9).

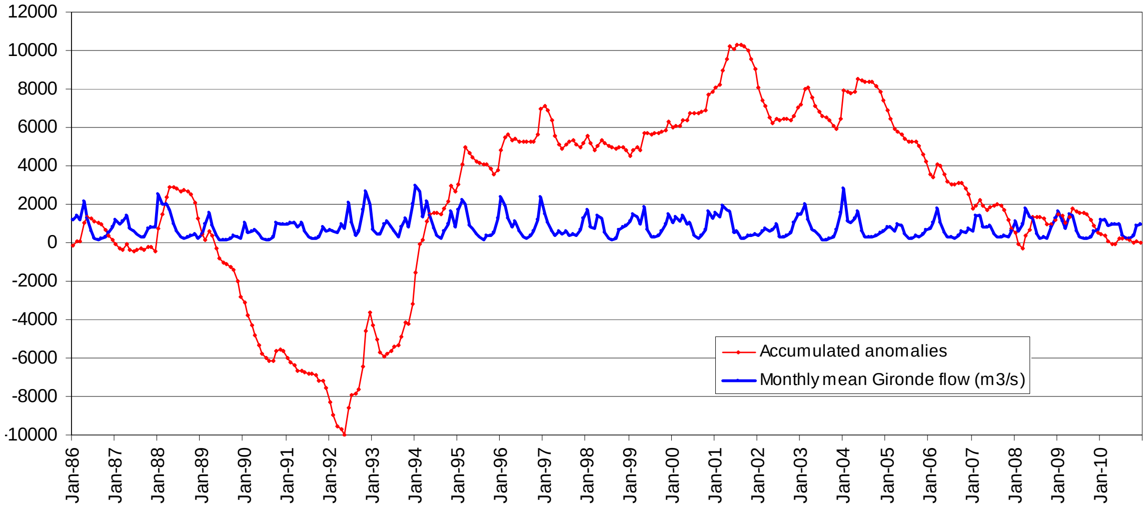


Figure 9. Monthly mean flow of the Gironde river ($m^3 \cdot s^{-1}$) in 1986–2010 period and accumulated anomalies. Data Courtesy of the 'Bordeaux Harbour Authority'.

Hydrography

Coastal and shelf waters

Coastal and shelf waters properties are modulated by the combination of local air-sea forcing, the development shelf currents and the river runoff. All these forcings have a strong seasonal character with regional differences:

- Seasonal warming/cooling cycle is enhanced towards the south-eastern Bay of Biscay due to the continental effect.
- The effect of shelf-slope currents is enhanced at the western Iberian margin (Galician area). This happens for both the upwelling in summertime and the IPC in wintertime.
- Precipitation peaks during autumn-winter periods in the whole area. However, river runoff at the main French rivers (influencing the eastern Cantabrian Sea) is dominated by spring snowmelt at the Pyrenees, while there is no significant snow accumulation in north Spanish mountains. Therefore the salinity surface minimum is delayed as we move towards the east (Figure10).

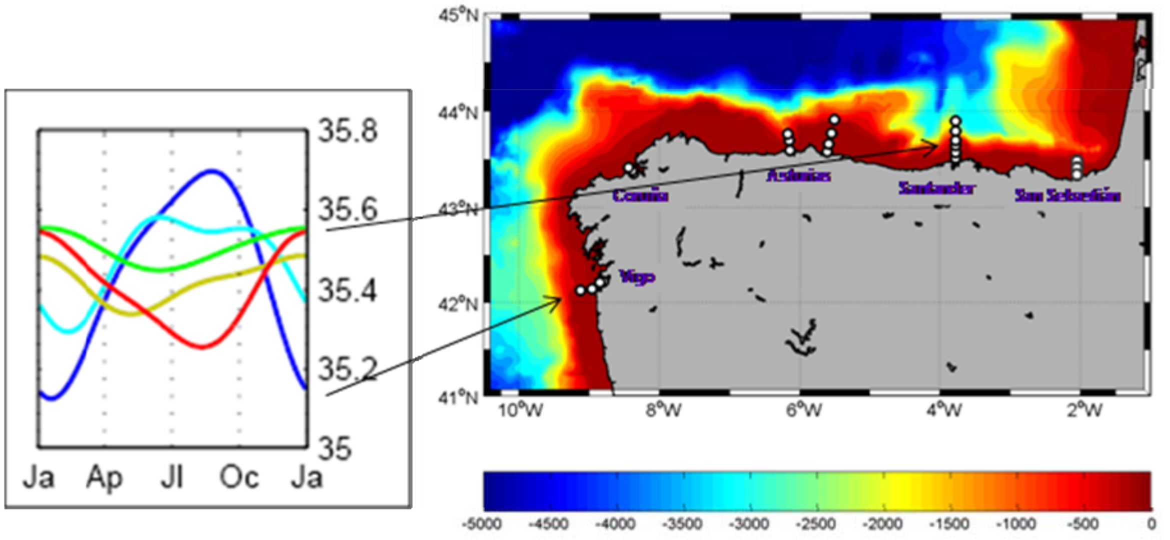


Figure 10. Surface salinity seasonal cycle at the shelf along the western Iberian margin and the Cantabrian Sea.

Contours of temperature and salinity (over the shelf, 100 m depth) in the Vigo and Santander sections are shown in Figures 11 and 12. The main characteristic of 2010 (seen at both places) is a strong arrival of two warm signatures and salty intrusions, in winter and late autumn, but none of them comparable to that of 2008. Another interesting feature of 2010 is that summer surface low-salinity signature at Santander is weak (Figure 12) and only appears a peak coinciding with a pronounced rainy event in late spring. Summer mixed layer was quite shallow, motivated by persistent summer upwelling conditions.

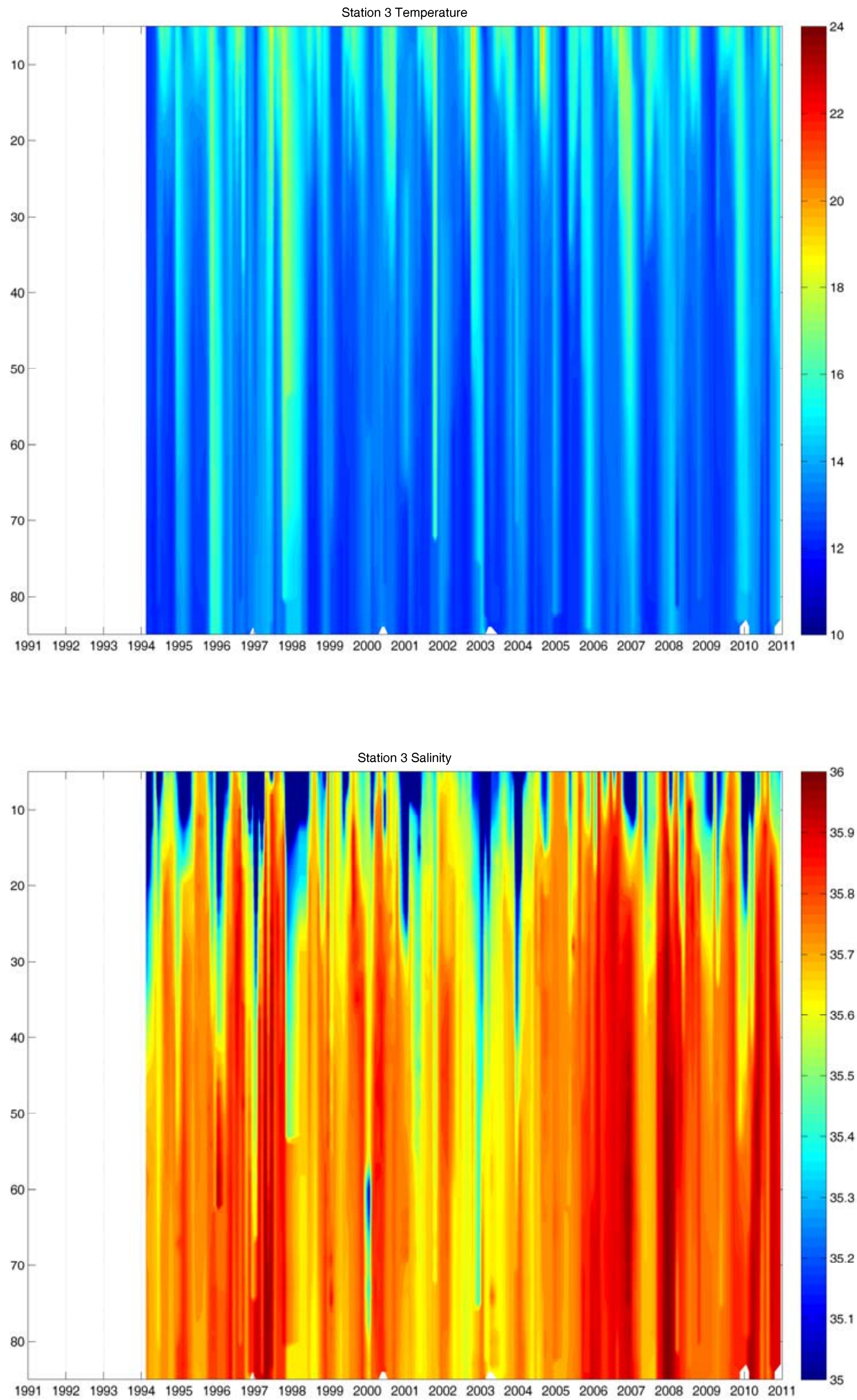


Figure 11. Time-series of temperature (upper) and salinity (lower) at the shelf at Vigo (42.08ºN, 8º57'W).

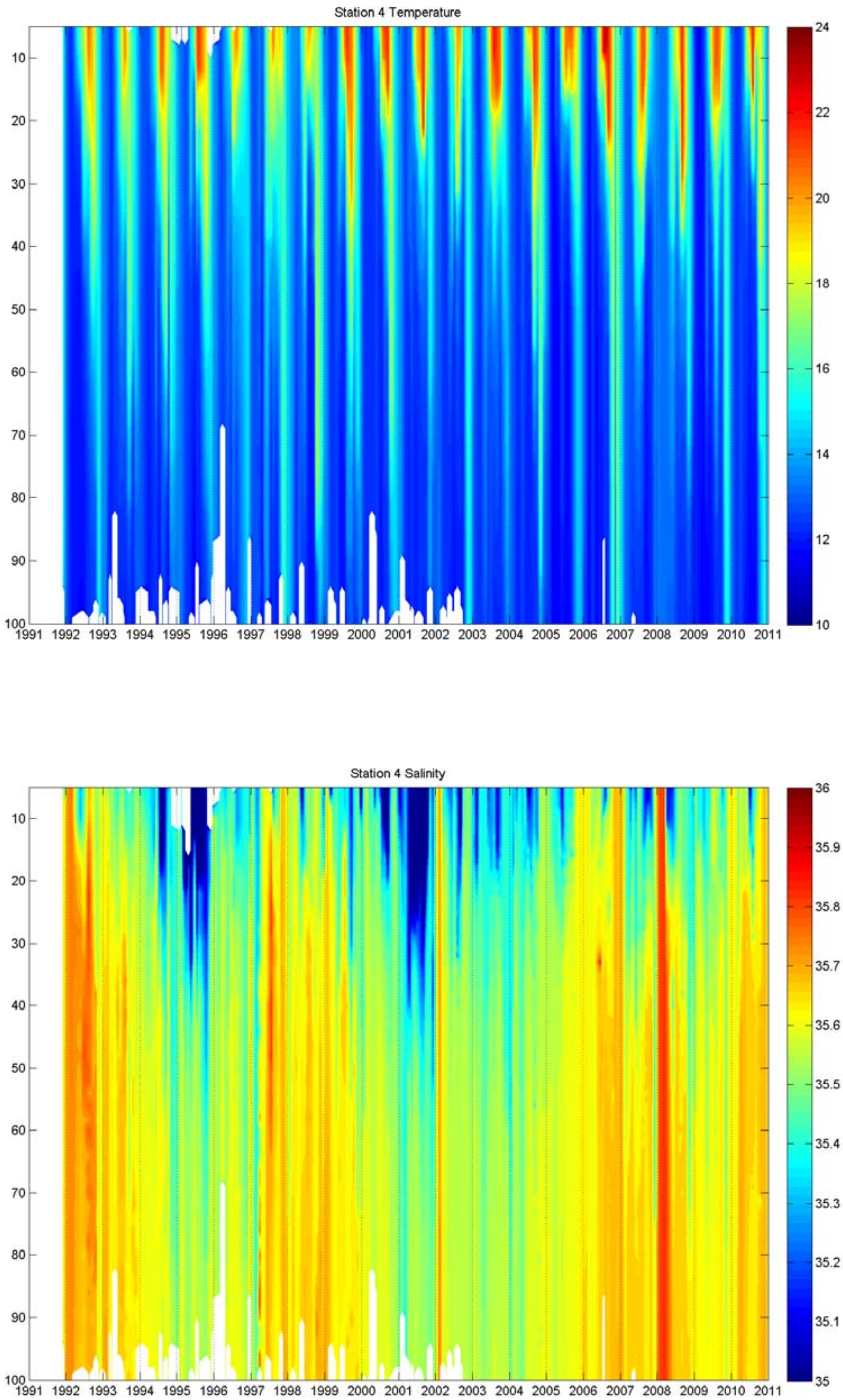
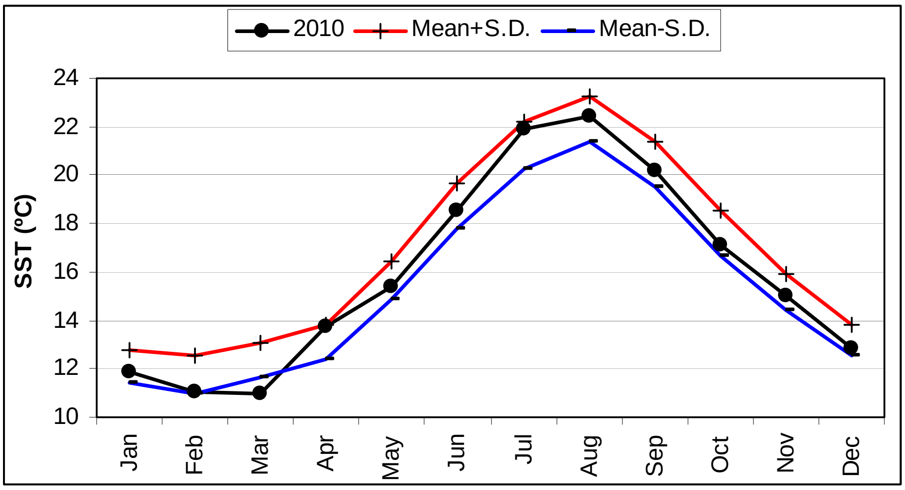


Figure 12. Time-series of temperature (upper) and salinity (lower) at the shelf at Santander (43º35′N,3º47′W).

Although the range of the anomalies is different long the area because of local climatic and morphologic peculiarities, the anomaly patterns and the general trends can be considered a reference for the sections located in the southern Bay of Biscay. Figure 13 show the evolution of the monthly averaged sea surface temperature (SST) in 2010 close to the coast (on the basis of a time-series obtained from the Aquarium of the Sociedad Oceanográfica de Gipuzkoa). In general, medium sea surface temperatures (around the mean 1986–2010 average) can be observed in spring and summer, excluding April and July (around the mean plus standard deviation for 1986–2010); and cold to average waters in winter and autumn. It is compared also with surface temperature at Santander section (slope station) from a shorter series data set.



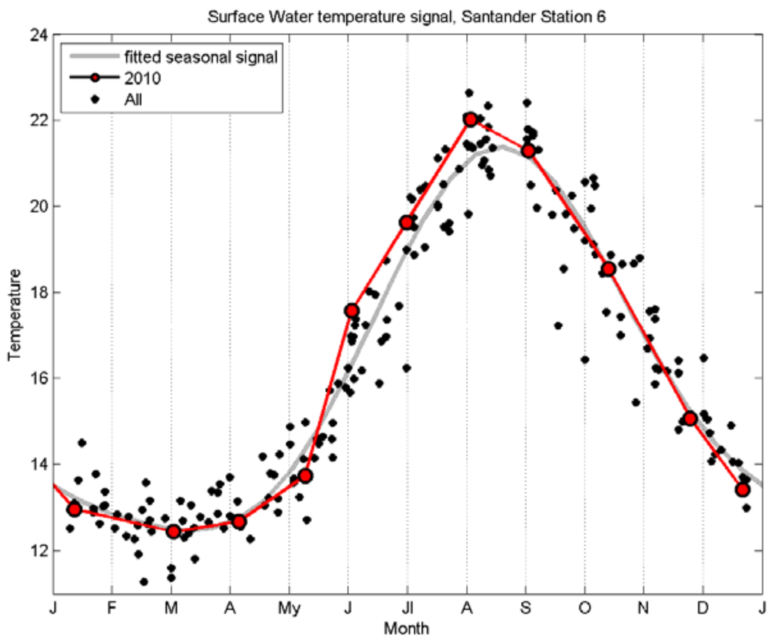


Figure 13. Monthly averaged sea surface temperature (°C) in San Sebastián (43°20′N 02°00′W) in 2010 in comparison with the mean ± standard deviation for the period 1986–2010 period. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'. Lower panel is SST at station 6 in Santander (43º 42.6'N,3º 47' W).

The peculiarities of the SST in 2010 can be observed within the context of the monthly mean temperatures of the reference period (1986–2010) and the evolution of the accumulated anomalies (Figure 14).

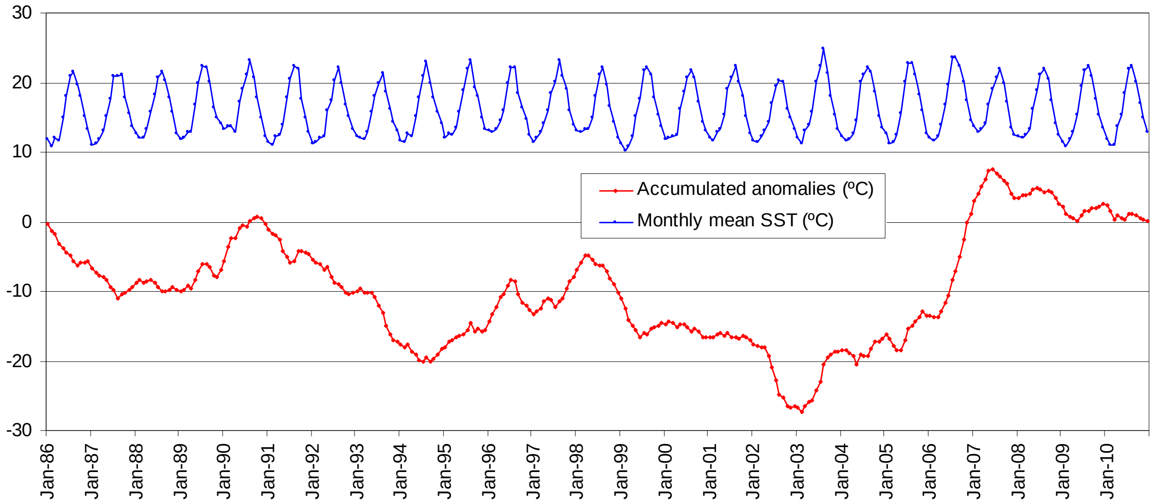


Figure 14. Monthly averaged SST (°C) in San Sebastián (43°20′N 02°00′W) during the 1986–2010 period, together with accumulated anomalies. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.

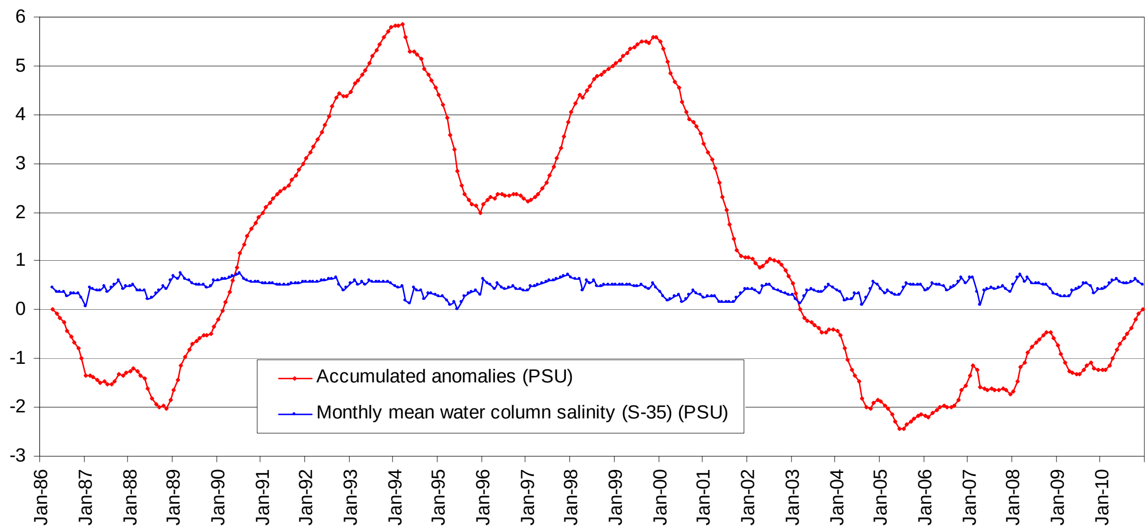


Figure 15. Monthly averaged corrected salinity (S-35) in 100 m water column in San Sebastián (43°30′N 02°00′W) in the period 1986–2010, together with accumulated anomalies.

A detailed view of hydrographic conditions in 2010 at the easternmost Bay of Biscay can be summarized from TS diagram representing the waters over the continental shelf at the easternmost Bay of Biscay (43°30′N, 02°00′W) as shown in Figure 16.

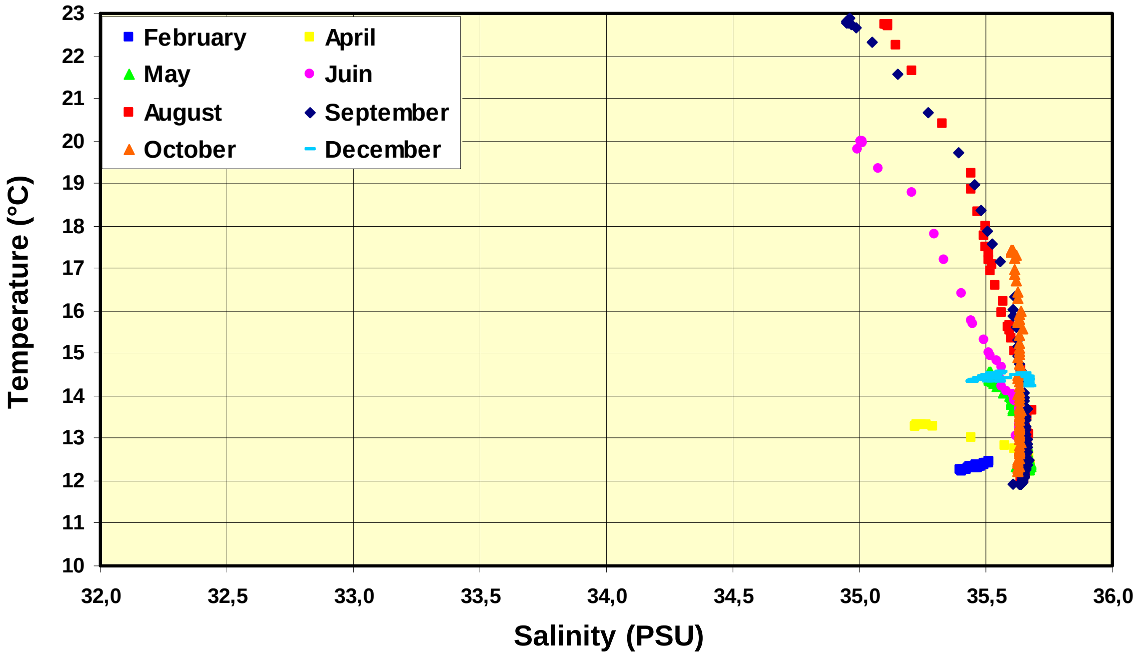


Figure 16. TS diagram of the waters over the continental shelf of the SE Bay of Biscay (43°30′N 02°00′W) in 2010.

February an April are characterised by relatively high precipitation and river runoff (Figure 5 and Figure 8), contributing to the development of haline stratification. Thermal stratification develops between May and October. Finally, the TS diagram is characterised by a thermal inversion in December, according to the relatively high precipitation (Figure 5). The TS diagram shows also the variability in the temperature and salinity values and in the T-S relationships for the waters located below the seasonal thermocline.

Aspects related to the hydro-meteorological conditions during 2010, over the SE Bay of Biscay, are listed in Table 2. The SST in winter 2010 remains around the mean minus standard deviation for the period 1986–2010 with relatively low air temperatures for this period. In spring 2010, the SST is around the 1986–2010 average with the exception of April, as a result of high air temperature (Figure 3b). In summer, the SST is around the 1986–2010 average with the exception of July, in response to high air temperature. In autumn, the SST is around the 1986–2010 average minus standard deviation. This pattern is also consistent with the atmospheric temperatures for the same period (Figure 3b).

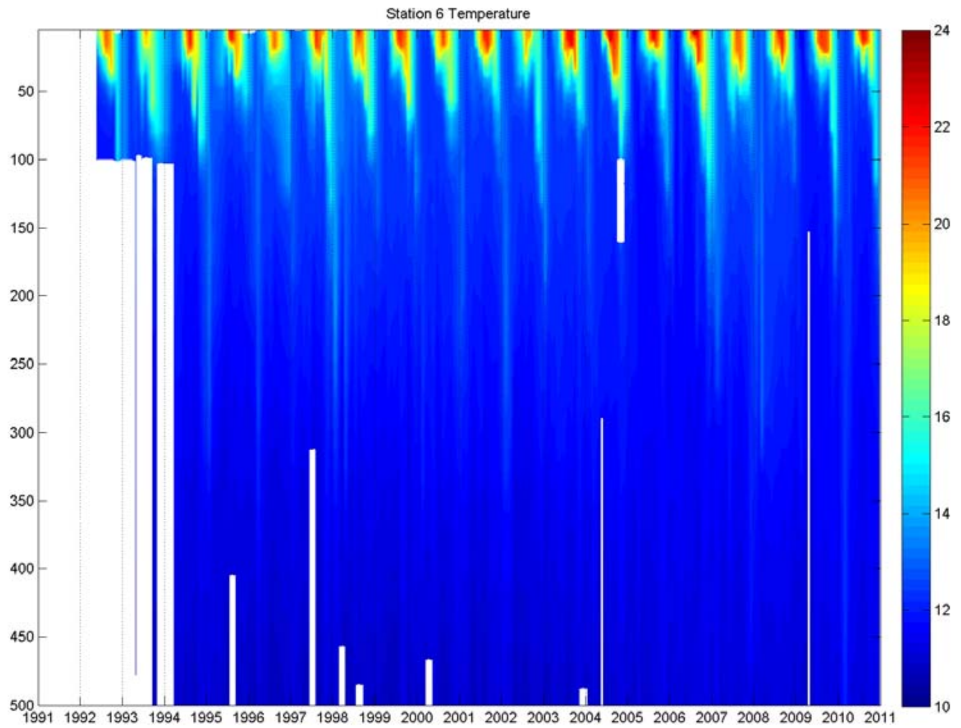
Table 2. Hydro-meteorological data in the shelf waters of San Sebastián (43°30′N 02°00′W) in 2010. Mean temperature and salinity calculated for 100 m water column.

2010	Air T (°C)	PP (mm)	Gironde flow ($m^3 s^{-1}$)	SST (ºC)	SSS (PSU)	Mean Temp. (ºC)	Mean Salinity (PSU)	Bottom Temp. (ºC)	Bottom Salinity (PSU)	14 ºC isotherm depth (m)
January	7.0	196	763	11.86		13.54	35.434			
February	7.7	71	714	11.03	35.403	12.31	35.451	12.43	35.510	T<14
March	10.0	52	548	10.99		12.41	35.531			
April	12.9	50	562	13.71	35.219	12.51	35.610	12.27	35.673	T<14
May	13.4	115	741	15.38	35.516	13.31	35.623	12.30	35.671	14
June	16.4	158	525	18.53	35.008	13.65	35.565	12.01	35.642	25
July	19.3	74	199	21.92		14.35	35.550			
August	19.3	112	106	22.42	35.111	14.35	35.535	12.00	35.639	40
September	17.4	69	115	20.19		15.17	35.578			
October	14.5	118	224	17.11	35.604	15.29	35.622	12.29	35.628	67
November	10.2	321	546	15.02		14.85	35.569			
December	7.3	142	544	12.85	35.442	14.41	35.515	14.24	35.674	T>14

Slope and Oceanic waters

Contours of temperature and salinity over the shelf-break (600 m depth) in the Santander section are presented in Figure 17. The most outstanding feature is the depth reached by the warm, salty intrusion (sampled in March 2010). In general the subsurface structure was conditioned by these strong intrusions of southern origin waters along the slope in winter and late autumn, the shallow summer mixed layer seen at the shelf is also noticed over the slope.

The overall combination of these features result, for the upper-ocean influenced by the mixed layer development (0–300dbar), in a year with very high values of salinity (among the highest) and colder than average temperatures (Figure 18).



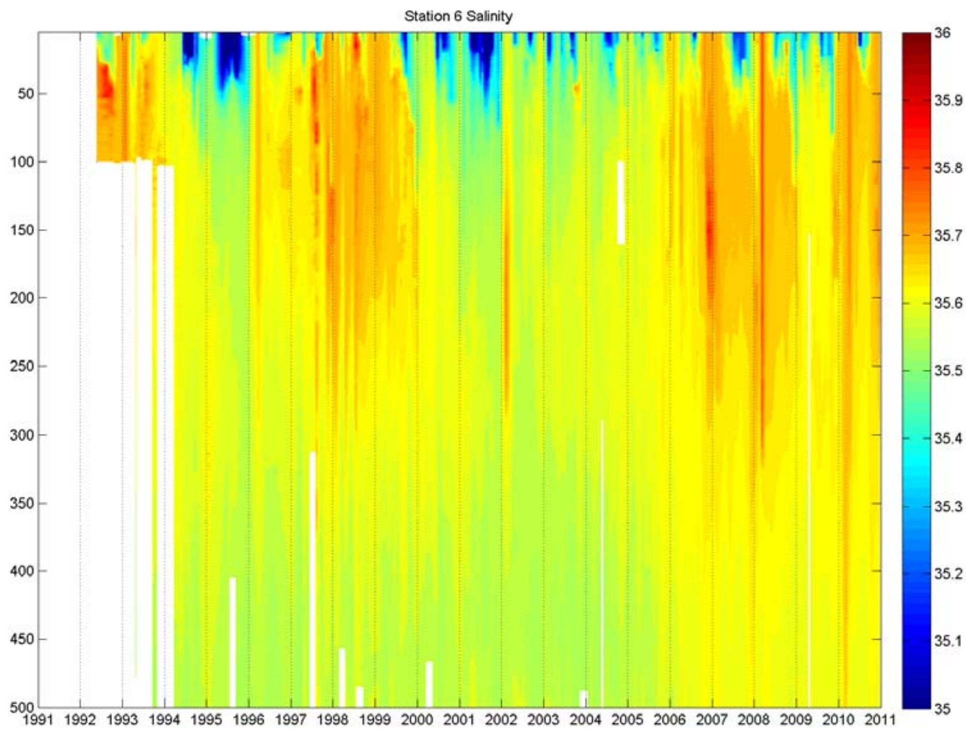
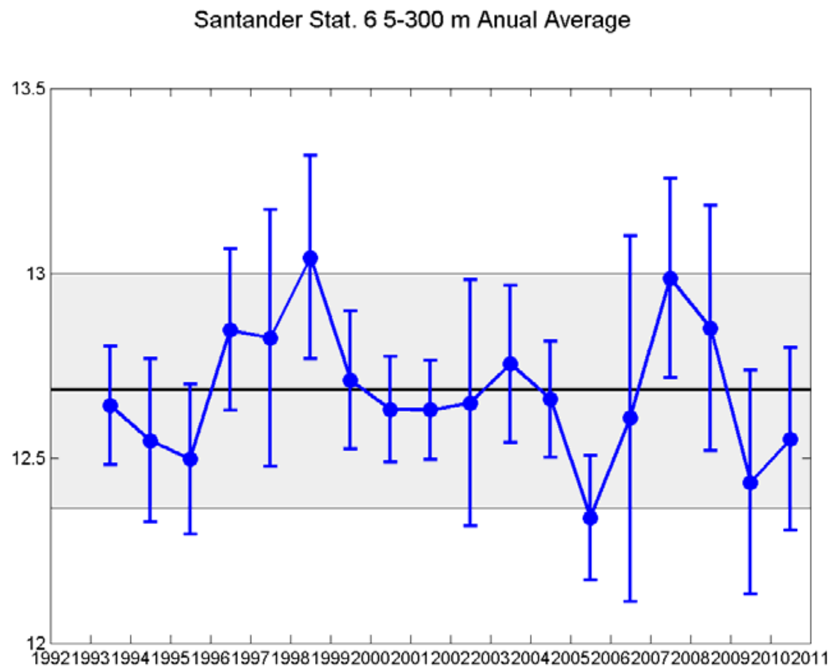


Figure 17. Time-series of temperature (upper) and salinity (lower) at the slope at Santander (43º42′N,3º47′W).



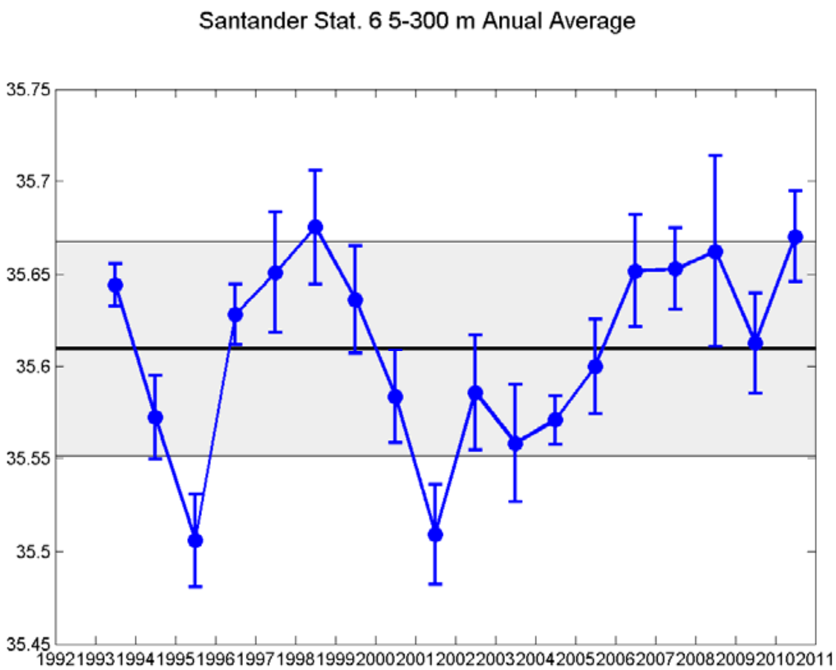


Figure 18. Temperature (upper) and salinity (lower) averages for the upper 300 m at the slope at Santander (43º42′N,3º47′W).

Deeper Water Masses

Figures 19 and 20 show the series of potential temperature and salinity from 200 to 1000 m depth over the slope in Santander (St 7). Overall warming trends are evident at most layers, corresponding to the East North Atlantic Central Water (200–600) and upper Mediterranean Water (600–1000). Salinity also shows a notable increase along the whole series but less smooth than temperature. The water masses evolution is strongly influenced by a strong shift in salinity at lower ENACW (~400 m) in 2005 after the occurrence of very strong winter mixing (Figure 20). Figure 21 shows the TS diagram of the series indicating such shift.

It is also observed in the series how 2009 presented the first cooling and freshening shift for the whole record, noticed as deep as ~800 m. 2010 is however characterized by the recovery to the previous pattern of long-term warming trend. Deeper at the level of the core of MW (~1000 m) water properties remained pretty stable in 2010 (actually this level has been quite stable in recent years.)

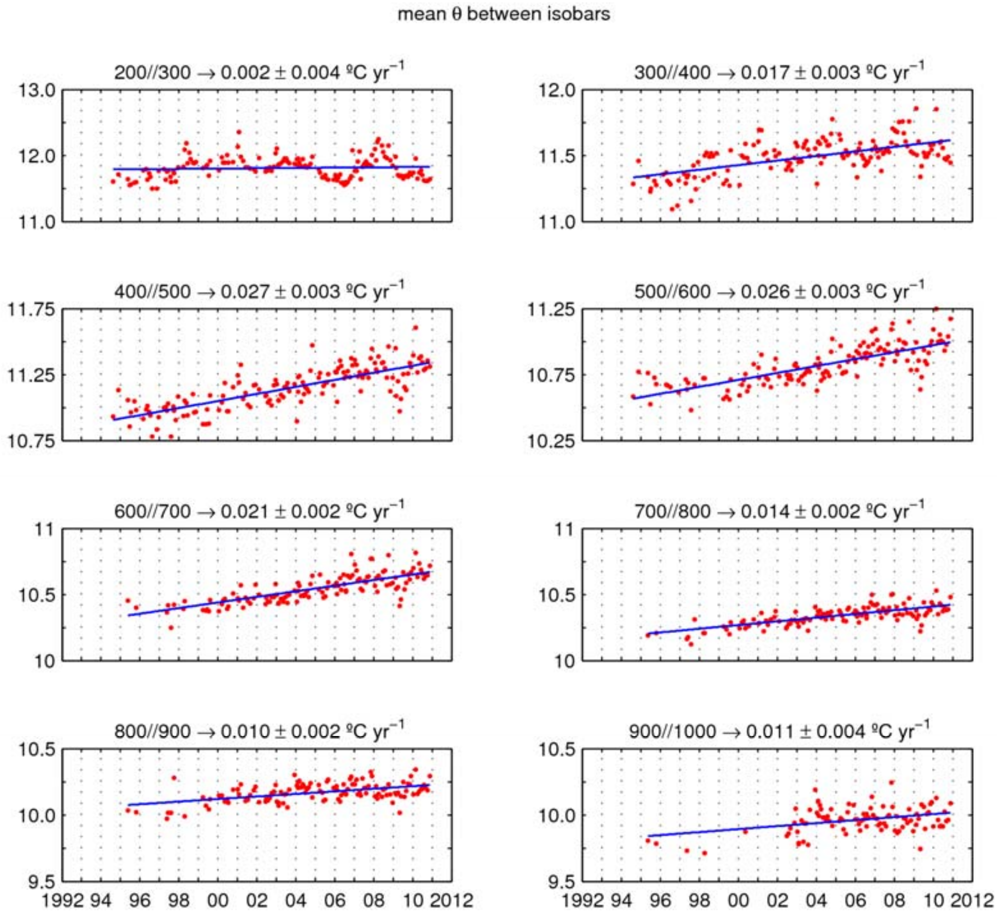


Figure 19. ENACW and MW potential temperature at Santander station 7 (43º 48’N, 3º 47’W; outer slope).

