ICES WGOH REPORT 2010

SCICOM STEERING GROUP ON ECOSYSTEM FUNCTIONS

ICES CM 2010/SSGEF:08

REF. SSGEF, SCICOM, ACOM

Report of the Working Group on Oceanic Hydrography (WGOH)

9–11 March 2010

Brest, France

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. 2010. Report of the Working Group on Oceanic Hydrography (WGOH), 9–11 March 2010, Brest, France. ICES CM 2010/SSGEF:08. 158pp. https://doi.org/10.17895/ices.pub.8785

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 2009

Highlights of the North Atlantic Ocean for 2009:

- The upper layers of the northern North Atlantic and the Nordic Seas were warm and saline in 2009 compared with the long-term average.
- A strong cold anomaly developed in the surface of the central North Atlantic during the summer.
- Warming and salinification of deep waters continues.

Highlights of the North Atlantic atmosphere in winter 2008/2009:

- Surface air temperatures in the central North Atlantic and Norwegian SEA were near normal, but they were > 1°C higher than average in the Labrador, Barents, and Greenland Seas.
- Mean winds were weaker than normal across the eastern North Atlantic, southern Labrador Sea, Nw European continental shelf, and Baltic, but stronger than normal east of Newfoundland and east of the Azores.
- The NAO INDEX in winter 2008/2009 was weakly negative.

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 prior to the formal meeting on day one which included a combination of talks from the host institution and invited WGOH members. Half of the meeting was spent reporting findings from each of the ICES standard oceanographic sections. The combined area reports are included as Annexes 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 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 will be completed and submitted to ICES in early May 2010 where many of the Expert Group’s key findings are presented.

Key recommendations

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.

ICES should encourage NAFO to make a decision on funding support for the Decadal Symposium on Hydrobiological Variability (2011) in Q2 2010.

The following scientists are proposed as honourees for the symposium:

Allan Clarke, Tom Rossby, Robert Dickson, Jens Meincke, Catherine Maillard

1 Opening of the meeting

The Working Group on Oceanic Hydrography, chaired by Glenn Nolan (Ireland) and Hedinn Valdimarsson (Iceland), met at the IFREMER, Brest, France, on 9–11 March 2010.

The meeting was attended by 15 WGOH members (Annex 1) representing 11 ICES nations.

Local host Fabienne Gaillard welcomed all WGOH participants to the meeting and provided all relevant logistical information to those present. The WGOH then proceeded to the nearby lecture theatre for the mini-symposium.

Mini-symposium presentations :

L. Marié, LPO: Measurements in the bay of Biscay and Ushant front.

E. de Boisseson, LPO: Mode water in the North Atlantic

G. Reverdin, LOCEAN: Near surface salinity measured with drifting buoys

Pascale Lherminier, LPO: Ovide Repeat hydrography section

2 Adoption of the agenda and key discussion points

2.1 Membership and Introductions

Member introductions took place and the agenda was formally adopted. The group welcomed a new member, Anna Akimova who replaces Manfred Stein of Vti.

2.2 ICES Decadal Symposium Planning

To build on the previous 2 symposia, Alicia Lavin of IEO will host this in Santander in 2011. A motion to host this was approved in late 2008 and €10k given in support. Letter also sent to NAFO (Don Power) to co-sponsor the meeting.

A group has been established to move forward the symposium planning including: Alicia Lavin (Convenor), Sarah Hughes, Alicia Lavin, Glenn Nolan, Steven Dye, Agnieszka Beszczynska-Möller, Victor Valencia, Penny Holliday, Bert Rudels, Hedinn Valdimarsson and Ken Drinkwater.

A scientific steering committee has been established comprising Einar Svendsen (Chair), Ken Drinkwater, Stephen Dye, Penny Holliday, Manfred Stein, Ross Hendry, Agnieszka Beszczynska-Möller, Bert Rudels, Hendrik Van Aken, Toby Sherwin, Victor Valencia, Luis Valdes, Eugene Colbourne, Harald Loeng, Benjamin Planque, and Peter Wiebe (Guest Editor). Bill Turrell will act as the ICES Journal Editor.

Other key points

WGOH wrote to the SSC Chair Einar Svendsen with some suggestions for theme sessions, honoraries etc. (Annex 3 to this report).

A decision on NAFO funding has still not been made. ICES should encourage NAFO to make a decision on co-funding as soon as possible.

The local host (Alicia Lavin) has made some progress in securing financial support from the Spanish authorities but many of these commitments need to be made firm.

Ana Akimova has offered to assist with the logo and branding for the symposium.

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

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

Holger Klein, Kjell Arne Mork, Alexander Trofimov, Waldemar Walcowski, Agnieszka Beszczynska-Möller, Fabienne Gaillard, Gilles Reverdin, Karen Borenas, Hedinn Valdimarsson, Glenn Nolan, Sarah Hughes and Anna Akimova. Igor Yashayaev sent on a presentation on recent trends in the Labrador Sea.

All area reports are included as annexes to this report.

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. Work is ongoing on this position paper and the expected launch of the Cooperative Research Report is mid-December 2010.

WGOH members were asked to review the document and provide feedback to Penny Holliday and Sarah Hughes by late April 2010.

2.5 Discussion of ICES SSGEF workplan and consider WGOH participation

Considerable attention was devoted to this agenda item during the WGOH meeting. Consideration was given to the group of tables circulated to WGOH by SSGEF and following a debate or where the WG felt we could contribute best, the tables were populated and circulated to Pierre Petitgas (SSGEF Chair) in mid-March 2010.

2.6 ICES Data Centre.

Hjalte Parner attended the WGOH meeting and gave an overview of recent and planned activities within the ICES data centre. He suggested that the time series submitted to compile the ICES Report on Ocean Climate also be submitted to the data centre. It is proposed that this take place on a trial basis in 2010 and that no 3rd party data sets are transferred to the data centre at present.

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

WGOH has been invited to attend the IGSG meeting in Woods Hole but is not in a position to take up this offer at present due to travel restrictions in many of the European Institutes.

Holger Klein maintains a link between WGOH and WGOOFE and informed the group about the website (www.wgoofe.org), the forthcoming meeting (June 2010) and Theme Session A of the ICES Annual Science Conference that will focus on "Operational oceanography for fisheries and environmental applications".

Sarah Hughes attended a WGPE meeting in Aberdeen in early 2010 on behalf of WGOH.

2.8 Relations with international climate monitoring programmes

WGOH has been invited to attend the PICES science meeting in Oregon to present on the activities of WGOH. It is likely that Eugene Colbourne of DFO, Canada will fulfill this invitation in late October 2010 (subject to agreement of his institute).

Barbara Berx (Marine Scotland) has asked WGOH members for feedback on the Integrated Framework for Sustained Ocean Observations Task Team. This task team was formed following the OceanObs meeting in Venice in late 2009.

A joint ICES/PICES symposium will be held in Korea in May 2012 looking at the Effects of climate change on the oceans. Sarah Hughes is on the SSC and is seeking members for the SSC.

2.9 ASC 2011 theme session proposal

Given the focus on the decadal symposium at present WGOH will propose one theme session for 2011 as follows:

The role of the Arctic and Sub-Arctic in a climate change perspective

Conveners: Harald Loeng, Norway and Bogi Hansen, Faroes

The Arctic Ocean and the Sub-Arctic regions of the North Atlantic are very important areas from a climate change perspective and play an important role in the global climate system. A number of physical processes will be affected by the changes anticipated in global climate during the 21st century. These include the effects of wind on the transport and mixing of water, and the circulation systems generated by freshwater input and thermohaline ventilation. A key issue is the extent to which each of these processes contributes to driving the inflow of Atlantic water to the Arctic. Models have shown that the heat transported by this inflow in some areas elevates the sea surface temperature to a greater extent than the temperature increase projected for the 21st century. A weakening of the inflow could therefore significantly reduce warming in these areas and might even induce regional cooling, especially in parts of the Nordic Seas. This session welcomes papers that deal with observations, process studies and model results that will help us to explain climate change and variability in the North Atlantic and the Arctic. An example is processes that affect the thermohaline circulation.

2.10 IROC Final review

The IROC will be produced in the first half of 2010 and submitted to ICES for printing and dissemination.

2.11 WGOH website

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

2.12 Next Meeting

The next WGOH meeting will be in Helsinki, Finland, on 23–25 March 2011.

WGOH thanked Fabienne Gaillard for hosting the meeting and excellent preparations.

Close of meeting.

Annex 1: List of participants

Name	Address	Country	Email
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Annex 2: Agenda

9–11 March 2010, Brest

Day 1, Tuesday 9th March

0900-1300: ICES Decadal Symposium Planning

1400: Mini-symposium (Ifremer conference room**)**

L. Marié, LPO: Measurements in the bay of Biscay and Ushant front.

E. de Boisseson, LPO: Mode water in the North Atlantic

G. Reverdin, LOCEAN: Near surface salinity measured with drifting buoys

Pascale Lherminier, LPO: Ovide Repeat hydrography section

Day 2, Wednesday 10th March

Start at 0900

1. Membership and Introductions

2. IROC (15-25 mins update from Sarah Hughes)

    Review of 2009 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 3 (morning only), Thursday 11th March

Start at 0900

4. Short 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

    SGGOOS

    WKOOP (see 2007 ToRs).

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

7. Discussion of ICES SSGEF workplan and consider WGOH participation.

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 2011

11. IROC Final review
12. WGOH website
13. Next Meeting
14. AOB

Annex 3: Letter from WGOH Co-chair to Decadal Symposium SSC chair

Dear Einar,

I hope you are keeping well up there. I just wanted to pass on some observations that were made at the WGOH meeting in Brest earlier this month regarding next year's decadal symposium.

1) We agree with Kens views on the need to focus on observations made in the decade 2000–2009 and put that in context with longer term variability/change.

2) In the conference call it is important to make clear that the conference will be multi-disciplinary, and that all submissions must be prepared in a way that they will be understandable by those from other disciplines (see also point 3 below).

3) We feel the discussion about theme sessions is becoming an unnecessary distraction. The symposium will run a single session over two-three days and we aim to get full participation at all sessions.

Therefore making 'theme sessions' is simply introducing artificial boundaries. Once submissions have been made they could be organised for presentation in a sensible way (i.e. grouped by depth, region, discipline?).

4) Although we accept that modelled data can offer useful insights and modelled data will certainly be presented at the symposium, we would like the symposium to focus on observations and we don't think it is necessary to get involved in future climate predictions.

4) Honoraries. Some suggestions were made for Bob Dickson, Jens Meincke, Catherine Maillard, Tom Rossby, Manfred Stein.

5) Keynotes - The number of keynote speakers needs to be decided soon.

If we are to offer travel funds for invited speakers we need to incorporate this into the budget.

6) It was suggested we invite keynote speakers who could give good summaries of our understanding of variability up to the last decade ie pre 2000, in order to set a context. The keynote speakers need to give a good general overview of the whole region to allow the symposium papers to be put into context. The IROC and Zooplankton reports could also be used to offer a general overview of the decade 2000-2009. Peter Rhines was a suggestion for a keynote speaker in physical oceanography. He has just submitted an interesting paper on North Atlantic circulation.

http://www.ocean.washington.edu/research/gfd/papers-rhines.html, so would be able to offer a very up to date viewpoint.

7) It was also suggested that we invite people to prepare summaries for the symposium proceedings. These people should be tasked with reviewing all submissions and pulling out the key messages from the decade of 2000-2009.http://www.ocean.washington.edu/research/gfd/papers-rhines.html.

8) The letter from ICES was discussed (attached). We felt that commissioning papers to prepare a review of the decade, prior to the symposium was an impossible task. Especially when the aim of the symposium itself is to review that last decade. We feel that the summary papers mentioned in (7) could provide the reviews that ICES felt to be necessary.

9) There was a suggestion that the honararies could be asked to give keynote talks, or write the summaries but we decided that it is probably better that this doesn't happen, it would be perhaps be awkward if some of the honararies were more involved than others.

10) Originally we wanted to prepare a flyer/call for papers by the ASC in September. We were made aware of the NAFO conference coming up in June so we suggest a flyer/poster be prepared in time for this. This means a rough design should be at ICES by end of April. Anna Akimova has offered to help with design and Stephen Dye will prepare the webpages, once the text has been finalised.

We hope these comments are useful to the scientific steering group and welcome any questions you have.

Very best wishes,

Glenn Nolan

Co-chair

ICES WGOH

Annex 4: WGOH Terms of Reference for the meeting in 2010

2009/2/SSGEF08 The **Working Group on Oceanic Hydrography** (WGOH), chaired by G. Nolan, Ireland; and H. Valdimarsson, Iceland, will meet in Brest, France, 9–11 March 2010 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) Contribute to ICES Climate Change position paper including:

1) Warming trends in the North Atlantic
2) Sea ice cover changes in "hot spots" chapter
3) Physical properties and circulation in the North Atlantic

g) Report by 15 March on potential contributions to the high priority topics of ICES Science Plan by completing the document named "SSGEF_workplan.doc" on the SharePoint site. Consider your current expertise and rank the contributions by High, Low or Medium importance;

h) Prepare contributions for the 2010 SSGEF session during the ASC on the topic areas of the Science Plan which cover: Individual, population and community level growth, feeding and reproduction; The quality of habitats and the threats to them; Indicators of ecosystem health.

WGOH will report by 30 April 2010 (via SSGEF) for the attention of SCICOM and ACOM.

Supporting Information

Priority:	The activities of this Group are fundamental to the work of the SGEF.
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 2009. 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. ToRs g) and h) This is in response to a request from SSGEF.
Resource Requirements	No extraordinary additional resources
Participants	WGOH members; Chair of SGEF
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 5: 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.	G. Nolan to write to the ICES Secretariat and Adi Kellerman again to move this forward.
2. ICES should encourage NAFO to make a decision on Funding support for the Decadal Symposium on Hydrobiological Variability (2011) in Q2 2010.	Adi Kellerman

Annex 6: Regional Reports – Area 1, West Greenland

Anna Akimova

Institut für Seefischerei, Johann Heinrich von Thünen-Institut (vTI)

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 2009

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.

To characterize the atmospheric condition in the area of research, we use data from three meteorological stations in southern Greenland: Nuuk, Angmagssalik and Egedesminde (Figure 1, Table 1). Absolute values of the annual air temperatures of Nuuk and Angmagssalik are close to each other (Figure 2) and a correlation between two time series is 0.85 (for the period from 1992 to 2009). Hence the western and the eastern coasts of Greenland undergo similar climatic conditions most of the time. The air temperature further to the north at Egedesminde is almost two degrees lower than at Nuuk (Figure 2), but both temperatures are strong correlated with a coefficient of 0.96. For further analyses, the longest time series of the air temperature observations at Nuuk weather station has been chosen as representative following Stein, 2002 and Stein, 2004.

In 2009 the mean air temperature at Nuuk was 1.2°C above long-term mean (the period from 1971 to 2000 is used throughout the chapter unless otherwise indicated) and continued a series of warm temperatures started approximately in the beginning of the 1990s (Figure 3). This reflected relatively high air temperature in 2009 over the whole region (Figure 4). The annual air temperature was high due to warmer winter and summer conditions, while for the rest of the year the monthly temperatures were close to their long-term mean (Figure 5). March and November 2009 are the only exceptions. The air temperature in November 2009 was 2.8°C lower than the long-term monthly mean and exceeded one standard deviation from the mean. But the area of the relative cold November air temperature didn't extend over the whole region and probably affected only the western part of Greenland and the eastern Labrador Sea (Figure 6).

The annual air temperature during the 2000s was between one and two standard deviation above its long-term mean, with the maximum of 0.56 °C in 2003, which was the fourth highest temperature during the whole period of observations since 1876 (Figure 3). The warm condition resulted in the high decadal (averaged over a decade) mean of -0.4 °C (Table 2), which is more than one degree higher than the long-term mean of -1.76 °C. These positive temperature anomalies might lead to erroneous conclusion, that the scheme "high NAO year =colder-than-normal conditions" didn't work properly in 2000s. However, if we consider the temperature anomalies with the respect to decadal mean from 2000 to 2009, we can see that the usual scheme kept going in the 2000s too.

It is worth to notice here that our conclusion about the warm air temperatures through the 2000s is based on the long-term reference mean, calculated from 1971–2000. These three decades were the coldest ones since 1900s (Table 2) and hence chosen long-term mean is predetermined lower than the one found for the whole time series. Between other consequences this might lead to artificial overestimations of the positive air temperature anomalies in the 2000s (Table 3).

The NAO index is widely used to characterize atmospheric conditions over the North Atlantic (Hurrell and Deser, 2010). 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 timeseries and winter NAO index timeseries 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 regional weather. That might explain the low correlation between two parameters.

In 2009 the atmospheric oscillation was slightly weaker than the long-term mean (1968–1996) that resulted in small negative NAO index of -0.4. No shift of the Icelandic Low was observed in winter 2009 (Figure 7). However, during the survey in October and November 2009 monthly sea level pressure fields were quite different from their long-term mean pattern (Figure 8). In October 2009, the Icelandic Low was shifted to the south and the pressure was higher than its long-term mean over the Irminger Sea and the Labrador Sea (Figure 8a, 8b). In November 2009, the Iceland Minimum strengthened considerably in comparison with October 2009, and the monthly long-term mean (Figure 8c, 8d), that strengthened the pressure gradients over both coasts of Greenland (Figure 8c).

The sea ice extent through the winter 2009 was close to its long-term mean in the study region. As an example, the sea ice extension in January 2009 is shown (Figure 9a). During June and July 2009 the sea ice melted faster than normally, probably because of the elevated air temperature (Figure 5). The ice boundary retreated significantly to the north along the east Greenland coast and in the Baffin Bay (Figure 9b). The low than normal ice extension in Baffin Bay was observed from June until October 2009 (Figure 9c). In November 2009 the ice started to grow fast due to unusually low air temperature and reach its long-term mean extension (Figure 9d).

Hydrographic Conditions

This chapter presents a short overview of the hydrographical condition west off Greenland during autumn 2009 in relation to long-term average conditions. 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, ISW and modified Irminger Sea Water (mISW) following the study of Myers *et al*., 2009 (Table 5). Deeper Labrador Sea Water and North-Atlantic Deep Water stay beyond the scope of this report.

In 2009, oceanographic observations during the survey were carried out at each fishery station and two standard ICES/NAFO sections (Figure 1). 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 1). 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 10). 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 (Station 199 in Figure 10). The potential temperature θ of the offshore ISW was slightly above 6°C and its salinity S exceeded 35.00 (Figure 10). The core of ISW at the most offshore station (Station 203 in Figure 10) was found at the upper 100 m and it deepened to 500 m water depth toward the shelf (Stations 200 and 201 in Figure 10).

The most offshore station occupied in 2009 (Station 203 in Figure 10) corresponds to the standard Cape Desolation Station 3, which was reported in ICES WGOH since 2001 (Stein, 2010). In 2009, no SPW was observed in the upper layer at this station in contrast to the previous two years (Figure 11). It might be due to strong and enduring storm winds, which were blowing west of Greenland during the survey in 2009 and kept the SPW over the shelf. The ISW was observed from the surface down to 650 m water depth that corresponds to unusually large thickness of the ISW layer. Even in 2003, when the warmest ISW was observed at Cape Desolation St. 3 (Stein, 2004), the vertical extension of the layer was less (Figure 11).

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 12) and it spread at least 110 km away from the shelf. The freshest water was observed to the east from the bank (Station 225 in Figure 12) with salinity as low as 32.56 and the salinity gradually increased offshore due to the mixing with underlying ISW. In 2009, the core of ISW (θ >6 °C, S>35.00) was found between 300 and 450 m water depth at the station 222 almost 40 km offshore (Figure 12).

The Station 222 at the continental slope at 900 m depth corresponds to standard Fyllas Bank Station 4 (e.g. Stein, 2002; Stein, 2004). In 2009, the potential temperature and salinity of SPW in the layer 0–75 m were close to their long-term mean (Figure 13). The ISW was observed at this location almost every autumn since 2003, and 2009 was not an exception. Furthermore, in 2009 the upper boundary of ISW was found at 200 m water depth that is the shallowest depth during the whole series of observations. The potential temperature and salinity of the ISW were comparable with those observed during the previous 6 years (Figure 13).

The general conclusions about the atmospheric and oceanic conditions west off Greenland in autumn 2009 are follows. The annual air temperature was higher than the long-term mean mostly due to the warmer winter and summer. The unusual low sea ice extent was observed from June to October, probably due to the high summer air temperatures, mentioned above. Despite the lower ice extent, the upper SPW layer was close to its long-term average condition. The potential temperature the ISW was lower than its maxima in 2003, but continued the warm phase started in early 1990s. The unusual large vertical extent of the Irminger Sea Water was observed at both standard stations that probably correspond to the larger volume of the ISW transported by WGC in 2009.

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
Angmagssalik	65.70	-37.93	Weather station
Egedesminde	68.51	-52.86	Weather station
Cape Desolation Station 3	60.45	-50.00	Oceanographic station
Fyllas Bank Station 4	63.88	-53.37	Oceanographic station

Table 2. Decadal air temperature (T_{air}) from 1990 to 2009. K(NAO, T_{air}) is a correlation coefficient between Hurrell winter NAO index and air temperature within corresponding decade.

Decade	T_{air}	K(NAO, T_{air})
1900–1909	-1.82	-0.5
1910–1919	-1.59	-0.7
1920–1929	-0.92	-0.7
1930–1939	-0.53	-0.6
1940–1949	-0.56	-0.9
1950–1959	-0.78	-0.2
1960–1969	-0.55	-0.4
1970–1979	-1.37	-0.3
1980–1989	-1.93	-0.7
1990–1999	-2.06	-0.6
2000–2009	-0.40	-0.5

Table 3. Annual air temperature at Nuuk station. T_{mean}(2000–2009) - mean air temperature from 2000 to 2009, T_{mean} (1971–2000) - mean air temperature from 1971 to 2000, T_{mean} (1876–2000) - mean air temperature from 1876 to 2000. $\Delta T_{1971-2000}$ is the difference between T_{mean}(2000–2009) and T_{mean} (1971–2000). $\Delta T_{1876-2000}$ is the difference between T_{mean}(2000–2009) and T_{mean} (1876 – 2000).

T_{mean} (2000–2009)	-0.40
T_{mean} (1971–2000)	-1.76
T_{mean} (1876–2000)	-1.34
$\Delta T_{1971-2000}$	+1.36
$\Delta T_{1876-2000}$	+0.94

Table 4. Winter Hurrell winter NAO index (NAO) and annual air temperature (T_{air}) from 2000 to 2009. $\Delta T_{1976-2000}$ is the air temperature anomaly, referenced to the long-term mean 1971–1990. $\Delta T_{2000-2009}$ is the air temperature anomaly, referenced to decadal mean 2000–2009.

Year	NAO	T_{air}	$\Delta T_{1976-2000}$	$\Delta T_{2000-2009}$
2000	2.8	-0.8	1.0	-0.4
2001	-1.9	-0.1	1.6	0.3
2002	0.8	-1.1	0.7	-0.7
2003	0.2	0.6	2.3	1.0
2004	-0.1	-0.4	1.4	0.1
2005	0.1	0.2	2.0	0.6
2006	-1.1	-0.2	1.5	0.2
2007	2.8	-0.6	1.2	-0.2
2008	2.1	-1.1	0.7	-0.7
2009	-0.4	-0.6	1.2	-0.2

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)	$\theta \geq 4.5$	$S \geq 34.95$
Modified Irminger Sea Water (mISW)	$3.5 \leq \theta \leq 5$	$34.88 < S < 34.95$

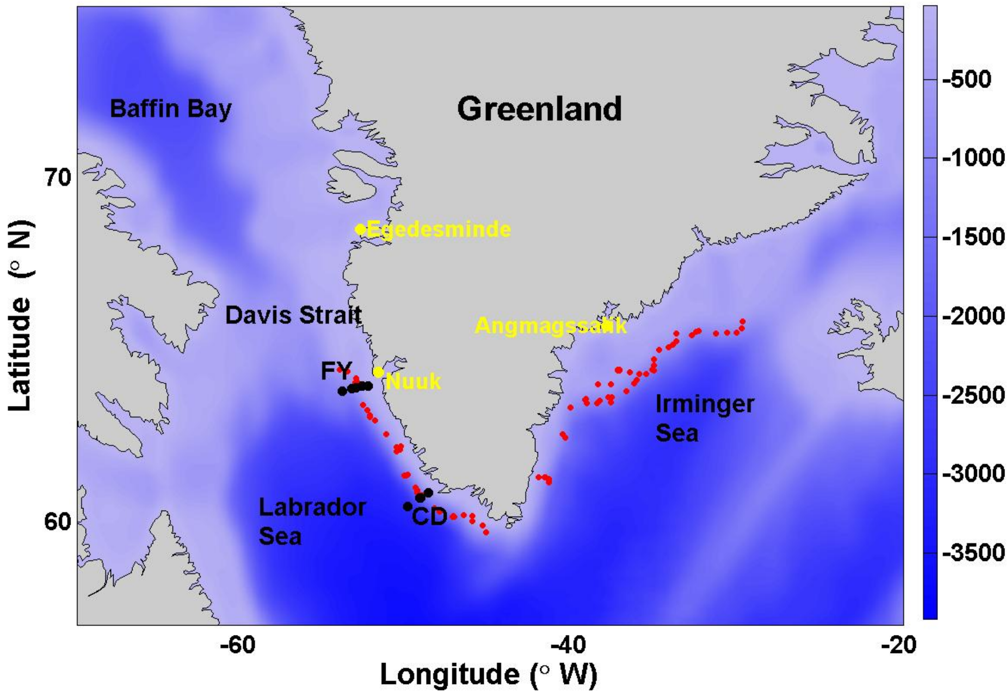


Figure 1. Map and bathymetry of the study region. Meteorological stations location is shown in yellow. Red dots show the location of the fisheries stations, occupied during the survey in 2009. Black dots mark two standard sections (CD – Cape Desolation section, FY – Fyllas Bank Section).

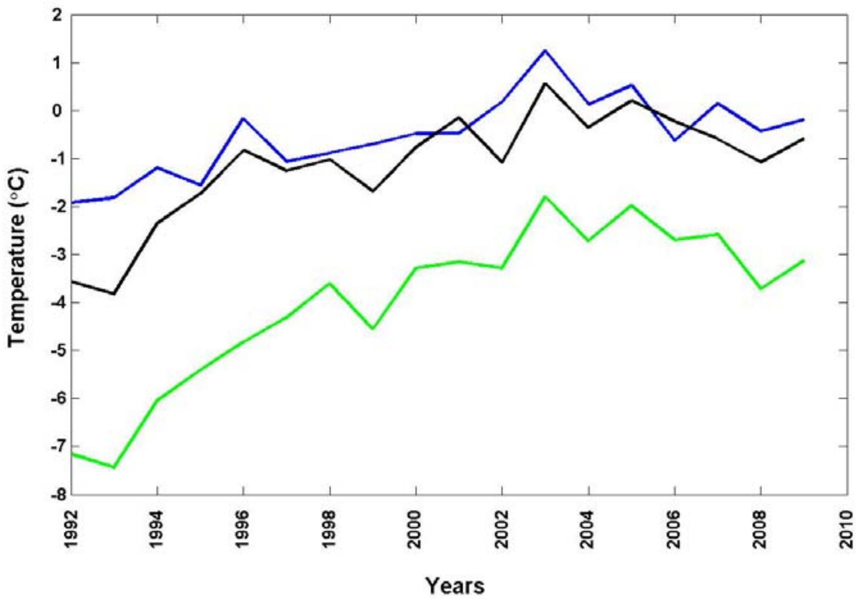


Figure 2. Annual mean air temperature at Angmagssalik (blue), Egedesminde (green) and Nuuk (black) stations. Location of the station is shown in Figure 1 and in Table 1.

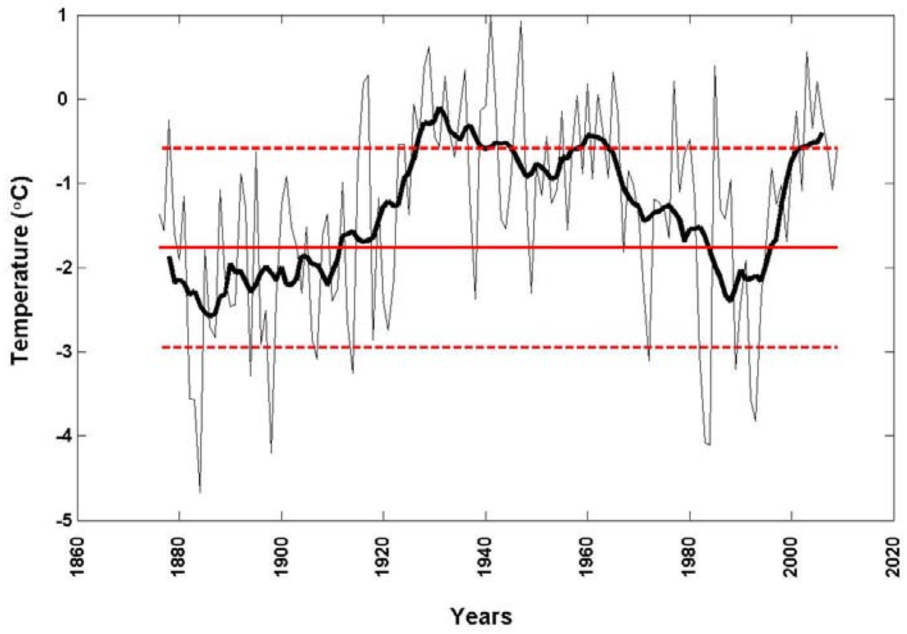


Figure 3. Annual mean air temperature at Nuuk station. Thick black line shows the 5-year smoothed data. Red solid line indicates the long-term mean temperature, referenced to 1971–2000. Dashed red lines mark corresponding standard deviations.

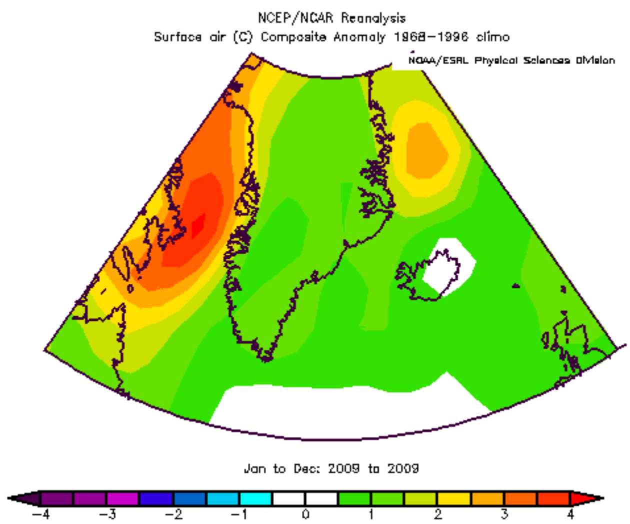


Figure 4. Map of 2009 annual air temperature anomalies in the study region. The long-term mean corresponds to 1968–1996. Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado.

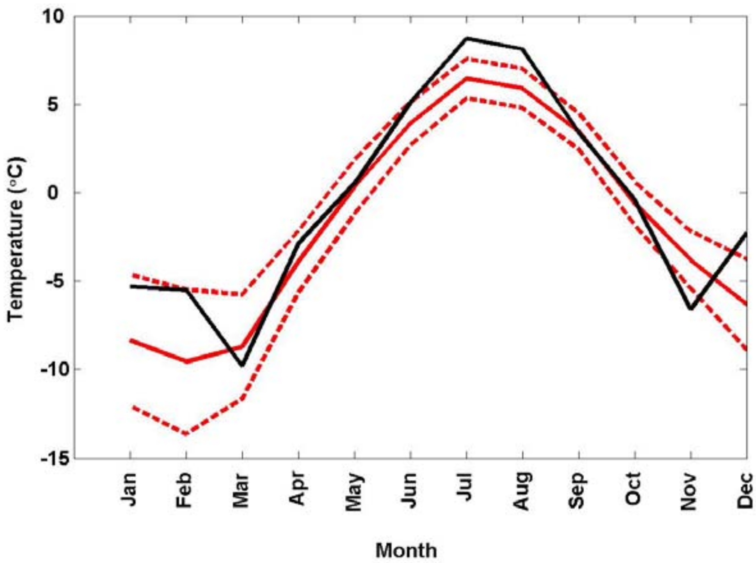


Figure 5. Monthly mean temperature at Nuuk station. Monthly mean temperature in 2009 (black line), long-term monthly mean temperature (red solid line) and one standard deviation (red dashed lines) are shown.

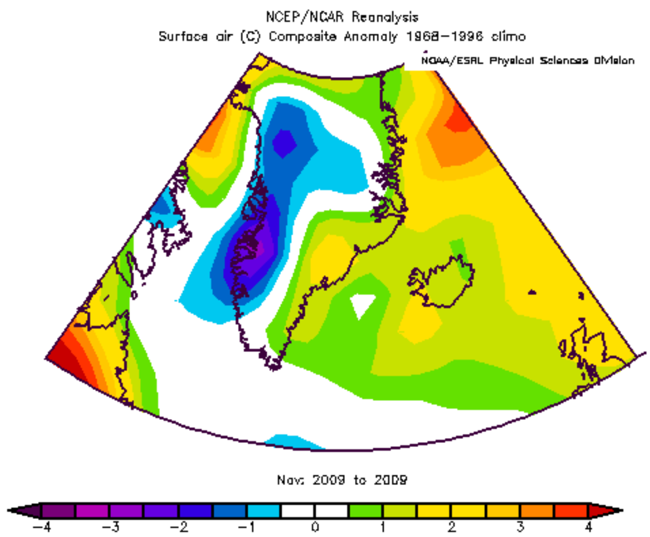


Figure 6. Map of 2009 November air temperature anomalies in the study region. The long-term mean corresponds to 1968–1996. Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado.

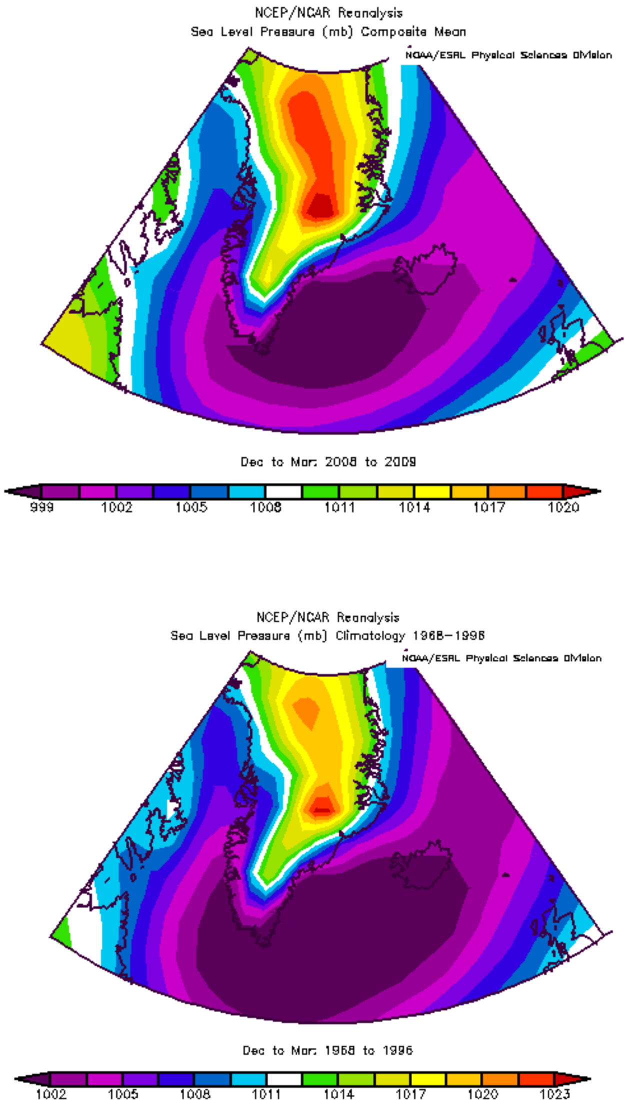


Figure 7. Maps of winter (DJFM) sea level pressure (SLP). Upper panel: mean SLP in winter 2009. Lower panel: mean winter SLP from 1968 to 1996. Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado.

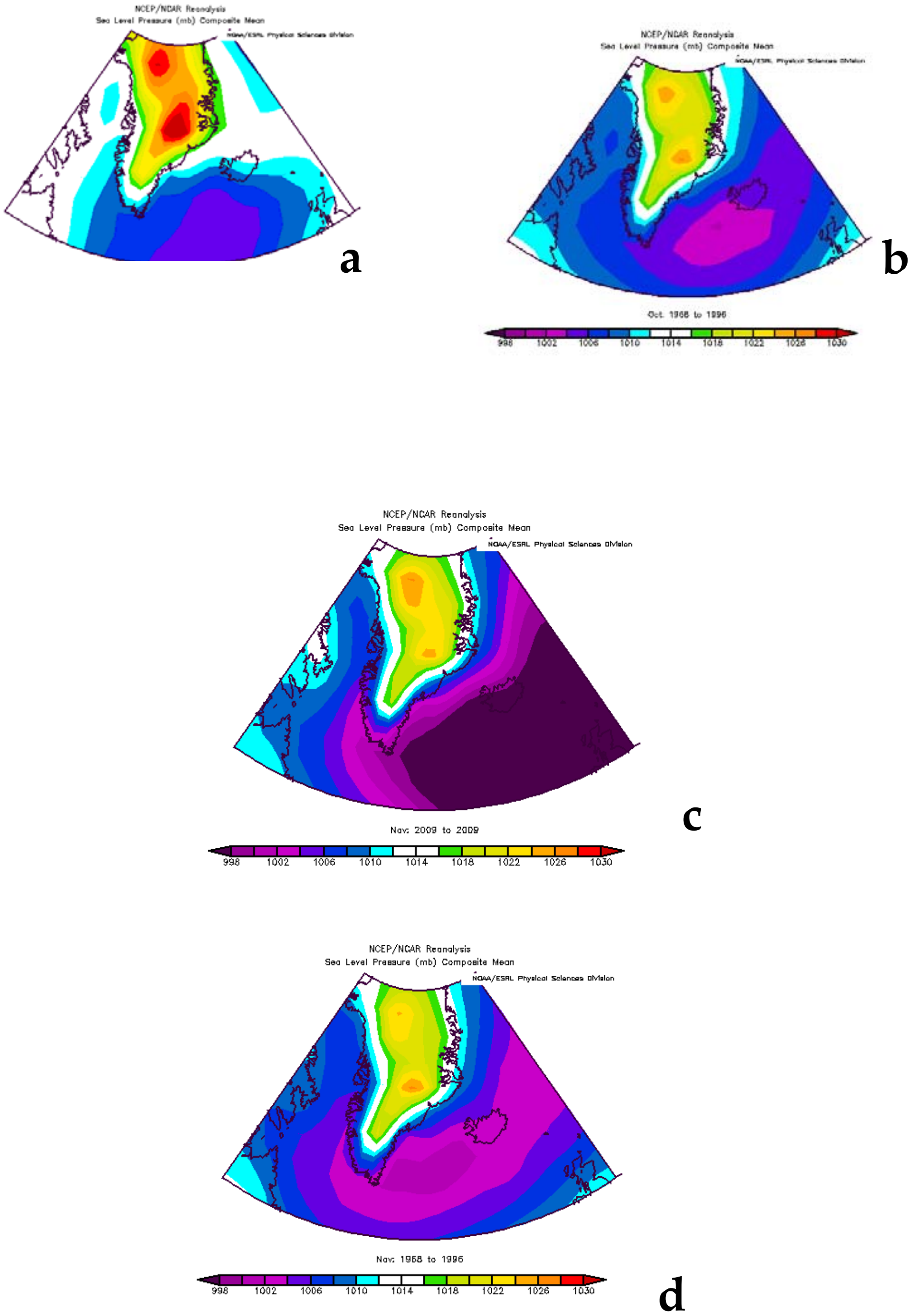


Figure 8. Sea level pressure during the survey in October (a) and November (c) 2009. Long-term (1968-1996) mean pressure distribution for October (b) and November (d) are shown. Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado.

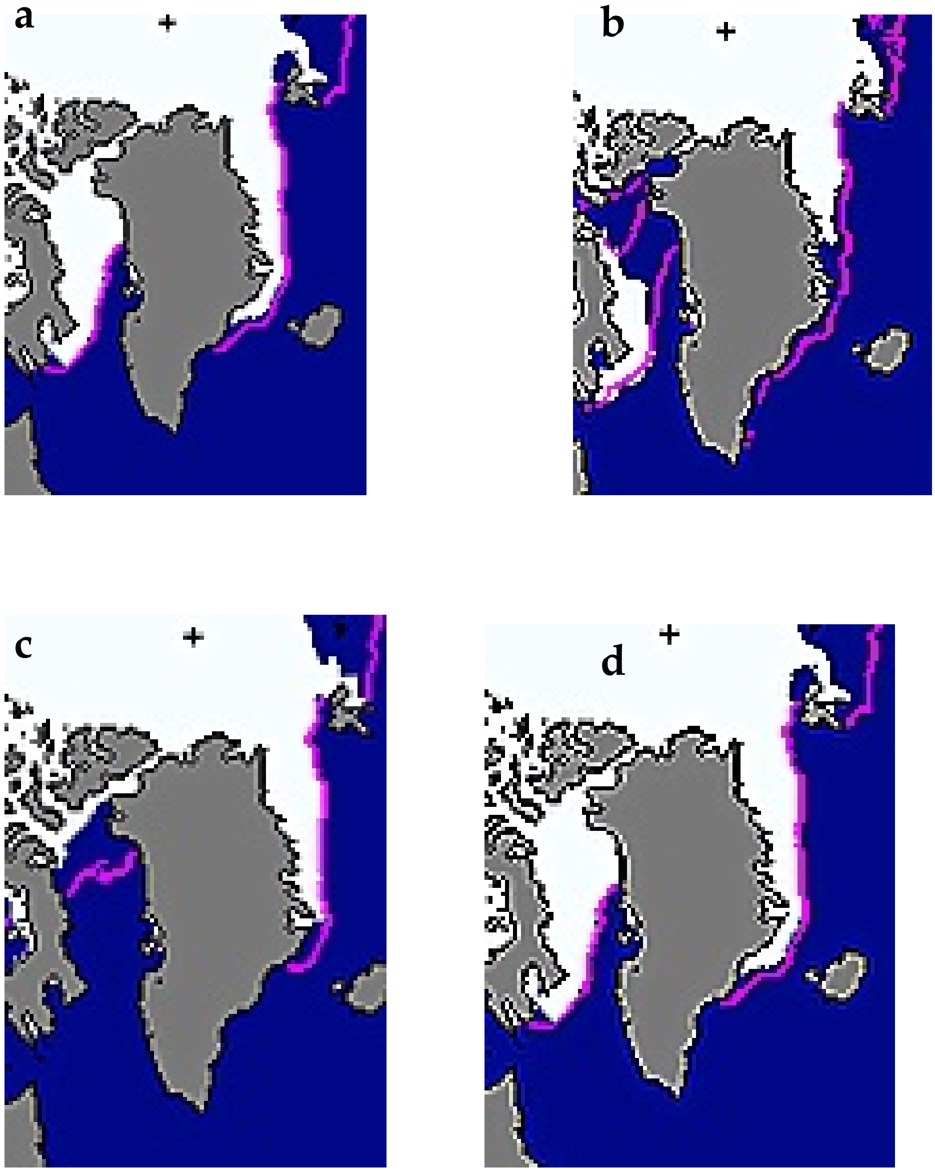


Figure 9. Sea ice extension in January (a), July (b), October (c) and November (d) 2009. Long-term mean ice extension (1971–2000) is marked by a purple line. The National Snow and Ice Data Center, Boulder, Colorado: Fetterer *et al.*, 2002, updated 2009.

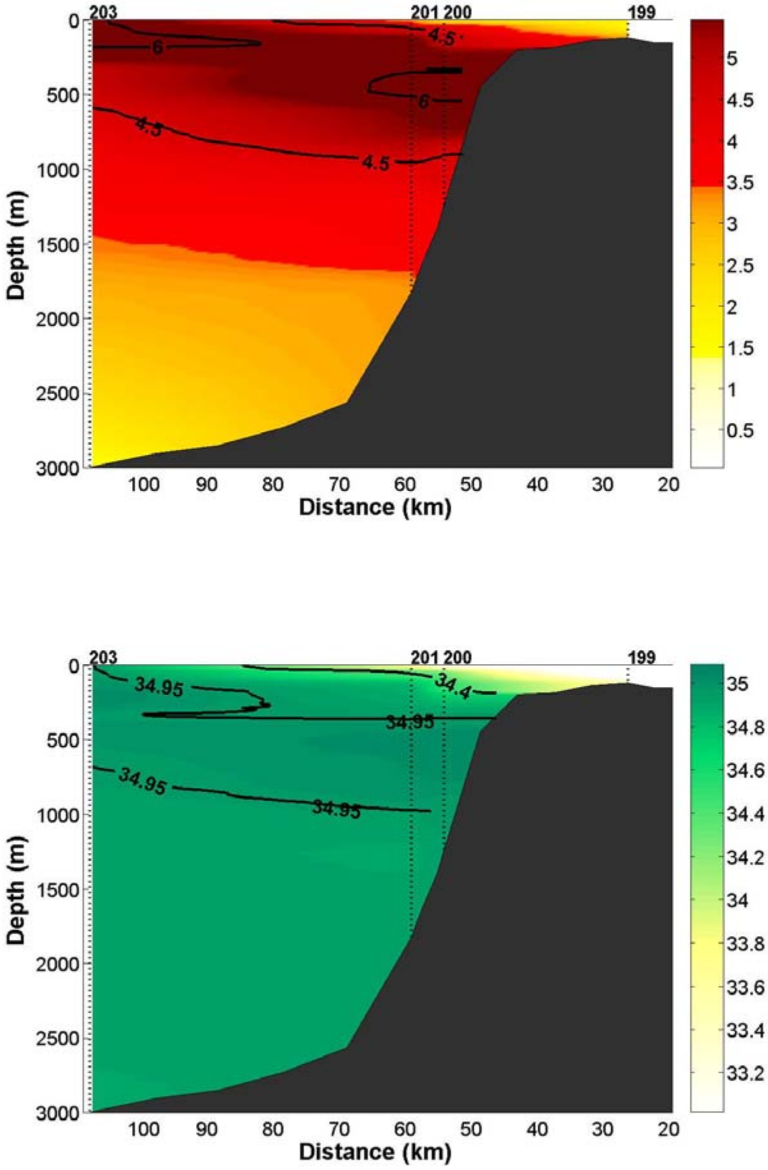


Figure 10. Vertical distribution of potential temperature (upper panel) and salinity (lower panel) along the Cape Desolation section (Figure 1) in 2009. The x-axis shows the distance from the Greenland shore.

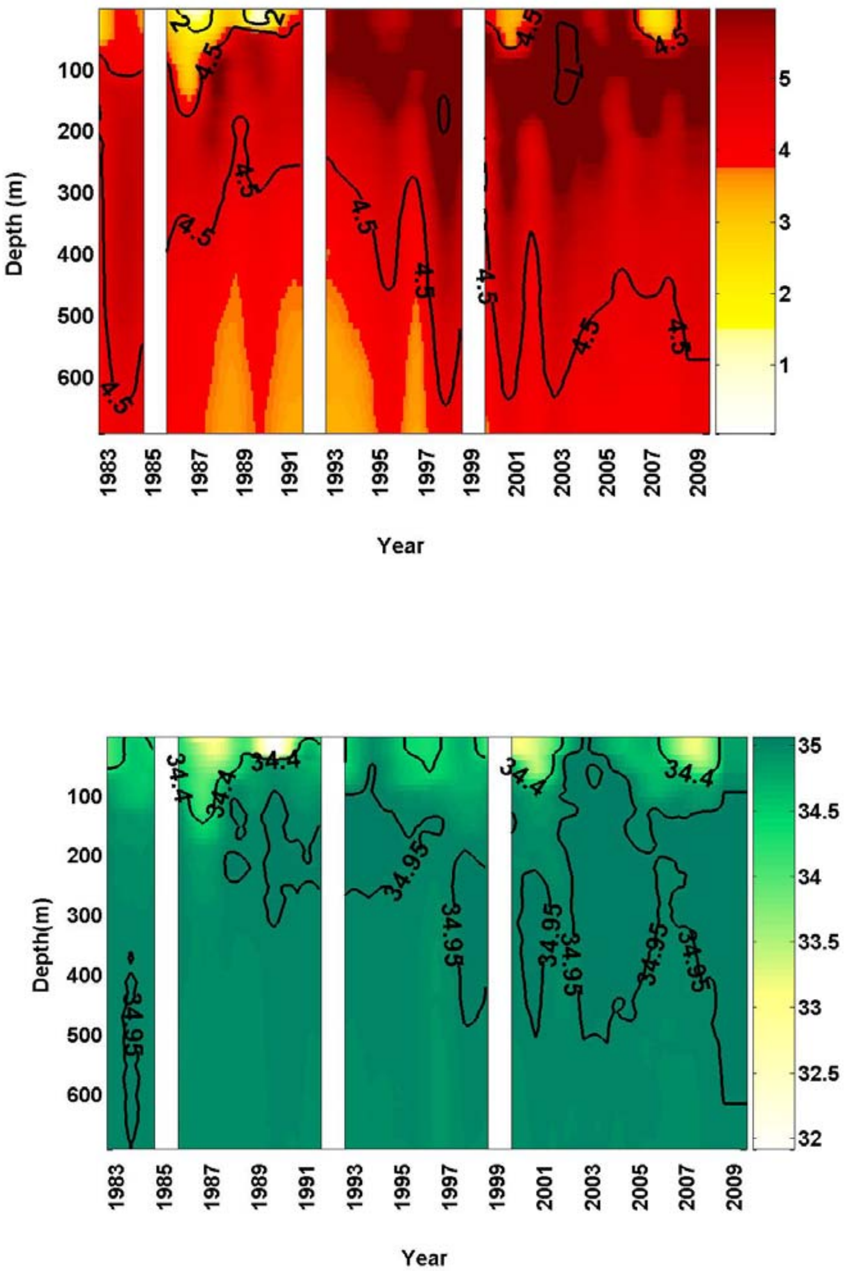


Figure 11. Hovmoeller diagram of the potential temperature (upper panel) and salinity (lower panel) in the upper 700 m at Cape Desolation Station 3 (Table 1).

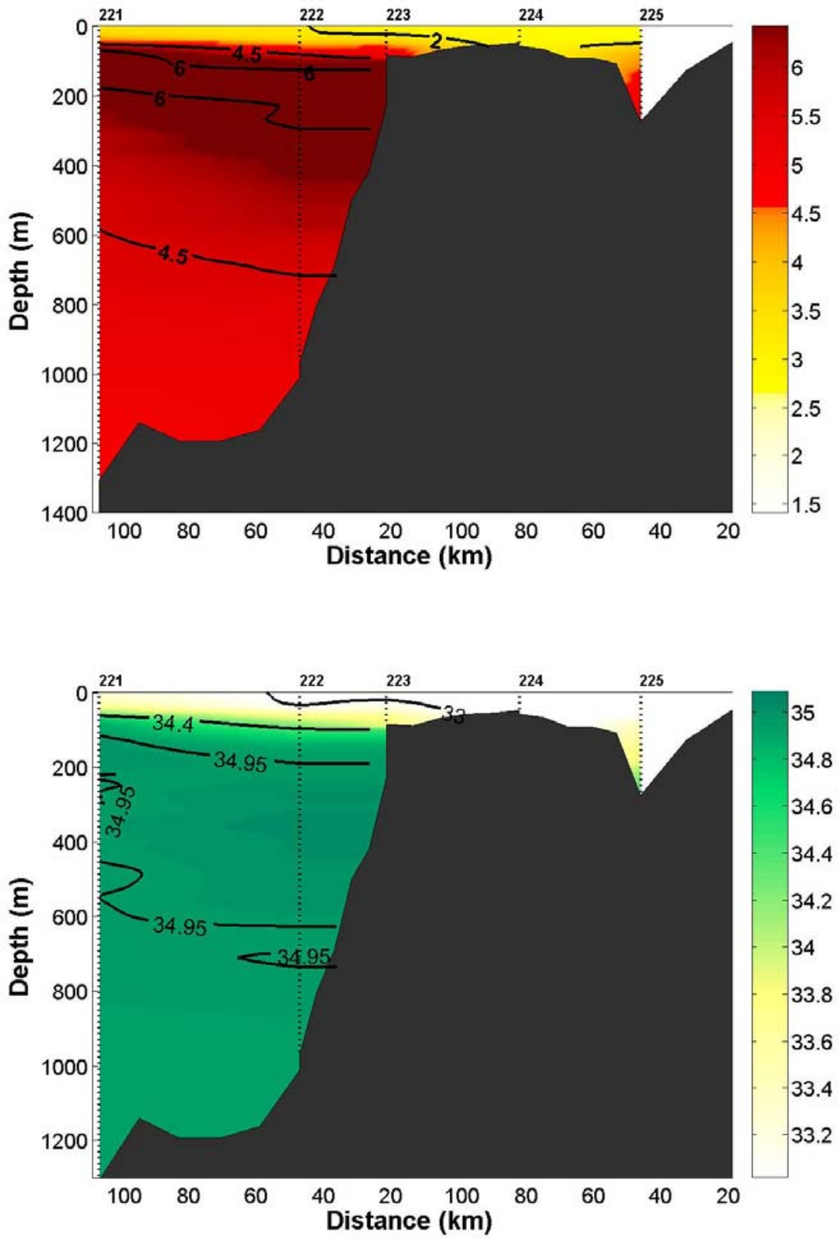
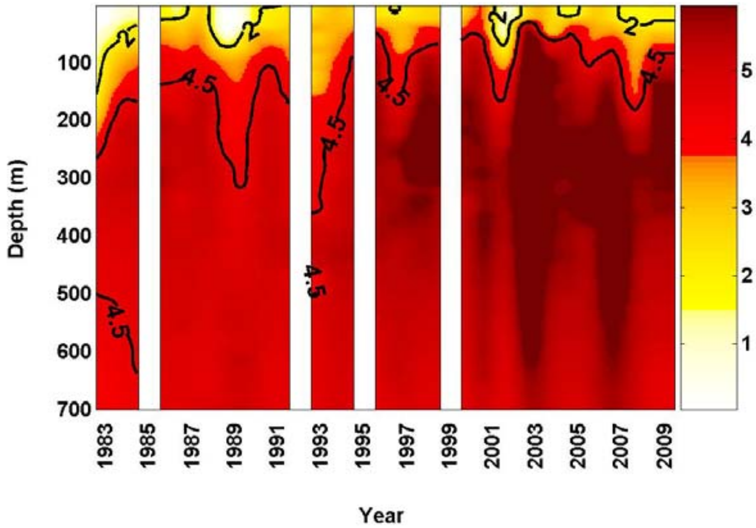


Figure 12. Vertical distribution of potential temperature (upper panel) and salinity (lower panel) along Fyllas Bank section (Figure 1) in 2009. The x-axis shows the distance from the shore.



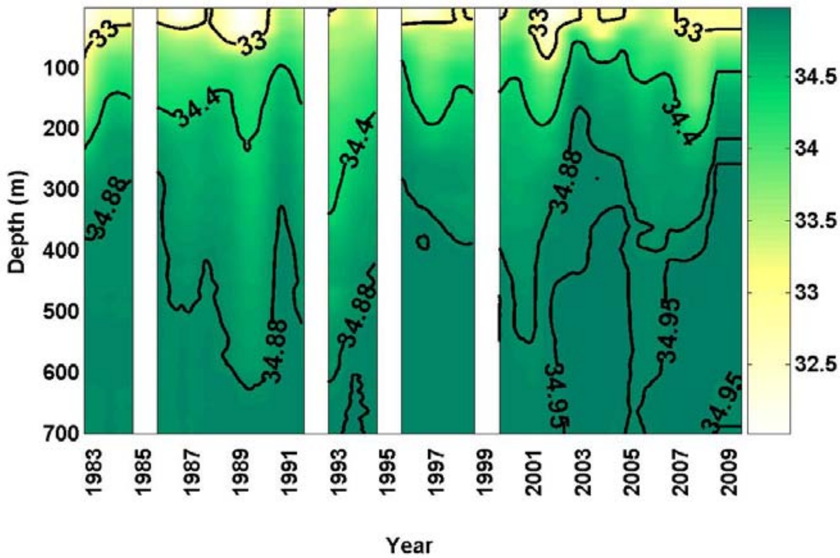


Figure 13. Hovmoeller diagram of the potential temperature (upper panel) and salinity (lower panel) in the upper 700 m at Fyllas Bank Station 4 (Table 1).

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Annex 7: Regional Reports – National report standard sections and stations, the Netherlands

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From September 23 to October 13, 2009 a hydrographic survey of the former WOCE AR7E section was carried out by RV Pelagia, cruise 64PE312. CTD observations were performed with a station distance of about 30 nautical miles (Figure 1). Because of favourable weather conditions All planned, stations, apart from one over the Rockall-Hatton plateau were occupied, and an additional small section was surveyed in the Rockall Trough. At each station a CTD cast from the sea surface to within 10 m from the bottom was recorded. No water samples were collected.

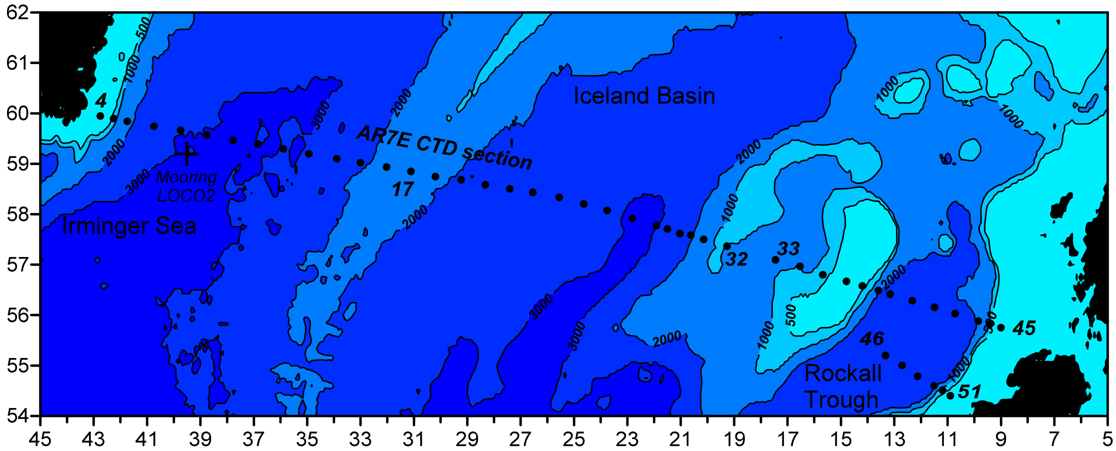

Figure 1. Hydrographic sections, occupied during Pelagia cruise 64PE312, in September-October 2009. CTD casts were recorded at all stations 4 to 45 along the former WOCE AR7E section, as well as at stations 46 to 51 along an additional section in the Rockall Trough.

Preliminary results

The Irminger Sea (region 5a)

The θ-S diagram for the CTD stations in the Irminger Sea (Figure 2) shows that the most saline water in this basin is observed over the Reykjanes Ridge (stations 15 to 17) and over the continental slope of Greenland (stations 6 and 7).

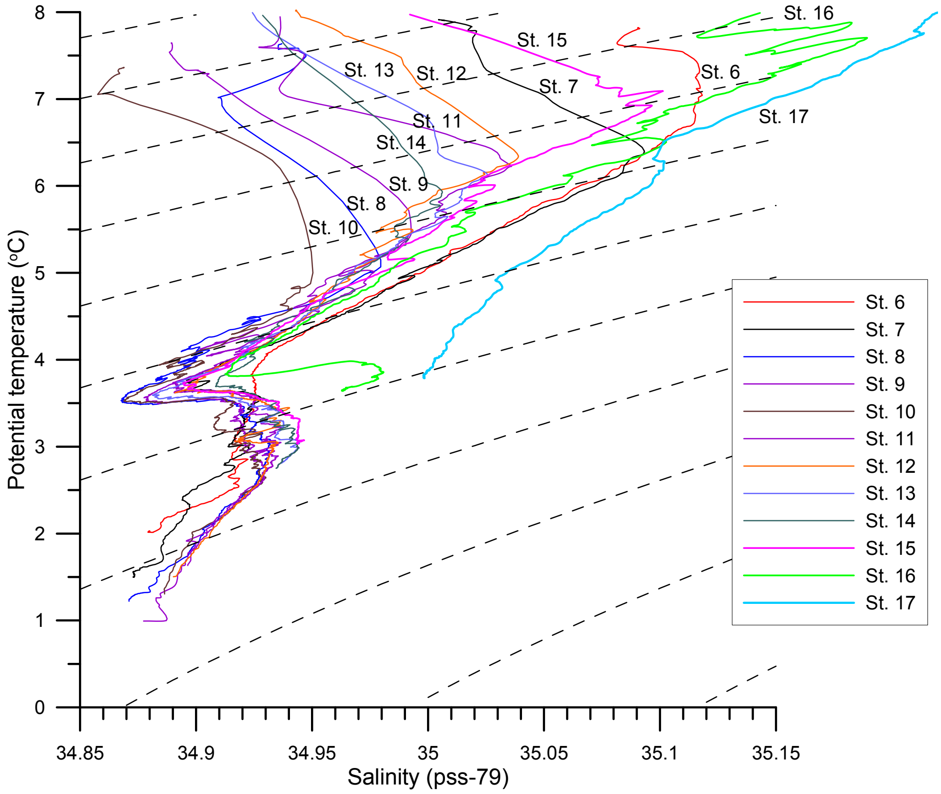

Figure 2. θ-S diagram for the CTD stations in the Irminger Sea, from the Greenland continental shelf to the top of the Reykjanes Ridge.

