ICES WGOH Report 2007

ICES Oceanography Committee

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Report of the Working Group on Oceanic Hydrography (WGOH)

27–30 March 2007

Göteborg, Sweden

ICES International Council for the Exploration of the Sea

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Contents

Executive summary

ICES Report on Ocean Climate 2006

- The Highlights of the IROC 2006 are as follows:
  - i) The upper layers of the North Atlantic and Nordic Seas were warmer and more saline than the long-term average. The largest anomalies were observed at high latitudes; the highest temperature in 100 years was recorded at the Kola section in the Barents Sea.
  - ii) The warm surface anomaly located in the Norwegian Sea and Barents Sea in 2005 moved into the West Spitsbergen Current and Fram Strait.
  - iii) The North Sea, Baltic Sea and Bay of Biscay had a cold winter and low sea surface temperatures, followed by an unusually warm summer and autumn and correspondingly high sea surface temperatures.
  - iv) The trend in the last decade (1996–2006) has been of warming and increasing salinity in the upper ocean.
- New products are being assessed for suitability for inclusion in future issues of IROC. These include temperature and salinity fields from the Coriolis project which operationally assimilates in-situ and satellite data (including Argo float profiles) into an ocean circulation model; annual cycles; 100-year Northern Hemisphere average ocean temperature.
- Most IROC 2006 data will be made available electronically for the ASC and on the ICES website.
- Information about data sources and the locations of full data set archives will included in IROC 2006 and future issues.

ICES Data Centre

- The WGOH would like to state in the strongest terms that an active oceanographic Data Center with adequate resources and specialist expertise is absolutely necessary for the proper functioning of ICES.
- ICES must maintain and develop a world-class oceanographic data centre with a regional focus and with specific expertise in physical data. The Data Center should prioritise the accumulation and quality control of historical and modern data in the ICES region. The Data Centre should have the capacity internally to generate products (gridded fields, time series etc) for use by its own Expert Groups and Advisory Committees.

Oceanography in ICES

- OSPAR: no requests for information have been made to WGOH from other EGs.
- Communication and interaction between WGOH and some specific EGs could be improved through coordination of annual meeting dates.
- NORSEPP: the quarterly reports are clearly written and contain a large amount of relevant information. The absence of direct measurements of Atlantic inflow to the North Sea was noted.

1 Opening of the meeting

The WGOH was welcomed to the Swedish Meteorological and Hydrological Institute (SMHI) in Göteborg, Sweden, by the local host, Karin Borenäs. A list of participants is given in Annex 1. Apologies for absence were received from Eugene Colbourne, Hendrik van Aken, Harald Loeng and Stephen Dye. The WGOH was pleased to welcome Adi Kellerman, Keith Brander and Gilles Reverdin to the meeting.

2 Adoption of the agenda

The meeting agenda was adopted (Annex 2), based on the 2007 Terms of Reference.

3 Introduction

3.1 Aims of the meeting

The primary aim of the meeting was to review scientific results from the standard sections and stations and to compile and continue the development of the ICES Report on Ocean Climate 2006 (IROC 2006). The Working Group also aimed to consider issues relating to the ICES Data Centre, the work of other ICES expert groups, and advice required by the ICES advisory committees.

An important aim of the meeting was to say thank-you to retiring member Tom Rossby for his enormous contribution to the WGOH. This was Tom's last WGOH meeting and his insight and enthusiasm will be greatly missed at future meetings.

3.2 2007 Mini Symposium

The annual mini-symposium associated with the WGOH is an excellent way to exchange the latest scientific results within the WG and between the WG and the host establishment. In accordance with a recommendation from the 2006 WGOH meeting, the mini-symposium was restricted to a half-day. The symposium was hosted by Karin Borenäs and Sheldon Bacon. An extended time slot was given to Tom Rossby who retired from the group after the 2007 meeting; some words of introduction and appreciation of his great contribution to the WG were given by Ross Hendry. The mini symposium talks are listed below:

i) Bert Rudels: The early Miocene onset of a ventilated circulation regime in the Arctic Ocean.

ii) Göran Björk: On the Lomonosov Ridge overflow.

iii) Ola Nordblom: Seatrack Web; an operational oil drift forecasting system for the Baltic Sea.

iv) Thomas Rossby: Merchant-marine based oceanography.

v) Kari Eilola: Modelling hypoxia and changes in phosphorus biogeochemistry in the Baltic Sea.

vi) Agnieszka Beszczynska-Möller: Atlantic Water warming and ice conditions north of Fram Strait.

vii) Bengt Karlson: Oceanographic observation systems.

4 Station Sections and Stations

WGOH members presented their national or regional reports. The full text of each report is included in **Annexes 6–19**.

5 ICES Report on Ocean Climate 2006

The WGOH meeting has the major task of collating the annual summary of oceanic conditions in the North Atlantic, Nordic Seas and adjacent seas (North, Baltic, and Barents). The main highlights of the report, which will also be highlights from this meeting, are given below. After a major overhaul of the format at the WGOH 2006 meeting, efforts this year were focussed on detailed improvements of the content and presentation of data. Specific items are discussed below.

5.1 Highlights for 2006

After reviewing the reports from standard sections and stations, and the information provided for IROC 2006, the WGOH agreed on the following highlights statements for the IROC 2006. The statements will also form part of the highlights from the WGOH meeting.

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

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

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

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

5.2 Atmospheric conditions

Although Stephen Dye was unable to attend the meeting he sent a presentation which Sheldon Bacon gave. In it was an overview of the atmospheric conditions in 2006, including the two winter North Atlantic Oscillation indices. Some potential new fields were suggested for the IROC 2006, including surface air temperature and wind fields. After some discussion it was agreed that the IROC 2006 would include mean and anomaly fields of sea level pressure and air temperature. It was also agreed that a polar stereographic projection would be an improvement over the usual mercator projection. The text will be improved to better explain the figures and their relevance to oceanic conditions. The discussion of the winter NAO index will focus on one the Rogers NAO index as it is most relevant to the western North Atlantic.

5.3 Salinity anomaly colour scale

In IROC 2005 the salinity normalised anomaly colour scale in the overview plots was graded from orange (fresh) to green (saline). Eugene Colbourne had requested that the WGOH discuss the option of making that colour scale match the red to blue scale adopted for the temperature anomalies. He argued that since many other parameters (ice cover, air temperature etc) can be presented in similar tables, it is useful to have consistent colouring for all. After some discussion the WGOH decided that the colour scale for salinity anomalies should remain orange to green, to distinguish it easily from the temperature plots, but that the sense should be reversed to orange (saline) to green (fresh).

5.4 Additional parameters for area reports

Eugene Colbourne had also suggested that members considered other available parameters to include in each area summary. Useful additions might be air temperature (often closely linked with sea surface temperature) and ice cover. The WGOH agreed with this suggestion and members were tasked with investigating additional parameters for their own area.

5.5 Centennial context of modern observations

Sarah Hughes presented the northern hemisphere average ocean temperature data from the 1880s to modern day (available from http://www.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html#an). The long term changes in ocean temperature provide a nice centennial-scale context for data from the most recent years, and the WGOH recommended that the editors include the information in the introduction to the IROC2006.

5.6 Products from operational data assimilation projects

In the French national report, Gilles Reverdin presented some ideas for products from the Coriolis system which assimilated Argo float profile data and generates gridded fields of temperature and salinity for the global ocean (http://www.coriolis.eu.org/default.htm). There are a variety of potentially useful products that Coriolis could provide for the IROC, with an emphasis on conditions in each recent year rather than long-term trends. Ideas included horizontal fields of subsurface temperature and salinity, mixed layer depth, and details of month-by-month conditions in selected regions. Gilles Reverdin, Sheldon Bacon, Sarah Hughes and Penny Holliday were tasked with selecting some suitable products for review by the WGOH next year and for subsequent issues of the IROC.

5.7 Annual cycles of temperature and salinity

Users of the IROC have suggested that it would be useful for individual areas to show annual cycles of temperature and salinity (mean conditions and anomalies for the recent year). The usefulness of such information was demonstrated by a plot of sea surface temperature in the Baltic which experienced an unusually cold winter followed by exceptionally warm summer and autumn. WGOH members were tasked with providing data in this form for future issues of the IROC.