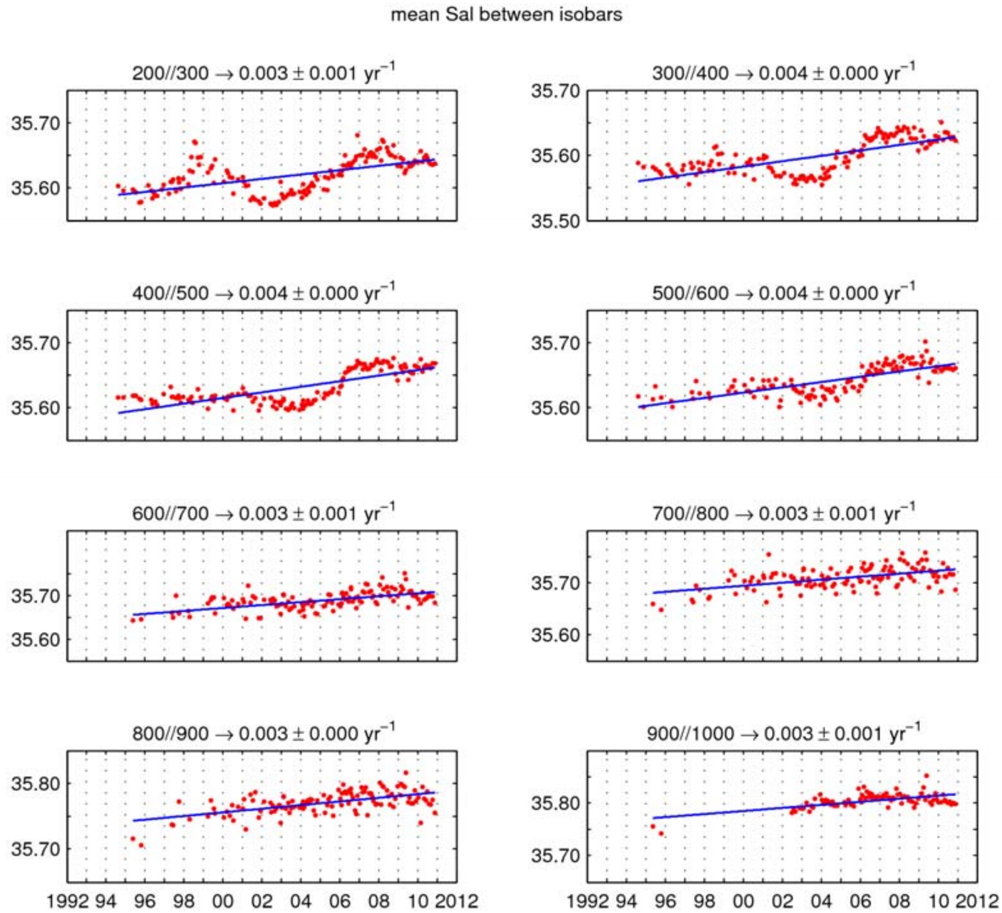


Figure 20. ENACW and MW salinity at Santander station 7 (43º 48′N, 3º 47′W; outer slope).

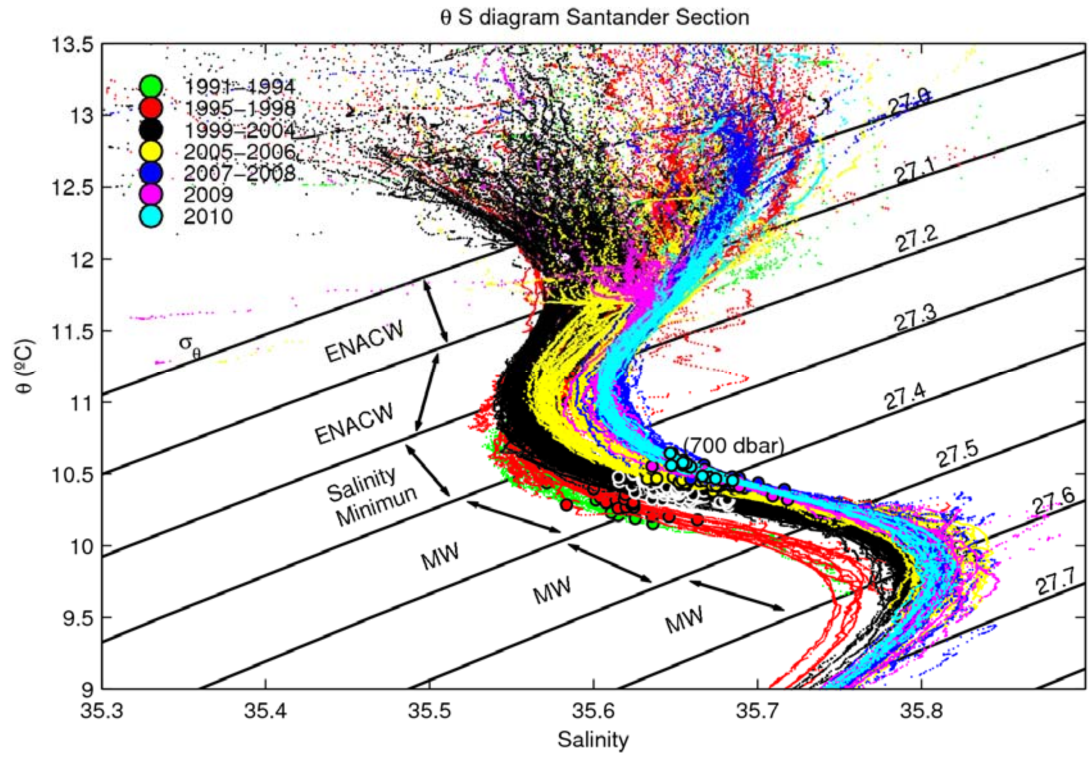


Figure 21. TS diagram of water mass properties at Santander station 7 (43º 48’N, 3º 47’W; outer slope).

Annex 10: Regional report – Norwegian Waters

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Main summary

The temperature decreased in 2010 compared to 2009 for all three Seas (North Sea, Norwegian Sea and Barents Sea) while salinity remained at a relatively high level. The observed transport of Atlantic water to the Norwegian and Barents Sea has been stable and normal since 2007, while the modeled inflow to the North Sea decreased in 2010. The sea-ice cover in 2010 was slightly less than in 2009 and below normal.

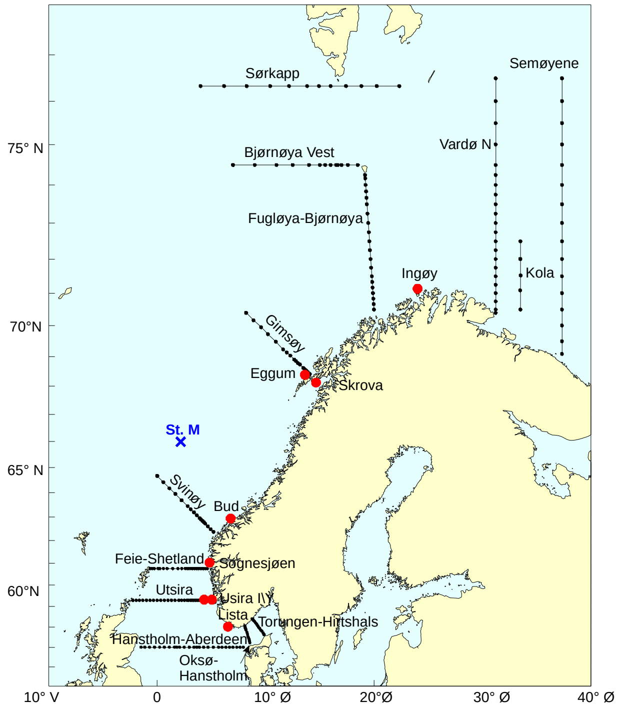


Figure 1. Standard sections and fixed oceanographic station worked by Institute of Marine Research, Bergen. The University of Bergen is responsible for station M, while the Kola section is operated by PINRO, Murmansk (ANON 2002). The dotted line is the extended Gimsøy-NV section that runs into the Greenland Sea.

The Norwegian Sea

Kjell Arne Mork

Summary

- Temperature in the inflowing Atlantic water decreased from 2009 to 2010 at all three sections (Svinøy-NV, Gimsøy-NV and Sørkapp-W) but was in 2010 still above their respective long term means (1977–2006): 0.4 °C, 0.2 °C and 0.2 °C respectively.
- Salinity in Atlantic Water was similar in 2010 as in 2009 and has still remarkable high values. Compare to the long terms means the salinity

anomaly was 0.09, 0.07, and 0.04 for Svinøy, Gimsøy and Sørkapp section, respectively.

- The inflow of AW at the Svinøy section has since 2007 been stable with values close to the normal, except for a relatively low value in winter 2010.

The hydrographic condition in the Norwegian Sea is characterized by relatively warm and salt water in the east due to the inflow of the Atlantic water from the south. In the west, however, the hydrographic condition is also influenced by the fresher and colder Arctic water that arrive from the Iceland and Greenland Seas. Figure 2 shows the development in temperature and salinity in the core of Atlantic Water for three different sections from south to north in the eastern Norwegian Sea (Figure 1). There has, in general, been an increase of temperature and salinity in all three sections from the mid-1990s to 2009. From around 2000 the annual temperatures were above normal in both the Svinøy and the Gimsøy section. After the record-high value in the Svinøy section in 2007 the temperatures in both Svinøy and Gimsøy section dropped to near the normal in 2008 but then increased again in 2009. As Atlantic water flows northward the temperature increase can also be observed further north in the Sørkapp section. In 2009, the annual temperature averages were about 0.7 °C above the long-term-mean for the time-series in both Svinøy and Gimsøy sections, while in the Sørkapp section the summer temperature was 0.5 °C above the long term mean. The positive salinity anomaly decreased northward and in 2009 it was about 0.09, 0.07, and 0.04 above normal for the Svinøy, Gimsøy and Sørkapp sections, respectively.

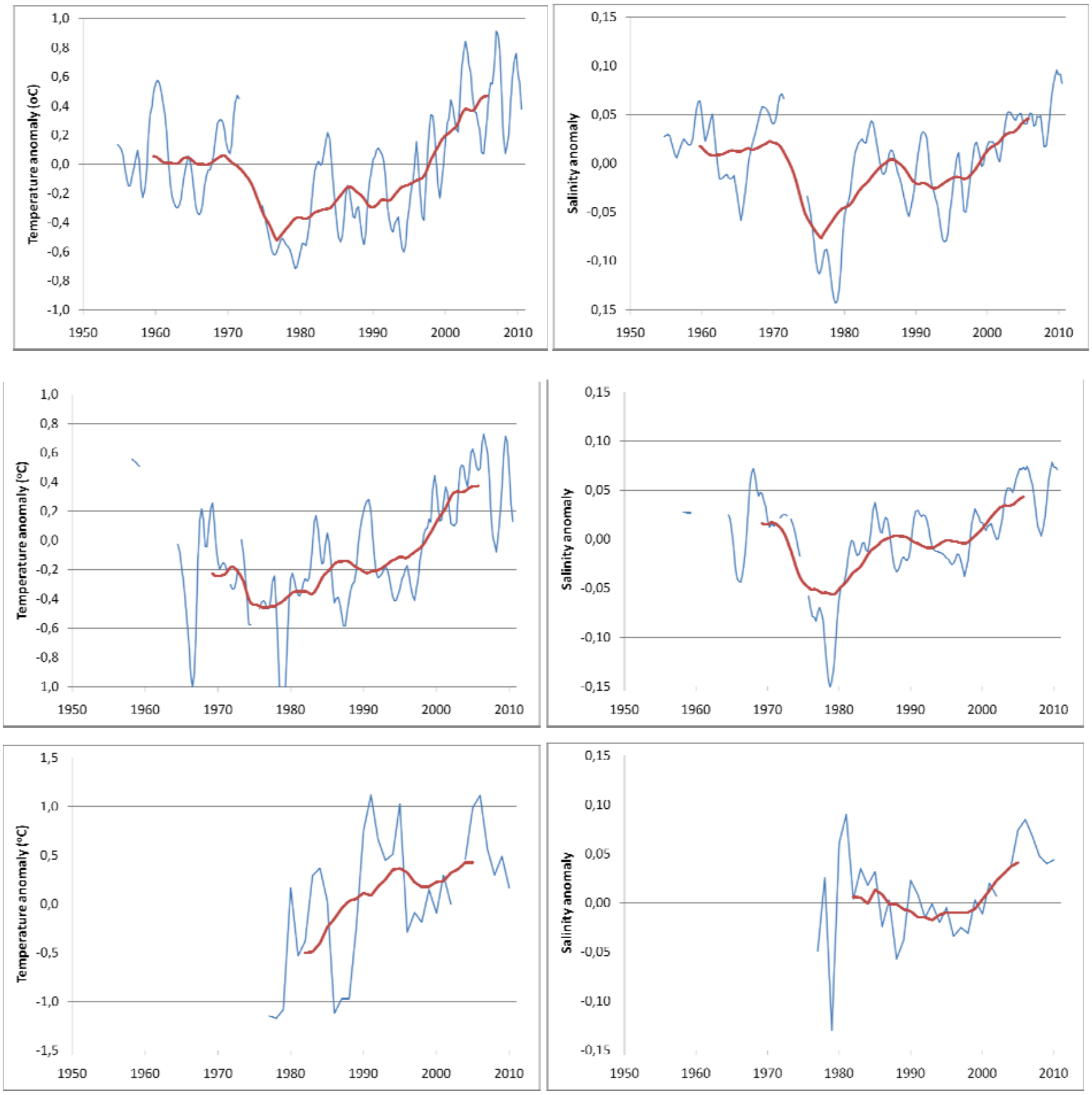


Figure 2. Temperature (left) and salinity (right) anomalies in the core of Atlantic water for the sections Svinøy-NW (upper figures), Gimsøy-NW (middle figures) and Sørkapp-W (lower figures), averaged between 50 and 200 m depth. Blue lines are one year moving averages (only summer values in the Sørkapp section) while red lines are ten years averages.

The volume transport in the Svinøy section in the eastern branch, the slope current along the shelf edge, has since 2007 been stable with normal values (Figure 3). There is some indication of a reduced inflow in 2009 but since the time-series ended in October 2009 the annual value for 2009 is missing.

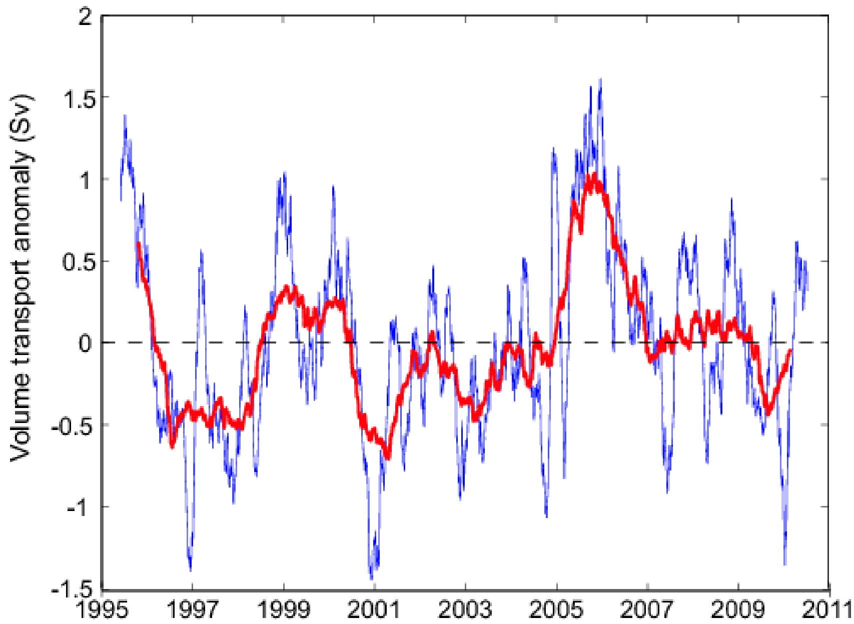


Figure 3. Volume transport anomaly in the Svinøy section. Updated from Orvik *et al.* (2001). The blue line is 3 months anomaly averages while the red line is one year anomaly averages.

In the period from end of April to beginning of June an international coordinated pelagic cruise has been performed every year since 1995. Figure 4 shows the temperature distribution at 100 m depth in 2009. The influence of the colder and fresher East Icelandic Current in the southern Norwegian Sea is clearly visible. In 2009 the temperature was larger than a long term mean (1995–2009), about 0–0.5 °C for most of the area.

The area of total occupied Atlantic Water in the Svinøy section is shown in Figure 5. After a relatively low extension of AW in the first half of the 1990s the area of AW has increased. After the area dropped in 2008–2009, it increased again in 2010 and in summer 2010 it was the highest ever in the time-series. The averaged temperature in the occupied AW has increased linearly since 1978 and has, during the whole period, become 0.7°C warmer for both Spring and Summer. In 2010 the temperature dropped and was lower the long term trend but still higher than the long term mean.

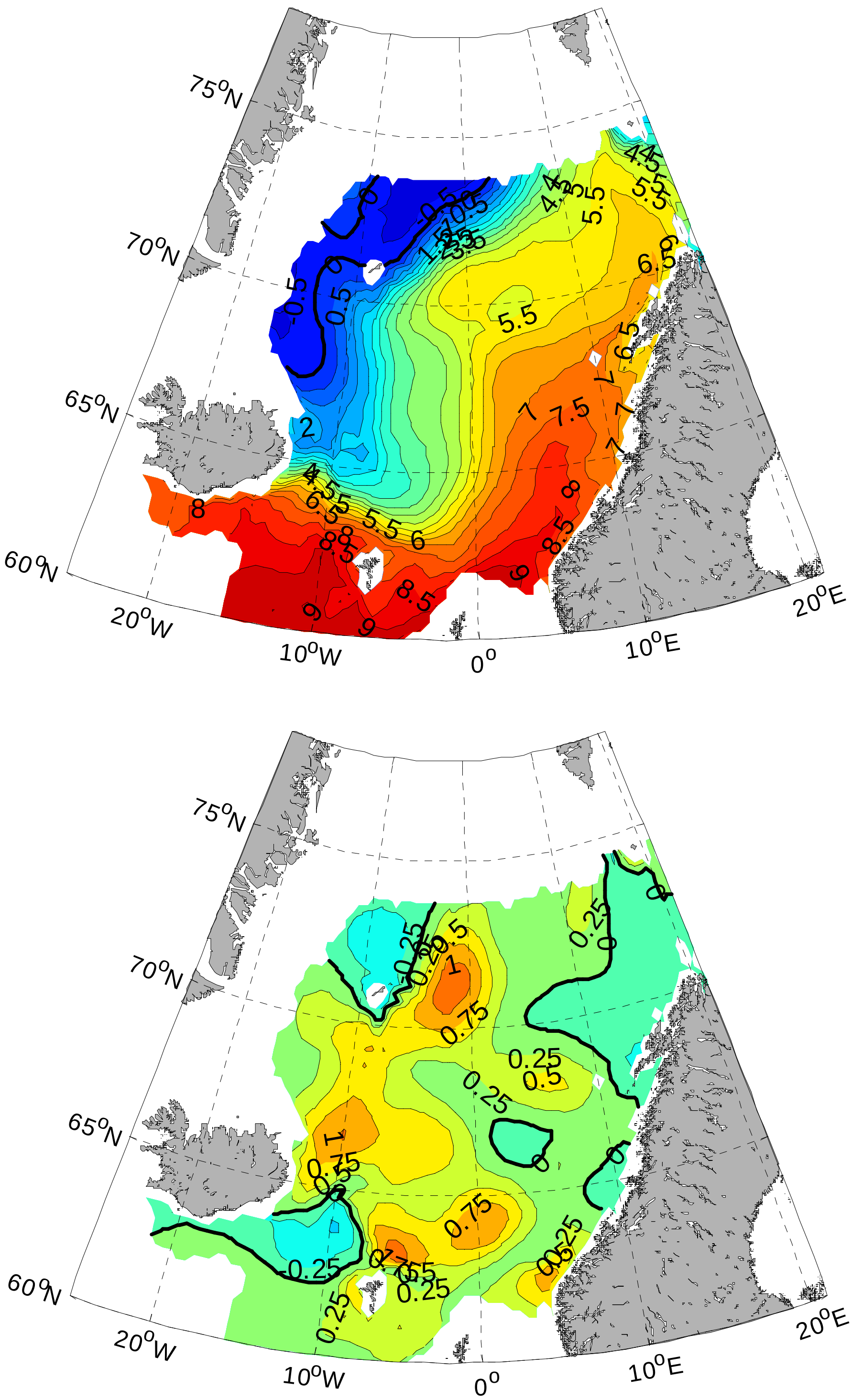


Figure 4. Temperature at 100 m depth in May 2010 (upper figure) and its anomaly relative to a 1995–2010 mean (lower figure).

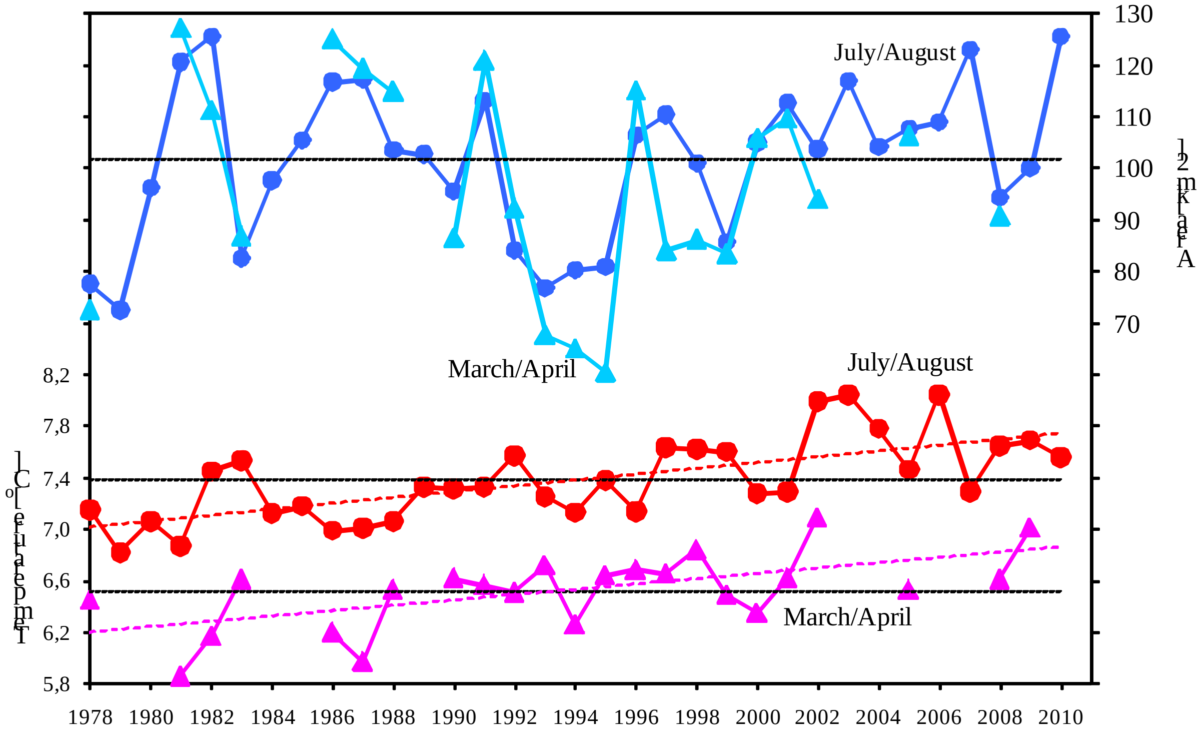


Figure 5. Area of Atlantic water and averaged temperature of AW in the Svinøy section for spring (March/April) and summer (July/August).

The Barents Sea

Randi Ingvaldsen

Summary

- The temperature continued the decrease since 2006 in both two sections (Fugløya-Bear Island and Vardø-N), but was in 2010 still above the long term mean.
- The salinity has been high the last years despite decreasing temperatures.
- There were slightly less ice in 2010 compared to 2009.
- The inflow to the Barents Sea has since 2007 been close to the long term mean.

The Barents Sea is a shelf area, receiving inflow of Atlantic water from the west. The inflowing water demonstrates considerable interannual fluctuations in water mass properties, particularly in heat content, which again influence on winter ice conditions. The variability in the physical conditions is monitored in two sections. Fugløya-Bear Island is situated where the inflow of Atlantic water takes place; the Vardø-N section represents the central part of the Barents Sea. In both sections there are regular hydrographic observations, and in addition, current measurements have been carried out in the Fugløya- Bear Island section continuously since August 1997. Coastal monitoring is performed at the station Ingøy.

The Fugløya-Bear Island and Vardø-North sections, which capture all the Atlantic Water entering the Barents Sea from south-west, showed temperatures close to 0.6–1°C above the long-term mean in early 2010 (Figure 6). This is lower than the last 5–6 winter. During winter the temperature anomalies decreased even more, and in March they were only 0.2–0.5°C above the long-term mean (Figure 6). This was due to lower air temperatures causing more intense heat loss in combination with weak inflow of Atlantic Water. During spring and summer the temperature anomalies were 0.3–0.6°C, and the annual mean temperature in 2010 was close to 0.3°C. The salinity variations usually show a close resemblance to temperature, but this relation broke down in 2008/2009 and the salinity has been high despite decreasing temperatures (Figure 6).

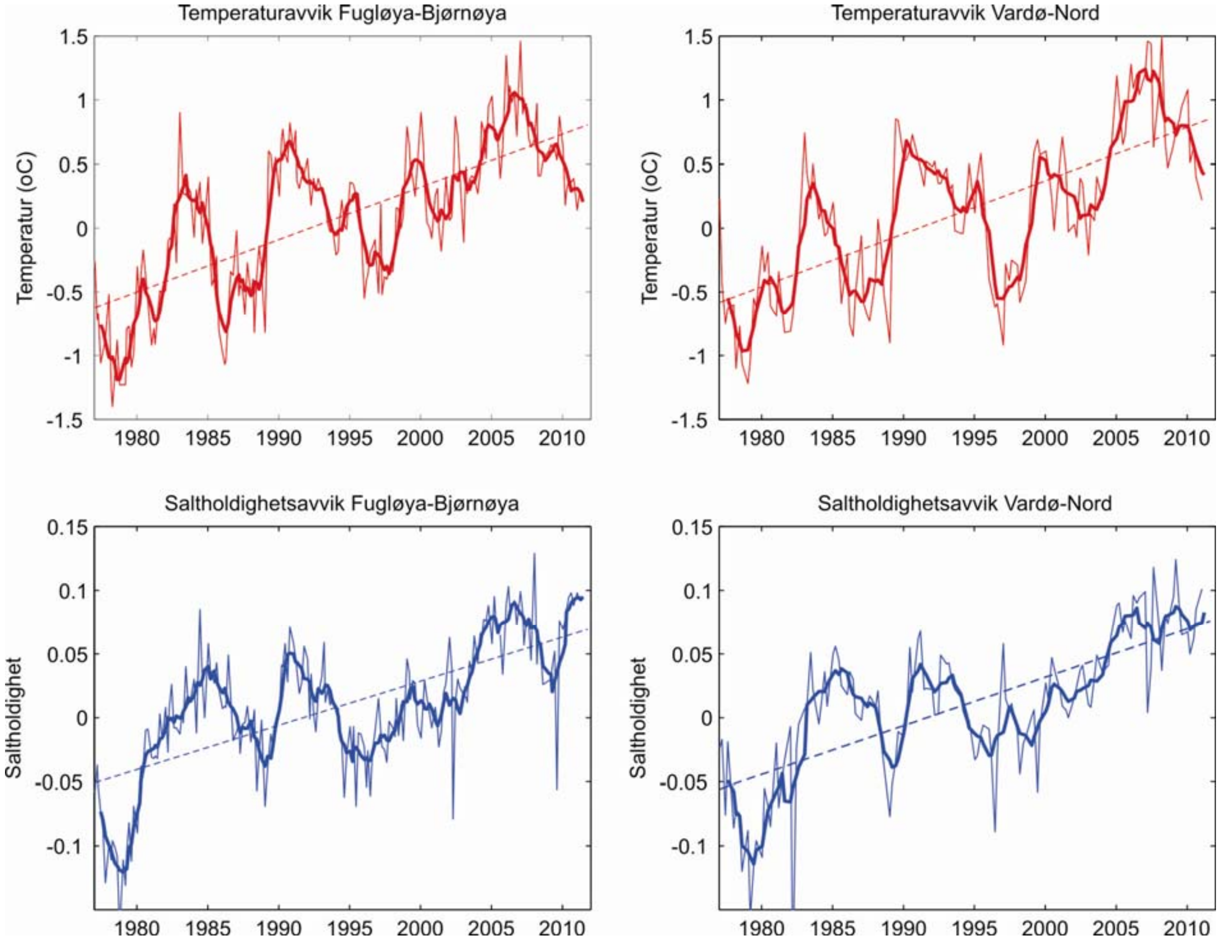


Figure 6. Temperature (upper) and salinity (lower) anomalies in the 50–200 m layer of the Fugløya-Bear Island section (left plates) and Vardø-N section (right plates).

The surface temperatures in the Barents Sea are closely linked to the air temperatures. The time-series from the surface coastal waters at Ingøy show that during 2010 the surface temperature was only slightly above normal through most of the year except in late summer 2010 when it was below normal (Figure 7). In the deeper waters (at 250 m), which is strongly influenced by Atlantic Water, the temperature was above normal throughout the year. In both the surface and deeper layers, the temperature decreased (relative to the normal) in late summer/fall 2010.

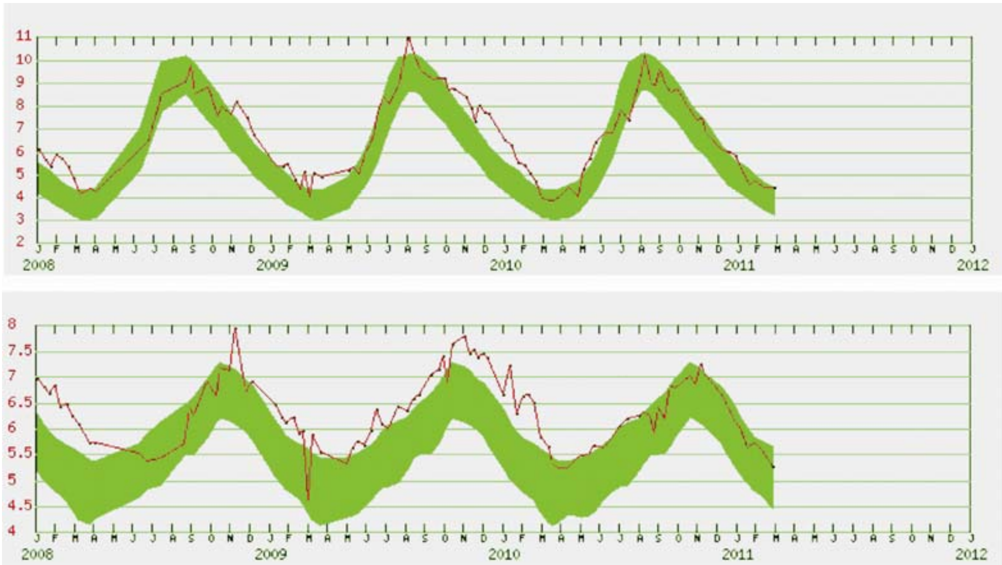


Figure 7. Monthly mean temperature at 1 m and 250 m depth at the fixed station Ingøy, northern Norway, situated in the Coastal Current at the entrance to the Barents Sea. Vertical axis is temperatures (°C) and horizontal axis is month. The green areas are the long-term mean for the period 1936–1944 and 1968–1993 +/- one standard deviation and represent the typical variations.

The variability in the ice coverage in the Barents Sea is linked to the temperature of the inflowing Atlantic water, the wind field and the import of ice from the Arctic Ocean and the Kara Sea. The ice has a response time on temperature changes in the Atlantic inflow (one-two years), and usually the sea ice distribution in the western Barents Sea respond faster than in the eastern part. Due to the high temperatures there have been small amounts of ice in the last years (Figure 8). During the period 2003–2006 the winter ice edge had a substantial retreat towards north-east, but since then the ice area has increased. In January 2010 the amount of ice was low, but the ice cover increased substantially during winter and in March the ice cover was close to the average for the period 1987–2007. In early summer there was less ice than normal, while in August/September the ice cover one again was close to the average. The ice border shifts rapidly due to changes in wind, and the ice cover in August/September was mainly caused by high ice import from the Arctic Ocean. As a whole, there were slightly less ice in 2010 compared to the year before.

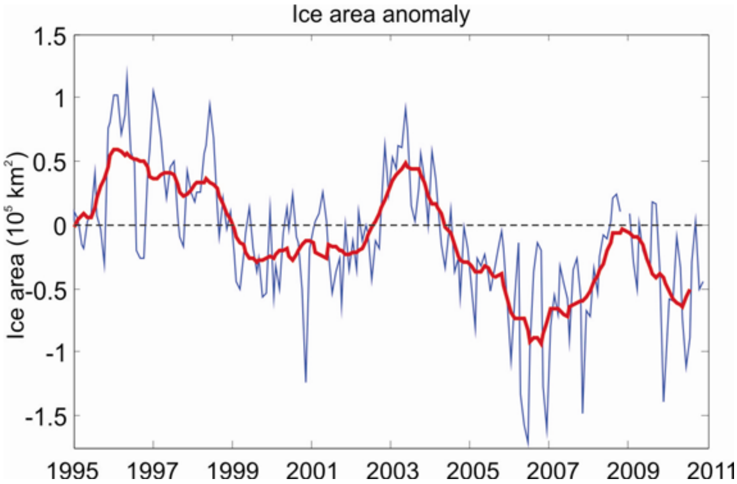


Figure 8. Ice area anomaly for the sector 25–45°E in the Barents Sea, which is the area with the highest variability in ice cover. Monthly mean (blue line) and 1 year moving average (red line) is shown relative to the mean ice area for the period 1995–2008.

The volume flux of Atlantic Water flowing into the Barents Sea has been monitored with current measurements in the section Fugløya-Bjørnøya since 1997. The inflow is predominantly barotropic, with large fluctuations in both current speed and lateral structure. In general, the current is wide and slow during summer and fast, with possibly several cores, during winter. The volume flux resembles the velocity field and varies with season due to close coupling with regional atmospheric pressure. Southwestly wind, which is predominant during winter, accelerates flow of Atlantic Water into the Barents Sea; whereas, weaker and more fluctuating northeastly wind common during summer, slows the flow. The mean transport of Atlantic Water into the Barents Sea for the period 1997–2010 is 2 Sv (Sv = 10^6 m^3s^{-1}) with an average of 2.2 Sv during winter and 1.8 Sv during summer. During years in which the Barents Sea changes from cold to warm marine climate, the seasonal cycle can be inverted. Moreover, an annual event of northerly wind causes a pronounced spring minimum inflow to the western Barents Sea; at times even an outward flow.

The volume flux varies with periods of several years, and was significantly lower during 1997–2002 than during 2003–2006 (Figure 9). The year of 2006 was a special year as the volume flux both had a maximum (in winter 2006) and minimum (in fall 2006). Since then the inflow has been low, particularly during spring and summer. The inflow in 2010 was much as in 2007–2009; moderate during winter followed by a strong decrease in spring. In late spring/early summer 2010 the flux was close to 0.5 Sv below the average, thereafter increasing toward the average. As the observational series still only have data until summer 2010, it cannot give information about the situation in fall 2010. There is no significant trend in the observed volume flux from 1997 to summer 2010.

Heat transport into the Barents Sea is formed by a combination of volume and temperature of inflowing water masses, although those two factors are not necessarily linked. The reason is that while temperature of inflowing water depends on temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This signals the importance of measuring both volume transport and temperature, since volume flux is essential to transport zooplankton, fish eggs, and larvae into the Barents Sea.

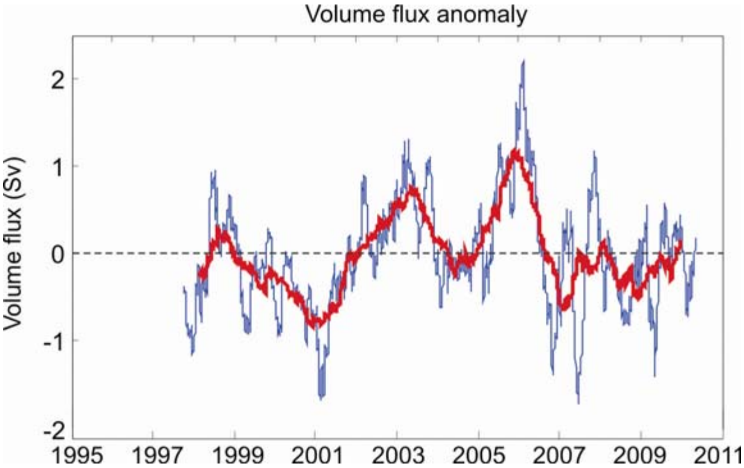


Figure 9. Observed Atlantic Water volume flux through the Fugløya-Bear Island section estimated from current meter moorings. Three months (blue line) and 12-months (red line) running means are shown.

The North Sea

Jon Albretsen, Morten D. Skogen and Solfrid S. Hjøllo

Summary

- Persistent winter cooling in 2010 resulted in deep convection and deep water renewal.
- Temperature in Atlantic water at 150 m depth decreased from 2010 to 2009, while salinity is still relatively high.
- The modelled inflow and heat content in the North Sea reduced from 2010 to 2009.

The sea surface temperature in the North Sea was slightly below normal at the start of 2010. A remarkably low NAO index and a persistent cooling of northern Europe caused the surface temperature to be 1–3°C below normal in January and February. The situation normalized during spring, and the summer temperature was above normal in most North Sea areas. An extensive cooling of the North Sea waters was again experienced during the last two months in 2010, and the surface temperature reached the low February anomaly level.