After the cold winter of 2008 a cold and fresh Sub-Arctic Mode Water was formed in the Irminger Sea with a potential temperature of about 4.5°C and a salinity of 34.85. During the THOR cruise from 2009 the central Irminger Sea was strongly salinified compared to 2008, with sub-surface salinity maxima from 34.93 to 35.01 near the density levels of the 2008 Mode Water.

At the levels of the Labrador Sea Water (LSW) class or vintage, formed in 2000, the θ-S properties hardly had changed compared to 2007. No trace was found yet of the Labrador Sea Water vintage, formed by deep convection in 2008. The high-density Labrador Sea water formed in the cold period of 1988 to 1994 (LSW_{94}), and still visible as a deep salinity minimum in the Irminger Sea in 2007 could not be recognized in 2009 from the θ-S properties.

The near-bottom temperatures and salinities in the homogeneous near-bottom layers in the western half of the Irminger Sea reflect that the temperature and salinity of the Denmark Strait Overflow Water is colder and less saline than observed during hydrographic surveys in 2007 and 2008.

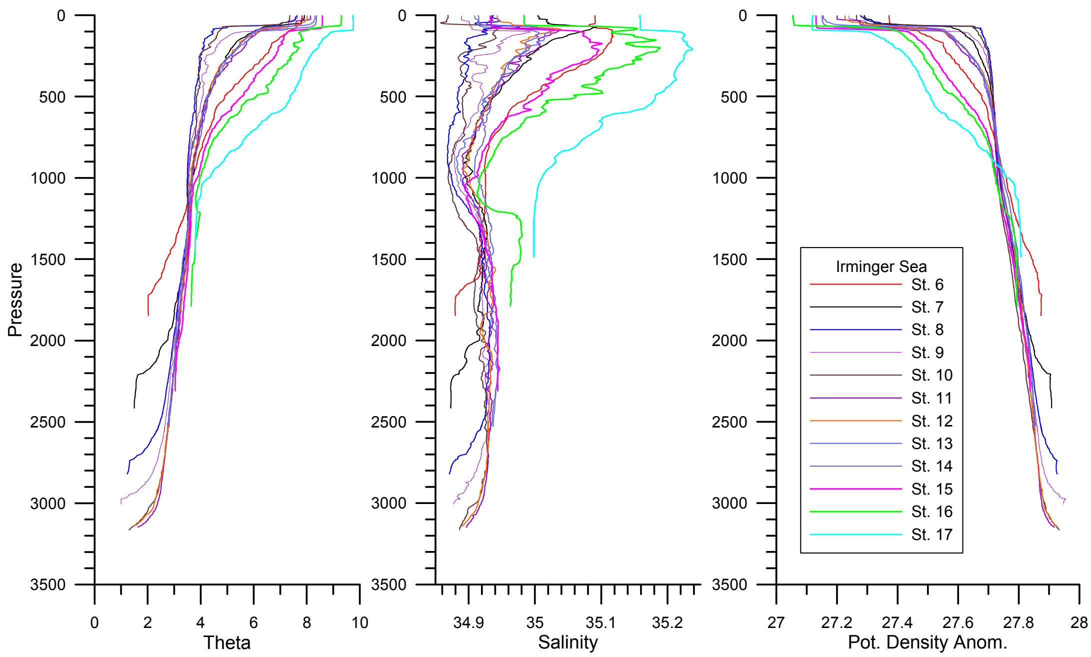

Figure 3. Profiles of potential temperature, salinity, and potential density anomaly from the CTD casts in the Irminger Sea.

The hydrographic profiles from the Irminger Sea (Figure 3) show a doming of the isopycnals in the cyclonic Irminger gyre (part of the sub-arctic gyre), with stations 8 to 10 in the centre of the gyre. These stations also show the lowest sub-surface salinities and temperatures. The density distribution in the upper 1000 m agrees with a southward baroclinic geostrophic transport west of station 8 relative to 1000 dbar of about 1.5 Sv (1 Sv = 10^6 m^3/s), and a northward transport between station 8 and station 17 over the Reykjanes Ridge of about 4.4 Sv.

The deep density differences between neighbouring CTD-stations over the continental slope of Greenland agree with a strong bottom intensified southward flow of Denmark Strait Overflow Water (DSOW) along the Greenlandic slope. The deep density gradient between stations 15 and 17 suggest a northward baroclinic flow of the saline Icelandic Slope Water en the upper parts of the North East Atlantic Deep Water along the Reykjanes ridge.

The Iceland Basin

In the upper layers of the Iceland Basin the main difference with the 2007 survey is a less strong gradient in the frontal zone of the North Atlantic Current in 2009. The range of the near surface salinity in the Iceland Basin is similar in both years.

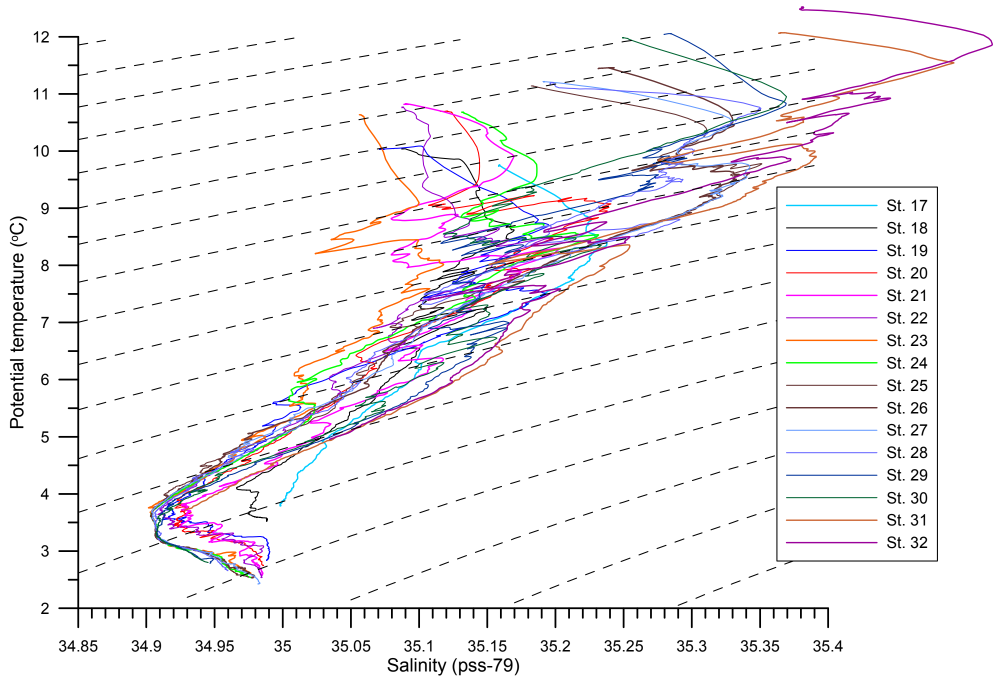

Figure 4. θ-S diagram for the CTD stations in the Iceland Basin between the Reykjanes Ridge and the Hatton Bank.

The θ-S diagram and the hydrographic profiles for the 2009 survey of the Iceland Basin (Figures 4 and 5) again show a thick layer with a salinity minimum. This is a combination of the LSW vintages formed in 1988 to 1994 and in 2004. The latter occupied the deeper part of the basin and is absent west of 27°W. The salinity value in the salinity minimum connected with the LSW2000 vintage has increased with over 0.01 since 2007. The salinity increase of the LSW94 class since 2007 is smaller, ~0.007. The relative salinity maximum, connected with the intermediate saline layer between both LSW cores increased in salinity value, but decreased in amplitude, compare to the salinities of both LSW cores.

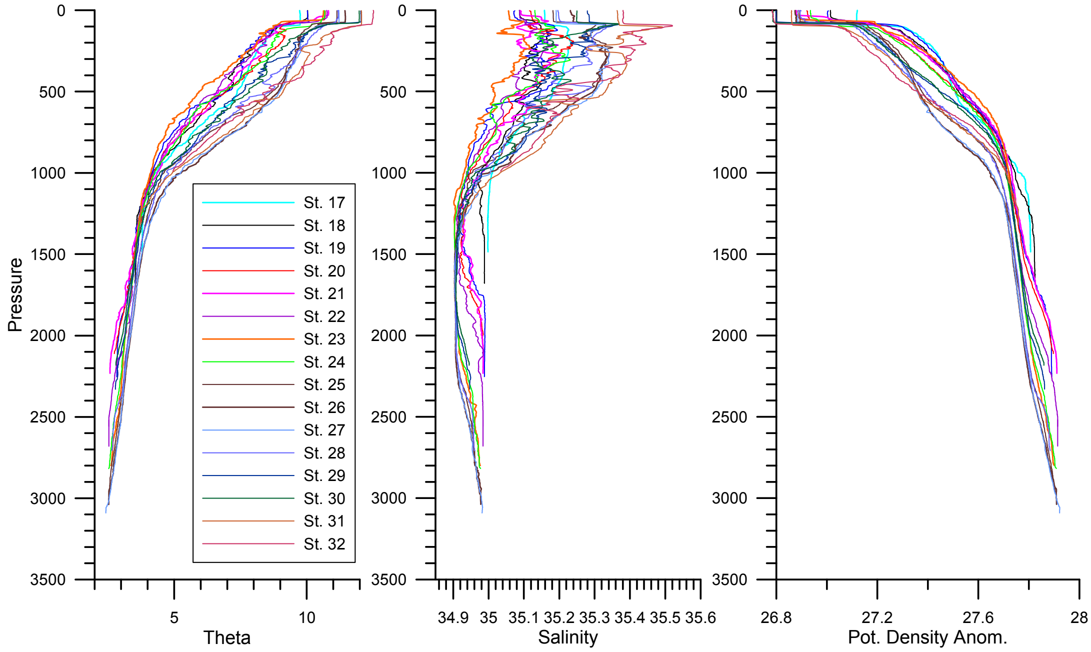

Figure 5. Profiles of potential temperature, salinity, and potential density anomaly from the CTD casts in the Iceland Basin.

As in 2007 a near bottom layer of Iceland-Scotland Overflow (ISOW) water can be recognized as the coldest water over most of the western slope in the Iceland Basin. The salinity and potential temperature of this water type in 2009 is warmer and more saline than in 2007. ISOW shows in the hydrographic profiles as a thick layer with near homogeneous, relatively high salinity. The relatively high potential density in these ISOW layers agrees with a baroclinic bottom intensified southward flow of ISOW over the western slope of the Iceland Basin. East of the deepest point in the Iceland Basin, The Maury Channel, the bottom density is also relatively high compared to the same levels at the station in the Iceland Basin further west, indicative for a bottom intensified northward baroclinic flow over the slope of the Hatton Bank. The usual near-bottom salinity minimum due to the presence of Lower Deep Water in this northward flow is absent in the 2009 data.

The Rockall Trough

Compared to the Irminger and Iceland Basins, the Rockall Trough does show less intrusive structures (Figure 6). Overall the θ-S structure in 2009 hardly differs from the structure observed in 2007. The salinity minimum near θ = 3.2°C, connected with the presence of a core of LSW, decreased in salinity with only about 0.003 over the last 2 years.

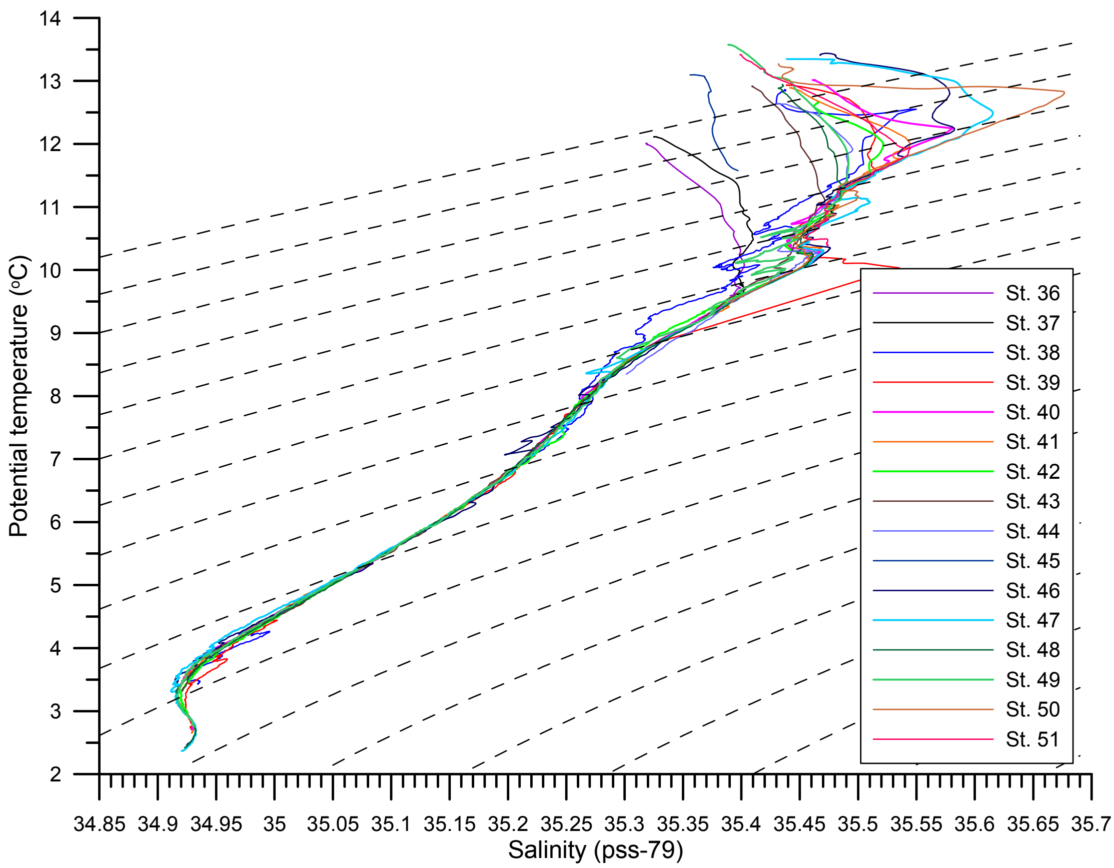

Figure 6. θ-S diagram for the CTD stations in Rockall Trough.

Below the salinity minimum of the LSW core, a salinity maximum of slightly over 34.93 is observed at a depth of about 2700 m, related to the aged ISOW. Near the bottom near 2900 m on the additional CTD section a salinity minimum of S = 34.92 is observed, related to the presence of the upper layers of Lower Deep Water (LDW), extending from the Porcupine Abyssal Plain into the Rockall Trough. The low salinity is caused by the presence of small amounts of Antarctic Bottom Water in the LDW. In 2007 the LDW reached further north, and could also be observed at the CTD station on the AR7E section.

Annex 8: Regional Reports – Area 3 – Icelandic Waters

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Marine Research Institute, Reykjavík

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.

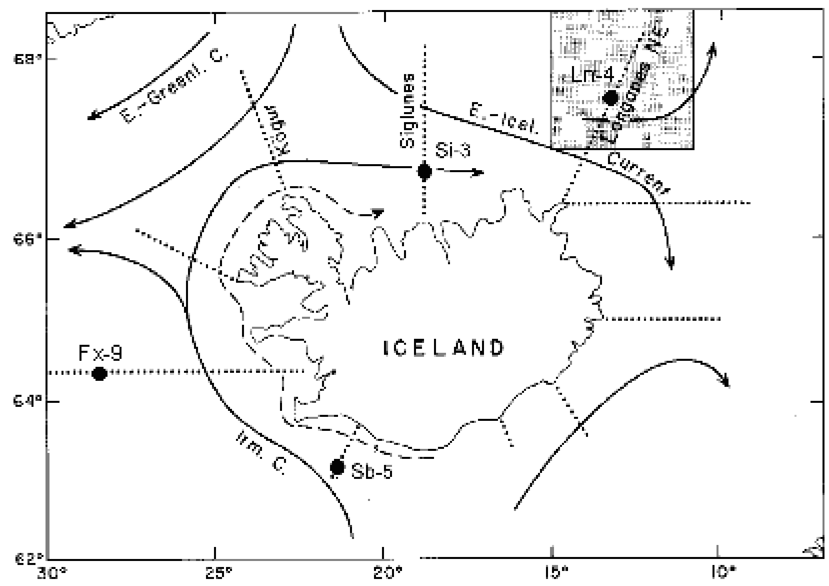

Figure 1. Main currents and location of standard hydro-biological sections in Icelandic waters. Selected areas and stations dealt with in this report are indicated.

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 2009 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 3b, 5 and 7), with the highest salinity in almost forty years occurring in 2009. The salinity in the East Icelandic Current in spring

2009 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, improving the 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 2009. In 2009 summer and autumn surface layers temperatures and salinities were high in the north especially the latter half of the year.

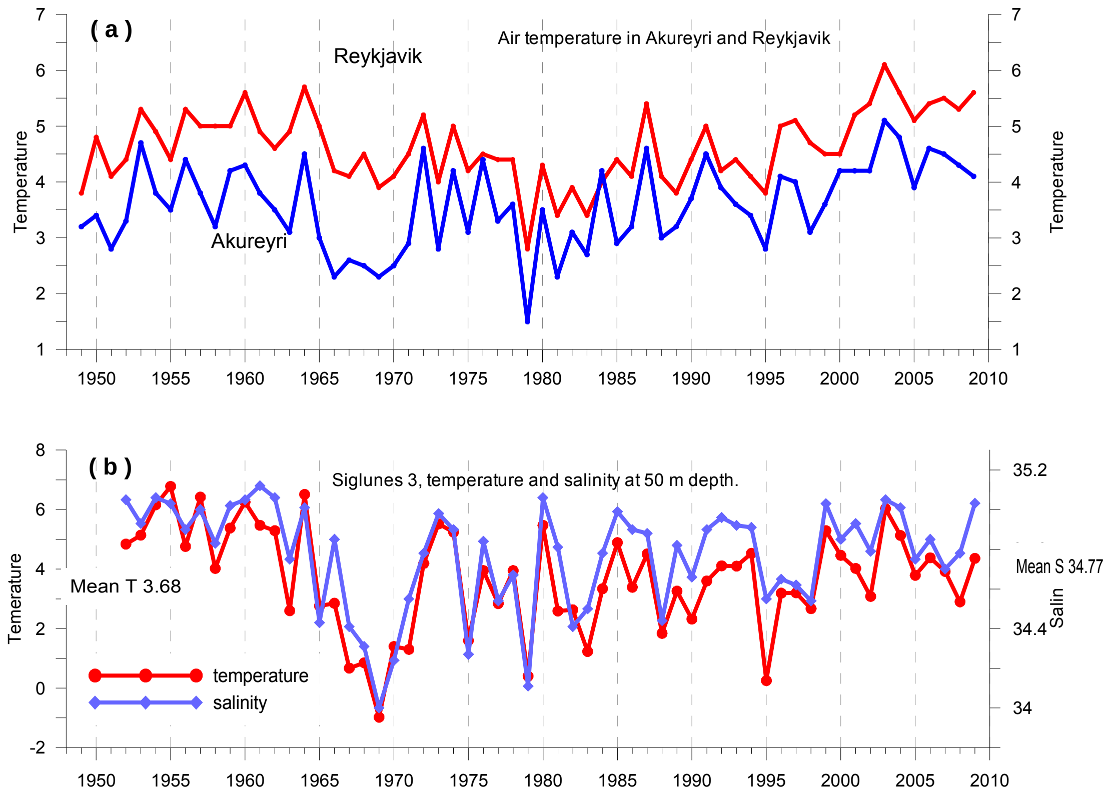

Figure 2.

a. Mean annual air-temperatures in Reykjavík and Akureyri 1949–2009

b. Temperature and salinity at 50 m depth in spring at Station Si-3 in North Icelandic waters 1952–2009

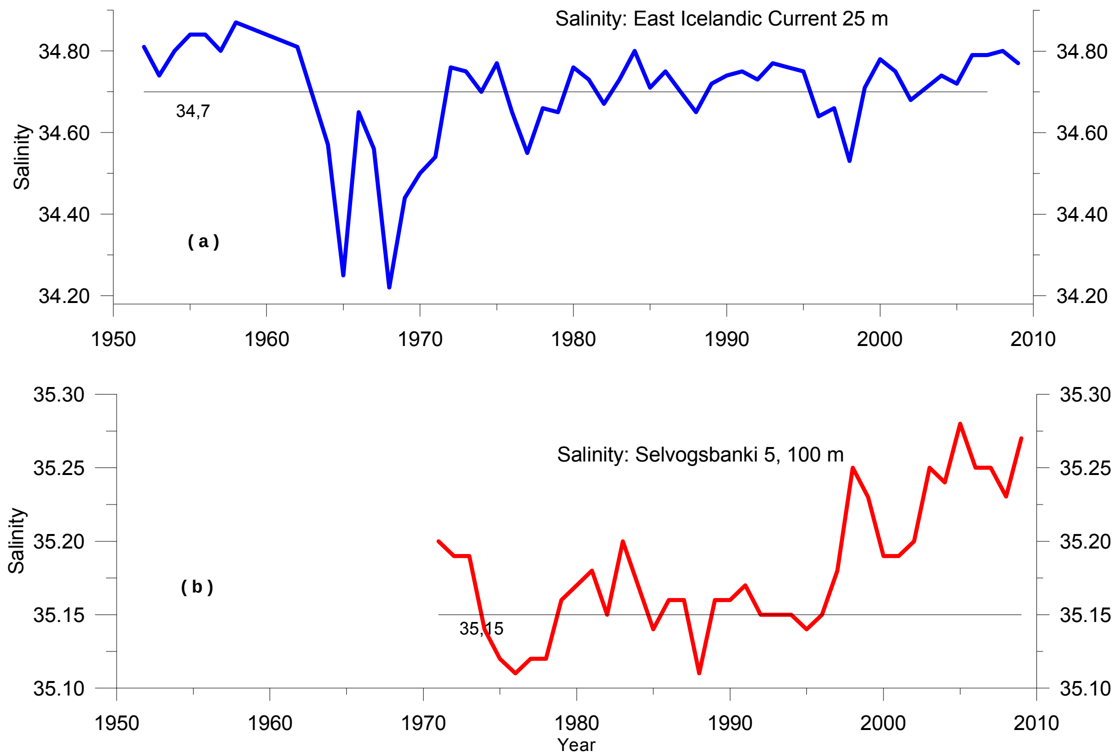

Figure 3. Salinity in spring at:

a. 100 m depth in the Irminger Current south of Iceland (Sb-5) 1971–2009

b. 25 m depth in the East Icelandic Current north-east of Iceland 1952–2009, mean from shaded area in Figure 1

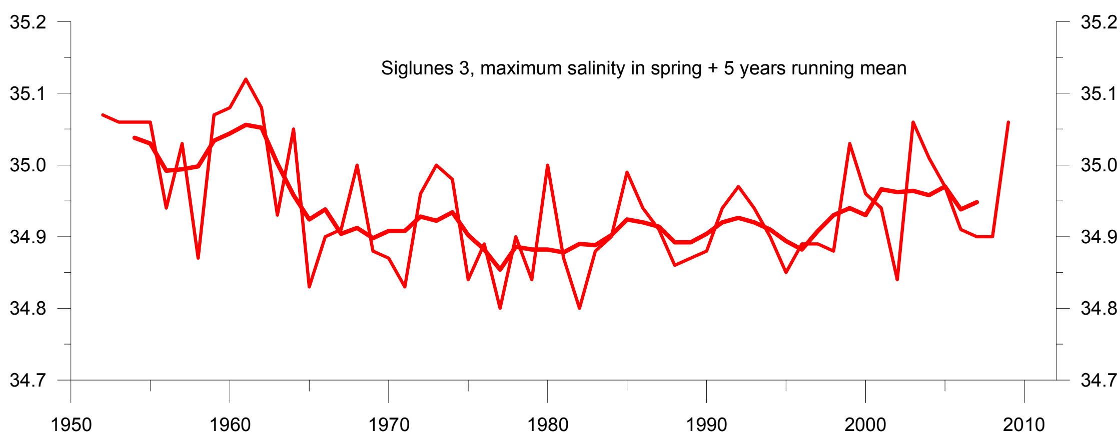

Figure 4. Maximum salinity in the upper 300 m in spring at station Si-3 in North Icelandic waters 1952–2009 and 5 years running mean.

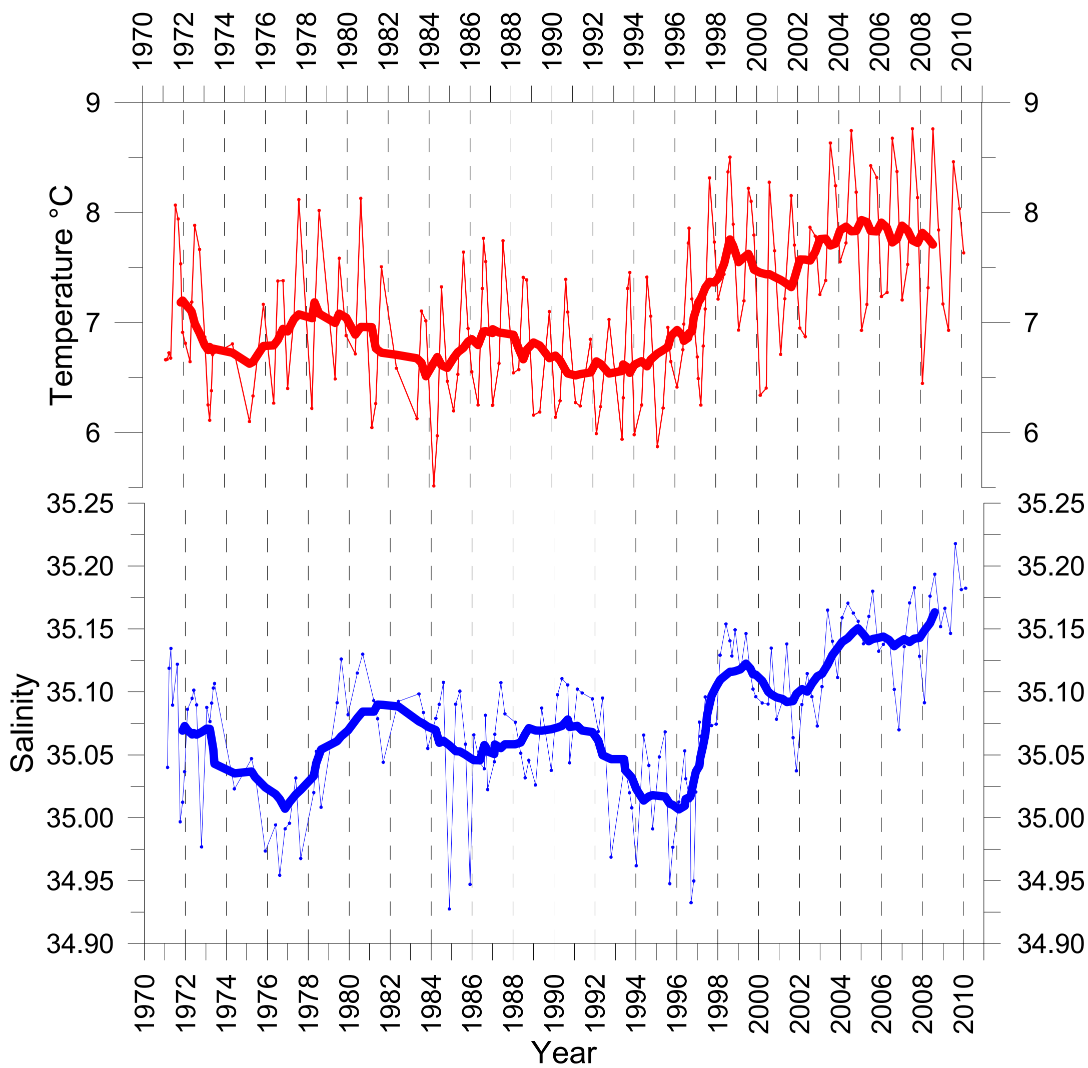

Figure 5. Mean temperature 0–200 m at the shelf brake west of Iceland, 1971–2010. Combined data from stations RE8 (1971–1984) and FX9 (1984–2010), 20 nm apart. Thick line is approx. 3 years running mean.

Annex 9: Regional Reports – Faroe Waters

Karin Margretha H. Larsen and Bogi Hansen

Hydrographic conditions in Faroe waters are monitored by regular CTD cruises along four standard sections, usually four times a year. In addition, a total of 9 ADCPs are moored on three of these sections (Figure 1). These activities are designed to monitor the properties (T and S) and volume transport of the Faroe Bank Channel (FBC) overflow and two Atlantic inflow branches: the Faroe Current north of the Faroes, and inflow through the Faroe-Shetland Channel (FSC) (together with the Marine Laboratory in Aberdeen that also has 2–3 ADCP moorings on the Scottish side of the Faroe-Shetland Channel).

Time series plots of the temperature (Figure 2) and the salinity (Figure 3) of the Atlantic water on the section across the FBC and northwards from the Faroes show that the increased temperatures and salinities from the mid-1990s still persist. Salinities increased in 2009 and were record high in November 2009, while temperatures were similar to the temperatures in the earlier years of this century.

The conditions still remain exceptionally warm and probably also saline in a century-long perspective as indicated by the Faroe coastal temperature time-series (Figure 4), although, like all coastal and shelf time-series, it is affected by atmospheric and terrestrial effects. In 2009 the annual averaged Faroe coastal temperature was equal to the record high temperature in 2003.

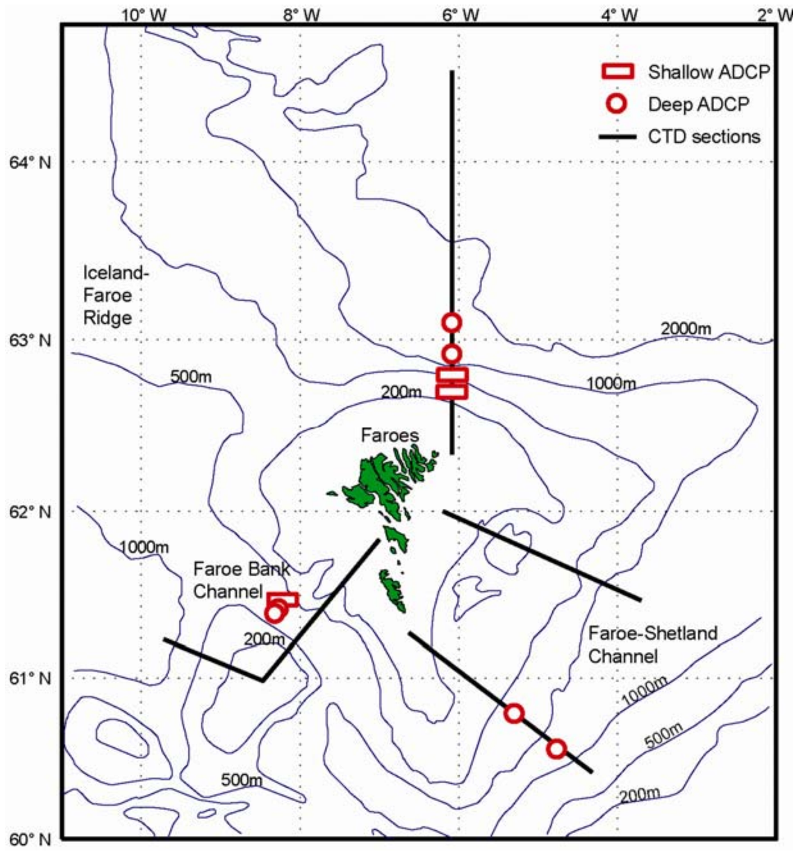

Figure 1. Standard sections (black lines) and moored ADCPs at the top of traditional moorings (red circles) or in trawl-protected frames (red rectangles). The two FSC standard sections are identical to those monitored by the Marine Laboratory in Aberdeen.

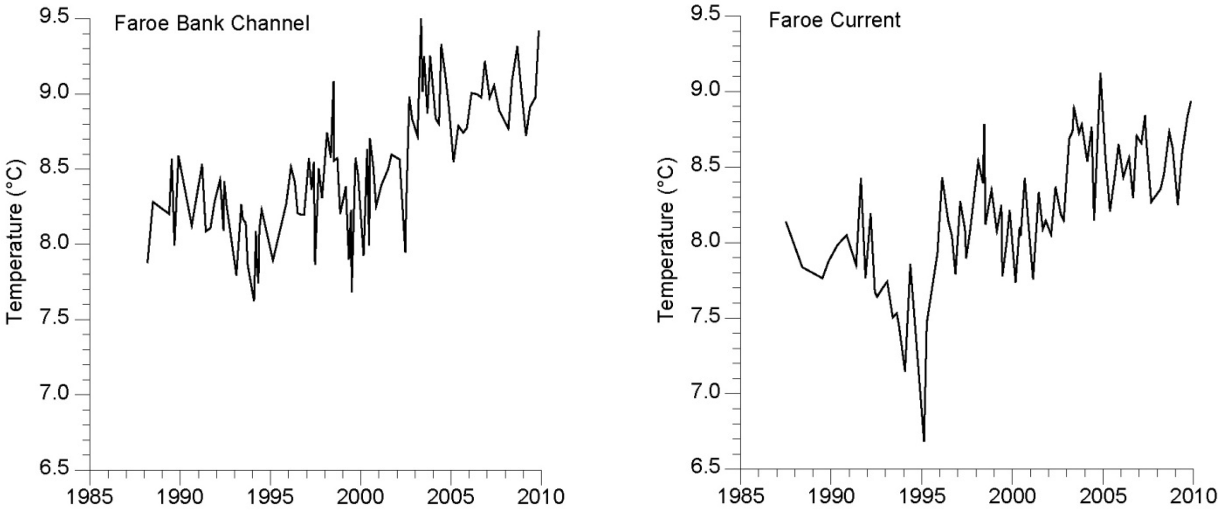

Figure 2. De-seasoned temperature from individual cruises in the FBC (left panel) and the core of the Faroe Current (right panel). In the FBC, the figure represents the average temperature in the 100–300 m layer from the two deepest stations. In the Faroe Current, the figure represents the average temperature in that 50 m layer on the section that has the highest salinity (the core).

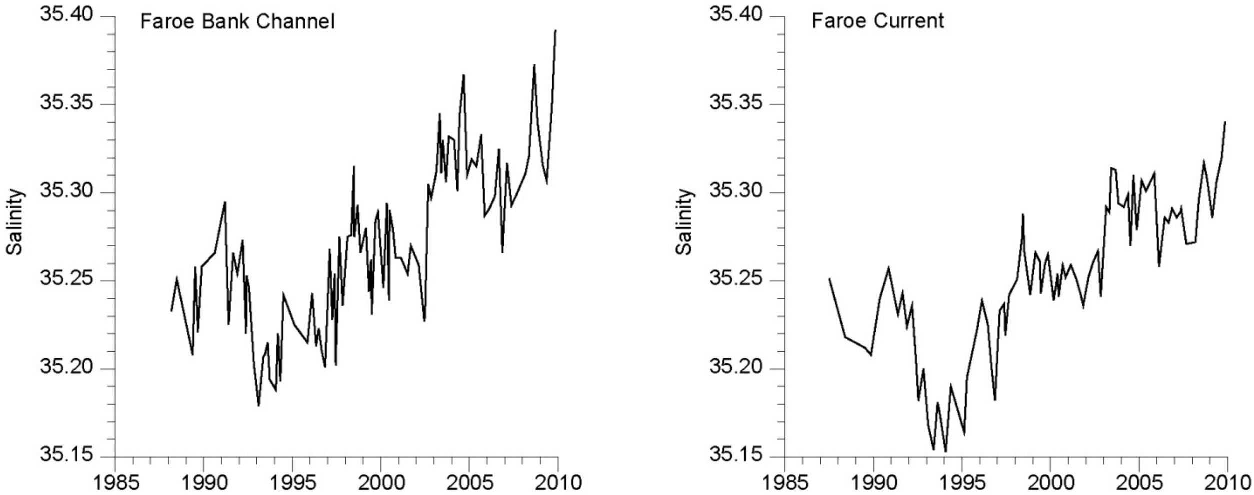

Figure 3. De-seasoned salinity from individual cruises in the FBC (left panel) and the core of the Faroe Current (right panel). In the FBC, the figure represents the average salinity in the 100–300 m layer from the two deepest stations. In the Faroe Current, the figure represents the average salinity in that 50 m layer on the section that has the highest salinity (the core).

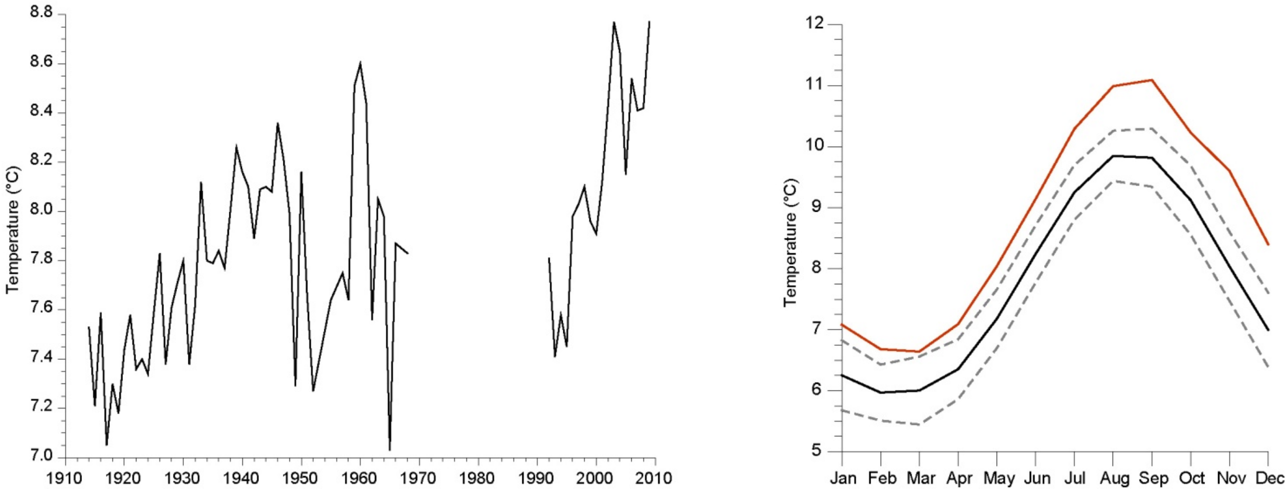

Figure 4. Annually averaged Faroe coastal temperature (left panel) monitored daily in Mykines 1914–1969 and several times daily at the neighbouring site Oyrargjógv from 1992. In the Mykines timeserie, years with less than 8 months of observations are omitted. The right panel shows the monthly averaged Faroe coastal temperature monitored at Oyrargjógv in 2009 (red line) and the monthly mean climatology from the Mykines timeserie (black line) ± one standard deviation (grey dotted lines). Inter-comparison experiments support that the two sites represent the same water mass (Faroe Shelf Water).

Annex 10: Regional Reports – Ireland

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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.

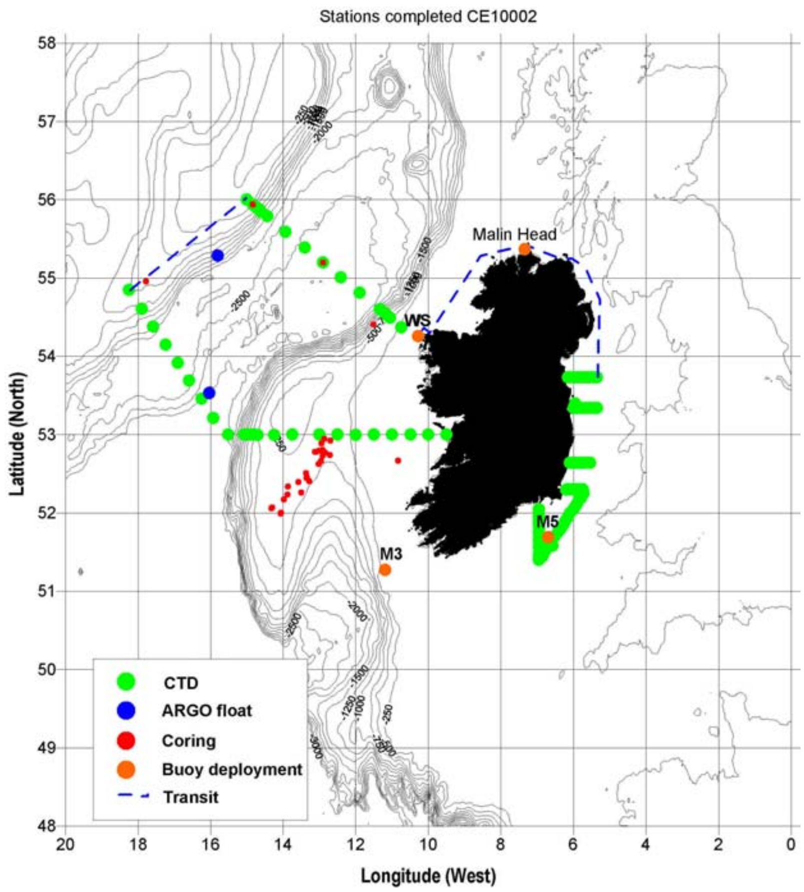


Figure 1. Location of key measurement sites in Irish waters.

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.

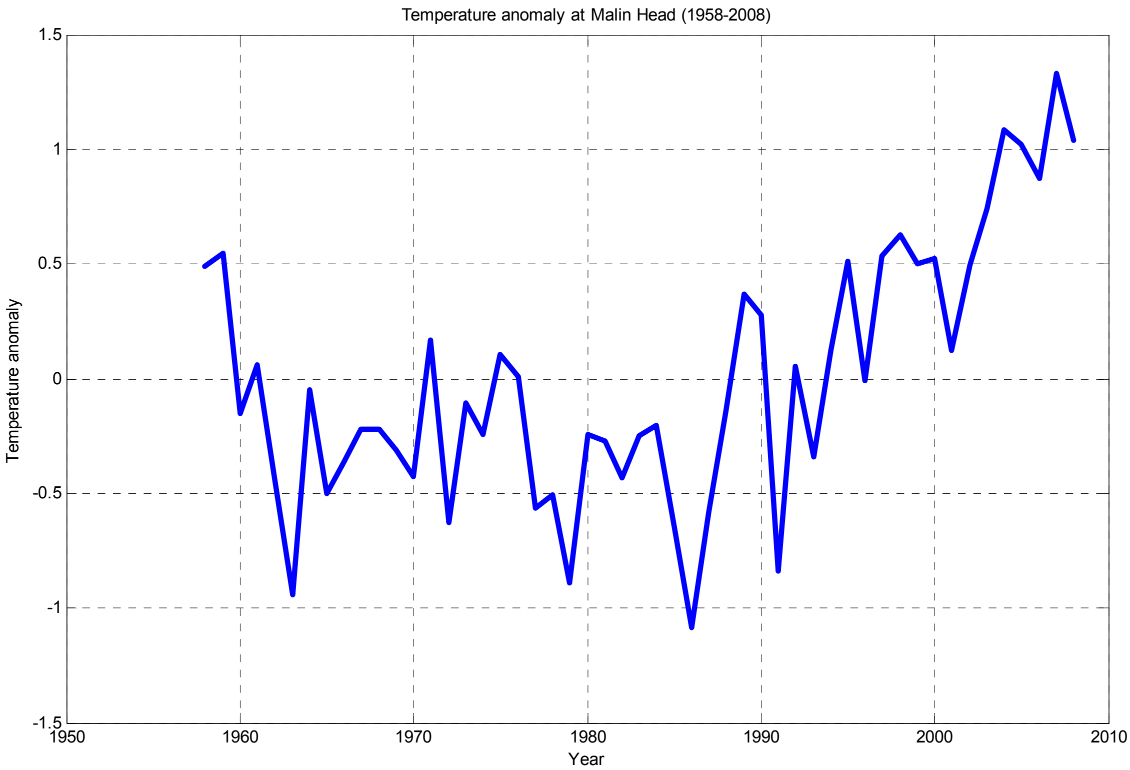


Figure 2. Sea surface temperature anomaly from Malin Head (Ireland) 1960–2008.

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.

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

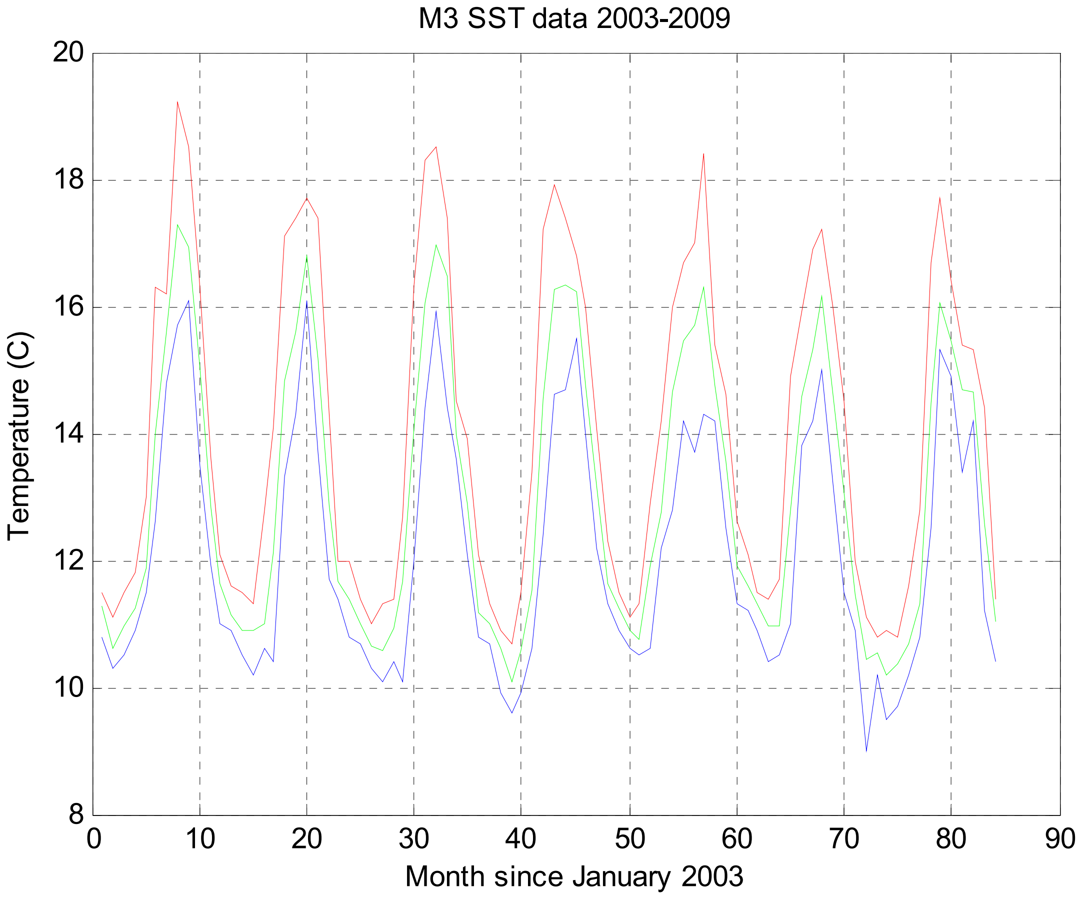


Figure 3. SST at the M3 weather buoy since its deployment in 2003 (blue is minimum, green is mean and red is maximum monthly values).

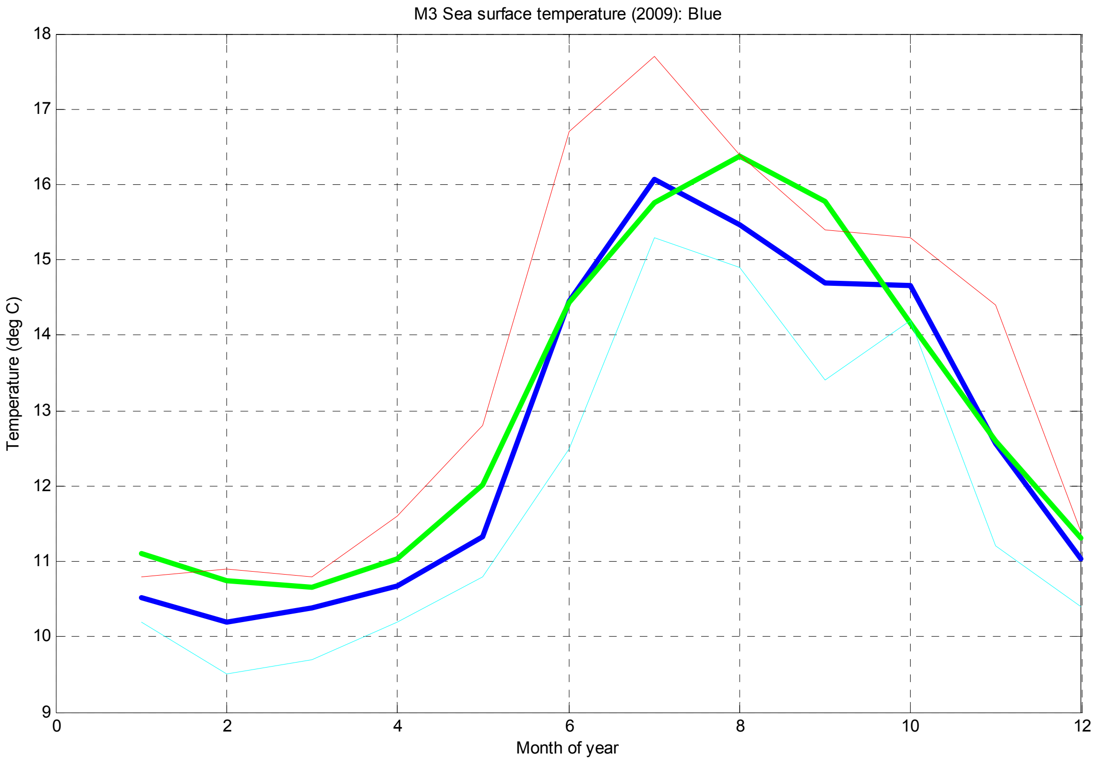


Figure 4. SST at the M3 weather buoy (blue line) in 2009 compared with the time series mean (green line).

Max and min values for 2009 also shown.

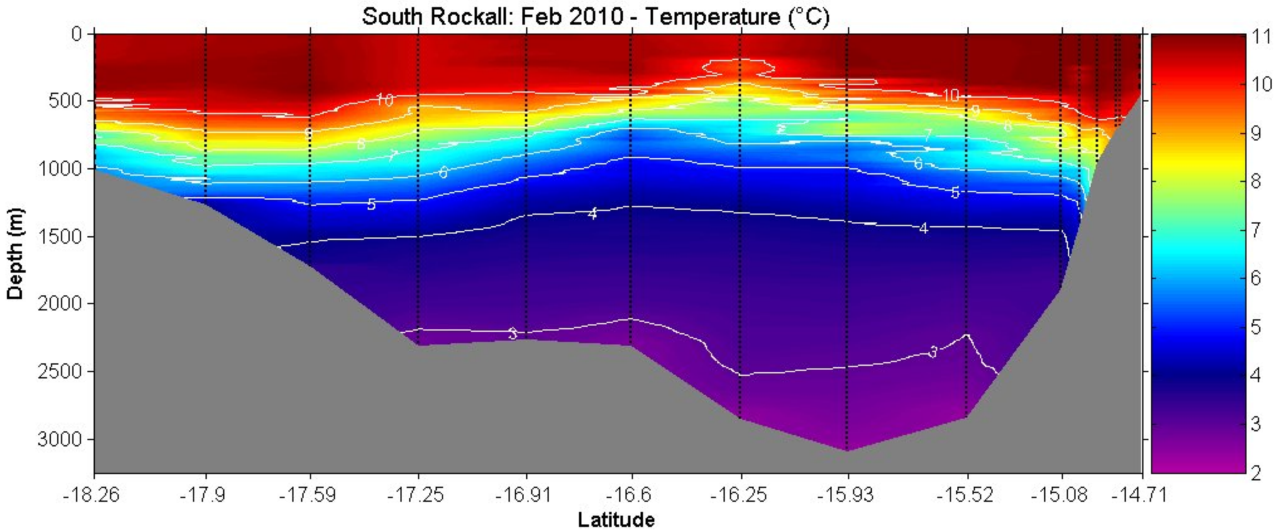
2009 temperatures started below the time series mean (2003–2009) until June. Temperatures remained generally below the time series mean in August and September and similar to the time series mean for the remainder of the year.

Offshore cruise activity

Celtic Explorer cruise CE1002 was conducted in February 2010 to examine hydrographic conditions in Rockall Trough. A total of 79 stations were occupied for a variety of parameters including CTDs, grab samples and cores, nutrients, salinity and phytoplankton. Three ARGO floats were also deployed (see Figure 1 for locations).

South Rockall line

Two transects across the Rockall Trough were completed on cruise CE10002. 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. A warmer saline core is evident on the eastern side of the section reflecting the Shelf Edge Current and some influence from the North Atlantic Current. The thermocline is often deeper on the eastern side of the trough also and shoals up as one progresses westward along the section. However in 2010, a fresher pulse of water 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. 1000m water depth on the eastern side of the section. Below 1000m the influence of Labrador Sea Water (LSW) is evident.



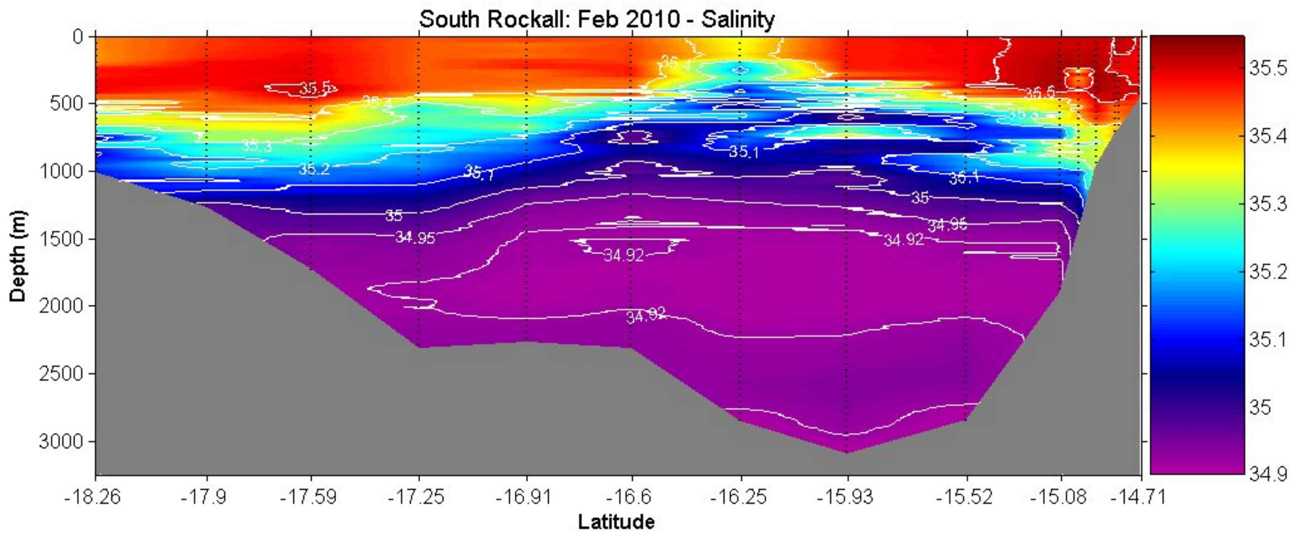


Figure 5. Temperature (upper panel) and salinity (lower panel) sections along the South Rockall Transect in February 2010.

The shelf break near Porcupine Bankmarks 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.

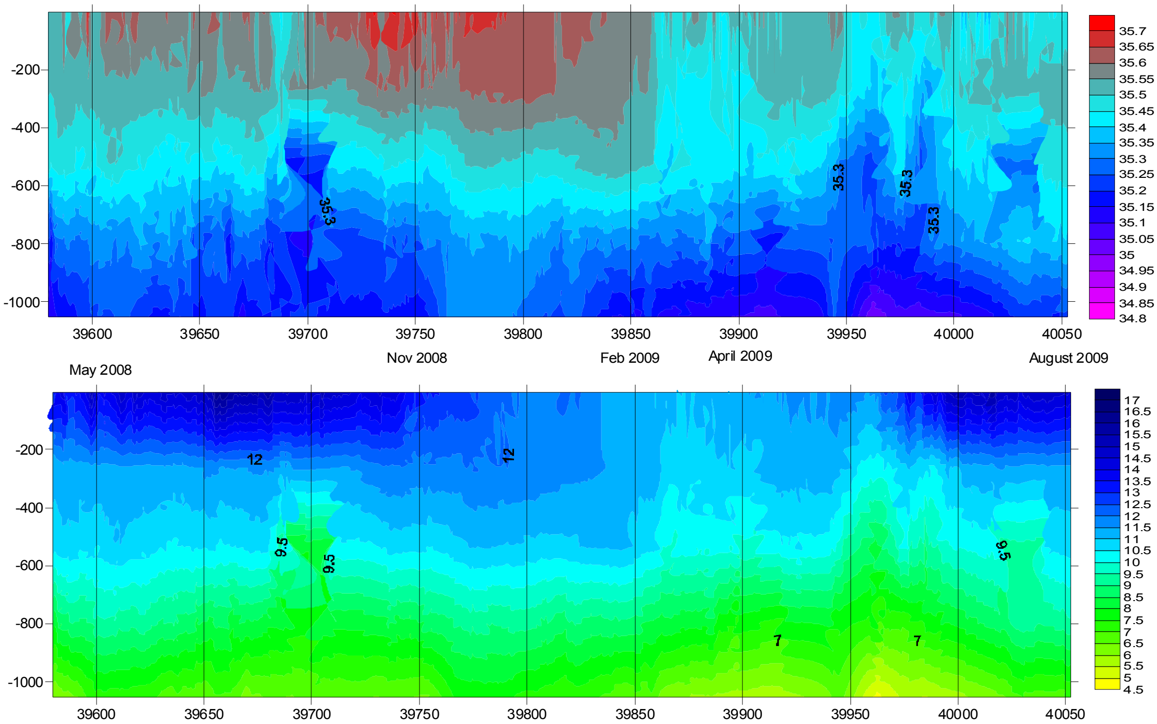


Figure 6. Initial results from M6 CTD string west of Porcupine Bank between May 2008 and August 2009 (salinity: upper panel and temperature: lower panel).