5.8 Data Availability

Another suggestion from users of the IROC was that the time series data from the report be made available in electronic form. Each contributor has been asked to note with their submission whether the data can be issued on the ICES Annual Science Conference CD-ROM. The WGOH recognises that for some data sets this will not be possible according to the data policy of the contributing institute or country. The majority of contributors have agreed to make their data available in electronic form.

5.9 Acknowledging data sources and archives

The WGOH recognise the importance of acknowledging sources of data presented in the IROC. The IROC 2005 included a list of acknowledgements, but the list was incomplete and inconsistent in the level of detail given for each area. There is also a concern that figures may extracted from the IROC without the correct acknowledgement of source. Finally the ICES data centre had requested that the IROC include information about the archive location of the data from which each time series was extracted. All these issues will be addressed in the IROC 2006. Each figure will have within it the name of the source institute and the IROC, and a table will be included in the report that lists for each area a contact person, their institute and email address and where the time series data are archived. That information needs to be provided with each data set provided.

5.10 Deep water section

Some contributions have been received for a new Deep Water section in the IROC (proposed at the 2006 meeting). Sheldon Bacon will compile the data for IROC 2006 and the WGOH will review the content at the 2008 meeting.

6 OSPAR Request

The WGOH was asked to provide support to other Expert Groups requiring information on oceanic hydrography in support of their responses to the OSPAR request on 'An assessment of the changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature. The WGOH hopes that the IROC provides most of the information that other Expert Groups might need, and the EGs were asked to contact the WGOH by December 2006 if they needed further information. In fact the WGOH received no additional request for support, so no action was required.

During the discussion of this topic it was noted that other similar requests are likely to be made of ICES in the near future.

7 Relations with international climate monitoring programmes

In early 2007 CLIVAR and the WGOH produced a special issue of the CLIVAR newsletter, Exchanges, devoted to the most recent scientific research carried out by members of the WGOH. Space constraints meant that not all members of the WGOH were represented in the newsletter, but the issue was well received by the international climate research community.

The WGOH discussed ideas for new efforts in 2008. A well-supported suggestion was that of an article for EOS, the newsletter of the American Geophysical Union, which reaches a large and varied audience of physical scientists. The article might have one of a number of different themes; the interesting history of the group, the range of interest from coastal to deep, academic to operational, or the most recent conditions in the North Atlantic. Tom Rossby was tasked with leading the writing of the EOS article, with help from all WGOH members.

8 Strengthening the role of WGOH and physical oceanography within ICES

Keith Brander, GLOBEC coordinator at ICES was invited to the WGOH meeting to contribute to the discussions about the OSPAR request, feedback for the IROC, and improving the exchange of information between the WGOH and other ICES Expert Groups. There is a particular need now for improved communication for implementation of an ecosystem approach to fisheries advice. For example, the WGRED (Working Group for Regional Ecosystem Description) uses the IROC information but a direct dialogue has not yet taken place between the two groups. Moreover in 2007 the WGRED met before the WGOH so they could not use the latest information collated at this meeting in their discussions. It was suggested that some coordination of annual meetings of the WGOH with WGRED and possibly other Expert Groups might be helpful. Adi Kellerman was asked to help facilitate such coordination of meetings.

The IROC is the most prominent output from the WGOH and as such needs to be continually assessed for its relevance to the user community. Keith Brander was asked to comment on the usefulness of the report and to suggest any potential improvements that could be made. He summarised some needs of users interested in interpreting the coupling of observed physical and biological changes in distribution and dynamics. One such need was for "filling the gaps" between time series, perhaps with gridded fields from assimilation projects. At present the

IROC contains all the data of which the WGOH is aware, but the sparse observations may be inadequate for understanding complex relationships between physical conditions and ecosystems. For example, to examine the role of advection of anomalies and individual species in the NW European slope current, continuous information is required along the pathway. Has the slope current intensified in recent years and contributed to the northward extent of exotic species? At the moment the full-depth time series are sparse and satellite sea surface temperature, while continuous, is noisy and restricted in its usefulness for this purpose. Possible ways to address this problem are firstly to rely on new initiatives to develop into sufficiently long time series (e.g. operational data collection and assimilation projects such as Argo and Coriolis), secondly to develop new activities to assimilate historical data into model hindcasts, and thirdly to direct resources into extracting parameters of interest from the large ICES data archive (see Section 11).

Keith Brander also highlighted the need for prediction of Baltic Sea inflow and its effect on salinity, citing the fact that cod in the Baltic Sea are presently at the limit of salinity that they can tolerate. He noted that extreme event analysis was of particular interest, though the time-scales are sometimes much shorter than those being addressed by the WGOH. In this respect though he noted the usefulness of mean annual cycles and recent deviations from them (see section 5.7).

The WGOH is the only source of information about physical conditions within ICES, and the IROC focuses on one aspect; the conditions in the most recent year in the context of long-term observations. There are many sources of other information potentially useful to ICES on the internet and it was agreed that the WGOH could support a web-based resource locator, i.e. a list of links to datasets and products (the list to be hosted at ICES). All members were tasked with providing links that they know of (Penny Holliday to collate and send to ICES).

9 Review of NORSEPP reports

The WGOH reviewed the NORSEPP quarterly reports. The general consensus was that the reports are clearly written and contain a large amount of relevant information. The absence of direct measurements of Atlantic inflow to the North Sea was noted.

10 Isopycnal analysis of *in situ* data

The isopycnal analysis of hydrographic data from the Nordic Seas by Vladimir Ozhigin, Tom Rossby and Sheldon Bacon has been concluded. Final results were presented to the meeting by Tom Rossby and the final report is given in Annex 5 a scientific paper will be published on the circulation analysis, and products will be generated for the IROC.

11 ICES Data Centre

The WGOH is tasked with providing ongoing guidance to the ICES Data Centre regarding oceanographic data. Adi Kellermann provided an update on the situation at the Data Centre; a replacement for the previous director, Julie Gillin, is being selected at this time. One of the two data managers responsible for oceanographic data has also left and it is very likely that replacement will be hired by the new director. The WGOH expressed alarm at the situation regarding oceanographic data; having no staff to manage those data must be resulting in a stagnation of the data set, something ICES cannot afford to let happen. With ever-growing numbers of requests for information, summaries and position statements, ICES needs to recognize that the WGOH alone will not be able to fulfil all these requests in the limited amount of time that individual volunteers can commit. If ICES is serious about including oceanographic data in its assessments then it needs to devote sufficient resources to the problem. At the very least this means maintaining and developing a world-class oceanographic data centre with a regional focus and with specific expertise in physical data. The Data Center should prioritise the accumulation and quality control of historical and modern data in the ICES region. The WGOH also believe the Data Centre should have the capacity internally to generate products (gridded fields, time series etc) for use by its own Expert Groups and Advisory Committees.

The WGOH would like to state in the strongest terms that an active oceanographic Data Center with adequate resources and specialist expertise is absolutely necessary for the proper functioning of ICES.

12 New Expert Group related to operational oceanographic products and services

A new Expert Group is being planned under the Oceanography Committee (planning group led by Einar Svendsen). The Working Group on Operational Oceanographic Products will have its ToRs agreed by correspondence and will meet in 2008. The aim of the WGOOP will be to discuss operational biological and physical products in the context of ICES requirements. WGOH member Sarah Hughes is a member of the planning group and other interested parties have been invited to express their opinions. One suggestion is that the ICES Steering Group for GOOS be amalgamated with WGOOP, but this is still open to debate.

During the discussion on this topic the issue of contributing near-real time CTD data to the GTS was raised. High quality (but low vertical resolution) temperature and salinity profiles are needed in real or near-real time for the purposes of assimilation into operational models, and also for the quality control of profiles from Argo floats. At the 2006 WGOH meeting a quick poll revealed that many members would like to make a subset of their data available but lacked information as how to do it. It transpired that in 2007 the situation was unchanged. However following the meeting, Bob Keeley (MEDS, Canada) provided some information: the MEDS website contains a copy of an IOC manual that provides the necessary information about creating messages suitable for the GTS (http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Prog_Int/J-COMM/J-COMM_e.htm). Members are advised to contact their national data centres to arrange for transmission of data.

13 Any other business

Draft Terms of Reference for the next meeting were agreed, and are presented in Annex 3.

A summary of recommendations resulting from this meeting was agreed is presented in Annex 4.