The persistent winter cooling of the North Sea area introduced a densification of the central North Sea waters which cascaded down into the Skagerrak Basin. In the deep water in the Norwegian Trench a total renewal of the water masses occurred in spring 2009 by inflow of Atlantic water, and during winter 2010 a new renewal took place by convection of cold North Sea water. The latter mechanism for bottom water exchange in the Skagerrak has been non-existent for about two decades due to lack of persistent winter cooling of the North Sea region. After the exchange, the bottom water then experienced an increase in the oxygen level to 2009 values, and the bottom temperature decreased from about 6°C to 4°C, the lowest value observed since 1970 (see Figure 10). In April the cooling of the Skagerrak Basin waters was also noticeable at higher levels. The salinity and temperature measurements at 150 m depth based on monthly observations in 2010 sampled approx. 10 km off Torungen lighthouse near Arendal show a shift in water properties from typical Atlantic waters to North Sea waters from March to April (Figure 11). The low salinity event lasted for about two months and then repositioned at typical level representing Atlantic waters. The low temperatures normalized after about two months, but with only a few exception years, this temperature level is relatively low compared to what is observed the last decade (Figure 12).

Results from the ocean circulation model NORWECOM show that the volume flux in and out of the North Sea was low in 2010 (Figure 13). The southward inflow of Atlantic water between the Orkney Islands and Utsira, Norway was estimated to be the lowest over the entire 1985–2010 period. The northward transport through the English Channel was also among the lowest (not shown).

Both seasonal variations and long-term oscillations of the heat content in the North Sea are computed from the 1985–2010 NORWECOM model simulation (Figure 14). The minimum and maximum heat content will reflect the degree of winter cooling and summer heating of the North Sea, respectively. The heat content in the North Sea during winter 2010 was estimated as relatively low, and this supports the negative surface temperature anomalies introduced by persistent cooling from the atmosphere. The heat content during summer was low as well, the lowest since 1996, and this is related to the minimum in the Atlantic inflow. The annual level of heat content in the North Sea is comparable to the minima in 1996 and in 1985–1987.

The monthly IMR cruises across the Skagerrak between Torungen lighthouse (Norway) and Hirtshals (Denmark) are especially valuable as they cover an area with hydrographic information of the Atlantic inflow to the North Sea and Skagerrak, the inflow of North Sea waters to the Skagerrak and the outflow of Baltic water. In addition it is located close to the origin of the Norwegian Coastal Current. Regarding the inflow of Atlantic water along the southern slope of the Norwegian Trench north of Denmark, the negative extremes in the modelled transport anomaly east of the Orkney Islands correspond well with the observed temperature minima (Figure 15). Winter periods with a relatively low inflow of Atlantic water is consistent with minima in North Sea heat content, and a larger proportion of the North Sea waters have then lowered the temperature in the intermediary Skagerrak (150 m used as example). In a climatic context we see that there was a shift in the hydrographic properties in the Atlantic inflow at 150 m depth in the Skagerrak around late 1980s. Both temperature and salinity have had higher values the last two decades, and we also see indications that the mean density has decreased.

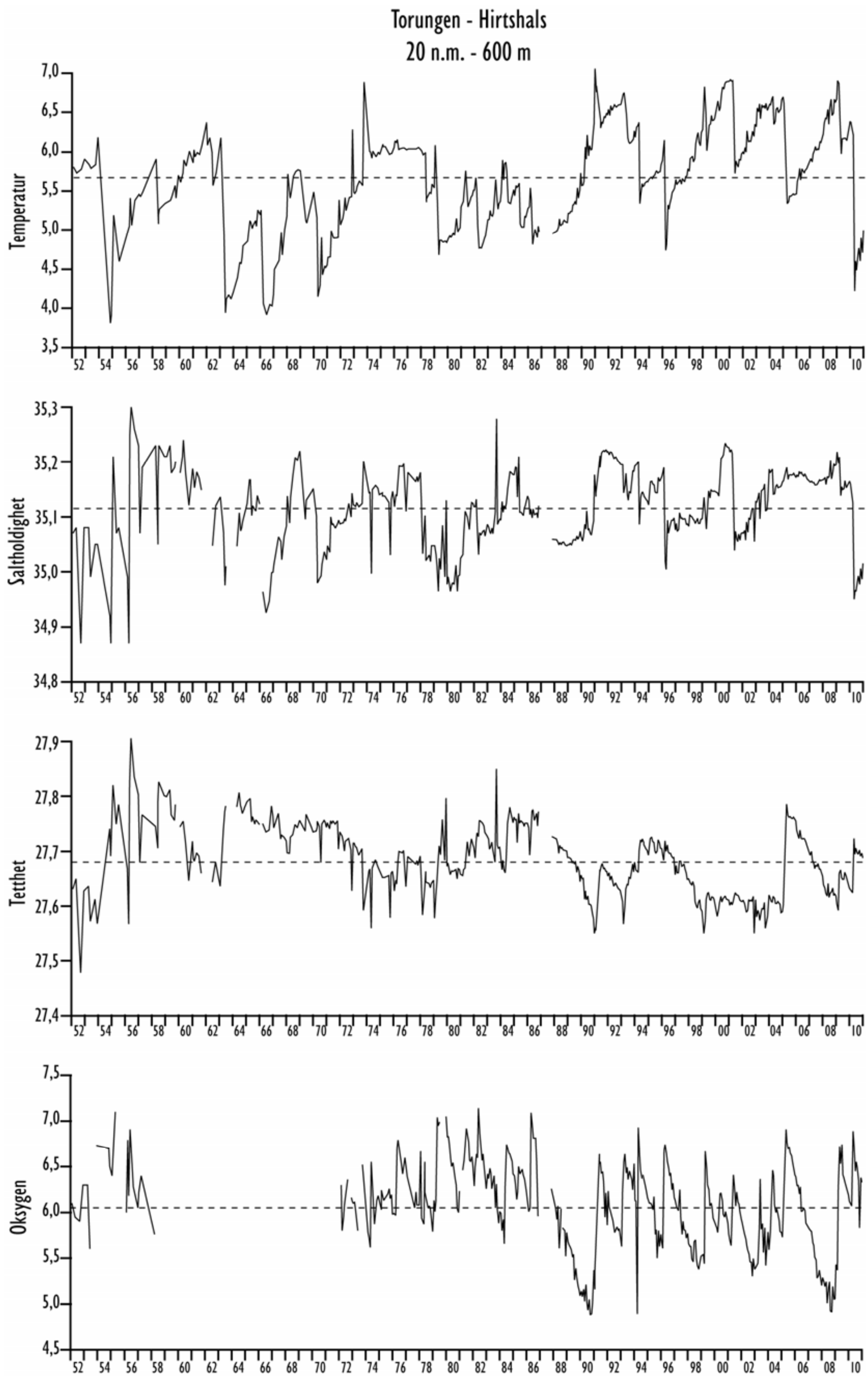
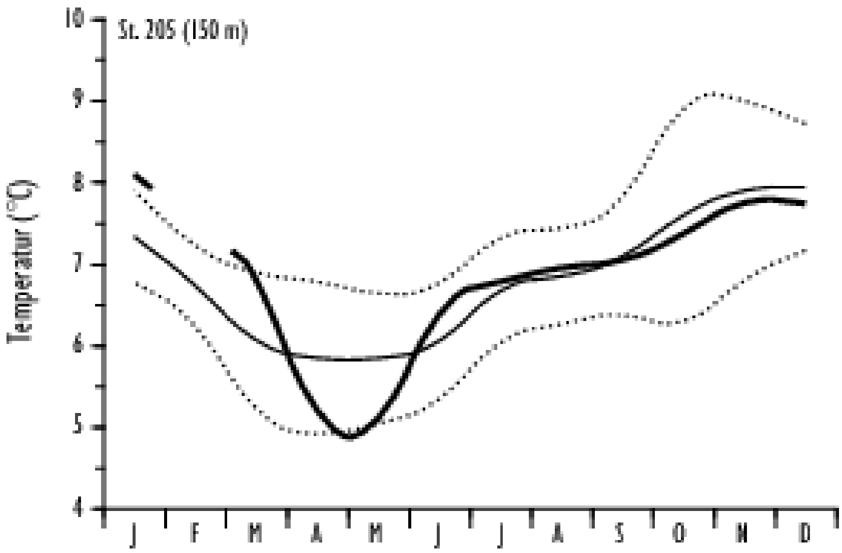


Figure 10. Temperature (°C), salinity, density (σ_t in kg/m³) and oxygen (ml/l) at 600 m depth in the Skagerrak Basin from 1952 to 2010.Thislocation depicts the physical environment in the Skagerrak bottom water.



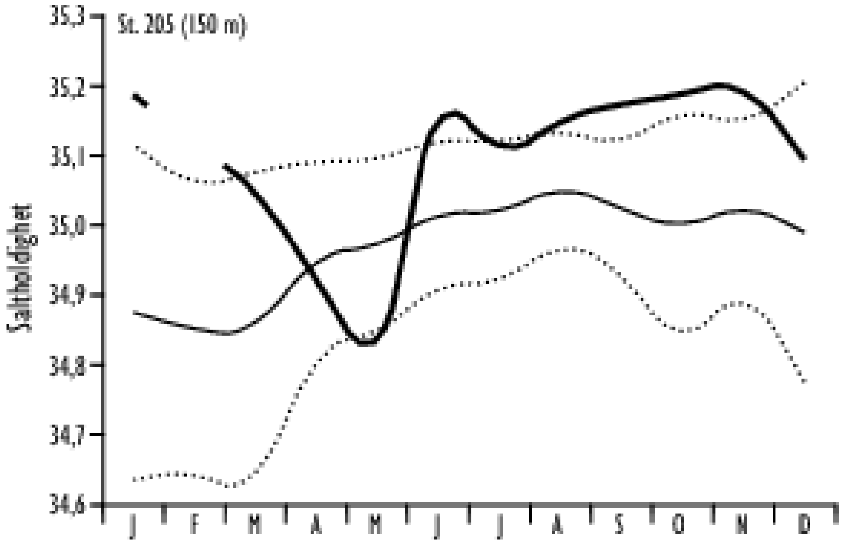


Figure 11. Temperature (upper panel) and salinity (lower panel) at 150 m depth based on monthly observations in 2010 sampled approx. 10 km off Torungen lighthouse near Arendal. The long-term mean (thin solid line) and the standard deviation (dotted line) are based on measurements sampled between 1961 and 1990.

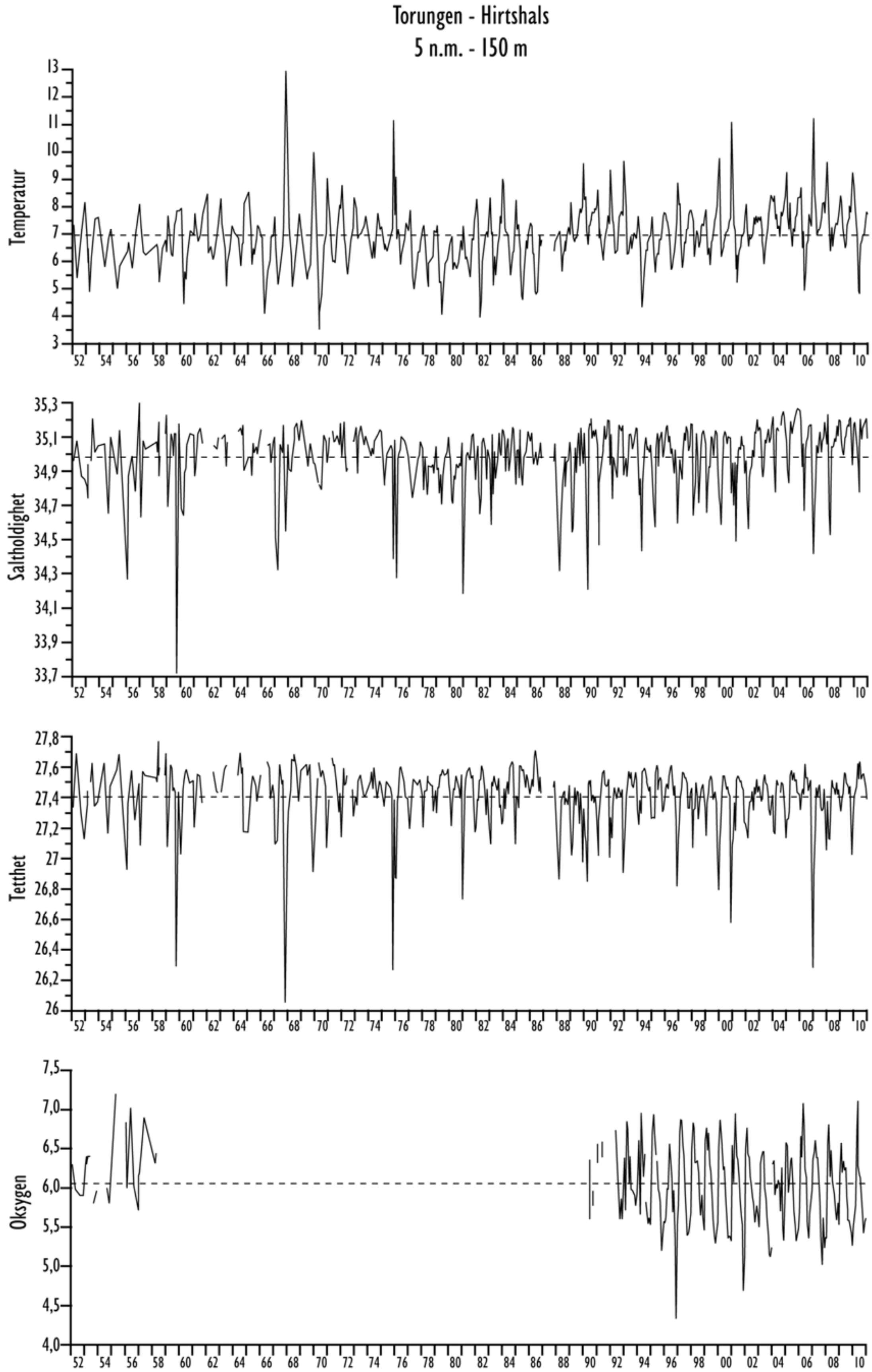


Figure 12. Temperature (°C), salinity, density (σ_t in kg/m^3) and oxygen (ml/l) at 150 m depth approx. 10 km off the Torungen lighthouse (Norway) from 1952 to 2010. This location is representative for the Atlantic water flow below the Norwegian Coastal Current.

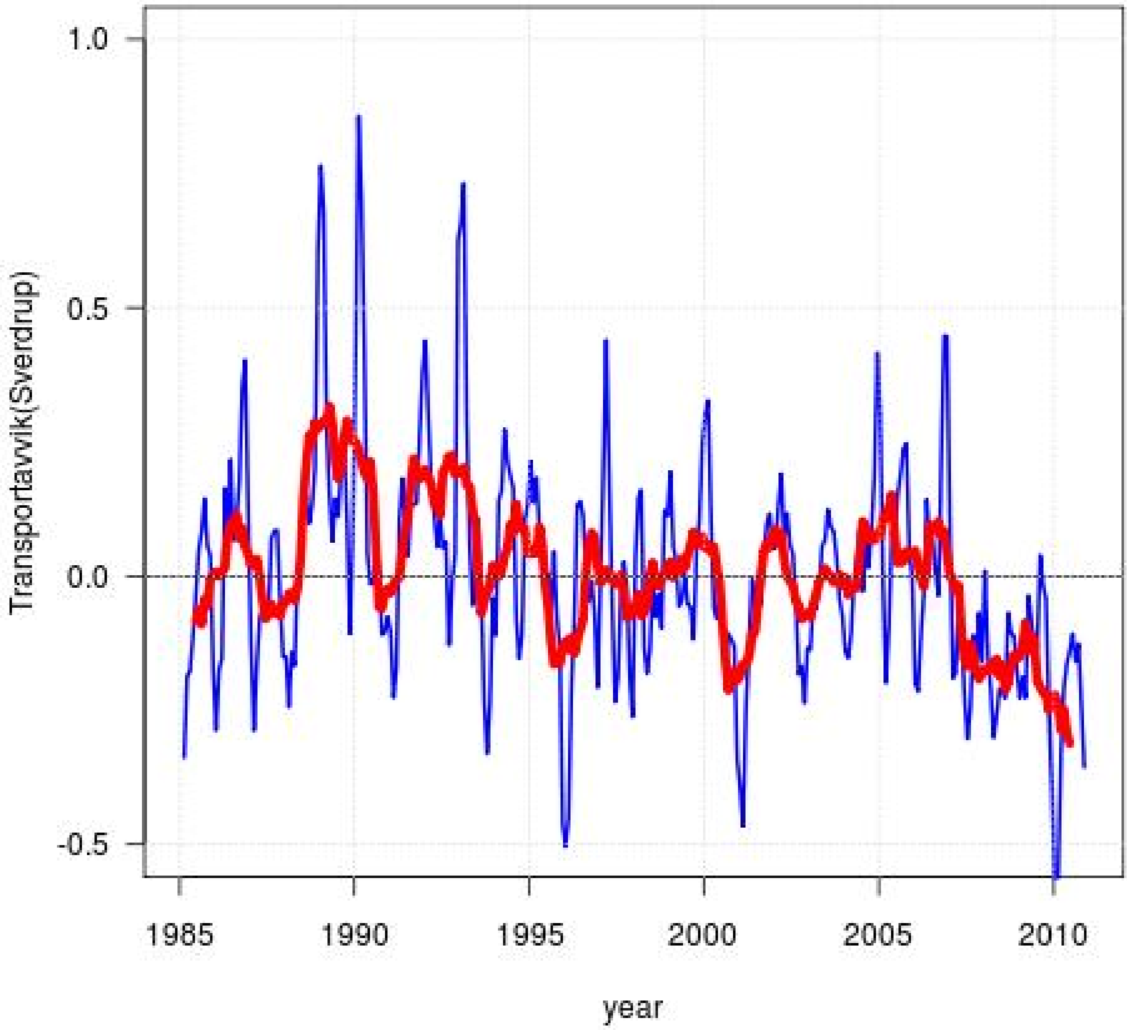


Figure 13. Time-series (1985–2010) of modelled monthly mean volume transport anomalies of Atlantic water into the northern and central North Sea southward between the Orkney Islands and Utsira, Norway. The vertical axis denotes transport anomaly in Sv ($10^6m^3s^{-1}$). The blue and red line displays the 3 and 12 months running average, respectively.

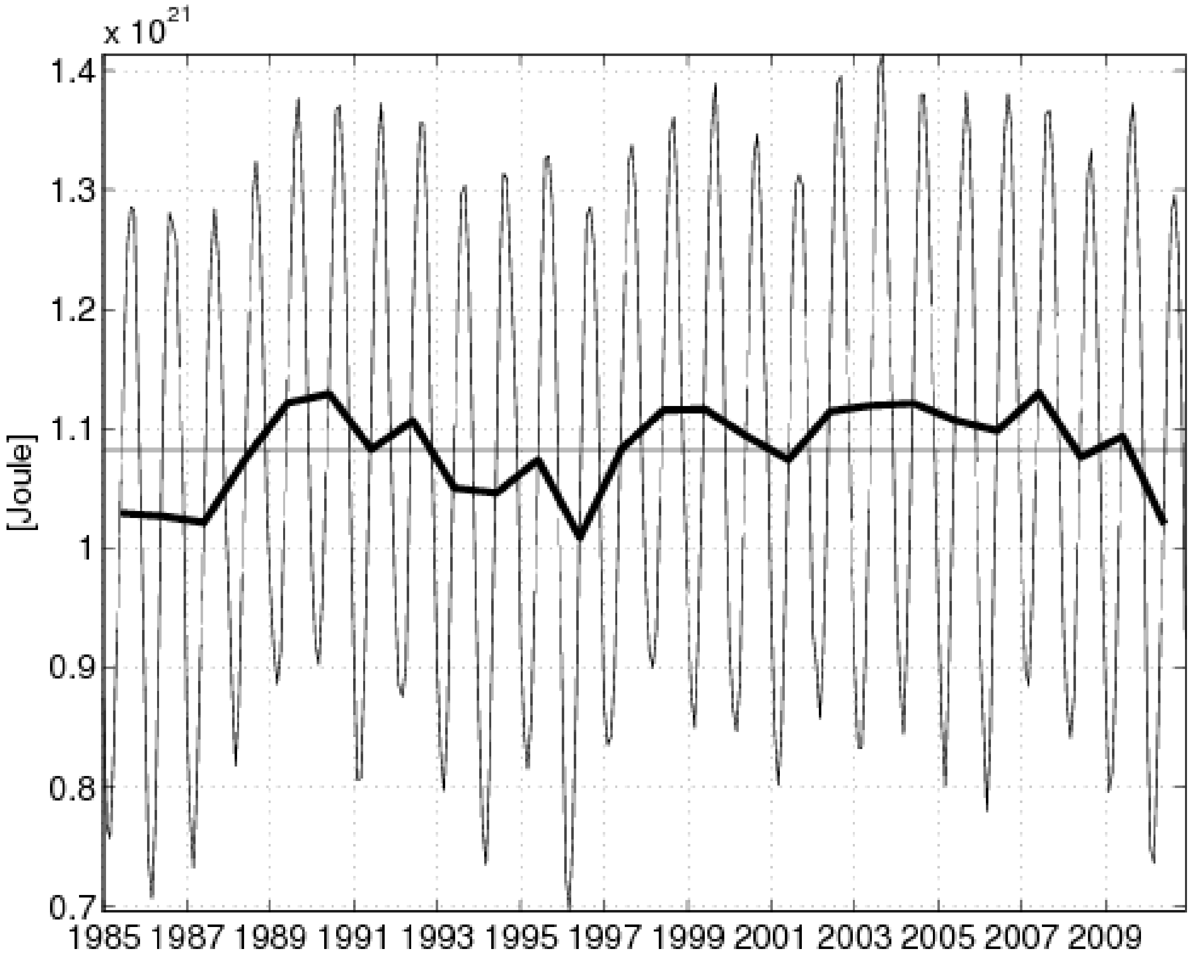


Figure 14. Modelled heat content (in J) in the North Sea from 1985 to 2010. Monthly (thin line) and annual (thick line) values are displayed.

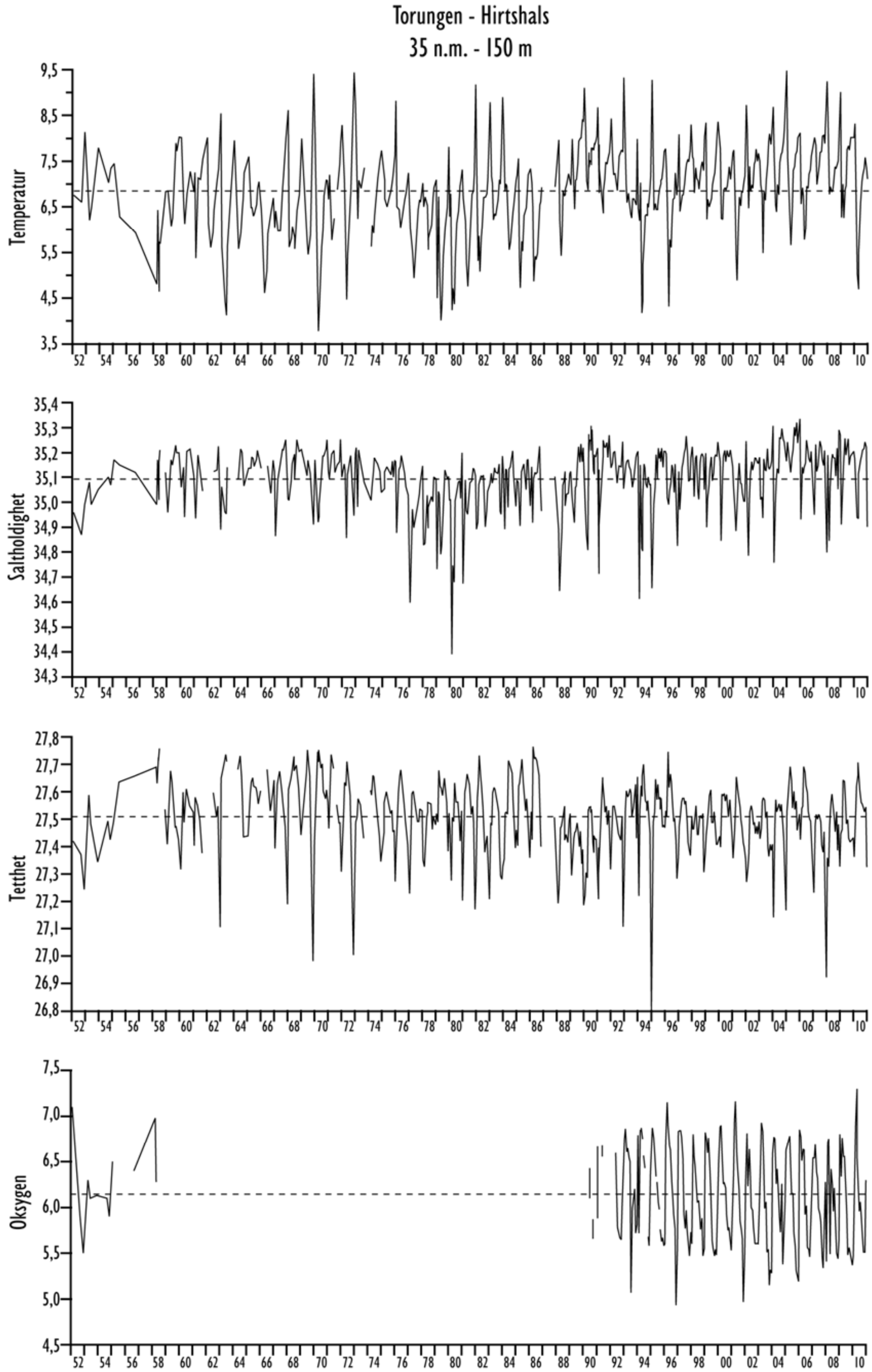


Figure 15. Temperature (°C), salinity, density (σ_t in kg/m^3) and oxygen (ml/l) at 150 m depth approx. 45 km north of Denmark from 1952 to 2010.This location is representative for the Atlantic inflow to the Skagerrak north of Denmark.

Annex 11: Regional report – Northern Baltic Sea 2010/ Finland

Pekka Alenius, Bert Rudels

The winter 2010/2011 was a hard ice winter with a large ice extent. In previous winter 2009/2010 the largest ice extent was 249 000 km² and in 2010/2011 it reached 315 000 km². The last time the ice extent was as large or larger occurred in 1987, when the ice extent was 407 000 km².

The annual course of sea surface temperature was close to the average except after mid May when there was a short very warm period. Another warm period occurred in July when the surface temperature was exceptionally high for two weeks or more. The late Autumn and especially December was exceptionally cold cooling the surface waters but the absolute values were only a couple of degrees Celsius below normal.

The slight warming of deep waters after 2004 seems to have stopped in 2009 and 2010. One may see a very faint increase in deep-water salinity, but the general salinity level is around the same as the last 15 years. In the Gulf of Finland there may be a rising trend in last 20 years, but the annual variation are large.

Oxygen depletion was present especially in August in the central Gulf of Finland at depths greater than 70 m. The layer of poor oxygen conditions began already at some 50 m depth. The oxygen depletion in August was worse than in 2009. The deep-water problems of the central Baltic Sea remain and affect the conditions in the Gulf of Finland. In the Gulf of Bothnia there are no problems with deep-water oxygen conditions.

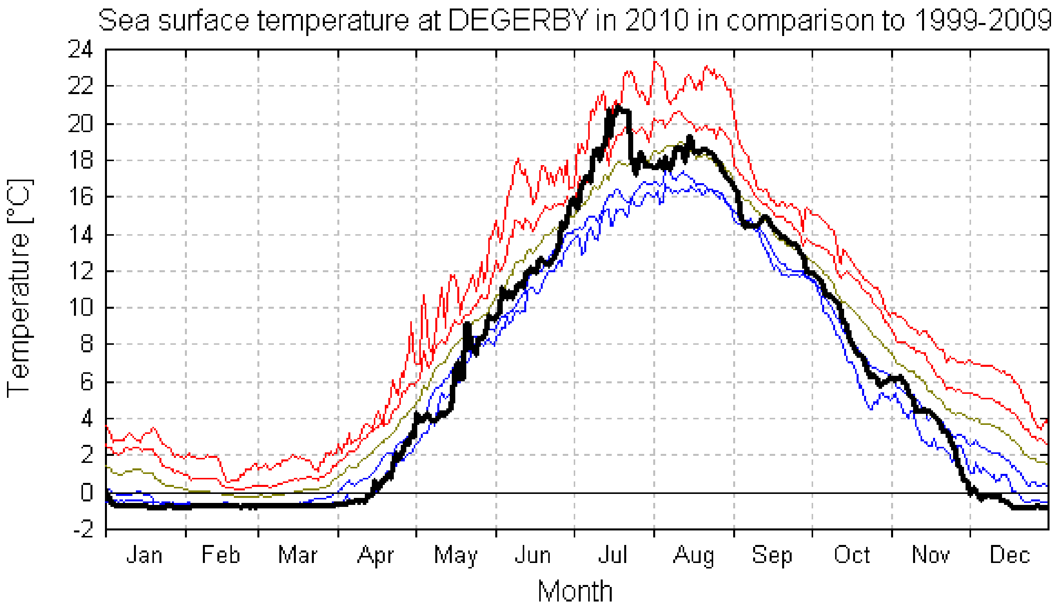


Figure 1. The annual sea surface temperature variation at Degerby (Åland) in 2010, black, the 1999–2009 mean, the 1999–2009 maximum, the 1999–2009 minimum.

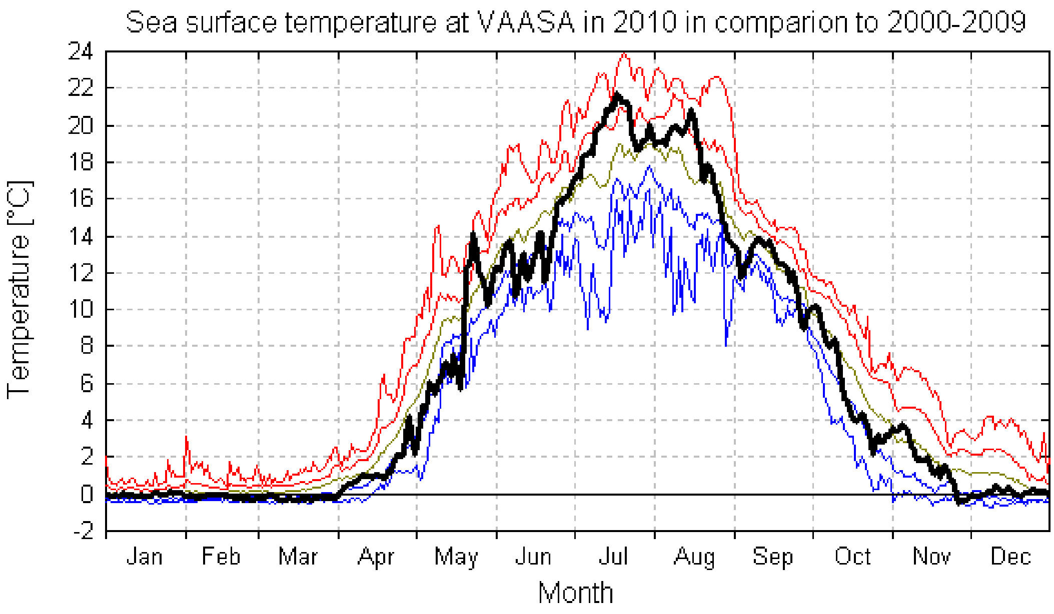


Figure 2. The annual sea surface temperature variation at Vaasa in 2010, black, the 2000–2009 mean, the 2000–2009 maximum, the 2000–2009 minimum.

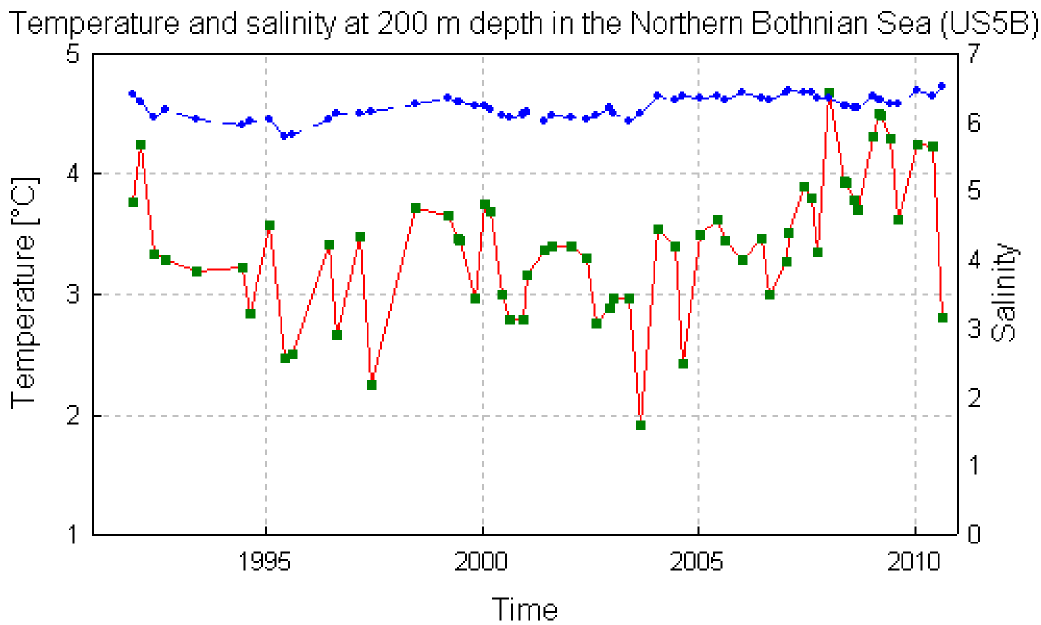


Figure 3. The temperature and salinity at deep water (200 m) in the northern Bothnian Sea (US5b).

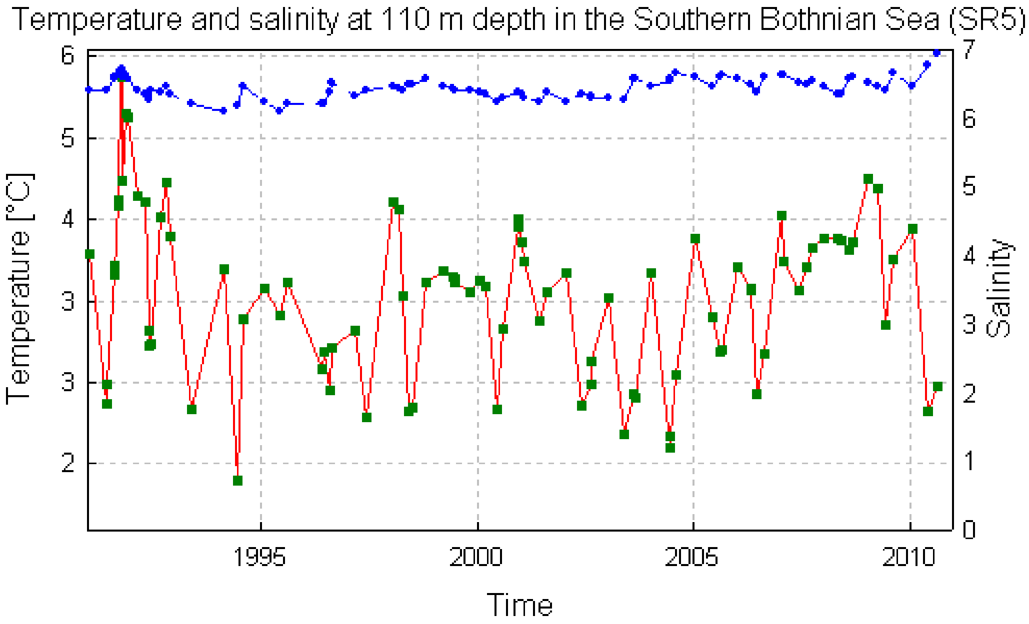


Figure 4. The temperature and salinity at deep water (110m) in the southern Bothnian Sea (SR5).

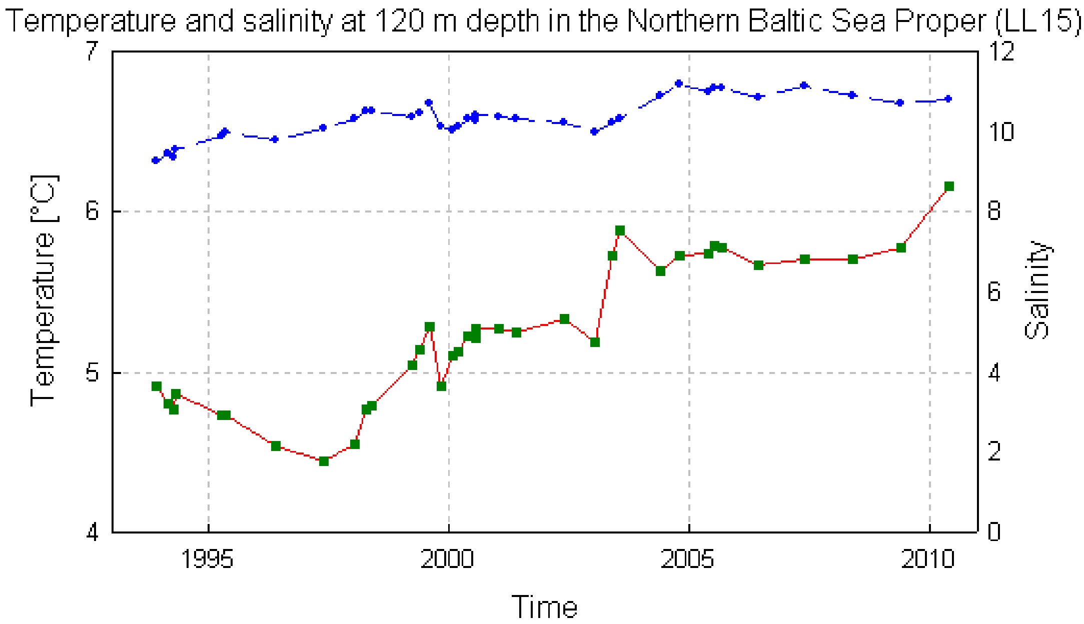


Figure 5. The temperature and salinity at deep water (120 m) in the northern Baltic Sea Proper (LL15).