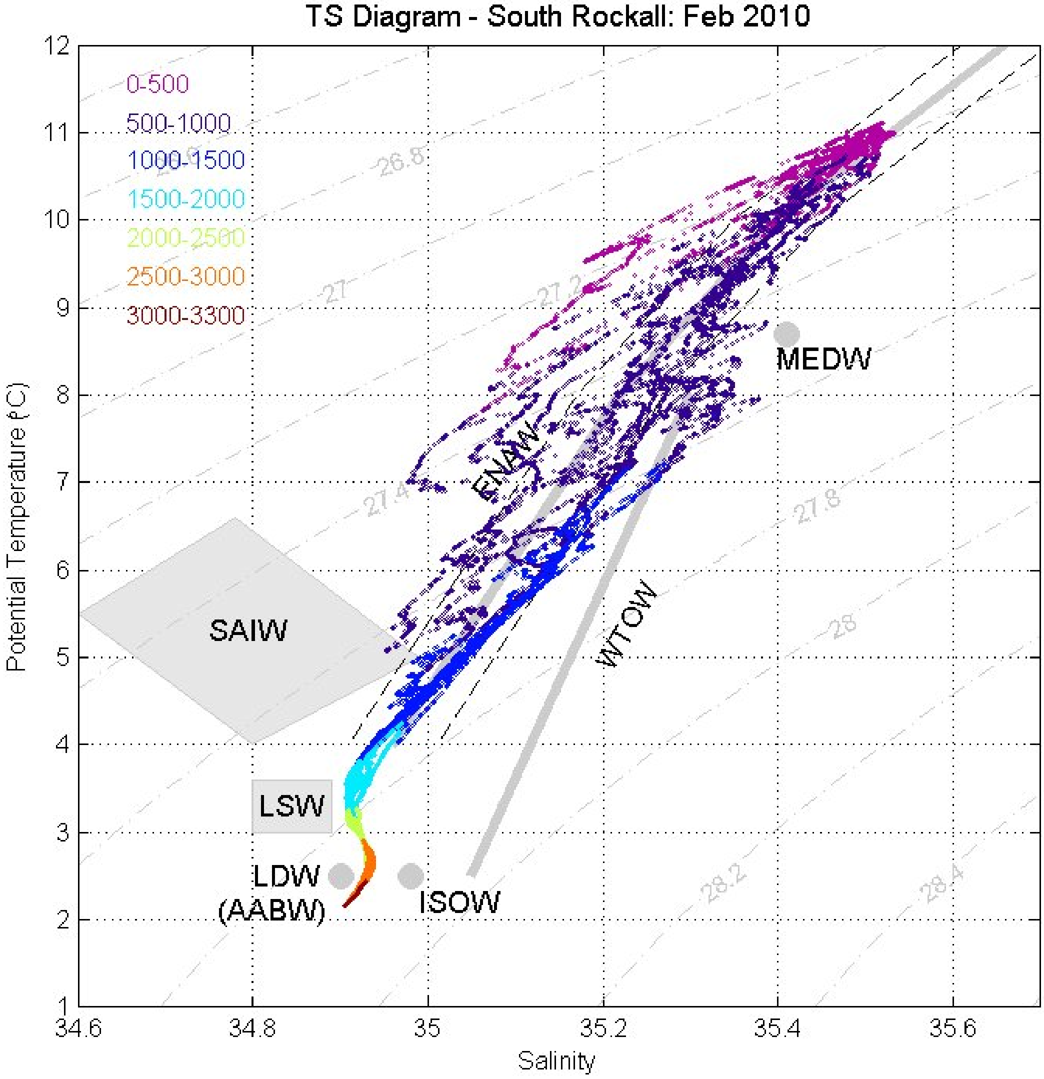


Figure 7. T/S curve for the South Rockall section during 2010.

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). Because this section is further north than the previous section, MEDW is not observed on the North Rockall line.

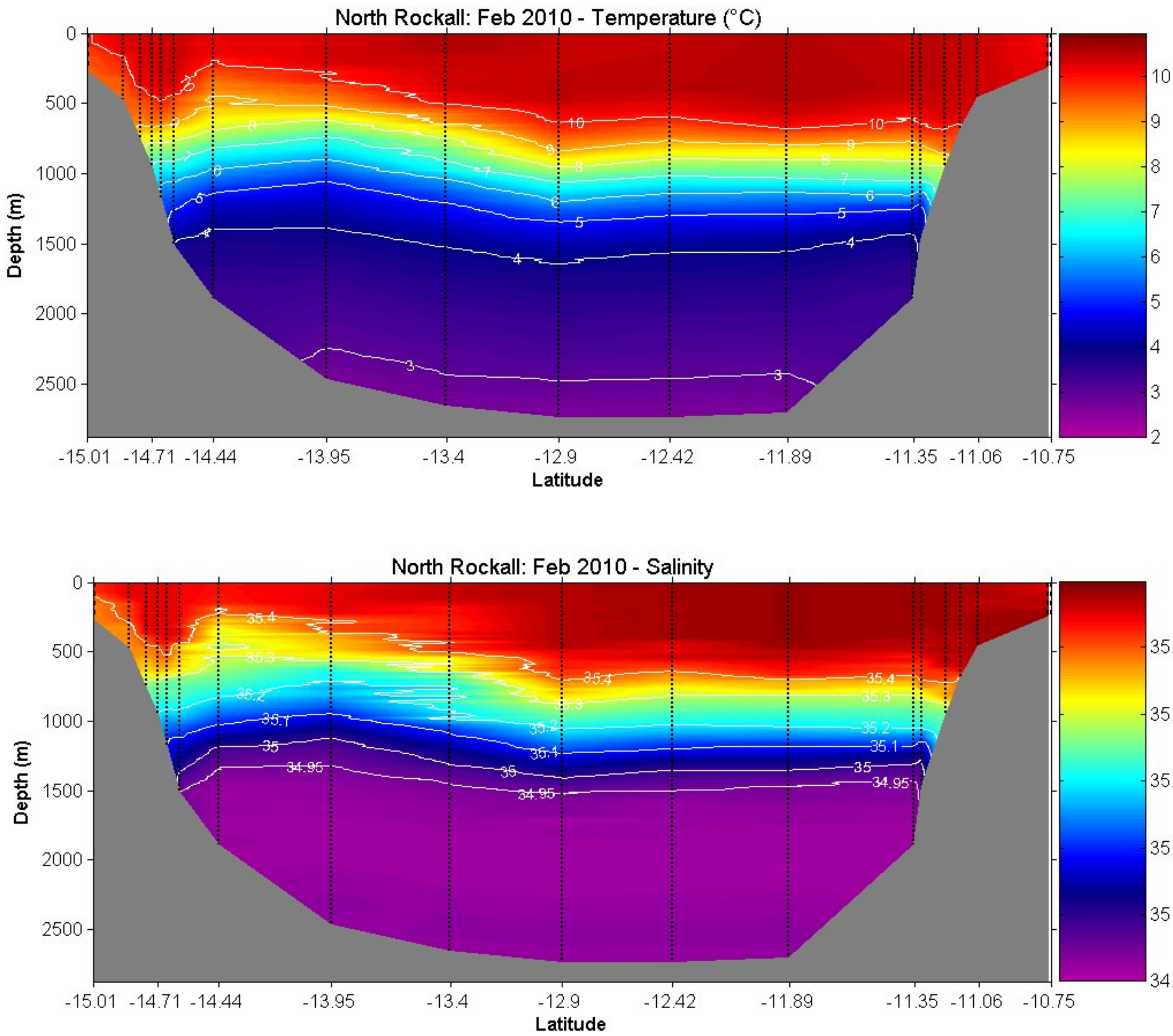


Figure 8. Temperature (upper panel) and salinity (lower panel) sections along the North Rockall Transect in February 2010.

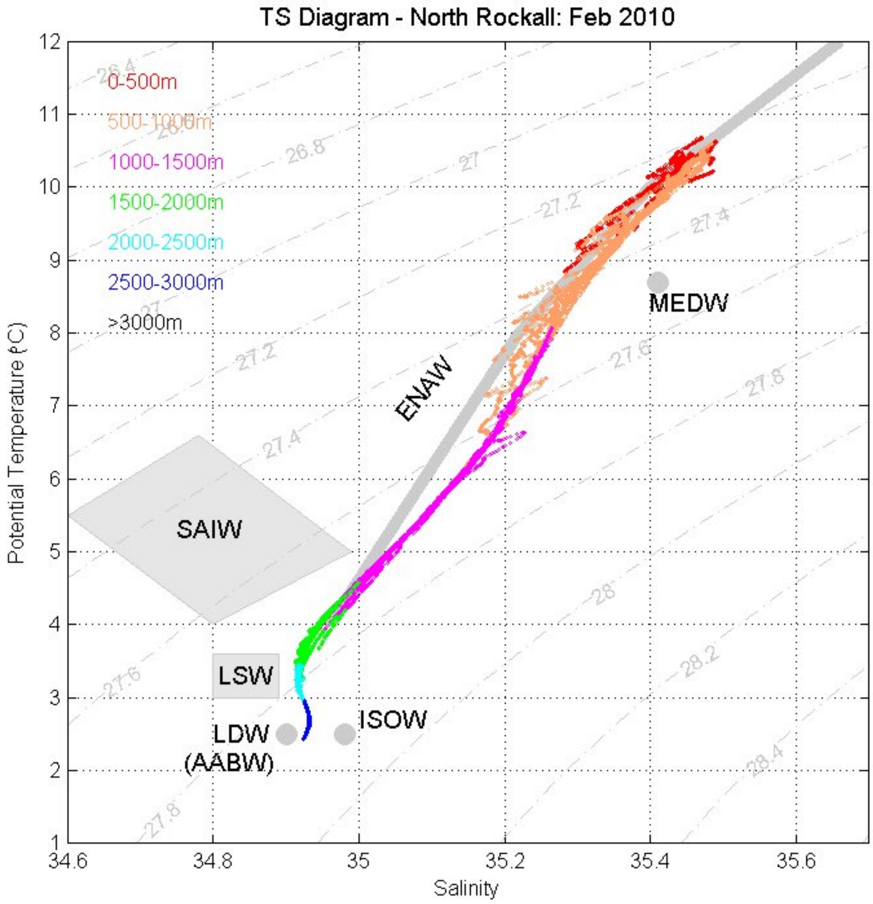


Figure 9. T/S Curve for the North Rockall section during February 2009.

A much tighter T/S relationship is apparent on the North Rockall section. There is no 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 11). 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 have increased in salinity by 0.01. 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.

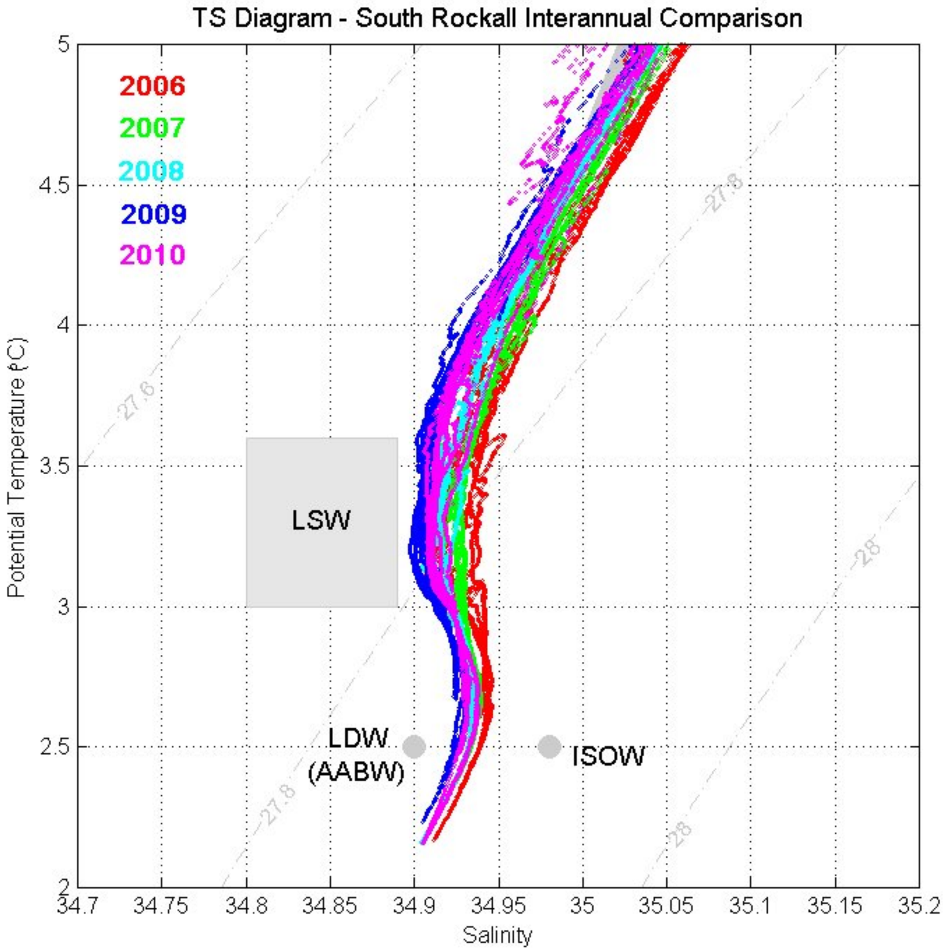


Figure 10. Interannual comparison of the deep water masses in Rockall Trough (2006–2009).

Conclusions

1) Significant inter-annual variability in the upper and intermediate waters
2) Strong SAIW influence at Porcupine in 2006 and 2008, shallower MLD in West Rockall (SAIW may stabilise water column)
3) LSW (freshening progressively since 2006) has become more saline in early 2010.
4) Irish coast SST above long-term mean but has decreased in last year or so

Acknowledgements

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

Annex 11: Regional Reports –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).

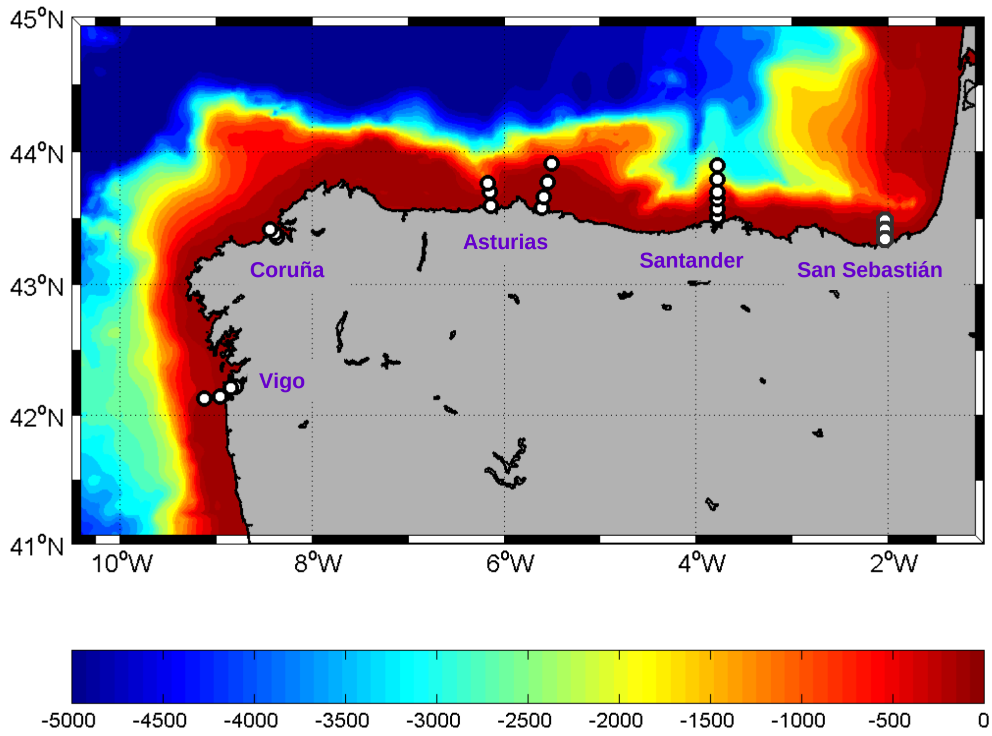

Figure 1. Spanish Standard Sections from the 'Instituto Español de Oceanografía' (Vigo, Coruña, Asturias, Santander) and from AZTI (San Sebastián).

The Bay of Biscay lies almost adjacent to the Atlantic, located between the eastern part of the subpolar and subtropical gyres. The region is affected by both gyres, depending upon latitude. However, the general water circulation in the area follows mainly the subtropical anticyclonic gyre, in a relatively weak manner (1–2 cm·s^{-1}). Because of the east to west orientation of the Basque coast, together with the north to south orientation of the French coast, onshore Ekman transport dominates clearly in autumn and winter due to the westerly and southerly winds. In spring and summer, easterly winds produce weak coastal upwelling events that compensate partly the convergence and downwelling.

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 2009 (source: Delegación en Cantabria de la Agencia Estatal de Meteorología) indicate that it was an average year relative to the period 1961–2009. The annual mean air temperature over the southern Bay of Biscay during 2009 was 14.7°C, only 0.2º over the 1961–2009 average, but well down the last twenty-year mean, being only five years colder than 2009 Figure 2 shows the plot of the annual means and total average.

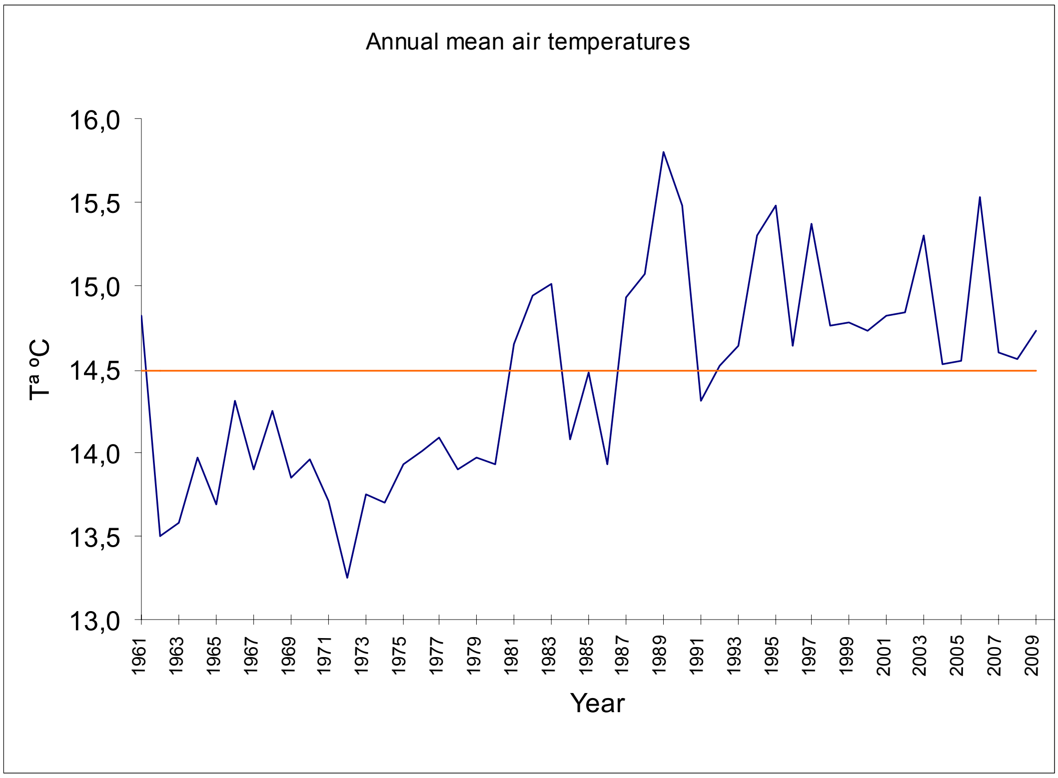

Figure 2. Annual mean temperatures in Santander (43.5ºN, 3.8ºW) Courtesy of the 'Agencia Estatal de Meteorología'.

In the annual cycle (Figure 3a) can be detected negative anomalies appearing in the winter (January–April), and positive anomalies for the rest of the year beginning in May and finishing in December. Especially important are the positive anomalies in November more than one standard deviation and the summer months with around half standard deviation. The seasonal cycle amplitude was 11.3º C from August (20.6ºC) to December (9.3ºC).

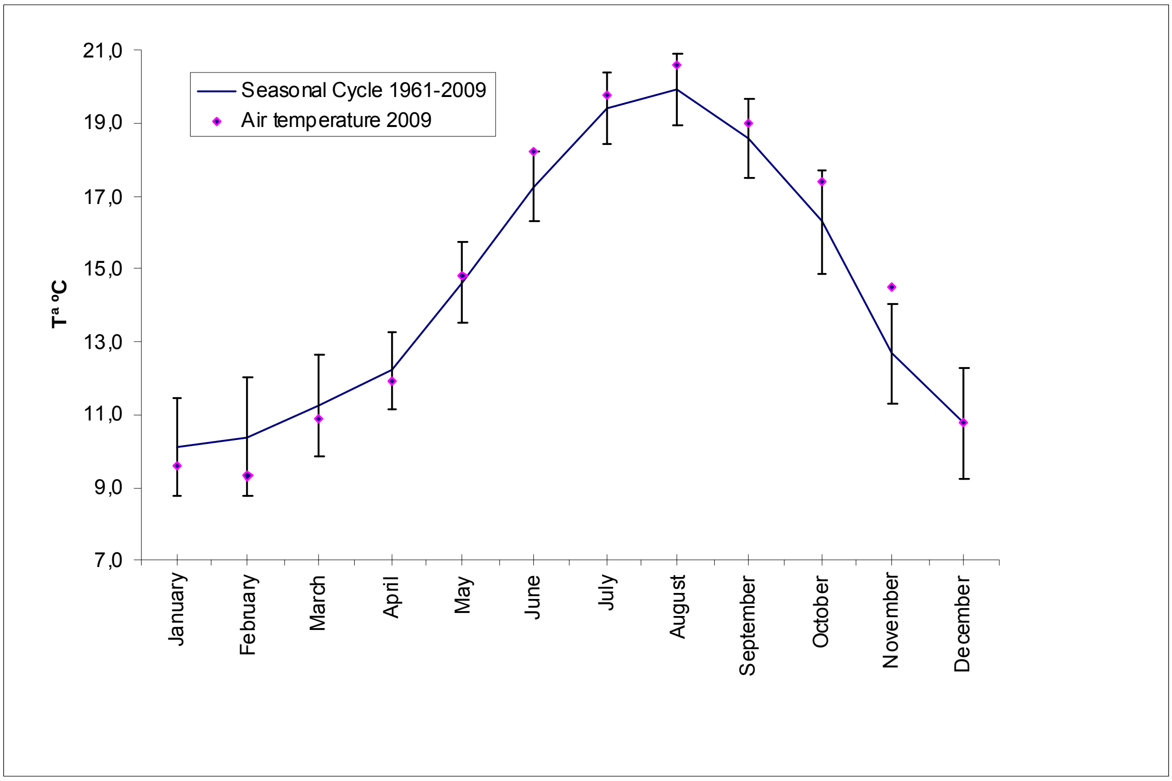

Figure 3a. Air temperatures in 2009 in Santander (43.5ºN, 3.8ºW) and mean value (1961–2009) and standard deviation.). Courtesy of the 'Agencia Estatal de Meteorología'.

Meteorological conditions in the SE Bay of Biscay in 2009 (Observatorio Meteorológico de Igeldo, San Sebastián, Agencia Estatal de Meteorología) were characterised by a cold winter (around the mean minus standard deviation for 1986–2009); a cold spring, with the exception of June; and an average summer and autumn seasons (around the mean for 1986–2009), excluding July and November (Figure 3b). The annual mean air temperature was 13.54º C, 0.08º C below the 1986–2009 average.

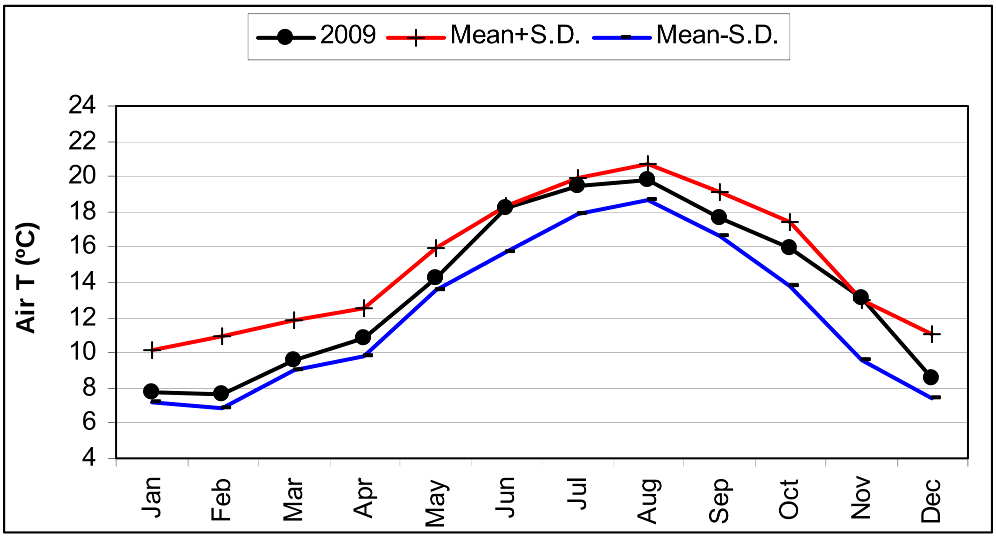

Figure 3b. Monthly mean air temperature (°C) in San Sebastián (43°18.5′N, 02°2.37′W) in 2009 compared with the mean ± standard deviation for the period 1986–2009. Courtesy of the 'Agencia Estatal de Meteorología'.

The peculiarities of the air temperature in 2009 can be observed in the context of the monthly mean temperatures of the period (1986–2009) and the evolution of the accumulated anomalies (Figure 4).

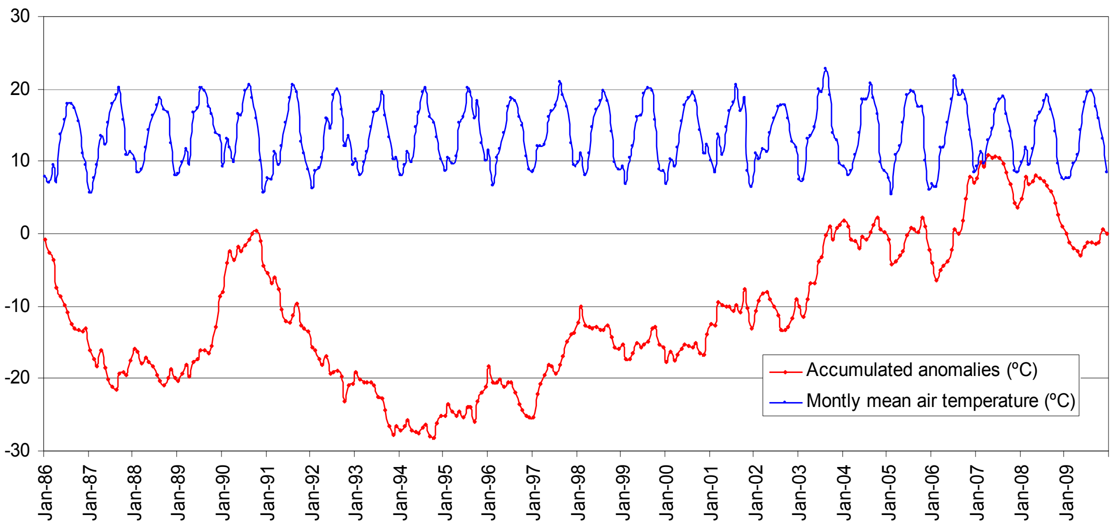

Figure 4. Monthly mean temperatures in San Sebastián (43°18.5′N, 02°2.37′W) in 1986–2009 and accumulated anomalies. Data Courtesy of the 'Agencia Estatal de Meteorología'.

Precipitation and evaporation

The strong rainfall was measured in the Santander AEMet Observatory during the autumn of 2008 follows in January, but after that the year was under the mean value (Figure 5a), The previous year, the higher in the last 12 years and January imported large amount of freshwater from the Cantabric and French rivers as well as direct rainfall over the sea surface and during spring as the snow melts, mainly by the French rivers. Looking at the seasonal pattern, (Figure 5b) we detected a high variability pattern with low rainfall over the year and only high rain in January, September and November. The rainy period (October 2008 – January 2009) totalize 770 ml, close to the 2007 total rainfall (886 ml). This amount of freshwater has to have important signal in the salinity conditions over the upper waters and in the mix layer water formed during the year.

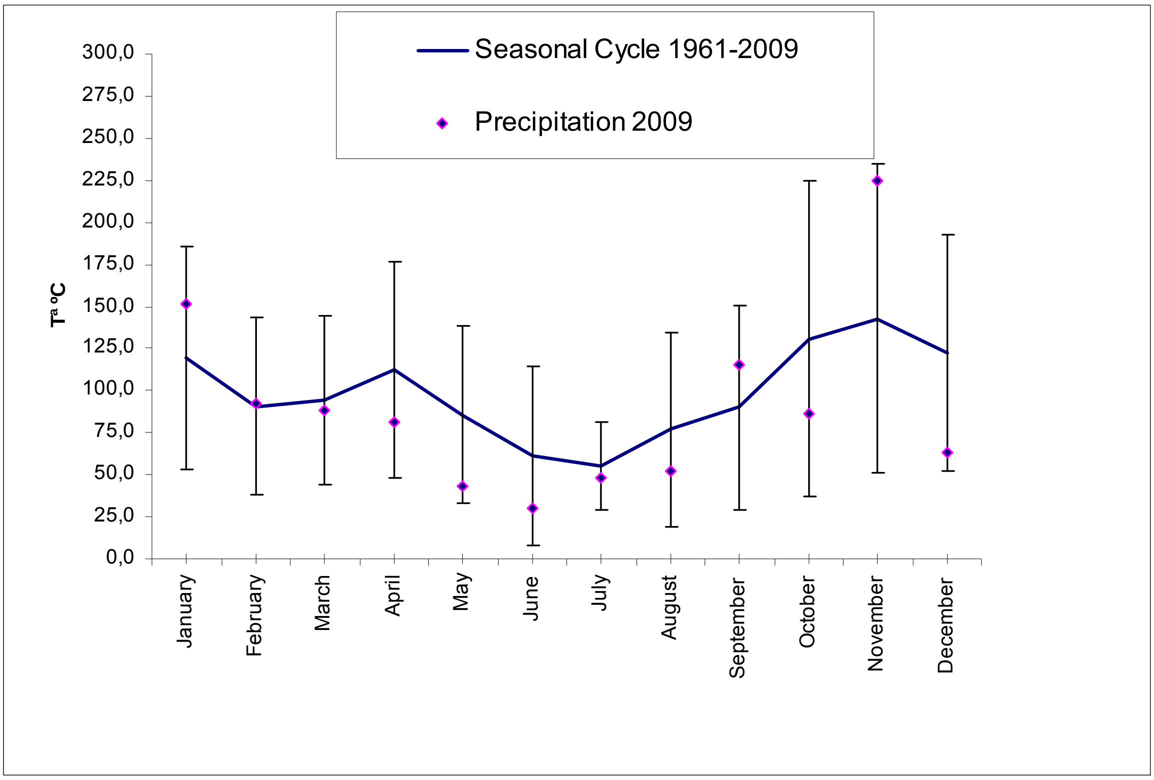

Figure 5a. Accumulated rainfall in 2009 in Santander (43.5ºN, 3.8ºW) and mean accumulated value (1961–2009) and standard deviation. Courtesy of the 'Agencia Estatal de Meteorología'

In San Sebastián, 2009 can be classified as a wet year, concerning the precipitation regime. Thus, only June was around the mean minus standard deviation for the period 1986–2009; conversely, January, April and July were around the mean plus standard deviation for the period 1986–2009; November was over the mean+standard deviation (1986–2009) (Figure 5). The monthly mean precipitation was 142 mm, 18 mm over the 1986–2009 average.

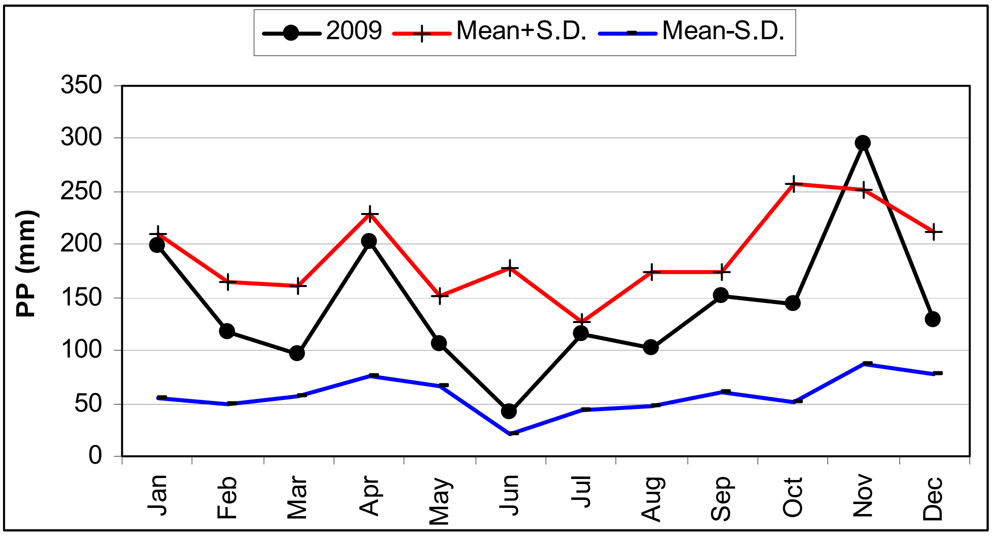

Figure 5b. Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 2009 compared with the mean ± standard deviation for the period 1986–2009. Data Courtesy of the 'Agencia Estatal de Meteorología'.

With regard to water balance, the year 2009, 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).

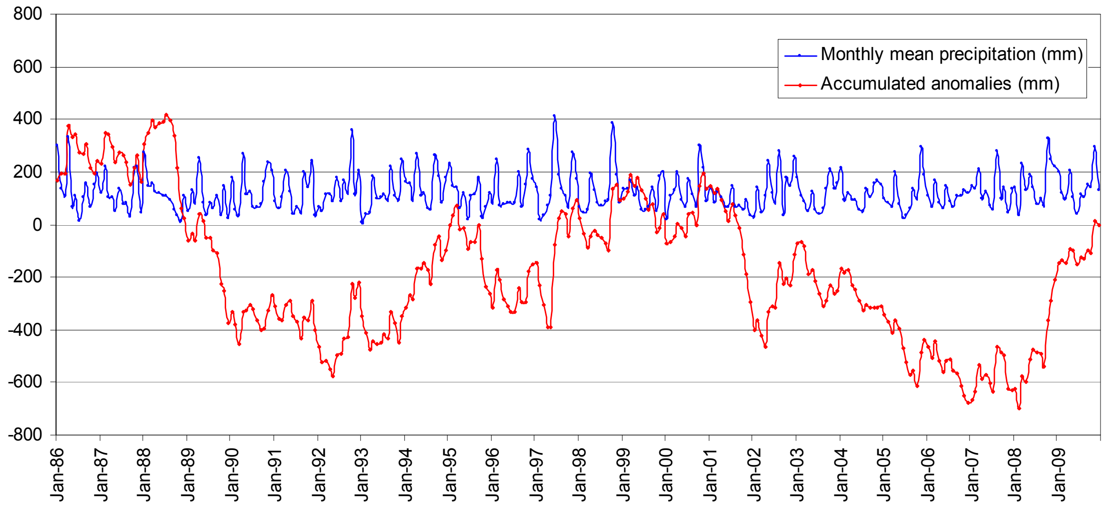

Figure 6. Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 1986–2009 and accumulated anomalies. Data Courtesy of the 'Agencia Estatal de Meteorología'.

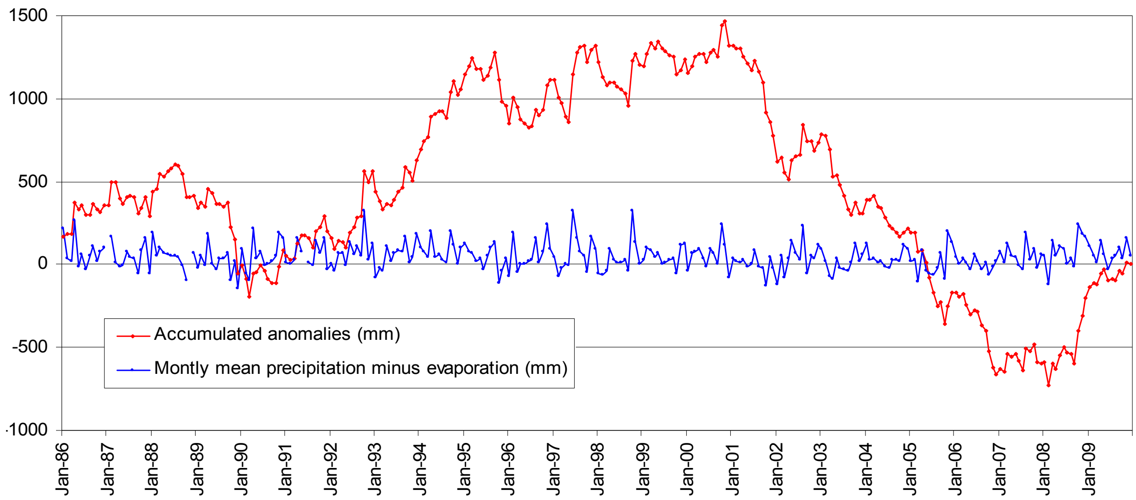

Figure 7. Monthly precipitation minus evaporation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 1986–2009 and accumulated anomalies. Data Courtesy of the 'Agencia Estatal de Meteorología'.

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 1986–2009. 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				0.54*
PP-EV AUTUMN				0.57**

The Gironde River flow in 2009 was around the 1986–2009 average; the annual mean river flow was 771 $m^3 \cdot s^{-1}$, only 53 $m^3 \cdot s^{-1}$ below the 1986–2009 average. In spring, the flow was around the monthly mean + the standard deviation for the period 1986–2009, in response to the increase of precipitations as well as spring thaw. In this context, the Gironde River flow is in agreement with the precipitation in San Sebastián except for the local precipitation events during November (Figures 5 and 8).

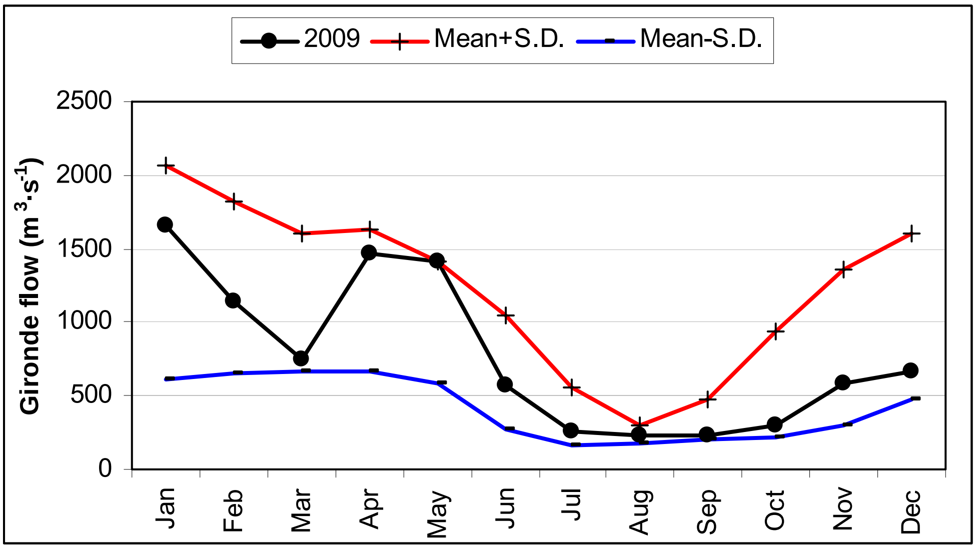

Figure 8. Monthly mean flow (m^3 s^{-1}) of the Gironde River in 2009 compared with the mean ± standard deviation for the period 1986–2009. Data Courtesy of the 'Bordeaux Harbour Authority'.

The peculiarities of the Gironde river flow in 2009 can be observed in the context of the monthly mean values of the reference period (1986–2009 and the evolution of the accumulated anomalies (Figure 9).

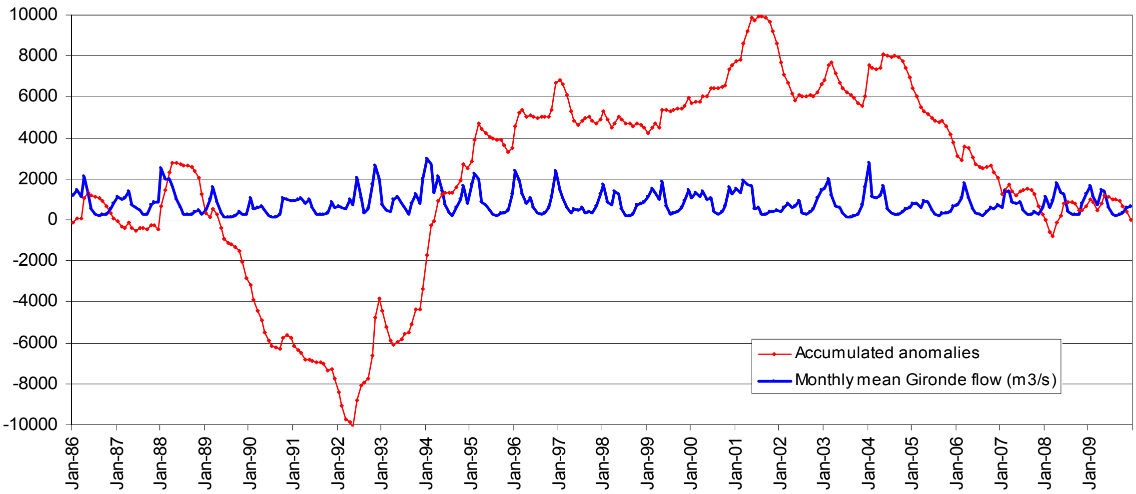

Figure 9. Monthly mean flow of the Gironde river (m^3·s^{-1}) in 1986–2009 period and accumulated anomalies. Data Courtesy of the 'Bordeaux Harbour Authority'.

Hydrography

Coastal and shelf waters

In order to obtain a first approximation of the hydrographic conditions in 2009, a TS diagram representing the waters over the continental shelf of the Bay of Biscay (43°30'N, 02°00'W) is shown in Figure 10.

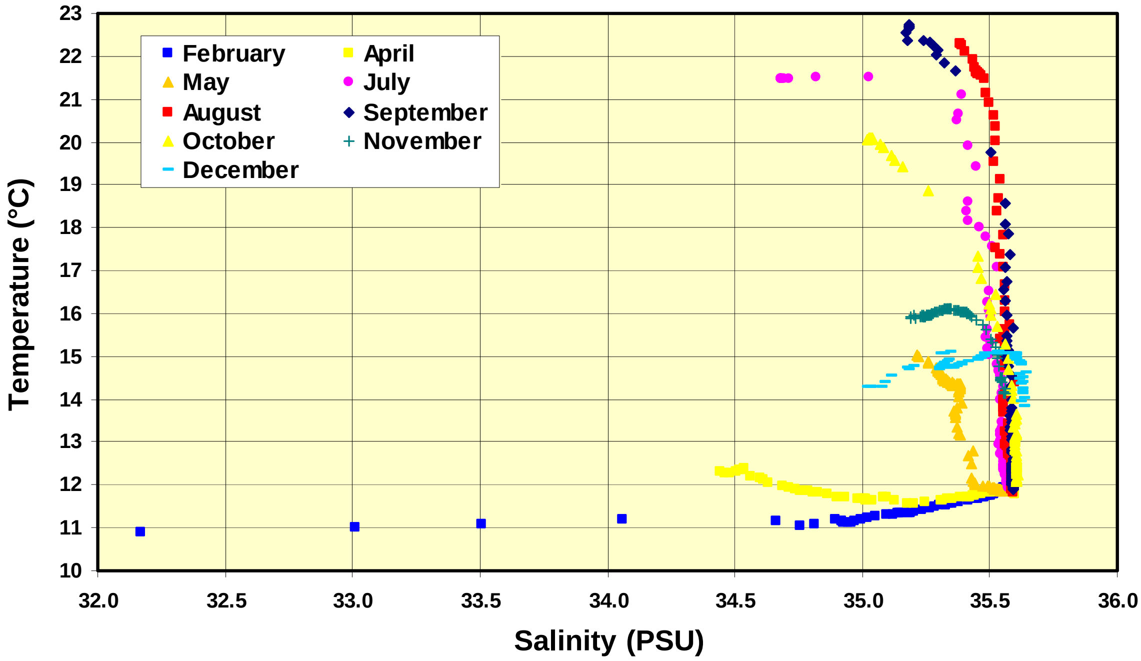

Figure 10. TS diagram of the waters over the continental shelf of the SE Bay of Biscay (43°30′N 02°00′W) in 2009.

The response of temperature and salinity of the upper layers to the meteorological factors described above is clearly observable in Figure 10. Late January and February are characterised by relatively high precipitation and river runoff (Figures 5 and 8), contributing to the development of haline stratification coupled with thermal inversion in the upper low salinity waters. After March relatively dry, haline stratification remains in April. 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.

Figure 11 shows the evolution of the monthly averaged sea surface temperature (SST) in 2009 (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 1986–2008 average) can be observed: winter severe cooling was compensated by warm waters in June, July and December. Finally, the annual averaged SST in San Sebastián in 2009 (16.13°C) was almost equal below to that of the 1986–2009 period (16.14°C).

The peculiarities of the SST in 2009 can be observed within the context of the monthly mean temperatures of the reference period (1986–2009) and the evolution of the accumulated anomalies (Figure 12).

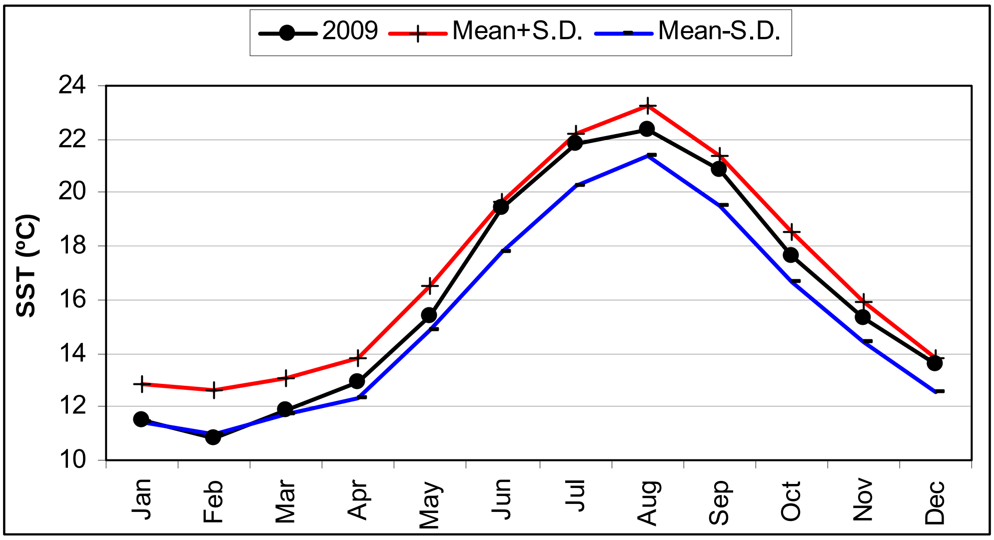

Figure 11. Monthly averaged sea surface temperature (°C) in San Sebastián (43°20′N 02°00′W) in 2009 in comparison with the mean ± standard deviation for the period 1986–2009 period. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.

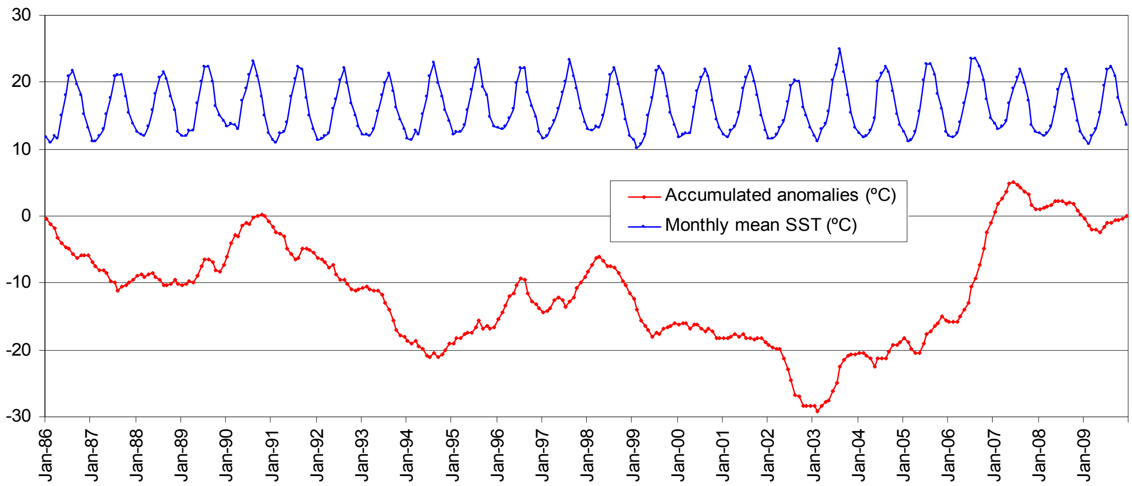

Figure 12. Monthly averaged SST (°C) in San Sebastián (43°20′N 02°00′W) during the 1986–2009 period, together with accumulated anomalies. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.

In a similar way, the evolution of the heat content (in terms of mean temperature) and the salt content (in terms of mean salinity minus 35) of the water column (100 m) over the continental shelf of the SE Bay of Biscay can be observed in Figures 13 and 14, respectively.

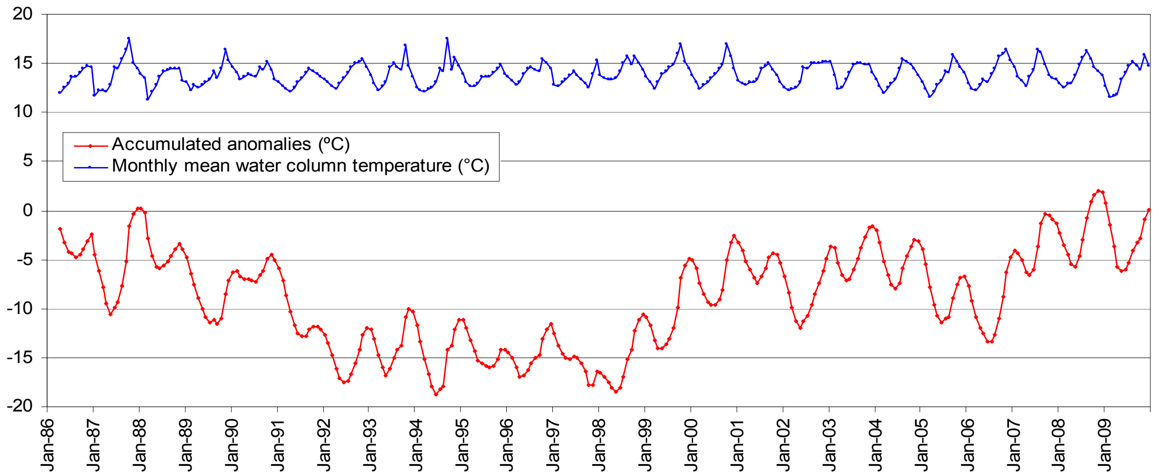

Figure 13. Monthly averaged water column temperature (°C) in San Sebastián (43°30′N 02°00′W) in the period 1986–2009, together with accumulated anomalies.

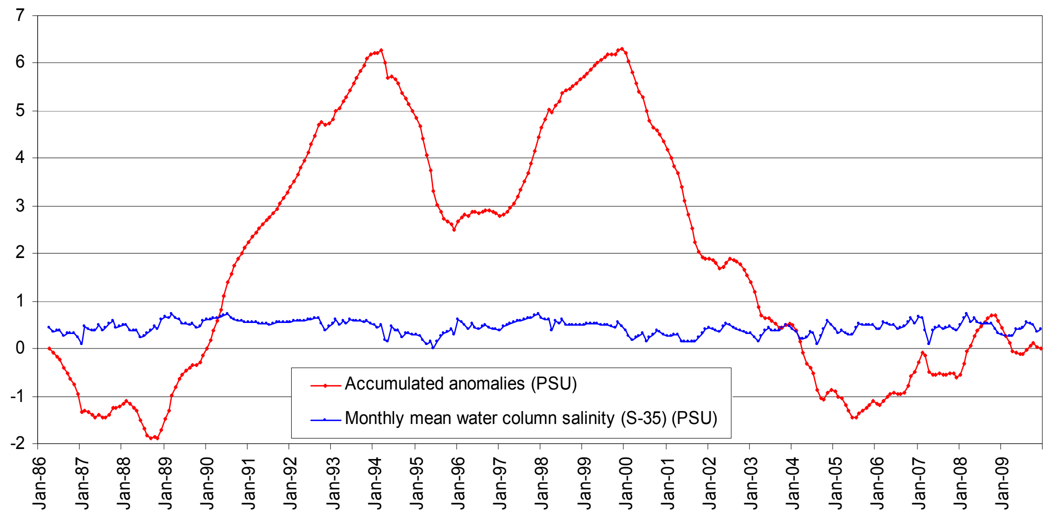

Figure 14. Monthly averaged corrected salinity (S-35) in 100 m water column in San Sebastián (43°30′N 02°00′W) in the period 1986–2009, together with accumulated anomalies.

Aspects related to the hydro-meteorological conditions during 2009, over the SE Bay of Biscay, are listed in Table 2. The SST in winter 2009 remains around the mean minus standard deviation for the period 1986–2009 (Figure 11), with relatively low air temperatures for this period. In spring 2009, the SST is around the 1986–2009 average with the exception of June, as a result of medium air temperature (Figure 3b). In summer and autumn, the SST is around the 1986–2008 average with the exception of July and December. This pattern is consistent with the atmospheric temperatures for the same period (Figure 3b).

February and April are characterised by haline stratification of the water column, resulting from the presence of cold waters of continental origin (Figure 10). After the increase in air temperature in April, the warming of the sea surface and the water column began to be evident in May. Thermal stratification remains until October 2009. In November, the increase of turbulence enhances vertical mixing of the water column. December is characterised by a thermal inversion, related to the conjunction of cooling and freshwater inputs.

Table 2. Hydro-meteorological data in the shelf waters of San Sebastián (43°30′N 02°00′W) in 2009. Mean temperature and salinity calculated for 100 m water column.

2009	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	7.7	199	1656	11.51		12.72	35.304			
February	7.6	117	1140	10.82	32.172	11.61	35.277	11.96	35.584	T<14
March	9.6	97	744	11.89		11.73	35.275			
April	10.8	203	1466	12.94	34.445	11.85	35.273	11.82	35.593	T<14
May	14.2	106	1419	15.36	35.213	13.37	35.405	11.87	35.544	50
June	18.2	42	564	19.46		14.03	35.422			
July	19.5	115	262	21.85	34.683	14.68	35.440	11.94	35.574	42
August	19.8	103	231	22.35	35.383	15.15	35.549	11.92	35.587	45
September	17.6	152	235	20.85	35.181	14.68	35.530	11.92	35.592	37
October	15.9	143	303	17.63	35.020	14.28	35.494	12.08	35.605	33
November	13.1	295	579	15.31	35.204	15.84	35.341	14.45	35.542	T>14
December	8.5	129	660	13.60	35.022	14.76	35.416	14.04	35.636	T>14

In the SE Bay of Biscay, the 14°C isotherm represents the mean annual temperature and also the lower layer of the thermocline, during the spring and summer stratification. In May, the 14°C isotherm depth was 50 m; from July to September, this layer was placed at around 42–37 m; and, in October it was placed at 33 m (Table 2) Convergence and vertical mixing in November and December break the cycle of the heat content and also the relative stability of the TS values of the bottom waters (Table 2, Figure 10).

Finally, considering the remaining influence of the previous autumn (autumn 2008), negative anomalies for temperature and positive anomalies for precipitation and river runoff, allow to a descent of both temperature and salinity of the water column over the continental shelf in the SE Bay of Biscay during 2009.

In similar way, contours of temperature and salinity (over the shelf, 100 m depth) in the Santander section are shown in Figure 11a and b. The seasonal cycle in temperature is clearly marked in the upper layers. Stratification develops between April-May and October/November, and during the rest of the period the water column is mixed. 2009 presents a very cold winter period and an average summer temperature and warm layer depth (20 m) similar to 2005.

Salinity contours show very low salinity values over the entire shelf. There is no evidence of an episode of Iberian Poleward Current after the strong episode of winter 2008. Salinity values are not as low as the typical summer low salinity water (less than 35) founded in 1994/1995 or 2000/2001, but reach 80 m at the beginning of the year, due to the strong rain in autumn 2008 and January 2009. Also at the end of the year salinity reduced again all over the water column, due to the mixing. This low salinity signal in the upper layers could be due to the advection from the east of warm surface water from river discharges in the southeastern Bay of Biscay as well as for strong rain over the Spanish coast. During the spring the rivers of the Bay of Biscay, mainly Adour and Gironde, has strong discharges due to the combination of high rainfall and snow melting. These discharges produce low salinity surface waters. This signal remains during the summer thermohaline stratification and, for example, reach to Santander section in July/August.

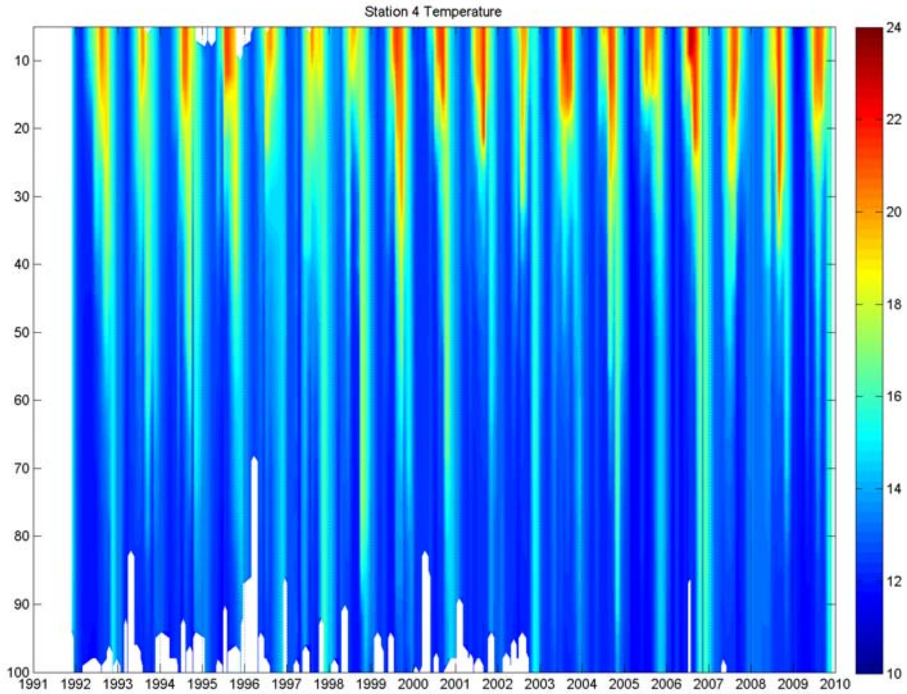

Figure 15a. Temperature evolution at Santander station 4 (shelf).

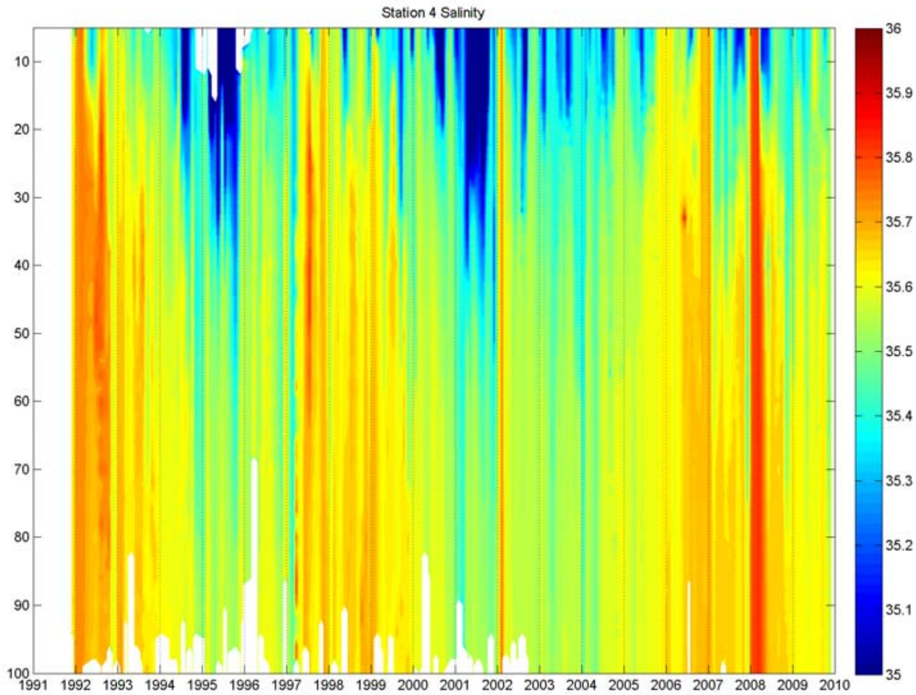

Figure 15b. Salinity evolution at Santander station 4 (shelf).