No further agenda items were proposed, so it remained only to suggest dates for the 2008 WGOH meeting. The WGOH will meet at ICES in Copenhagen, and proposed a meeting in either of the weeks starting 3 March or 10 March 2008 and will last 2.5 days. ICES Secretariat will confirm the final dates according to meeting room availability. The WGOH requested that the Secretariat also considered co-ordinating the meeting dates with other interested WGs such as the WGRED and WGECO, to allow some direct interaction.

Finally the WGOH thanked their local host, Karin Borenäs for the very warm welcome that she extended to the group. The local facilities were excellent and the WGOH enjoyed their visit to SMHI.

Annex 1: List of participants

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Annex 2: Agenda

1) Welcome; review aims of the meeting; local arrangements;

2) Update and review results from standard sections and stations (ToR a);

3) 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 (ToR b);

4) provide support to other Expert Groups requiring information on oceanic hydrography in support of their responses to the OSPAR request on 'An assessment of the changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature. (Further details on the interpretation and handling of this ToR will be provided by ACE; Expert Groups requiring support have been asked to contact WGOH) (ToR c);

5) Review and improve relations with international climate monitoring programmes (ToR d);

6) Take action for strengthening the role of WGOH and physical oceanography within ICES (ToR e);

7) Review the value of the NORSEPP status report (ToR f);

8) Conclude and report on the isopycnal analysis of *in situ* data (ToR g);

9) Provide expert knowledge and guidance to ICES Data Centre (possibly via sub-group) on a continuous basis (ToR h);

10) Take part in the intersessional work led by PGOOP in developing the mission and draft resolutions for a new Expert Group related to operational oceanographic products and services (ToR i);

11) AOB;

12) Terms of Reference, date and location of next meeting.

Annex 3: WGOH Terms of Reference for the next meeting

The **Working Group on Oceanic Hydrography** [WGOH] (Co-Chairs: S. Bacon, UK, and P. Holliday, UK) will meet in ICES HQ, Copenhagen, Denmark in March 2008 (date to be confirmed by ICES) 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 in support of their responses to the OSPAR request on 'An assessment of the changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature. review and improve relations with international climate monitoring programmes;

d) review and improve relations with international climate monitoring programmes;

e) take action for strengthening the role of WGOH and physical oceanography within ICES;

f) provide expert knowledge and guidance to ICES Data Centre (possibly via sub-group) on a continuous basis;

g) take part in the intersessional work led by PGOOP in developing the mission and draft resolutions for a new Expert Group related to operational oceanographic products and services;

WGOH will report by [date] for the attention of the Oceanography Committee, ACME and ACE.

Supporting Information

PRIORITY:	The activities of this Group are fundamental to the fulfilment of the Oceanography Committee's Action Plan.
SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN	Action Plan Nos. 1.2, 1.3, 1.6, 1.7, 1.10, 5.13.4, 5.14 and 6.3. a) 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 2006. b) 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. c) This is in support of a request from OSPAR. d) 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. e) 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. f) This is in compliance with a request from the ICES Data Centre g) The work of the proposed Expert Group will be relevant for WGOH.

Annex 4: Recommendations

RECOMMENDATION	ACTION
1. IROC: Investigate the availability of supporting parameters (e.g. air temperatures, ice cover) for each area report.	All IROC contributors
2. IROC: Include centennial time series information in introduction	IROC Editors (Hughes, Holliday)
3. IROC: Include selection of Coriolis products.	IROC Editors (Hughes, Holliday), Bacon, Reverdin
4. IROC: Include annual cycles of temperature and salinity for each area report where data exist	All IROC contributors
5. Outreach: Compile article on WGOH for EOS (newsletter of AGU)	Rossby plus WGOH members
6. Meeting: Coordinate 2008 meeting dates with WGRED and WGECO	Kellerman
7. Data Centre: Provide adequate resources (including expert staff) for oceanographic data in the ICES Data Centre.	ICES

Annex 5: An Isopycnal Analysis of the Nordic Seas Hydrography

BY: Tom Rossby, Vladimir Ozhigin, Victor Ivshin, and Sheldon Bacon

Abstract

The waters of the Nordic Seas exhibit very large spatial variations in temperature and salinity due to the close proximity of waters from the Atlantic in the eastern basins and from the Arctic in the western basins. In order to distinguish between dynamical and thermodynamical effects we use isopycnal analysis to map the depths of these surfaces on the one hand and property change along these surfaces on the other. Depth variations reflect dynamics whereas property variations result principally from isopycnal advection and mixing. In this final report to an earlier progress report presented at the ICES ASC in 2006 we focus on the specific volume anomaly surface $2.1x10^{-7}$ m^3kg^{-1}. As we showed then, this surface shoals to the north, towards the Greenland Sea in the west and the Barents Sea in the east. Using a database comprising ~300,000 hydrographic stations, most to 1000 m, we construct a 50-year mean field from a set of ten 5-year averages. We find that this isopycnal is deeper in the center of the Lofoten basin than anywhere else in the Nordic Seas. This is quite remarkable given the cyclonic windstress patterns across all of the Nordic Seas. Identifying the processes responsible for this pattern is of fundamental importance to a proper understanding of the dynamics of the region as well as to identify transport pathways of physical, chemical and biological properties through the Nordic Seas. The isopycnal analysis also reveals a conspicuous T/S-anomaly maximum in the eastern Lofoten Basin.

A time series analysis of the depth of the isopycnal in the Lofoten Basin shows it to be rather stable over time with a distinct annual cycle superimposed. However, in 1968–1969 it shoaled over 400 m. Almost certainly this reflects excessive heat loss to the atmosphere during a couple of very cold winters. A few years later, 1975, the surface was substantially deeper than average. The reasons for this even more intense anticyclonic density pattern are completely unknown.

Introduction

No ocean region has been studied for as along or as thoroughly as the Nordic Seas. Already in 1887 Mohn published a chart of the circulation of the Norwegian Sea clearly indicating the inflow of warm North Atlantic waters on the eastern side and flow south of Arctic waters in the west. This study was followed a couple of decades later by the groundbreaking study by Helland-Hansen and Nansen (1909) of the hydrography of these northern waters. Using both water mass analysis (reversing thermometers and accurate salinity titrations) and the dynamic method the circulation patterns they published have stood the test of time impressively well. Even today their figure of salinity in the southern Norwegian Sea and across the Iceland-Faroe Ridge stands out as an extraordinarily prescient synthesis of circulation in the region. They detailed the route by which warm North Atlantic waters flowed north through the Norwegian Sea and beyond towards the Barents Sea and Svalbard. A striking aspect about the Helland-Hansen and Nansen study was their emphasis on the horizontal structure of the density field. They could do this thanks to the systematic hydrographic surveys throughout the Norwegian and Greenland Seas. For a nice, up-to-date overview of our knowledge of the Nordic Seas, please see the paper by Blindheim and Østerhus, 2005.

Many hydrographic surveys have been conducted throughout the region. Some focused on the hydrographic properties and how these vary spatially and temporally, but the majority of the surveys have taken place as part of fish stock assessment studies in particular areas such as around the Iceland-Faroe Ridge, the Lofoten region and throughout the Barents Sea. While these surveys concentrate on the upper ocean with limited coverage of deeper waters, they constitute an enormous resource for examining the mean fields of the upper ocean and how they vary with time.

In this final report we develop and illustrate the power and advantage of isopycnal analysis to clearly distinguish between dynamical variations and actual change in water properties along isopycnal surfaces. The latter are typically quantified through inspection of T/S diagrams on a regional basis. But with a large enough database, one can look at the isopycnal surfaces directly, their depths and their physical properties. This way one retains the full spatial context in which these variations take place. A change in depth of an isopycnal implies a change in the density and hence pressure field, a change of dynamical consequence, whereas a change in temperature/salinity composition on an isopycnal implies a change in water type. The latter does not impact the pressure field although it contains much information on advection, mixing and indeed diapycnal processes. In the progress report given at the ICES ASC in autumn 2006 we reported on three sigma-t surfaces. In this report we work with specific volume anomaly, which better represents adiabatic communication (advection and mixing). The purpose of this final report from the working group on oceanic hydrography is thus to document the usefulness of isopycnal analysis, not merely in term of T/S diagrams, but specifically the spatial information on a specific volume anomaly or delta surface, in this case $\delta=2.1x10^{-7}$ m^3kg^{-1}.