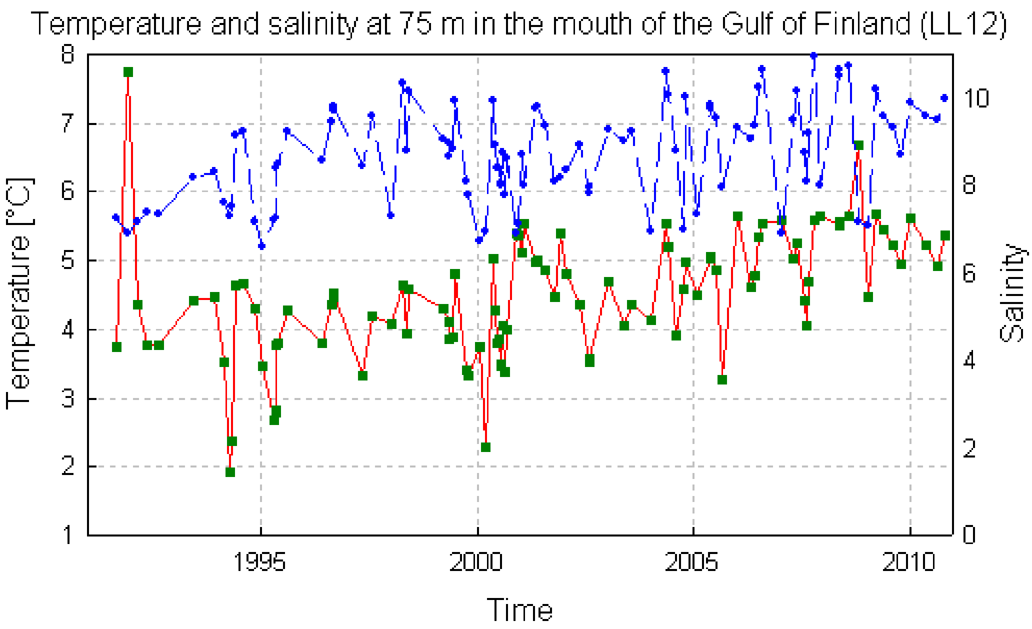


Figure 6. The temperature and salinity at deep water (75 m) in the mouth of the Gulf of Finland (LL12).

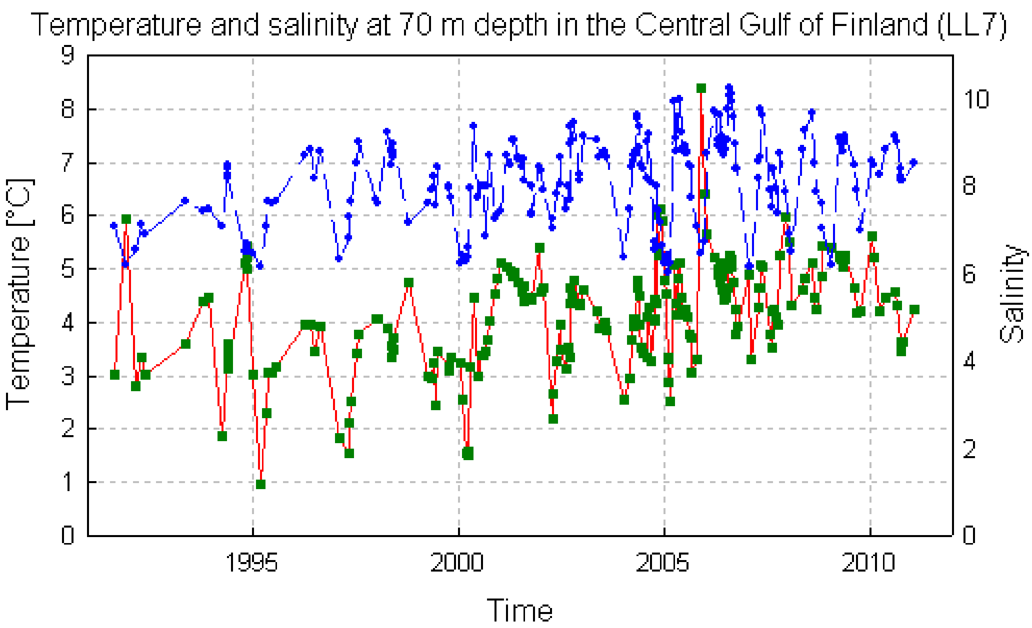


Figure 7. The temperature and salinity at deep water (70m) in the central Gulf of Finland (LL7).

Annex 12: Regional report – Skagerrak, Kattegat and the Baltic (area 9b)

Karin Borenäs, SMHI

Owing to its central location relative to the Skagerrak, Kattegat, and Baltic, the weather in Sweden can be taken as representative for the area. The weather 2010 was characterized as being more continental than maritime; with cold winter months and a period with very high temperatures during the summer. The mean air temperature 2010 was below normal almost everywhere in Sweden. The average for the whole country was around 1°C below normal, which makes 2010 the coldest year since 1987, with the largest anomalies found in the western parts. In the south of Sweden December was the coldest ever recorded for the last hundred years. The precipitation was in general above normal with snow depth records registered in the south of Sweden at the beginning of the year. The westerly and south-westerly winds were weaker and less frequent than normal in the south of Sweden while the opposite was true for winds from the north and east, again reflecting the continental type of weather in 2010. The number of sun-hours was normal in most places.

Annual cycles of surface temperature and salinity

A large number of hydrographic stations are regularly visited in the Baltic Sea, the Kattegat and the Skagerrak, as exemplified in Figure 1. From five of these stations the annual cycles of surface temperature and salinity are presented in Figure 2. In Skagerrak the surface temperature and salinity was well below normal in January and February. Low temperatures were also found in December. For the rest of the year the values were close to normal. The surface temperature in Kattegat was below normal in February and December and above normal in July. In January and February the surface salinity was below normal. The temperature in the surface water was close to normal in the Baltic Proper for most of the year except for June and July which were warmer than normal and December which was colder. In the Bothnian Bay and Bothnian Sea the surface temperature was well below normal in December. For the rest of the year the conditions in the northern Baltic Sea were close to normal except for late May and July when surface temperatures were exceptionally high.

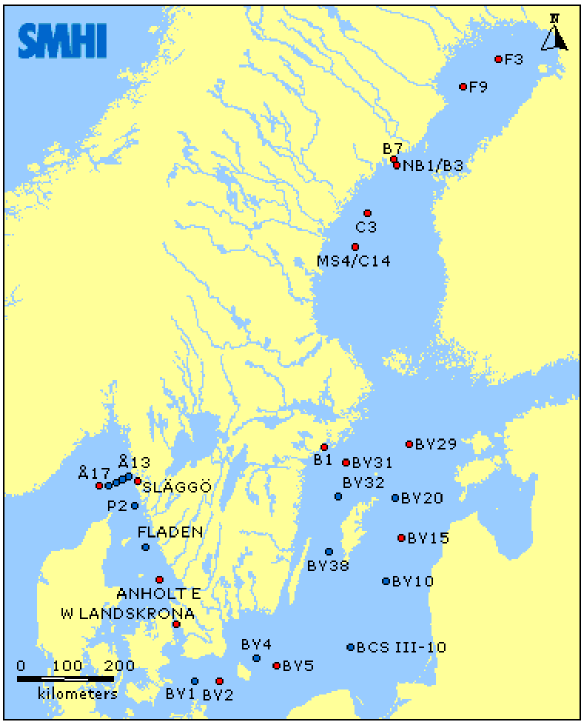


Figure 1. Position of stations visited on a regular basis. Stations marked with red pertain to the Swedish National Monitoring Programme while stations in blue are additional stations sampled by SMHI.

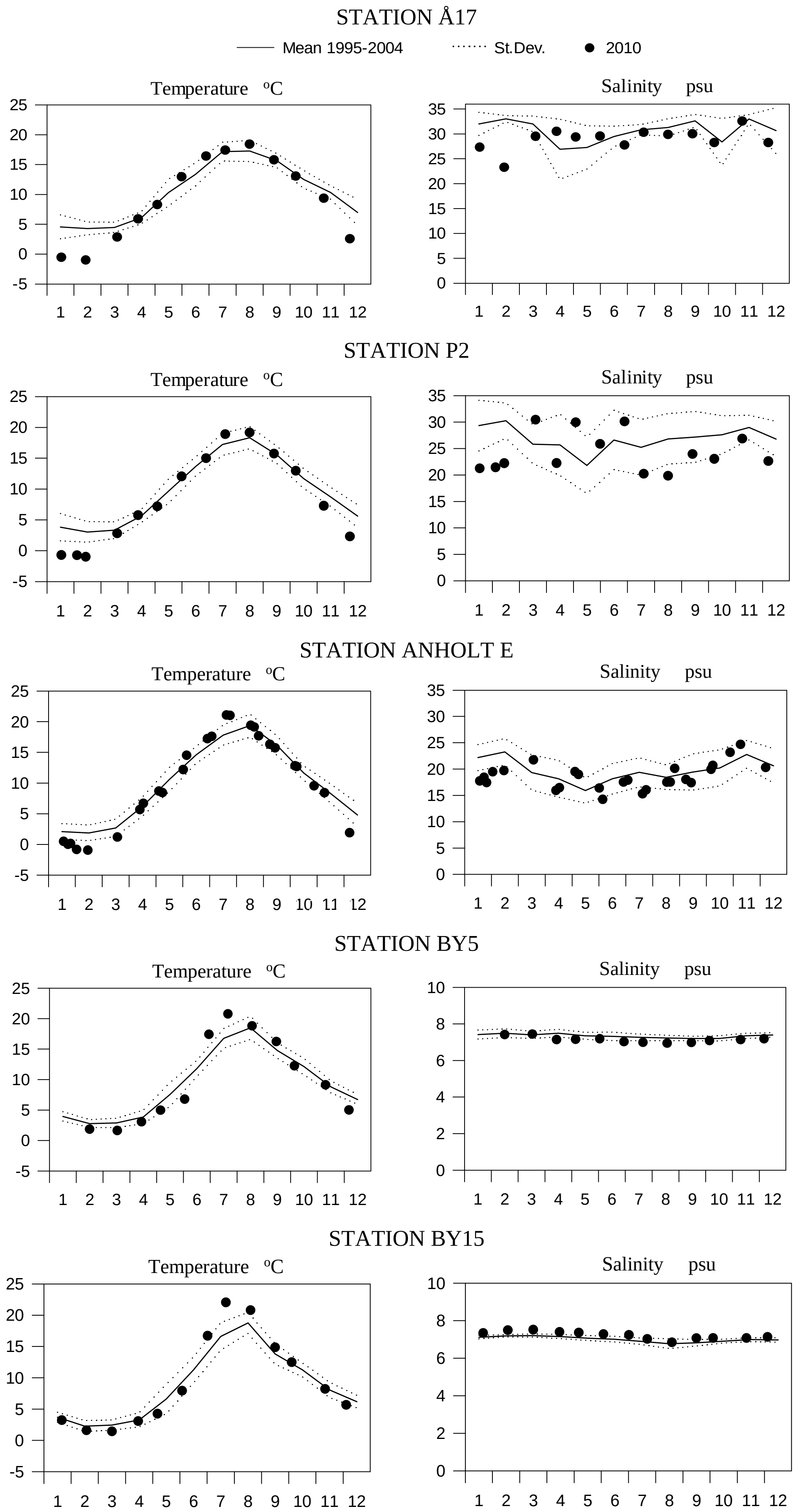


Figure 2. Annual cycles of temperature and salinity, see Figure 1 for station positions (SMHI).

Long term observations at BY15

At station BY15, east of Gotland, the mean surface temperature for 2010 continued to decrease for the third consecutive year. The decrease was somewhat larger than for the two previous years. The anomaly is still positive relative to the period 1990–1999 but it is now less than 1°C. The mean surface salinity at BY15 showed again a slight increase and the weak positive trend, indicated by the five-year running mean, continued (Figure 3, lower panel).

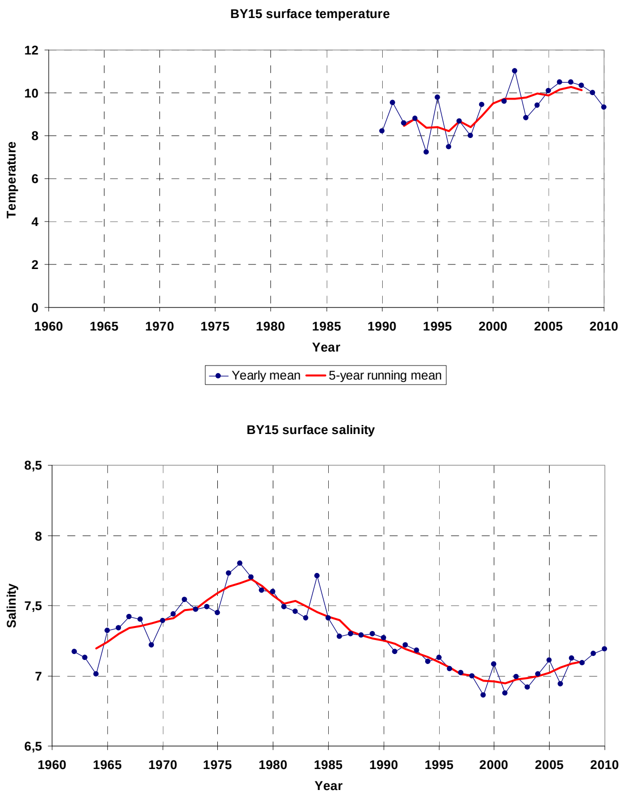


Figure 3. Sea surface temperature (upper panel) and salinity (lower panel) at BY15 (see Figure 2) in the Baltic Proper. Yearly mean (red curve) and 5-year running mean (blue curve; SMHI).

Water exchange

There were several minor inflows to the Baltic during the fall, improving the oxygen conditions in deeper parts of the Arkona and Bornholm basins. However, for the Bornholm Basin the effect of the inflows was not lasting very long and low oxygen values soon reappeared. The accumulated inflow through the Öresund to the Baltic is shown in Figure 4.

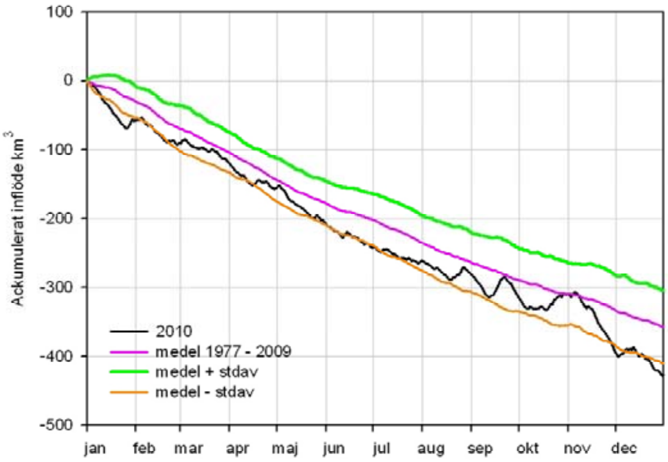


Figure 4. Accumulated inflow (km³) through the Öresund to the Baltic in 2010 compared to 1977–2009 (SMHI).

Ice conditions

The ice season 2009/2010 was considered the most severe since 1987 with a maximum ice extent being 239 000 km², which is more than twice that of the previous season. The maximum ice extent occurred on February 17 and at that time parts of Skagerrak, Kattegat and the Sounds were also ice covered, see Figure 5. The maximum ice thickness was found in the northernmost archipelago and measured more than 70 cm.

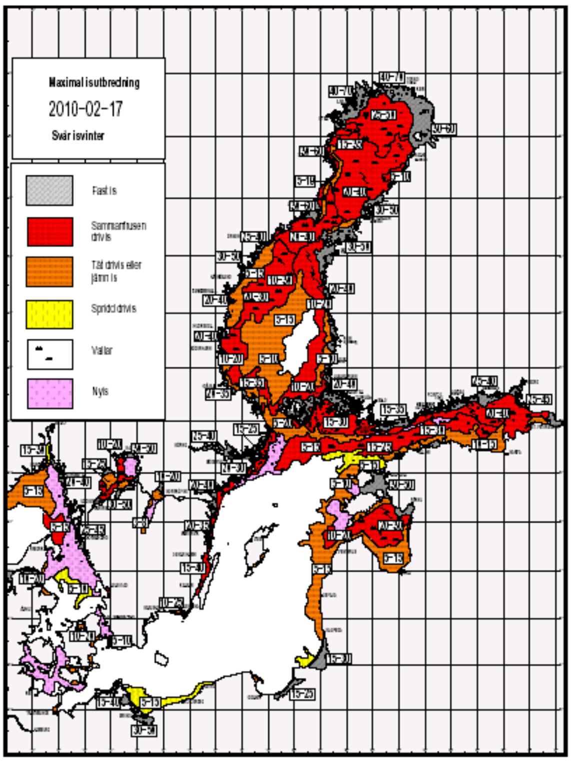


Figure 5. The maximum ice extent in the Baltic Sea during the winter 2009/2010. The map was constructed by the Ice Service at SMHI.

In Figure 6 the maximum ice extent in the Baltic is plotted for the period 1960–2011. Hence, the diagram also includes the preliminary value for the present ice season (2010/2011) which, again, exceeded the previous one.

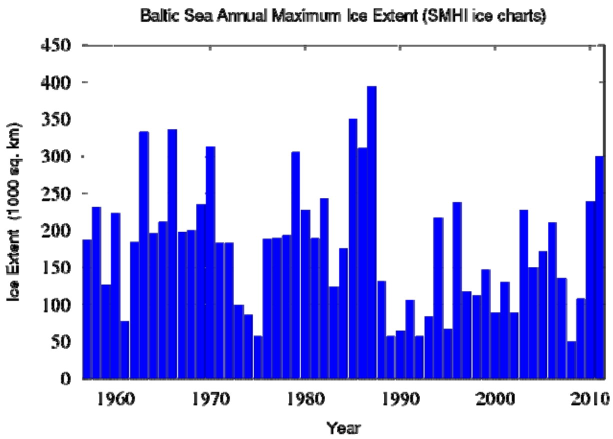


Figure 6. The maximum ice extent in the Baltic starting from 1960. The ice season 2010/2011 is also included (Graph constructed by Lars Axell, SMHI).

Oxygen conditions

An extensive survey of the oxygen conditions in the Baltic Proper was carried out in October 2010 showing that the situation in the deep water continues to be serious. Around 17% of the bottom area was characterized by anoxic conditions (the black area in Figure 7), corresponding to approximately 10% of the water volume of the Baltic Proper.

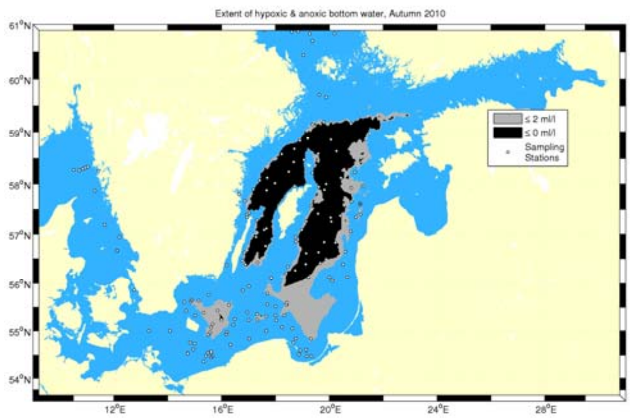


Figure 7. The oxygen situation in the Baltic Proper in October 2010. The map is based on measurements carried out by SMHI, together with data from Poland and Latvia. Visited stations (grey dots), hypoxia (grey) and anoxia (black).

Hypoxia (<2ml/l) was affecting 28% of the bottom area (shown in grey in Figure 7) which corresponds to around 20% of the volume.

Annex 13: Regional report – North Sea 2010

Holger Klein, Alexander Frohse, Peter Löwe, Birgit Klein, Achim Schulz, Giesela Tschersich

Bundesamt für Seeschifffahrt und Hydrographie, Hamburg (Federal Maritime and Hydrographic Agency)

1. North Sea 2010: Annual Survey

1.1. Global Radiation

During April, June and July 2010 the monthly means of global radiation at the East Frisian island of Norderney (Figure 1.1) considerably exceeded the long-term mean. The remaining months were close to the long-term mean.

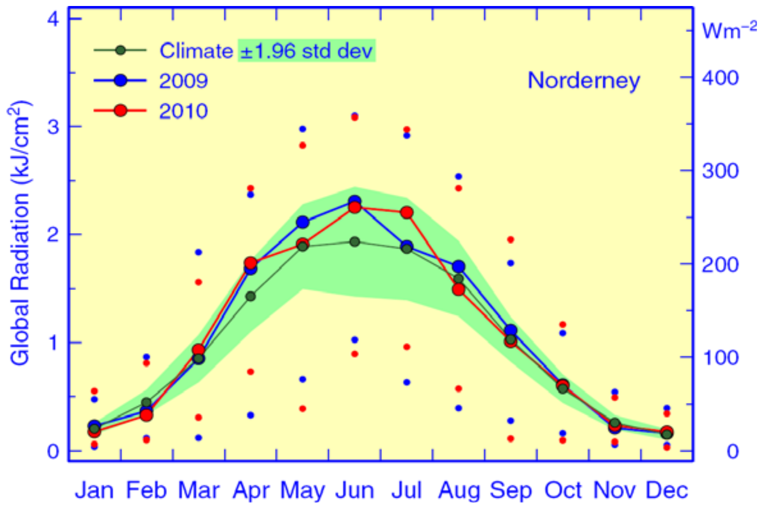


Figure 1.1. Seasonal cycle 2009 and 2010 of monthly averaged daily global radiation totals at Norderney with intra-monthly extremes, 1971–2000 base period monthly means and 95%-band (climatology±1.96 standard deviations)in [kJ/cm²]. Data provider: German Meteorological Service (DWD).

1.2. Elbe River Run-Off

During March and from August until December the monthly Elbe river run-off increased clearly compared to the long-term mean (Figure 1.2) due to snowmelt and increased precipitation. Also the annual averaged run-off of more than 30 km^3/year year exceed the long-term mean of 21.6 km^3/year considerably, however, the value is still in the 95% confidence interval (Figure 1.3).

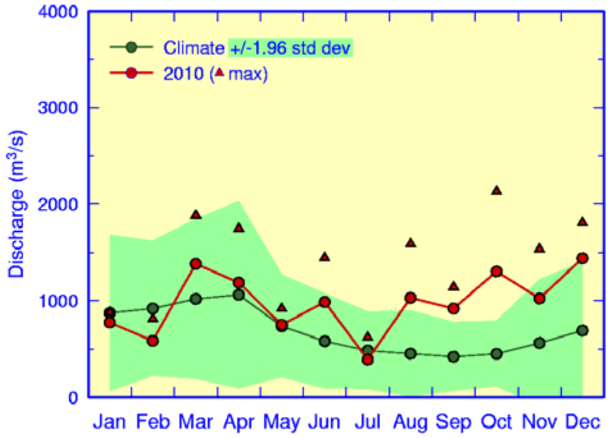


Figure 1.2. Monthly means of Elbe discharge at gauge Neu Darchau and 95%-band (climatology±1.96 standard deviations in 2010 (Data provider: BFG / WSA Lauenburg).

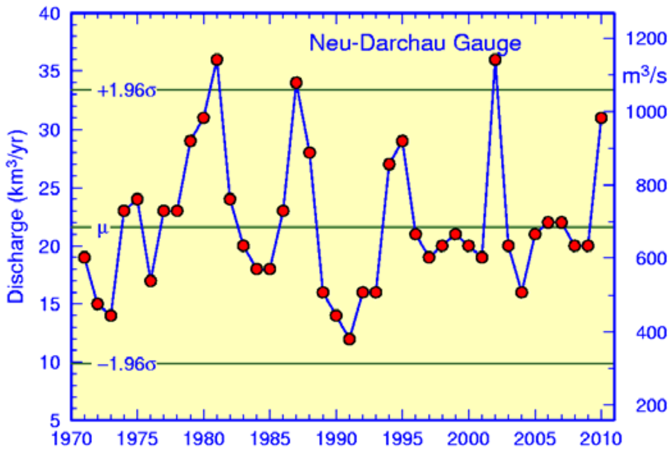


Figure 1.3. Yearly averaged Elbe run-off 1971–2010 at gauge Neu Darchau (Data provider: BFG / WSA Lauenburg).

1.3. North Sea SST

Figure 1.4 shows the weekly means of area averaged North Sea SST from December 2009 until November 2010 and Figure 1.5 displays the spatial pattern of monthly SST anomalies for 2010. Reference period for both figures is 1971–1993. Fall 2009 was still marked by unusual warm SSTs until December but due to the strong winter 2009/2010 the SST dropped below the reference cycle from January to March 2010 with anomalies between –0.3 and –0.6 K. During this period the North Sea was characterised by positive anomalies in the north-western part due to the inflow of warmer Atlantic Water at the northern boundary and negative anomalies along the eastern coasts due to the strong continental winter. This pattern could also be observed in May and June, while April exhibited positive anomalies over large areas of the North Sea due to high solar radiation values (see Figure 1.1). Not before summer the SSTs exceeded again the reference cycle with anomalies between +0.2 and +0.8 K. Due to the early beginning of the winter 2010/2011 the SST dropped rapidly during December 2010 (not shown in Figure 1.4) resulting in an anomaly of -0.8 K with negative anomalies over nearly the whole North Sea area.

The annual averaged anomaly was +0.1 K (2009: +0.8 K). Besides the inflow of warmer Atlantic Water at the northern boundary and through the English Channel, much of the SST variability is caused by the local ocean–atmosphere heat flux.

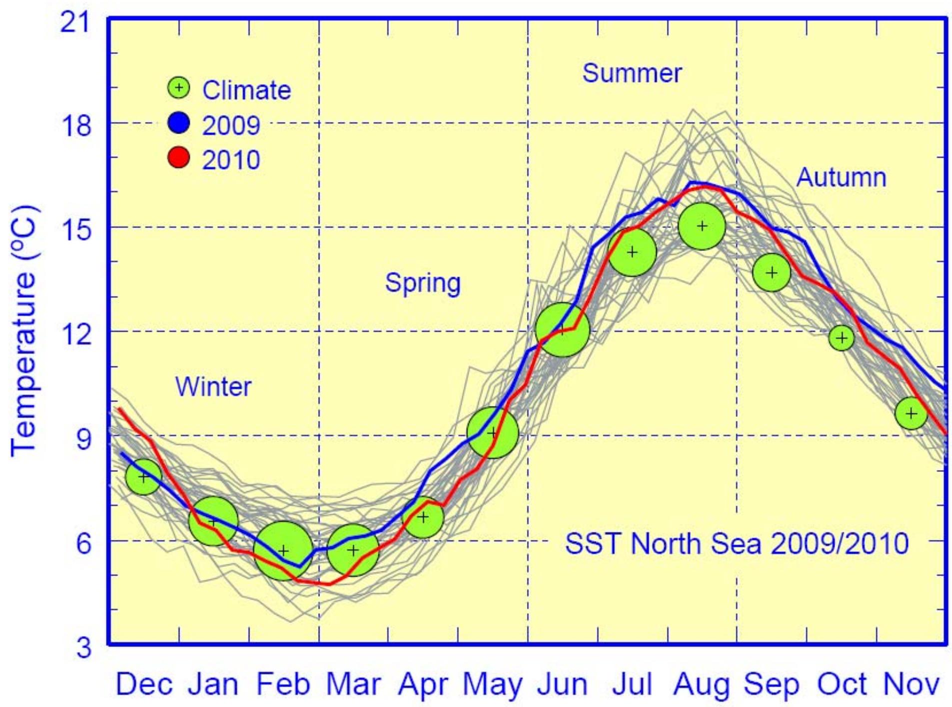


Figure 1.4. Weekly means of area averaged North Sea SST from December 2009 until November 2010 (red line) and from December 2008 until November 2009 (blue line). The grey lines show the annual cycles back to 1968. The green circles give the monthly means of the reference period 1971–1993, the radius gives the inter-annual standard deviation.

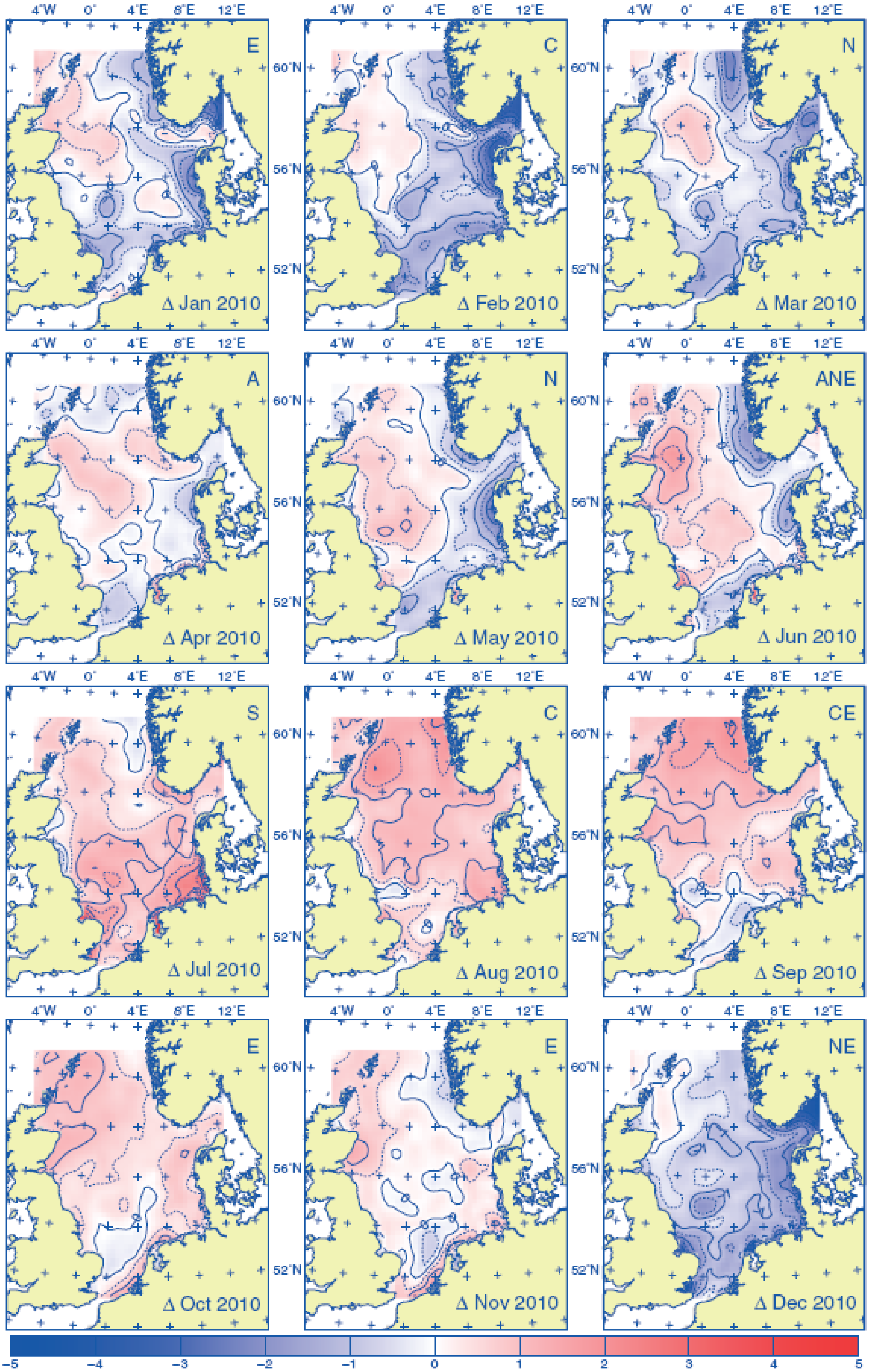


Figure 1.5. Monthly SST anomalies 2010, reference period 1971–1993. The capital letters in the upper right corner give the anomalies of the atmospheric forcing.

The time-series in Figure 1.6 shows the annual (December to November) North Sea SSTs 1968–2010. The solid line showing trend free intervals was calculated for the 1968–2008 period. The added means for 2009 and 2010 possibly indicate a fall-back into a cooler period.

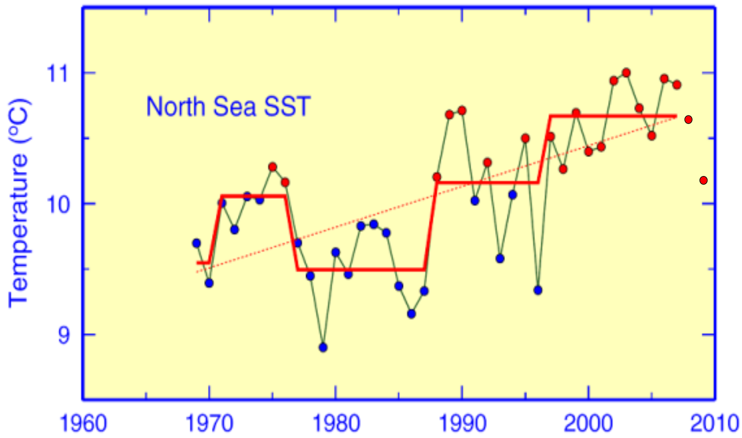


Figure 1.6. Annual (December to November) North Sea SSTs 1968–2010. The solid line showing trend-free intervals was calculated for the period 1968–2008.

1.4. Monthly mean temperature of the total North Sea Volume

Figure 1.7 shows the monthly mean temperatures of the total North Sea volume between 2000 and 2010, based on results of the operational BSH model 'BSHcmod'. The pronounced warming and increasing length of the summer season observed during the last years was regressing in 2010.

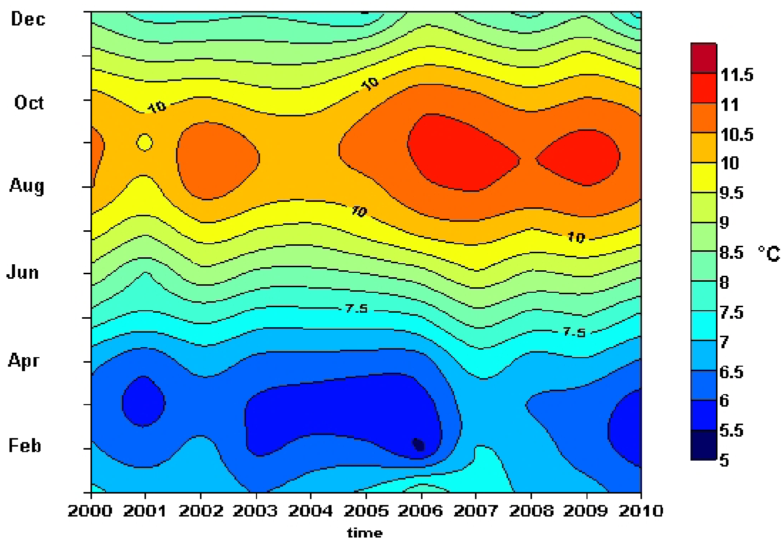


Figure 1.7. Monthly mean temperature of the total North Sea volume 2000–2010 (BSHcmod model data)

1.5. Temperatures at Light Vessel *EMS*

Figure 1.8 shows the temperature at different depths at the MARNET station on the light vessel *EMS* (54° 10′ N; 6° 21′ E, water depth 35 m) from January 2005 until the beginning of March 2011. The time-series exhibits some gaps due to technical problems, bio-fouling or maintenance of the vessels. The solid line gives the climatological cycle (1900–1996) according to Janssen *et al.*, 1999[2] which is characterised by a pronounced annual cycle with an amplitude of about 8 K. Evident is a strong inter-annual variability and a distinct shift of the annual cycle during the last years. Generally, seasonal stratification starts around April and lasts until the end of September when the North Sea is generally vertically mixed again until the next spring due to strong winds. However, at the *EMS* position there is an irregular alternation between vertical mixing and a re-established stratification which shows a strong inter-annual variability in intensity and frequency. The station is located in the range of the tidal-mixing front which is drifting across the station according to the prevailing winds and tides. Also periods of strong winds occasionally destroy the stratification during summer.

The most obvious signal during the last decade was a strong increase of the seasonal minimum temperatures by about 2.5 °C during the winters 2006/2007 and 2007/2008. In 2007 and 2008 seasonal heating started about one month early compared to climatology. Unusually warm temperatures were also evident during fall 2005 and probably most of the second half of 2006. In 2006 we also observed the highest summer temperatures during the last decade and the strongest temperature changes between the vertical mixing events. During fall 2008 the temperatures were close to the long-term mean and the winter minimum 2008/2009 approached again the climatological minimum. During winter and spring 2009 the temperatures were very close the long-term mean, but the second half of the year was again warmer. At the end of the year the temperatures came back to the long-term mean and showed even negative anomalies at the beginning of 2010. During spring and fall 2010 the temperatures were slightly cooler than the long-term values, but the summer values again exceeded the climatological cycle.

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[2] Janssen F., C. Schrumm and J.O. Backhaus, 1999: A Climatological Data Set of Temperature and Salinity for the Baltic Sea and the North Sea, German Journal of Hydrography, Supplement 9, 245pp.

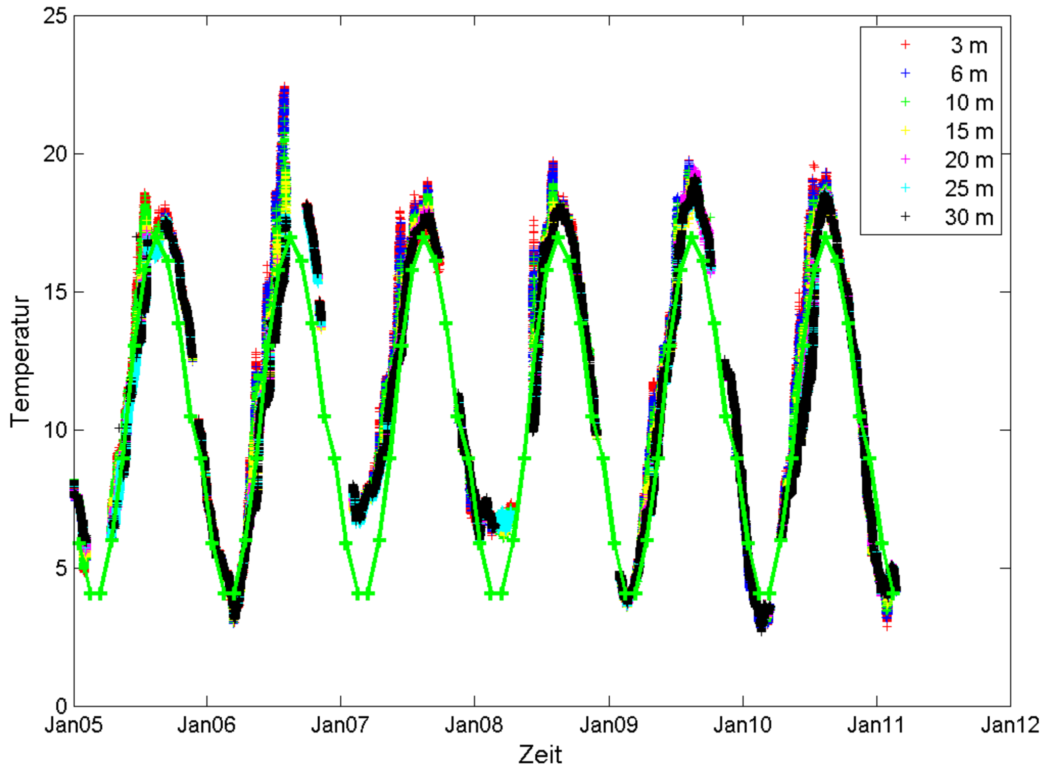


Figure 1.8. Temperatures at light vessel Ems 2005–2010. Green line climatology according to Janssen *et al.*, 1999.