As a consequence of the different geographical location and coast orientation the mean hydrographical features the annual cycle at the Vigo standard section is moderately different of the standard cycles in Santander and San Sebastián. The differences are related mostly with a stronger influence in this area of the main advection mechanisms (winter poleward current and summer upwelling). Anyway, even if the range of the anomalies may be different because of local climatic and morphologic peculiarities, the anomaly patterns and the general trends can be considered referable to those described for the sections located in the southern Bay of Biscay.

Contours of temperature and salinity over the shelf in the Vigo section from 1994 to 2010 are presented in Figure 16. In summer cold waters were present at depth due to upwelling, while warm waters were at the surface in summer due to insolation. In the winter 2008/2009 a coastal poleward surface current that transports alongshore southern warm water not come and the temperature reflect the more boreal water origin that occupies the shelf. The situation in winter 2009/2010 with respect to temperature is normal with a poleward current well developed as usual in the last 20 years. Salinity contours are similar to the recent years.

The year 2009 with respect of the water thermohaline seasonal characteristics may be classified as normal, in the middle of the time series range.

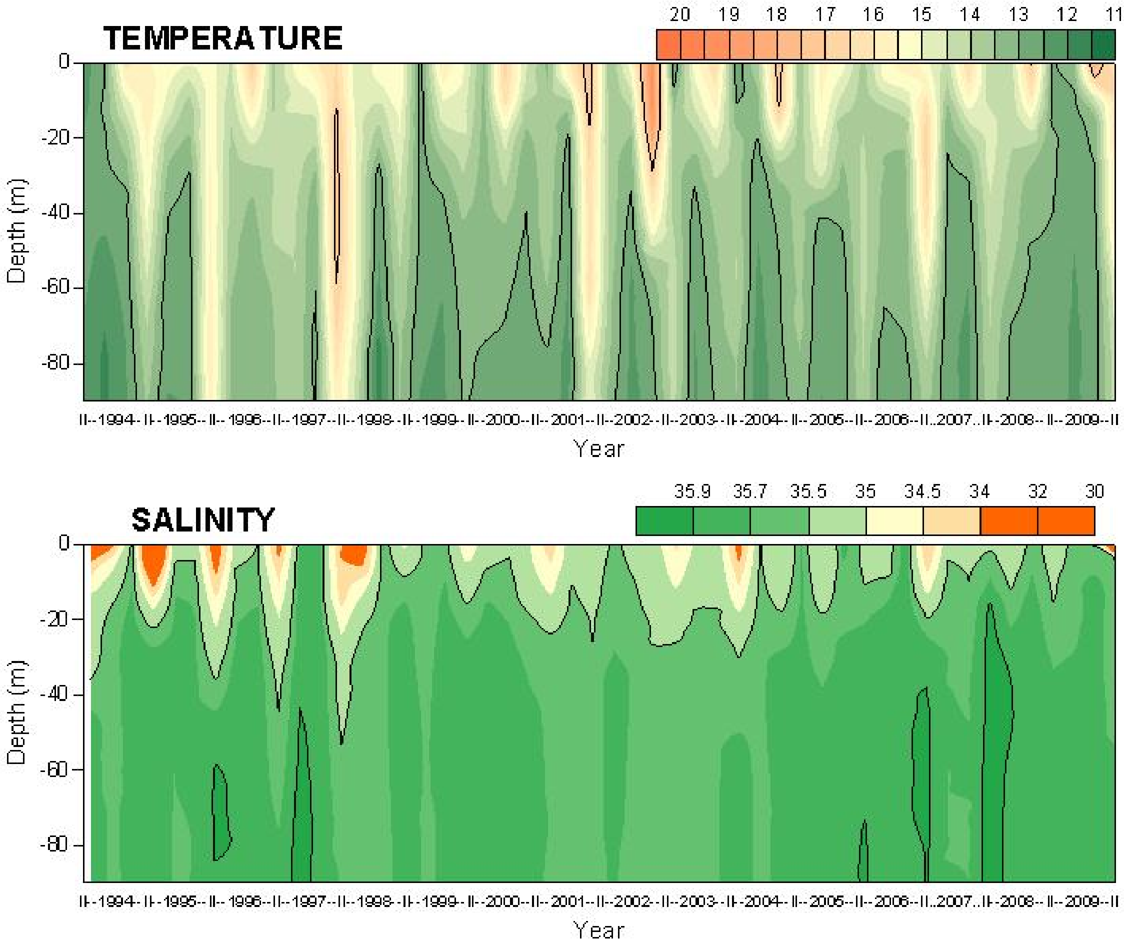

Figure 16 a and b. Seawater evolution at Vigo (42.1ºN, 9.0ºW) station of Temperature and Salinity.

Offshore and Slope waters

Contours of temperature and salinity over the shelf-break (600 m depth) in the Santander section are presented in Figure 17a and b. During the first period (1992–1994) only upper layers were sampled.

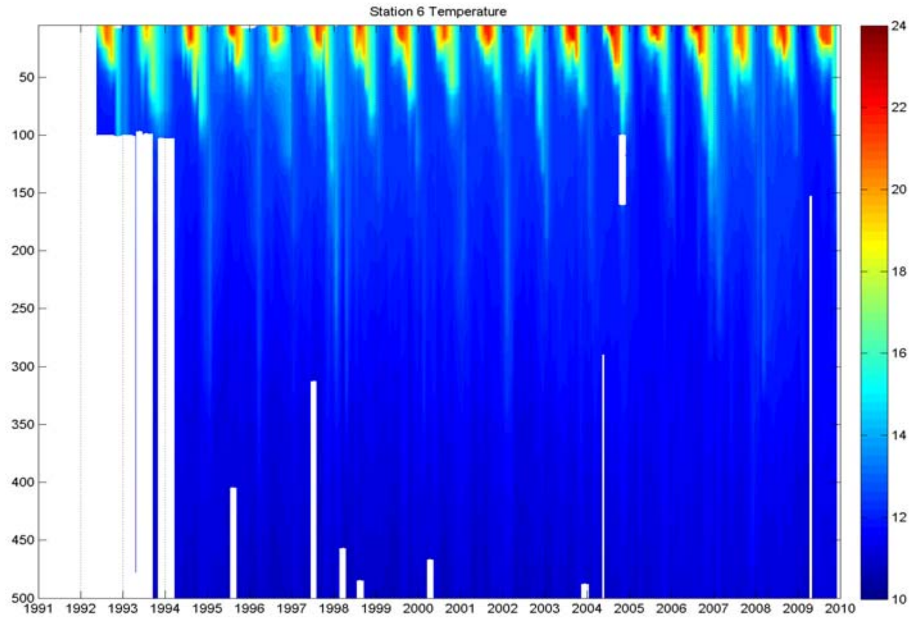

Figure 17a. Temperature evolution at Santander station 6 (shelf-break).

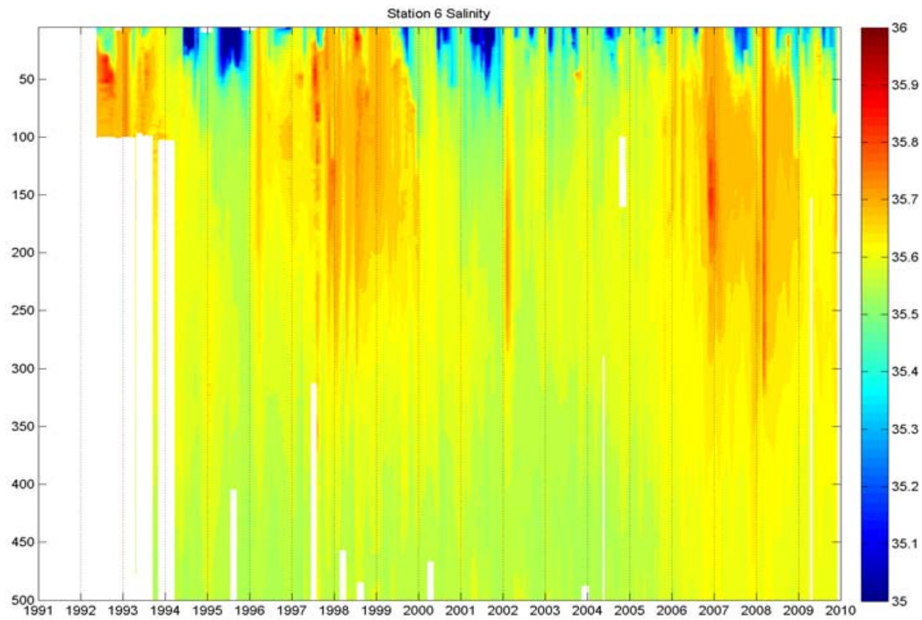

Figure 17b. Salinity evolution at Santander station 6 (shelf-break).

Winter mixing reached maximum MLD at the beginning of March (5 March) with a final depth within 260 meters. The signal of salty water could be seen until around 120 m in winter and around 80 in autumn. Winter period seems to be long and cold and summer sort and shallow. The last episode of warm and salty waters due to the Iberian poleward current between 2007 and 2008 has finished and the signal has been reduced in a large amount. As happened over the shelf and it has been seen in years before, the period of low salinity in the upper waters (1994/1995 and 2000/2001) was reduced in a greater extent from 2002 to 2006, increased again in 2007 and 2008 and reduce during 2009. Salinity values reduce to the previous years of 2004 or 2005 values.

Below the mixed layer, salinity fell from 1992 to 1995 and increased to 1997/1998 before falling almost continuously until the end of 2004 except for the increase in salinity in the upper 300 m during the 2002 winter. This episode of salinity increase disappeared in spring and was caused by the poleward current observed during that winter. From 2005 to 2007 the causes of the maintaining the increase in salinity could be related to atmosphering forcing at the area of formation of this water mass specially during the extreme cold and dry 2005 winter (Somavilla *et al.*, 2009). The decreasing during 2009 probably has been caused by the large amount of freshwater input from rain and rivers discharges in previous autumn and winter as well as rivers discharges in spring due to snow melting of the Pyrenees and advection of this water into the southern Bay of Biscay.

The deep winter mixing layer that occurs in the Bay of Biscay on 2005 and 2006 produced an increase of salinity and decrease of temperature at NACW levels. But in autumn 2006 winter 2007, a strong IPC reached Santander section with increase salinity in a large amount between surface and 300 m depth, and strong signal between 100 and 200 m. During 2008 salinity under the mix layer keeps high, but a strong episode of high salinity occurred mainly in March, but salinity maintains high after the change in mode waters occurred in 2005/2006. The large amount of low salinity waters accumulated in most superficial waters seems to have decreased salinity at deeper levels during autumn-winter mixing.

The deep winter mixing layer that occurs in the Bay of Biscay on 2005 and 2006 produced an increase of Salinity and decrease of temperature at NACW levels. But in autumn 2006 winter 2007, a strong IPC reached Santander section with increase salinity in a large amount between surface and 300 m depth, with strong signal between 100 and 200 m. During 2008 salinity under the mix layer keeps high, but a strong episode occurred mainly in March, but salinity maintains high after the change in mode waters occurred in 2005/2006. The large amount of low salinity waters accumulated in most superficial waters seems to have decreased salinity at deeper levels during autumn-winter mixing.

In general, stratification develops between April/May and October/November, mainly reaching 50 m depth. In 2009, this presence of low salinity waters has dominated seasonal cycle and a double stratification has been observed in several months with a shallower stratification mainly determined by a haline component (within 20 meters depth) and a deeper thermal stratification.

If we look at thin layer superficial waters, we expect to find an approximate mirror of atmospheric forcing. Due to the thermal inertia of the seawater surface, the temperature seasonal cycle does not follow a sinusoidal cycle but presents a rapid warming period in late spring, whereas the autumn cooling is less abrupt.

Fitting the temperature signal by two harmonic terms plus a linear trend, we can reproduce the signal approximately (Figure 18). Taking this into account, we can compare the year 2009 with the climatological mean for surface waters. SST was lower than the mean value for the winter and the beginning of the spring. The minimum was detected in February, the colder temperature ever reached in the station, 11.28ºC, more that 1 ºC under the adjusted value, also March temperature was 0.7 ºC under the adjusted value. However, it is important to note that both values are associated with the presence of cold and fresh waters in the surface (within the first 15 meters depth) not being SST a direct reflection of MLD deepening but a consequence of advection of cold and fresh waters. During the summer and autumn, SST is around the mean or lightly over. Only July and October are 0.5 and 1ºC over the main value. October has presented one of the warmers years in the time series.

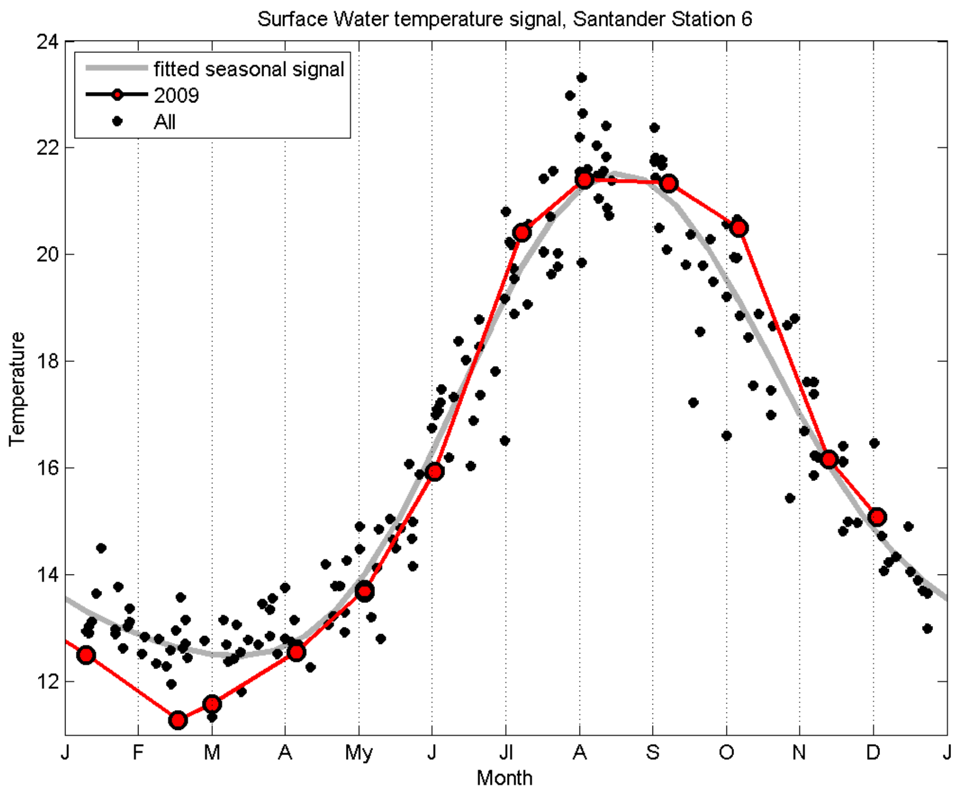

Figure 18. Seawater Surface Temperature at Santander station 6 (shelf-break).

The amplitude of the seasonal cycle of SST was of 9.9 ºC, and the air temperature seasonal cycle for the year (10.2 ºC). SST cycle is wider than the mean 8.7 and air temperature 9.8 ºC is close to the long term mean.

The anomalous cold winter and spring, and lightly warmer summer and autumn produced a yearly temperature under the average sea surface temperature (Figure 19). Winter anomaly was more that 1 ºC for three months and extends half a year. It is not directly related with an extreme deepening of mixed layer depth as occurred in winter 2005, due to the presence of very low salinity waters at surface that hinders winter mixing. Only October present positive anomaly of 1 ºC.

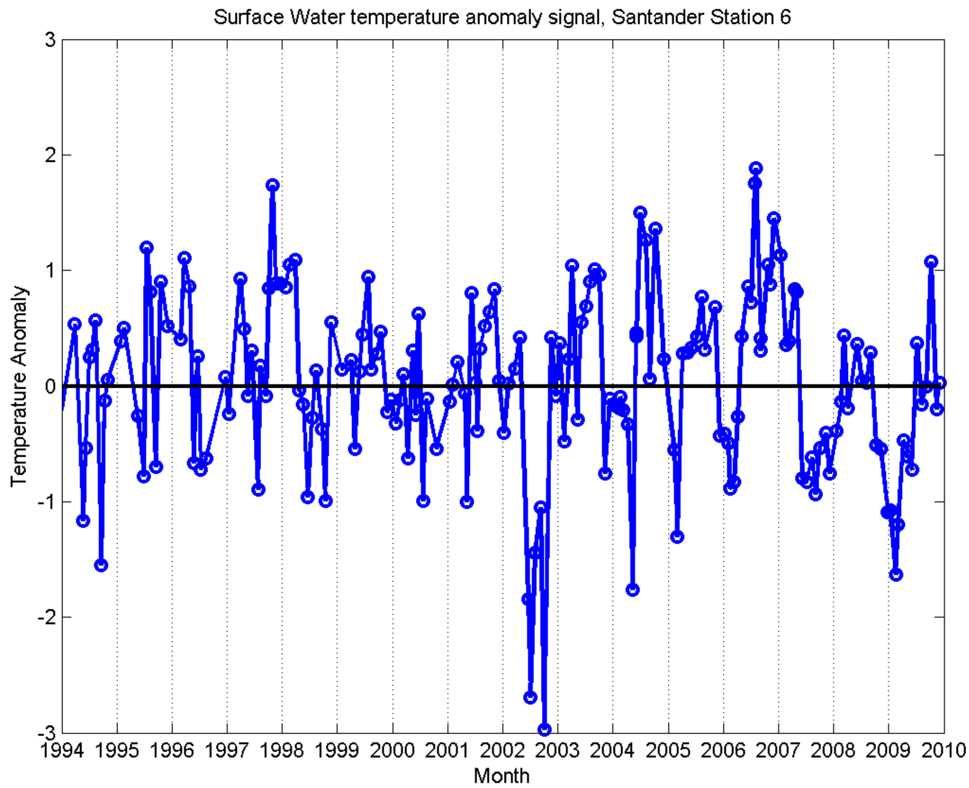

Figure 19. Seawater Surface Temperature anomalies at Santander station 6 (shelf-break).

When the analysis is produced all over the upper waters to 300 m depth, 2009, due to the cold winter, was one of the colder years, only 2005 was colder (Figure 20). The mean temperature value was less than 12.5, the second cold year after 2005.

A salinity average of this layer (5–300 m) is shown in Figure 21 for station 6. The 2009 mean value is close to the mean value of the time series. After the high salinity episode from 2006 to 2008 salinity has reduced again to the mean value.

The strong amount of freshwater due to strong precipitation at the end of 2008 and the lack of episode of Iberian poleward Current has produced this deficit in salinity. 1998 presented the highest salinity. Between 1998 and 2001, evidence of a decline in salinity was found up to a depth of 300 m. In 2002 this trend was inverted, especially during the Iberian Poleward Current episode at the beginning of the year. During the end of 2006 and beginning of 2007 an important increase in salinity has been observed in the upper 300 meters. The strong episode of Iberian Poleward Current detected in 2008, similar to the 2002 one, adds more salinity to the water column and made 2008 reach the maximum of the trend started in 2003. But values were decreasing during 2008 after the maximum value reached in winter and low values seems to reach in December, due to strong precipitations at the end of the year. The salinity behaviour of the complete time series seems to be related with the atmospheric forcing in the area of formation of the ENACW, as it has been mentioned before and specifically with the difference between precipitation and evaporation.

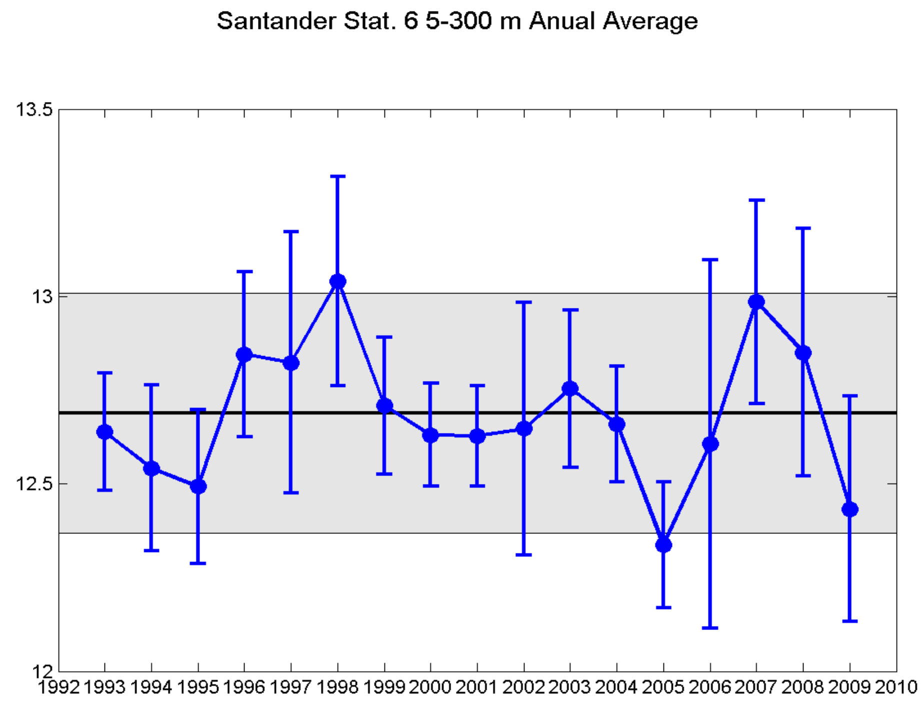

Figure 20. Annual average temperature (5–300m at Santander station 6 (shelf-break).

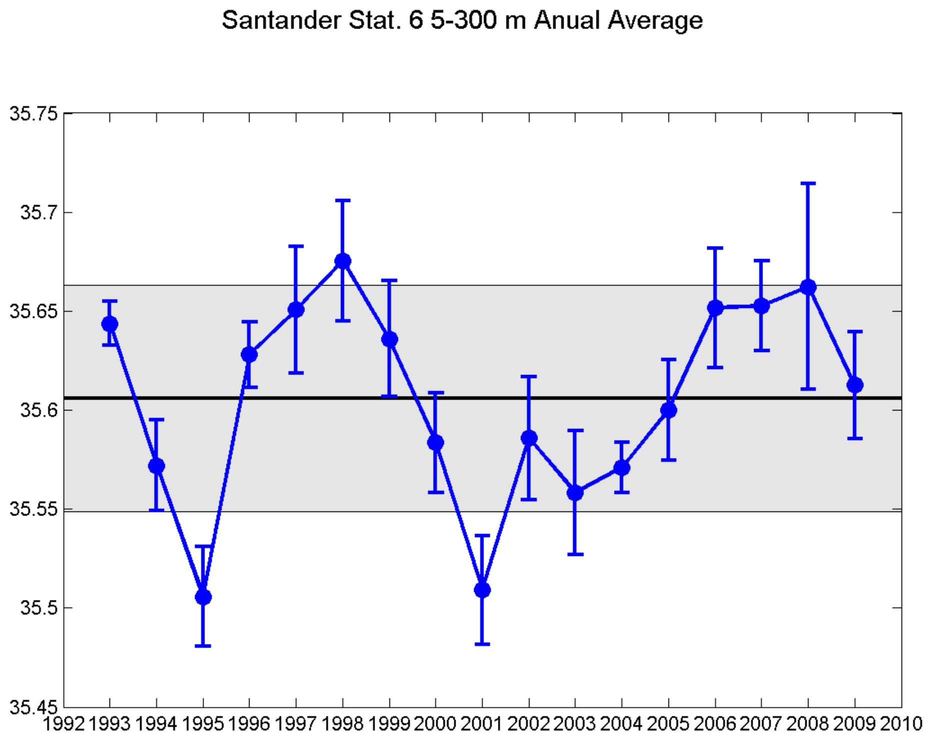

Figure 21. Annual average salinity (5–300m) at Santander station 6 (shelf-break).

In figure 22 distributions of potential temperature between 100m isobars from 200 to 600 meters and 600–1000 meters corresponding to ENACW and MW (Mediterranean Water) respectively is presented at St 7 over the slope. Upper waters reflects the variability in properties of mixed layer waters among cold winters (e.g. 2005 and 2009) versus warm winters as 2007. A warming trend is observed in ENACW deeper that 300m of around 0.23 ºC/decade and in between 0.15 and 0.09 ºC/decade in the MW. The cold episode of winter 2005 and 2006 seem to have caused a downward transfer of heat from seen as deep as the level 400 to 600m depth where potential temperature has increased around 0.25 ºC/decade. 2009 also presented a crude winter but this time it seems to be linked to, at least, transient cooling for most of the water layers.

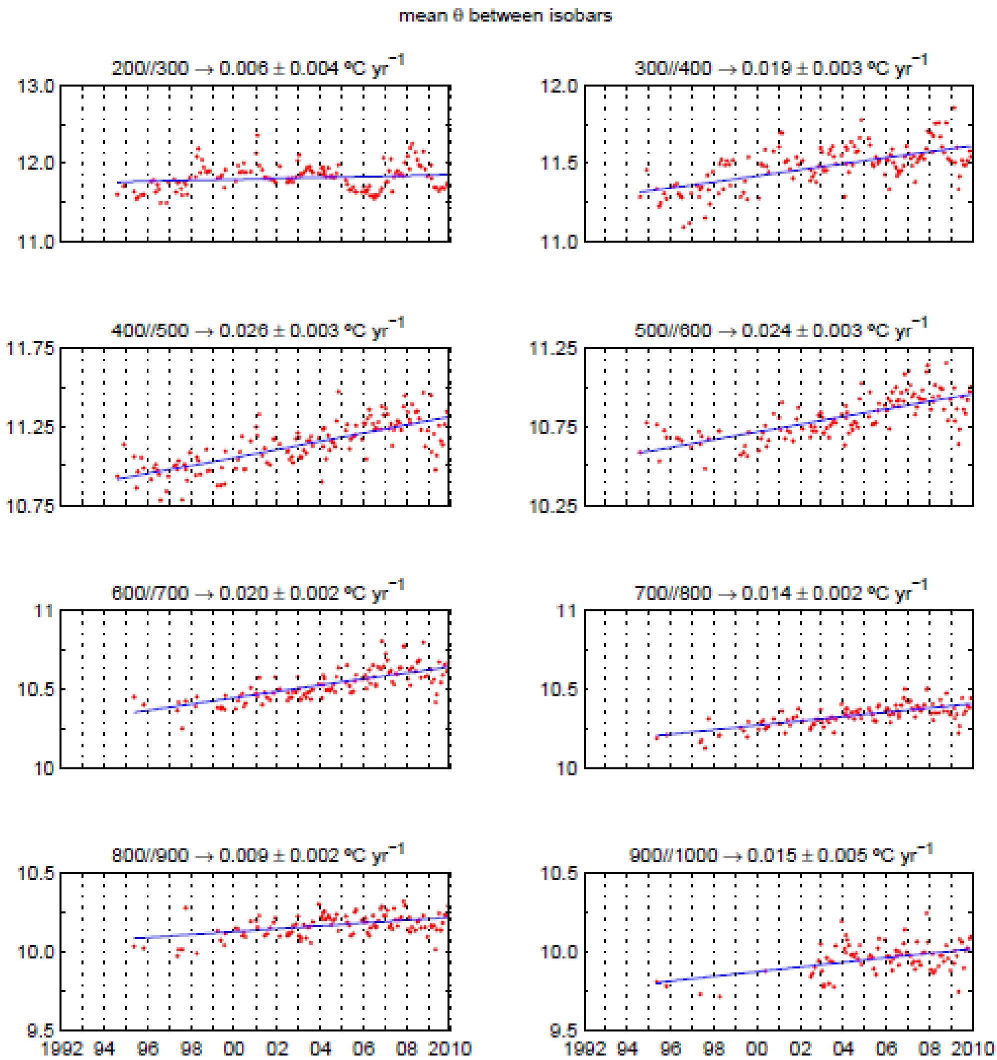

Figure 22. Mean Temperature evolution between isobars of ENACW (200–600m) and MW (600–1000m) water at Santander station 7(43º 48’N, 3º 47’W) (slope).

Water Masses

After the deep winter anomaly in the mixed layer and upper Central Waters in 2005 and the 2006, the water column was recovered. Nevertheless, winter 2009 present an episode similar of cooling, with the mixed layer depth reaching 260 dbar in this case. The strong rainfall and advection of low salinity waters seem to have hindered the deepening of winter mixed layer, but more analysis are also necessary. The previous anomaly 2005/2006 was over after the extremely warm summer/autumn 2006 and winter 2007.

In the figure 23 it can be seen the θ/S diagram of water masses at the southern Biscay from the Santander Standard Section data set, the sequential colour code also provides a first approach to the interannual variability. ENACW is found just below the mixed layer (typically about 200 dbar) and it is described by a straight line which ends in a Salinity Minimum level located about 500 dbar. Below this level it is n Water (MW) which has its core about 1000 dbar the limit of our sampling until 2007. From the data set it can be observed that MW have increased its temperature and salinity compensating its density until 2005/2006 but then it has stabilised, whereas the variability in the ENACW is not so evident in the θ/S diagram. The main changes evident in ENACW are the increase in temperature and salinity since 2005 onwards and the interruption of the θ/S straight line below the 27, in isopycnal level in the last years and the recovering again after the warm winter of 2007. 2009 also is conditioned by a new cold episode with strong signature on the T/S signal at the 27.15 isopicnal, similar to the 2005 episode and a deep mix layer. For the first time in the whole time series there is a slight freshening in the whole water column.

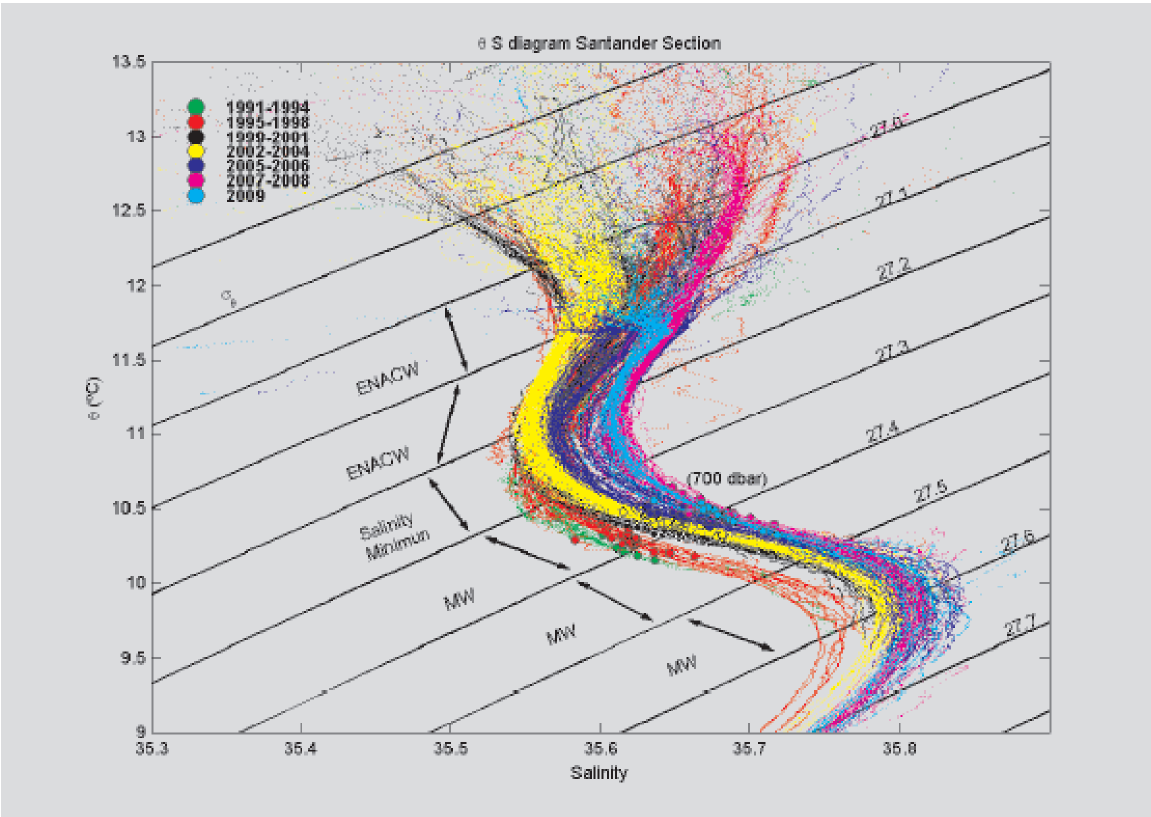

Figure 23. Water masses at Santander stations 6 and 7 presented in a TS diagram.

Annex 12: Regional Reports –North Sea 2009

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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 and water samples (see dots in Figure 7). 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 sampled T, S, fluorescence (chlorophyll-a, yellow substance), and oxygen concentration. Additionally, a thermosalinograph and optical sensors were mounted in the ship moon pool at about 4 m depth.

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
2000–2009 average ± std dev		1.543±0.079	15.98±0,99	1.142±0.006 (without 2001)

In 2009 the towed system had to be recovered halfway between station 52 and 53 due to bad weather and rough sea.

Global Radiation

Between April and June 2009 the monthly means of global radiation at the East Frisian island of Norderney (Figure 1) exceeded the long-term mean, from July on the global radiation was very close to the long-term mean.

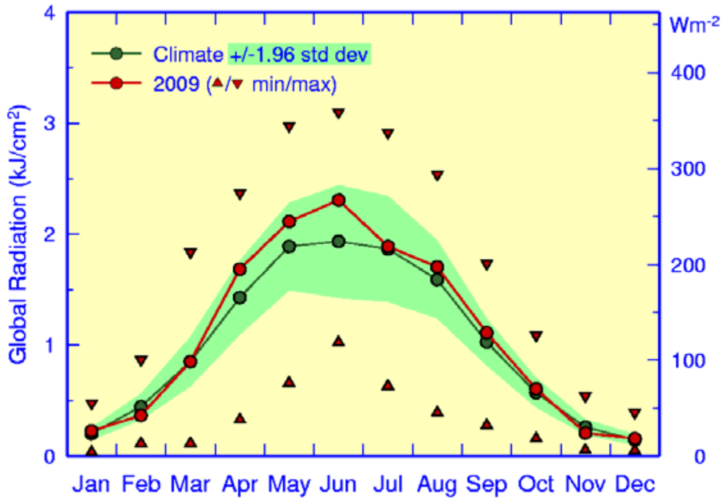

Figure 1. Seasonal cycle 2009 of monthly averaged daily global radiation totals at Norderney with intra-monthly extremes, 1971–2000 base period monthly means and 95%-band (climatology±1.96 standard deviations)in [kJ/cm²].

Data kindly provided by the German Weather Service (DWD).

Elbe River Run-Off

Between January and February monthly Elbe river run-off was about one standard deviation below and during March about 1.5 standard deviations above the long-term mean (Figure 2). The annual averaged run-off amounts about 20 km³/year which is slightly below the long-term mean (Figure 3). The data were kindly provided by the WSA Lauenburg.

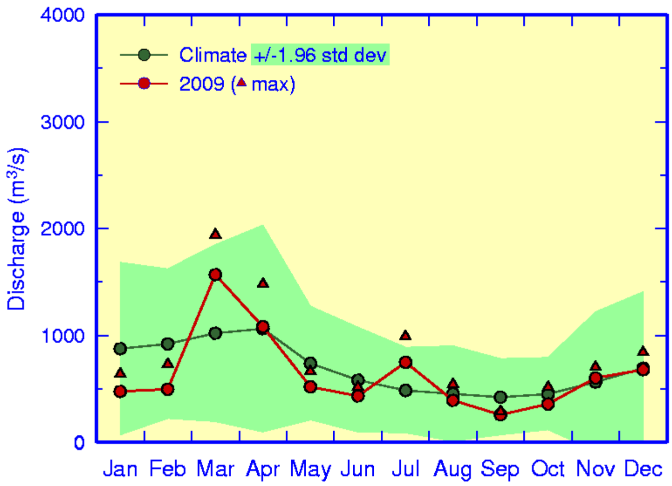

Figure 2. Monthly means of Elbe discharge at gauge Neu Darchau in 2009 (WSA Lauenburg).

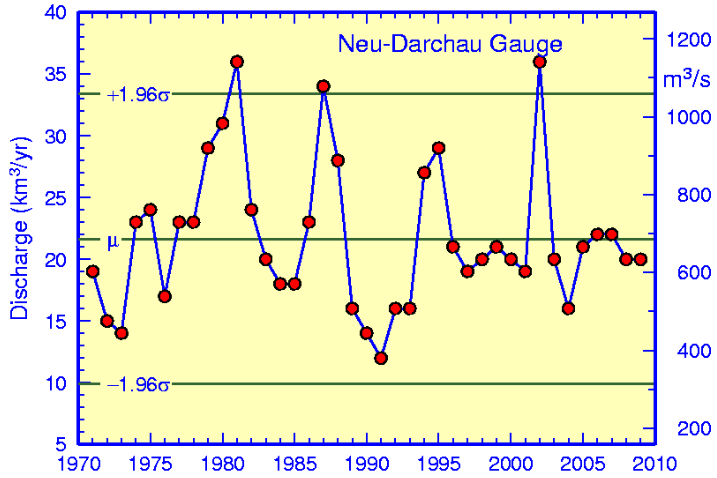

Figure 3. Yearly averaged Elbe run-off 1971–2009 at gauge Neu Darchau (WSA Lauenburg).

North Sea SST

During the first half of 2009 the weekly means of area averages SST were close to the long-term means, i.e. there was no heat excess from the previous (Figure 4). The monthly anomalies between January and June varied between -0.1 and +0.9 °C. Between June and July there was a pronounced warming, the monthly anomaly increased from 0.8 to 1.6 °C and varied between 0.8 and 1.3 for the last 5 months. The annual anomaly was 0.8 °C.

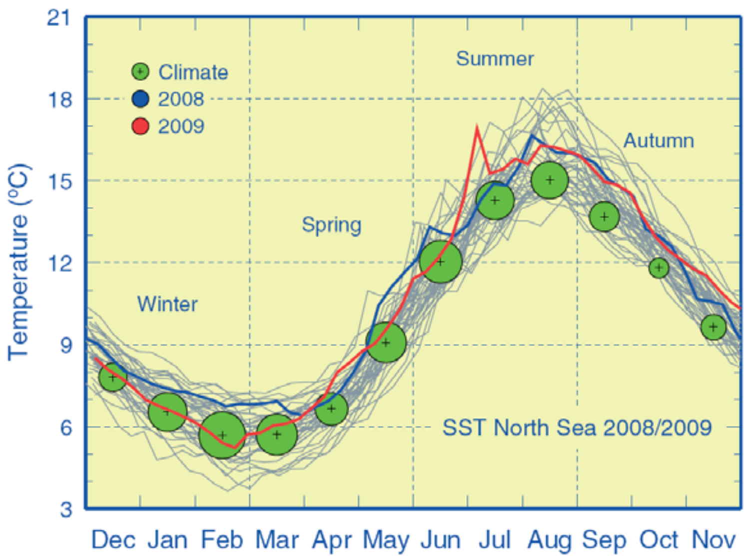

Figure 4. Weekly means of area averaged North Sea SST from December 2008 until November 2009 (red line) and from December 2007 until November 2008 (blue line). The grey lines are the annual cycles back to 1968. The green circles give the long-term monthly mean, the radius gives the inter-annual standard deviation for the period 1971–1993.

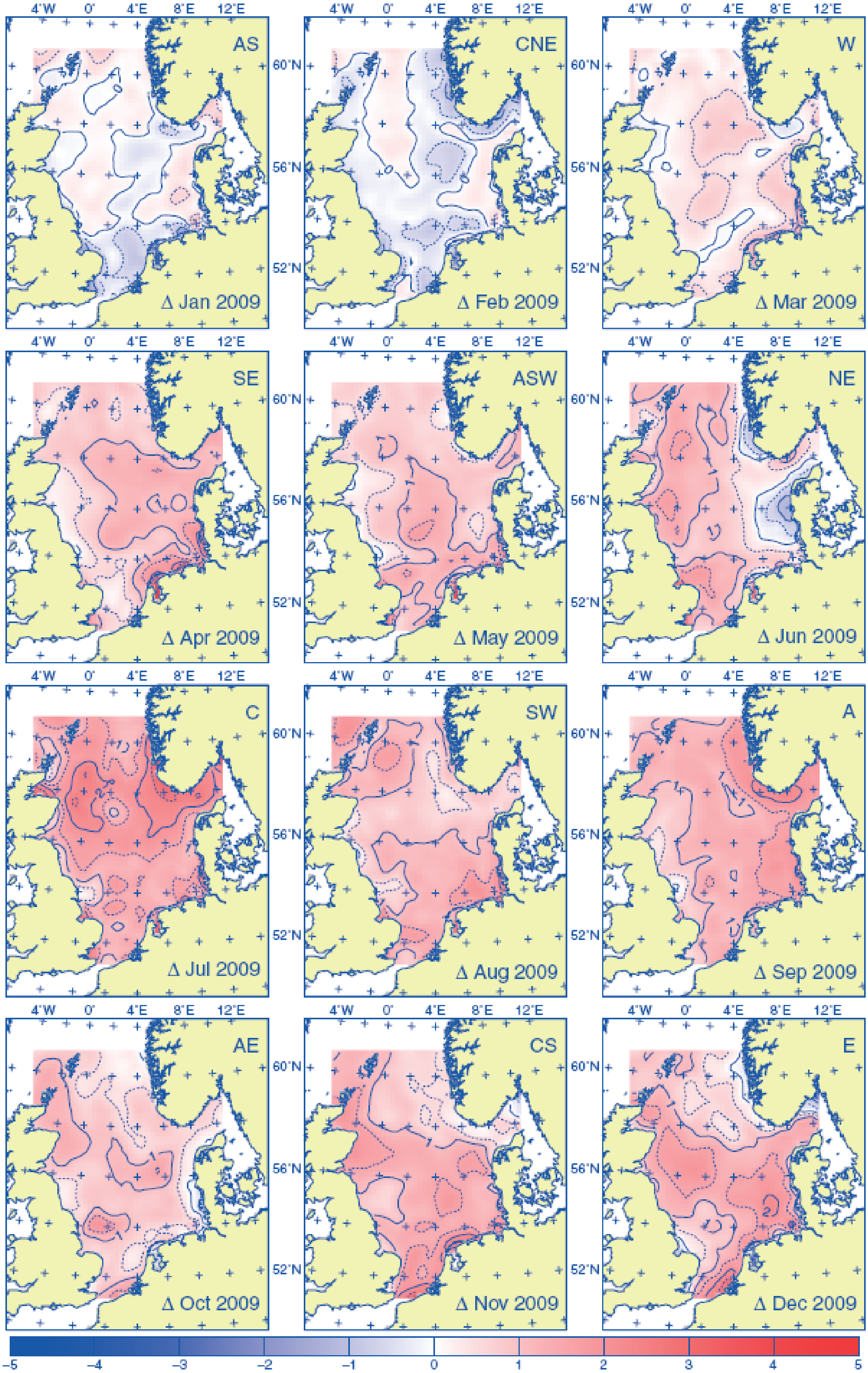

Figure 5. Monthly SST anomalies 2009, reference period 1971–1993.

Figure 5 shows the monthly SST anomalies for 2009. Beside 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. This is evident by comparing June and July 2009.

North Sea Summer Temperatures

In contrast to 2008, the near-surface temperature in 2009 exhibits the typical gradient with increasing temperatures from the open northern boundary towards the inner German Bight with isotherms running approximately from SW to NE. The bottom distribution is comparable to 2008. The vertically mixed areas along the southern and Danish coast are warmer than 2008 with temperatures close to 20 °C (Figure 6). The isolines in Figure 7 show the difference between the surface and bottom temperature. The left panel gives the strength of the maximum vertical temperature gradient and the right panel the gives the correspondent depth of the maximum vertical temperature gradient (depth of thermocline). In the central North Sea and Skagerrak area the thermocline depth exceeds 40 m with maximum gradients of about 3°C/m.

This is also visible in the temperature sections shown in Figure 8: A solid warm surface layer bounded by a sharp thermocline at about 40 m depth. The sharpness of the thermocline is gradually decreasing north of 57 °N. The local depression of the thermocline at about 7° E along the 58 °N-section, which was observed in 9 of 12 years, shows a record depth of about 80 m.

The bottom layer is generally thinner and warmer compared to 2008, however, the 2009 cruise was carried out one month later compared to the previous surveys and the bottom layer is generally expected to reach its temperature maximum about one month later than the surface layer. The 54° N section was completely vertically mixed due to tidal mixing, the 55° N section was vertically mixed at its eastern section and above the Dogger Bank, but stratified east off 1.5° E.

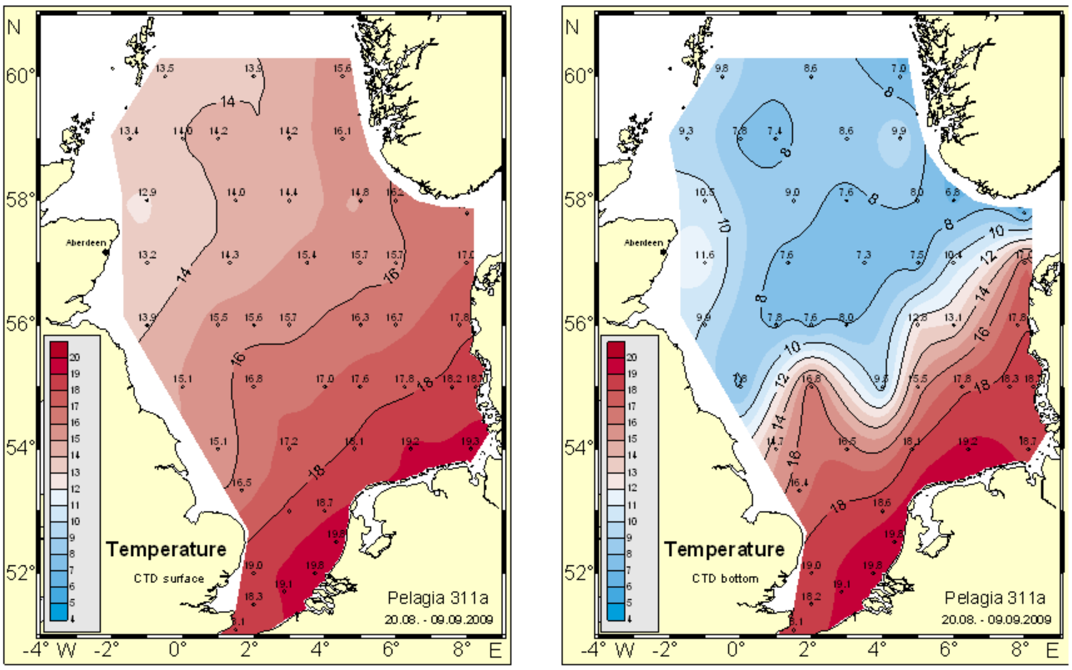

Figure 6. Horizontal surface (left) and bottom (right) temperature distribution [°C], PELAGIA 311a, 20 August – 8 September 2009.

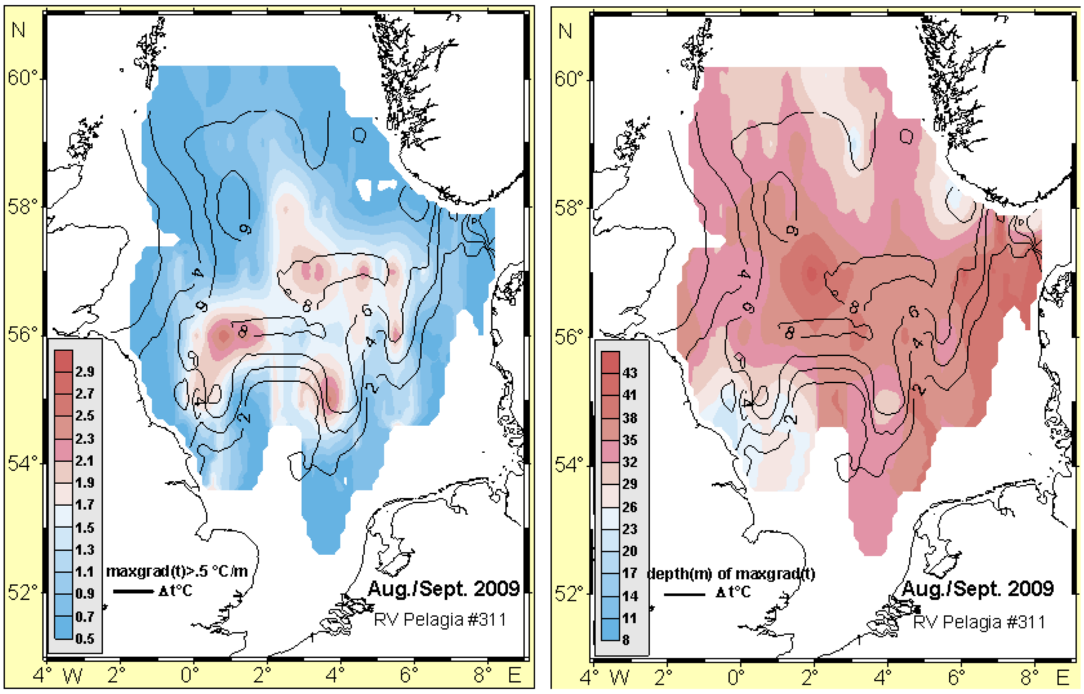

Figure 7. Isolines: T_{sur}-T_{bot} [°C], left: strength of maximum gradient [°C/m]; right: depth of maximum gradient [m]. PELAGIA 311a, 20 August – 8 September 2009.

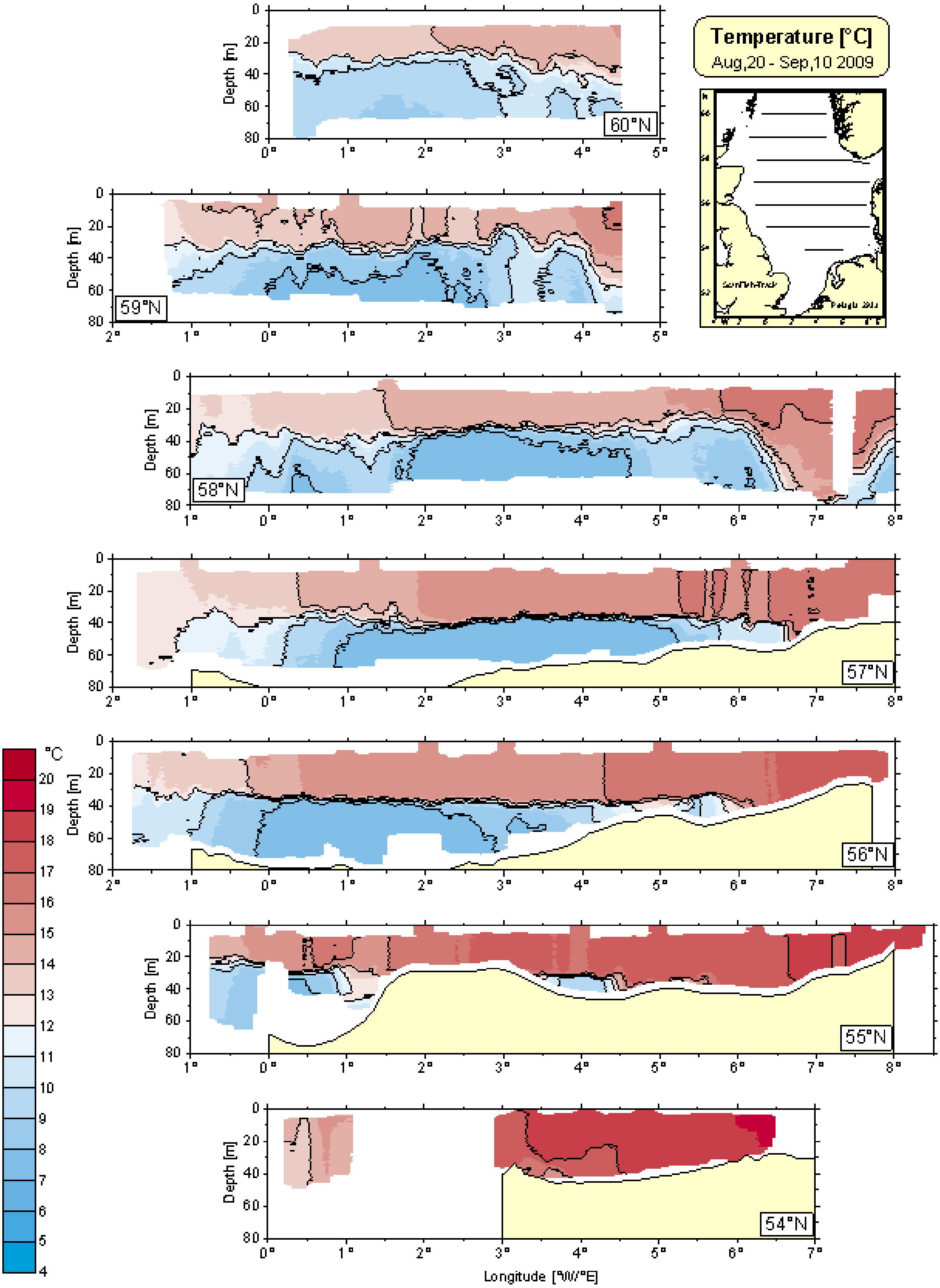

Figure 8. Temperature section from PELAGIA 311a, 20 August – 8 September 2009.

Temperatures at Light Vessel Ems

The BSH's monitoring station on the light vessel EMS (54° 10′ N; 6° 21′ E, water depth 35 m) provides the most continuous temperature time series, even though this time series exhibits some gaps due to technical problems, bio-fouling or maintenance of the vessels. Figure 9 shows the temperature evolution at different depth from January 2005 until the beginning of 2010. The solid line gives the seasonal cycle calculated from the climatological data set of Janssen *et al.*, 1999[1], which includes all available data recorded between 1900 and 1996. It shows a pronounced annual cycle with an amplitude of about 8 °C. Evident in the EMS record is a strong inter-annual variability and a distinct shift of the annual cycle during the last years. Generally, seasonal stratification starts around April, but there is an irregular alternation between vertical mixing and a re-established stratification until the end of September when the North Sea is generally vertically mixed again until the next spring. The EMS station is located in the range of the tidal-mixing front which is drifting across the EMS position according to the prevailing winds and tides. Occasionally strong winds can also destroy the stratification during summer.

Compared to the average seasonal cycle the years from 2005–2009 show significant deviations. The most obvious signal is the strong increase in winter minimum temperatures by about 2.5 °C in 2006/2007 and 2007/2008. During these winters seasonal heating started about a month early compared to the climatology. Unusually warm temperatures were also evident during fall of 2005 and probably most of the second half of 2006 although there are larger gaps in the record. The period May to July is usually characterised by swift changes between stratification and vertical mixing episodes which show inter-annual variability in intensity. Highest summer temperatures were reached in 2006 and during this time the strongest temperature changes occurred between vertical mixing events. During fall 2008 the temperatures, like the SST, were close to the long-term mean and the winter minimum 2008/2009 approached again the climatological minimum. During the first half of 2009 the temperatures were very close the long-term mean, but the second half 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.

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[1] 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.

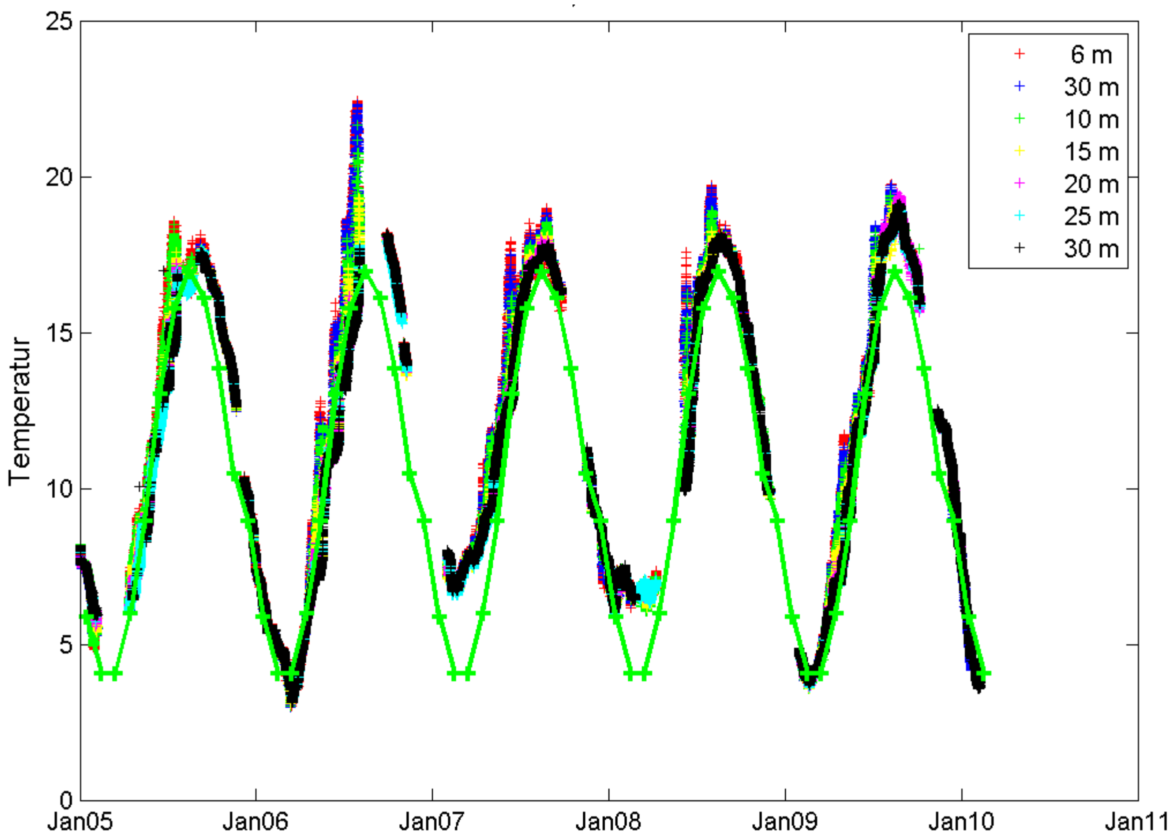


Figure 9. Temperatures at light vessel Ems 2005–2009. Green line climatology according to Janssen *et al.*, 1999.

Total Heat Content

The total heat content is a climate relevant index which integrates the effects of solar radiation, advection of Atlantic Water, seasonal stratification, and atmospheric heat exchange. Figure 10 shows the total North Sea heat content for the summer cruises 1999–2009 related to the masked area in Figure 6. The heat content was steadily decreasing from 2003 until 2006 but rising again between 2006 and 2007. Between 2007 and 2008 the heat content fell back to the 2005 value (cf. Table 1). Concerning the high value in 2009 it must be kept in mind, that the 2009 survey was about one month later compared to most of the previous surveys. Because the maximum temperatures in the bottom layer occur about one month delayed compared to the surface layer, this maximum might be an artefact.

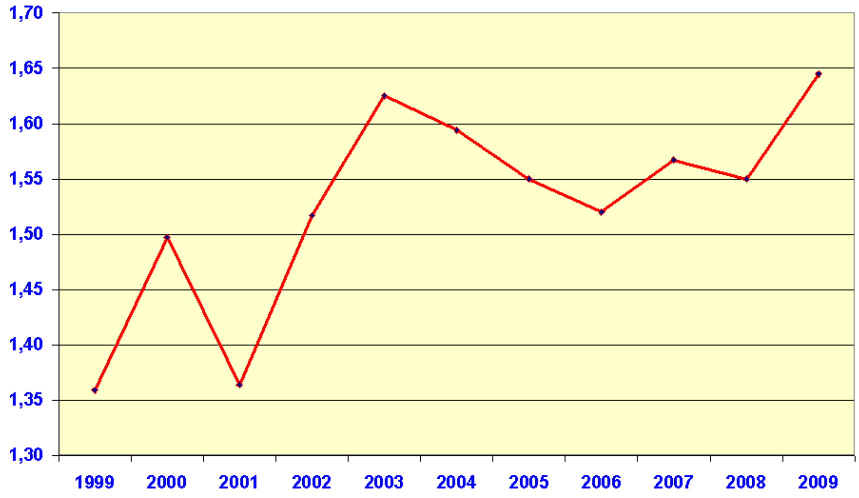


Figure 10. Total heat content in J x 10^{12}, 1999–2009.

Figure 11 shows the monthly mean temperatures of the total North Sea volume between 2000 and 2009 based on results of the operational BSH model 'BSHcmod'. Beside the pronounced warming during the last years the data show the increasing length of the summer season: Seasonal warming starts earlier and cooling much later. This pattern is already known from the SST data, but is also valid for the total North Sea volume.