The approach taken here will be first construct the mean hydrographic state of the $\delta=2.1x10^{-7}$ m^3kg^{-1} surface and then show how it can change over time. By focusing on this one surface we seek to emphasize change over time in the horizontal. We are accustomed to thinking in the vertical or of vertical change for that is how virtually all our information is obtained. However, in order to maintain focus on the novel aspect of this study we focus just on one surface. Future studies will examine in detail the upper ocean as a whole.

The bathymetry of the Nordic Seas plays a major role in defining the hydrography of the Nordic Seas. The major ridges and basins are identified in Figure 1. As we will see, the Jan Mayen Ridge, the Mohn Ridge and the Knipovich Ridge play an overarching role in separating the cold waters on the western side from the warm waters from the Atlantic on the eastern side.

In the next section we describe the database and the procedures for quality control. Given the very large volume we limit ourselves to the standard check that the stations are in geographically plausible places, that the values are not totally outrageous and that the profiles are stably stratified. However, given the large range in T/S variability we do not impose any individual restrictions on how these may vary. A more comprehensive study might want to reopen this question, or consider further checks on the data. The following section describes the mean state and annual cycle of this delta surface across the Nordic Seas for the 1951–2000 periods. It is quite interesting and reveals features that have not before been articulated. We then discuss interannual variability of depth of and properties on this surface during this half-century period. Lastly, yet significantly, we will show how given the mean field description one can then – at any time – show what of state a region is in. We will show the enormous departures from the mean state that took place in the late 1960s and mid-1970s. One could even go backwards using this mean state description to examine the state of the Nordic Seas at the time of the Helland-Hansen and Nansen study.

Data preparation

The data used here combine data (1951–2000) in the ICES archives and Russian data at PINRO in Murmansk, Russia. The database comprises more than 300,000 stations throughout the Nordic Seas from the Iceland-Faroe Ridge in the southwest to the Barents Sea in the northeast. Each station can be used to calculate depth, temperature and salinity of isopycnal surfaces, in this case specific volume anomaly or delta, δ=2.1x10^{-7} m^3kg^{-1}, which by choice corresponds closely to the σ_t=27.9 surface used in last year's report. From now on we will refer to this surface as the delta surface. Given pressure, temperature and salinity (P, T and S), delta values were calculated for all measured depths for each hydrographic station. Based on adjacent delta values, density inversions were checked for each hydrographic station. Stations with a density decrease (inversion) of more than 0.005 $kg/m^3/m$ were eliminated (deleted). Pressure, temperature, salinity and delta were linearly interpolated between adjacent measurement depths to this delta to yield the following parameters for each station in the data set. We will call these D21 (depth), T21 (temperature) and S21 (salinity). It should be added here that the vertical spacing of measurements on many of the hydrocasts, which were taken primarily for fisheries surveys, is sometimes rather large. This means that linear interpolation between two bottles 200 m apart can lead to an additional estimation error that is beyond the scope of this study to examine in further detail. We rely on the very large volume of data to smooth out most of the scatter due to interpolation. Figure 2 shows the seasonal distribution of hydrographic stations used in this study. Clearly the summer months have the best coverage and the winter months the least. This is particularly true of the open waters of the Norwegian and Greenland Seas. The Barents Sea and all coastal waters have better coverage all-year round.

For each month between 1951–2000, D21, T21, and S21 were interpolated into grid nodes. Grid spacing was 30' along parallels (30°W to 30°E) and 15' along meridians (58°N to 80°N). The surface mapping system SURFER 8.01 (Golden Software, Inc) was used with the *Triangulation with Linear Interpolation* and *Kriging* methods applied for gridding D, T and S. Of the two methods the former is an exact interpolator (honors data points exactly when the point coincides with the grid node, meaning a coincident point carries a weight of 1.0). It creates a good representation of moderate-sized data sets (250–1000 observations) and does not extrapolate values beyond the range of data. It is especially good with regularly spaced data. When stations are patchy as with our data set this method interpolates data between clusters of stations (over empty areas). This is the main weakness of this method. *Kriging* is much better for plotting maps from irregularly spaced data. It does not interpolate between data clusters but extrapolate values slightly outside the data area (cluster). This is a much smaller disadvantage with our data set in our opinion.

The gridded fields created at the previous stage are rather "patchy" reflecting station availability in a particular month of a particular year. To get climatic fields of D, T and S, pentadal averaging of the monthly gridded fields was implemented as follows. For the first pentad (1951–1955) January-March gridded fields (of D for example) are available from the previous stage (5 for each month, 15 in total). These 15 gridded fields (or layers) are averaged, i.e. interpolated values are averaged but only for corresponding grid nodes having 3 and more values. Doing so we look for the areas where data clusters overlap. We use 3 values per a grid node to serve as a criterion. This number is a compromise of some sort. Increasing this number from 1 to 5 cuts off areas with sparse data and reduces the coverage for that mean pentadal field. Similar computations are performed for the other 9 pentads (1956–1960,...,1996–2000). The result is one mean field for each pentad.

With 10 pentadal gridded fields (or layers) available we again look for areas with good data overlapping and calculate average values for grid nodes having not less than four values. This number is also a compromise. Result is the mean field for January-March. Then computations are made for the other quarters (April-June, July-September and October-December). Exactly the same procedure is applied to construct the 50-year mean fields for T and S.

This approach, with double averaging, reduces sensitivity to bad data and produces smooth and solid mean fields. The limitation is the loss of coverage in the north and west in winter and fall (where and when data are sparse and rare).

The mean state and annual cycle

This discussion in this section consists of two parts: the overall means of depth, temperature and salinity of all data on this delta surface, followed by a discussion of the annual cycle. In the next section we report on interannual variability in the Lofoten Basin and their possible causes.

The mean state

We begin by showing in Figure 3 the mean field of depth, temperature, salinity and Montgomery potential on this delta surface for the April-June quarter. It was intended that this surface be the shallowest one that does not outcrop in winter anywhere. This turned out not to be quite the case: it does surface in the central parts of the Greenland Sea in winter as shown in Figure 4 of surface delta throughout the Nordic Seas as well as in the central Greenland Sea in spring. The low delta values in the Greenland Sea result from very low temperatures despite the low salinity in the Greenland Sea. For comparison, the delta values along the Norwegian coast are quite high, in part due to higher temperatures but also due to fresh water run-off leading to very low salinities and hence densities there. For the same reason one can observe higher values indicating run-off around Svalbard in spring.

Returning to Figure 3, as described in the previous section, these 50-year fields were constructed by first averaging all data into monthly groups that were averaged into 5-year subgroups (or pentads). The pentads were then averaged together to yield the 50-year mean fields shown here. The three panels show depth (meters), temperature (°C), salinity (PSU), and Montgomery potential, left-to-right, top-to-bottom. By definition salinity is a mirror image of temperature and might be thought superfluous, but it is useful to see the actual salinities and their spatial variability. The depth of the isopycnal shows clearly the baroclinic structure of the Iceland-Faroe Front, turning straight north and away from the Norwegian coast towards the western Lofoten Basin where the isopleths turn almost east and northeast and north towards the Fram Strait. This would be the pathway of North Atlantic waters that have entered the Nordic Seas between Iceland and the Faroes. This pattern coincides rather well with the sketch of the North Atlantic inflows in Orvik (2004).

The panels of temperature and salinity show clearly presence of warm salty waters of the North Atlantic on the eastern side and the cold fresh waters from the Arctic in the Greenland and Iceland Seas. We further see a very sharp gradient in water properties (which we will call spiciness, i.e. hot/salty vs. cold/fresh) along the Jan Mayen, Mohn, and Knipovich Ridges. This appears to be a very fundamental result: these ridges serve as barriers to mixing between the water masses from the North Atlantic and Arctic, respectively. Without this barrier, one might surmise that the fresh waters from the Arctic could reduce the salinity of the North Atlantic waters to the point that they could not sink in wintertime and produce the dense waters that spill back out into the Atlantic and beyond.

It is interesting to note that the high gradients of spiciness do not coincide with gradients in depth of this surface, or what we will refer to as regions of baroclinity from now on. The latter indicates a velocity shear, whereas the former indicates a transition between watermass types. At this juncture it is important to keep in mind that a property gradient may imply a lack of mixing or exchange of waters, but this does not preclude a cross-ridge flow, but one that is masked by eddy mixing or homogenization to either side while suppressed over steep topography. Interestingly, the property front coincides quite well over the Mohn Ridge whereas it sits to the west of the Knipovich Ridge suggesting a cyclonic circulation of warm salty waters from east to west across the Knipovich Ridge.