1.6. Chlorophyll-a Surface Distribution

Figures 1.9a,b show the monthly averaged near-surface chlorophyll-a concentrations as detected by the Medium Resolution Imaging Spectrometer Instrument (MERIS) of the Envisat satellite and processed with the algorithm of the Free University Berlin (FUB). The composites show for all months enhanced chlorophyll a concentrations along the Danish, German, and Netherlands coasts and east off East Anglia. In many months high concentrations are also seen in the East Anglia plume, which is also characterised by high suspended matter concentrations. This plume can occasionally be traced as far as into the German Bight (see Figure 1.9b, November).

Strong blooms are visible in April and May in the southern bight east off the Strait of Dover, during May also in the northern North Sea. During winter (January, November) higher concentration enter the North Sea at the northern boundary with the inflow of Atlantic Water.

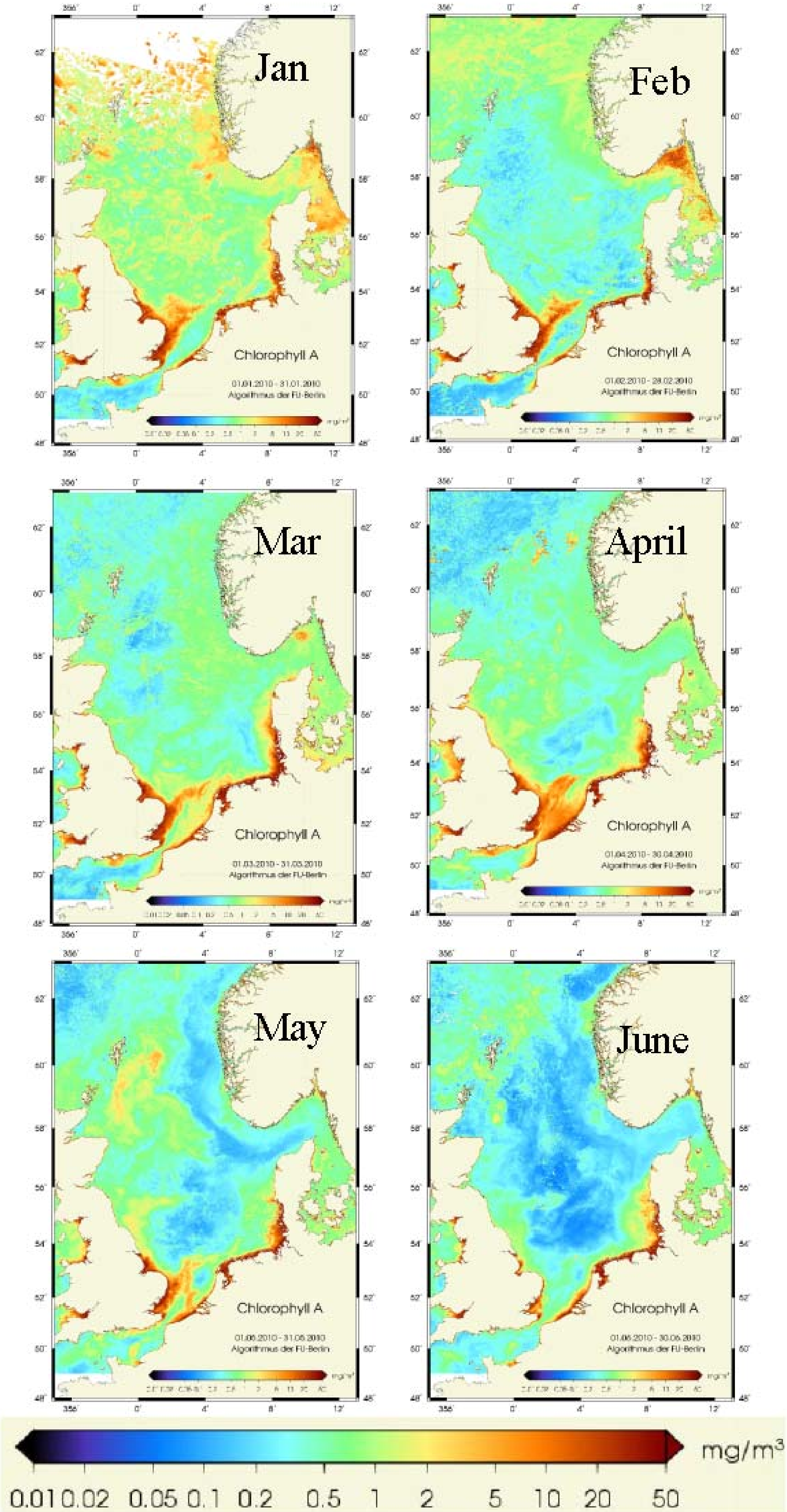


Figure 1.9a. Monthly averaged Chlorophyll-a concentration January–June 2010 (MERIS data, FU-Berlin algorithm).

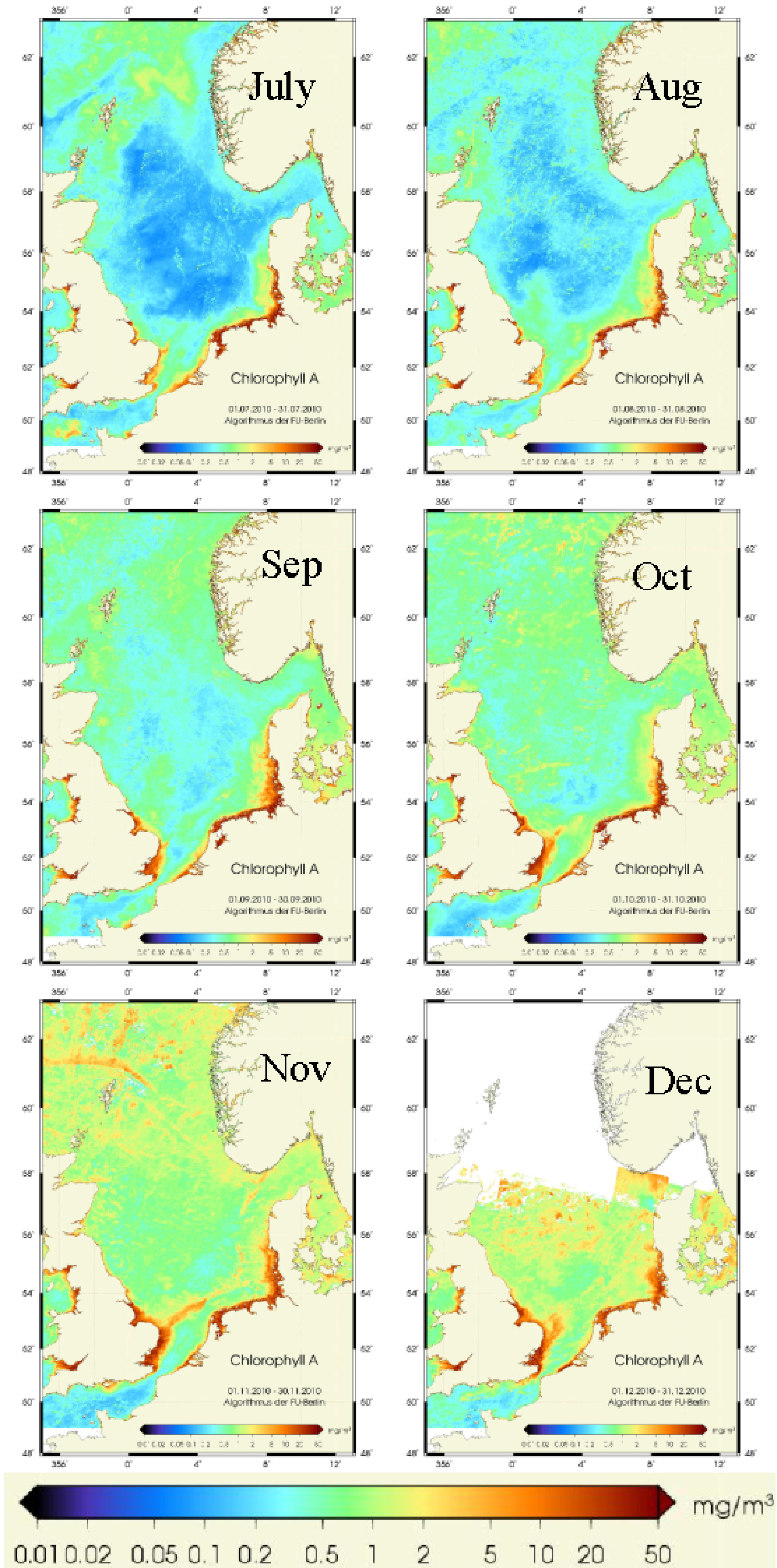


Figure 1.9b. Monthly averaged Chlorophyll-a concentration July–December 2010 (MERIS, FU-Berlin algorithm).

2. North Sea Summer Status 2010

2.1. The BSH North Sea Summer Surveys

In 1998 the Federal Maritime and Hydrographic Agency (BSH, Bundesamt für Seeschifffahrt und Hydrographie) started its annual summer surveys which cover the entire North Sea between 52° and 60°N. The surveys were realised at a time when thermal stratification is expected to be at its maximum and phytoplankton production has passed its maximum (see Table 1). The surveys include seven coast to coast East-West sections between 54° and 60°N and additional stations between 54°N and the entrance of the English Channel. With the exception of the first survey in 1998 all surveys served a fixed station grid for vertical CTD casts and water samples (see red dots in Figure 2.1). Between the fixed CTD-stations a towed CTD-system (1998–2008 BSH *Delphin*, since 2009 EIVA *ScanFish*) oscillated between a depth of 3–10 m (depending on weather and sea state) and a about 5 metres above the bottom in order to record the 3-dimensional distribution of relevant oceanographic parameters. Both CTD-systems sample T, S, fluorescence (chlorophyll-a, yellow substance), and oxygen concentration. Additionally, a thermosalinograph and optical sensors are mounted in the ship moon pool at about 4 m depth. In order to sample the transition area between North Sea and Atlantic in 2010 the survey was expanded to 62.5° N (see Figure 2.1).

Table 1. H_{tot} and S_{tot} : Total heat and salt content of the North Sea, data from summer cruises with R/V GAUSS (G) and R/V PELAGIA (P). SST: area averaged North Sea SST during the observation period.

date of cruise	cruise id	H_{tot} [x10^{21}J]	SST [°C]	S_{tot} [x10^{12}t]
24.06.1998 – 16.07.1998	G317	-	13.5	-
02.07.1999 – 22.07.1999	G335	1.359	15.2	-
09.08.2000 – 23.08.2000	G353	1.497	15.3	1.140
11.07.2001 – 02.08.2001	G370	1.346	15.2	-
16.07.2002 – 31.07.2002	G385	1.517	15.4	1.135
28.07.2003 – 13.08.2003	G405	1.625	17.8	1.138
05.08.2004 – 20.08.2004	G425	1.594	17.1	1.148
10.08.2005 – 29.08.2005	G446	1.550	14.9	1.153
02.08.2006 – 20.08.2006	G463	1.520	17.0	1.138
03.08.2007 – 17.08.2007	P273	1.567	15.3	1.143
21.07.2008 – 05.08.2008	P293	1.550	16.1	1.143
20.08.2009 – 09.09.2009	P311	1.645	15.7	1.140
04.08.2010 – 24.08.2010	P323	1.515	16.0	1.141
10 year average 2000-2009 ± standard deviation		1.543±0.079	15.98±0,99	1.142±0.006 (without 2001)

Due to the restricted availability of ship time the timing of the cruise was not always optimal. Using the weekly SST maps for the whole North Sea issued by BSH, the survey time was related to the maximum of the seasonal SST cycle (see X in Table 2). The 1998, 1999 and 2002 surveys were much too early, this must be considered concerning the estimates of inter-annual temperature variability the budgets of total heat and salt content.

Table 2. Timing of the BSH Summer Surveys in relation to the seasonal SST cycle. Blue: Survey time. X: week of seasonal SST maximum.

date of cruise	cruise id	June		July					August					September		
24.06.1998 – 16.07.1998	06GA 317										X					
02.07.1999 – 22.07.1999	06GA 335									X						
09.08.2000 – 23.08.2000	06GA 353											X				
11.07.2001 – 02.08.2001	06GA 370							X								
16.07.2002 – 31.07.2002	06GA 385												X			
28.07.2003 – 13.08.2003	06GA 405									X						
05.08.2004 – 20.08.2004	06GA 425										X					
10.08.2005 – 29.08.2005	06GA 446					(X)						X				
02.08.2006 – 20.08.2006	06GA 463							X								
03.08.2007 – 17.08.2007	64PE 273									X						
21.07.2008 – 05.08.2008	64PE 293								X							
20.08.2009 – 09.09.2009	64PE 311										X					
04.08.2010 – 24.08.2010	64PE 323										X	X				
								2	1	3	4	3	1			

X = weekly SST maximum

2.2. North Sea Summer Temperature Distribution and Total Heat Content

The general horizontal temperature distribution of the surface and bottom layer is comparable to the previous year with isotherms running approximately from SW to NE. However, the ribbon of warm vertically mixed water along the continental coast smaller and about 1 K cooler compared to 2009 (Figure 2.1).

The isolines in Figure 2.2 show the difference between surface and bottom temperature. In the central North Sea this difference increased by about 2 K compared to 2009 The left panel gives the maximum of the vertical temperature gradient and the right panel gives the depth of this maximum, i.e. the depth of thermocline. Over large areas the thermocline depth is between 20 and 30 m compared to more than 40 m in 2009. The maximum gradients exceed 1.5K/m in small areas only. Areas with gradients less than 0.5K/m are not shown.

This structure with a relatively shallow warm surface layer and with a smooth thermocline is also visible in Figure 2.3. Only at 55° and 56°N there is sharp themocline eastwards off the Dogger Bank. The sharpness of the thermocline is gradually decreasing north of 56°N. The local depression of the thermocline above the Norwegian trench at about 7°E along the 58°N-section, which was observed in 10 of 13 years, had a depth of about 50 m compared to 80 m in 2009.

In return the colder bottom layer occupies a greater volume and the tongue of 8°C bottom water is reaching far to the south (55°N). This is also evident in the total heat content H_{tot} of the North Sea. H_{tot} is a climate index which integrates the effects of solar radiation, advection of Atlantic Water, seasonal stratification, and atmospheric heat exchange. The total heat content dropped to *1.515* x 10^{21}J which is the lowest value since 2002 (see Table 1 and Figure 2.4).

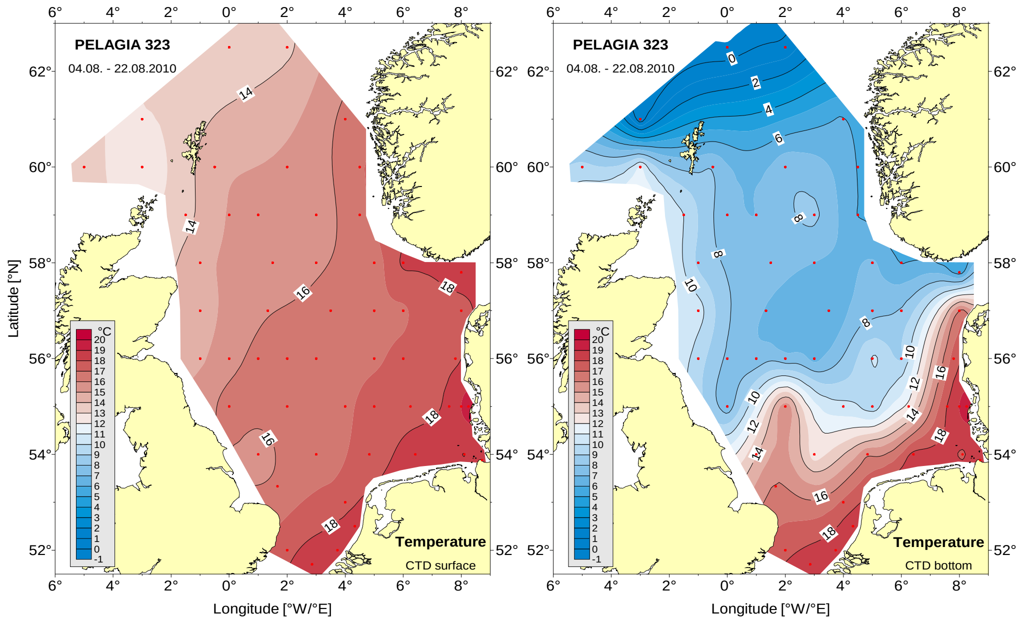


Figure 2.1. Horizontal surface (left) and bottom (right) temperature distribution [°C], PELAGIA 323a, 4–22 August 2010.

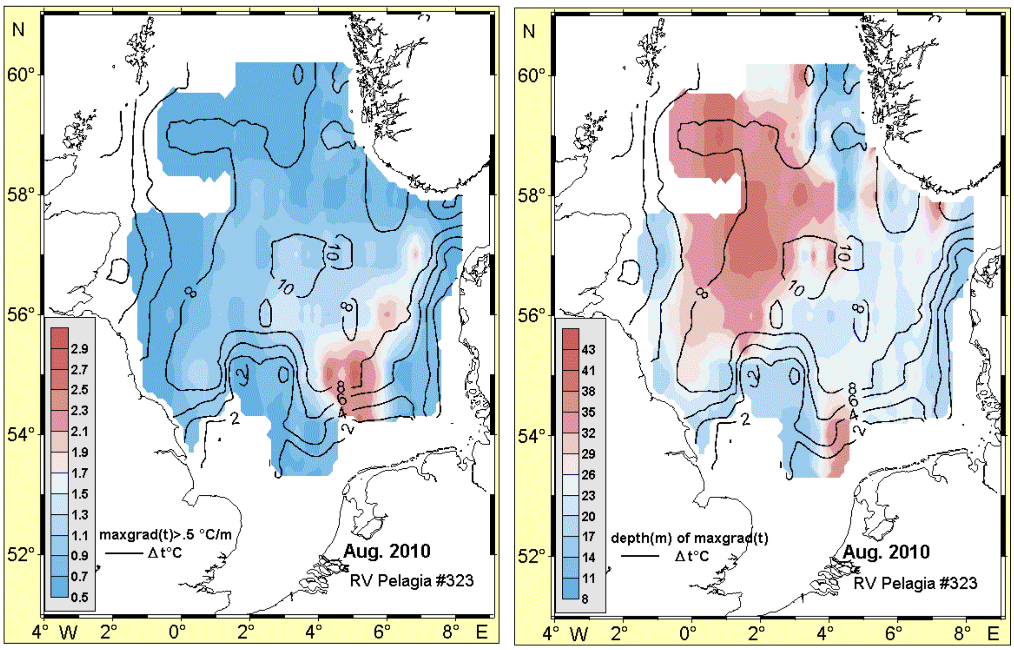


Figure 2.2. Isolines: T_{sur}-T_{bot} [°C], left: strength of maximum gradient [°C/m]; right: depth of maximum gradient [m]. PELAGIA 323a, 4–22 August 2010.

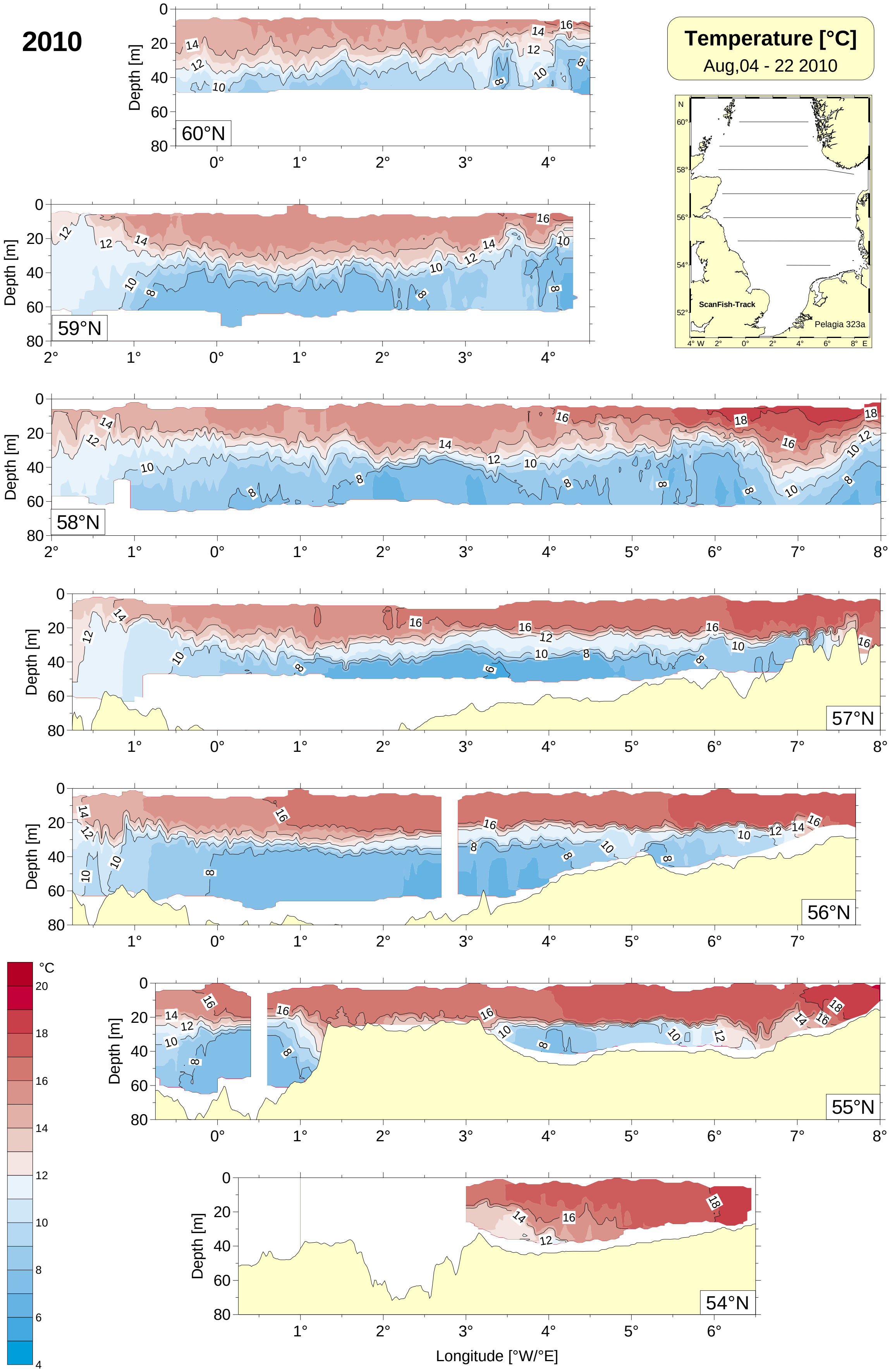


Figure 2.3. Temperature section from PELAGIA 323a, 4–22 August 2010.

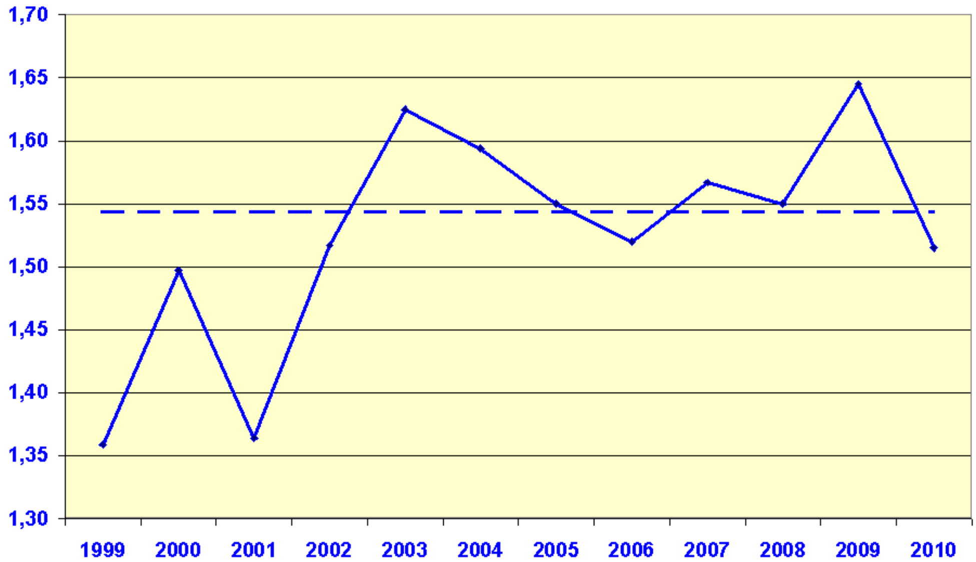


Figure 2.4. Total heat content in J x 1012, 1999–2010. Broken line: 2000–2009 average 1.543±0.079 x 1021J (summer cruise data).

2.3. North Sea Summer Salinity Distribution and Total Salt Content

The horizontal salinity distribution in the surface and bottom layers are very similar to 2009, in both years the 35-isohaline intruded from the North down close to 56°N at surface and bottom. The ribbon of water <34 parallel to the continental coast is a little broader as in 2009 and represents roughly the average position for the 1998–2010 period (see Figure 2.5 and 2.6). The bottom salinity south off 56°N is generally higher as in 2009 and less patchy.

The salinity sections (Figure 2.7) show a very homogeneous intrusion of high saline water in the north-western North Sea. Also in the southern North Sea the vertical structure is less patchy compared to previous years. The total salt content of 1.141 x 10^{12}t is close to the 2002–2009 average of 1.142 x 10^{12}t (see Figure 2.8 and Table 1).

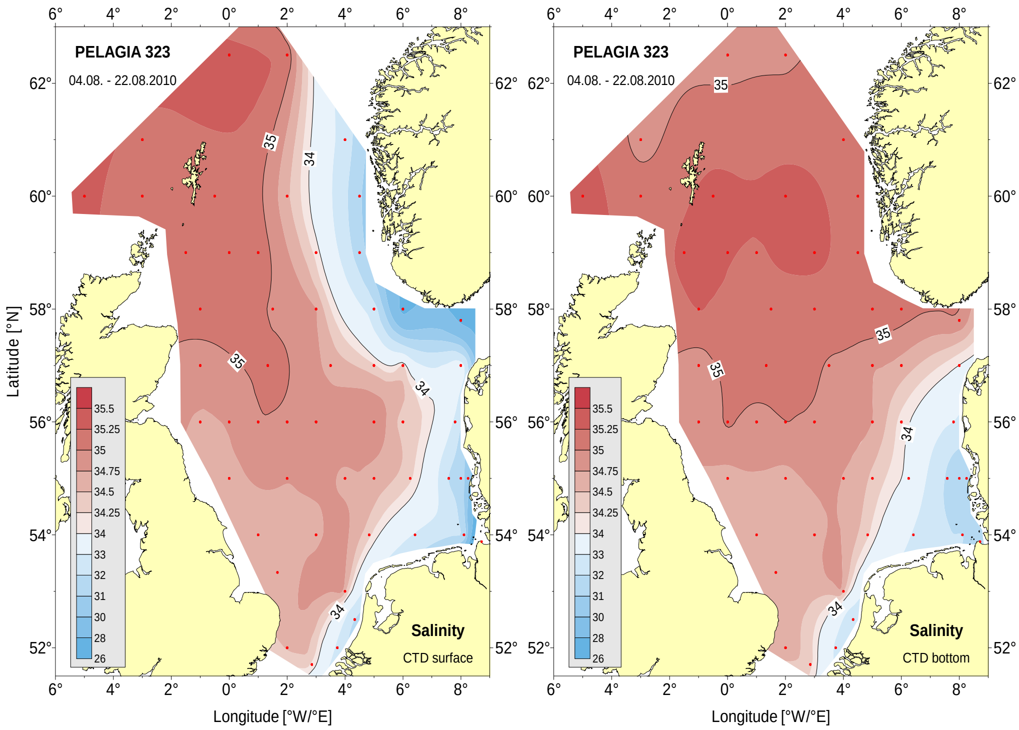


Figure 2.5. Horizontal surface (left) and bottom (right) salinity distribution, PELAGIA 323a, 4–22 August 2010.

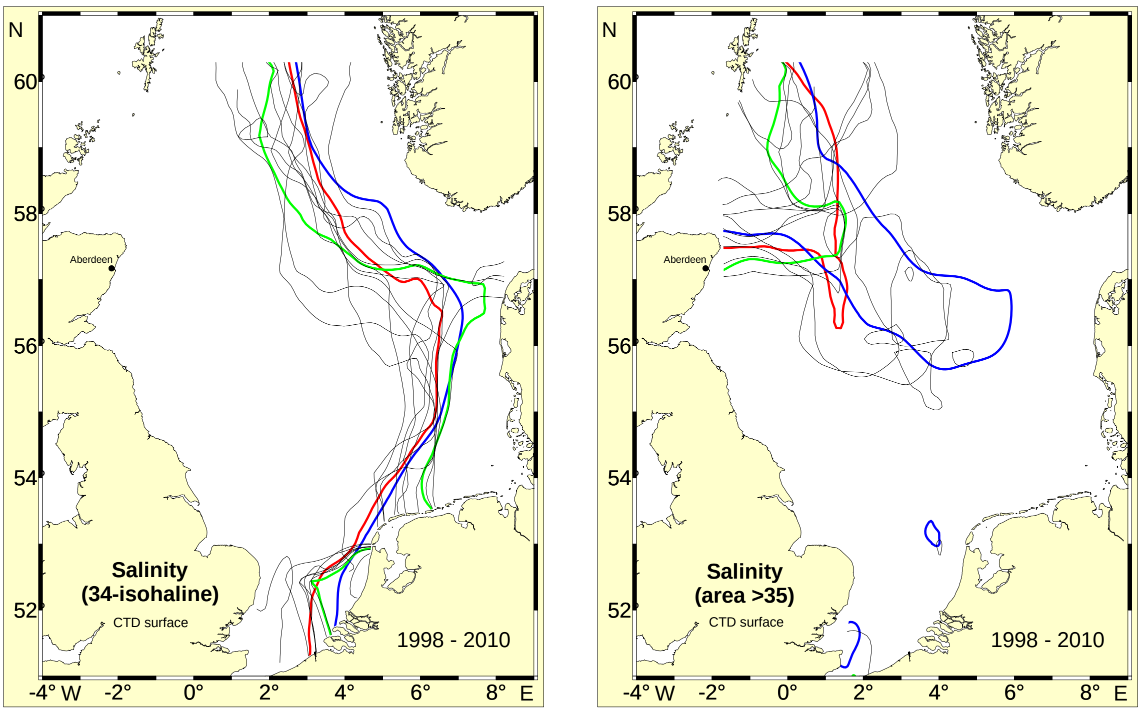


Figure 2.6. Position of the 34 (left) and 35 (right) isohalines 1998–2010. Red: 2010, blue: 2009, green: 2008, black: 1998–2007.

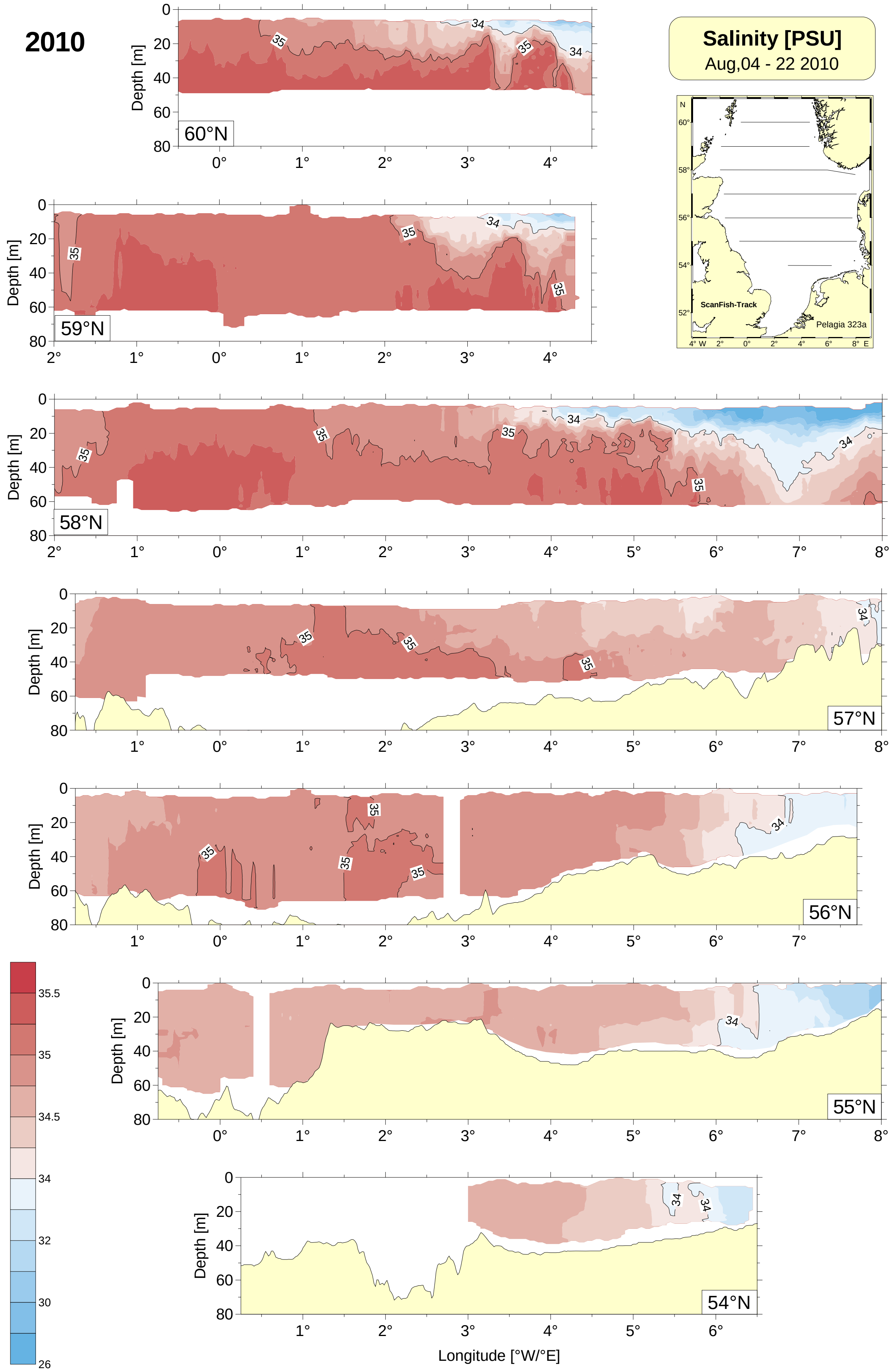


Figure 2.7. Salinity sections from PELAGIA 323a, 4–22 August 2010.

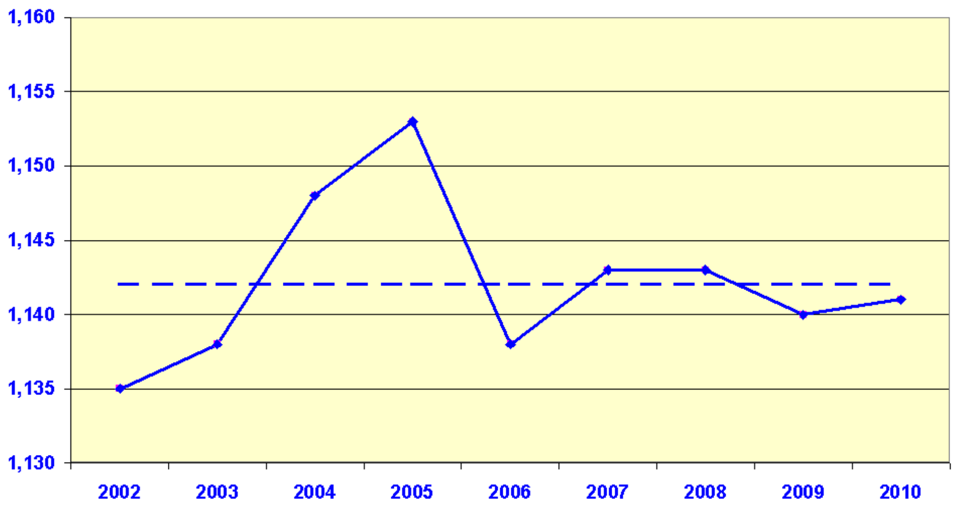


Figure 2.8. Total salt content in 1012 tons from 2002 to 2010. Broken line: 2002–2009 average 1.42±0.006 x 1012t (summer cruise data).

2.4. North Sea Summer Oxygen Saturation

The oxygen saturation during late summer was uncritical. Only at the bottom some patches in the Dogger Bank area exhibit a saturation slightly below 80 % (Figure 2.9). Not until oxygen saturation falls below 40 % marine life experience substantial stress.