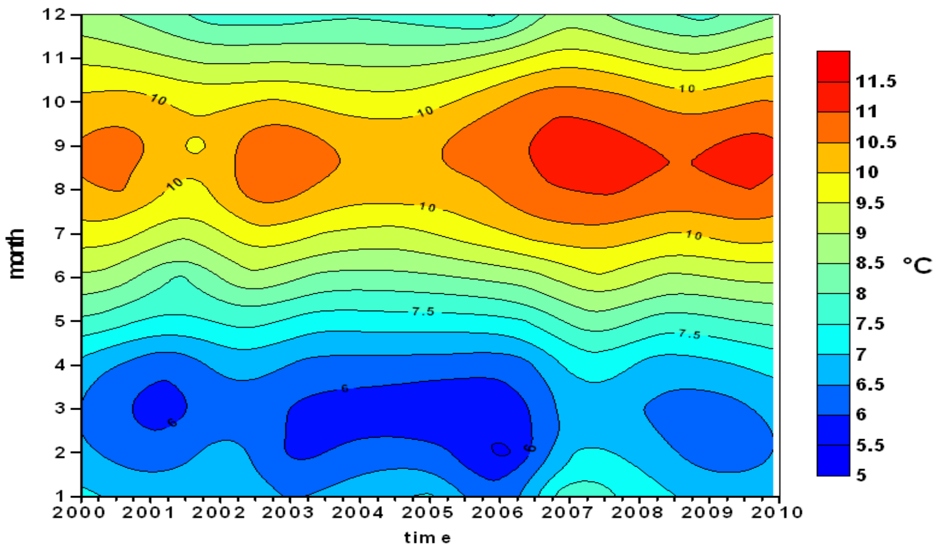


Figure 11. Monthly mean temperature of the total North Sea volume 2000–2009.

(BSHcmod model data)

North Sea Salinity and Total Salt Content

Compared to 2008 the salinity concentrations in the surface and bottom layers increased in the northern part of the North Sea. The tongue of Atlantic Water with salinity S>35 in the near-surface layer reached nearly 2 degrees further to the south and about 4 degrees further to the east. Also in the outflow region of the English Channel small lenses with S>35 were detected in both layers. Generally, the influence of the Channel is bigger compared to previous years (Figure 12). The ribbon of low saline water in the surface layer along the Norwegian Coast with S<34 is smaller compared to 2008, but broader in both layers along the Dutch, German, and Danish coast. Therefore, the total salt content decreased a little bit compared to 2008 (Figure 13 and Table 1).

The salinity section (Figure 14) show, that between 3 and 5.5 °E there is a block of warm high saline water lying over colder low saline water on the 56 °N section, this is very unusually. The 57°N section shows vertical columns or intrusions of high saline water between the surface layer and the bottom layer. This might be caused by the strong and rapidly changing winds during the cruise.

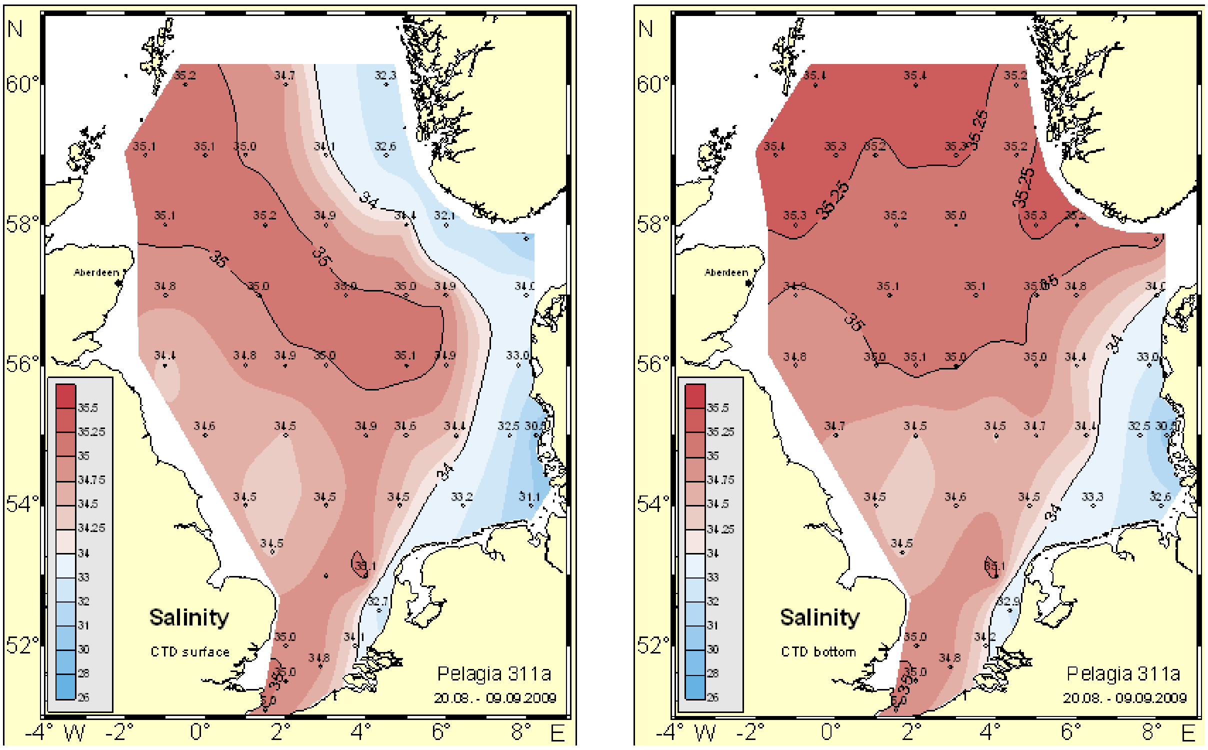


Figure 12. Horizontal surface (left) and bottom (right) salinity distribution, PELAGIA 311a, 20 August – 9 September 2009.

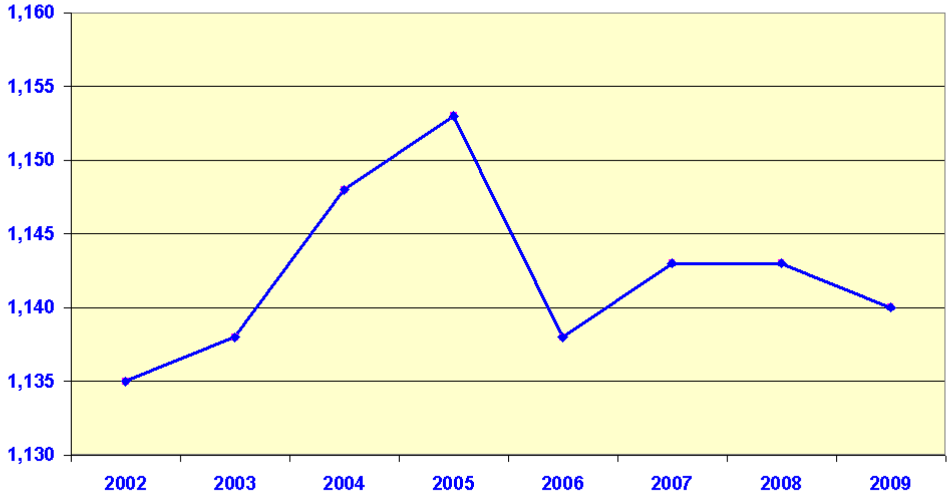


Figure 13. Total salt content in 10^{12} tons from 2002 to 2009.

(GAUSS and PELAGIA cruise data).

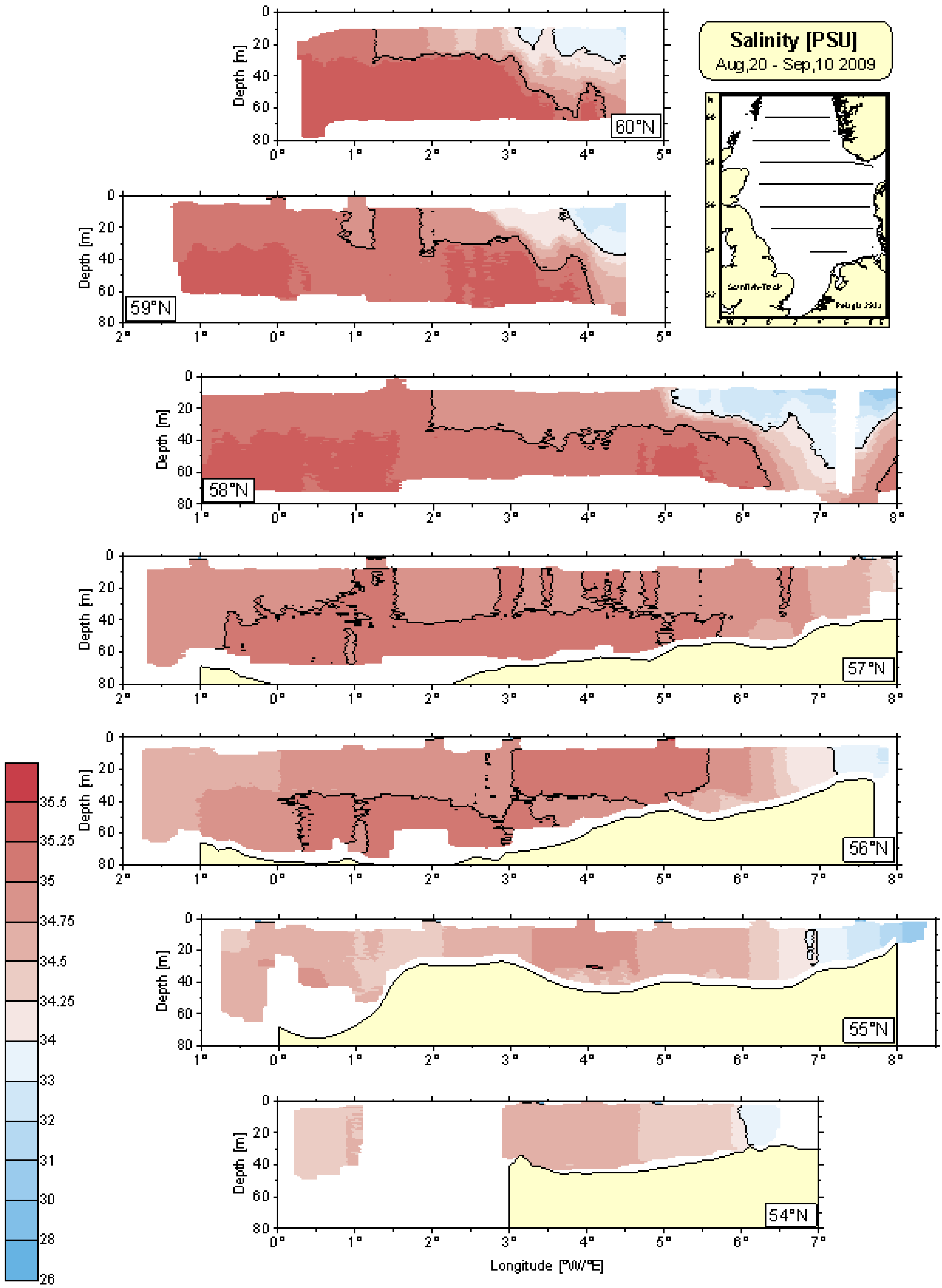


Figure 14. Salinity sections from PELAGIA 311a, 20 August – 8 September 2009.

Oxygen Saturation

The oxygen saturation during late summer was uncritical. Only small patches west off Jutland exhibit a saturation slightly below 70 % (Figure 15). Not until oxygen saturation falls below 40 % marine life experience substantial stress.

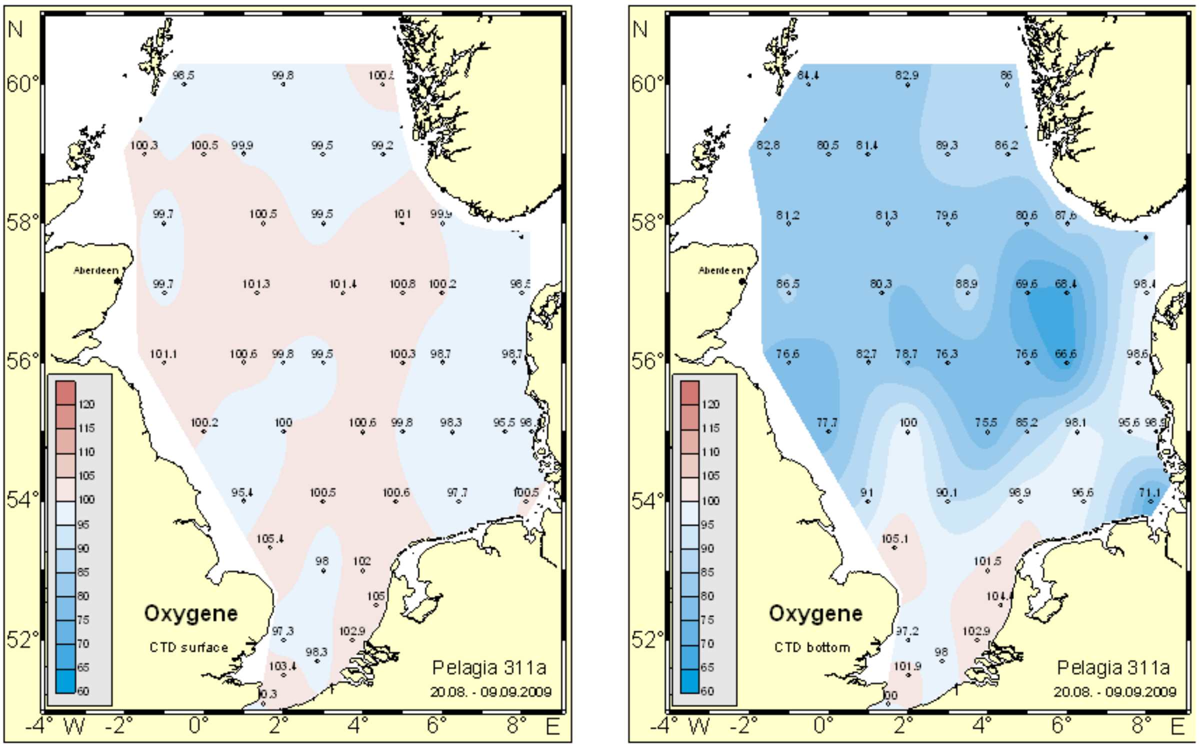


Figure 15. Surface (left) and bottom (right) oxygen distribution [%]. PELAGIA 311a, 20 August – 8 September 2009.

Secchi-Depth

Due to stormy and rapidly changing weather condition there was no consistent spatial Secchi depth pattern. Local maxima reached values up to 14 m.

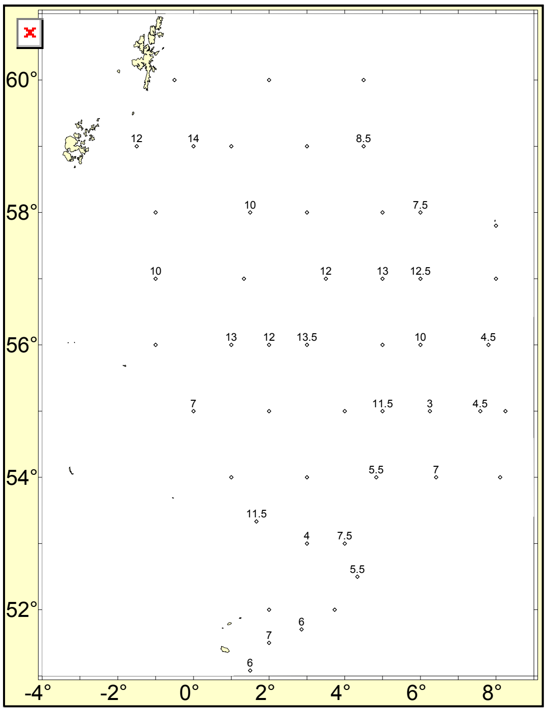


Figure 16. Secchi-depth [m]. PELAGIA 311a, 20 August – 8 September 2009.

Chlorophyll-a Distribution

Figure 17 shows the monthly averaged near-surface chlorophyll-a concentrations of the North Sea for March, April, May, June, November and December recorded by the Medium Resolution Imaging Spectrometer Instrument (MERIS) of the ENVISAT satellite. To improve the resolution a logarithmic scale is used. Chlorophyll production started during March and reached its maximum during April and May. The status shown for June kept stable until September. Due to the warm SST there was a late "bloom" in November/December. Additionally, strong wind during September and October might have mixed nutrients to the surface.

The vertical distribution of chlorophyll-a along the sections of the summer survey is shown in Figure 18. The chlorophyll maximum is located directly under the thermocline and near the surface where no stratification has established (compare Figure 8).

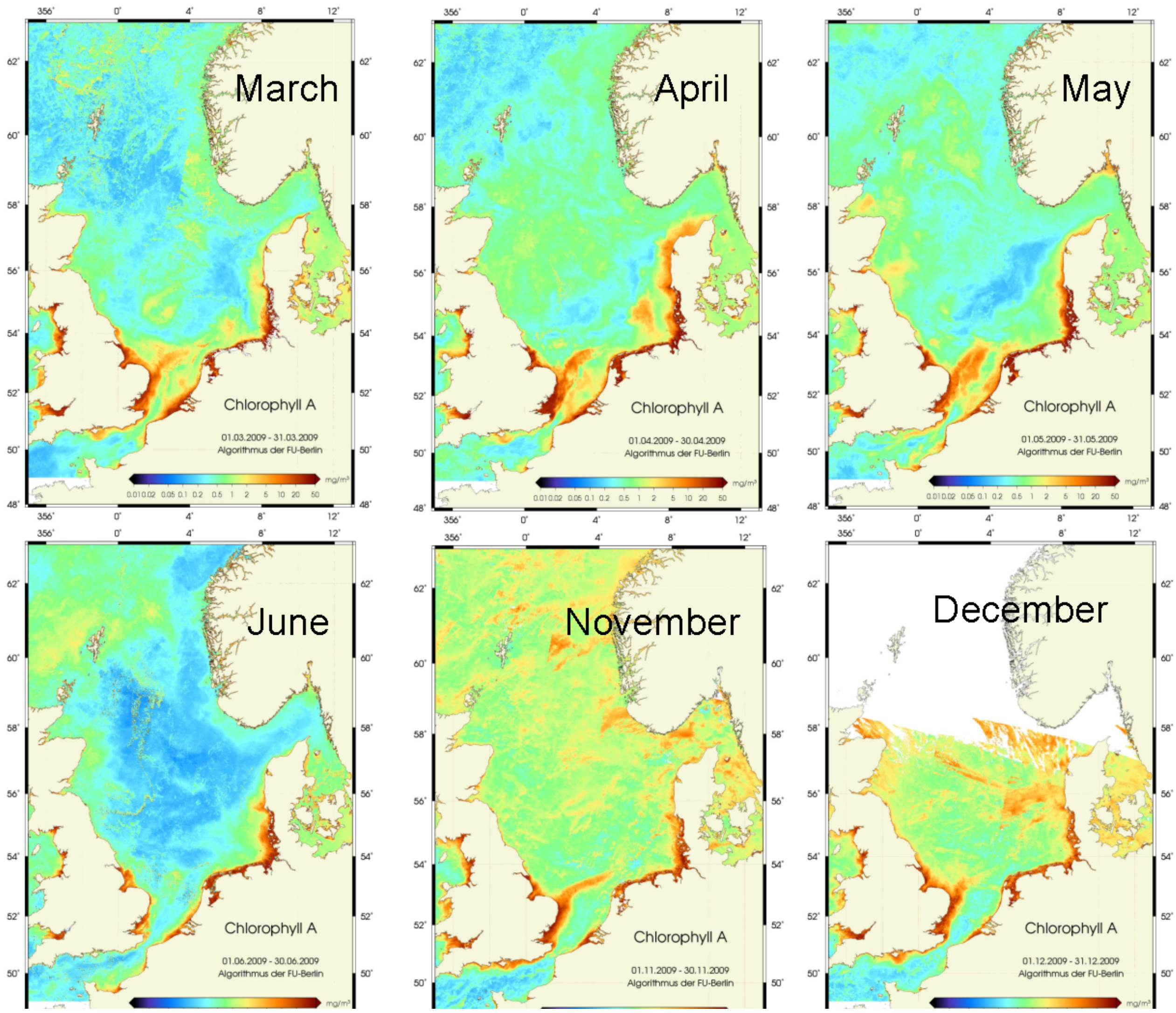


Figure 17. Monthly averaged Chlorophyll-a concentration (MERIS) during March, April, May, June, November and December 2009.

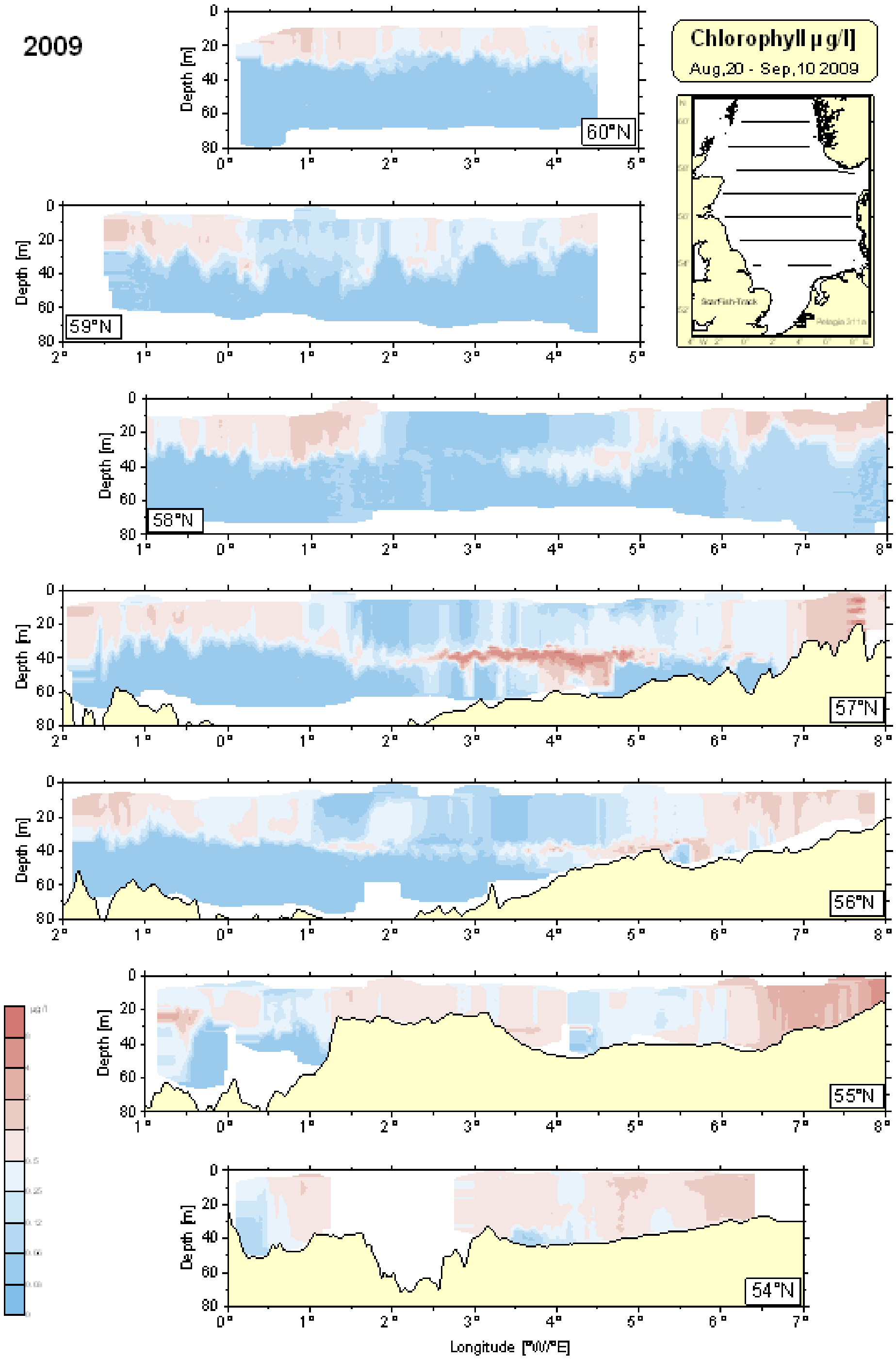


Figure 18. Chlorophyll-a sections from PELAGIA 311a, 20 August – 9 September 2009.

Annex 13: Regional Reports – Area 9b – Skagerrak, Kattegat and the Baltic

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 mean air temperature during 2009 was 0.5–1.5°C above normal in most parts of Sweden but below the temperatures of the previous years. In contrast to 2007 and 2008 it was a cold start of the year. April was sunny and warm while the beginning of the summer was unusually cold. Highest air temperatures were obtained at the end of June/beginning of July. At the end of December the whole country was snow covered. The precipitation was higher than normal except in the northernmost and southernmost parts of Sweden. The winds were somewhat weaker than normal, as in 2008, and the number of sun-hours were above 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 six of these stations the annual cycles of surface temperature and salinity are presented in Figure 2. The temperature in the surface water was close to normal (compared with the 1995–2004 mean) in the Baltic Proper for the entire year while the salinity was slightly above normal. In Skagerrak and the northern part of Kattegat the surface water in February was colder and less saline than normal. At the end of June the sea surface temperature was well above normal in Kattegat and Skagerrak. Due to strong westerly winds at the beginning of October the surface salinity became unusually high in this area. In the Bothnian Bay and Bothnian Sea the surface salinity was close to normal.

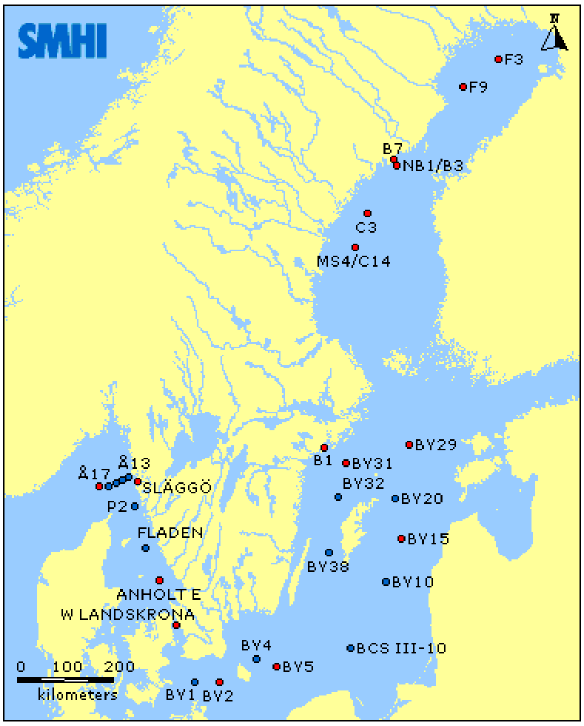
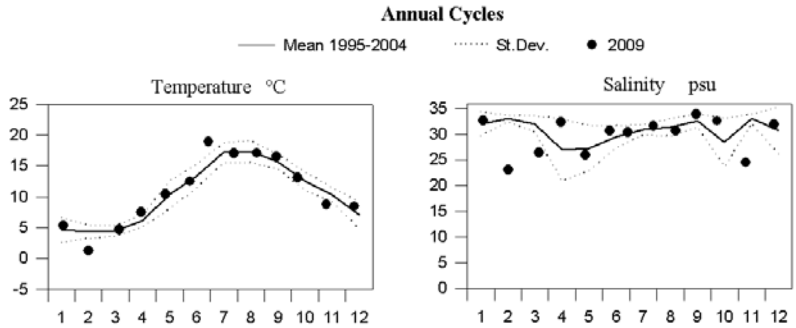
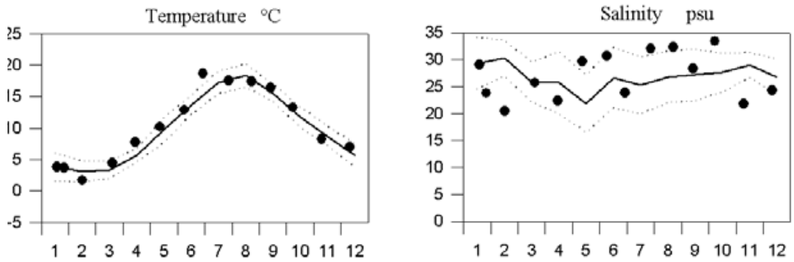


Figure 1. Position of stations visited on a regular basis. Stations marked with red pertain to the Swedish National Monitoring Programme while stations in blue are additional stations sampled by SMHI.

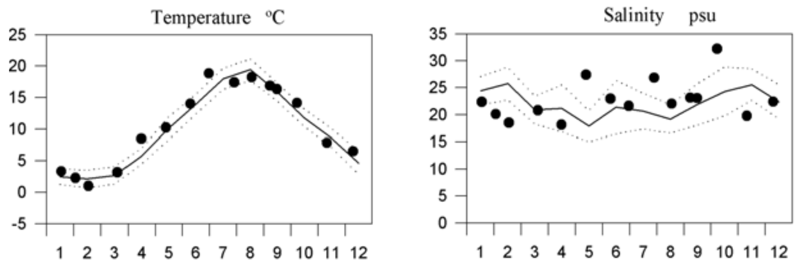
STATION Å17



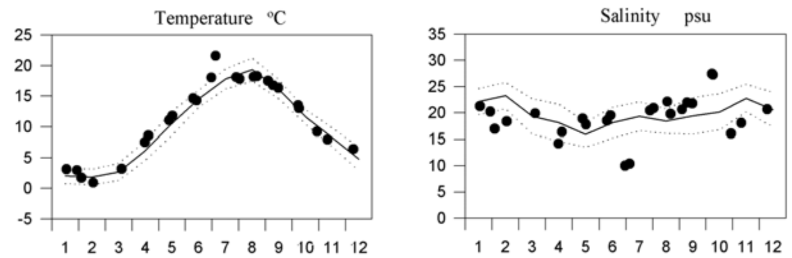
STATION P2



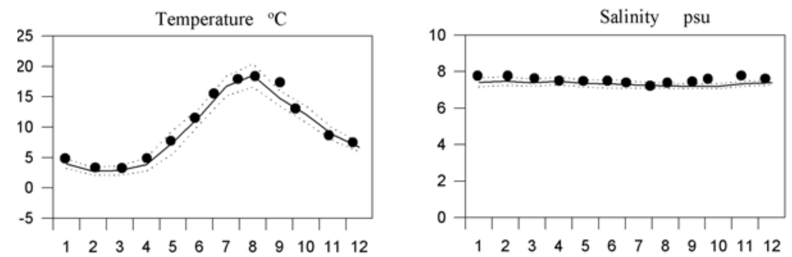
STATION FLADEN



STATION ANHOLT E



STATION BY5



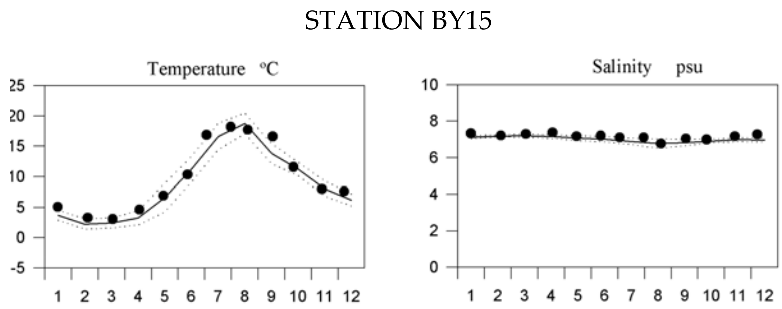


Figure 2. Annual cycles of surface temperature and salinity, see Figure 1 for station positions (SMHI).

Long term observations at BY15

At station BY15, east of Gotland, the mean surface temperature for 2009 was lower compared to 2007 and 2008 (Figure 5, upper panel). The decrease was fairly small and for the last 5 years the mean surface temperature has remained relatively constant with a positive anomaly of 1.5–2 °C relative to the 10-year period 1990–1999. The mean surface salinity at BY15 showed a slight increase and the five-year running mean continues to show a weak positive trend (Figure 3, lower panel).

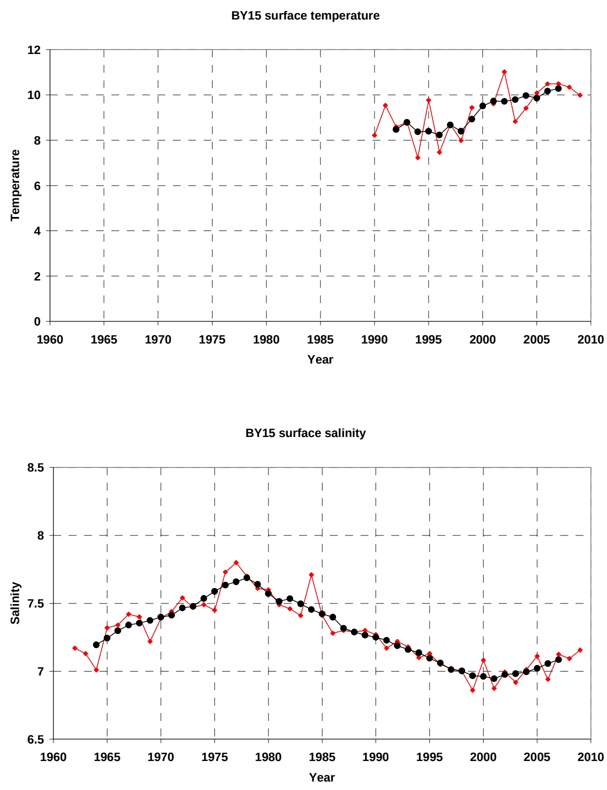


Figure 3. Sea surface temperature (upper panel) and salinity (lower panel) at BY15 (see Figure 2) in the Baltic Proper. Yearly mean (red curve) and 5-year running mean (black curve)/ SMHI.

Water exchange

A storm over the southern part of the Baltic in the middle of November gave rise to an inflow to the deeper parts of the Arkona and Bornholm Basins, improving the oxygen conditions in this area. This event was the largest inflow during 2009, amounting to 35 km^3. For the rest of the year only minor inflows of no significance took place. The accumulated inflow through the Öresund to the Baltic is shown in Figure 4.

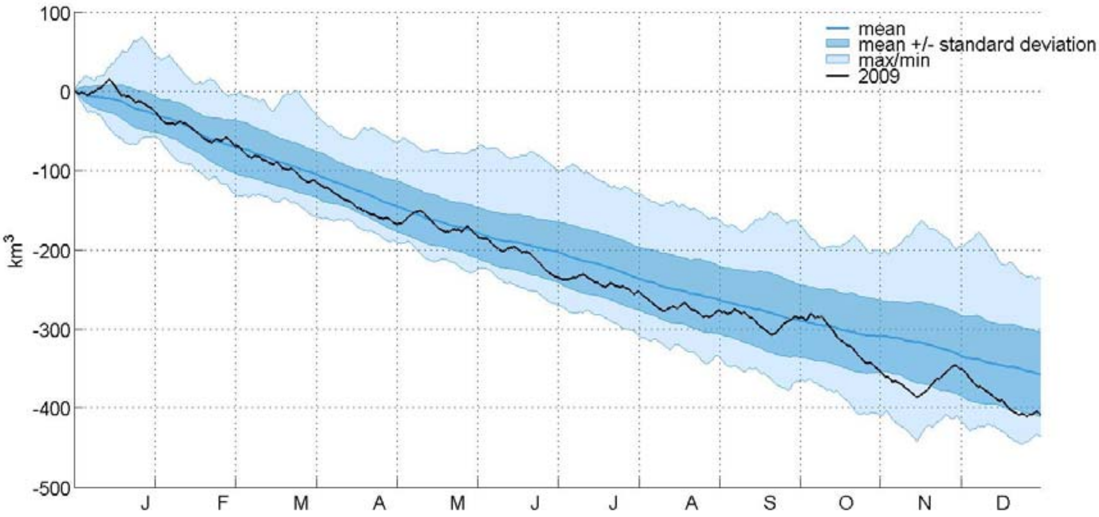


Figure 4. Accumulated inflow (km³) through the Öresund to the Baltic in 2009 compared to 1977–2007 (SMHI).

Ice condition

After a slow start of the ice season cold periods in January and February caused rapid ice formation. The maximum ice extent occurred on February 20, see Figure 5, which was quite early. The Bothnian Bay was ice-covered but the interior of the Bothnian Sea was ice-free for the whole season. On May 25 the ice season ended, which is about normal.

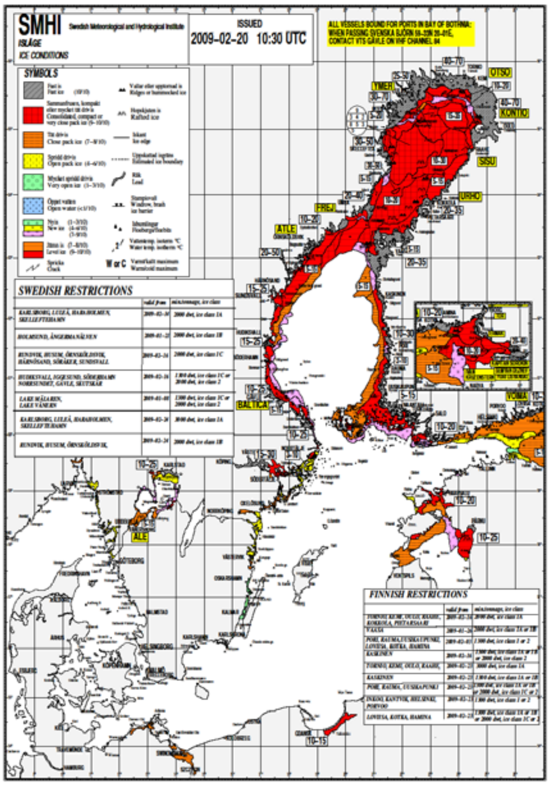


Figure 5. The maximum ice extent in the Baltic Sea during the winter 2008/2009. The map was constructed by the Ice Service at SMHI.

The ice season 2008/2009 was considered mild but the maximum ice extent, 110 000 km^2, was still more than twice that of the previous season. This is demonstrated in Figure 6 in which the maximum ice extent in the Baltic is plotted for the period 1960–2009. The preliminary value of the maximum ice extent for the present ice season (not included in Figure 6) seems to be twice that of 2008/2009; that is, more than 200 000 km^2.

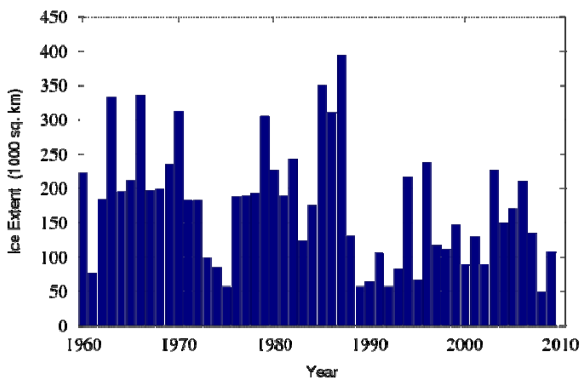


Figure 6. The maximum ice extent in the Baltic starting from 1960. Graph constructed by Lars Axell (SMHI).

Annex 14: Regional Reports – Northern Baltic Sea. Finnish national report

Pekka Alenius and Bert Rudels

Finnish Meteorological institute

The winter 2009/2010 was a slightly harder ice winter than the average. Maximum ice extent was over 249000 km^2. This was in large contrast to the previous winter 2008/2009 that was the mildest measured. The previous notable ice winter was 2002/2003 when the maximum ice extent was 230 000 km^2. The winter 2009/2010 caused some bigger problems to navigation.

The annual course of surface temperature showed rather normal early spring and then an exceptionally warm end of May. After the warm May surface waters cooled so that most of June was cold. Then again a short warm period followed in late June/early July. There was a remarkable uppwelling before mid July that lowered the surface water temperatures much below average. The first half of August, when the surface temperature generally is the highest, was much warmer than the average observed during the last decade. The warm period continued up to end of September. The late autumn was cooler than the average.

The deep water conditions seemed to continue in the same trend as during previous years. There has been slight warming of the deep waters in recent a couple of years. The salinity conditions were more or less similar to those in the previous years. No dramatic changes have been seen.

Oxygen depletion is a serious issue in the Baltic Sea Proper and in the Gulf of Finland. The conditions in the most intensively observed station in the central Gulf of Finland showed that the year 2009 began with a well mixed situation that had brought oxygen down to near bottom layers, too. However, in the spring and during the summer there was stronger stratification that usual, leading to poor oxygen conditions in the deep water. The poor oxygen conditions in the deep water in Baltic Sea Proper and in the Gulf of Finland have remained similar to those in previous years.

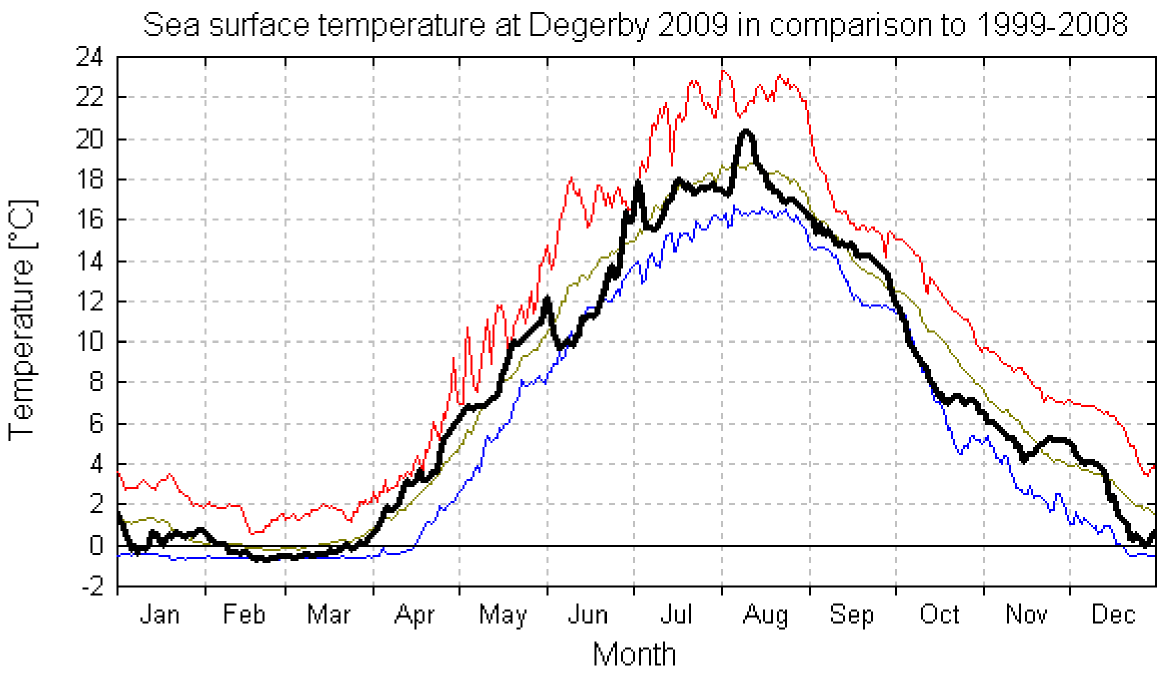


Figure 1. The annual sea surface temperature variation at Degerby (Åland) in 2009, black, the 1999–2007 mean, the 1999–2007 maximum, the 1999–2007 minimum.

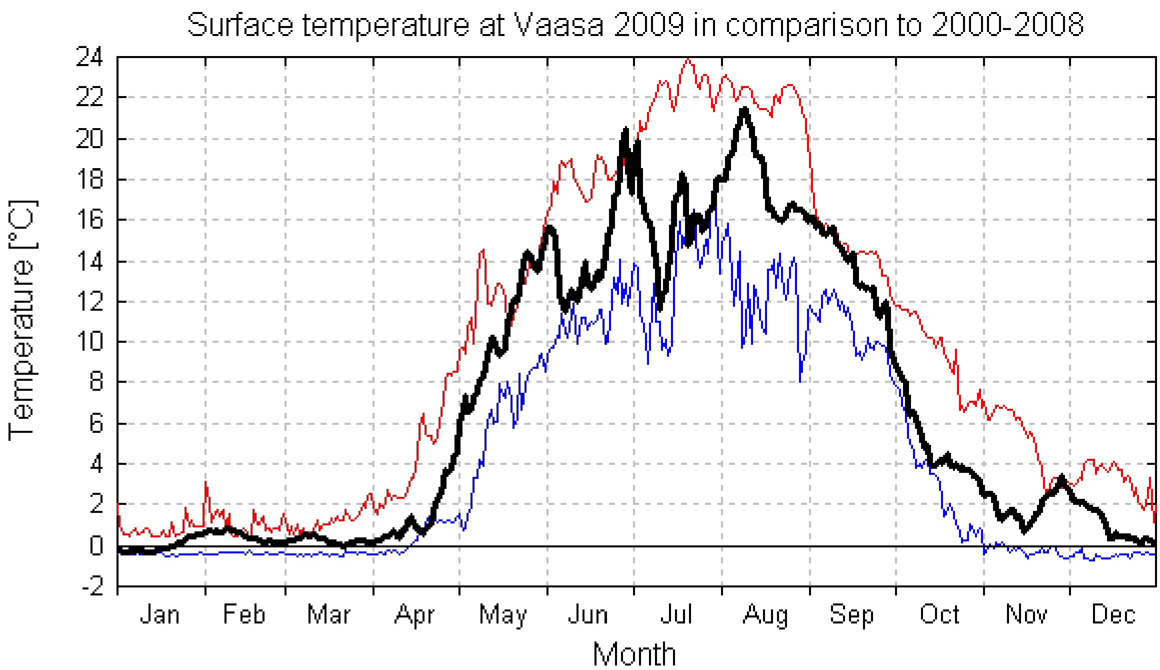


Figure 2. The annual sea surface temperature variation at Vaasa in 2009, black, the 2000–2007 mean, the 2000–2007 maximum, the 2000–2007 minimum.

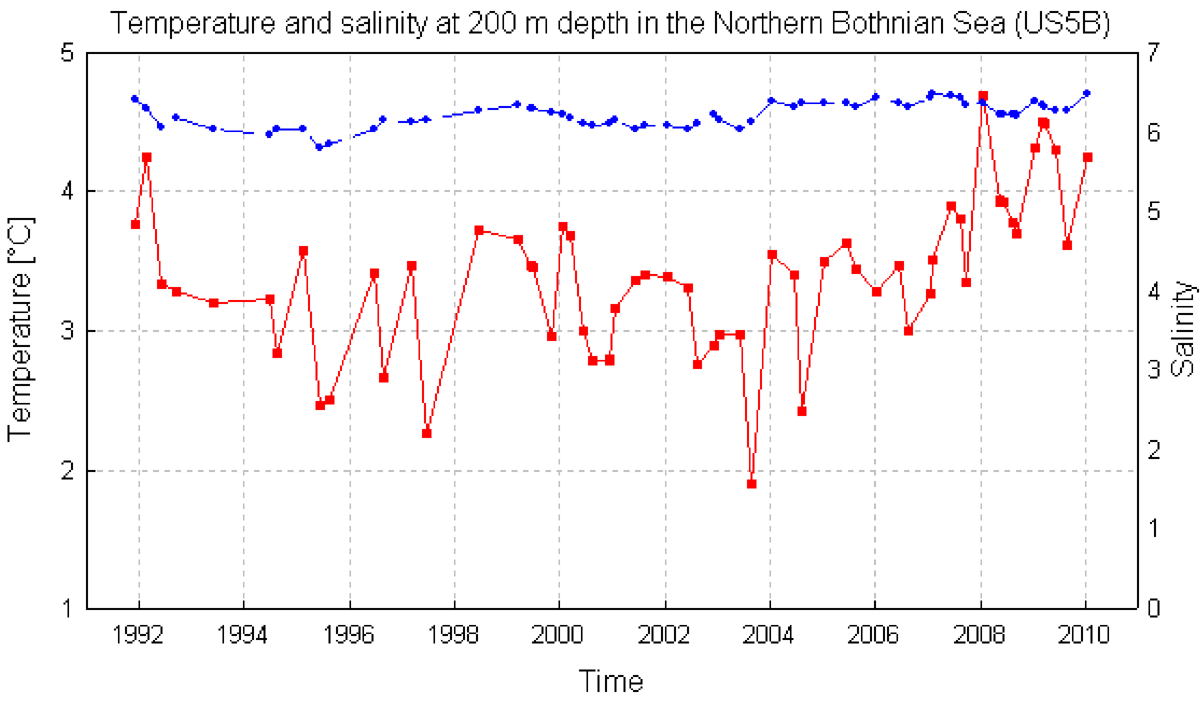


Figure 3. The temperature and salinity at deep water (200m) in the northern Bothnian Sea (US5b).

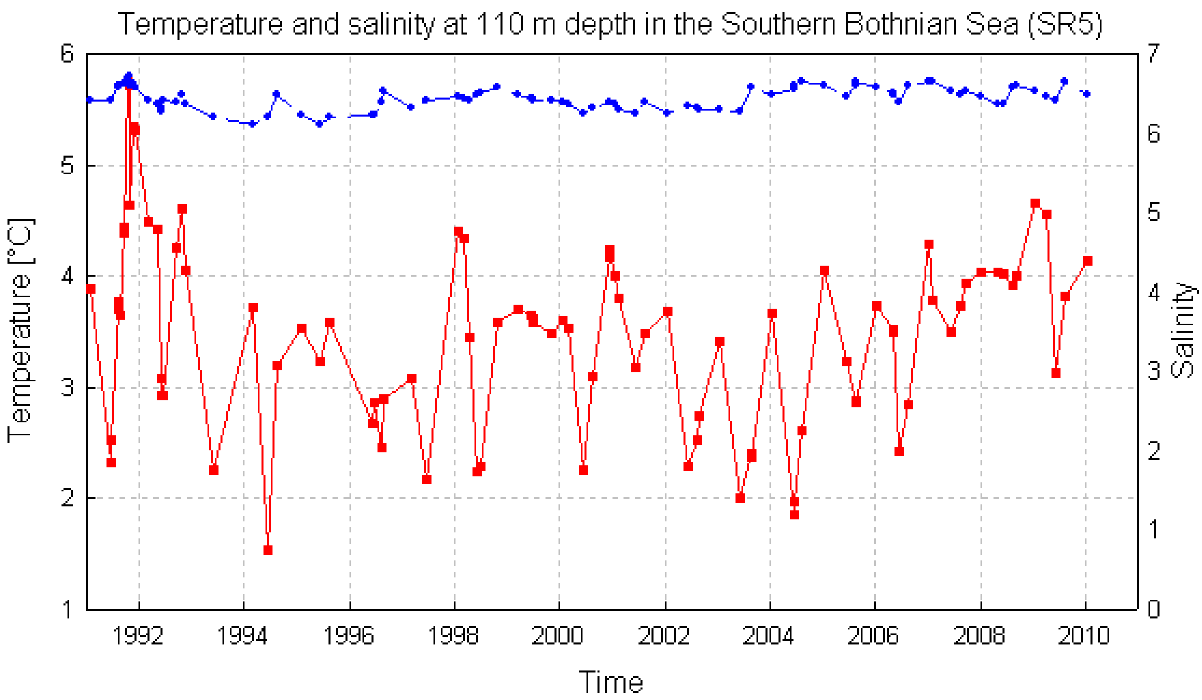


Figure 4. The temperature and salinity at deep water (110m) in the southern Bothnian Sea (SR5).

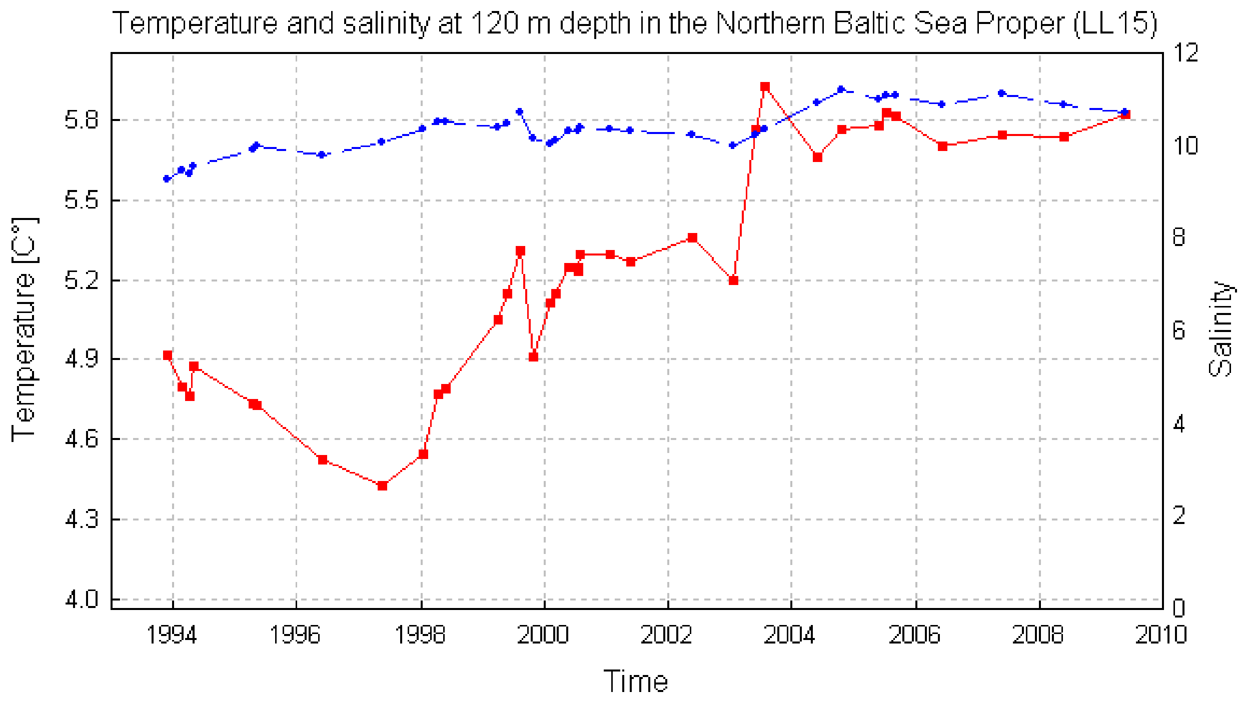


Figure 5. The temperature and salinity at deep water (120 m) in the northern Baltic Sea Proper (LL15).

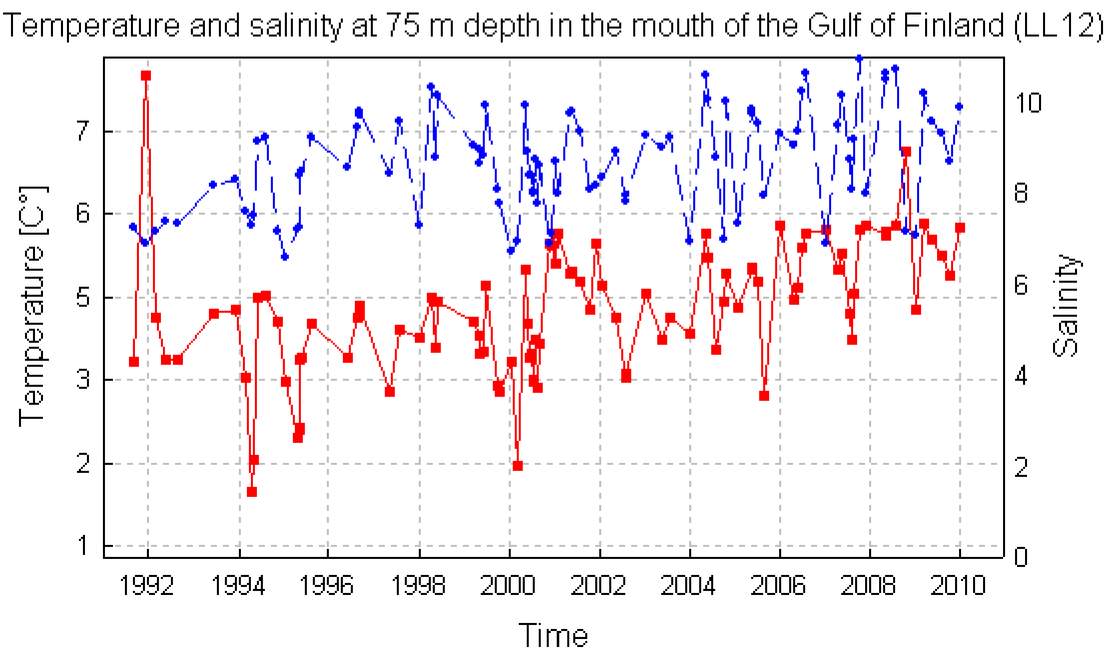


Figure 6. The temperature and salinity at deep water (75 m) in the mouth of the Gulf of Finland (LL12).

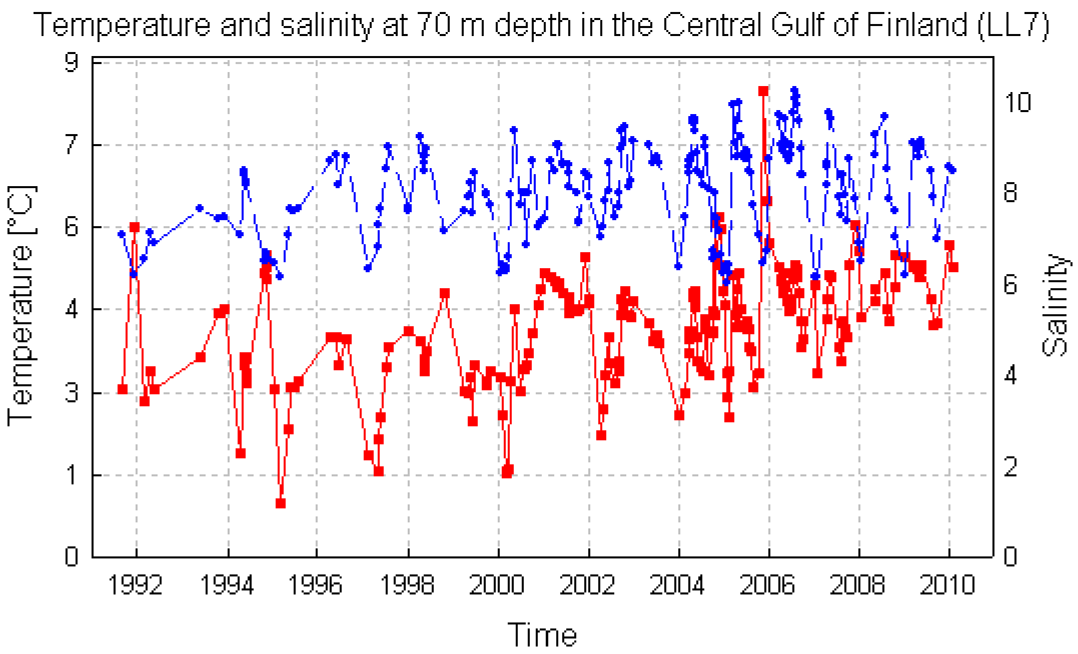


Figure 7. The temperature and salinity at deep water (70m) in the central Gulf of Finland (LL7).

Annex 15: Regional Reports – Norwegian Waters

Randi Ingvaldsen, Kjell Arne Mork, Morten Skogen, Henrik Søiland, and Harald Loeng

Institute of Marine Research, Norway

Summary

The temperature in Barents Sea was in 2009 similar as in 2008 and 0.5 °C above normal. The sea-ice cover was in 2009 less than normal. In 2009 the Atlantic water in the Norwegian Sea was considerable warmer and saltier than normal, respectively between 0.5–1.0 °C and 0.05–0.08. Both temperatures and salinity in the North Sea were in 2009 also higher than normal.