The isopycnal analysis also reveals a field or region of warm salty water extending east from the Lofoten Basin into the Barents Sea. Since the T/S distribution pattern indicates a local extremum without any link to a remote source of spicy waters, they must be produced locally. The source would presumably be in the Lofoten Basin filling out much of the eastern Nordic Sea basins (but not the entire Norwegian Sea to the south) and spreading into the Barents Sea. How are these spicy waters produced? The only option available, regardless of the precise mechanism, would appear to be a diapycnal flux from the lighter but saltier waters above. This local excess spiciness would result from the loss of heat and consequent 'densification' of the salty surface waters. As these waters sink and equilibrate on a deeper isopycnal, they appear saltier than the pre-existing waters. This is a well-known phenomenon from overwintering warm-core rings north of the Gulf Stream and the production of intermediate-depth lenses (Prater and Rossby, 1999). How this densification takes place at the surface in the Lofoten Basin - whether by mesoscale eddy production (lenses) or small-scale convection - we do not know. The actual mechanism by which this vertical flux takes place through the water column needs much more study, but salt fingering seems a possible if not likely candidate (Pereskokov, 1999).

The annual cycle

The quarterly mean fields of depth, Figure 5, show rather little change over the year, but if one differences the summer from the winter quarter one finds that its depth in the Lofoten Basin is greater in winter and shallower in summer, Figure 6. Interestingly, the greatest differences occur just along the margin of available data. Further study will be needed to understand this better. Clearly the extension of the extremum across the Lofoten Basin is real, but does this pattern give any hint about what causes it? Throughout the rest of the Nordic Seas the differences are quite minor, only slightly less deep in summer. This can be seen in Figure 7 (top panel), which shows mean quarterly depth of the delta surface in the area 69–71°N, 0–10°E. One sees a general shoaling of the surface between winter and summer seasons of about 100 m. This is far larger than can be explained by Ekman suction alone. A typical wintertime windstress curl might be about $2x10^{-7}$ Nm^{-3}, Figure 7 (bottom). This translates into a vertical displacement over half a year of at most ~20m. This might be able to account for a broad shoaling in the Nordic Seas between winter and summer, but certainly not a shoaling as local and intense as that observed in the Lofoten Basin (see Jonsson, 1991).

The corresponding seasonal variations in temperature on this surface are quite minor, as one might expect, Figure 8. The low temperatures in the Greenland Sea in spring reflect the reappearance of this density surface as spring warming starts to take place. The warm (and saline) water in the Lofoten Basin shows up all year round making this is robust feature. (It shows up on shallower isopycnals as well.)

Interannual variations

With the mean state and annual cycle now well-defined, we can use the extensive data set to explore variations from year to year. After we had conducted a preliminary analysis of interannual variations we noticed some very large perturbations in the Lofoten Basin in the late 1960s. Given the anomalous nature of this region we constructed a time series of depth for the entire 50-year period. What emerged was a remarkable event in 1968–1969 when the delta surface shoaled some 400 m all but lifting it to the level of the surrounding waters, Figure 9 (top panel). Since this event lasted for a few years we use data from the best-covered months to estimate its magnitude: the rise is sharp and the decay appears to be somewhat more gradual. Almost certainly this event was caused by a couple of very bitter winters during which the loss of heat to the atmosphere must have been extreme. Here we simply show Dec-Jan-Feb temperatures for the period 1958–2000, Figure 9 (bottom panel). Note the nearly 5°C lower mean winter air temperatures for the 1968 and 1969 winters. Very few winter data are available for the 1968–1969 winters in the Lofoten Basin but it seems likely the area for which the delta surface outcrops did expand. However, in adjacent areas where data are available for this period the delta surface was deeper than 100 m at the least. No other extreme event such as this occurs in either record during this 50-year period. The coincidence between the two is striking and clearly worth further study. Finally, Figure 10 shows the spatial pattern of depth anomalies for two periods, May-August 1969 and May-August 1975. Note the very different distributions, the top panel corresponds to the summer following the second cold winter while the bottom panel is for a period when the delta surface was substantially deeper than its 50 year average (from the top panel of Figure 9). What drives these regional variations in depth of the delta surface even in the absence of extreme winters is not at all clear although it might be noted that in the late 1960s the NAO index was very low while the mid-1970s it was significantly positive. It might be added that these extrema of the delta surface do not show up at Station 'M', 400 km to the south.

Examination of temperature on this surface in the Lofoten Basin reveals some striking changes as well. First, one sees a rather sharp drop in temperature at the time of the extreme winters, Figure 11. But one also notices that the temperatures continue to drop throughout the 1970s due to the Great Salinity Anomaly after which the temperatures remain rough 0.5°C lower than in the 1950s and 1960s on this delta surface.

Spatial Variability

We now briefly examine how this delta surface varies spatially. Not surprisingly, in view of the previous section, the RMS depth variability of this delta surface is greatest in the Lofoten Basin with sharp limits towards the Mohn Ridge and Vøring Plateau to its north and south, Figure 12. One also sees an extension of greater variability extending south along the eastern margin of the Jan Mayen Ridge and along the Knipovich Ridge to the north. The variability does not appear to reach the Norwegian continental slope. There is a slight hint of the Faroe Current north of the Faroes (contour >100m) but not of the Norwegian Atlantic Current to its north. These patterns and their amplitudes are not significantly affected by the extreme 1968–1969 winters.

The T/S variability on this surface exhibits an entirely different character, Figure 13. Here the region of largest variance follows the thermal (property) front rather closely, along the Mohn Ridge NE, and north just west of the Knipovich Ridge. The variability within basins is significantly less, especially in the southeast where the delta surface is deep and well out of reach of the atmosphere. In the west where the surface is shallow and outcrops in some areas in winter, the variability is noticeably larger. There is also greater activity in the Lofoten Basin perhaps consistent with greater diapycnal activity. The actual variability in the Norwegian Sea is probably less than indicated because some of the scatter quite likely results from the low bottle density in many of the fisheries-research stations and hence greater interpolation in the vertical. But the pattern of greater variability over and along topography, which tends to separate water masses, stands out clearly. Why the property front and this T/S variability lie to the west of the Knipovich Ridge axis is curious. Clearly there is a cyclonic recirculation of Atlantic waters towards Greenland and back south north of 76°N, but what controls the location of property front west of the ridge needs explanation. One possibility might be that the Knipovich Ridge is not that effective since it is less high than the Mohn Ridge, and perhaps more striking for its deep narrow mid-ridge valley.

Summary

The isopycnal analysis developed here seeks to distinguish between dynamical change as measured by changes in depth *of* an isopycnal surface, and property change due to T/S variations *on* that surface. In conventional x-y-depth displays it can be difficult to distinguish between the two due to the basic stratification of the water column. In this study we take advantage of the large volume of stations in the Nordic Seas to explore the spatial structure of the density field and how it varies, not merely on regional T/S diagrams, but on selected *isopycnal surfaces.* In an earlier preliminary report to ICES we considered three sigma-t surfaces. Here we focus on one specific volume anomaly or delta surface. A central result here is that the mean fields of depth and property have distinctly different patterns. This is also true of their patterns of variability. We find that the mid-Atlantic ridges serve as a dynamical (in the sense that the ridges, although deep, constrain fluid motion throughout the entire water column) barrier to interbasin exchange. But property fronts need not and often do not coincide with dynamical fronts, i.e. currents. This is not so obvious when we examine fields as a function of depth because what looks like a large property change across a front, may actually result from water of the same property appearing at different depths.

Once the basic or mean state has been determined, it can serve very effectively as a basis for exploring anomalies and their behaviour in the Nordic Seas. This is where the large database can be very useful. Looking from one year to the next one can observe very substantial variations in both isopycnal layer depth and properties anomalies, and these can persist for several years. Depth variations on annual and longer time scales reflect variations in Ekman pumping while T/S anomalies result from subduction and advection of past exposure to surface wintertime conditions. We show how the deep pycnocline in the Lofoten Basin can vary considerably in depth over time. The cause of this extremum and its variability needs much further study, but appears to be too extreme to result from Ekman pumping. In short, this isopycnal approach allows one to more clearly distinguish between the effects of mechanical and thermodynamic forcing. We plan to continue these studies. But it is also clear that these products, or reanalyses to borrow a phrase from meteorology, may prove useful for testing and verifying numerical models and simulations of the Nordic Seas circulation.