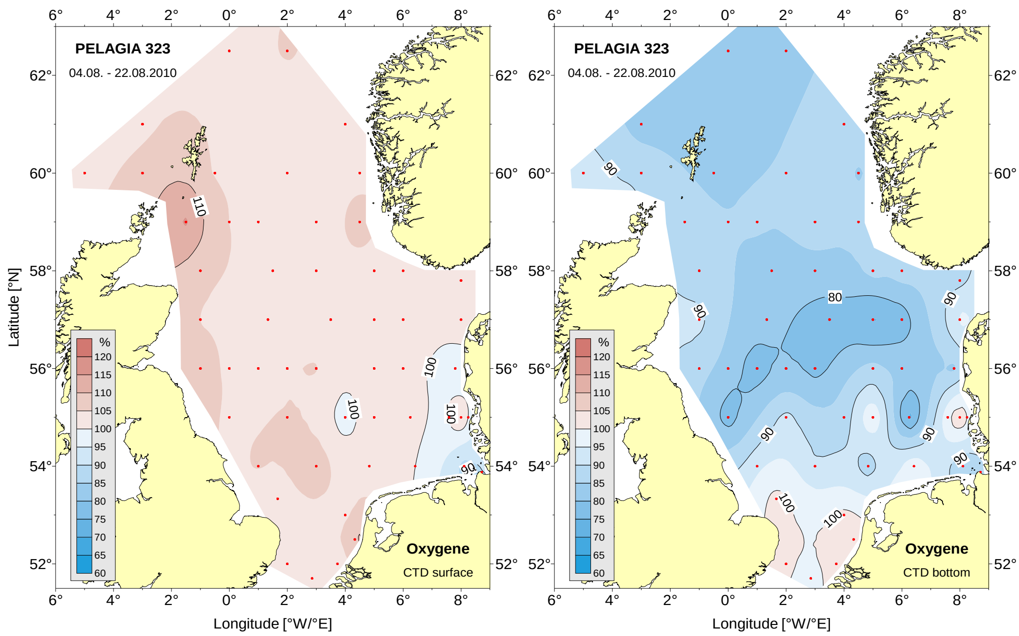


Figure 2.9. Surface (left) and bottom (right) oxygen distribution [%], PELAGIA 323a, 4–22 August 2010.

2.5. North Sea Summer Secchi-Depth

The Secchi depth shows two distinct maxima south off the Bergen Bank and south off the Dogger Bank in the outer German Bight with depths greater, respectively close to 20 m. Because Secchi depth measurements can be taken by daylight only, not all stations could be sampled.

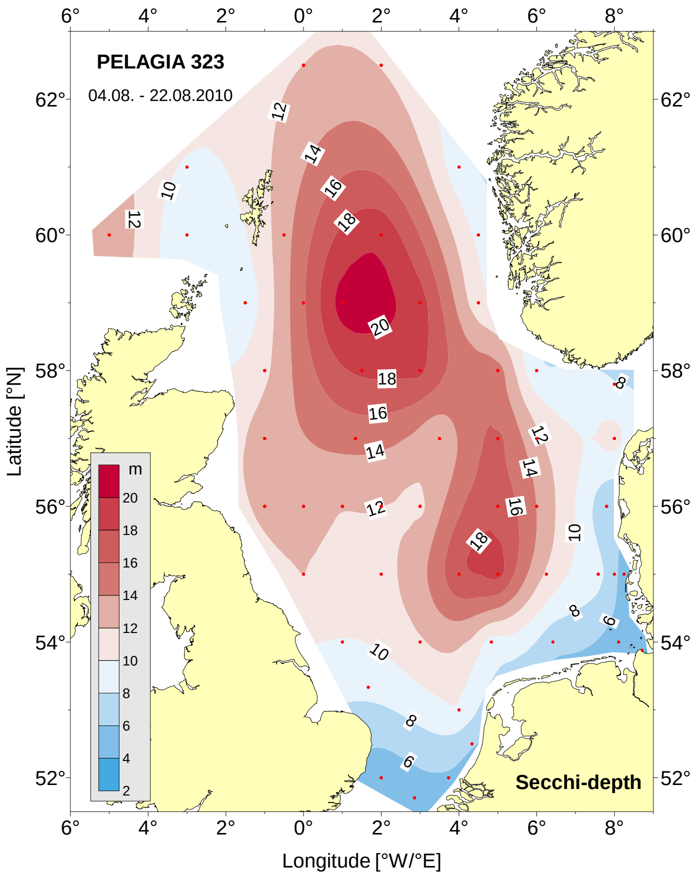


Figure 2.10. Secchi-depth [m], PELAGIA 323a, 4–22 August 2010.

2.6. North Sea Summer Chlorophyll-a Distribution

The vertical distribution of chlorophyll-a along the sections of the summer survey is shown in Figure 2.11. The chlorophyll maximum is located directly under the thermocline and near the surface where no stratification has established (compare Figure 2.3). At the eastern part of the 54°N Section chlorophyll-a is vertically mixed with local maxima close to the bottom.

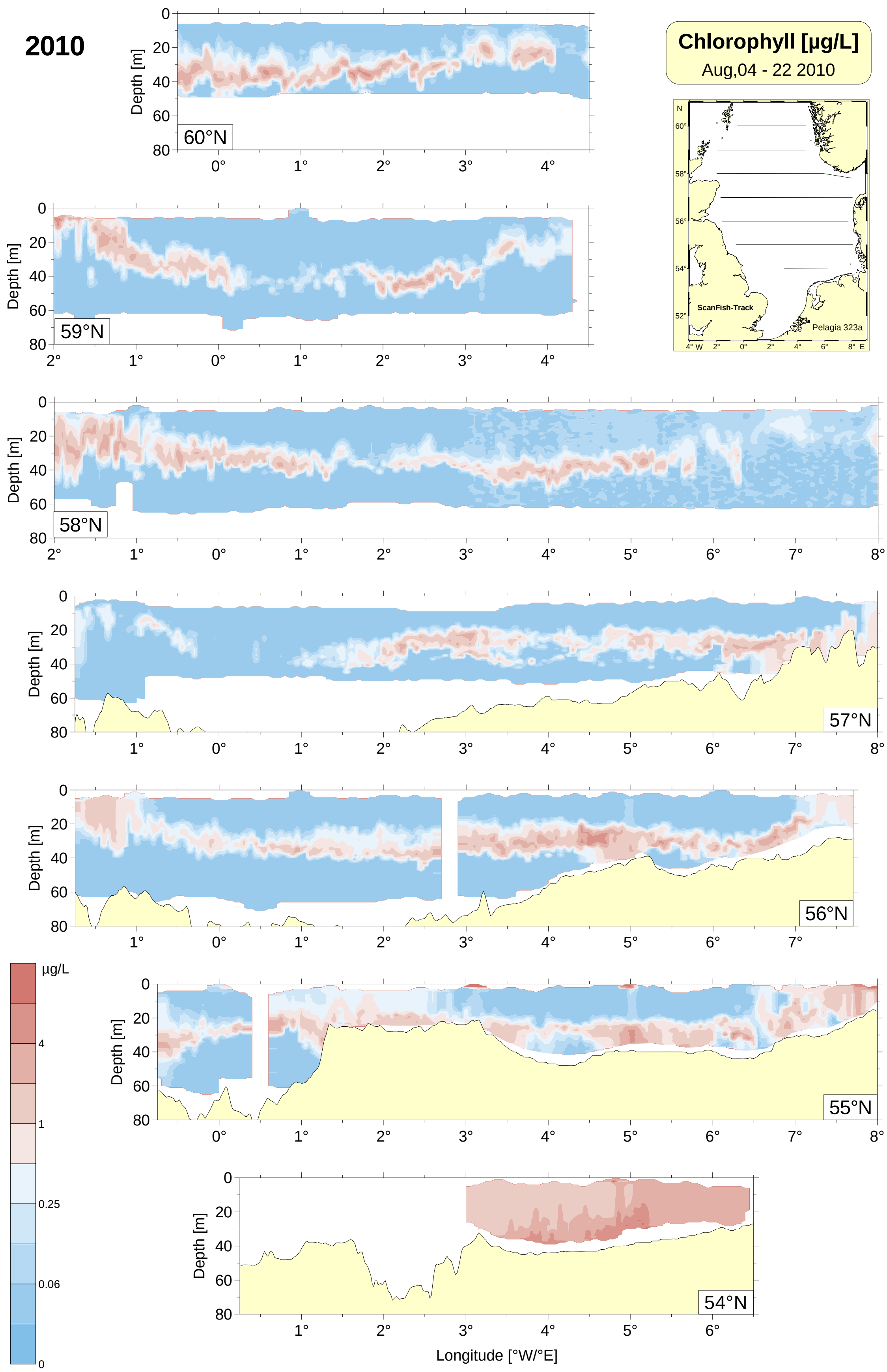
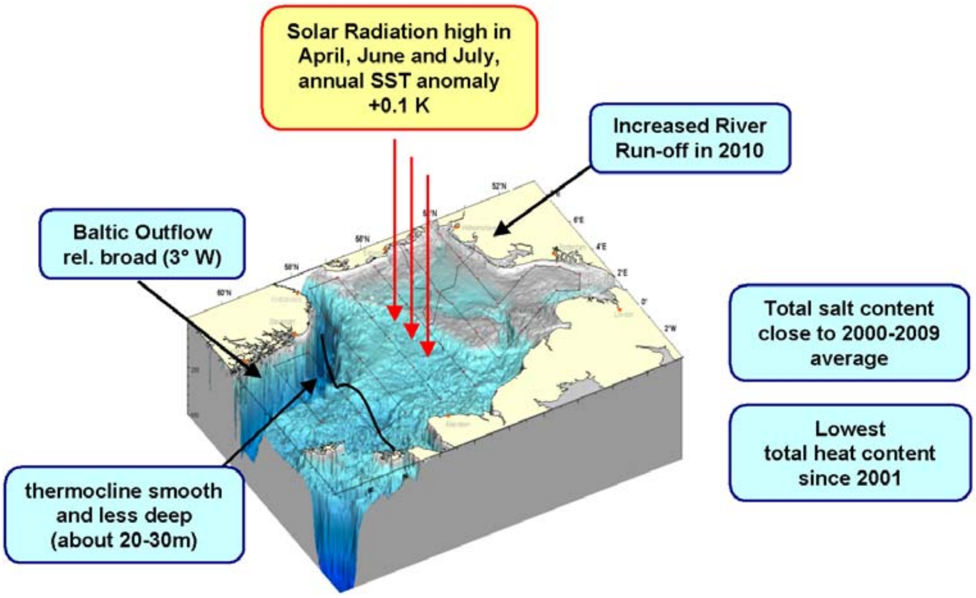


Figure 2.11. Chlorophyll-a sections from PELAGIA 323a, 4–22 August 2010.

2.7. Summary


Solar Radiation high in April, June and July, annual SST anomaly +0.1 K
Increased River Run-off in 2010
Baltic Outflow rel. broad (3° W)
Total salt content close to 2000-2009 average
Lowest total heat content since 2001
thermocline smooth and less deep (about 20-30m)

Annex 14: Regional report – French national report

F. Gaillard, LPO, UMR 6523, Ifremer-CNRS-IRD-UBO, Brest, France

P. Morin, CNRS-IUEM, SB-Roscoff, France

G. Reverdin, LOCEAN, CNRS, Paris, France

1. ARGO gridded temperature and salinity fields

A summary of recent conditions in the North Atlantic can be established using the ARGO global observing system based on profiling floats. Temperature and salinity fields are estimated on a regular half degrees (Mercator scale) grid using ISAS (In Situ Analysis System, Gaillard *et al.*, 2009) a tool developed and maintained at LPO (Laboratoire de Physique des Océans) within the SO-Argo (http://wwz.ifremer.fr/lpo/SO-Argo-France). The datasets used are the standard files prepared by the Coriolis data center for the operational users. They contain mostly ARGO profiles, but CTDs, buoys and mooring data are also included. Some changes with respect to the results presented in the 2010 report have been introduced: 1) The latest version ISAS_V5.3 has been used for the processing; 2) The ARGO 'adjusted' data type is selected instead of the 'raw' data type in the 2010 report; 3)The reference field is the average of the 2002–2008 analyzed fields (WOA05 was used in the previous report), and the a priori variances have been re-evaluated using the same 2002–2008 period.

Near surface, the north Atlantic winter was anomalously cold south of the North Atlantic current, including the eastern boundary (Figure1). A warm anomaly started to develop in spring around Greenland, in the Labrador sea and along the western boundary. It culminated in summer when spread until nearly covering the whole basin. The anomaly persisted, but with reduced intensity through autumn.

Regarding salinity, a fresh anomaly developed in the central-west part and reached its maximum in summer and autumn (Figure2). Simultaneously, waters were anomalously salty along the coast of Norway, Greenland and around the Labrador Sea.

In average over the year 2010, the surface layer exhibits a positive temperature anomaly over most of the basin (Figure3). This anomaly is particularly intense (more than 1.5°C) around Greenland and along the coast of North America. The surface salinity shows a fresh anomaly in the central basin, surrounded by waters saltier than normal, the North-West boundary is particularly salty (0.3 PSS above average). The very warm Irminger and Labrador Seas, and fresh central basin characterize the 2010 year in the 2005–2010 time-series (Figure4).

At 300 m the structure of the temperature anomaly remains the same as near surface, but warm and cold anomalies there are more balanced regarding surface and amplitude. The extent of the fresh anomaly observed near surface is reduced at that depth, leaving space for a positive anomaly over most the basin. At that level, temperature and salinity anomalies are nearly anticorrelated.

At 1000 m the influence of the Mediterranean water (warm and salty anomaly) is increased south of 48°N and decreased north of this latitude as was already the case in 2009.

At greater depth (1600 m) the Greenland Sea, the Irminger Sea and the Labrador Sea are warming, especially at 1600 m where this temperature anomaly is associated with saltier water. These features have been continuously developing since 2004 (Figure5).

The February mixed layer depth (defined as the depth were temperature differs by more than 0.5° from the 10 m value) is followed over time (Figure6). In 2010 the mixed layer is particularly deep along the eastern boundary (North of the Bay of Biscay in particular) and extends zonally westward in the basin with a sharp south limit at 42°N. A deep mixed layer is observed also above the Reykjane ridge.

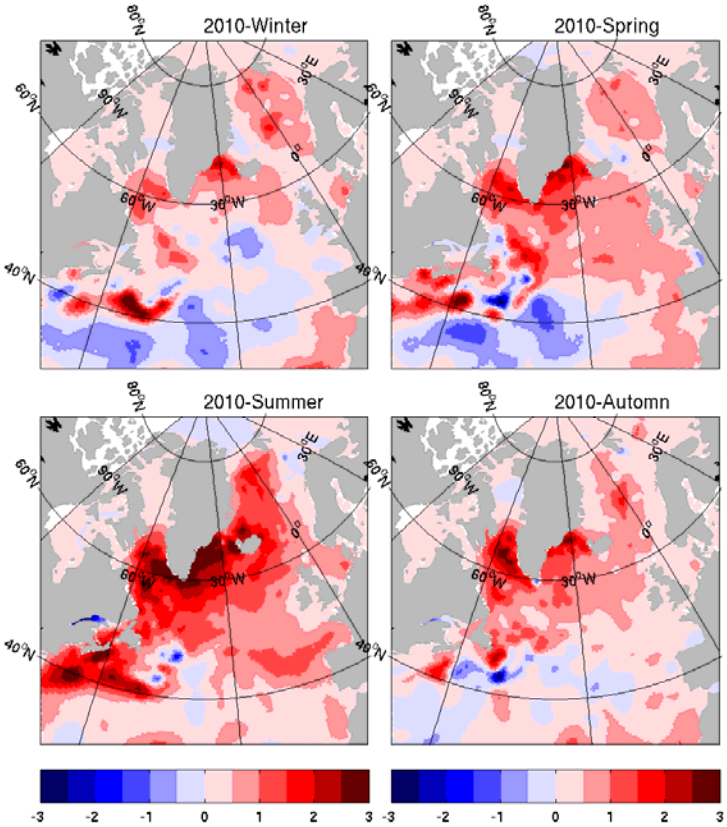


Figure 1. Near surface temperature anomaly (10 m) for February, May, August and November 2010. The anomalies are computed relative to the World Ocean Atlas (WOA-05).

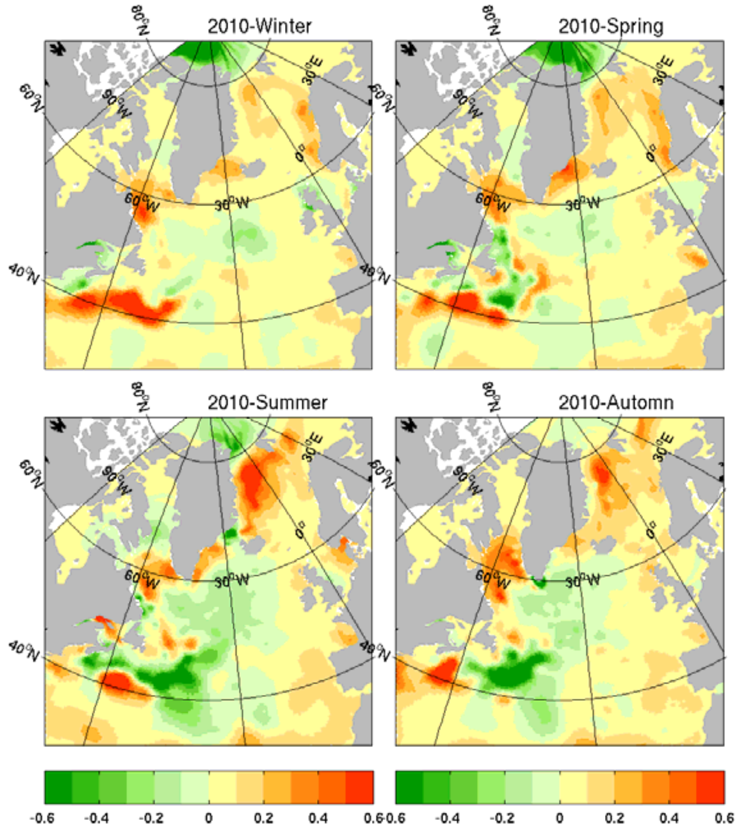


Figure 2. Near surface salinity anomaly (10 m) for February, May, August and November 2010. The anomalies are computed relative to the World Ocean Atlas (WOA-05).

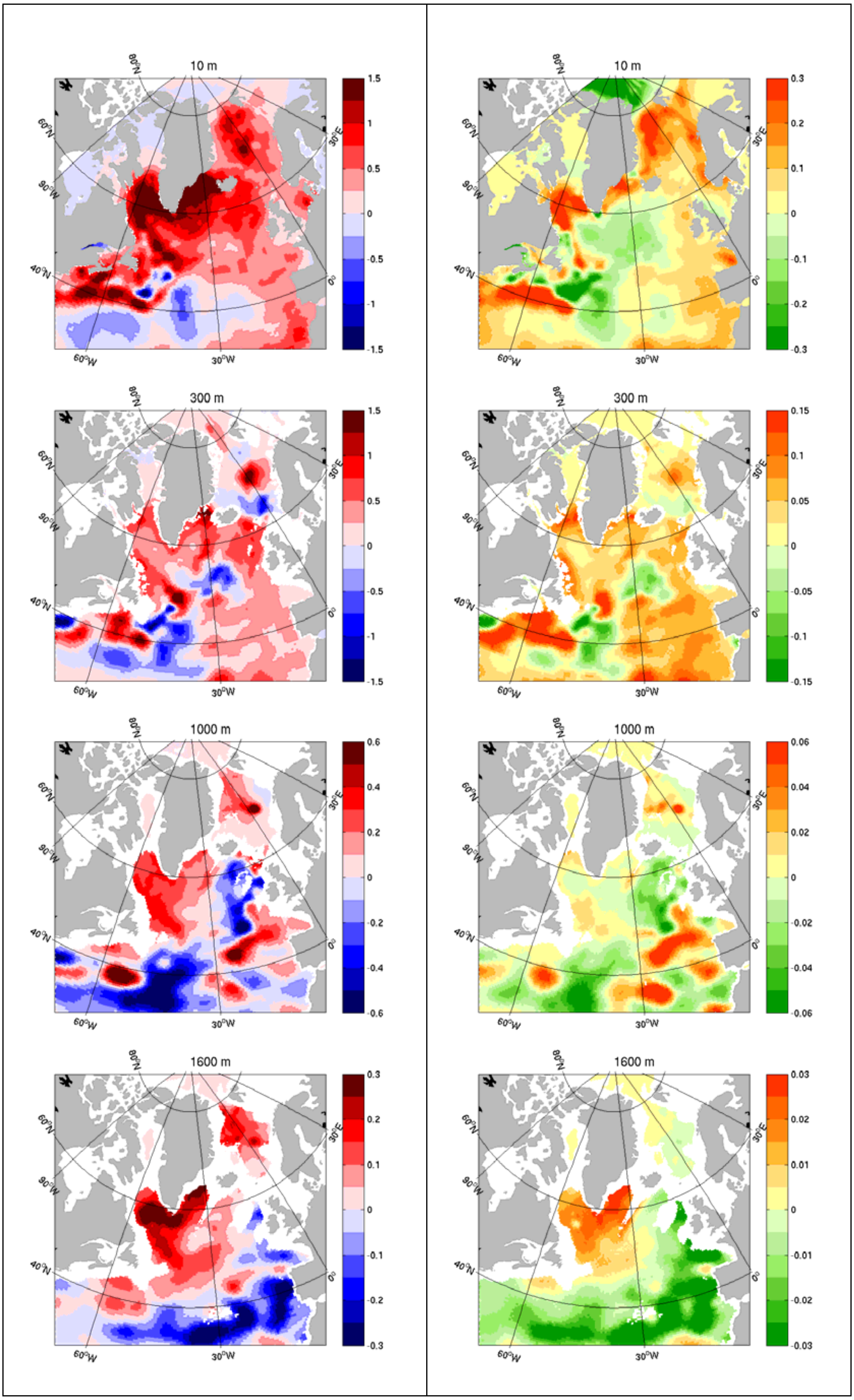


Figure 3. Annual mean 2010 temperature (left) and salinity (right) at 10m, 300m, 1000m and 1600m.

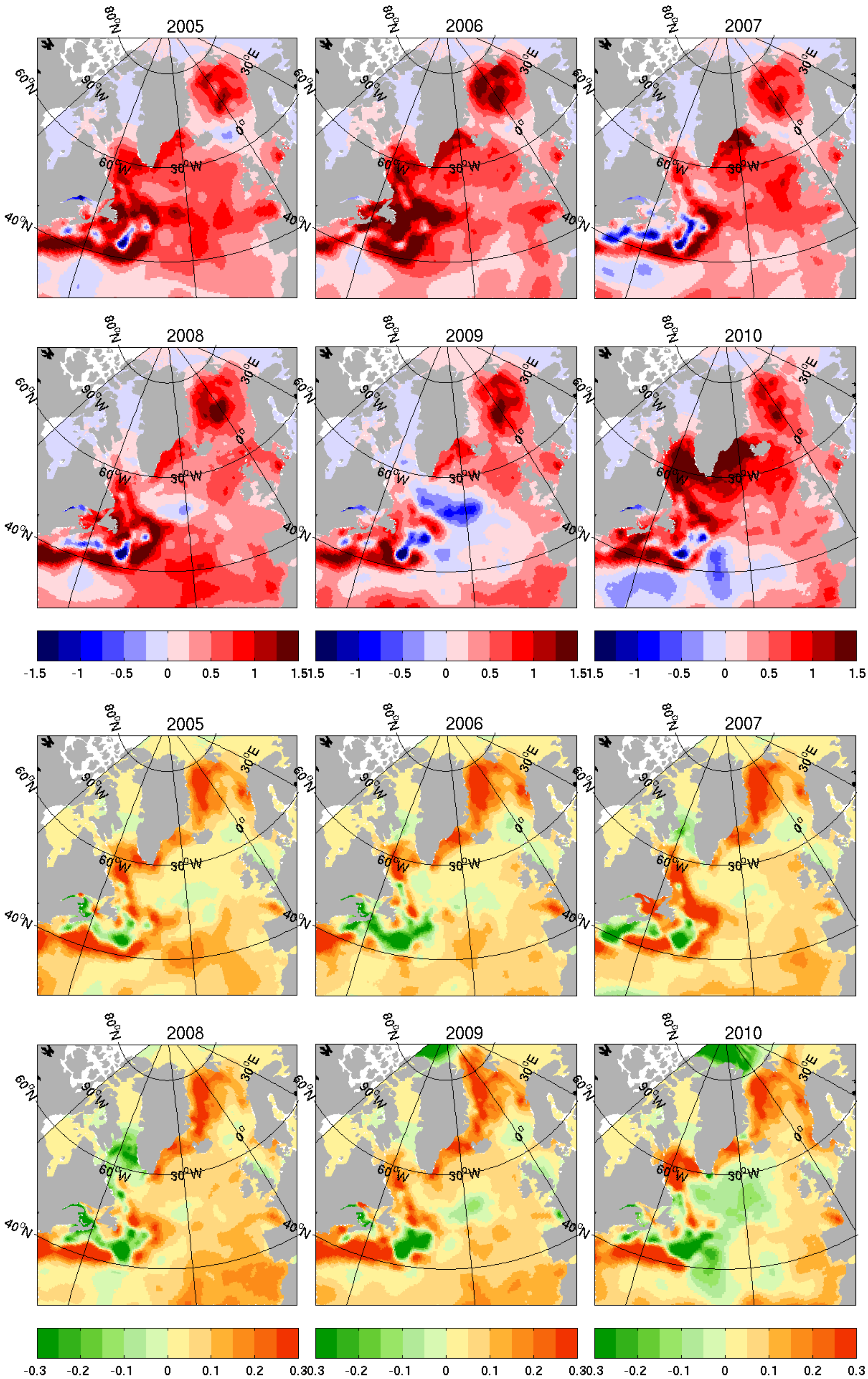


Figure 4. Annual average temperature (top) and salinity (bottom) anomalies at 10 m during 2005–2010.

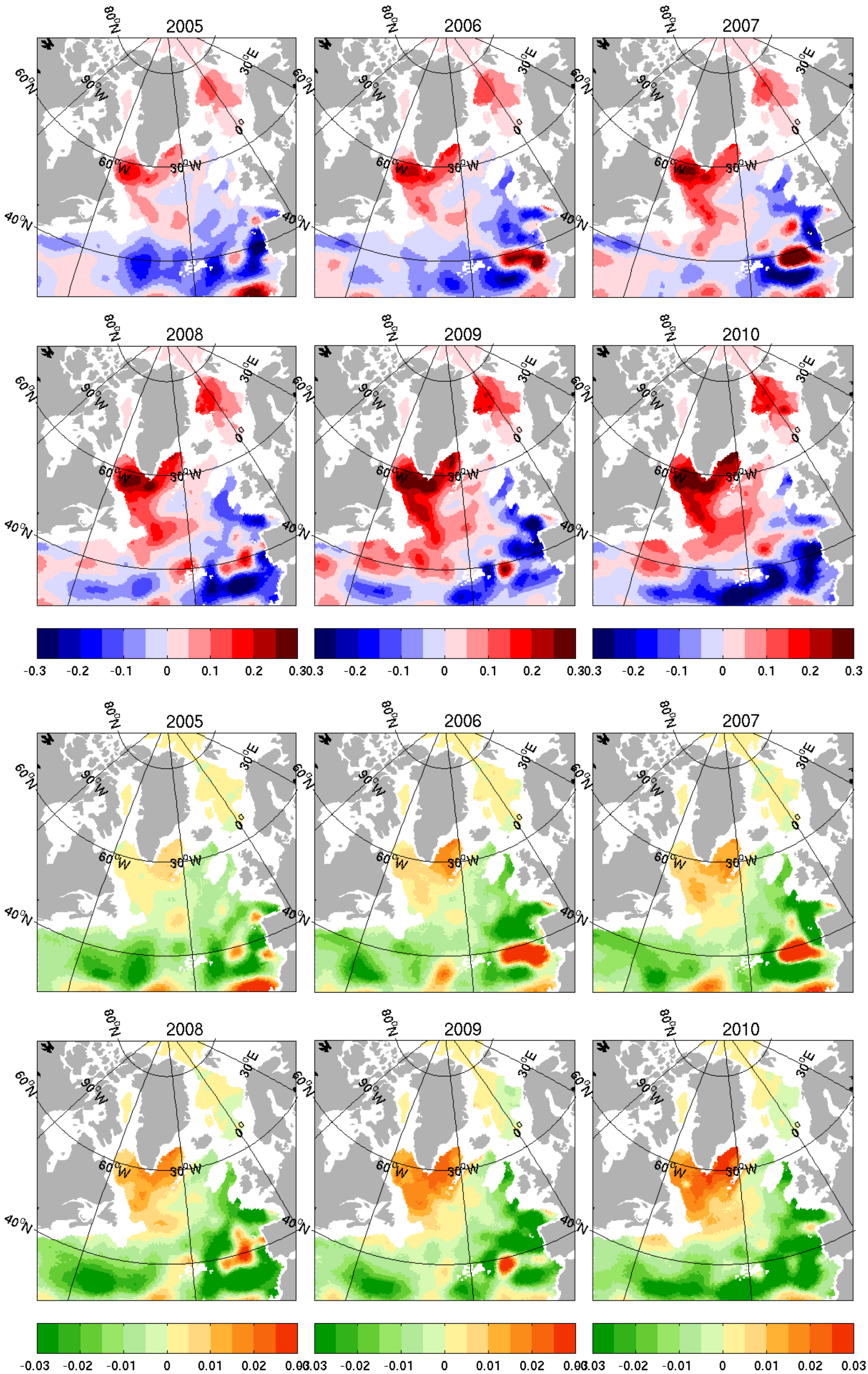


Figure 5. Annual average temperature (top) and salinity (bottom) anomalies at 1600 m during 2005–2010.

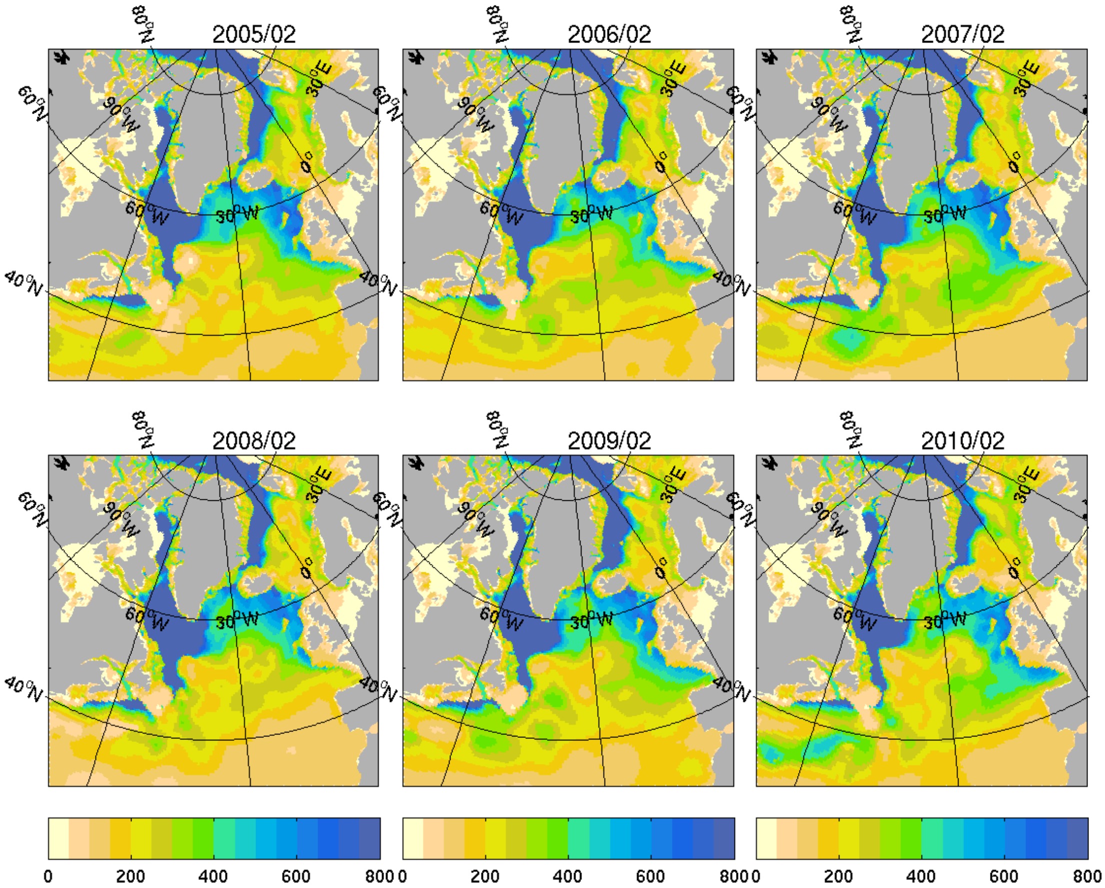


Figure 6. Mixed layer depth in February (defined on the criteria ΔT = 0.5°).

2. Ships of opportunity

Here, we report data from the Nuka Arctica TSG that are available since June 1997, and for which quality control and validation have been completed using water samples and comparison, with nearby Argo data. The TSG was initially installed in the bow of the ship, but different operation problems, in particular since it was coupled with a pCO2 equilibrator system (University of Bergen), have induced us to change it to a new location since early 2006 by mid-ship. The depth of intake is a little deeper than before, but the intake is less prone to be in the air during bad weather. Since late 2006, we have had sufficient flow through the TSG with a temperature difference of the TSG with respect to the intake temperature (University of Bergen) on the order of 0.1°C, which is corrected. The route most commonly sampled by the Nuka Arctica is across the subpolar gyre between Cape Farewell and the Shetlands Islands near 59°N–60°N, and then across the North Sea.

Salinity anomalies, obtained after removal of an average seasonal cycle (Figure7) show that a low salinity area appeared around 20 W at the end of 2009. It grew and spread mostly westward during 2010.

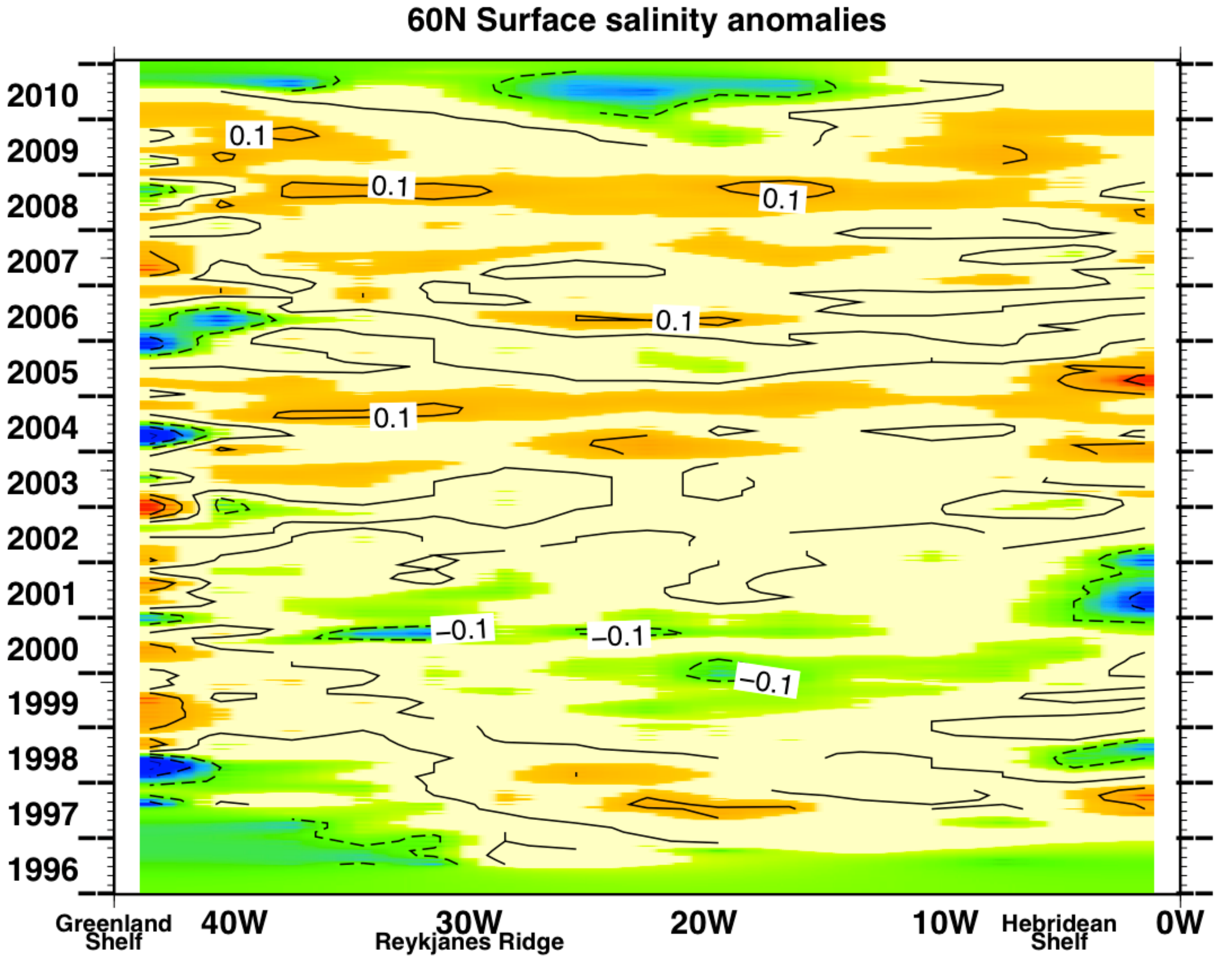


Figure 7. Salinity anomalies with respect to the average seasonal cycle in 1996–2010 mapped near 60°W between the vicinity of the southern Greenland shelf and the Orkney Islands. Based mostly on TSG data from the Nuka Arctica.

3. Coastal time-series: Astan and Estacade

Measurements collected twice a month at two stations located on the coastal area on the north coast of Brittany in France are presented here (red point on Figure 8). The Estacade site is located at the end of a pier in the city of Roscoff (France) where the bottom depth varies from 3 to 12 m depending on the tides. Measurements began in 1985. They are collected at 1 m depth. Its exact location is 3°58′58W and 48°43′56N.The Astan site is located 3.5 kilometres offshore from the Estacade site and measurements began in 2000 at 3°56′15W and 48°46′40N. Properties at this site are typical of the Western Channel waters. Bottom depth is at about 60 m depth and the water column is well mixed for most of the surveys. More details can be found at http://www.domino.u-bordeaux.fr/somlit_national/.