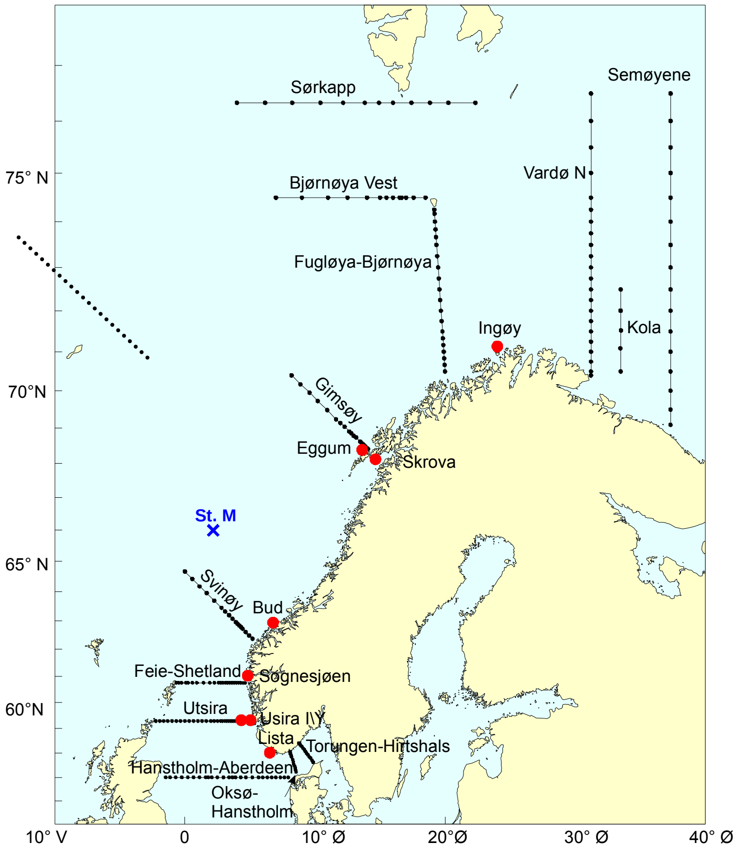


Figure 1. Standard sections and fixed oceanographic station worked by Institute of Marine Research, Bergen. The University of Bergen is responsible for station M, while the Kola section is operated by PINRO, Murmansk (ANON 2002). The dotted line is the extended Gimsøy-NV section that runs into the Greenland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

The Norwegian Sea

- Both temperature and salinity increased in 2009 compared to 2008 for all sections except for the Sørkapp-W section where only temperature increased. Both temperature and salinity were above normal for all sections and in the open ocean respective 0.5–1.0 and 0.05–0.08.
- The inflow of AW at the Svinøy section has since 2007 been stable with values close to the normal.

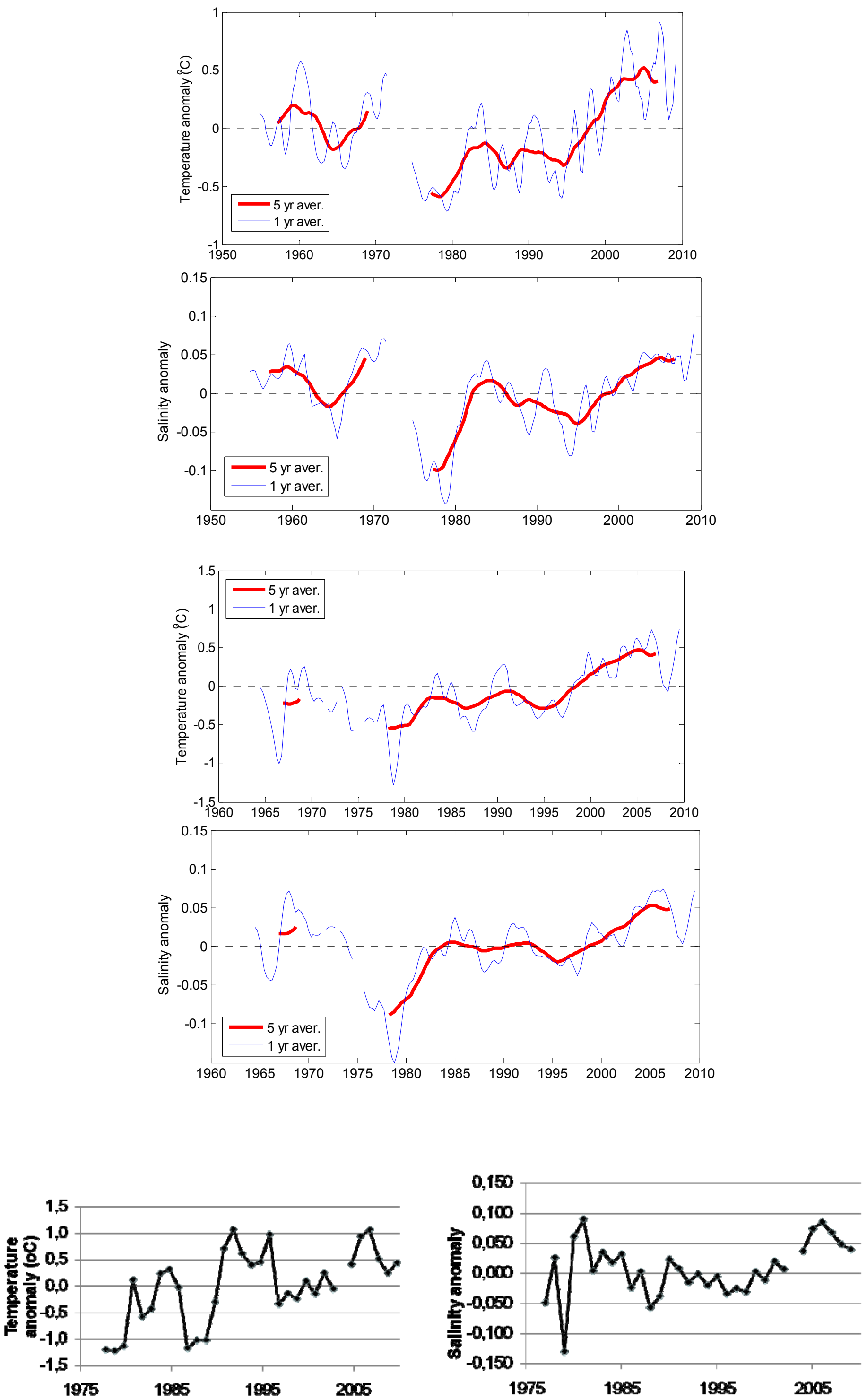


Figure 2. Temperature (left) and salinity (right) anomalies in the core of Atlantic water for the sections Svinøy-NW (upper figures), Gimsøy-NW (middle figures) and Sørkapp-W (lower figures), averaged between 50 and 200 m depth. Blue lines are one year mving averages (only summer values in the Sørkapp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

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.

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.

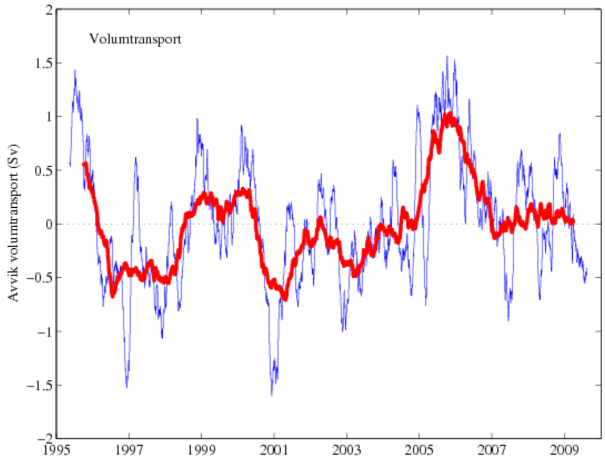


Figure 3. Volume transport anomaly in the Svinøy section. Updated from Orvik *et al.* (2001).The blue line is 3 months anomaly averages while the red line is one year anomaly averages.

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.

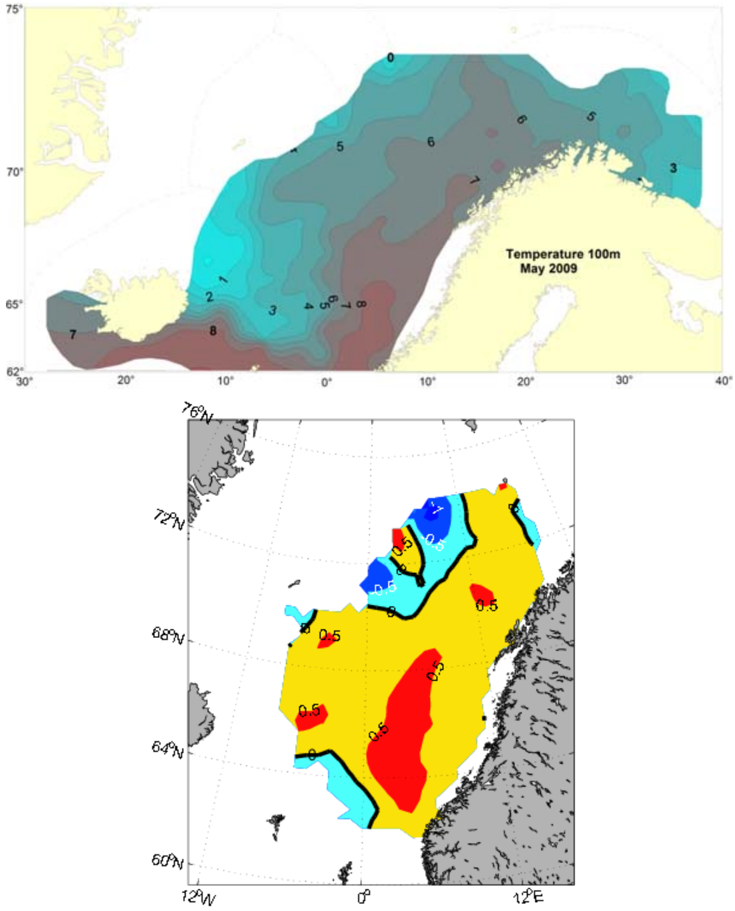


Figure 4. Temperature at 100 m depth in May 2009 (left figure) and its anomaly relative to a 1995–2009 mean.

The potential temperature and salinity along an extended Gimsøy-NV section (see Figure 1 for location) is shown in Figure 5. The thickness of the Arctic intermediate layer below the Atlantic layer is still increasing, and also the deep/bottom water in the Greenland Sea is warming. In 2009 this deep water was in the extended Gimsøy section warmer than –1°C.

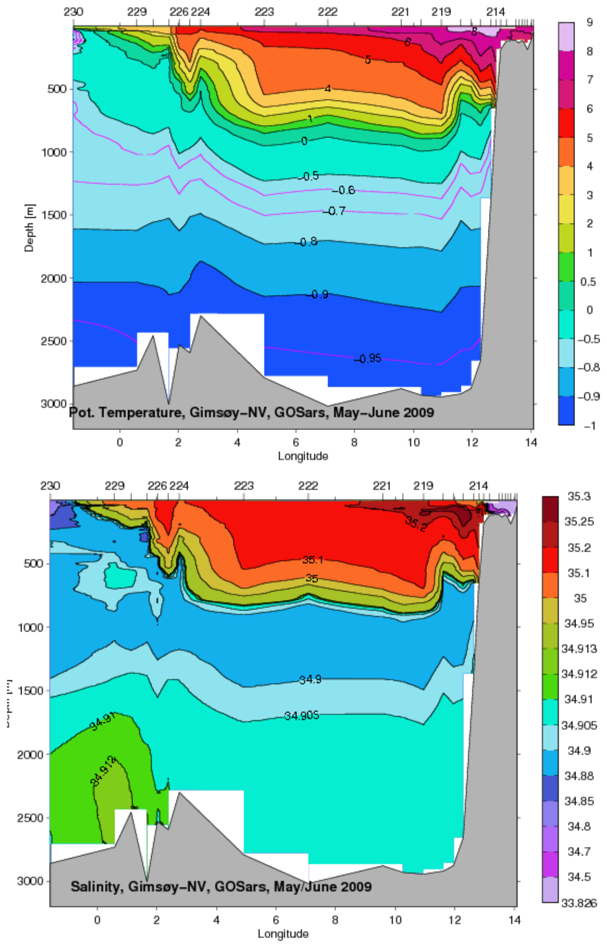


Figure 5. Potential temperature and salinity in the extended Gimsøy section (for location see Figure 1) in May/June 2009.

The Barents Sea

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 0.5°C above the long-term mean in early 2009 (Figure 6). This is lower than the last 5-6 winter, and is due to lower air temperatures causing more intense heat loss in combination with weak inflow of Atlantic Water. Over the year the temperatures increased, and in October 2009 the temperature in south-west was 0.9°C above the long-term mean (Figure 6). The annual mean temperature in 2009 was close to the year of 2008. The salinity variations are show a close resemblance to temperature, although not completely. In Fugløya-Bear Island the salinity has been decreasing since 2006, while in Vardø-N it has increased over the last years.

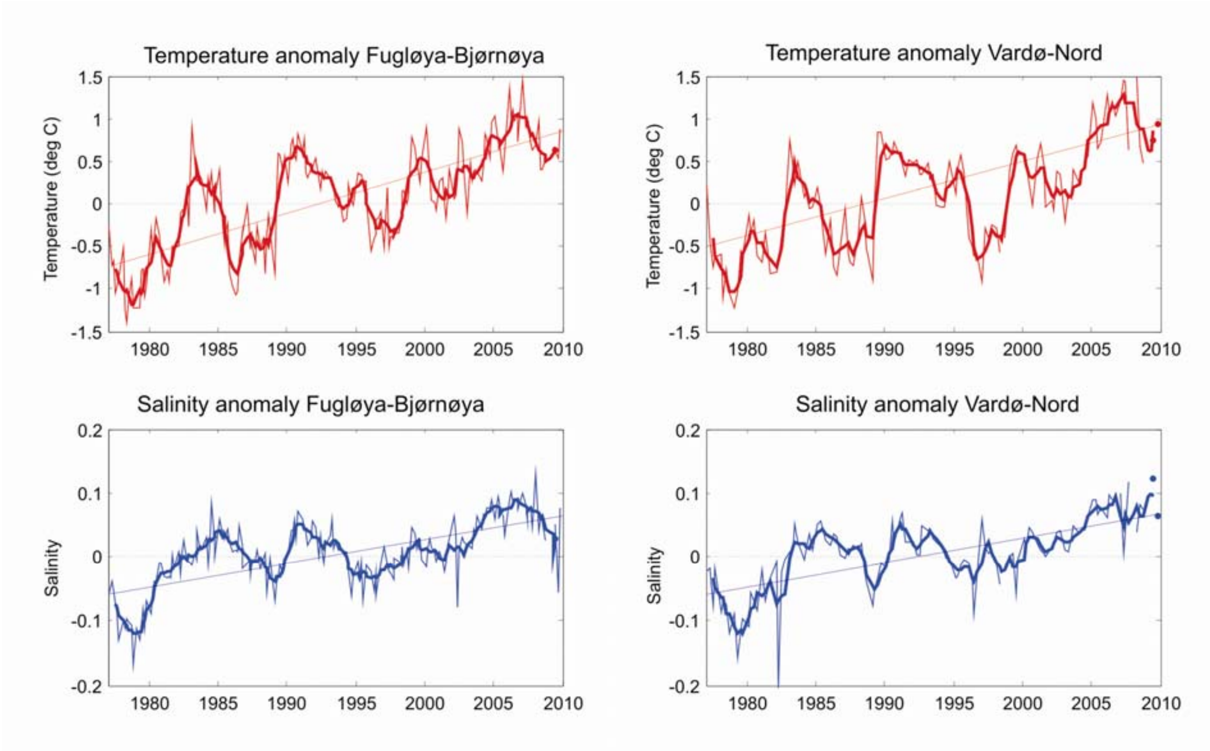


Figure 6. Temperature (upper) and salinity (lower) anomalies in the 50–200 m layer of the Fugløya-Bear Island section (left plates) and Vardø-N section (right plates).

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 2009 the surface temperature was only slightly above normal through most of the year except in late fall/early winter 2009/2010 (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 increased (relative to the normal) in late fall 2009/early winter 2010.

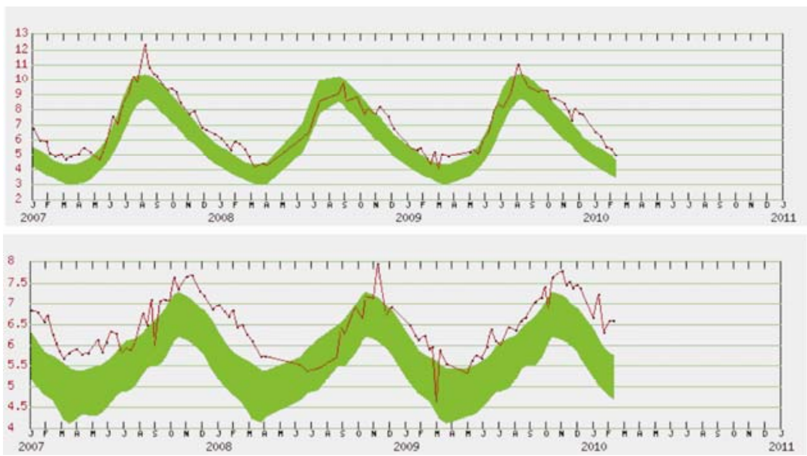


Figure 7. Monthly mean temperature at 1 m and 250 m depth at the fixed station Ingøy, northern Norway, situated in the Coastal Current at the entrance to the Barents Sea. Vertical axis is temperatures (°C) and horizontal axis is month. The green areas are the long-term mean for the period 1936–1944 and 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 northerly winds, and 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), but usually the sea ice distribution in the western Barents Sea respond a bit quicker than in the eastern part. Due to the high temperatures there has been little 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 winter 2009 the amount of ice was slightly more than the year before. In summer 2009 there were more ice than normal in the area east of Svalbard, but less ice than normal in the eastern Barents Sea. Due to unusual high air temperatures in Arctic in fall 2009, the ice cover in the Barents Sea increased slowly in fall 2009. By the end of 2009 the ice cover therefore was less than normal.

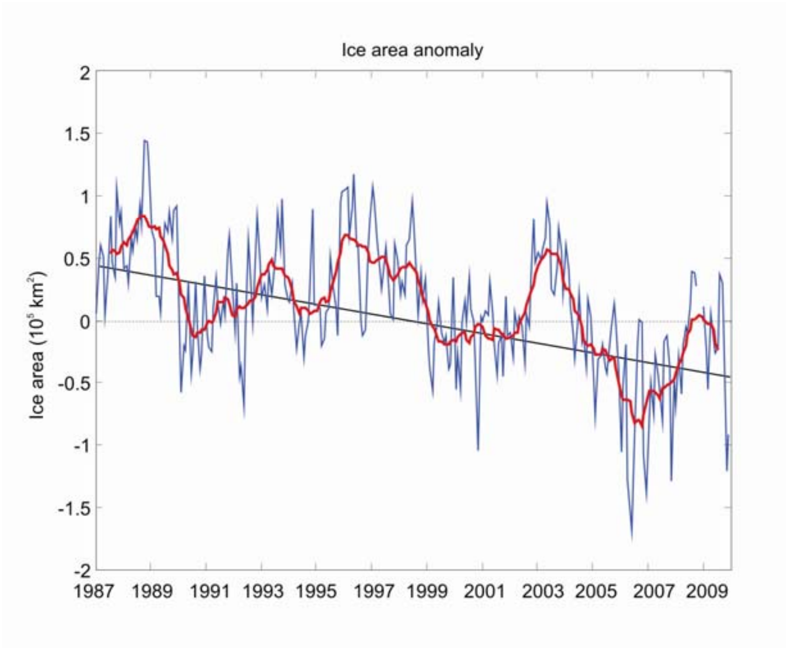


Figure 8. Ice area anomaly for the sector 25–45°E in the Barents Sea, which is the area with the highest variability in ice cover. Monthly mean (blue line) and 1 year moving average (red line) is shown relative to the mean ice area for the period 1995–2008. The strait line indicates the trend line.

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 1997–2009 is 2 Sv (Sv = 10^6 m^{3}s^{-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 time series of volume transport reveals fluxes with strong variability on time scales ranging from one to several months (Figure 9). The strongest fluctuations, especially in the inflow, occur in late winter and early spring, with both maximum and minimum in this period. The recirculation seems to be more stable at a value of something near 1 Sv, but with interruptions of high outflow episodes.

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 2009 was much as in 2007 and 2008; moderate during winter followed by a strong decrease in spring. In early summer 2009 the flux was close to 1.5 Sv below the average. As the observational series still only have data until summer 2009, it cannot give information about the situation in fall 2009 and early winter 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.

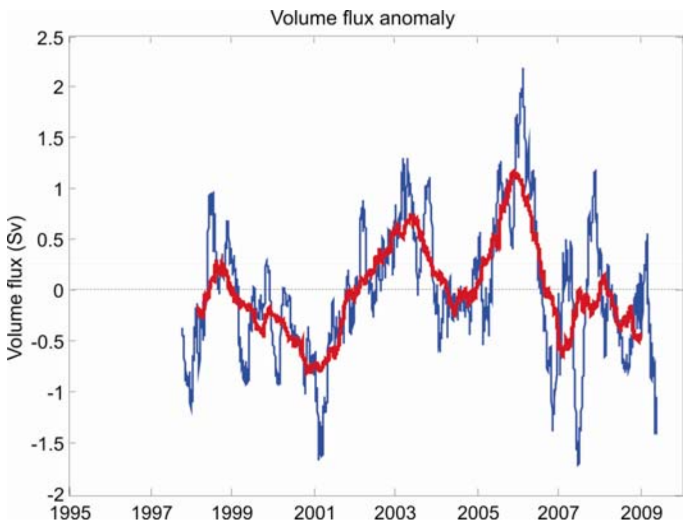


Figure 9. Observed Atlantic Water volume flux through the Fugløya-Bear Island section estimated from current meter moorings. Three months (blue line) and 12-months (red line) running means are shown.

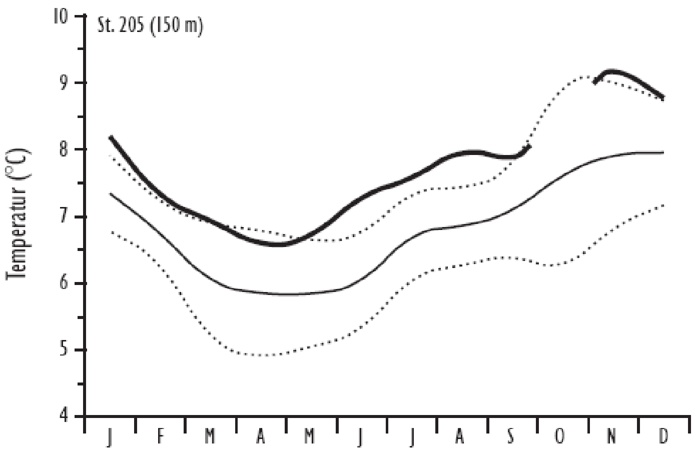
The North Sea

The sea surface temperature in the North Sea was close to the normal at the start of 2009, but increased during the year and was at the end of the year 1–2 °C higher than normal. Subsurface the temperature and salinity in Atlantic water have the recent years had values above normal. This situation continued also in 2009, and the temperature and salinity values were then about one standard deviation above the normal (Figure 10).

In the deep water at the Skagerrak Basin, a total renewal of the water masses occurred in spring 2009 - the first time since 2005. This resulted in a relatively large increase of the oxygen content and a temperature decrease of 0.5 °C (Figure 11). At this depth both temperature and salinity have the last 20 years been considerable larger than the years before. A reason for this may be that, at present, the renewal of deep water occurs by lateral advection of Atlantic water while earlier it occurred by winter cooling that gave a denser deep water.

Results from an ocean model show that the volume flux in and out the North Sea was low in 2009 (Figure 12), and had also one of the lowest value for the whole period (1985–2009).

Simulations of the heat content in the North Sea for 1985–2009 (Figure 13), using the NORWECOM model, show both seasonal variation and long-term oscillations. The summer value in 2009 was relatively high, and averaged over the whole year there was a small increase in heat content for 2009 compared to 2008. A weak linear trend over the whole period (1985–2009) is observed, which relates to a mean temperature increase of 0.66 °C for the North Sea. This is mainly due to an increased ocean-atmosphere heat flux over the area.



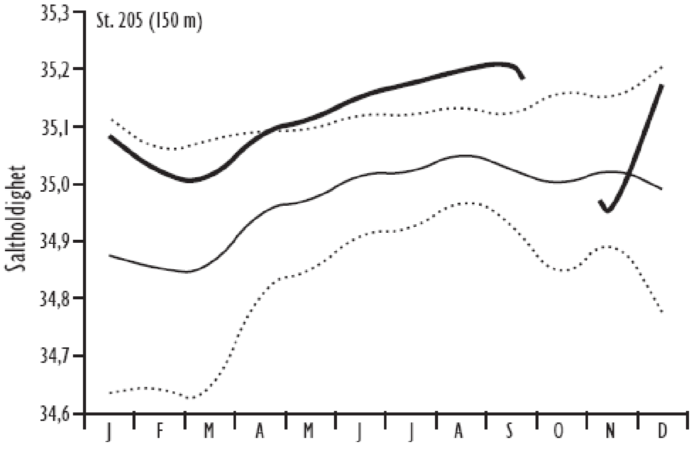


Figure 10. Monthly values of temperature and salinity at 150 m depth during 2009 near Torungen (Norwegian coast, thin line). Long-term mean (thick line) and standard deviation (dotted line) for 1961–1990 are also shown.

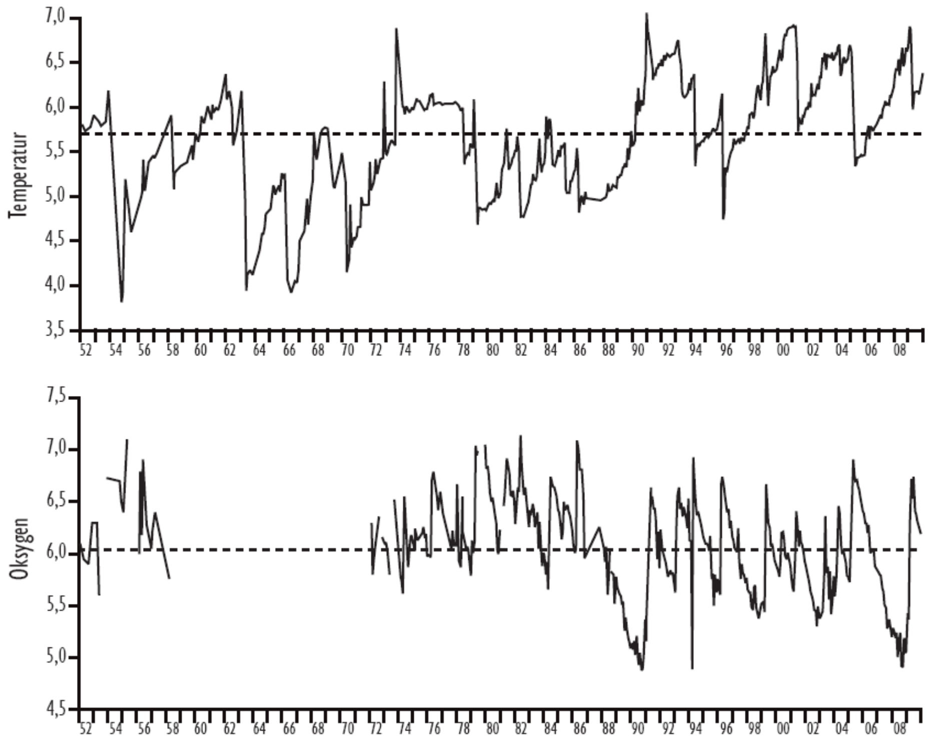


Figure 11.Temperature and oxygen at 600 m depth in the Skagerrak Basin during 1952–2009.

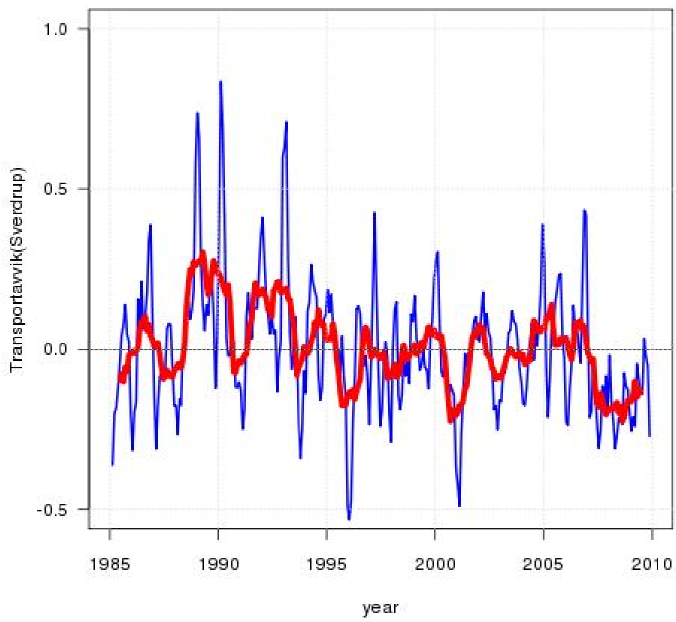


Figure 12. Time series (1985–2007) of modelled monthly mean volume transport anomalies of Atlantic water into the northern and central North Sea southward between the Orkney Islands and Utsira Norway. 1 Sv = $10^6 m^3 s^{-1}$. 3 months (blue line) and 12 months (red line) averages are shown.

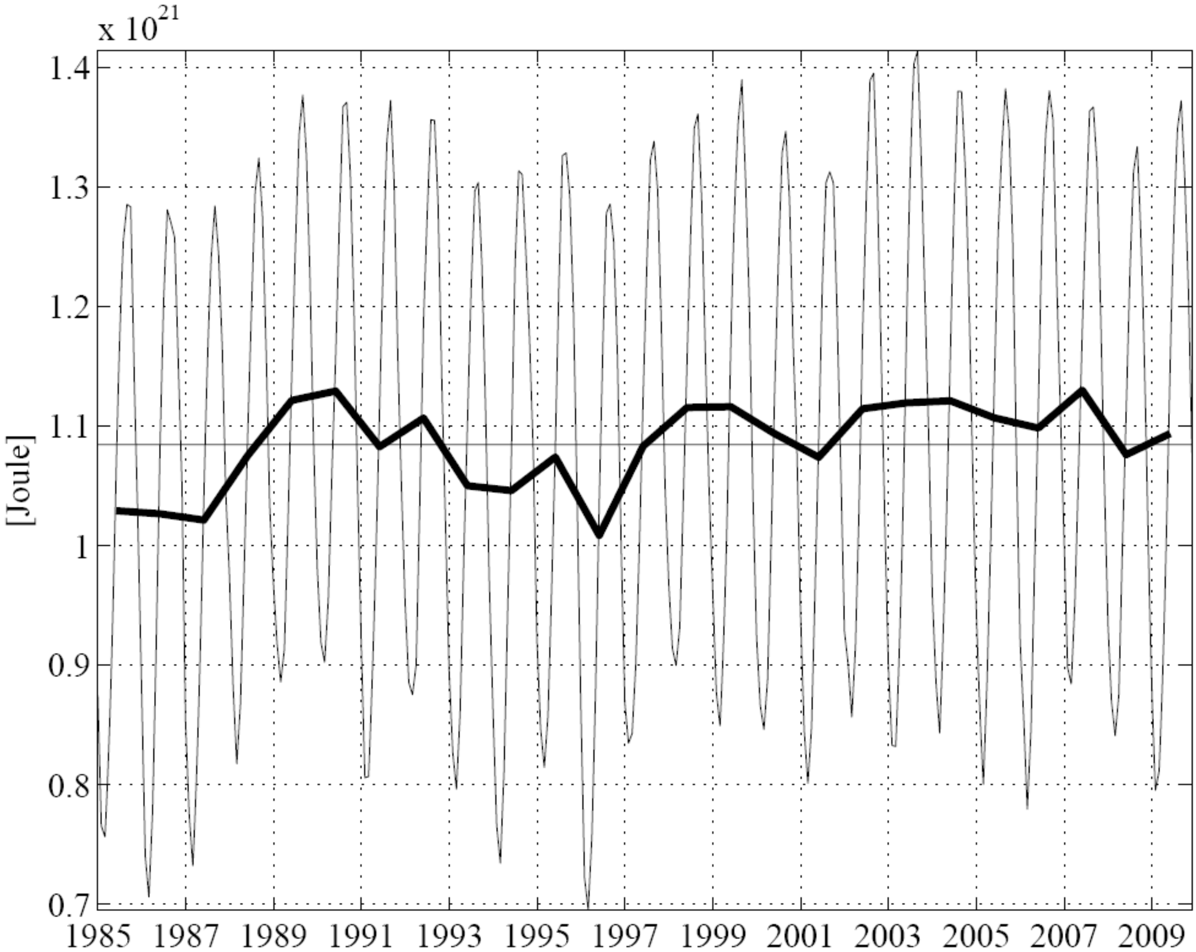


Figure 13. Modelled heat content in the North Sea (1985–2009). Monthly and annual values.

Annex 16: Regional Reports – Atlantic Domain and the Nordic Seas (Area 8,10,11)

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Observations 2009

AREX2009 cruise of Institute of Oceanology Polish Academy of Sciences (IOPAS) vessel R.V Oceania was performed in period of 8 June 2009 – 19 July 2009. 204 CTD casts along 11 sections in the Norwegian and Greenland Sea were done (Figure 1). The advection of Atlantic Water (AW), heat content and transport by the West Spitsbergen Current were mainly investigated.

The SBE 9/11 device was used. Measurements of currents were done by means of two (upper and down looking) lowered Acoustic Doppler Current Profiler (LADCP). The self-recording 300 kHz RDI devices were used to profile entire water column during the standard CTD casts. During the whole cruise continuous currents measurements by the vessel-mounted ADCP, RDI 150 kHz were conducted.

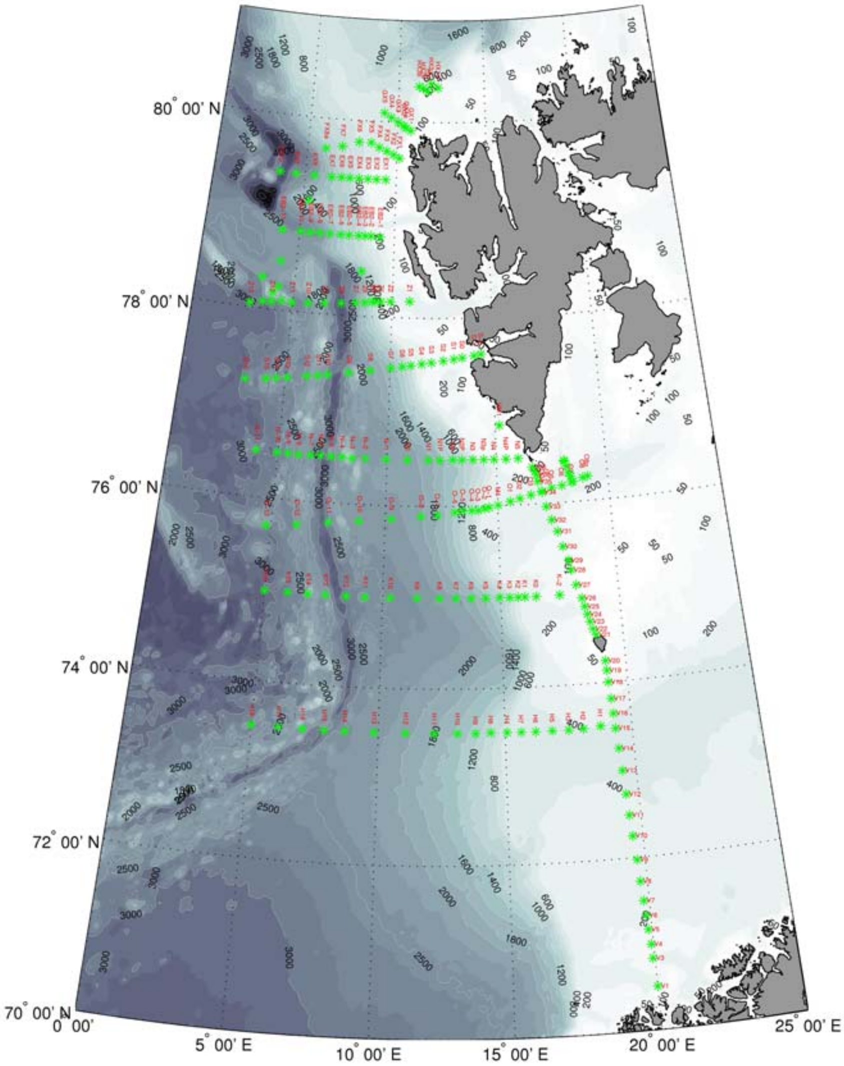
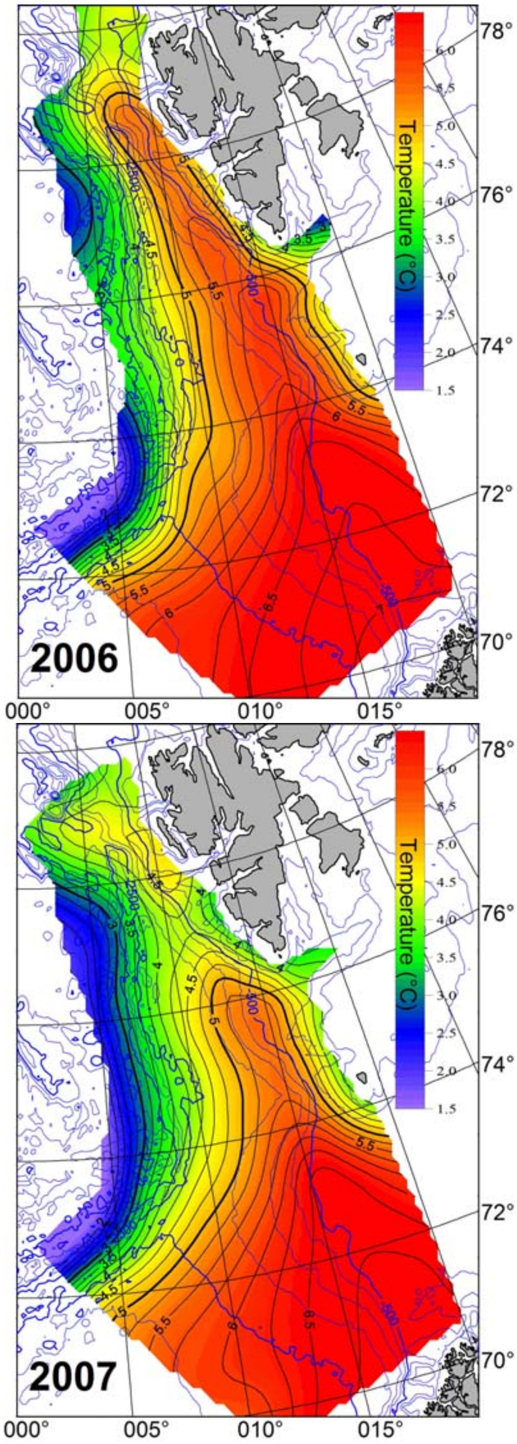


Figure 1. Stations grid performed during R.V 'Oceania' cruise, summer 2009.

Hydrographic conditions

After the record high temperature of the Atlantic Water in summer 2006, rapid decreasing of temperature in 2007 and 2008 has occurred. In summer 2009 Atlantic Water temperature has raised again, warm AW tongue shifted northward (Figure 2).


Temperature (°C)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
78°
76°
74°
72°
70°
2006
2007
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015°

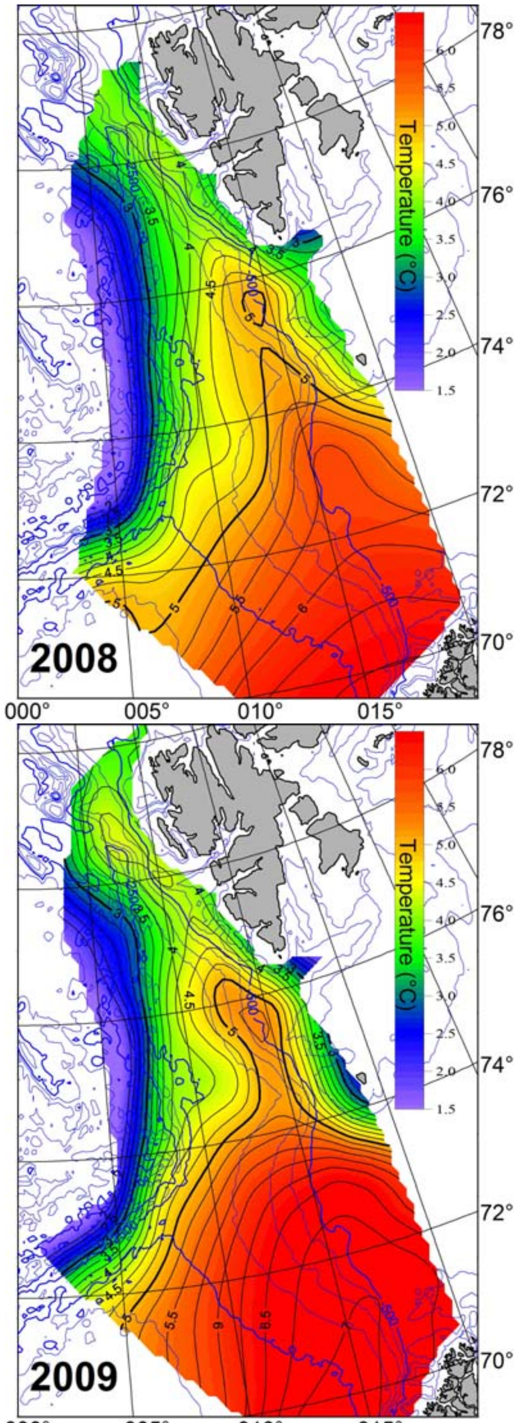


Figure 2. Temperature at 100 dbar in June/July 2006–2009.

At standard section 'N' along the 76°30'N, in July 2009 temperature at 200 dbar was 3.53°C (Figure 3), 0.36 higher than 1996–2009 mean. Salinity at 200 dbar was 35.09, 0.031 higher than 1996–2009 mean. The temperature and salinity trends are positive, 1.06°C/10 years, 0.086/10 years respectively.

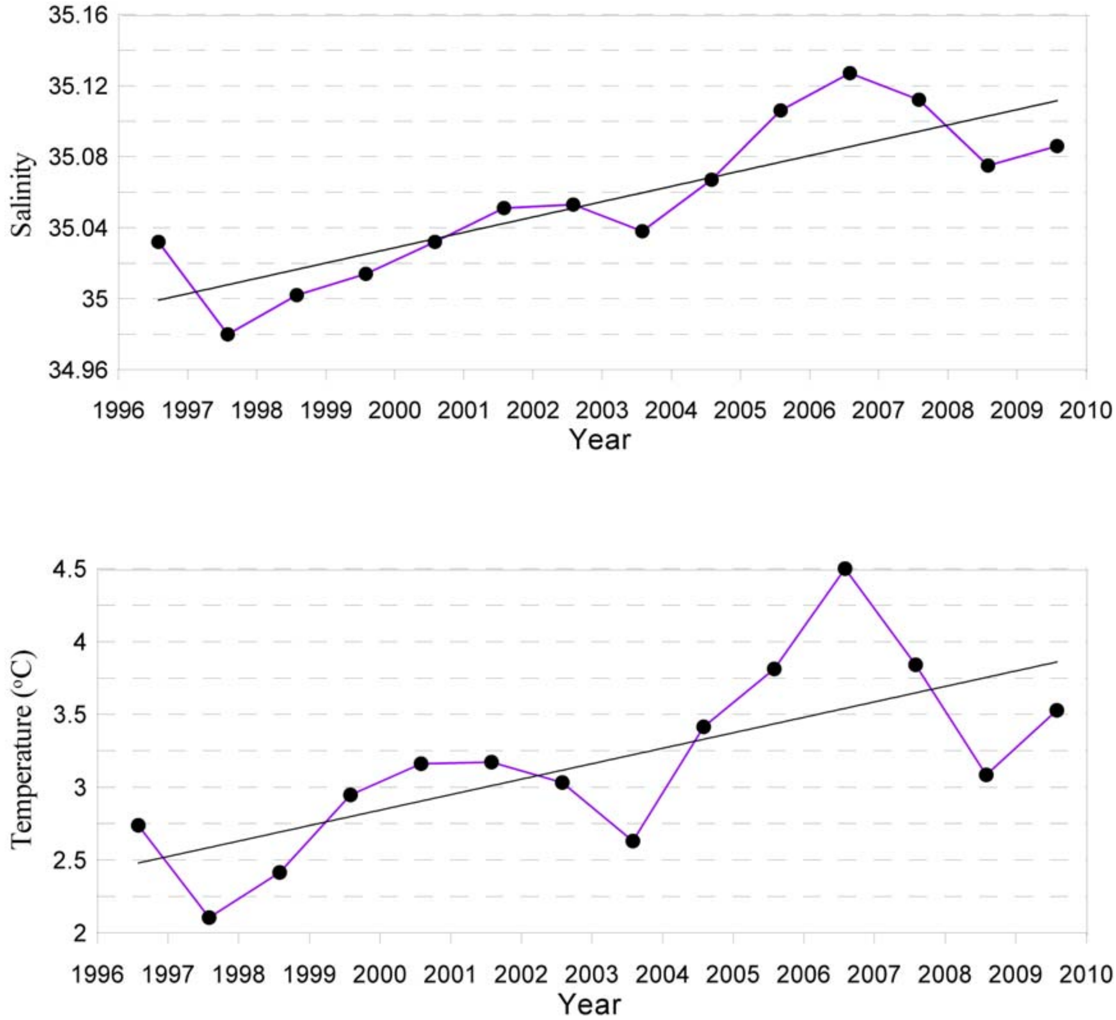


Figure 3. Mean salinity (upper panel) and mean temperature in summer (July) at section 'N' (76°30' N) at 200 m, between longitudes 009°-012° E. Linear trends are marked.

Dynamics

Figure 4 presents the distribution of baroclinic currents (arrows) and baroclinic flow kinetic energy at 100 dbar (calculated for the reference level of 1000 m.). Baroclinic flow into the Barents Sea is weak, more intensive inflow into the Fram Strait exists. Both branches of the West Spitsbergen Current are well visible. Convergence of the branch flowing over the Mohna Ridge and WSC core at 78° N is pronounced.

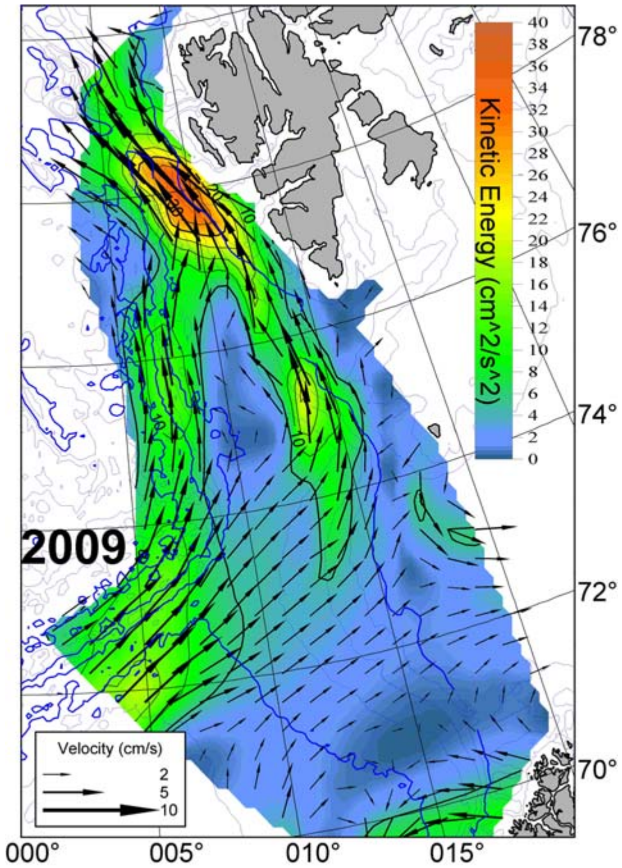


Figure 4. June/July 2009. Baroclinic currents kinetic energy distribution (colour scale), and baroclinic currents at 100 dbar. Reference level 1000 m.

Annex 17: Regional Reports – Greenland Sea and Fram Strait (area 12)

Beszczynska-Möller, G. Budeus, E. Fahrbach, A. Wisotzki,

Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

Introduction

In summer 2009 the hydrographic measurements in the Greenland Sea (section along 75°N) and in Fram Strait (section along 78°50'N) were continued by Alfred Wegener Institute and Norwegian Polar Institute. These two sections allow to monitor the northward flow of Atlantic Water along the eastern boundary of the investigated area as well as the AW return flow located farther westward. Both sections cover also the outflow of Polar Water to the south. The section at 75°N intersects the Greenland Gyre to investigate the variability of its ventilation due to the winter convection.

Bottom water renewal in the Greenland Sea by deep convection in interplay with ice coverage and atmospheric forcing is a major element of the water mass modification in the Arctic Mediterranean. It influences both the waters of the central Arctic Ocean and the overflow waters in the North Atlantic.

However, since the hydrographic observations became more frequent in 1980s no bottom water renewal by winter convection took place. The vertically homogenous deep water dome structure in the Greenland Gyre, reaching close to the surface was replaced by the two layer arrangement with an intermediate layer decoupled from deep waters by enhanced salinity and density gradient. Nowadays the ventilation activity is affected by a present stratification. Under a sufficient meteorological forcing and depending on the existing halocline, i.e. amount of Polar Water advected into the gyre, two ventilation scenarios are possible: deepening of a mixed layer and the plume convection (Ronski and Budeus, 2005).

The Atlantic water enters the Arctic Ocean either through the shallow Barents Sea or through the deep Fram Strait. The transfer of heat and freshwater is affected by the different ocean-atmosphere interaction over both regions and the spreading of Atlantic water along the different pathways affects the climatic conditions in the Arctic. During transition through the Barents Sea, the warm Atlantic Water is exposed to strong surface cooling and mixing and finally enters the Arctic Ocean with temperature below zero. Thus the AW inflow through Fram Strait is the main source of heat for the Arctic Ocean. The Atlantic water has a strong influence on the stratification and internal circulation in the Arctic Ocean and the outflow from the Arctic Ocean is either transferred south by the East Greenland Current or enters and affects the water mass modification in the Nordic Seas. The complicated topographic structure of the Fram Strait leads to a splitting of the West Spitsbergen Current into at least three branches. One part follows the shelf edge and enters the Arctic Ocean north of Svalbard. It constitutes the AW source for the interior of the Arctic Ocean as it continues in the boundary current along the Eurasian Basin slope. A second branch flows northward along the north-western slope of the Yermak Plateau and the third branch recirculates immediately in the northern part of Fram Strait. The size and strength of the different branches largely determine the input of oceanic heat to the inner Arctic Ocean. The East Greenland Current, carrying water from the Arctic Ocean southward has a concentrated core above the continental slope, west of Greenland.

In the central Greenland Sea a long-term zonal CTD section at 75°N was performed in June/July 2009 with a regular station spacing onboard 'Polarstern' (Figure 1). However due to limited ship time, the section was not extended to the east as far as usually and ended at 5°E, thus without a full coverage of the Atlantic water inflow at the eastern rim of the Greenland Sea. Due to the same reason, the following cruise leg devoted to the Fram Strait standard CTD section and mooring work was restricted only to the eastern and central Fram Strait (Figure 1). The CTD stations east of 5°W were measured at 78°50′N section and only moorings F1 to F6 located in the West Spitsbergen Current were exchanged. All CTD and mooring work at 75° and 78°50′N sections was done in the ice free area (Figure 2).

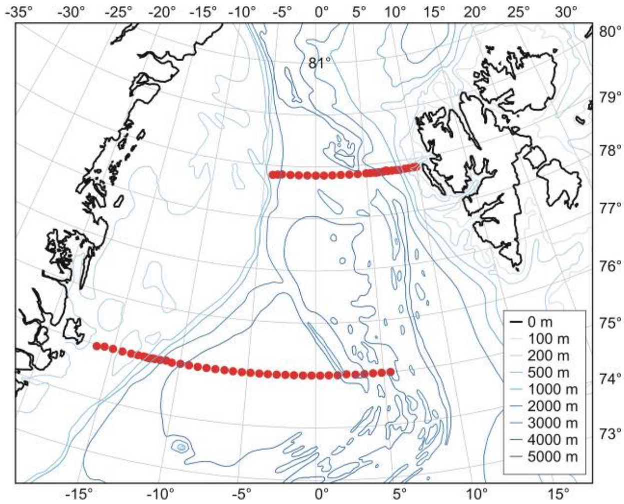


Figure 1. Location of CTD stations in Fram Strait and Greenland Sea in 2009.

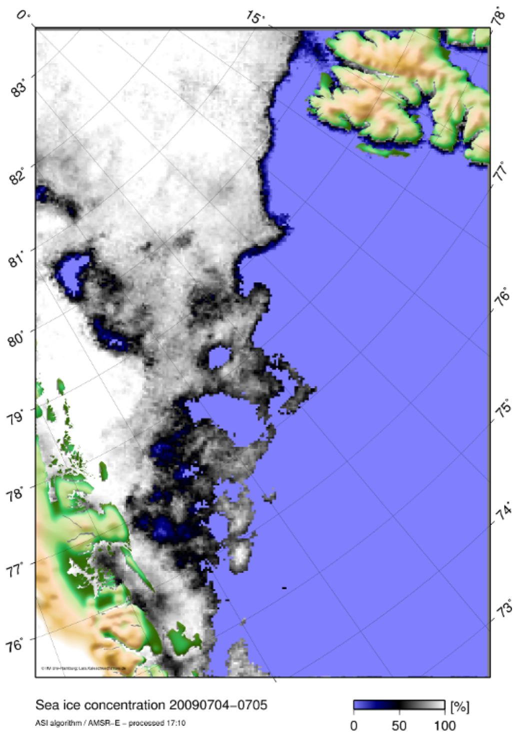


Figure 2. Sea ice concentration in Fram Strait in July 2009.Data source: IUP, University of Bremen, (Spreen *et al.*, 2008).

The obtained time series of temperature and salinity in the Greenland Sea and Fram Strait were compiled from the AWI sections combined with the earlier data sets to describe the long-term variability of different water masses. Time series of the currents, temperature and salinity were also provided by recovering 8 of 16 moorings. Since 1997 the year-round measurements at the array of moorings have been carried out in Fram Strait with the aim to estimate mass, heat and salt/freshwater fluxes between the Nordic Seas and Arctic Ocean. Until 2000 the observations were done in the framework of the VEINS project, in 2003–2005 the work was carried out as a part of international programme ASOF-N, in 2006–2009 in a frame of the EU DAMOCLES project and since 2009 it has been continued under the EU ACOBAR project. The moorings array covers the entire deep part of Fram Strait from the eastern to the western shelf edge. Altogether 18 moorings are deployed along 78°50'N and twelve of them are maintained by AWI. The Norwegian Polar Institute operates the remaining 6 moorings in the western part of the strait (Schauer *et al.*, 2008).

Greenland Sea (75°N)

Since 2008, the assessment of average conditions and convection history in the central Greenland Sea is more complex and ambiguous than before. The reason is the laterally two parted structure which stems from convection in winter 2007/2008 (Figure 3). During this winter, winter convection supplied both salt and heat into the intermediate layers by a mixed layer type convection. As a result, temperatures and salinities were vertically quite homogenous down to 1600 m after this winter, and stabilities attained a long term minimum in a layer above this depth. However, almost half of the Greenland Sea had been shielded from convection due to the unusual western location of the Arctic Front (boundary between Atlantic Waters and Greenland Sea Waters). This scenario resulted in the seemingly paradox pattern, that salinities below the Atlantic Waters in the Atlantic Domain were lower than in the freshly ventilated central Greenland Gyre. The described situation illustrates once again, that the balance between Atlantic and Polar Waters is crucial for the hydrographic development of the area and is in a different mode than during the 1990s.

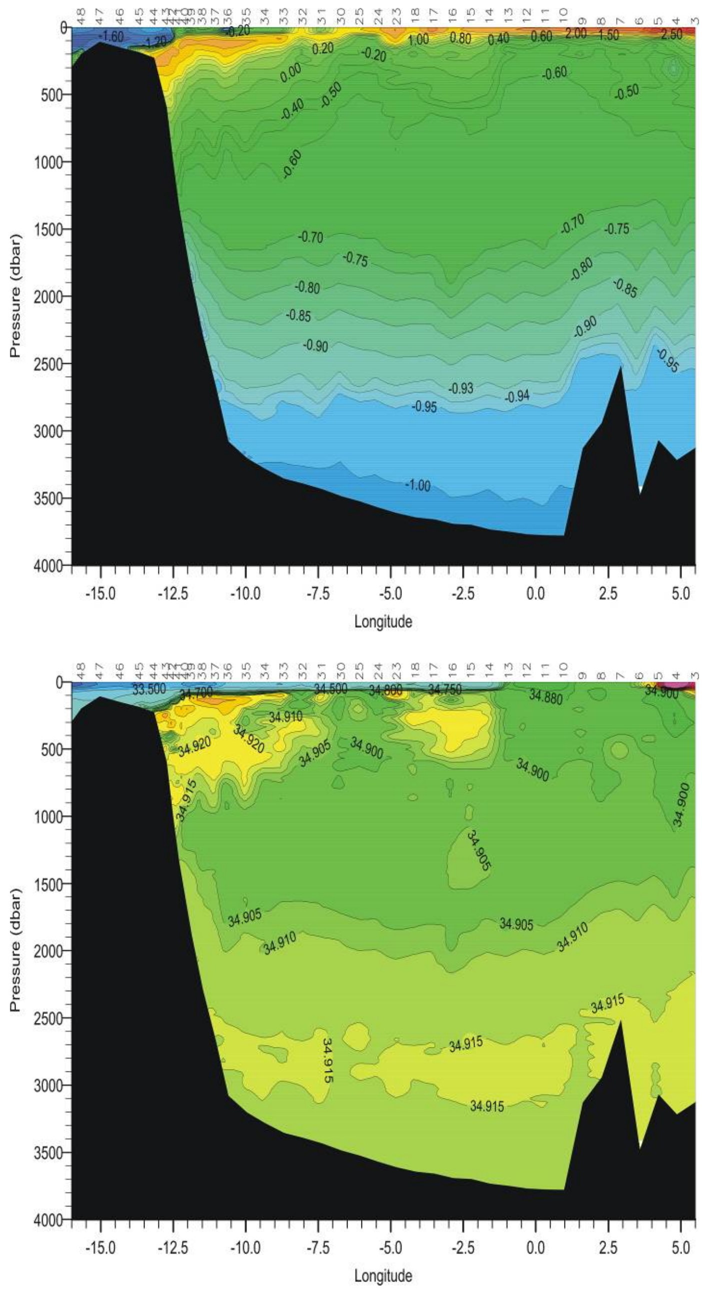


Figure 3. Distributions of potential temperature (upper figure) and salinity (lower figure) at the section at 75°N in the Greenland Sea measured in summer 2009 (G. Budeus).

At the boundaries of the Greenland Sea the averaged properties of the Atlantic Water (AW), entering along the eastern rim, are given as temperature and salinity averages over the depth range from 50 to 150 m of the stations between 10° and 13°E while the Return Atlantic Water (RAW) found along the western rim, is characterized by the temperature and salinity maximum below 50 m averaged over 3 stations west of 11.5°W (Figure 4). Due to shorter than usual section, the AW domain was not covered in 2009 and time series is not updated. In the RAW domain temperature remained similar to 2008 and close to its long-term mean. A drop in mean salinity was observed in the RAW in 2009, resulting in a value close to the long-term mean.