References

Blindheim, J., and Østerhus, S. 2005. The Nordic Seas, Main Oceanographic Features. *In* 'The Nordic Seas – *An Integrated Perspective*' Ed. by Helge Drange *et al.* AGU Geophysical Monograph 158.

Helland-Hansen, B., and Nansen, F. 1909. The Norwegian Sea: Its Physical Oceanography based on Norwegian Researches 1900–1904. *In* Report on Norwegian fishery and marine investigations, vol. 2. Bergen, Norway, 390 pp + 25 plates.

Jonsson, S. 1991. Seasonal and interannual variability of wind stress curl over the Nordic Seas. Journal of Geophysical Research, 96(C2), 2649–2659.

Orvik, K. A. 2004. The deepening of the Atlantic water in the Lofoten Basin of the Norwegian Sea, demonstrated by using an active reduced gravity model. Geophysical Research Letters, 31, L01306, doi:10.1029/2003GL018687, 2004.

Pereskokov, A. I. 1999. On the physical nature of the large-scale anticyclonic eddy in the water column of the Norwegian Sea. Doklady Akademii Nauk (Contributions of the Academy of Science, 364(4), 549–552.

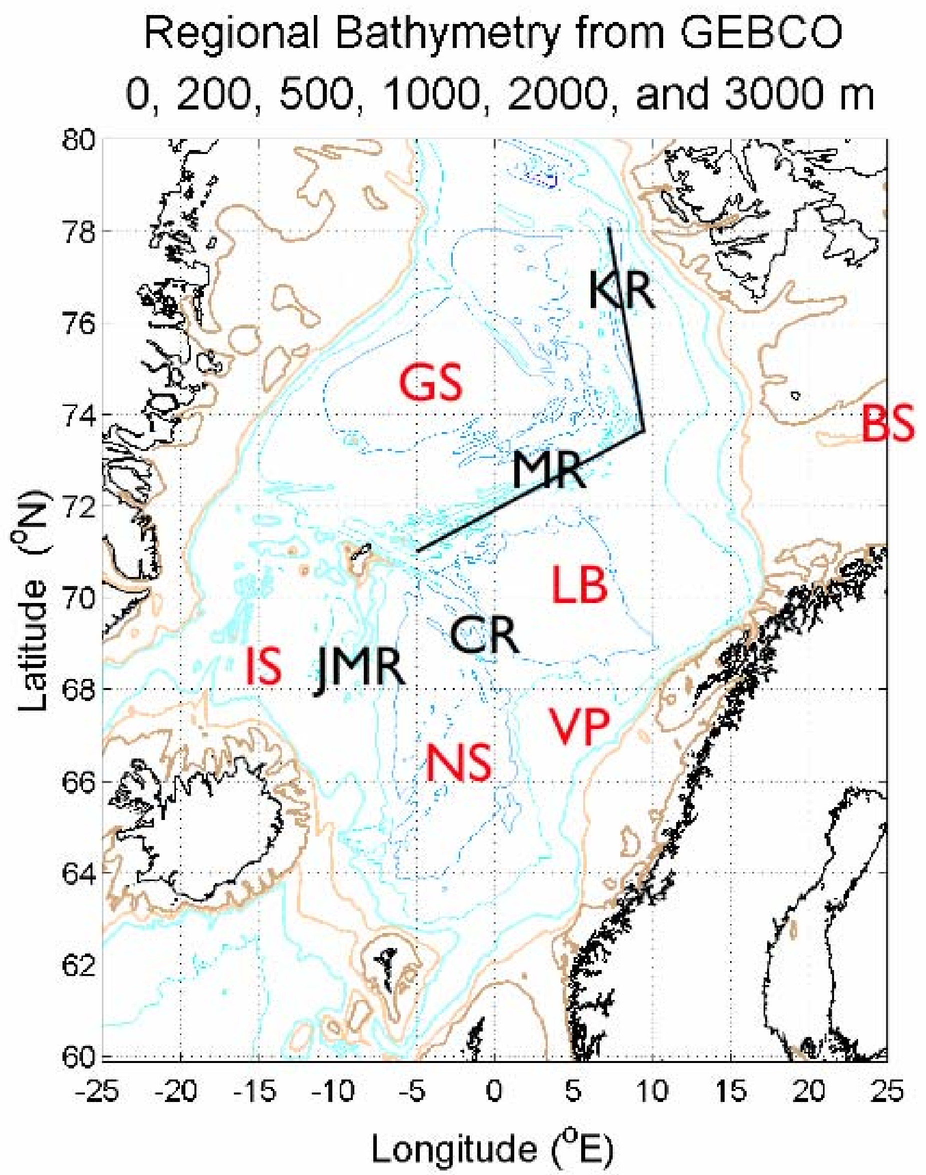

Figure 1. The bathymetry of the Nordic Seas. KR = Knipovich Ridge, MR = Mohn Ridge, CR = connecting ridge, JMR = Jan Mayen Ridge, GS = Greenland Sea, BS = Barents Sea, LB = Lofoten Basin, IS = Iceland Sea, VP = Vøring Plateau, NS = Norwegian Sea.

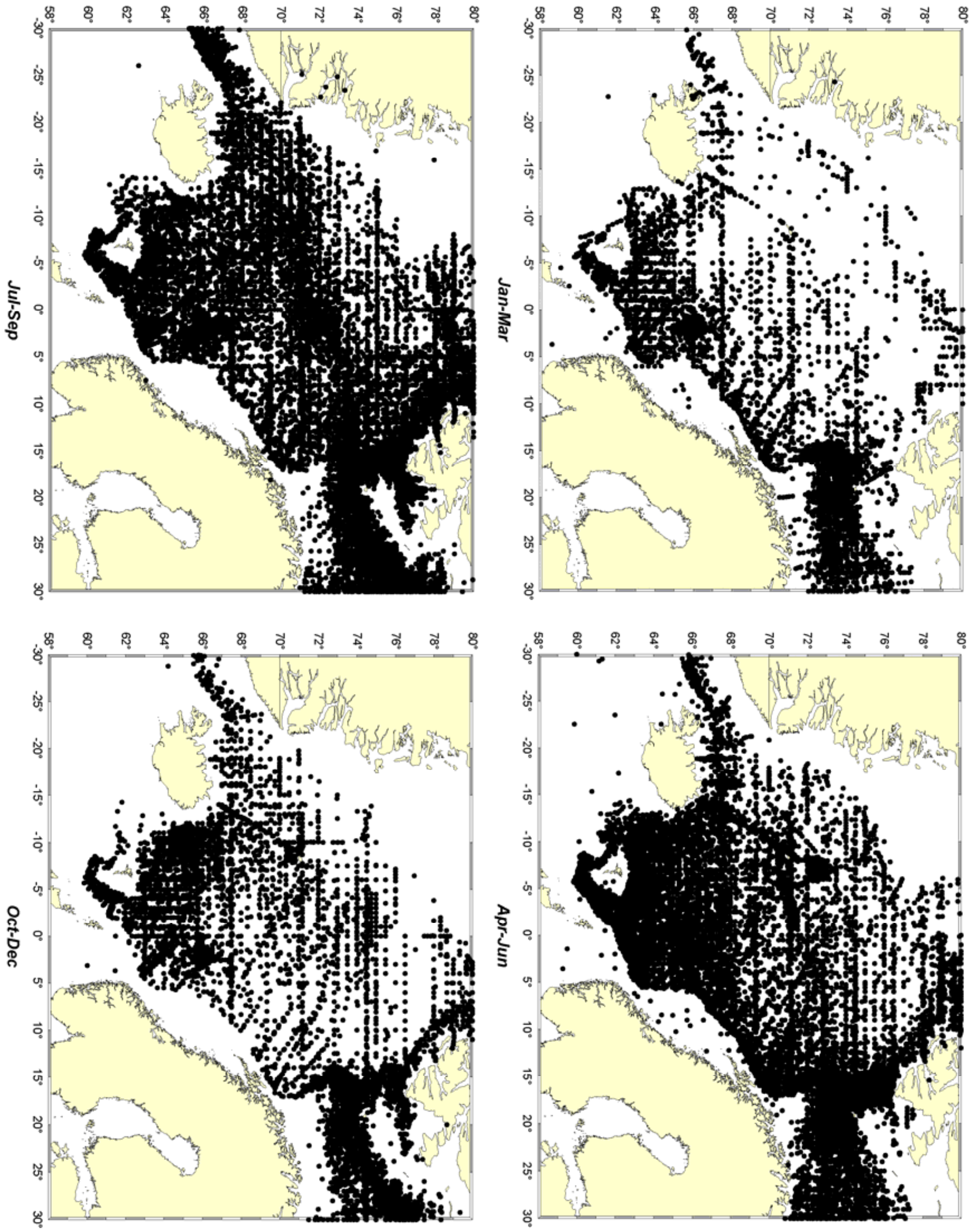

Figure 2. The available hydrographic database for the Nordic Seas as seen on the 2.1e-7 m^3 kg^{-1} (~27.9 σ_t) surface.