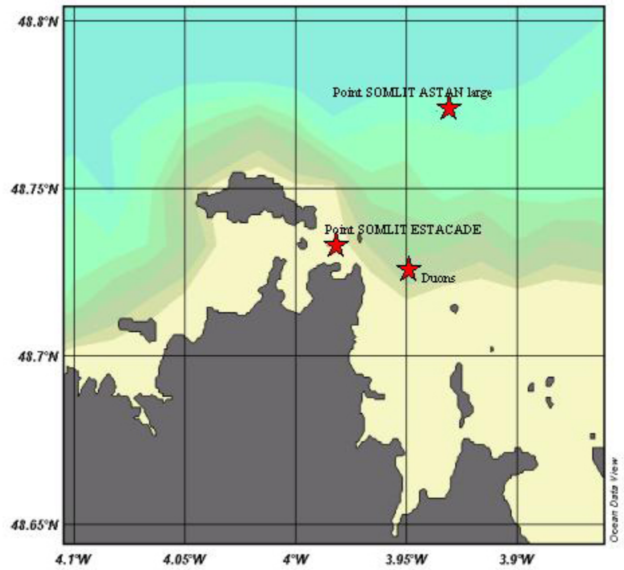


Figure 8. Localisation of the ESTACADE and ASTAN sites.

The first panels (Figure9, Figure10) present the 2010 cycle of temperature, salinity and nitrate compared to the mean annual cycle at the Astan and Estacade stations. At both stations temperatures during 2010 were lower than the monthly mean temperature cycle at the two stations. Between January and March, temperatures were lower (< -1.0 °C) than the average values at Astan site station. During the whole spring and early summer, temperatures remained lower than averaged values. Excepted from august and September when temperatures were close to the average, temperatures remained always lower than averaged values with again a marked minimum in December (-1.75°C at Estacade). 2010 mean annual temperature at Astan was the lowest observed since 1994. Salinity annual cycles at the two sites were characterized in 2010 by a minimum observed in march at Estacade and later in April at Astan. Deviations of salinity to the averaged values were -0.18 PSU in march at Estacade and -.014 PSU in April at Astan. From spring to summer, salinity increased regularly at both stations. During summer, salinity values were slightly higher than averaged values : +0.04 PSU at Estacade and +0.07 PSU at Astan. During autumn and early winter, salinity values were again lower than the averaged values (e.g. -0.25 PSU at Estacade in December). During 2010 nitrate concentrations were close to the averaged values during the whole annual cycle excepted in march and December at Estacade when high concentrations (deviation of +3.1 and 3.4 $\mu M/l^{-1}$ to the averaged concentrations respectively) were observed at salinity minimums. During summer as usually observed in this well-mixed waters nitrate concentrations were not exhausted by phytoplankton development and concentrations were close to usually observed concentrations.

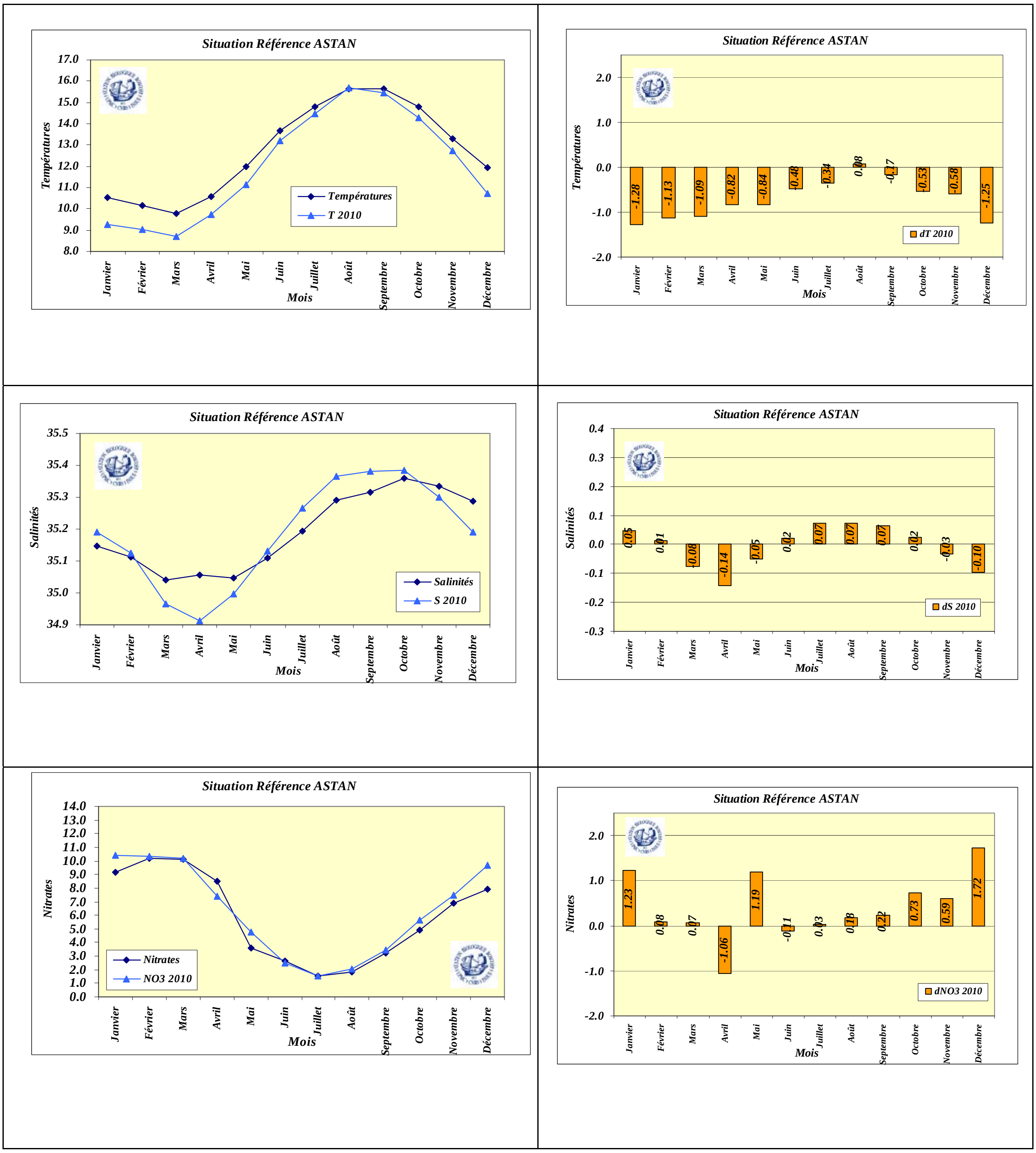


Figure 9. Comparison between times series of temperature (upper), salinity (middle) and nitrate (lower) at the ASTAN site in 2010 with the climatological cycle. Left panels: Dark blue line represents the mean annual cycle and light blue line represent 2010 data. Right panels: 2010 deviations to mean values.

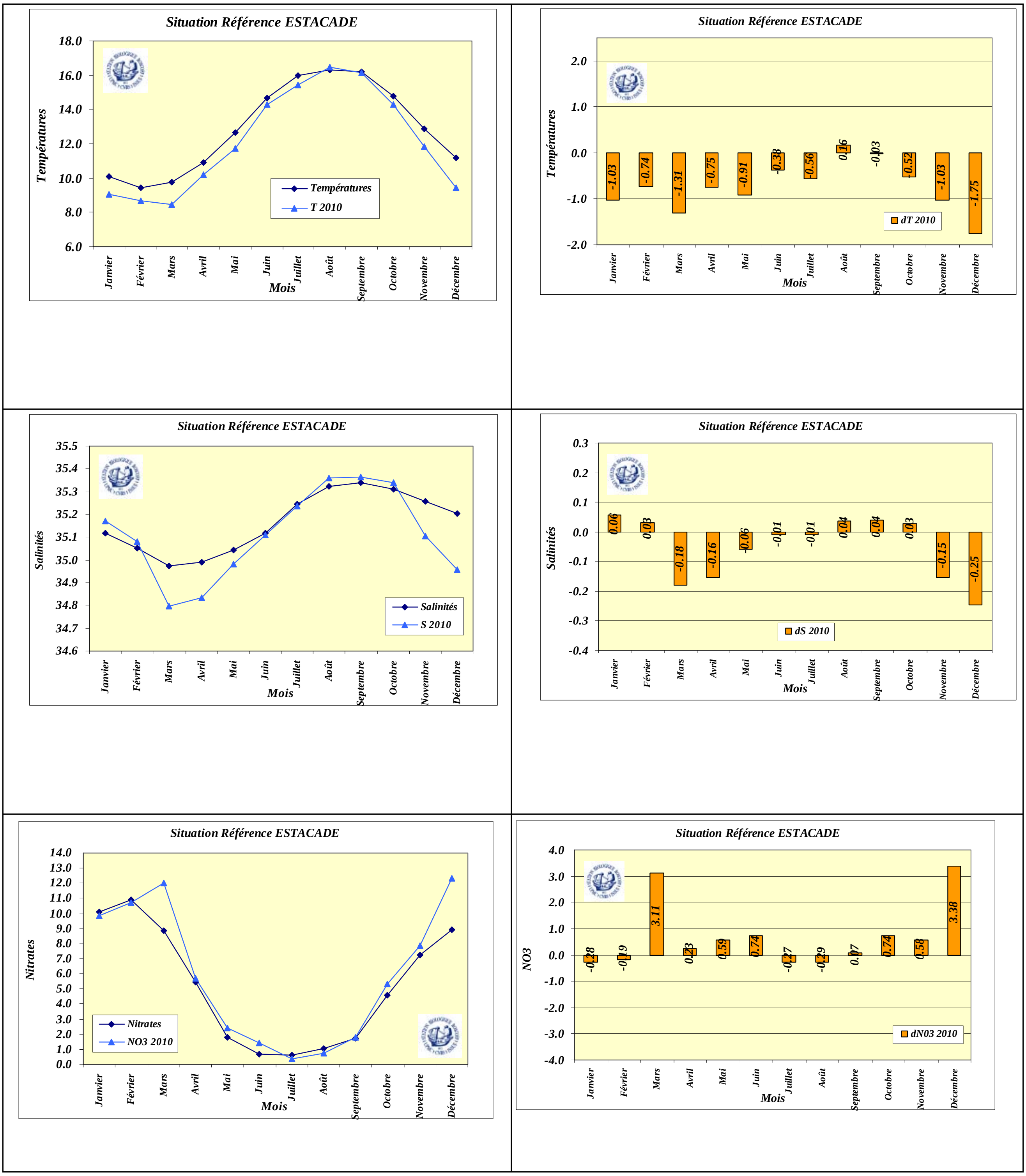


Figure 10. Comparison between times series of temperature (upper), salinity (middle) and nitrate (lower) at the ESTACADE site in 2010 with the climatological cycle. Left panels: Dark blue line represents the mean annual cycle and light blue line represent 2010 data. Right panels: 2010 deviations to the mean values.

Figure11 show time-series of temperature, salinity and nitrate at Astan over the period 2000–2010 and at Estacade over the period 1985–2010 with a large gap from 1992 through 2000 for salinity and nitrate measurements. At the Astan site, winter 2010 minimum temperatures were the lowest values since 2000 and at Estacade site, winter 2010 minimum temperatures were the lowest values since winter 1991. During spring and summer 2010, Western Channel waters were generally well-mixed over the entire water column since no temperature differences between surface and bottom waters were observed (Figure12). A low vertical vertical temperature gradient ($\Delta T = 0.4°C$) was episodically observed in late summer (late August – early September) during a sunny neaps tide period. In 2010, salinity cycle is characterized as mentioned above by a late winter minimum which value was comparable to the previous winter minimum. Nitrate concentrations as salinity present a large interannual variability particularly in the winter maximum values, which is linked to the interannual variability in the oceanic influence in the Channel waters. Maximum nitrate winter concentrations ($\approx 11.0\ \mu M/l^{-1}$) were comparable to the two previous years winter values. Year 2010 was characterized by high residual summer nitrate values ($\approx 1.0\ \mu M/l^{-1}$) which may be explained by a lower phytoplankton uptake due to the existence of less favourable environmental conditions than usual during a cloudy summer.

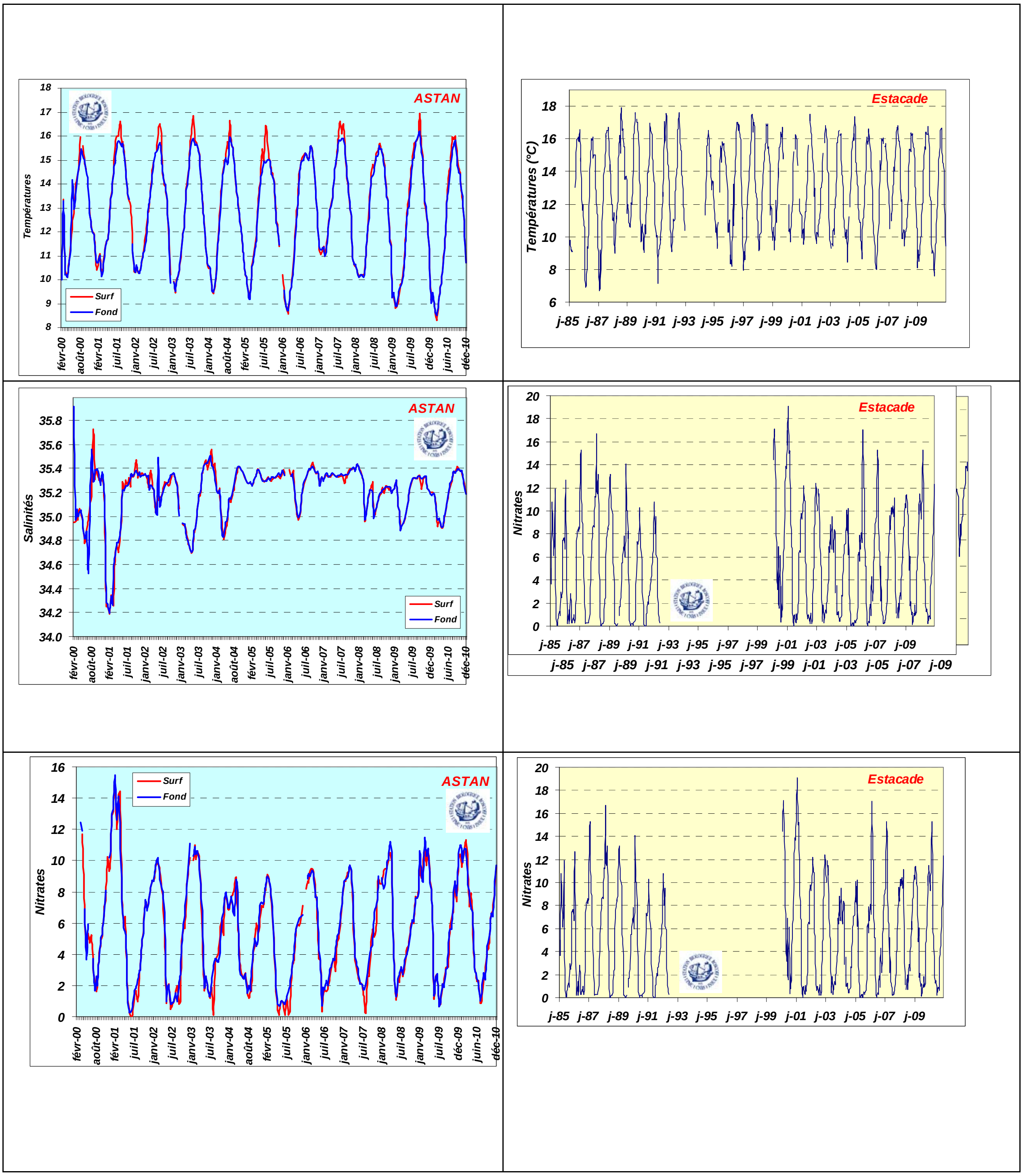


Figure 11. Interannual variability of the temperature, salinity and nitrate at the Astan site over 2000–2010 (left panels) and at the Estacade site over 1985–2010 (right panels).

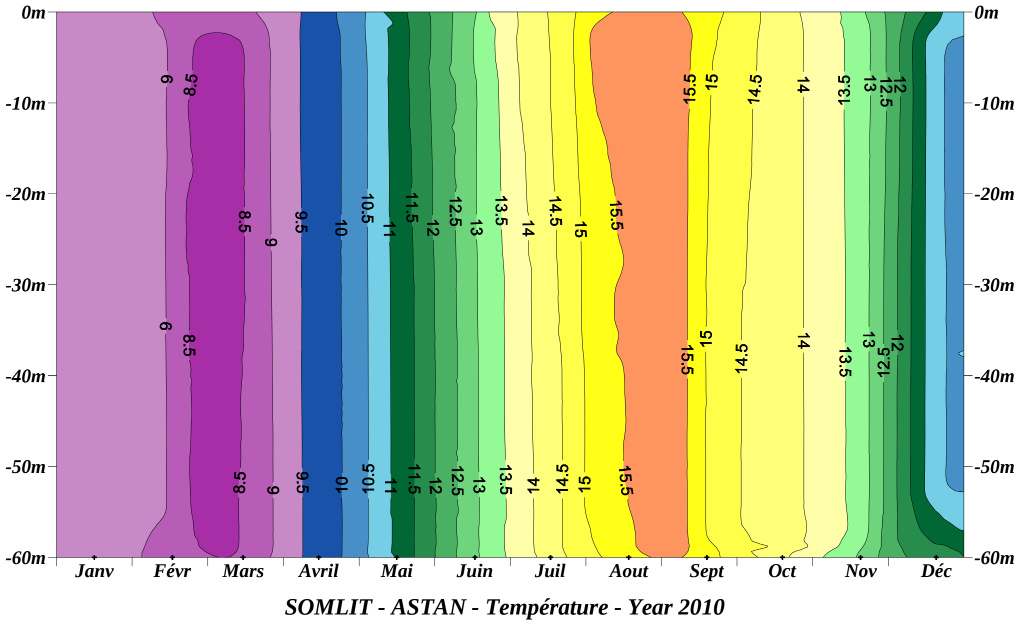


Figure 12. Vertical distributions of temperature at ASTAN site during 2010 (bimonthly CTD profiles). Well-mixed waters were observed during most of the year excepted in late summer when a low vertical gradient was episodically observed.

4. References

Gaillard, F., E. Autret, V.Thierry, P. Galaup, C. Coatanoan, and T. Loubrieu , 2009 : Quality control of large Argo data sets. JOAT, Vol. 26, No. 2. 337–351.

Annex 15: Regional report – Hydrographic conditions in the Atlantic Domain of the Nordic Seas

Waldemar Walczowski and Ilona Goszczko

IOPAS report from the ICES Areas: 10, 11 and 12

Observations

The Arctic Experiment of the Institute of Oceanology, Polish Academy of Sciences (IOPAS), the so-called AREX2010, was performed aboard RV Oceania between 20 June and 19 July 2010. During this time vertical profiles along standard sections were done. As in previous years the sections were perpendicular to the general direction of the Atlantic Water (AW) inflow according to the West Spitsbergen Current (WSC) location, which is situated between the Barents Sea slope in the south-east area, the west Spitsbergen shelf-break/slope region in the north-east and a system of underwater ridges: Mohn Ridge and Knipovich Ridge on the west. Because of the convergence of the isobaths in the northern part, currents pattern and structure is complicated and forms a wedge, wide in the southern part and narrower on the north. As before, our main effort concentrated in the northern part of the Atlantic Domain where processes controlling the AW inflow into the Arctic Ocean through the Fram Strait and the westward recirculation occur.

All in all, 179 CTD profiles were taken along 12 sections (Figure 1). The Seabird CTD (SBE 911+) system with duplicate temperature and conductivity sensors (temperature sensors SBE3, conductivity sensors SBE4 and SBE 50 digital oceanographic pressure sensor, SBE 43 dissolved oxygen sensor and fluorometer) was used. Temperature and conductivity sensors were calibrated by the Sea-Bird Electronics service.

Currents measurements were performed at all the CTD stations with two (upper and down looking) lowered Acoustic Doppler Current Profilers (LADCP) as well. The self-recording 300 kHz RDI devices were used to profile entire water column during the standard CTD casts. Moreover, sustained currents measurements were performed during the whole cruise with the ship-mounted ADCP, RDI 150 kHz.

Hydrographic conditions

Distribution of physical parameters at standard section N along the 76°30’N shows the WSC core over the west Spitsbergen slope (Figure 2). High records of the AW temperature and salinity were observed in summer 2006. After that both parameters decreased rapidly in 2007 and 2008, in summer 2009 the AW parameters raised again. According to our measurements, both temperature and salinity anomalies in 2010 were still above the mean, however, compared to the last year salinity was higher but temperature was lower. Temperature at standard section N in July 2010 (50–200 dbar layer) equaled 3.44°C, 0.25°C more than 1996–2010 mean. Salinity reached value of 35.10, about 0.039 more than 1996–2010 mean (Figure 3 and Figure 4). Both temperature and salinity trends are positive.

Dynamics

Distribution of baroclinic currents and temperature at 100 dbar (calculated for the reference level of 1000 m) in summer 2010 is shown in Figure 5. Baroclinic inflow into the Fram Strait is intensive, flow into the Barents Sea seems to be weaker. Two branches of the WSC are clearly visible, as well. Calculation made for AW at standard section N indicates increasing of baroclinic volume and heat transport (Figure 6) during the last fifteen years.

Moored instruments

The mooring system was deployed by the IOPAS personnel on 16 September 2009 during the KV Svalbard cruise under the ACOBAR Project. Recovery and re-deployment operation were conducted next year on 16 September 2010 during similar KV Svalbard cruise, performed as part of ACOBAR Project, as well. The new geographical location of IOPAS mooring was slightly shifted southward from the previous year position and was established on the continental slope at the bottom depth of about 800 m in the main core of the WSC.

The system deployed in the 2009 was equipped with the McLane Moored Profiler (MMP) and two conductivity-temperature-depth (CTD) sensors sets made by Sea-Bird Electronics Inc. (SBE). MMP is an autonomous platform for CTD sensors and an acoustic current meter (ACM). CTD sensors are manufactured by SBE and ACM - by Falmouth Scientific Inc. The instrument profiles up and down along a vertical mooring cable at a pre-programmed profiling interval (every 12 hours). CTD sensors sets were located at two constant levels (140 and 840 dbar). The system was re-deployed without lower CTD sensors which required repair.

MMP made a total of 734 profiles during the whole year of measurements. It moved twice per day along a vertical mooring cable between 130 and 730 m (96% of profiles are more than 550 m long). Instruments recorded all measured variables on the inside memory cards. Measurement of a single profile lasted for approximately 30 minutes.

Future plans for monitoring

IOPAS is planning to continue measurements at the standard sections in the WSC area. Moreover section located close to the Norwegian Gimsøy section will be performed as it was before 2006. The MMP mooring will be re-deployed again. New mooring system will be installed south of Sørkapp (shallow water deployment). The shelf/slope area will be examined as well. Influence of ocean on local climate will be also investigated.

References

Walczowski, W., Piechura, J. 2011. Influence of the West Spitsbergen Current on the local climate, International Journal of Climatology 31, 000–000, in press.

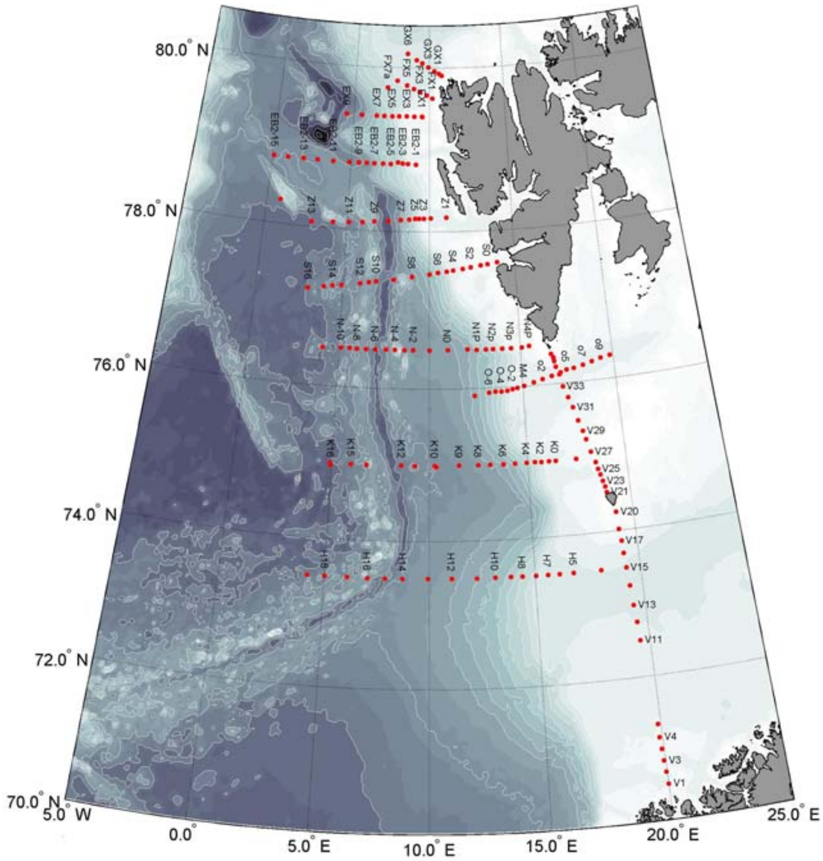


Figure 1. Geographical locations of CTD stations performed during IOPAS Arctic Experiment AREX2010 aboard RV Oceania in summer 2010.

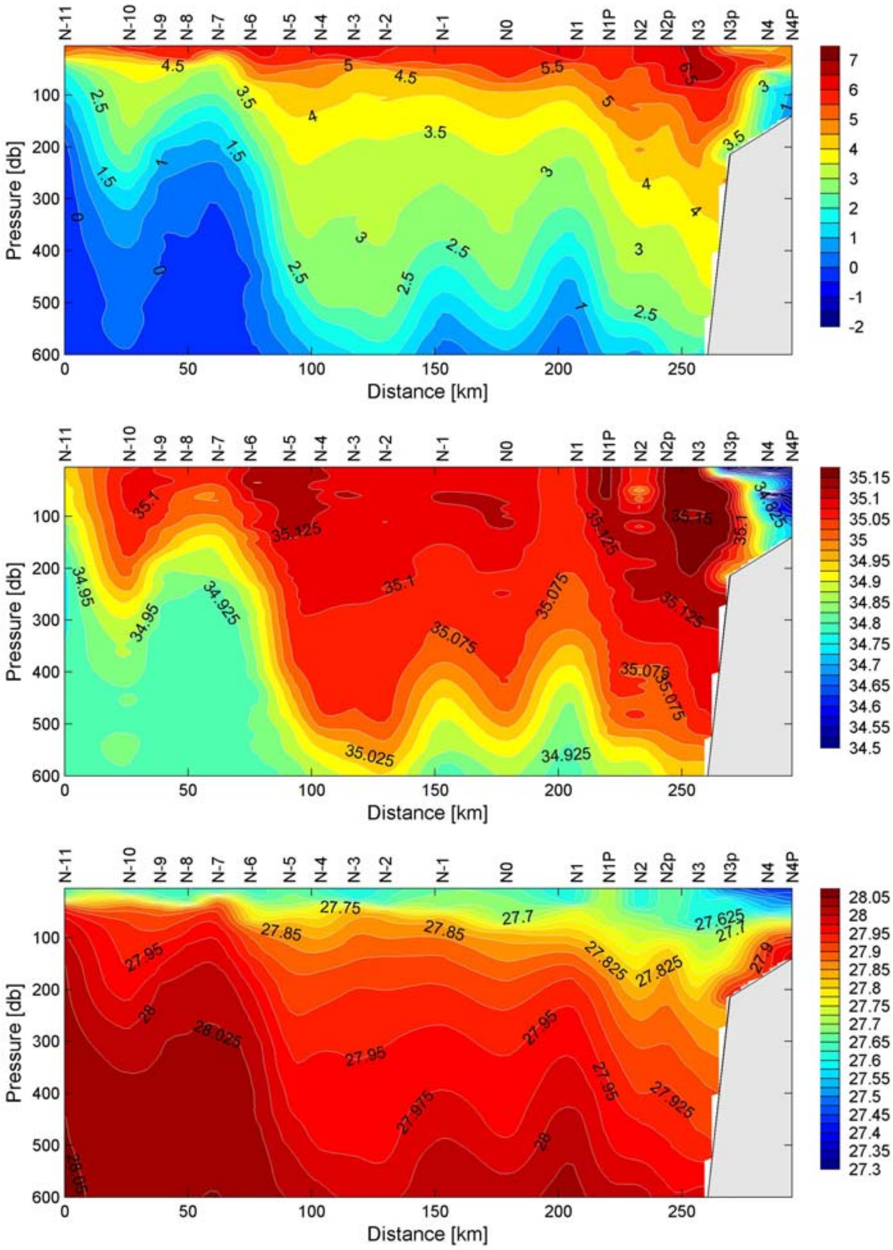


Figure 2. Temperature (θ), salinity and density (σ_θ) distribution along section N (76°30′N) in the AW layer.

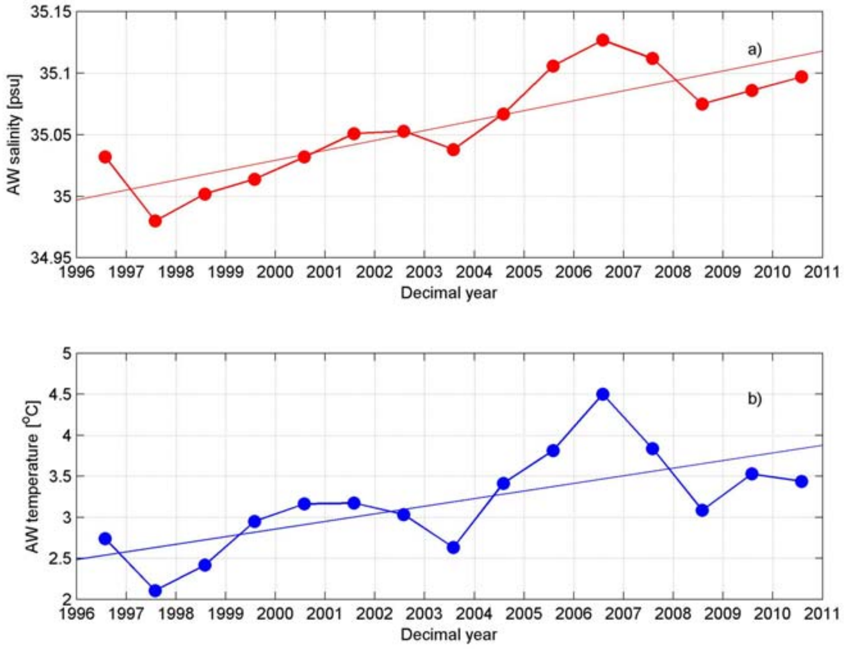


Figure 3. AW a) salinity and b) temperature at the standard section N (76°30′N, between 9°E and 12°E).

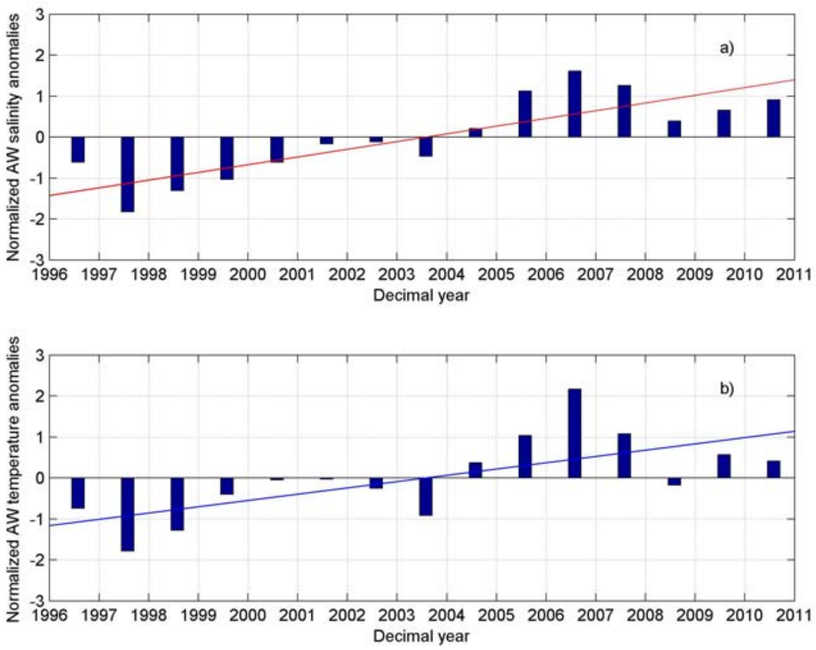


Figure 4. Normalized anomalies of AW a) salinity and b) temperature at the standard section N (76°30′N, between 9°E and 12°E).

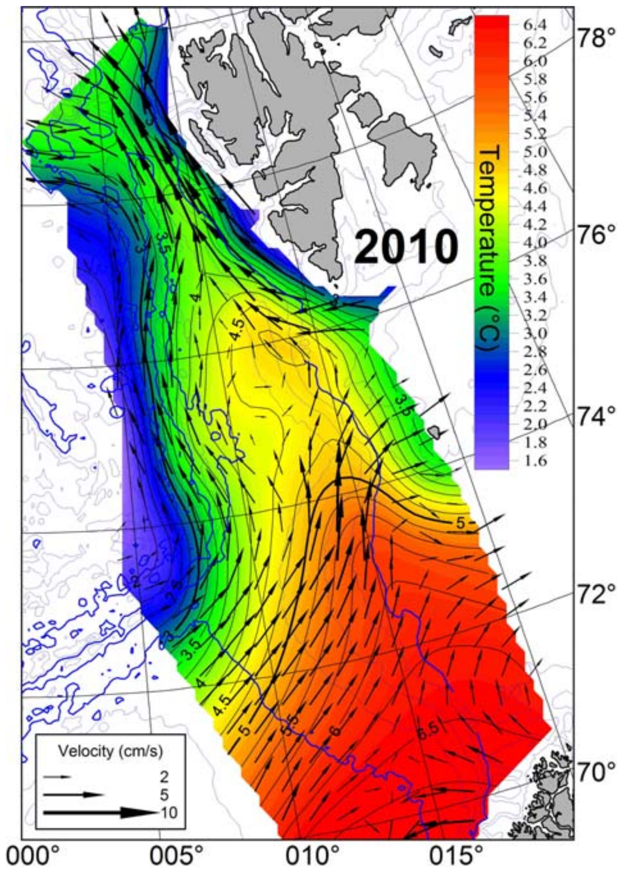


Figure 5. Temperature and baroclinic currents at 100 dbar. Data from Gimsøy section provided by the Institute of Marine Research, Bergen were used.

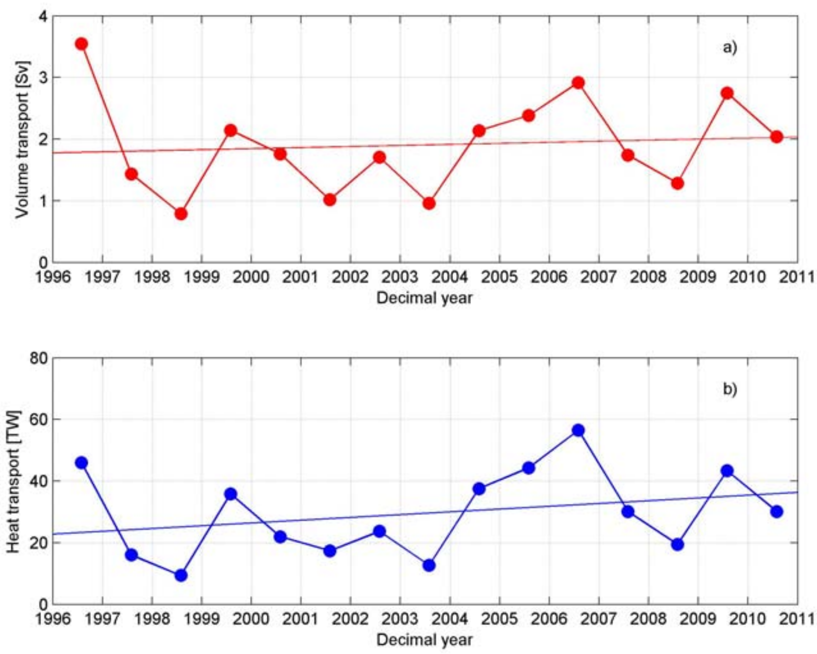


Figure 6. AW baroclinic a) volume and b) heat transport across the standard section N (76°30′N, between 9°E and 12°E).

Annex 16: Regional report – Ireland area report

Glenn Nolan, Kieran Lyons, Sheena Fennell, Guy Westbrook, Triona Mc Grath and Alan Berry

Oceanographic Services and Marine Chemistry team Marine Institute

Coastal time-series

Several coastal time-series are maintained around the Irish coast. These include SST measurements at the M3 weather buoy (southwest Ireland) and a longer-term SST record at Malin Head. The locations of these measurements are shown in Figure 1.

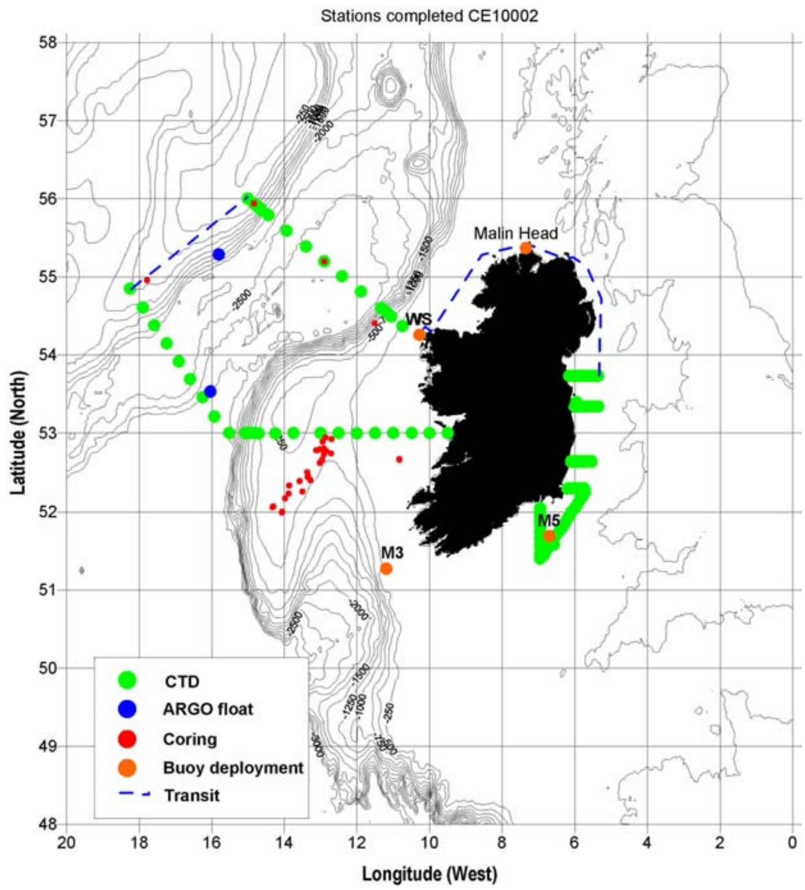


Figure 1. Location of key measurement sites in Irish waters.