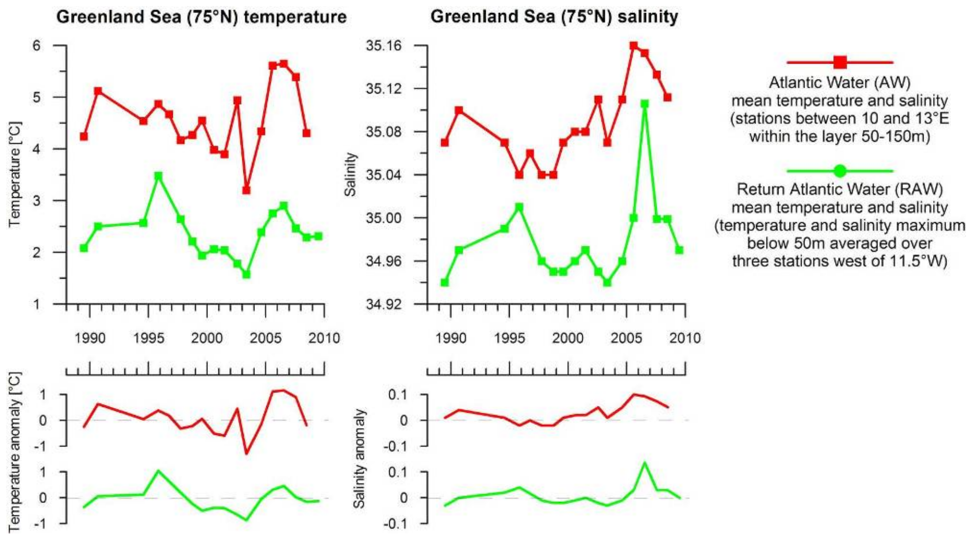
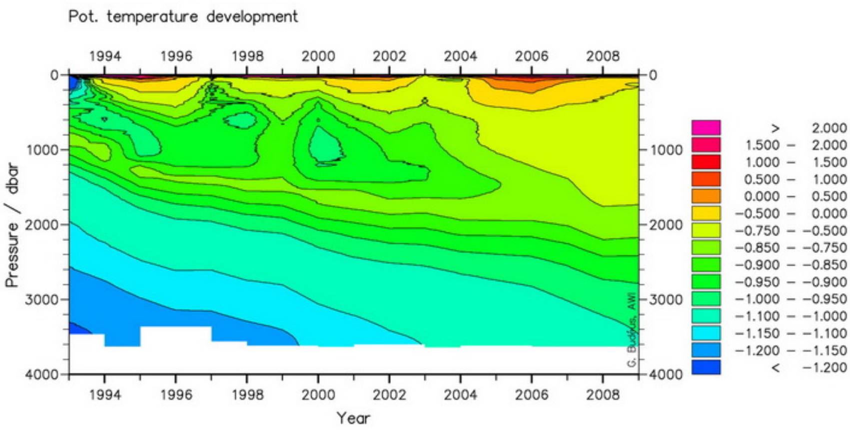


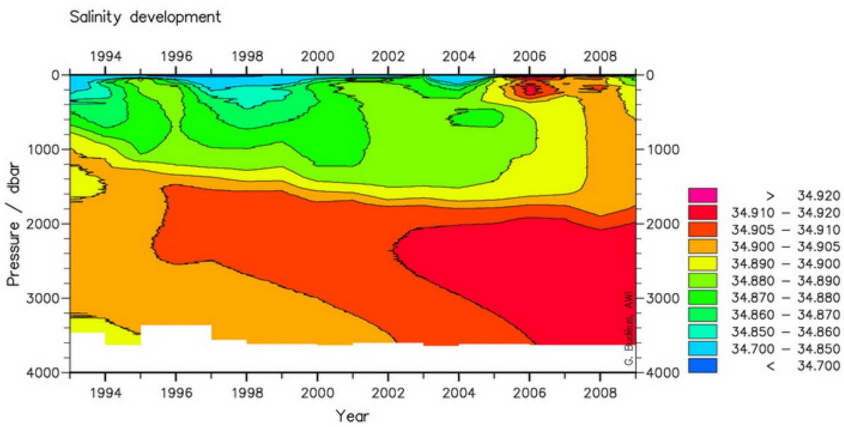
Figure 4. Time series of mean properties of the Atlantic Water and Return Atlantic Water in the Greenland Sea at the section along 75°N (G. Budeus, S. Ronski). Anomalies from the long term means shown at the bottom plots.

Time development of temperature and salinity in the central Greenland Basin, within the Greenland Gyre is shown on Figure 5. Both temperature and salinity developments in the upper layer are dominated by the interplay between convection and advective modifications. For the subsurface layer the advection of AW plays a more prominent role than the atmospheric heat input confined to the surface layer under summer conditions. The interface with enhanced temperature, salinity and density gradient has steadily descended since the beginning of measurements in 1993 by more than 1000 m.

The laterally bi-parted structure remained until winter 2008/2009, but not without being advected. In summer 2009 we find half of the Greenland Gyre, and this is the western half, filled with a thick layer of AW derivates (Figure 5b, d), while between about 3°W and the Arctic Front winter convection introduced fresher and colder waters downward, so to say in the classical manner of Greenland Sea convection (Figure 5a, c). This makes it impossible to refer to a mean state of the Greenland Sea hydrography in the upper 1600 m (in a context that is related to hydrographic processes, at least).



a)



b)

Figure 5. Time development of a) temperature and b) salinity in the central Greenland Gyre in 1993–2009 (G. Budeus).

The winter convection depths (Figure 6) have been determined by means of the multiparameter method proposed by Ronski and Budeus (2005). Convection in the Greenland Sea can be detected by comparison of two successive years when the direction of modification of the upper layer in the gyre can be defined. If temperature and salinity decrease, density increase or homogenization is observed in comparison to the previous year, they can only be caused by a winter convection and serve as possible criteria for the convection depth. Convection history in this winter might well differ between the two parts found in summer 2009. But even within each of those parts, it is extremely difficult to estimate convection depths: Oxygen had been freshly supplied in winter 2007/2008, and stability already was at a minimum. A temperature or salinity reduction remains as a possible indicator of winter convection. Indeed such a signal can be recognised in one part of the Greenland Gyre, but in the other part, below the Atlantic Water derivatives, this is lacking. However, such a lack of immediately apparent indicators is not synonymous to the absence of winter convection.

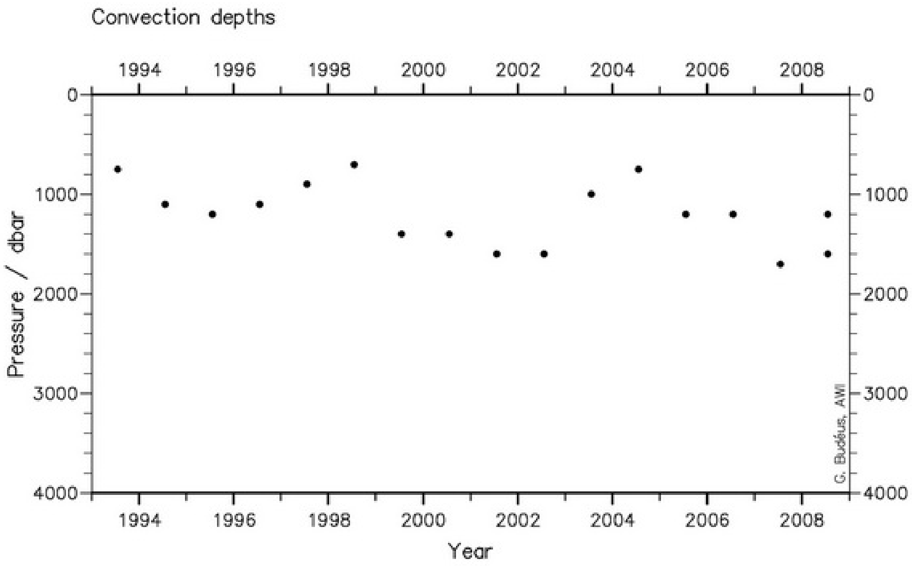


Figure 6. Time series of the winter convection depths in the Greenland Sea in 1993–2009, obtained with the multiparameter method by Ronski and Budeus (2005).

The downward introduction of fresher and colder waters can be seen in the data of the autonomously profiling mooring (Figure 7). Since 2007, the profiling mooring system consists of two parts in order to cover the entire water column from the sea surface proper to the ocean bottom. The deep part is profiled by the EP/CC-yoyo, the shallow part between 160 m and the surface is covered by a profiler utilising an underwater winch produced by NGK, Japan. It is apparent from the time series between 2008 and 2009 that a surface layer of fresher waters persisted during summer and fall 2008, and that winter convection distributed these waters downward thus eroding the previously present high saline layer between a few hundred and about 1200 metres. After the cease of convection, these waters were advected away from the mooring position and were replaced by very saline AW derivatives. We can determine a convection depth of *at least* 1200 m from the moored profilers.

On the transect performed in July 2009, the newly established low salinity pool is present between 1°W and 5°E. In this area there is also a pool of waters which are colder than in the previous year (at about 1000 m), thus unambiguously indicating winter convection. Oxygen contents do not provide a clear indication, however. The high oxygen pool on transect is of similar concentrations in 2009 and 2008, and its extent is similar, too. Stabilities can hardly fall below the values attained in 2008. A probable indication that convection has taken place also below the already mentioned 1200 m is the fact that stabilities did not increase during the course of the year in the low stability pool directly above 1600 m, and that this low stability pool seems to be slightly enlarged in 2009. From this, a *maximum* convection depth of about 1600 m would be derived.

SCVs are still present in the Greenland Gyre, as can be seen from station 0160 on the 2009 transect. According care has to be taken when construction mean hydrographic profiles of the area. As already mentioned, this makes little sense in 2009 for the upper 1600 m, but the part below this depth is laterally homogeneous enough to allow for a construction of a mean.

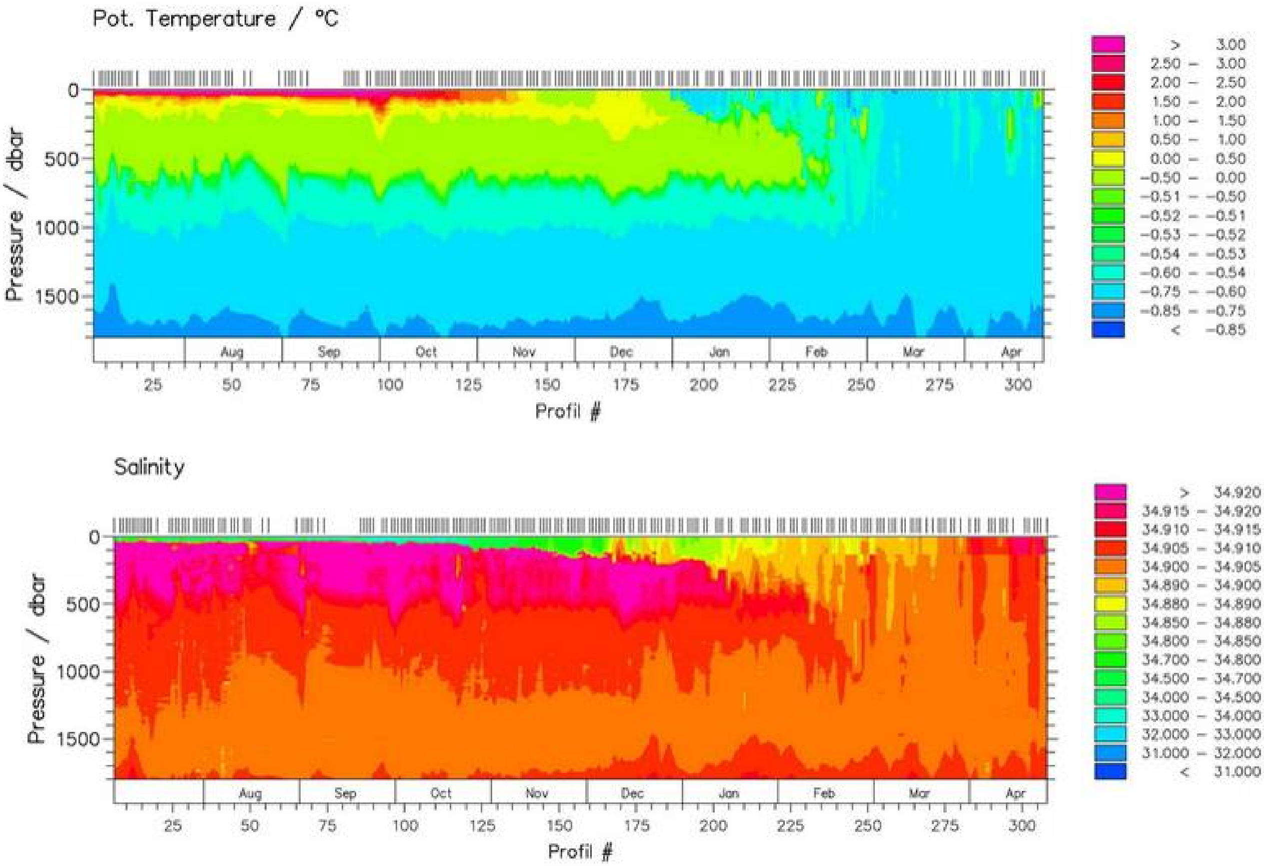


Figure 7. Time series of potential temperature (upper panel) and salinity (lower panel) measured by the profiling mooring in the central Greenland Sea in 2008–2009 (G. Budeus).

While the bottommost temperatures increase from -0.9820°C in 2008 to -0.9694°C in 2009 (Figure 8), there is no temperature change above 2500 m in the lower layer of the Greenland Sea (upper boundary of which is defined by the salinity and density 'step' at about 1800 m). The temperature structure in the deep ocean at the Greenland continental slope in 2009 is particularly indicative of a deep water export there. Salinities in the bottommost waters are 34.9150 in 2008 and 34.9152 in 2009. Salinities in the deep waters of the Greenland Gyre have obviously attained the values of the deep Arctic outflow and therefore cannot rise further (unless the outflow properties change), but the continuing deep water temperature increase shows that deep Arctic waters are persistently mixed into the deep Greenland Waters also in 2009.

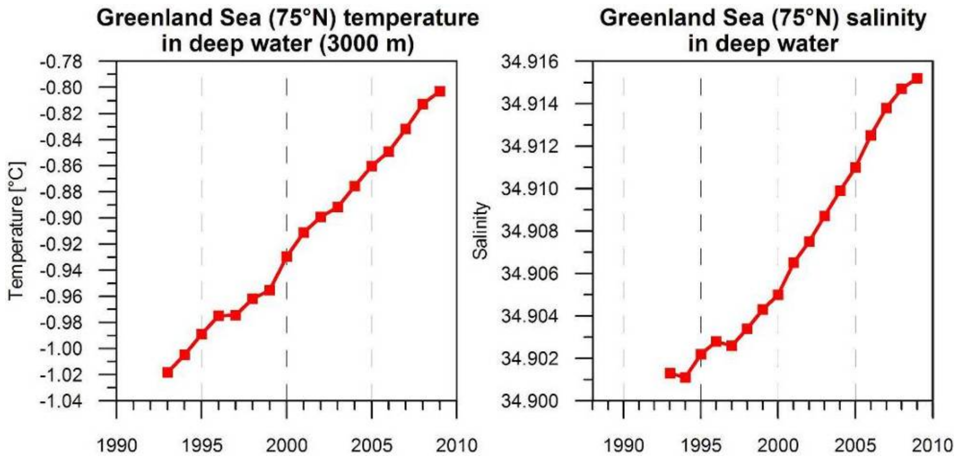


Figure 8. Time series of temperature (left panel) and salinity (right panel) of the deep water (3000 m) in the central Greenland Sea in 1993–2009 (G. Budeus)

The hydrographic situation in the Greenland Sea is characterized since a number of years by the increasing and overwhelming influence of Atlantic Water inflow. This trend continues in one half of the Greenland Gyre during 2009, but is interrupted by a fresh water event in the other half. Still, the volume of waters which would be classified as 'Greenland Sea Water' in the 1990s (i.e. show salinities below 34.900), is negligible in 2009 despite this fresh water event.

Fram Strait (78°50'N)

Since 2007 the negative anomaly of the sea surface temperature (SST, anomaly relative to the long-term mean annual cycle 1997–2009) has been observed in the eastern part of Fram Strait after the last positive anomaly which dominated since late 2004 (Figure 9). In winter 2008/2009 the SST was lower than the year before. In late summer and autumn 2009 SST has been rising and in winter 2009/2010 it returned to the long-term mean value.

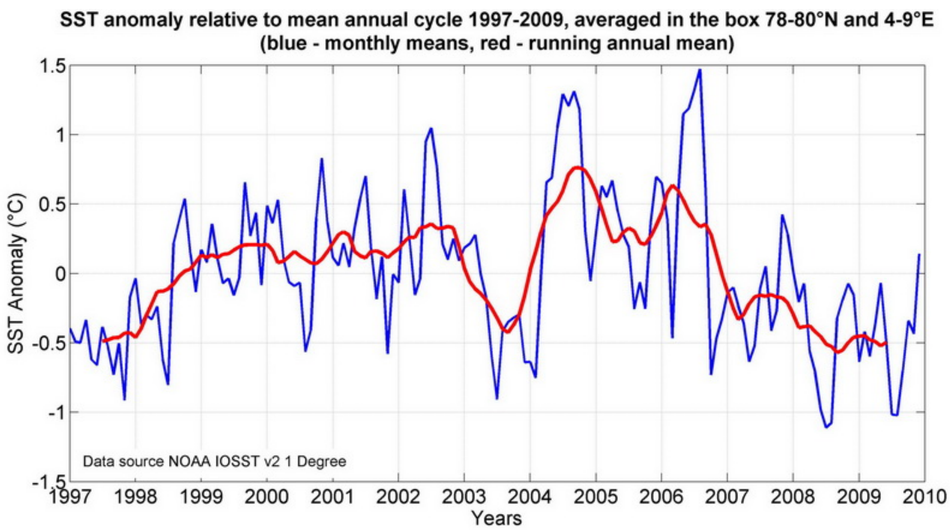
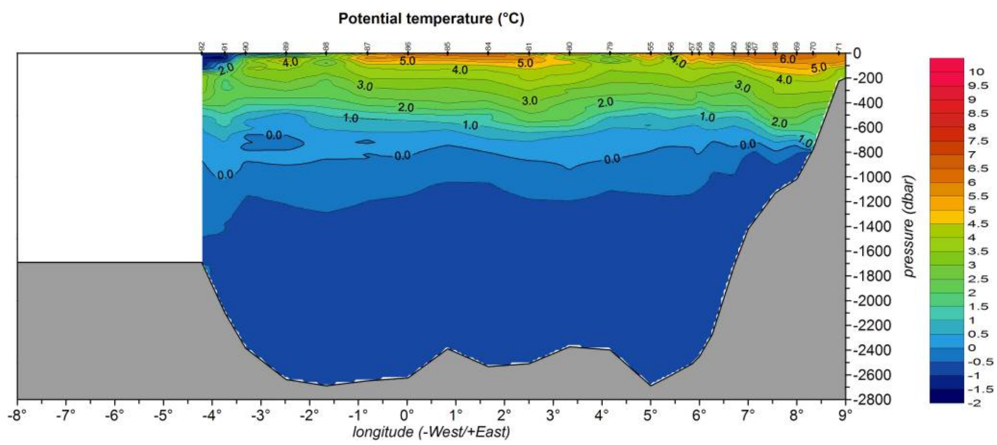


Figure 9. SST anomaly relative to the long-term average (1997–2009) in Fram Strait in the WSC domain. NOAA OISST_V2 1 Degree data set provided by the NOAA/OAR/ESRL PSD from the web site at http://www.cdc.noaa.gov/ (Reynolds *et al.*, 2002).

In summer 2009 the significant warming and increase of salinity was observed in the eastern and central Fram Strait at the section 78°50′N as compared to the previous summer (Figure 9). In the West Spitsbergen Current between 5 and 9°E temperature (Figure 10a) returned to the long-term mean (1997–2009) in the whole water column, remaining within ± 0.5°C anomaly. The thickness of the AW layer was only slightly larger than in previous year but all the AW layer across the strait was filled with water warmer than 3°C (in 2008 water with temperature larger then 3°C was present only in the WSC and within a small patch of the recirculating AW). The position of the Arctic Front between Atlantic and Polar waters at 78°50′N was significantly shifted westward to ca. 2°W as compared to its position at ca. 2°E observed in 2008. The AW layer thickness was nearly the same in the eastern and central part of Fram Strait due to the big pool of the recirculated AW, present across the whole strait between the WSC and Arctic front. The upper 1000 m layer was warmer in 2009 than in 2008 but the most pronounced differences were found in the central part of Fram Strait in the RAW domain (Return Atlantic Water, temperature differences up to 6–7°C due to replacing the PW in the uppermost layer by the AW) and in the upper part of the East Greenland Current (Figure 10c).

In 2009 salinity (Figure 10b) in the WSC was higher than the year before and similar to observed in 2007. In the uppermost layer of 100m, only small patches of less saline (freshened) water were found, there were also warmer than usually observed low saline surface water (in 2009 minimum temperature was not lower than 3°C). In the deep part of Fram Strait, where the big pool, of recirculation AW was found, salinity was higher than in summer 2008 and area occupied by highly saline AW was significantly larger than the year before. Except the PW at the surface in the EGC at the western end of the measured section and small surface patches, the whole upper 500 m water column was filled with water with salinity over 34.96. When compared to summer 2007, when hydrographic conditions in Fram Strait were similar as in 2009, the maximum salinity in the recirculating AW was higher in 2007 but areal coverage by highly saline AW was larger in 2009.

a)



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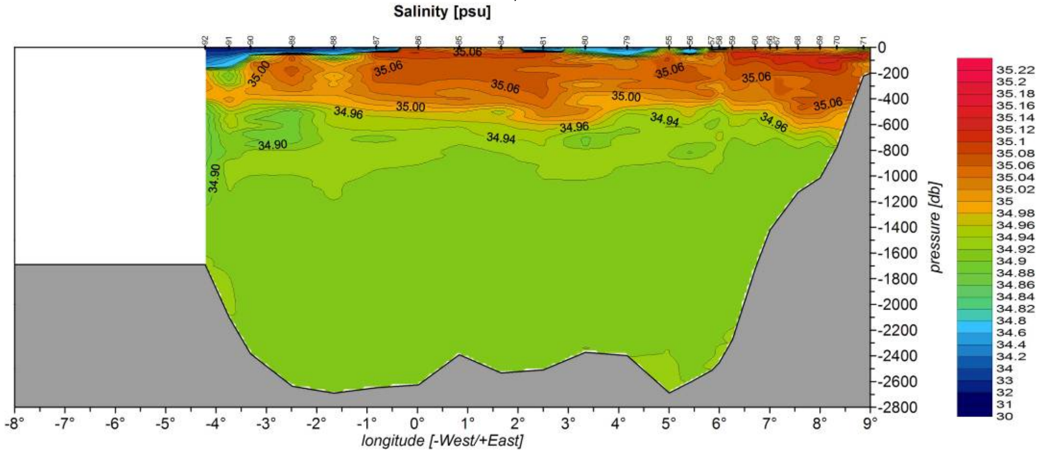

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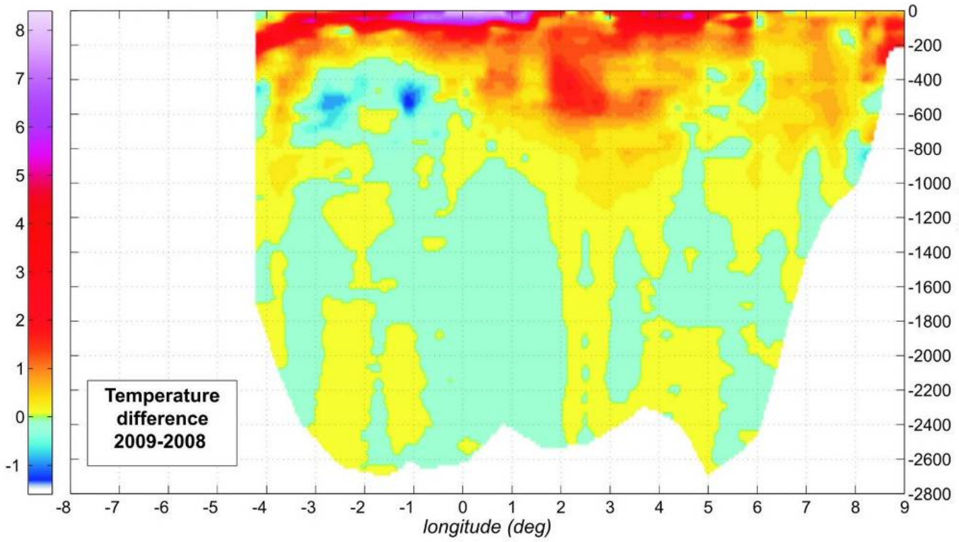


Figure 10. Vertical distribution of (a) potential temperature and (b) salinity at the section through Fram Strait at 78°50'N measured in 2009 and (c) temperature difference between 2009 and 2008.

Time series of mean temperature and salinity in Fram Strait in the upper layer 50-500 m were determined for three characteristic areas, distinguished in relation to the main flows: the West Spitsbergen Current (WSC) between the shelf edge and 5°E, the Return Atlantic Current (RAC) between 3°W and 5°E, and Polar Water in the East Greenland Current (EGC) between 3°W and the Greenland shelf (Figure 11). After their record high maxima in 2006, the mean temperature and salinity in the WSC domain has decreased until reaching decadal minima in 2008. In 2009 both temperature and salinity recovered from minima, coming back to the long-term mean value (temperature) or exceeding it (salinity). The mean salinity observed in RAC in 2009 were record high and mean temperature the second record high, exceeding their long-term mean values by 0.06 (salinity) and 0.64 (temperature). The time series for the EGC were not updated because the section did not cover the entire EGC domain between 3°W and the shelf edge east of Greenland.

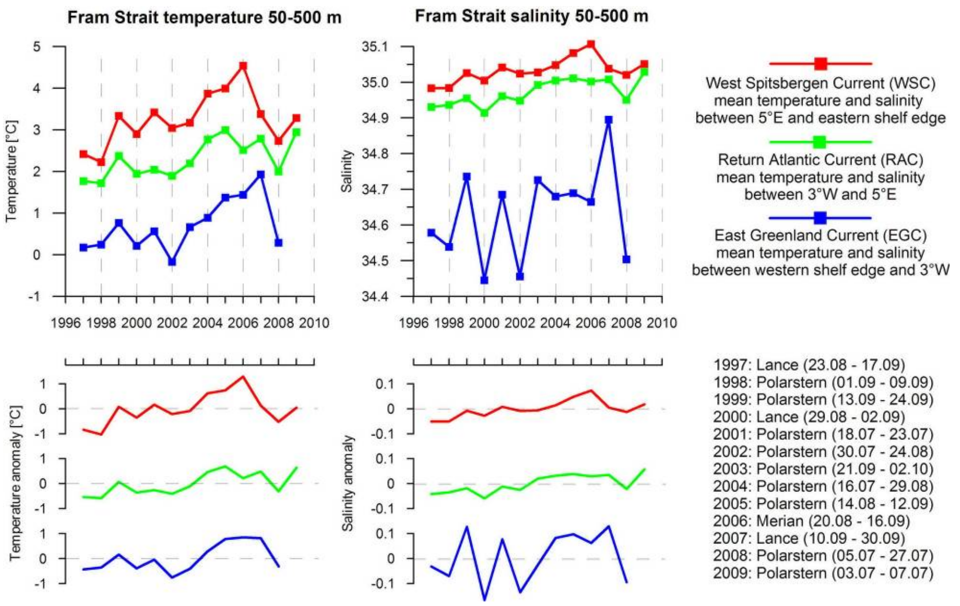


Figure 11. Time series of the mean temperatures and salinities in Fram Strait in the West Spitsbergen Current (WSC), Return Atlantic Current (RAW) and East Greenland Current (EGC) in the layer 50–500m.Anomalies from the long term averages are shown at the bottom plots.

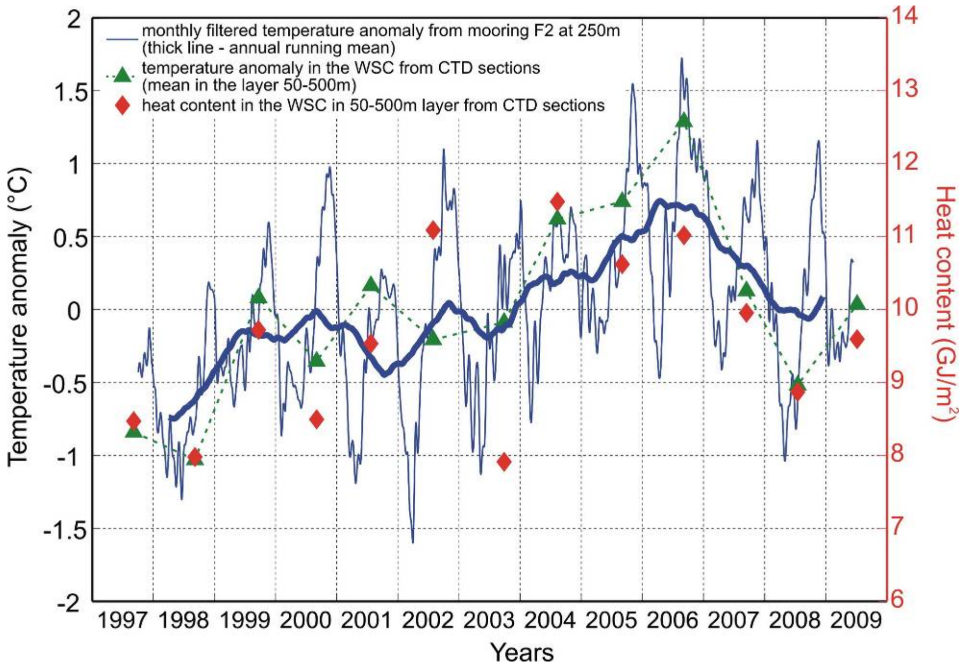
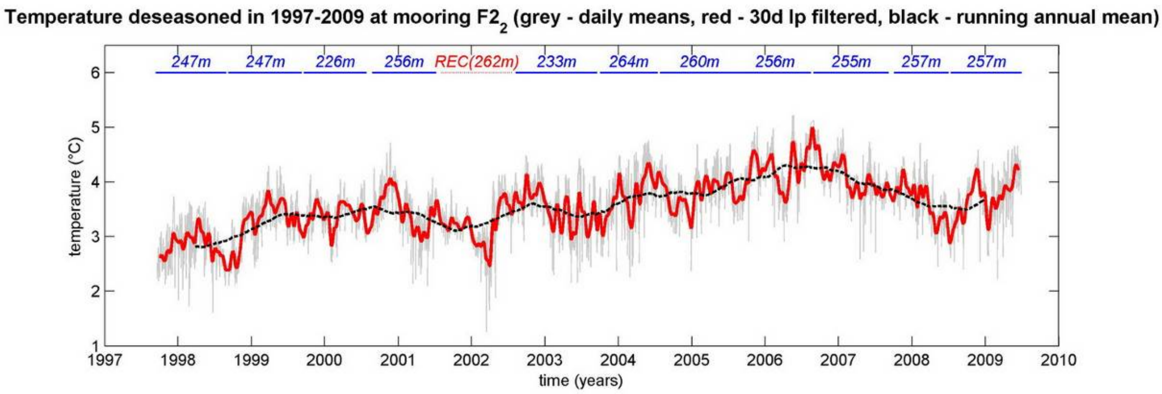


Figure 12. Comparison of temperature anomaly measured at the depth of 250 m by the mooring in the core of the WSC (blue line) and obtained from summer hydrographic sections by averaging in the layer 50–500 m in the WSC domain (domain defined as in Figure 11, green triangles) and mean heat content (relative to freezing temperature) in the same layer (red diamonds).

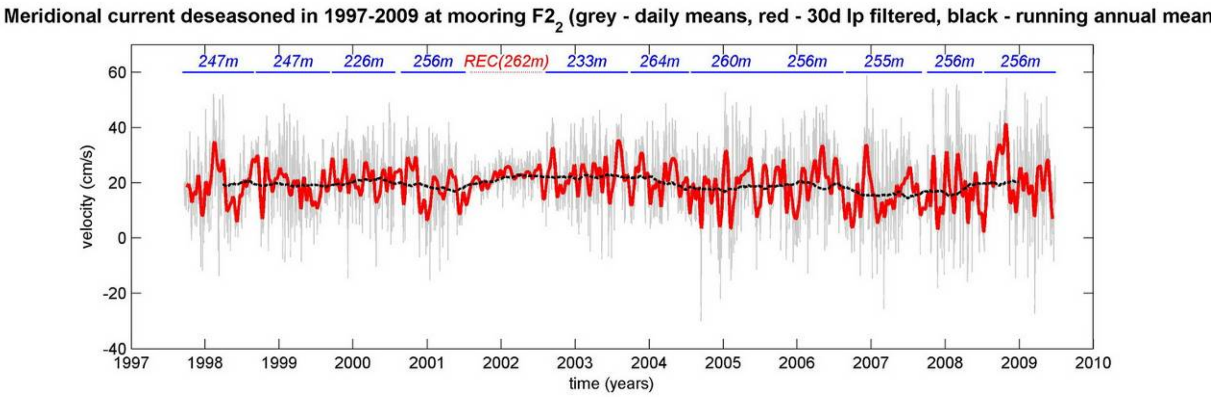
Anomalies of temperature, measured at the mooring in the core of the WSC at the depth of 250 m (in the middle of AW layer) and calculated from summer hydrographic section as an average in the WSC domain in the layer 50–500 m (Figure 12) show similar features. The maximum anomaly of temperature had been reached in summer/autumn 2006 and since then it has decreased until minimum in summer 2008. However, while 2008 minimum based on averaged temperature from section repeated every summer/autumn is the record low in the last decade, the continuous observations at the mooring in the WSC core suggest returning of temperature to the moderated values, observed in early 2000s before the 2006 peak. Mean heat content in the upper 50–500 m layer recovered from the minimum in 2008 and was close to the average for the whole record.

Time series of temperature and current velocities, recorded at the array of moorings since 1997 are used to calculate volume and heat fluxes through Fram Strait. However, in 2009 only six easternmost moorings were exchanged. The deseasoned temperature observed in the AW layer at the mooring F2 (the WSC core) and mooring F4 (the offshore WSC branch) confirm a decrease found from the CTD section (Figures 13a and 13c). After a maximum in the second half of 2006, temperature has started to drop in both WSC branches and reached minimum in summer 2008. Temperature started to rise again since late summer 2008 (in the WSC core) and since autumn 2008 (in the offshore branch). In the first half of 2009 temperature has been rising in both WSC branches. For the whole observation period (1997–2009) the positive trends were observed in the AW in the WSC core (0.08°C/year) as well as in the WSC offshore branch (0.09°C/year). In 2009 the strong cross-section current dominated in the WSC core through late autumn but was followed by weaker than normal flow in winter months (Figure 13 b) while in the offshore branch the relatively strong northward flow was observed in spring 2009 after lower values in winter. No significant trends were found in the cross-section current velocities in both locations.

a)



b)



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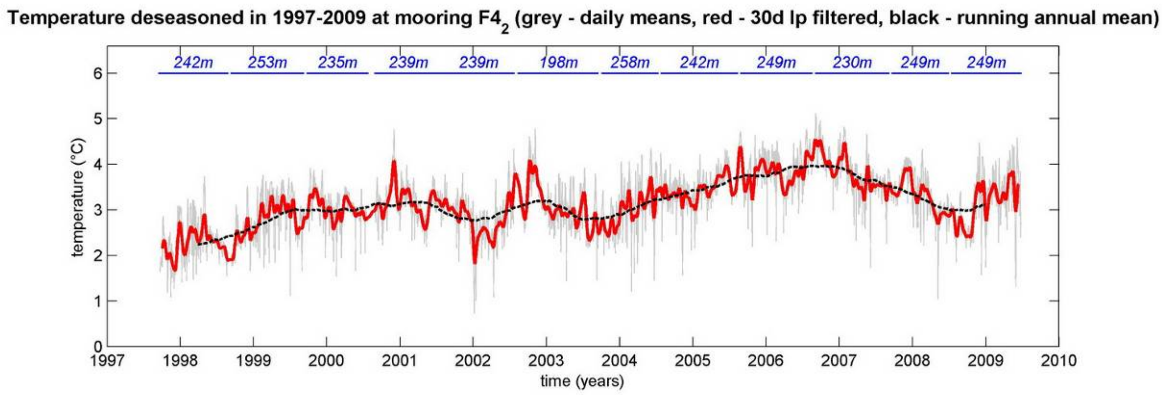
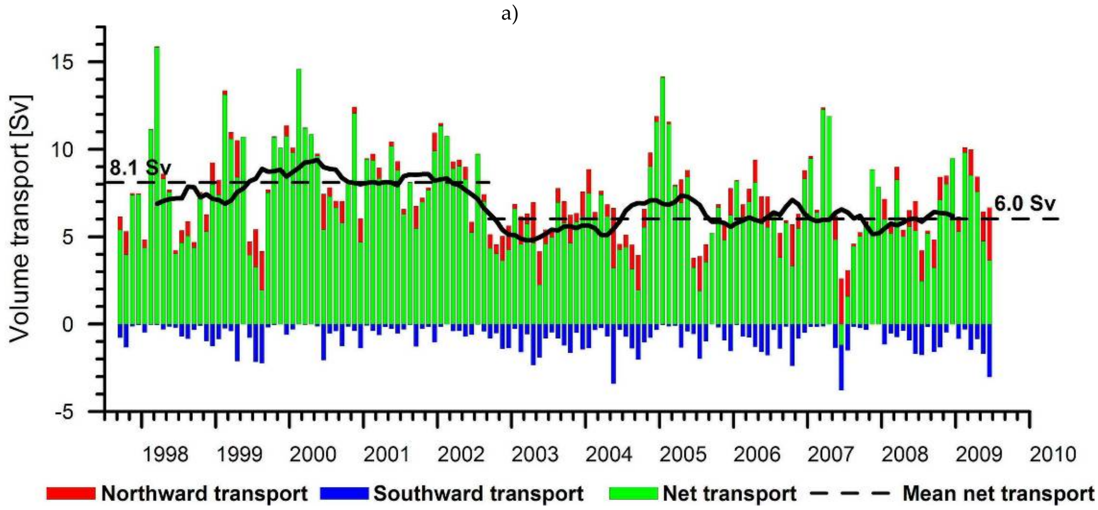


Figure 13. Time series of deseasoned temperature (figures a and b) and cross-section current (figure c) at the mooring F2 (the WSC core) and temperature at the mooring F4 (in the WSC offshore branch) at the depth of 250 m in the AW layer.

Due to limited recovery of moorings in Fram Strait in 2009, the time series of volume transport can be updated only for the West Spitsbergen domain (between 5° and 8°40′E). The heat transport cannot be evaluated without data from the entire section and will be updated in 2010 when all moorings will be recovered. The monthly means of volume transport in the WSC are shown on Figure 14a. The winter centred annual mean of the volume net transport in 2008/2009 was 6.3 Sv, slightly higher than the long-term mean (2002–2009) of 6 Sv. Winter maximum in volume transport was moderate, weaker than in maximum transport year 2004/2005 and 2007 but stronger then in low transport winters 2003/2004 and 2005/2006. Exceptionally low (for winter months) transport was observed in January 2009.

Volume transport of Atlantic water and mean temperature of AW (defined by temperature T>1°C) in the WSC are shown on Figure 14b. Lower AW temperatures in winter 2008/2009 together with stronger inflow should result in a similar heat input in the WSC as in the winter before when AW temperature was higher but AW transport was lower. However, significantly higher temperature of AW in summer 2009 together with similar transport as in summer 2008 should result in higher input of warm AW water into the Arctic Ocean in 2008/2009 than in 2007/2008. But due to high temperatures observed in the central Fram Strait in recirculating AW in summer 2009 (from CTD section) where the southward transport prevails, the expected heat transport through Fram Strait into the Arctic Ocean (which depends both on temperature of inflow and outflow of AW, see Schauer *et al*., 2008) will be the most likely relatively low in 2008/2009. The heat flux will be calculated when the full data set from Fram Strait will be available.

a)



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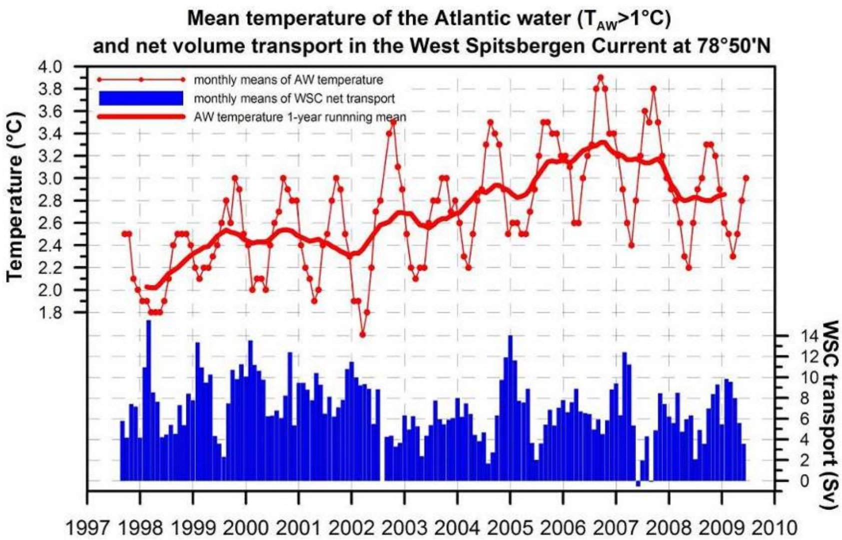

Figure 14. Monthly means of the northward, southward and net volume transport in the West Spitsbergen Current in 1997–2009 (figure a) and mean AW temperature and AW inflow in 1997–2009 (figure b).

The general conclusion for 2009 is that in the Greenland Sea mixed hydrographic conditions dominated: partially the after convective regime (higher salinity, homogeneous layer mixed down to 1600 m), partially the regime with prevailing AW derivatives in the upper layer (warmer and saltier). This bi-partial structure results in non definite convection depth in the Greenland Gyre, estimated on 1200 to 1600 m depending on the region. Warming and increase of salinity in the deep layers of the Greenland Sea, found during the whole observation period, have continued in 2009. In Fram Strait temperature and salinity of AW inflowing in the WSC in 2009 recovered from the minimum in 2008 and were close to their long-term means. However, a large amount of warmer than average AW recirculated in the central Fram Strait, shifting the Arctic Front westward and influencing the EGC. Volume transport of AW in the WSC was close to the long-term average.

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Annex 18: Regional Reports – Russian standard sections in the Barents Sea

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The analysis of hydrographic conditions in the Barents Sea is based on the available observations along standard sections and the data from fish stock assessment surveys. The total number of hydrographic stations made by PINRO in 2009 was 1480 including 248 stations at the standard sections.

Figure 1 shows the main Russian standard sections in the Barents Sea, the data from which are discussed further.

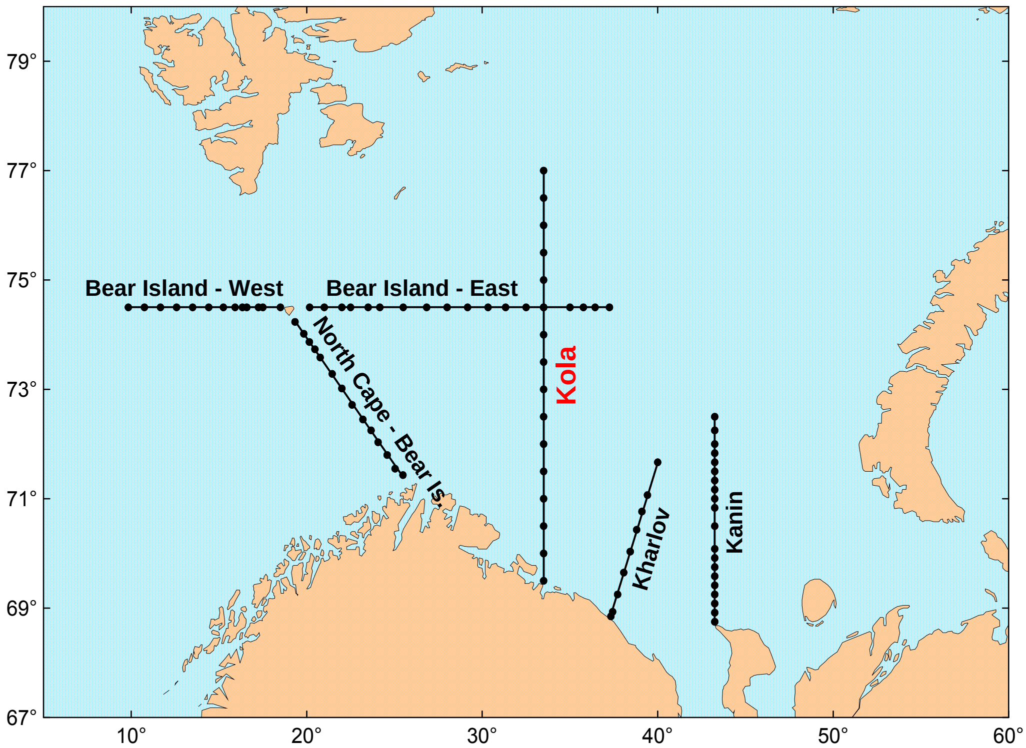

Figure 1. Main Russian standard sections in the Barents Sea.

The observations along these hydrographic sections have been made since the first half of the last century (the Kola Section – since 1900, the North Cape – Bear Island Section – since 1929, the section Bear Island – West – since 1935, the section Bear Island – East and the Kanin Section – since 1936). The Kola Section has been occupied more than 1100 times by now.

The published time series from the main standard sections (Bochkov, 1982; Tereshchenko, 1997, 1999; Karsakov, 2009) are also used in this analysis.

The weather over the North Atlantic was determined by cyclonic activity throughout the year, and by an intensification of the Iceland Low in autumn and winter. The distinctive feature of the year of 2009 was rather intensive cyclonic activity during summer with a southward shift of the Iceland Low. As a result, northerly and easterly winds prevailed over the Barents and northern Norwegian Seas.

Air temperature data were taken at http://nomad2.ncep.noaa.gov and averaged over the western (70–76°N, 15–35°E) and eastern (69–77ºN, 35–55ºE) parts of the sea. In winter and spring, the air temperature was higher than normal, with maximum positive anomalies (3.9–4.1 °C) in the eastern Barents Sea in January and March. In summer, positive air temperature anomalies did not exceed 1 °C, and small negative anomalies were observed in some months. In autumn, the air temperature was higher than normal over most of the sea, with maximum positive anomalies (3.1–3.7 °C) in November.

Sea surface temperature (SST) data were taken at http://iridl.ldeo.columbia.edu and averaged over the Bear Island – Spitsbergen area (74–79ºN, 08–25ºE) as well as over the central (71–74ºN, 20–40ºE) and southeastern (69–73ºN, 42–55ºE) Barents Sea. The SST shows much of the same variations as the air temperatures. In winter, due to the warmer-than-usual air masses over the central and eastern Barents Sea and therefore the less-than-usual atmospheric cooling, the SST was higher than normal, with maximum positive anomalies (1.0 °C) in the central part of the sea. In the western and north-western Barents Sea, on the contrary, the SST was lower than normal throughout most of the year, with maximum negative anomalies (–0.5 °C) in April and July. The weaker-than-usual spring-and-summer warming caused decreasing anomalies of SST. From June to August, negative anomalies of SST were observed in most of the sea. In autumn, SST anomalies increased due to the intensification of cyclonic activity and warm air-masses transport; maximum positive anomalies of SST (up to 1.6 °C) were found in the southern areas in November.

For the first eight months of the year of 2009, the sea ice extent was less than normal, but more than in 2008 (Figure 2). In comparison with the previous year, the ice coverage (expressed as a percentage of the sea area) was 10–18 % more in January–May, 5–9 % more in June and August and the same in July. Ice melting in summertime was more intensive than in 2008. By July, the south-eastern Barents Sea was ice-free that occurred almost one month earlier than in 2008. Ice formation started in the northernmost sea only at the end of October. In October, the ice coverage was only 4 %, that was 13 % less than normal and 5 % less than in 2008. Low air temperatures at the end of November and the beginning of December caused ice formation in the south-eastern Barents Sea. By December, the ice coverage of the Barents Sea was only 8 % less than normal and more than that of 2008.

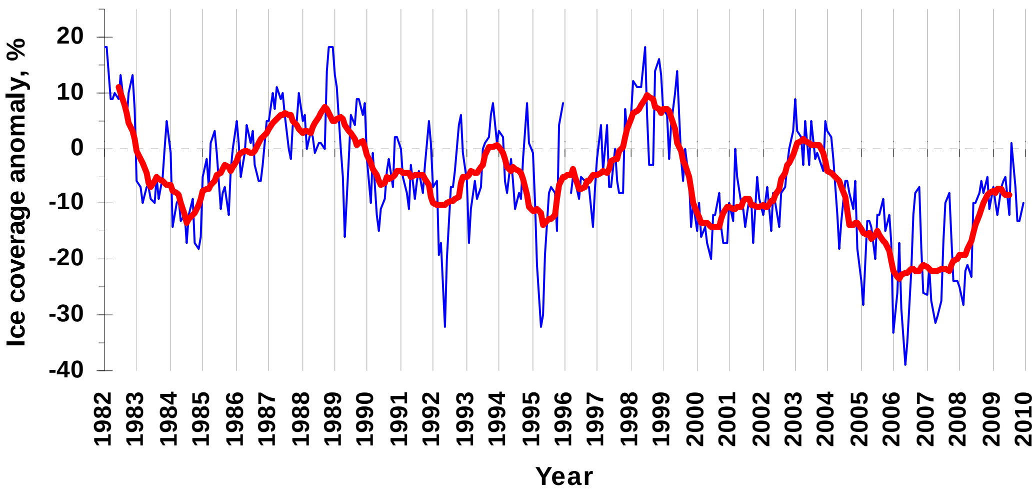

Figure 2. Anomalies of mean monthly ice extent in the Barents Sea in 1982–2009. A blue line shows monthly values, the red one – 11-month moving average values (Anon., 2010).

According to the observations along the Kola Section occupied 8 times in 2009, the active layer (0–200 m) temperature in the southern Barents Sea was higher than normal throughout the year of 2009 (Figure 3). At the beginning of the year, the weaker-than-usual seasonal cooling caused an increase in positive temperature anomalies (by 0.1–0.3 °C) in the Atlantic water compared to December of 2008. Maximum positive anomalies were found in the Central branch of the North Cape Current, where they exceeded 1.0 °C in all layers through March and in deeper layers through May. In spring and summer, easterly and northeasterly winds prevailed that caused decreasing water temperature anomalies. Along the Kola Section, by August, positive temperature anomalies in the active layer decreased by an average of 0.2–0.3 °C in the Coastal waters and in the Murman Current; the most significant decrease in temperature anomalies (0.5–0.6 °C) was observed in the northern part of the section, in the Central branch of the North Cape Current. Since June, the active layer temperature was higher than in 2008. At the end of the year, temperature anomalies in the main warm currents increased due to the intensification of cyclonic activity and air-mass transport from the west. By December, temperature anomalies exceeded 1.0 °C in all parts of the Kola Section, and the highest December temperature for the period from 1951 to the present was observed in the Murman Current (Figure 3).

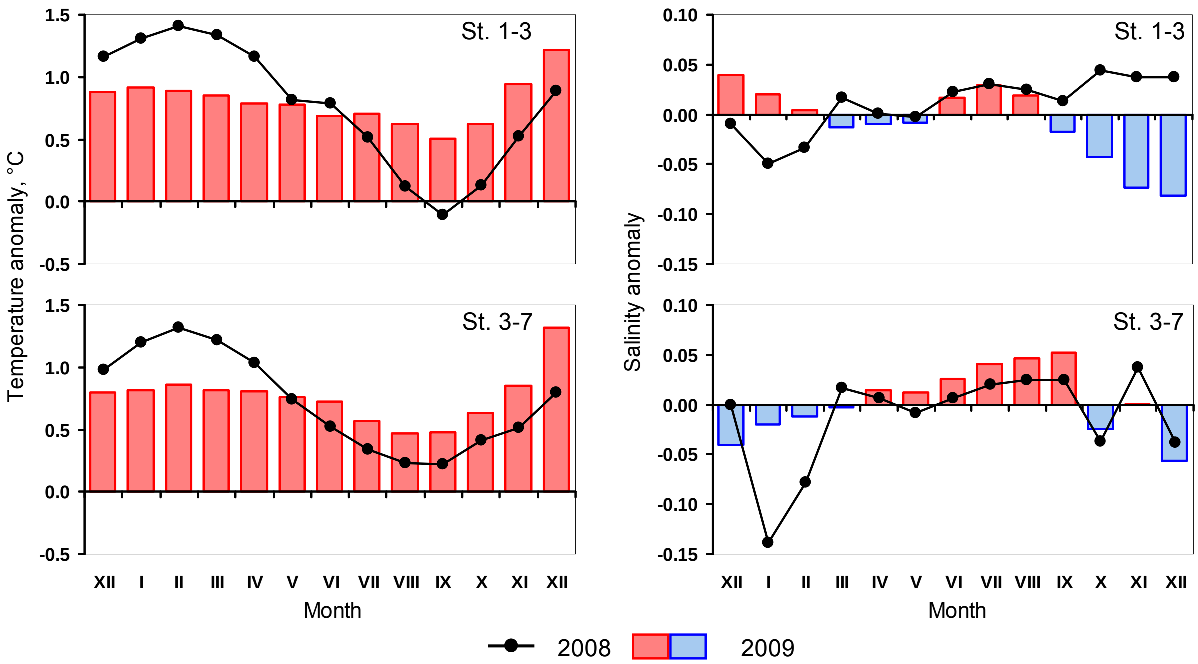

Figure 3. Monthly mean temperature (left) and salinity (right) anomalies in the 0–200 m layer of the Kola Section in 2008 and 2009. St. 1–3 – Coastal waters, St. 3–7 – Murman Current (Anon., 2010).

In the southern Barents Sea in 2009, water salinity was typical of warm years. Negative salinity anomalies were observed mainly in autumn and winter in intensifying cyclonic activity. In summer, positive salinity anomalies (up to 0.05) were observed (Figure 3).

On the whole, the 2009 annual mean temperature in the 0–200 m layer of the Kola Section was typical of anomalous warm years and close to that of 2008 (Figure 4). The 2009 annual mean salinity in the 0–200 m layer of the section was near normal and slightly higher than in 2008 (Figure 4).

In the North Cape - Bear Island Section, the observations were made in April, June and November of 2009. Positive anomalies of temperature in the 0–200 m layer of the North Cape Current increased from 0.8 ºC in April to 0.9 ºC in June and further to 1.1ºC in November.

In 2009, the section Bear Island – West (along 74º30′N) was occupied one time in November. Temperature in the 0–200 m layer of the Eastern branch of the Norwegian Atlantic Current (74º30′N, 13º30′–15º55′E), was 1.0 °C higher than normal.

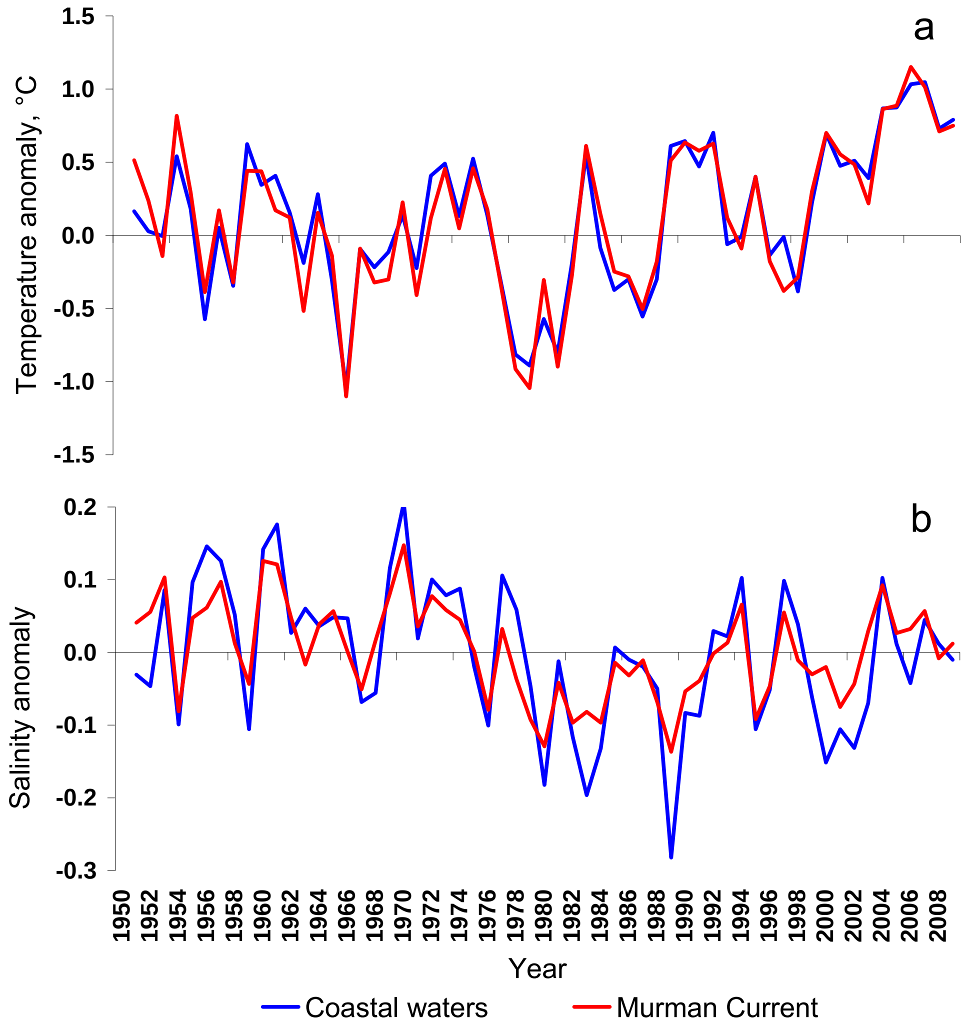

Figure 4. Annual mean temperature (a) and salinity (b) anomalies in the 0–200 m layer of the Kola Section in 1951–2009. St. 1–3 – Coastal waters, St. 3–7 – Murman Current (Anon., 2010).

In 2009, the section Bear Island - East (along 74º30′N) was occupied three times. Temperature in the 0–200 m layer of the Northern branch of the North Cape Current (74º30′N, 26º50′–31º20′E), was significantly higher than the long-term mean, with maximum positive anomalies (1.1 ºC) in March and November. By April, positive temperature anomalies decreased to 0.9 °C.

In the Kharlov Section, the observations were made in March, May, July, October and December of 2009. In the 0–200 m layer of the Murman Current, positive temperature anomalies were 1.0 °C in March, May and July, then they decreased to 0.7 °C in October and finally increased to a maximum value of 1.1 °C in December.

In the Kanin Section (along 43º15′E) located in the eastern Barents Sea, the observations were made in March and September of 2009. In the 0–200 m layer of the Novaya Zemlya Current (71º00′–71º40′N, 43º15′E), positive temperature anomalies decreased from 1.6 °C in March to 0.7 °C in September.

Temperature in the bottom layer in August-September 2009 was typical of warm and anomalous warm years. Positive temperature anomalies were observed in most of the surveyed area and were, on average, 0.3–1.0°C. The largest positive temperature anomalies (> 1.5°C) were observed in the eastern Barents Sea, in the areas adjacent to the Eastern Basin (Figure 5).

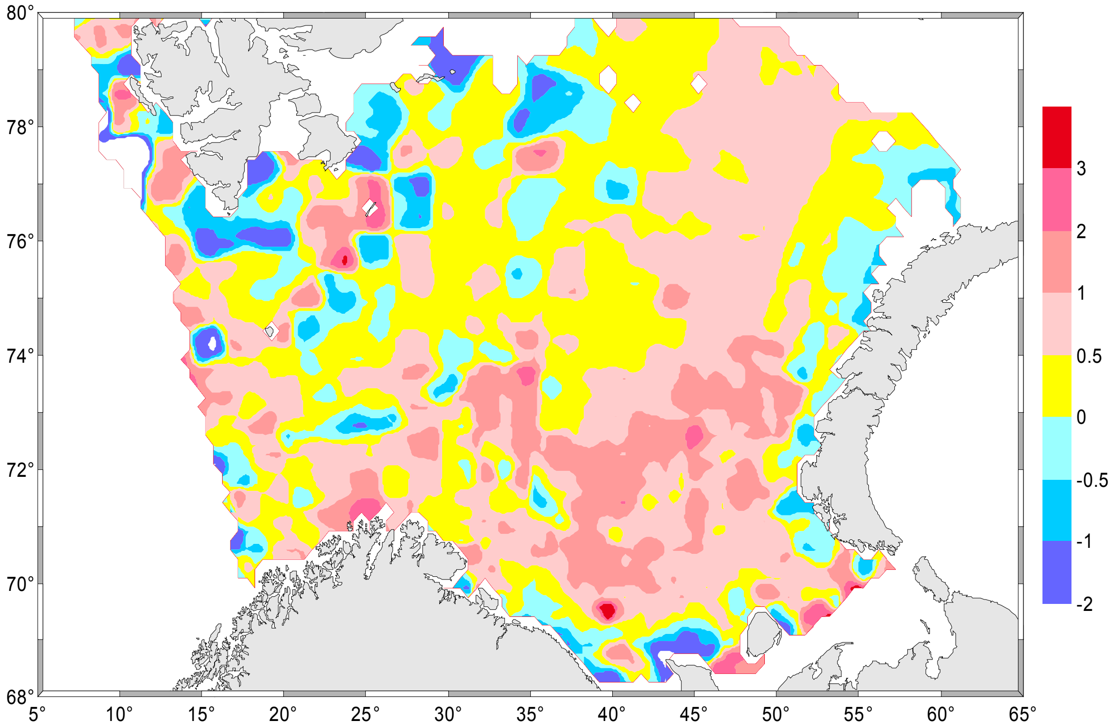

Figure 5. Bottom temperature anomalies in the Barents Sea in August/September 2009 (Anon., 2010).