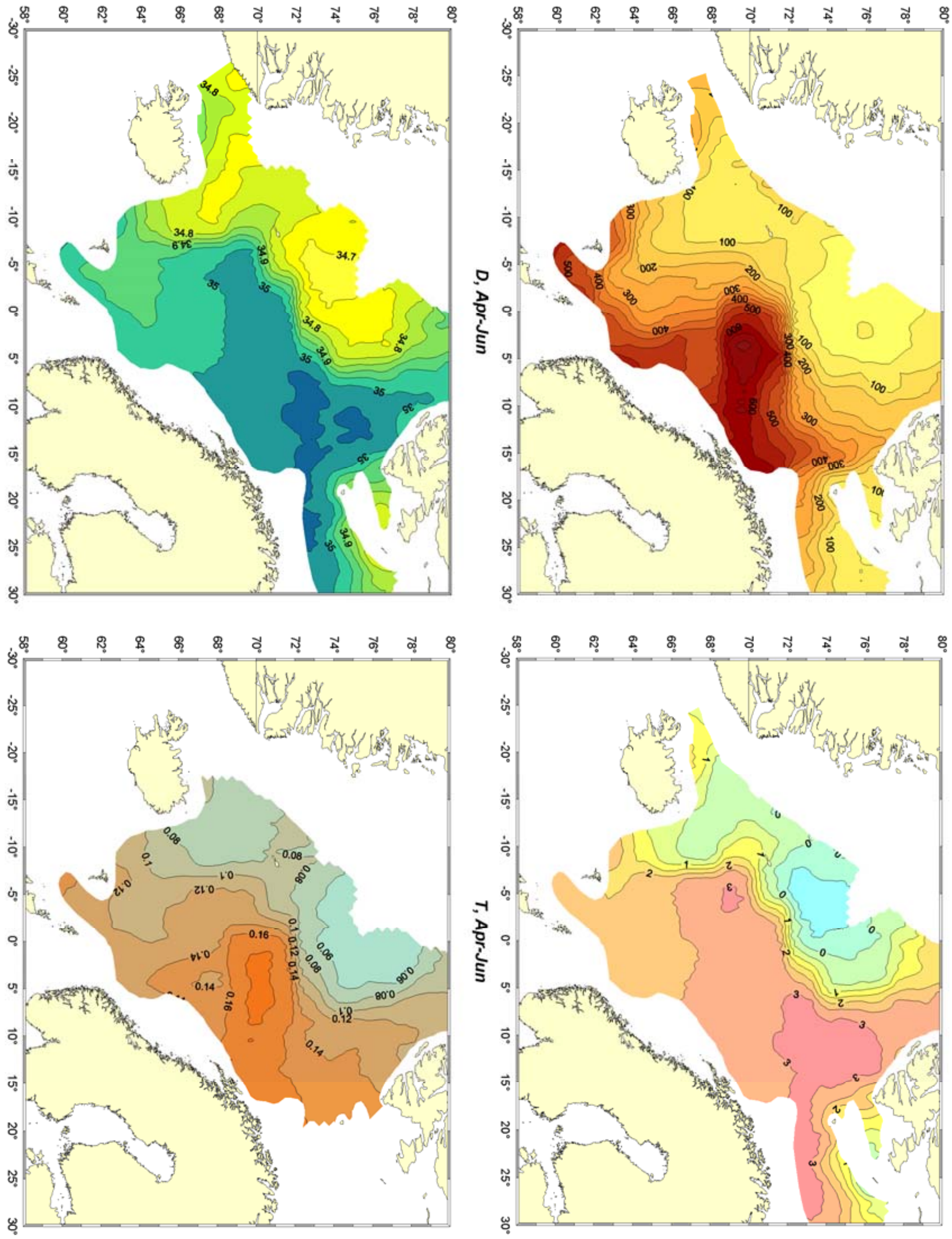

Figure 3. Depth, temperature, salinity and Montgomery potential for the 2.1e-7 m^3 kg^{-1} (~27.9 σ_t) surface for the April-June quarter. Note that T and S, mirror images of each other, are rather uniform within basins, but not across boundaries between them. Depth shows a very strong A/C structure within the Lofoten Basin.

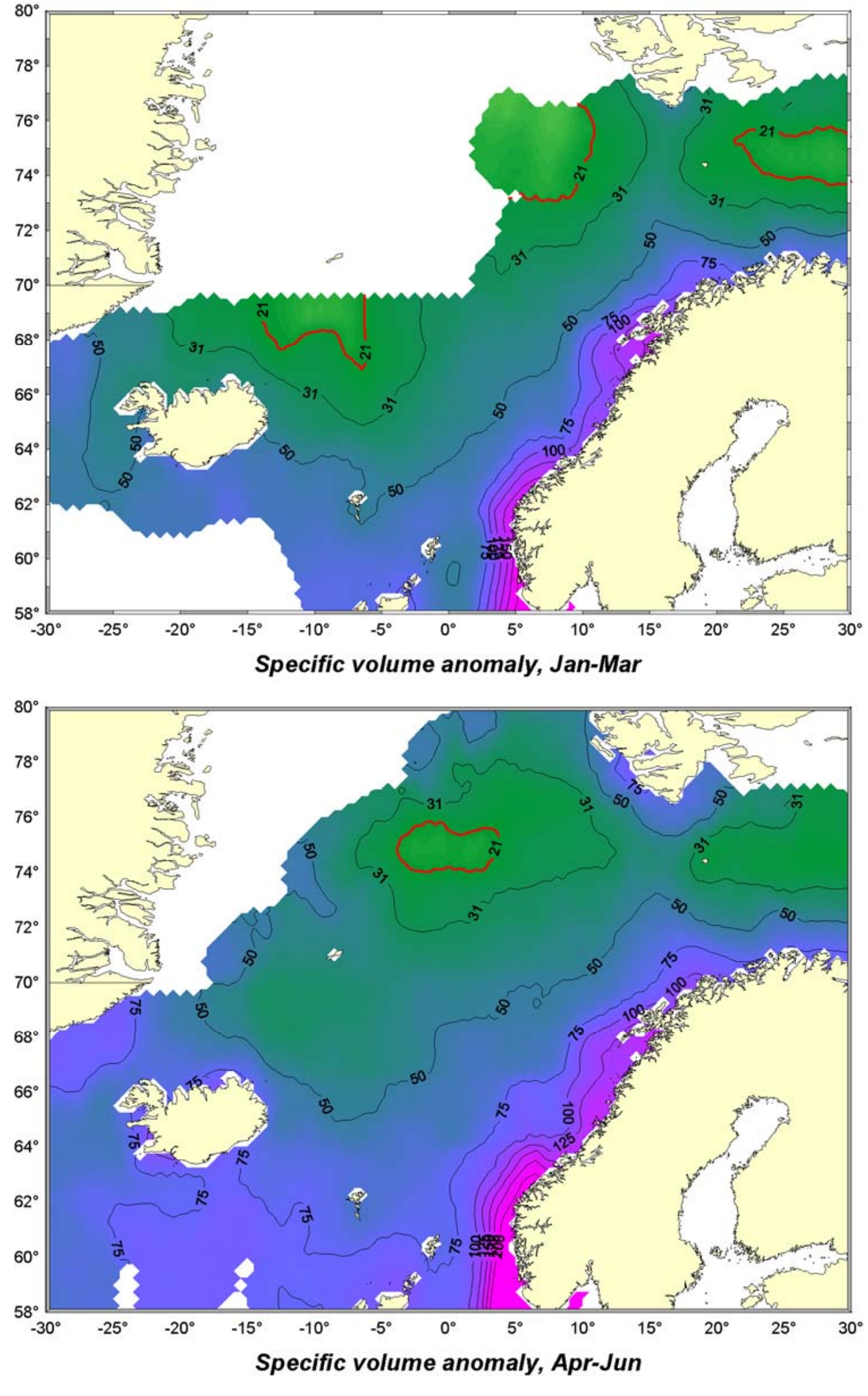

Figure 4. Distribution of delta at sea surface during winter and spring quarters. Note the very low values in the center of the Greenland Sea and the complete absence of a high in the Lofoten Basin. Instead the lightest waters are found against the Norwegian coast due to low salinity.