Malin Head Sea surface temperature

A long-term sea surface temperature data set has been maintained at Malin Head since 1958. Temporal variability in sampling frequency ranges from hourly to daily over the period. Sea surface temperature anomalies from this station are presented in the figure below.

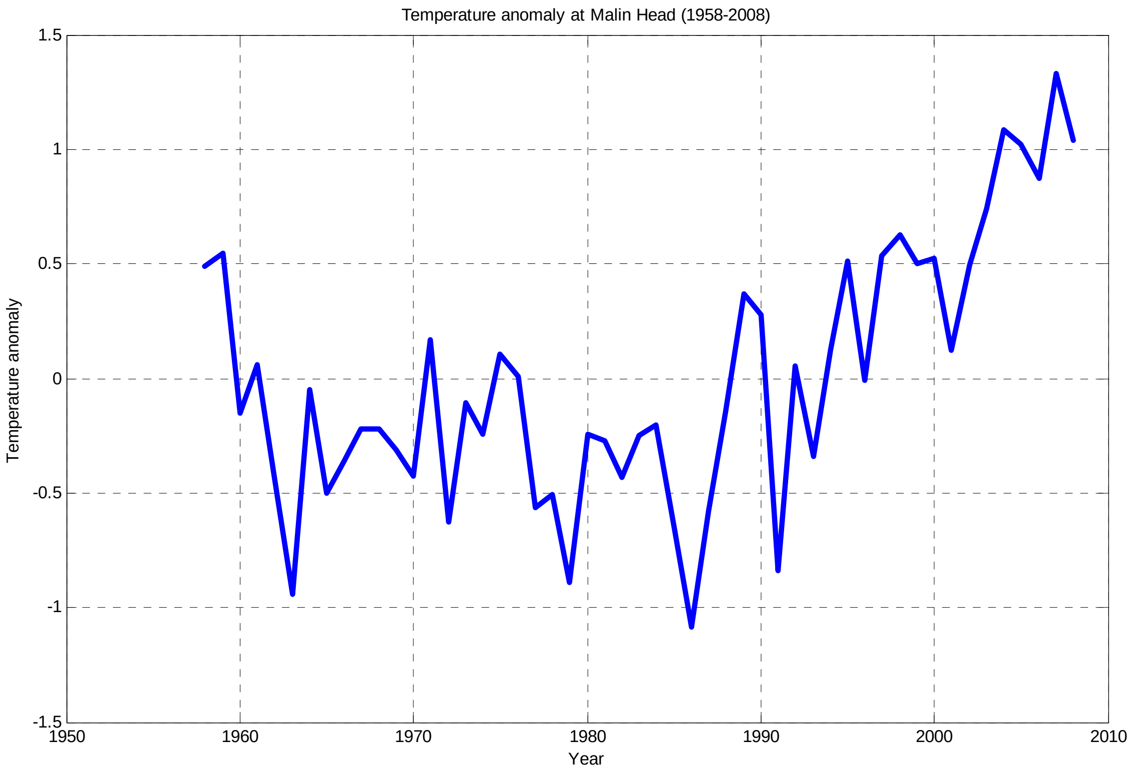


Figure 2. Sea surface temperature anomaly from Malin Head (Ireland) 1960–2008.

One of the noteworthy points in this data set is the presence of colder winter SST values in the early part of the record with values between 4°C and 6°C. Where these lower temperatures are observed in winter there is a less pronounced heating season in summer of that year. This is particularly apparent in 1963, 1978, and 1985/1986. This can be related to the Atlantic Multidecadal Oscillation (AMO) cool phase. Winter temperatures are typically >6°C since 1990 and summer temperatures are more pronounced in that period also. This corresponds with the more recent warm phase of the AMO.

Some analysis is currently taking place to investigate offsets between different sensors and measurement techniques at the Malin Head site with results expected during 2011.

M3 Buoy

An offshore weather buoy is maintained at 51.22°N 10.55°W off the southwest coast of Ireland since mid 2002. Sea surface temperature data are measured hourly at this location and archived after quality control procedures have been completed. There is considerable inter-annual variability at this site (Figure 3). 2003 and 2005 saw the warmest summer temperatures of the record while 2007 saw the warmest winter temperatures. 2006 saw winter temperatures below the time-series mean.

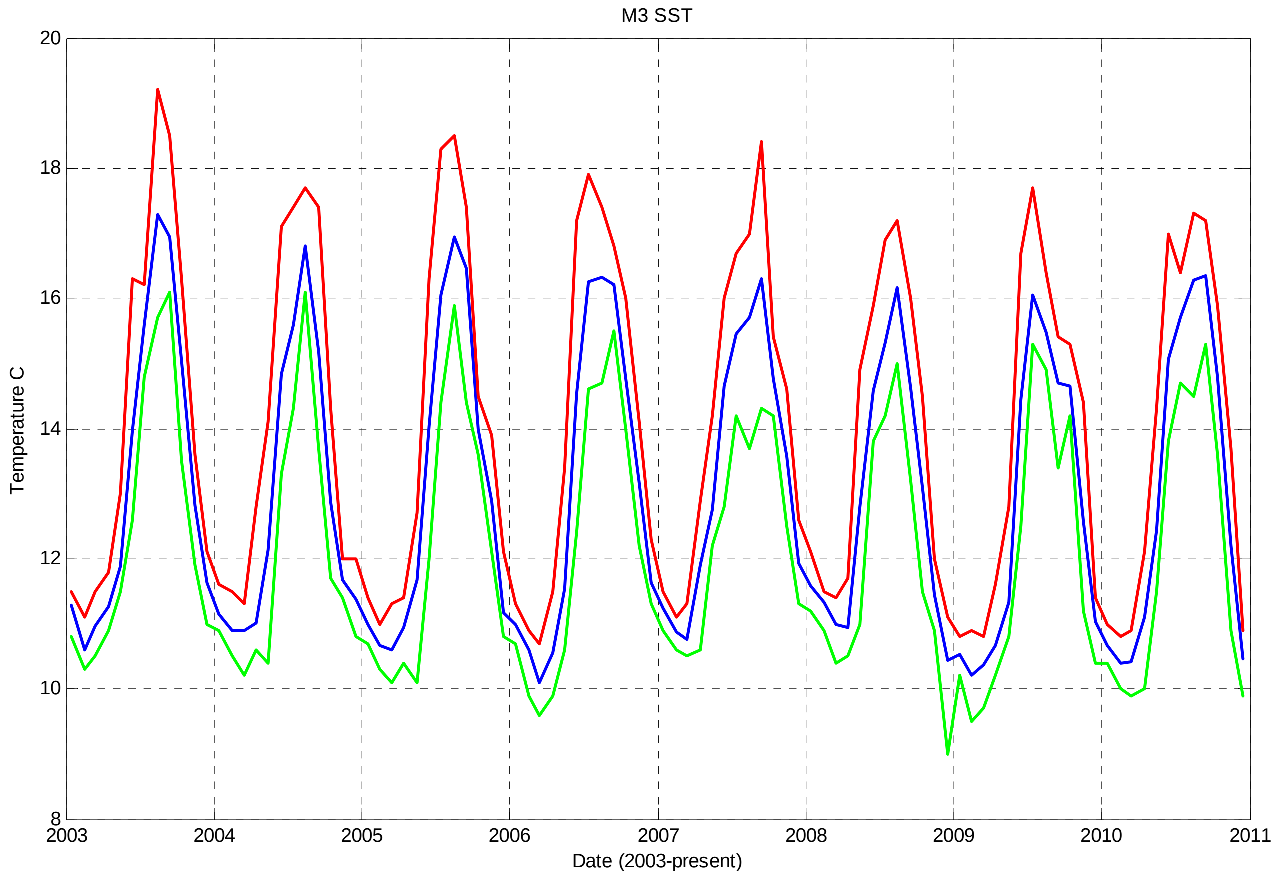


Figure 3. SST at the M3 weather buoy since its deployment in 2003(blue is minimum, green is mean and red is maximum monthly values).

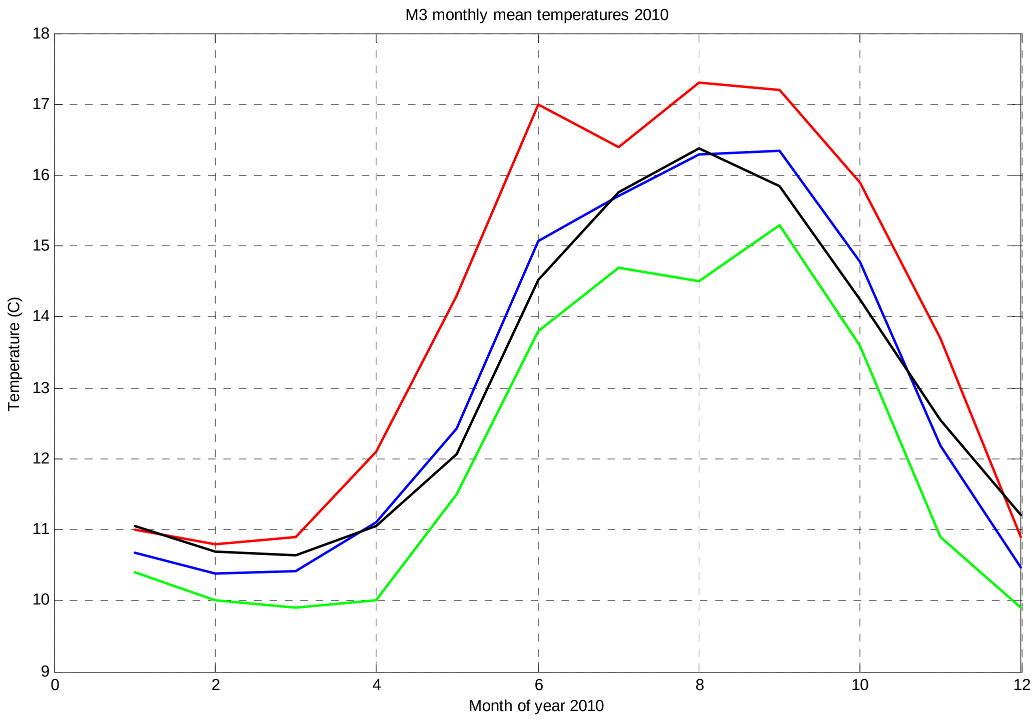


Figure 4. SST at the M3 weather buoy (blue line) in 2010 compared with the time-series mean (black dashed line). Max and min values for 2010 also shown.

2010 temperatures started below the time-series mean (2003–2009) until April. Temperatures remained similar to the time-series mean for the remainder of the year with some evidence for colder winter temperatures in December 2010.

Offshore cruise activity

Celtic Explorer cruise CE11001 was conducted in January 2011 to examine hydrographic conditions in Rockall Trough. A total of 44 stations were occupied for a variety of parameters including CTDs, grab samples and cores, nutrients, salinity and phytoplankton.

South Rockall line

Two transects across the Rockall Trough were completed on cruise CE11001. The first was the South Rockall Line which runs from Porcupine Bank to Southern Rockall Bank. Some stations on this transect exceed 3000 m water depth. The thermocline is often deeper on the eastern side of the trough also and shoals up as one progresses westward along the section. An eddy is seen in the central Rockall Trough. In the salinity plot is more complex with Sub Arctic Intermediate Water and Mediterranean water present as intermediate water masses. The influence of several water masses is evident in the T/S diagram for the section including a strong Mediterranean Water signal at ca. 1000 m water depth on the eastern side of the section. Below 1000 m the influence of Labrador Sea Water (LSW) is evident.

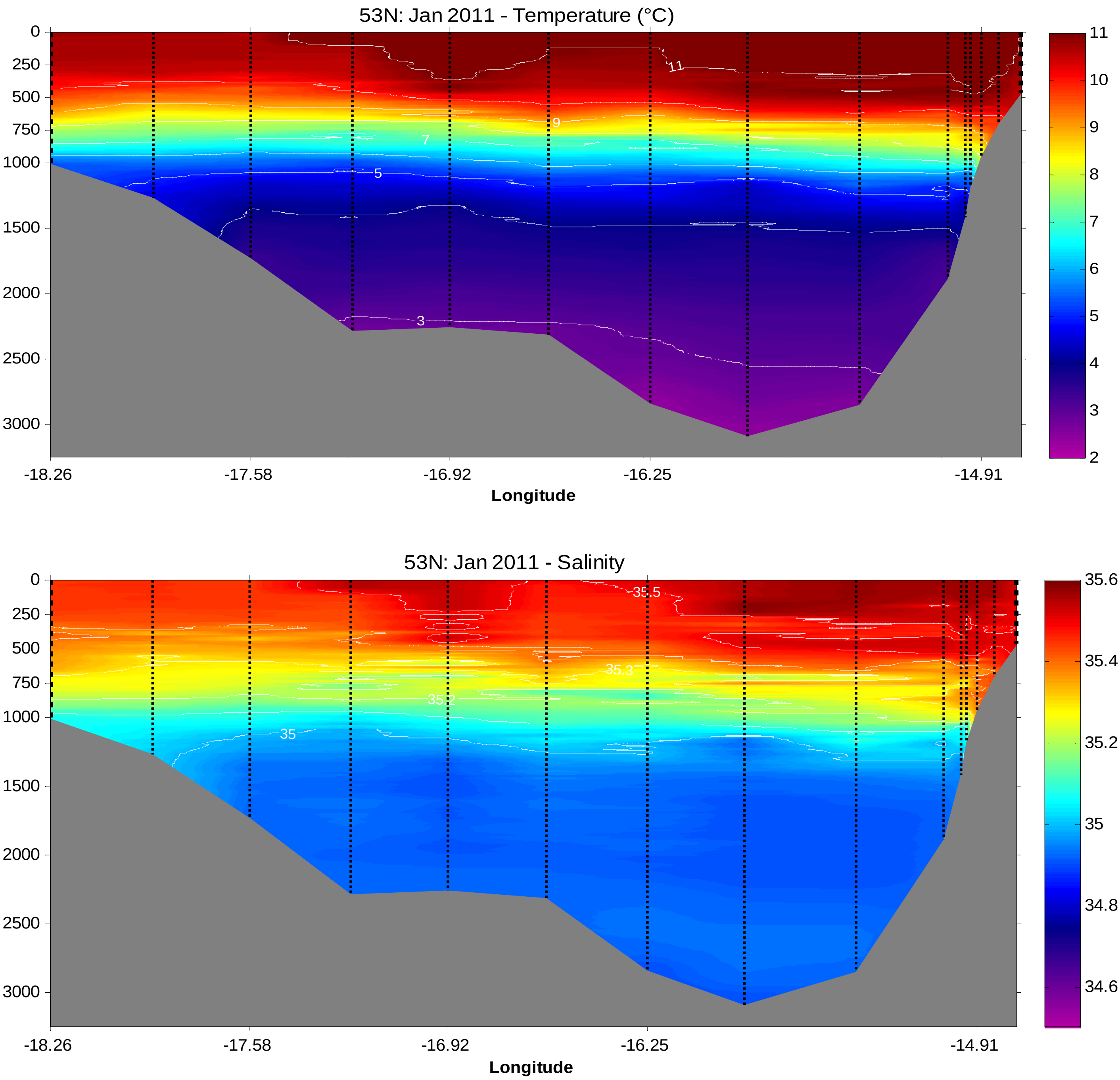


Figure 5. Temperature (upper panel) and salinity (lower panel) sections along the South Rockall Transect in January 2011.

The shelf break near Porcupine Bank marks a region where various intermediate water masses interact, most notably SAIW and MEDW. A closer look at this region shows a strong SAIW influence in some years (e.g. 2006 and 2008) and other years where this influence is much less pronounced (e.g. 2007 and 2009). Hatun *et al.* (2005) has linked this to changes in the position of the sub-polar front. If the sub-polar front is located to the southeast of its mean position, SAIW can encroach past Rockall Bank into Rockall Trough while if the front is further to the northwest, subtropical waters from the south are likely to dominate the upper and intermediate waters of the Rockall Trough. Initial results from a mooring west of Porcupine Bank are shown below showing the periodic pulsing of SAIW at this location.

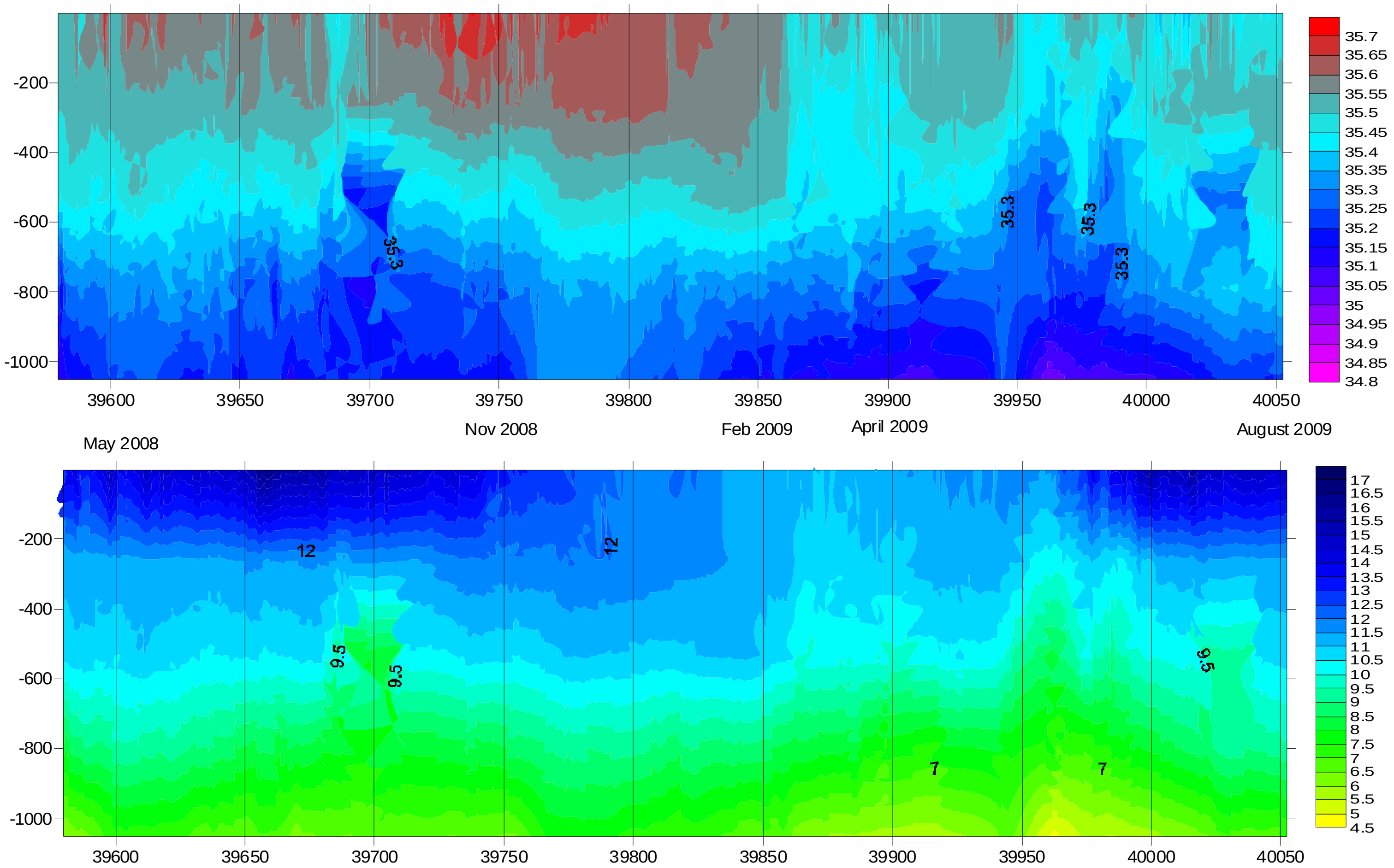


Figure 6. Initial results from M6 CTD string west of Porcupine Bank between May 2008 and August 2009 (salinity: upper panel and temperature: lower panel).

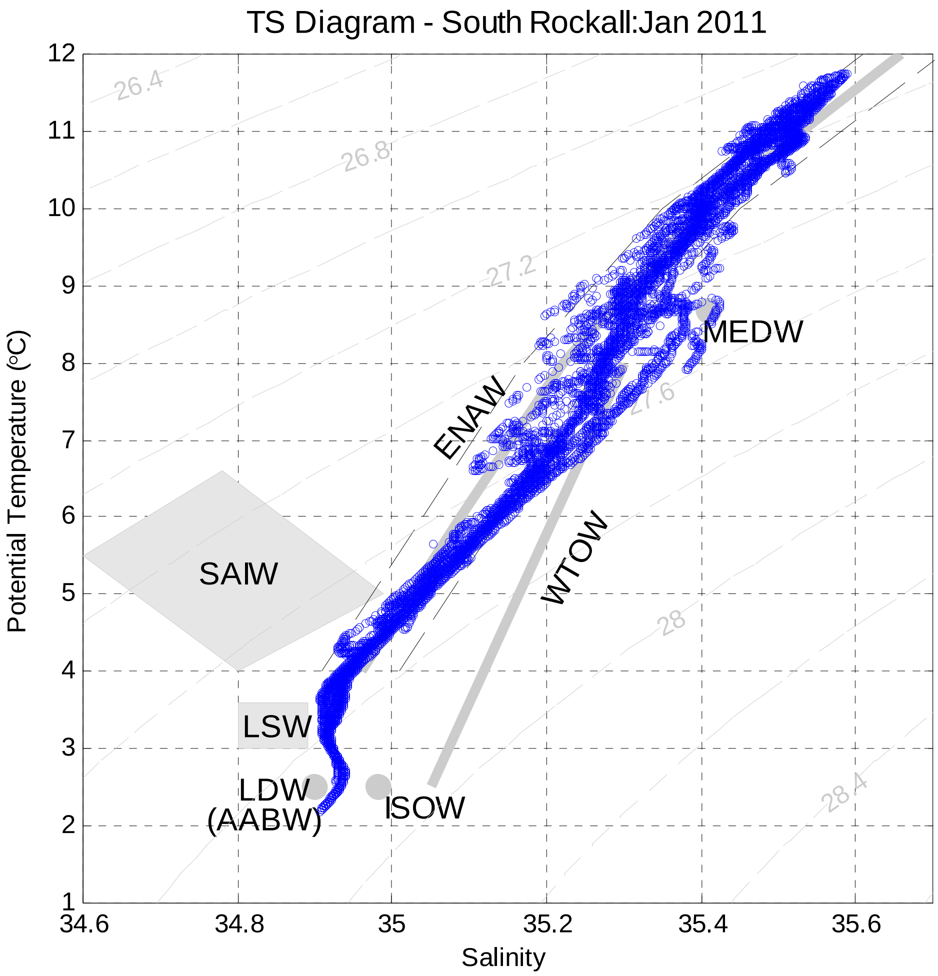


Figure 7. T/S curve for the South Rockall section during 2011.

North Rockall line

The second traverse of the Rockall Trough conducted is the North Rockall line which traverses from Rockall Bank to Erris Head. A shoaling of the permanent thermocline is evident from east to west on this section, as previously observed in 2006 and 2007 (Figure 8). A significant deepening of the thermocline is evident in the central Rockall Trough. Because this section is further north than the previous section, MEDW is typically not observed on the North Rockall line.

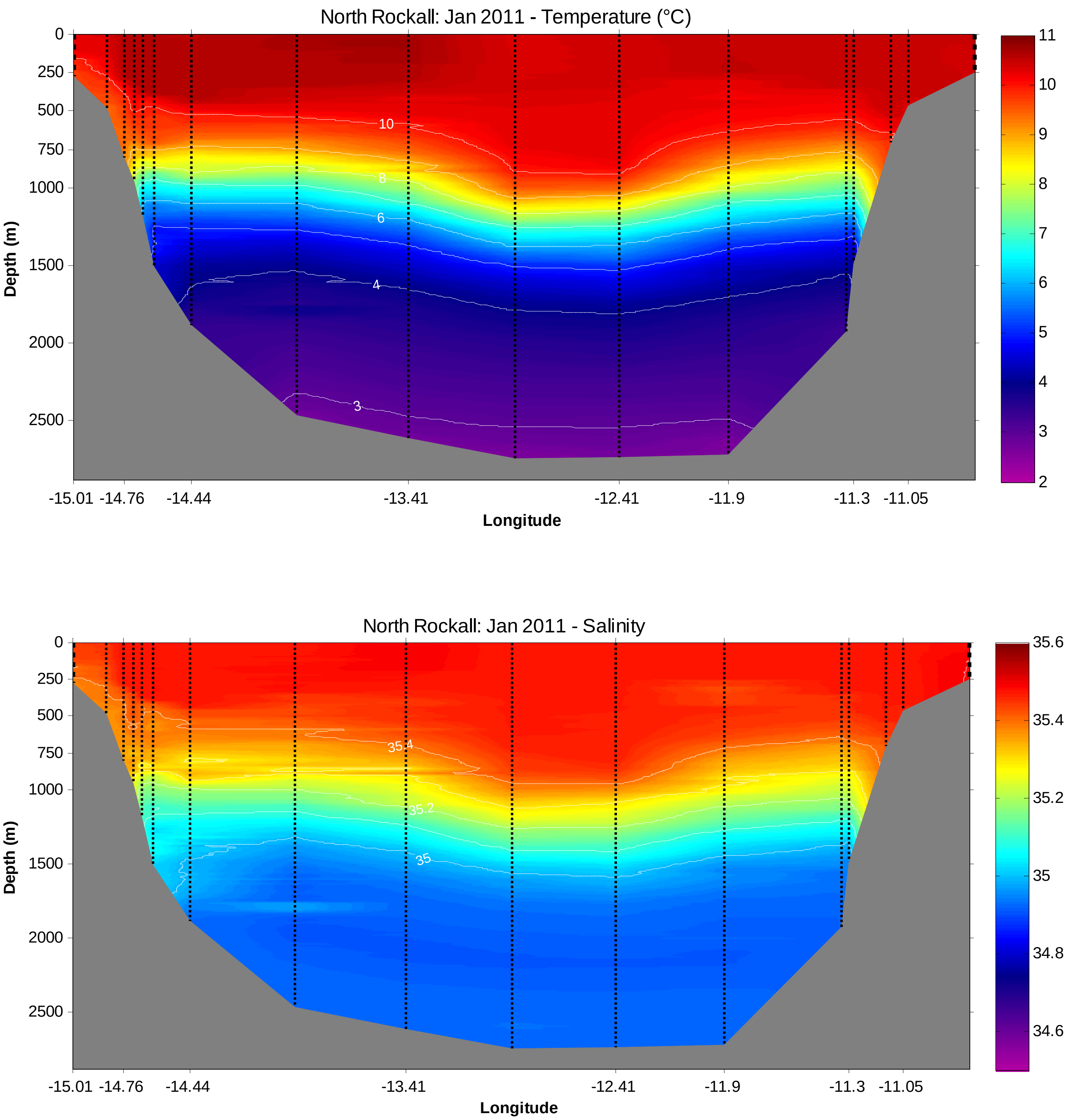


Figure 8. Temperature (upper panel) and salinity (lower panel) sections along the North Rockall Transect in January 2011.

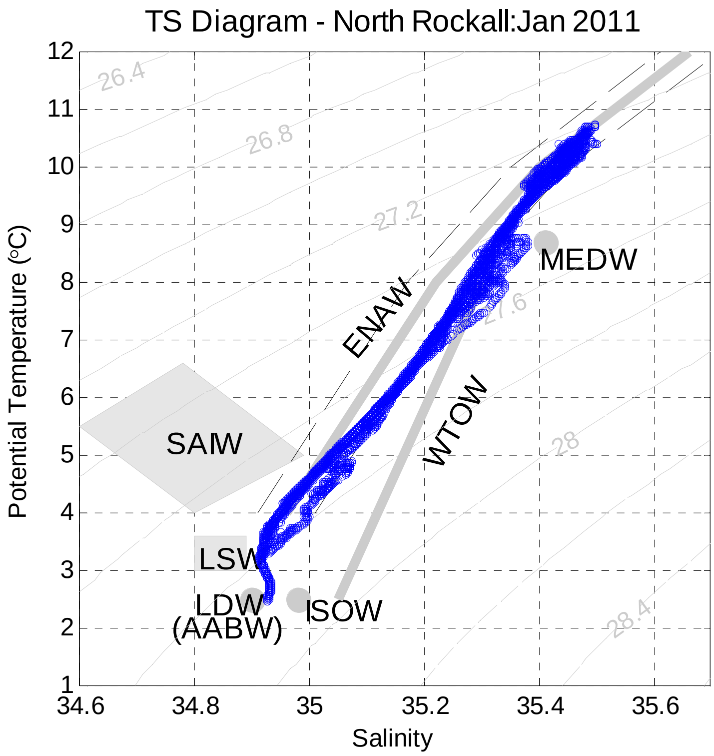


Figure 9. T/S Curve for the North Rockall section during February 2009.

A much tighter T/S relationship is apparent on the North Rockall section. There is limited MEDW influence here. Characteristics of the surface and deep water masses are similar to South Rockall.

Deep waters of Rockall Trough

The time period between 2006 and 2009 has seen considerable freshening of the Labrador Sea Water (LSW) centred on 1800m in the Rockall Trough (Figure 10). This is conceivably the arrival of LSW formed in the source region in 2000 that has transmitted itself through the deep water pipeline in the North Atlantic to reach the eastern basin. In early 2010, the deeper water masses increased in salinity by 0.01. This salinification continued in 2011.We will continue to monitor this water mass over the coming years to explore its effect on the overall water column, including potential vorticity and steric height.

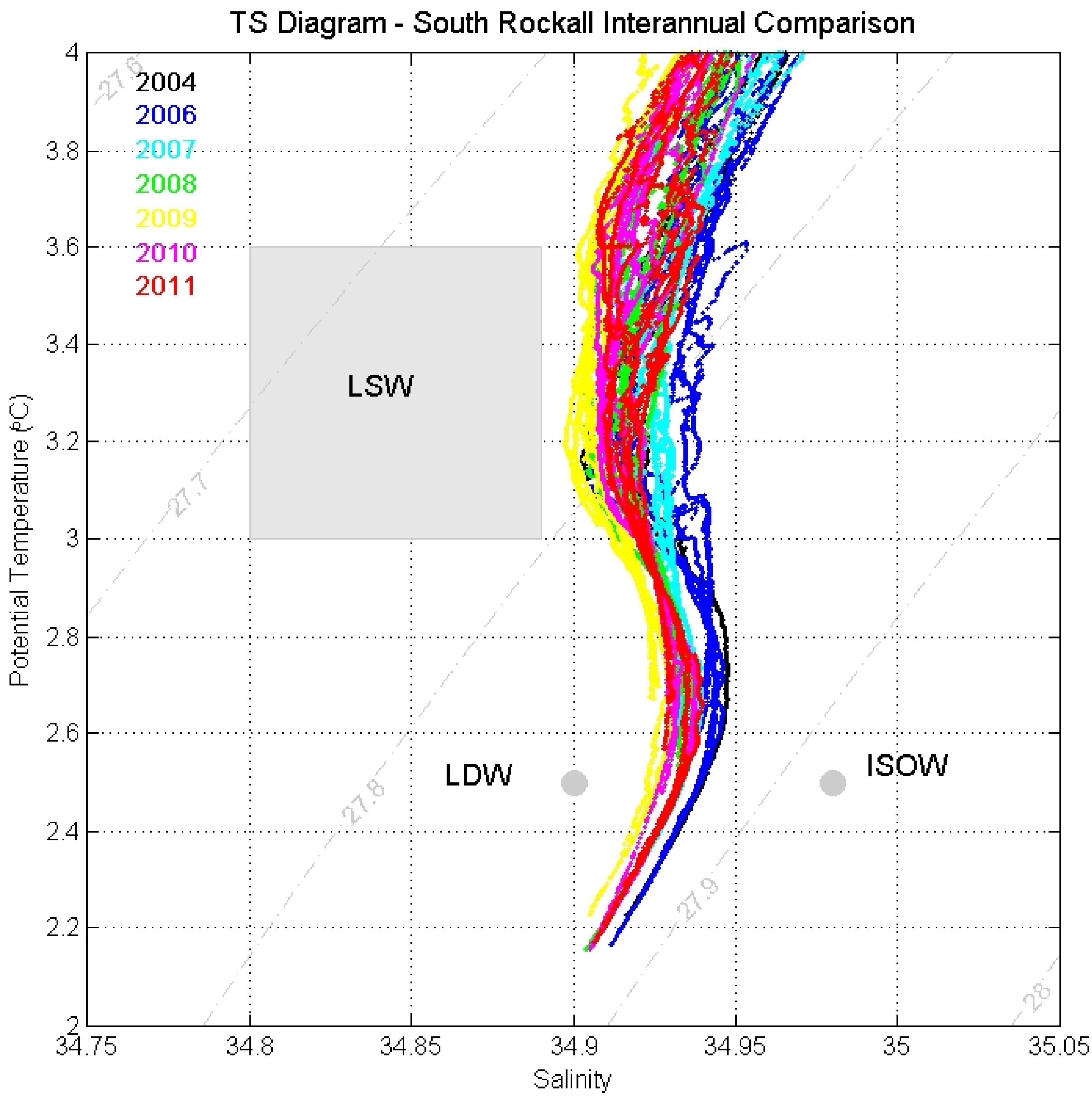


Figure 10. Interannual comparison of the deep water masses in Rockall Trough (2006–2011).

TransAtlantic XBT section 2011

In February 2011, the Celtic Explorer made passage from Ireland to St. John's, Newfoundland collecting XBT data along the ship's track.

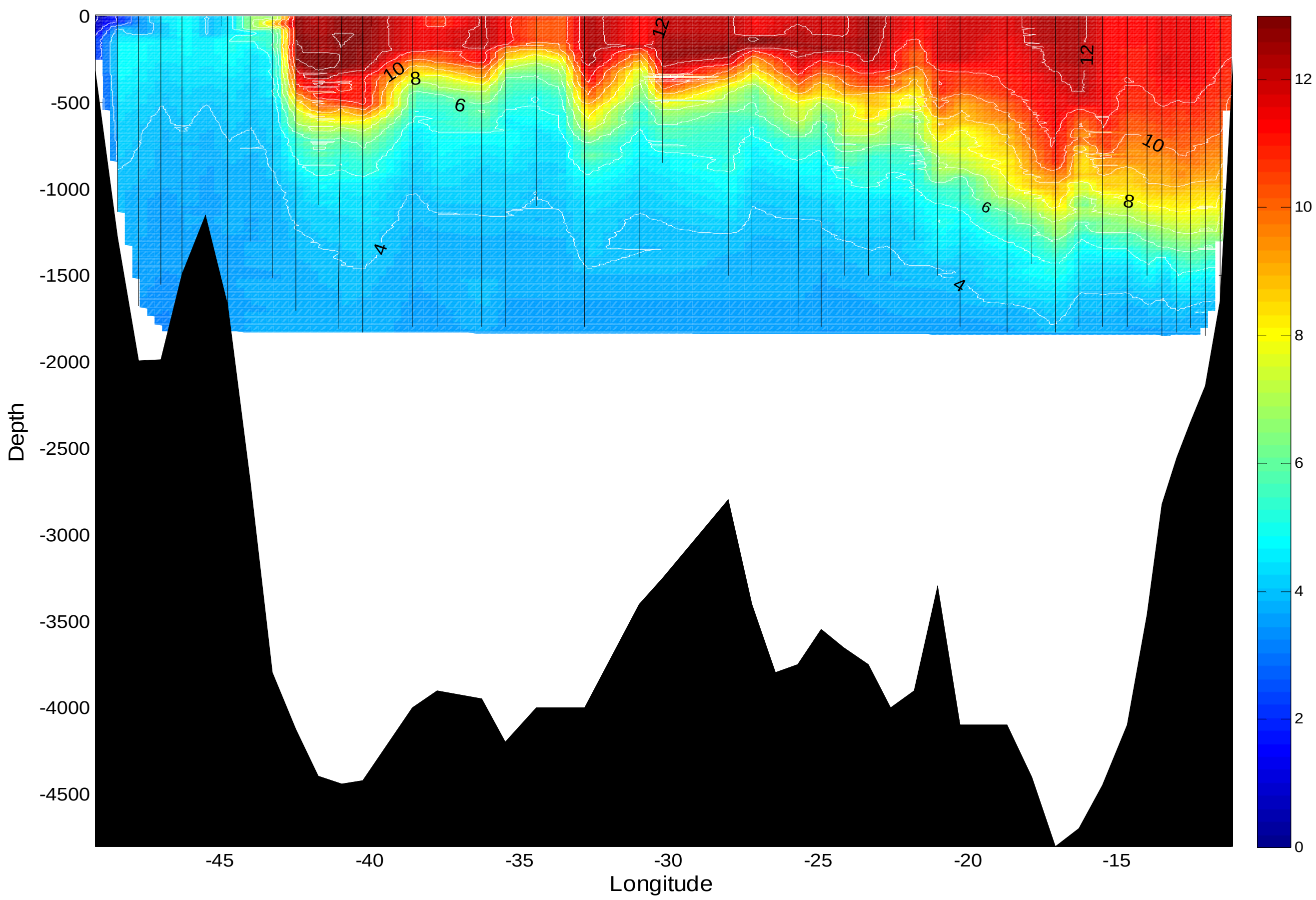


Figure 11. Temperature section from XBTs deployed on TransAtlantic transit (Feb 2011).

Several interesting features are evident from the section, namely the distinctive signal of the wall of the Gulf Stream at ca. 43W and the progressive deepening of the mixed layer as the section progresses from west to east.

Conclusions

1) Significant inter-annual variability in the upper and intermediate waters.
2) SAIW influence strongest in SW Rockall (Argo data).
3) LSW (freshened between 2006 and 2009 and then increased salinity in 2010 and 2011).
4) Irish coast winter SST below time-series mean (reflecting extreme air sea processes over last 2 winters).

Acknowledgements

We thank the scientists and crew on board the Celtic Explorer for their hard work and commitment. Thanks also to Aodhan Fitzgerald for his help in collecting XBT data and to POMS technicians Micheal Roper, Kieran Adlum and Damien Glynn for their work in maintaining buoys and coastal stations around Ireland.