Compared to 2008, the volume of cold Arctic waters increased significantly in the northern Barents Sea, and for the first time in the last three years waters with negative temperature were found in the Eastern Basin. So, in comparison with the previous year, it caused decrease in the spatially averaged bottom temperature of the surveyed area except the southern Barents Sea occupied by the Murman Current and the Central branch of the North Cape Current.

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Annex 19: Regional Reports – French national report

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1 Atmospheric conditions

According to the NCEP-NCAR re-analysis, the winter 2008–2009 is characterized by weak pressure and sea surface temperature anomalies and lower than normal wind speeds over most of the northern sector (Figure 5), leading to a slightly negative NAO index (Figure 1).

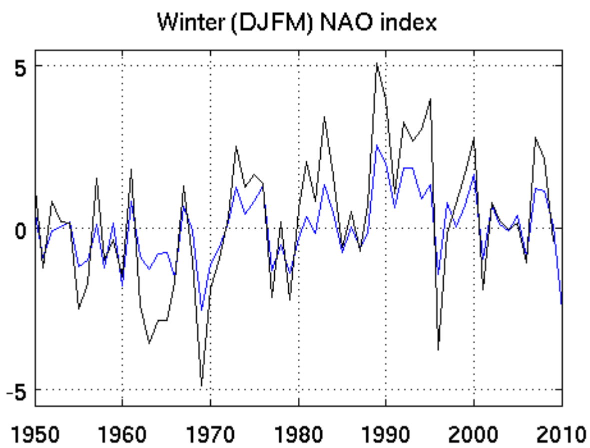

Figure 1. NAO index for winter (December to march). In Black the Hurrell index defined as the sea level Pressure difference between Azores and Iceland. In blue the principal component of mode 1.

A more detailed analysis of the 4 dominant weather regimes (Cassou *et al.*, 2004; Frankignoul *et al.*, 2005) indicate that the 2008–2009 winter is characterized by a stronger excitation of the AR mode (+30%) and weaker NAO- mode (–42%); see Figure 2. The two other regimes show normal occurrence. January in particular experienced large positive EA mode anomalies (inducing cold air outbreaks over parts of western Europe between 50–60°N), and warm temperatures over the North Atlantic at those latitudes further west. The dominance of AR regimes is consistent with the La Nina Pacific event (Cassou *et al.*, 2004). The SST anomaly structure at the end of the winter is consistent with the atmospheric forcing. During this winter, the situations had very low persistence, most events lasted 2–3 days.

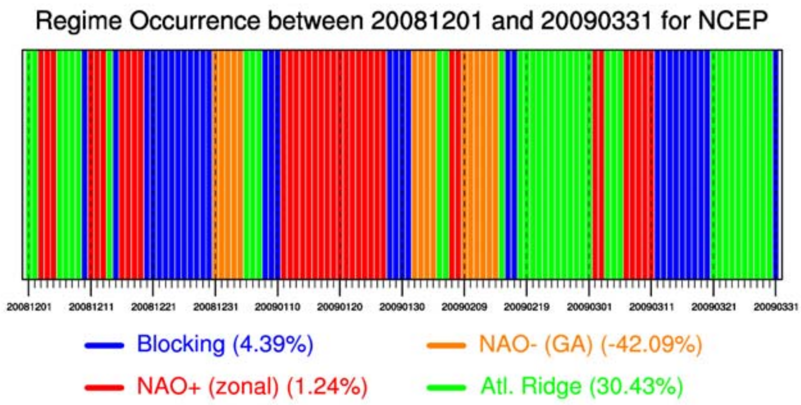

Figure 2. Daily weather regime during winter 2008–2009. In parenthesis: average percentage of abnormal occurrence.

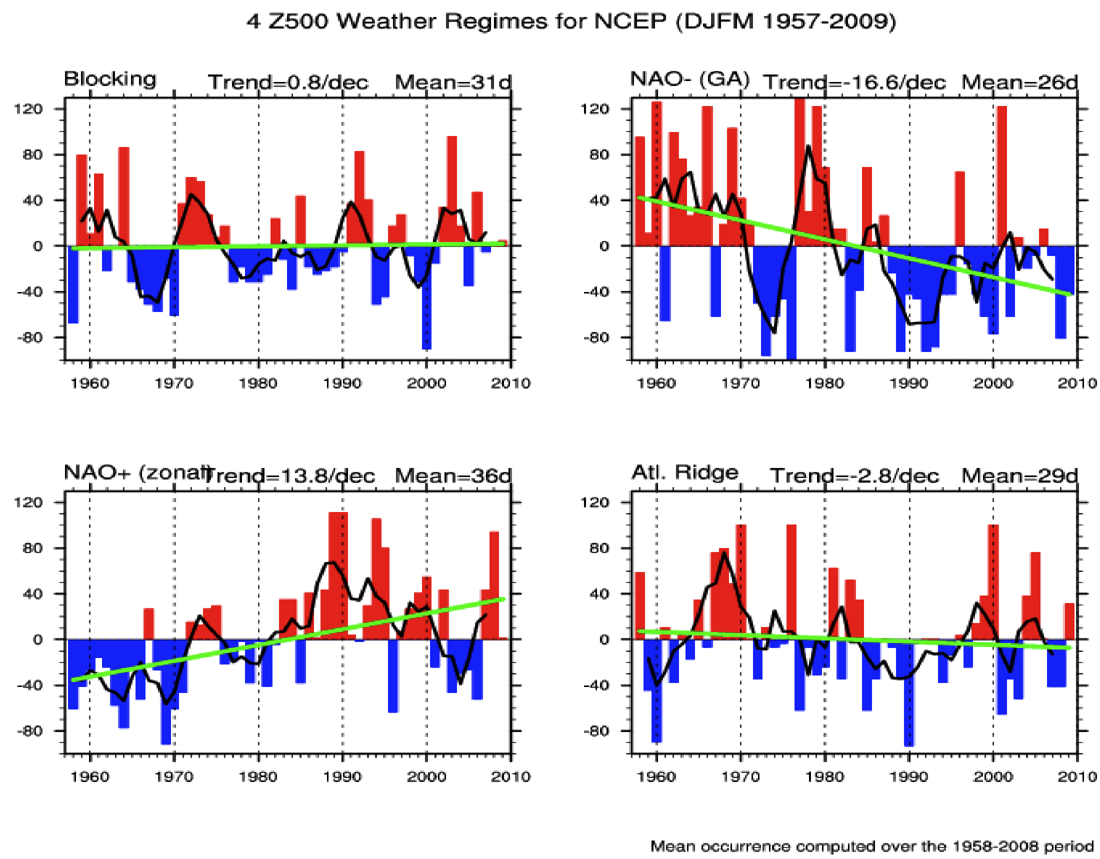

Figure 3. Interannual occurrence anomaly for the 4 weather regimes expressed as a percentage.

Westerly winds remained relatively strong in the central North Atlantic throughout the spring and summer (see Figure 4, Figure 5) inducing the development of cold temperatures in the 35–55°N and between 15 and 45°W. This pattern which somewhat remained through September, might have been conducive to the development later on of rather negative NAO situations together with positive EA situations. This combination culminated in December with the lowest NAO index since 1963 (in December) with all the months from October through March 2010 (except November

2009) having large negative NAO indices, and all months since August 2009 having large positive EA indices. These conditions were conductive to the development of a band of negative SST anomalies from western Europe (40–60°N) to the Carribean, with positive anomalies developing to its South-east and North-west.

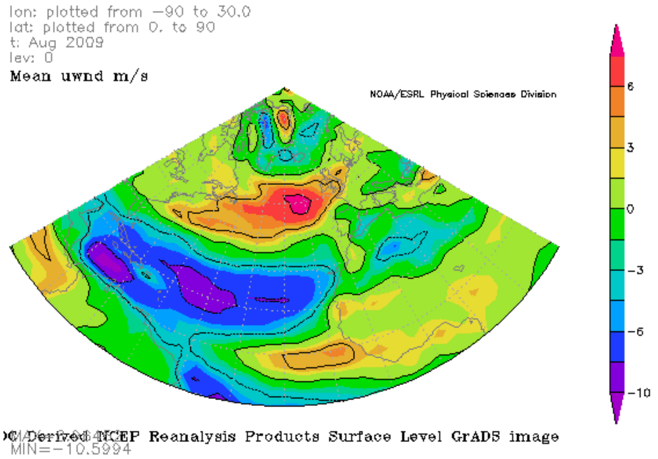

Figure 4. Zonal wind at sea level during august 2009 from NCEP-NCAR re-analysis.

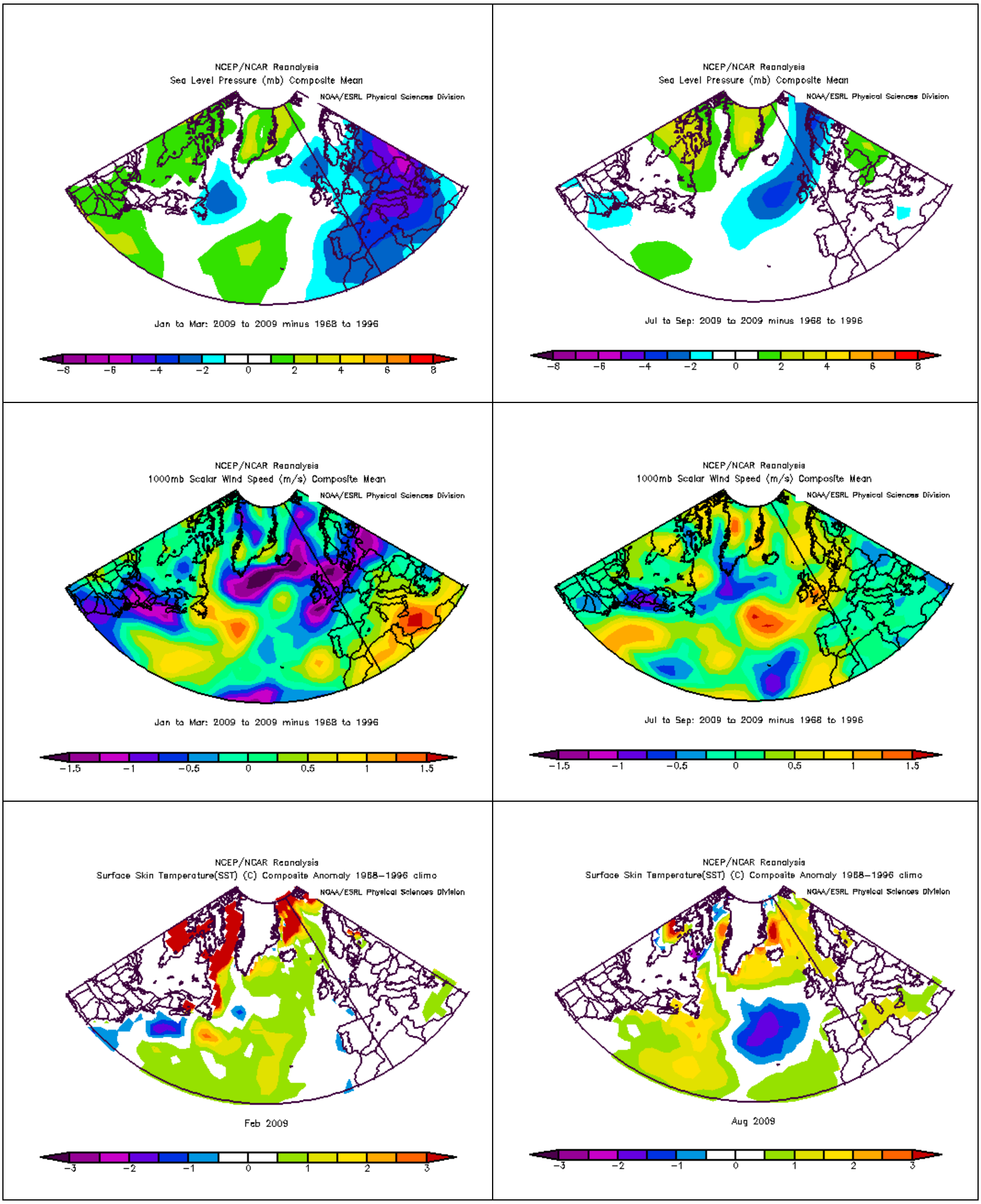

Figure 5. Averages winter (left) and summer right) situation in the NCEP-NCAR re-analysis.

2. Gridded temperature and salinity fields (ARGO)

Temperature and salinity fields are estimated on a regular half degree (Mercator scale) grid using ISAS (In Situ Analysis System) a tool developed and maintained at LPO (Laboratoire de Physique des Océans) within the CREST-Argo project (http://wwz.ifremer.fr/lpo/observation/crest_argo). The latest version, ISAS_V5.2 (Gaillard et Charaudeau, 2008 and Gaillard *et al.*, 2009) has been used to produce monthly gridded fields of temperature and salinity on depth levels from 0 to 2000 m. The datasets used are the standard files prepared by Coriolis for the operational users. They contain mostly ARGO profiles, but CTDs, buoys and mooring data are also included.

2.1 Near surface temperature

The unusual atmospheric summer situation, with strong winds on the center of the basin around 45–55N is associated with a very strong cold sea surface temperature anomaly that peaked in august (Figure 6), simultaneous with a strong warm anomaly on the Greenland sea, that progresses south-westward along Greenland.

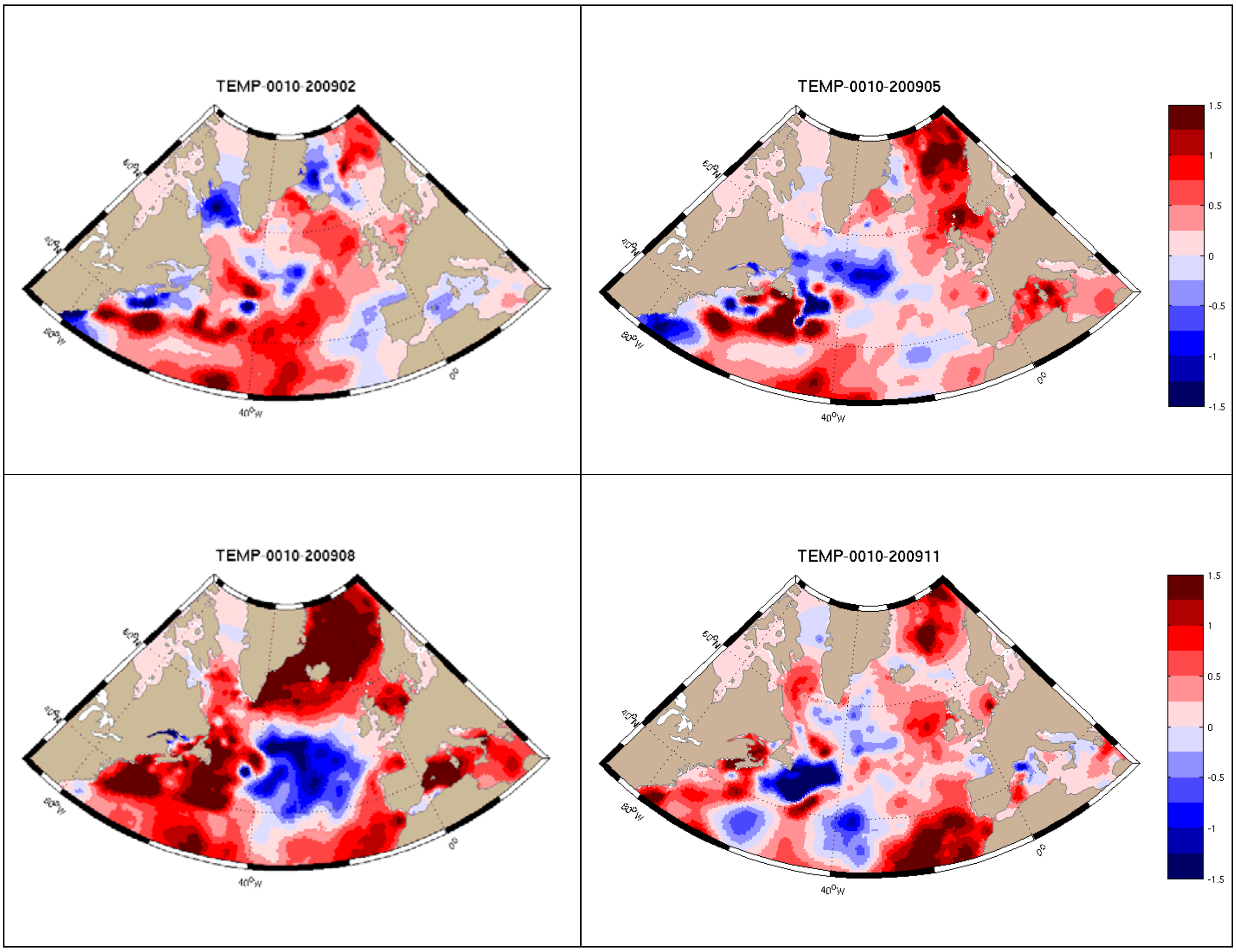

Figure 6. Near surface temperature (10m) for February, May, August and November 2009. The anomalies are computed relative to the World Ocean Atlas (WOA-05).

2.2 Annual averages

In average over the year 2009, North-East of a line joining Cape Finisterre to the south of Greenland, the North Atlantic has been warmer than the climatology in the near surface layer (10 m), the warm anomaly was more intense in the Greenland sea

(Figure 7) where it appears to be an increasing signal since 2004 (Figure 8). The summer cold anomaly in the center of the basin has imprinted the annual mean and appears as the most salient feature of this year. A positive salt anomaly is noticed progressing along the western boundary, from the North-East of Greenland to the west of the Labrador sea and along coast of North America, this salty anomaly has replaced the fresh anomaly observed in the Labrador sea in 2008. A fresh anomaly is associated with the coldest areas (center of the basin and New Foundland banks). The cold and fresh area is still visible at 300 m depth.

At greater depth (1000 and 1600 m) the Greenland sea is warmer, it is also slightly saltier than climatology in the western part (along Greenland). The Irminger and Labrador seas are warmer, especially at 1600m where this temperature anomaly is associated with saltier water. These features have been gradually developing since 2004.

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. At 1600 m the influence of the Mediterranean water appears to be reduced. The tendency for decrease in temperature and salinity is particularly obvious along the eastern boundary (Figure 9).

2.3 Seasonal cycle

The mixed layer (Figure 10) was exceptionally deep in the area of Madeira mode water in 2009 and generally along the eastern boundary, including the bay of Biscay, while it has been shallower than in 2008 in the Labrador and Irminger seas.

Time series of temperature and salinity at 10 meter have been extracted from the monthly 3D fields at 8 selected points (Figure 11). The main features of the seasonal cycle at those points are :

1) Mediterranean outflow: Winter was similar to climatology. Summer was warmer than in 2008 and becomes the second warmest summer since 2002. Fall was the warmest of the period.

2) Bay of Biscaye (south part): Winter, and February in particular was colder than climatology. Summer was slightly warmer than climatology.

3) 50N–20W : Winter was among the warmest of the period and summer was the coldest.

4) Gibbs fracture zone: The whole seasonal cycle was below climatology, and the coldest of the period, especially August and September (1° below normal).

5) Iceland basin : 0.5° warmer than climatology, except in fall, similar to 2008.

6) Irminger sea: Winter is similar to climatology, and coldest of the period. Summer 1.5° above climatology, autumn slightly colder than climatology. Similar to 2008 except in spring (colder).

7) Labrador Sea : Winter was cold, but similar to climatology, as in 2008. Summer was slightly warmer than climatology.

8) Greenland Sea (centre) : The 2009 cycle was in the average of the 2002–2009 period and above the climatology for all month.

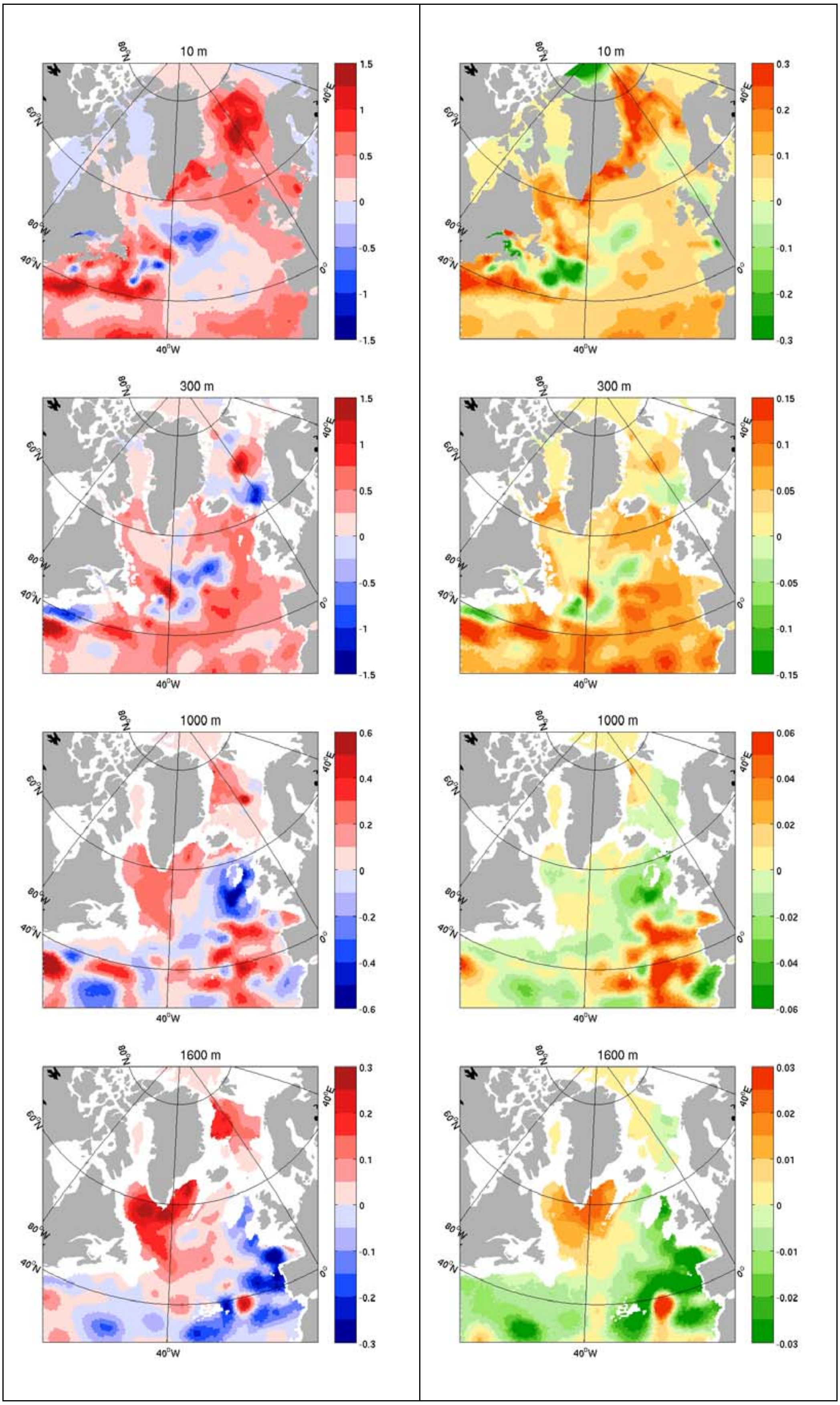

Figure 7. Annual mean 2009 temperature (left) and salinity (right) at 10m, 300M, 1000m and 1600m.

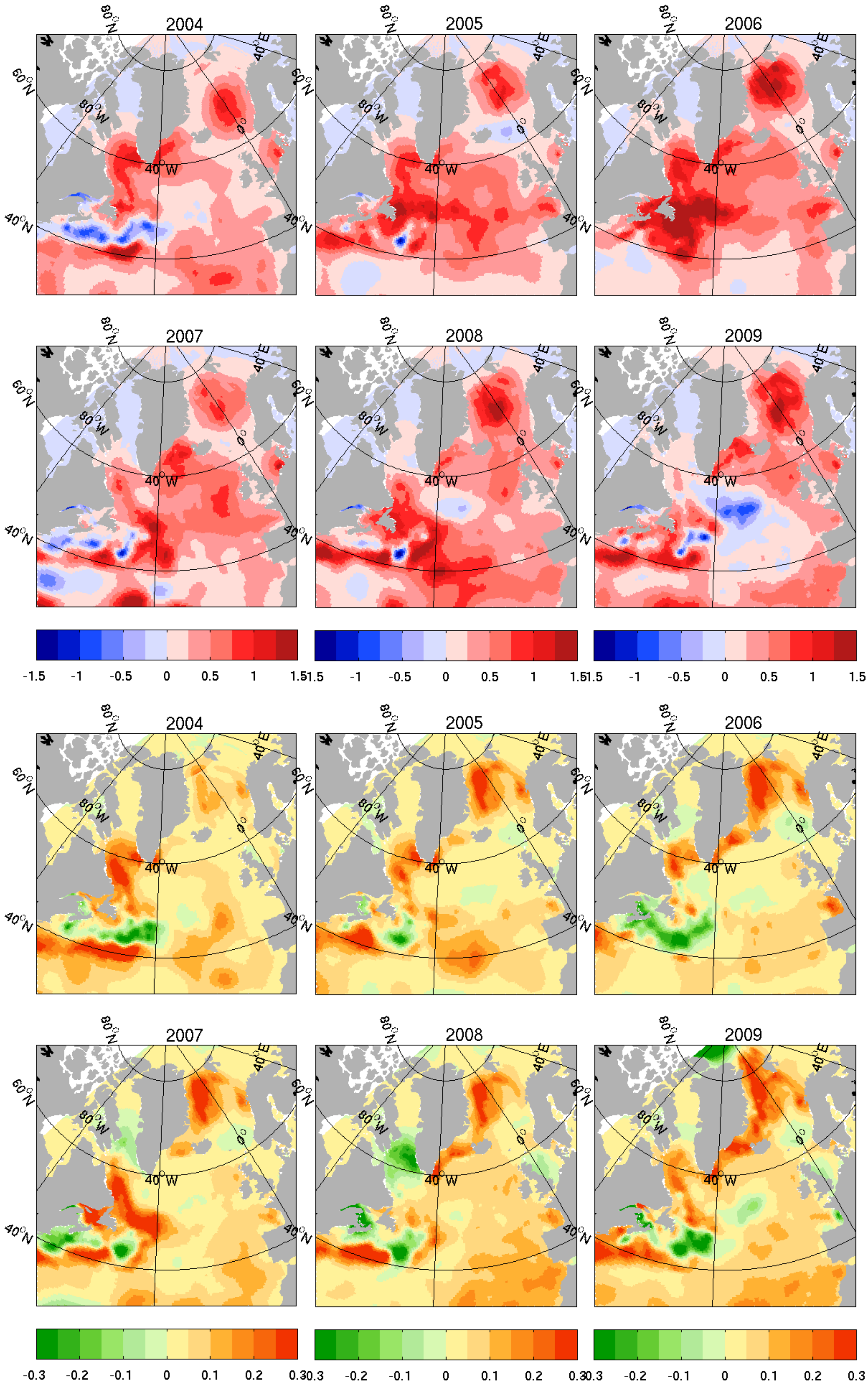

Figure 8. Annual average temperature (top) and salinity (bottom) anomalies at 10 m during 2004–2009.

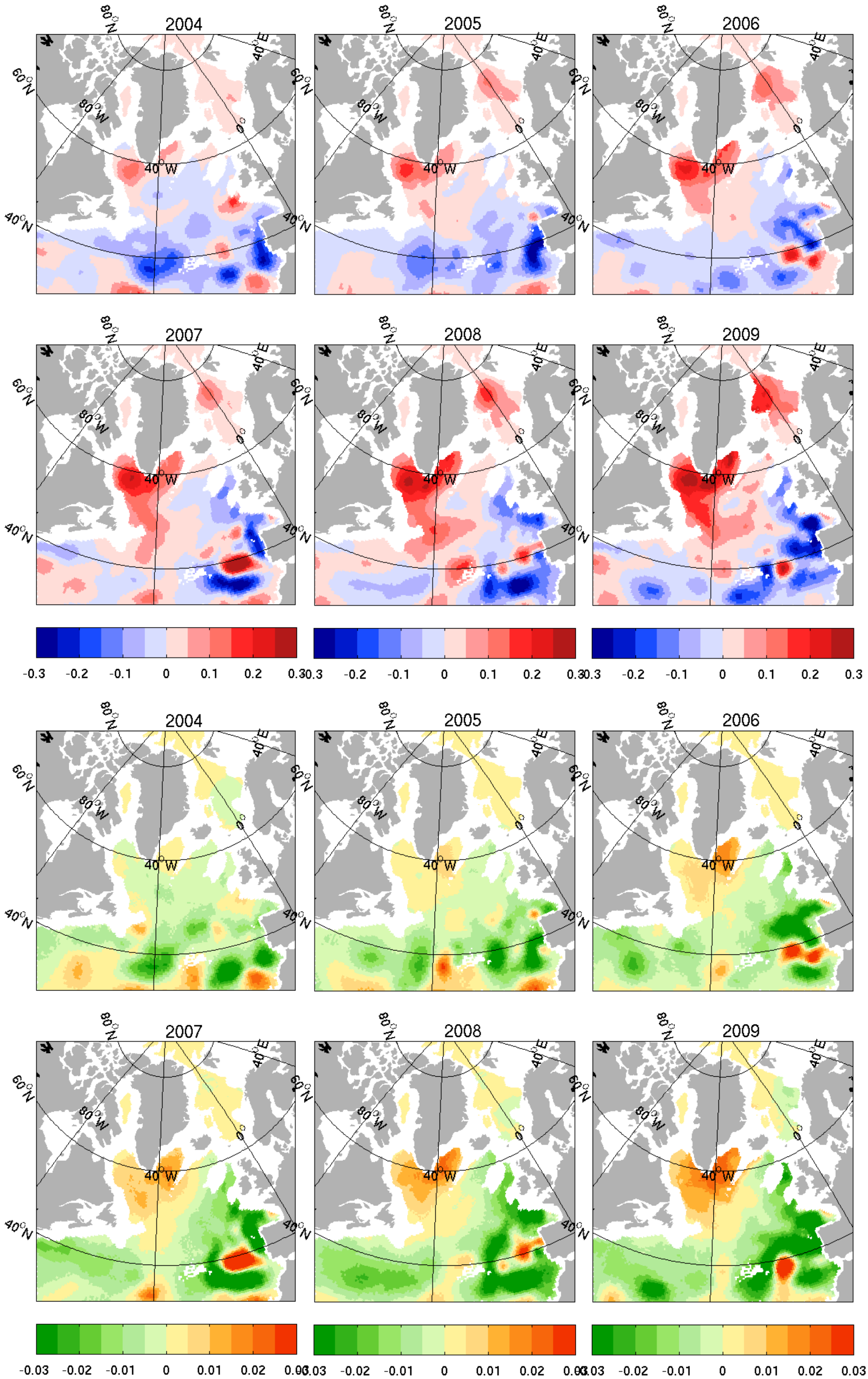

Figure 9. Annual average temperature (top) and salinity (bottom) anomalies at 1600 m during 2004–2009.

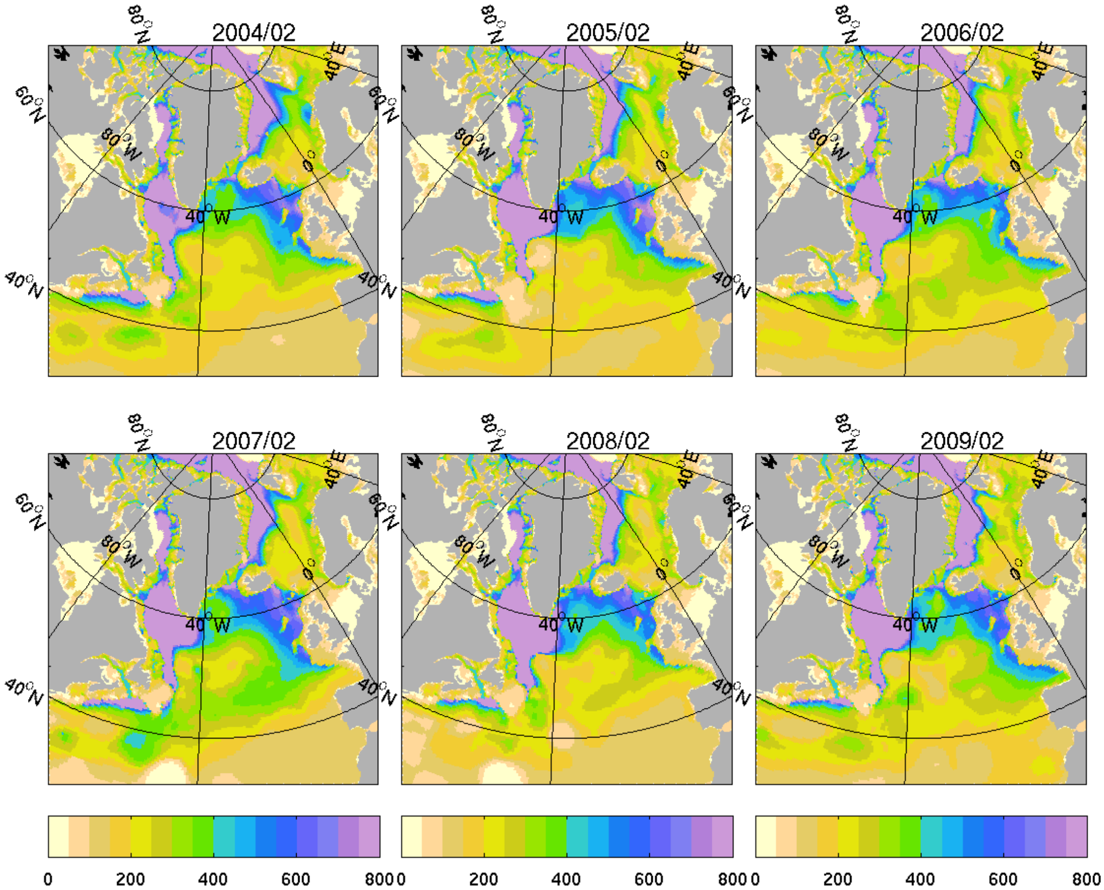

Figure 10. Mixed layer depth in February (defined on the criteria ΔT = 0.5°).

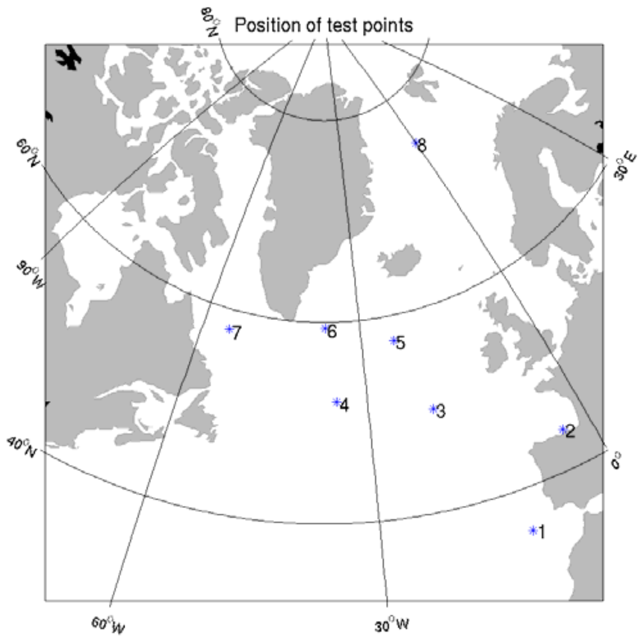

Figure 11. Position of points where seasonal cycle has been extracted.

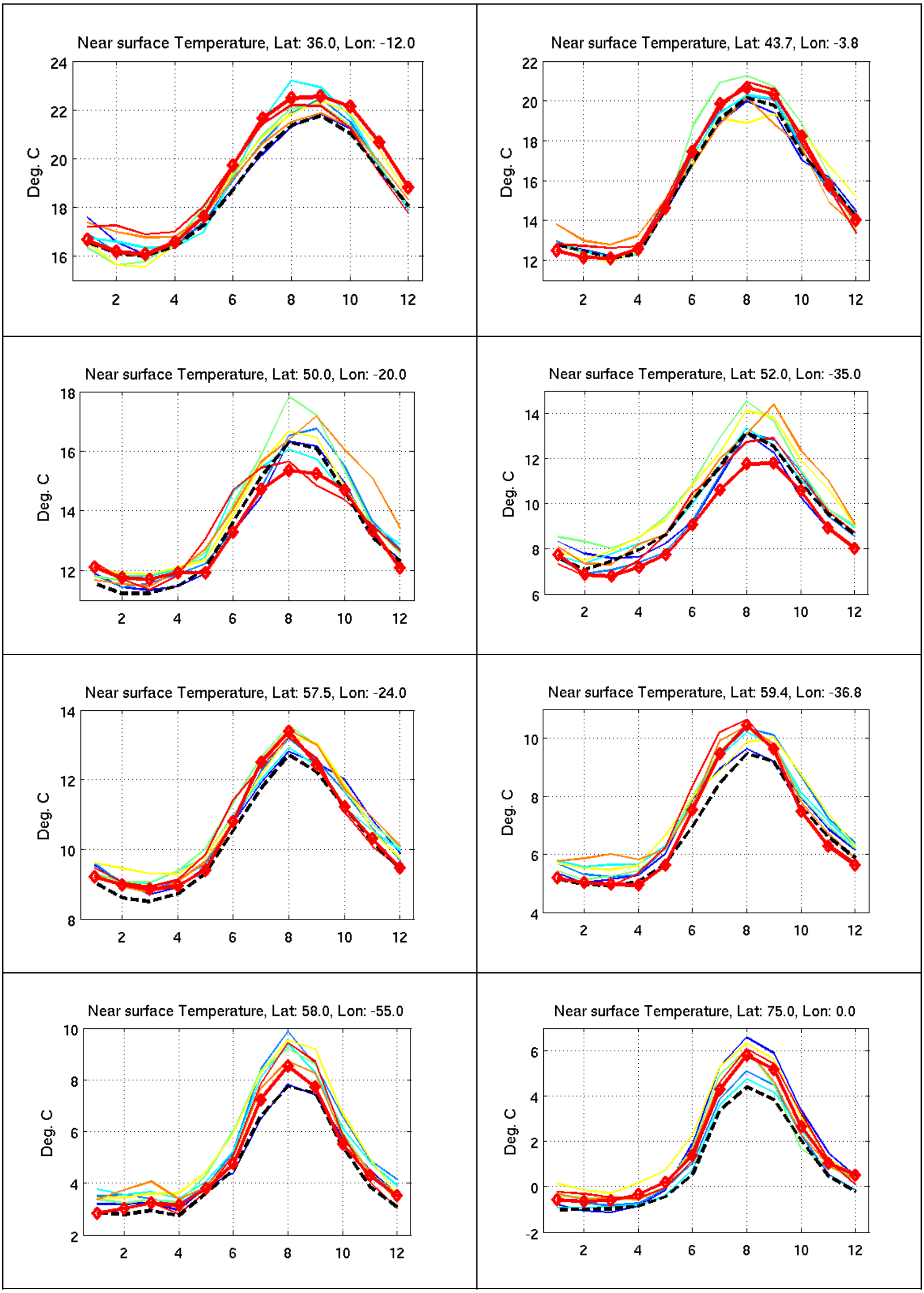

Figure 12. Seasonal cycle at different points. Heavy read line : 2009, dashed black : WOA05 climatology.

3. Ships of opportunity

Near surface temperature and salinity measurements are collected from ships of opportunity in the North Atlantic. Six merchant vessels equipped with thermosalinographs, contributing to the French ORE SSS (sea surface salinity research observatory, http://www.legos.obs-mip.fr/observations/sss) are part of this network, which includes also vessels equipped for the CARBOCEAN EU FP6 project and by NOAA, and complement along-way data collected from research vessels (GOSUD project, http://www.ifremer.fr/gosud). On some of the vessels, ancillary data are also obtained to study inorganic carbon in the upper ocean. All the vessels have been active in 2008, and most of them have reported useful data, although with a return rate of usable data that can be as low as 50%. The ORE SSS vessels include the Nuka Arctica, usually between Denmark and west Greenland, the Nokwanda between France and South Africa, the Monte Olivia between the Channel and eastern South America, and two vessels (Toucan and Colibri) on an irregular basis between the Channel, north-western Mediterranean and French Guyana. There is also one vessel (Matisse) between France, North America and Panama, crossing the North Atlantic 6 times each year. Water samples are collected on a nearly-daily basis on all the vessels, and comparison with nearby ARGO near-surface temperature-salinity data is also done, in order to correct the salinity data from the TSGs. In addition, water samples are collected on the Skogafoss between Iceland and north-east North America four times a year as part of a project to study ocean inorganic carbon changes.

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. The TSG was initially installed in the bow of the ship, but different operation problems, in particular since it was coupled with a pCO_2 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. Data have been collected through most of 2008, missing data only in February and from March 16 to April 10. They are usually of good quality, except during periods of bad weather when air entering in the TSG is still a problem.

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. Anomaly salinity data after removal of an average seasonal cycle in 1996–2008 (Figure 13) show that the higher-than-usual salinities found in late 2007 have usually persisted through 2008, in particular in the western part of the section, whereas salinity anomalies have decreased in the eastern part of the gyre. The seasonal cycle remains more pronounced, except in the western Irminger Sea, in 2008, compared to the early part of the record. Close to the Greenland shelf, deviations from the seasonal cycle are very large and tended to be positive in 2006–2008. However, this region is not always sampled at the same latitude (depending on the presence of ice on the Greenland shelves), so the salinity data are prone to a large variability, related to the latitude of the section. Temperature anomalies are not presented, but they are mostly coherent with the SST maps produced by NOAA (OI SST product http://www.emc.ncep.noaa.gov/research/cmb/sst_analysis/), although these are independent data. They illustrate a continuation of the positive SST anomalies which have tended to be present along that latitude in recent years, even in the Irminger Sea, where atmospheric forcing in winter 2007–2008 were however favourable to more cooling, resulting in increased vertical mixing and deeper mixed layer than in previous years (Vage *et al.*, 2009).

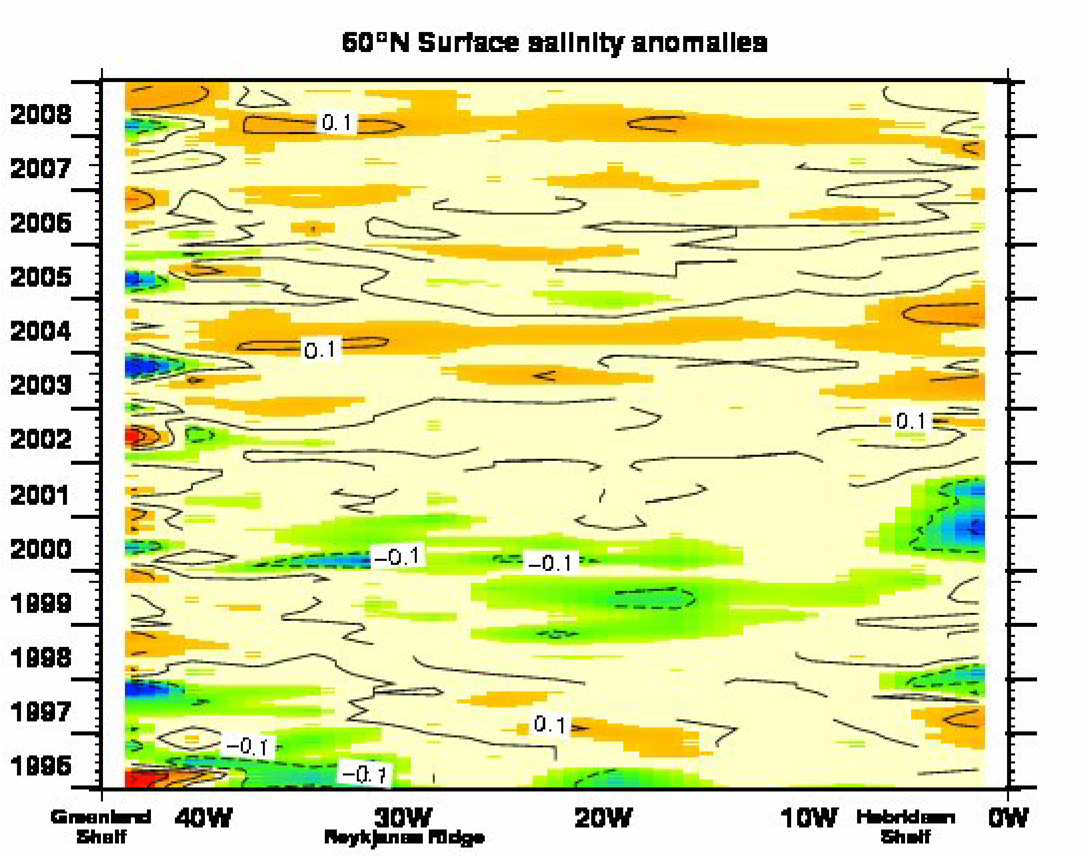

Figure 13. Salinity anomalies with respect to the average seasonal cycle in 1996–2008 mapped near 60°W between the vicinity of the southern Greenland shelf and the Orkney Islands. Based mostly on TSG data from the Nuka Arctica.

4. Coastal time series (Western English Channel)

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 14). The Estacade site is located at the end of a peer 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 Channel water. Bottom depth is at about 60 m depth and the water column is nearly homogenous for most of the surveys. More details can be found at http://www.domino.u-bordeaux.fr/somlit_national/.

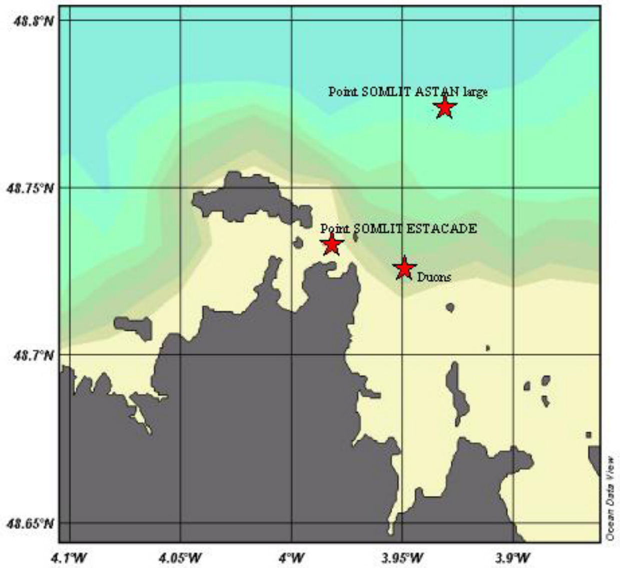

Figure 14. Location of the ESTACADE and ASTAN sites.

The first panels (Figure 15) present the 2009 cycle of temperature, salinity and nitrate compared to the mean annual cycle. Both stations show that winter 2008–2009 has been colder than normal. Temperature remained well under (- ~ 1.30°C) the averaged values until July. Temperatures were generally warmer than averaged values until October and close to them in autumn. Salinity at the two sites was characterized by a well-marked seasonal cycle with minimum values under (– ~ 0.15) the averaged values in late winter, higher (+ ~ 0.10) than averages in the beginning of summer and again values lower than averages from October to December. The annual evolutions of nitrate concentrations at the two sites were very close to the climatological cycle during the major part of the year. Higher nitrate concentrations than averages were observed concomitently with salinities lower than averages from October to December. These high nitrate concentrations originate from nitrate enriched low salinity advected in the coastal waters of the Western Channel from rivers. Nitrate enrichment was more pronounced in the coastal Estacade site which is clearly more under anthropogenic influence than Astan site.

Figure 17 show time series of temperature, salinity and nitrate at Astan over the period 2000–2009 and at Estacade over the period 1985–2009 with a large gap from 1992 through 2000 for salinity and nitrate. At the Astan site similar values are observed in surface and bottom waters. In this part of the Western Channel, due to strong tidal currents waters are well mixed over the entire water column height during most of the year. In late summer (late august, early September), during neaps tides, a weak thermal stratification (δT ~ 1°C) is generally observed in surface waters. At the Astan site, the 2009 winter minimum temperature winter was the second coldest winter observed since 2000. In summer 2009, the maximum temperature (16.95°C) observed in September is the maximum value observed since 2000.

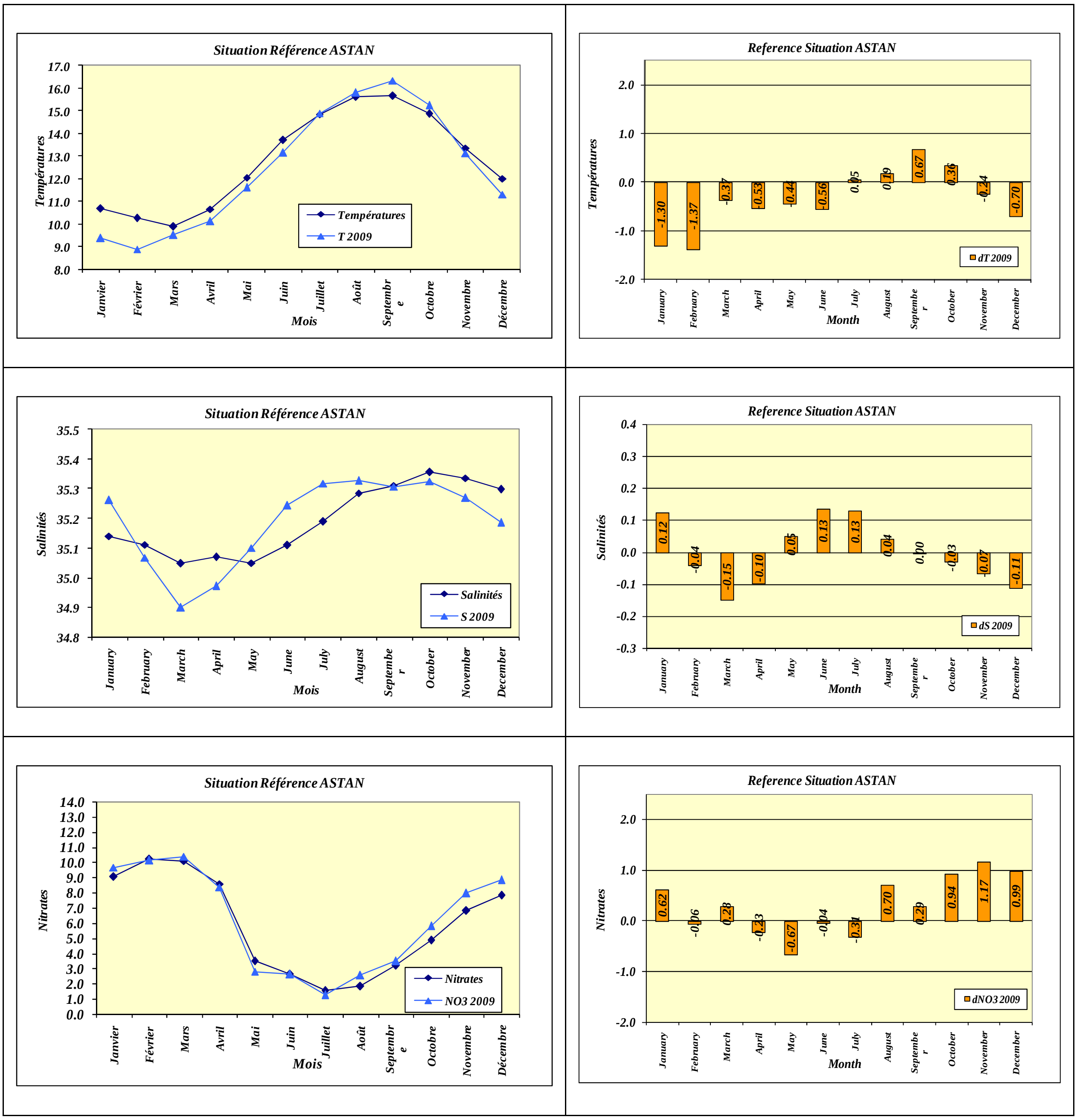

Figure 15. Comparison between times series of temperature (upper), salinity (middle) and nitrate (lower) at the Astan site in 2009 with the climatological cycle. (Left panels) 2009 values. Dark blue line represents the mean annual cycle and light blue line represent 2009 data. (Right panels) 2009 anomalies.

Salinity is subject to large interannual variability (in particular in the winter-spring season) with years characterized with predominant oceanic influence (2005 and 2007) or pronounced freshwater influence (2001). The 2009 winter minimum salinity was the most marked since 2004. 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. Nitrate winter maximum values were increasing since 2004 but this tendency has been interrupted in 2009. Temperature time series at the Estacade site show that at the beginning of the 2000s, winter temperatures were warmer than at the end of the 1980s. Colder winter temperatures were observed in the second part of the 2000s and 2008/2009 winter was the sixth colder over the period 1985–2009.

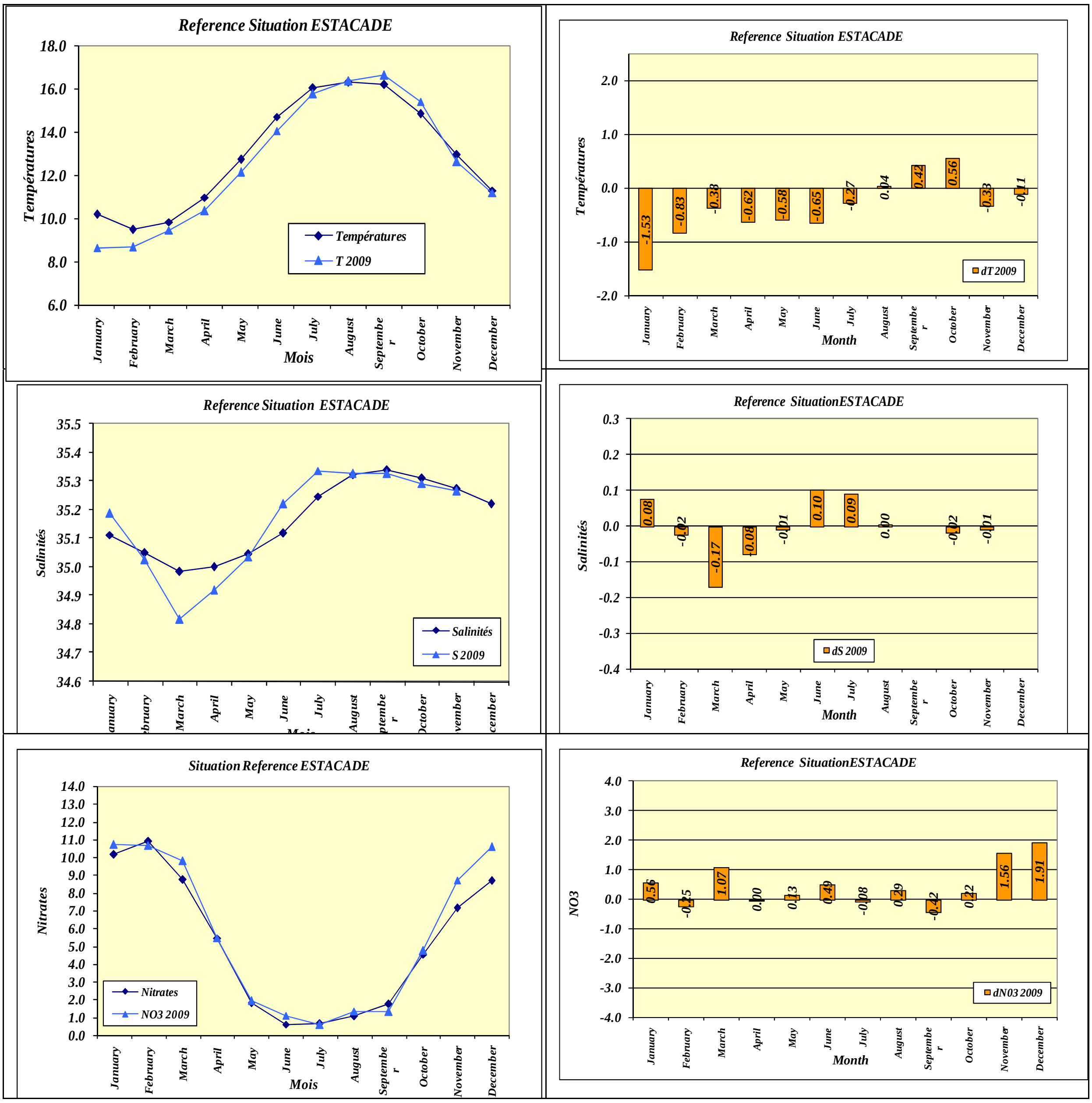

Figure 16. Comparison between times series of temperature (upper), salinity (middle) and nitrate (lower) at the Estacade site in 2008 with the climatological cycle. (Left panels) 2008 values. Dark blue line represents the mean annual cycle and light blue line represent 2008 data. (Right panels) 2008 anomalies.

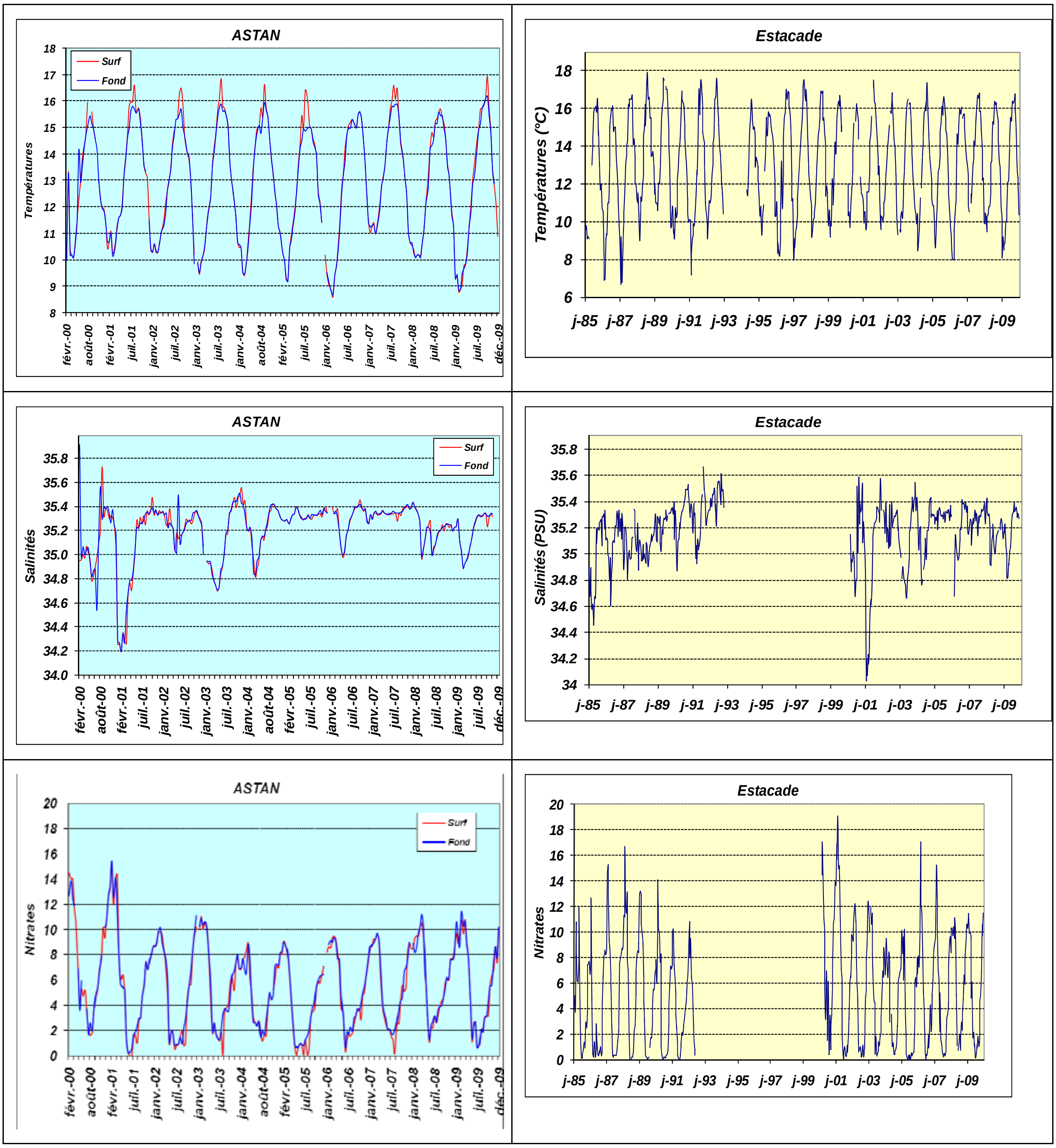

Figure 17. Interannual variability of the temperature, salinity and nitrate at the Astan site over 2000–2008 (left panels) and at the Estacade site over 1985–2008 (right panels).

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