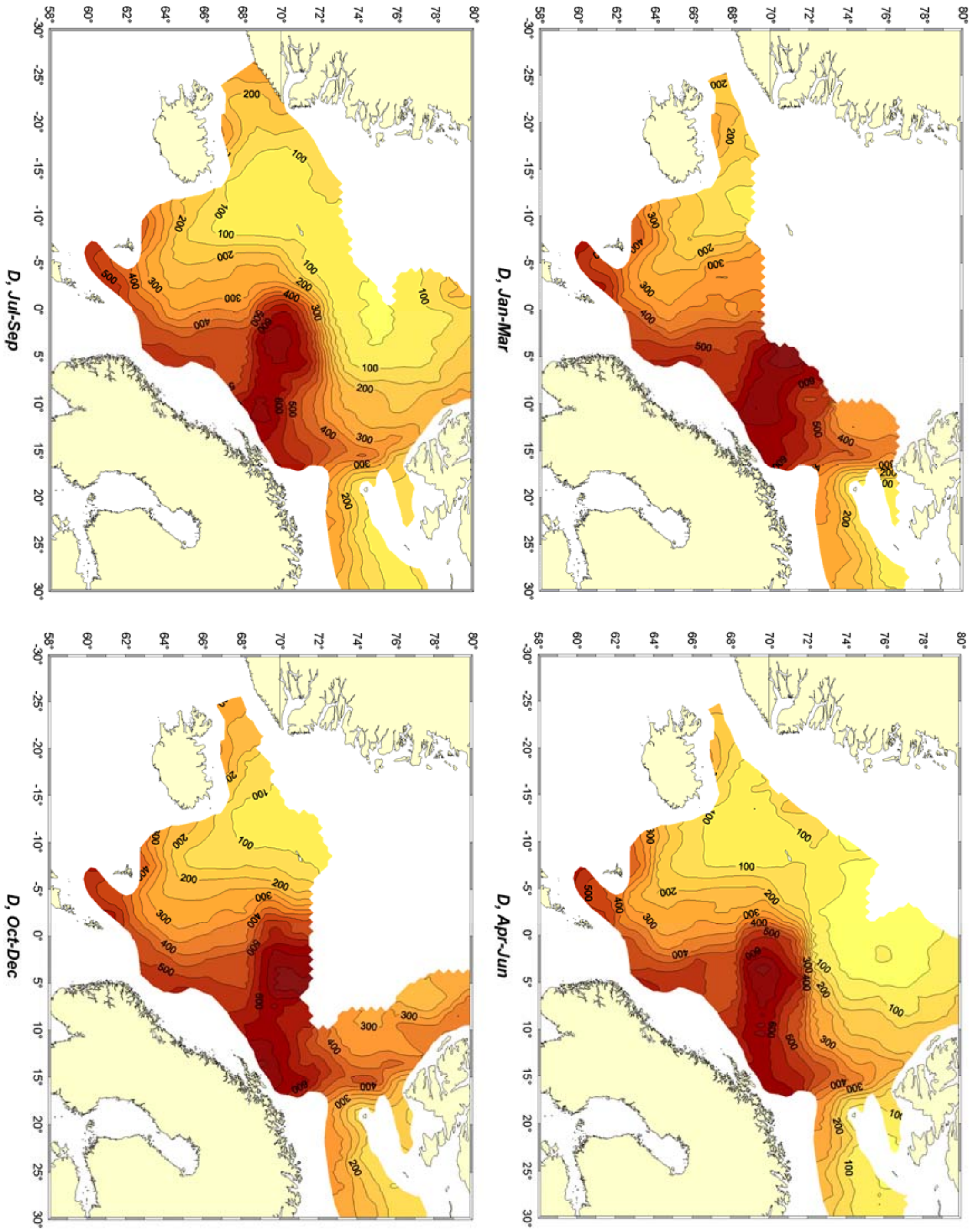

Figure 5. Depth pattern of the delta surface as a function of season. Lack of winter data in the Greenland Sea results from sparse sampling and outcropping of the surface (see Figure 4).

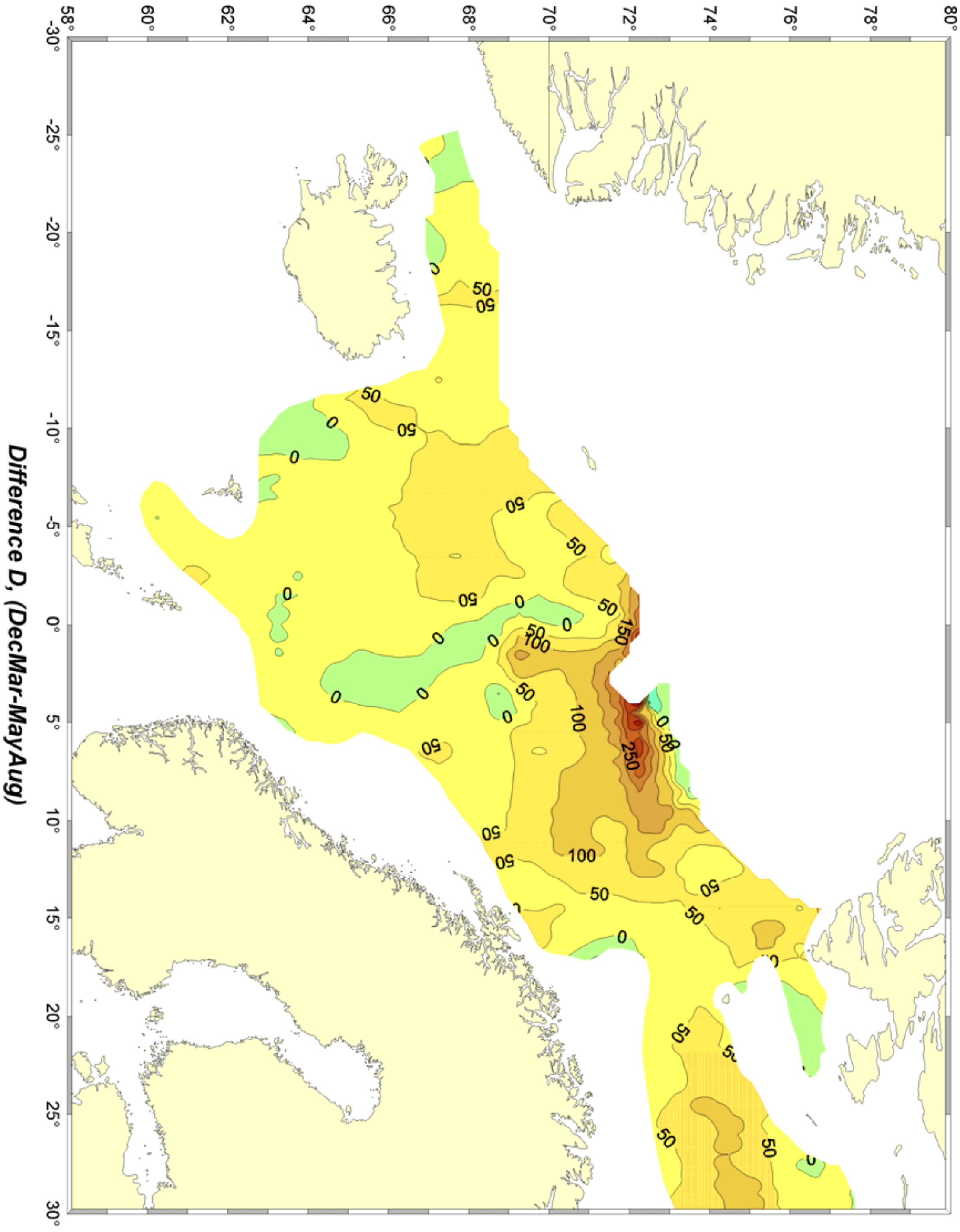

Figure 6. Difference in depth of the delta surface between winter and summer. Note the significantly greater depth in winter in the Lofoten Basin and very little change elsewhere.

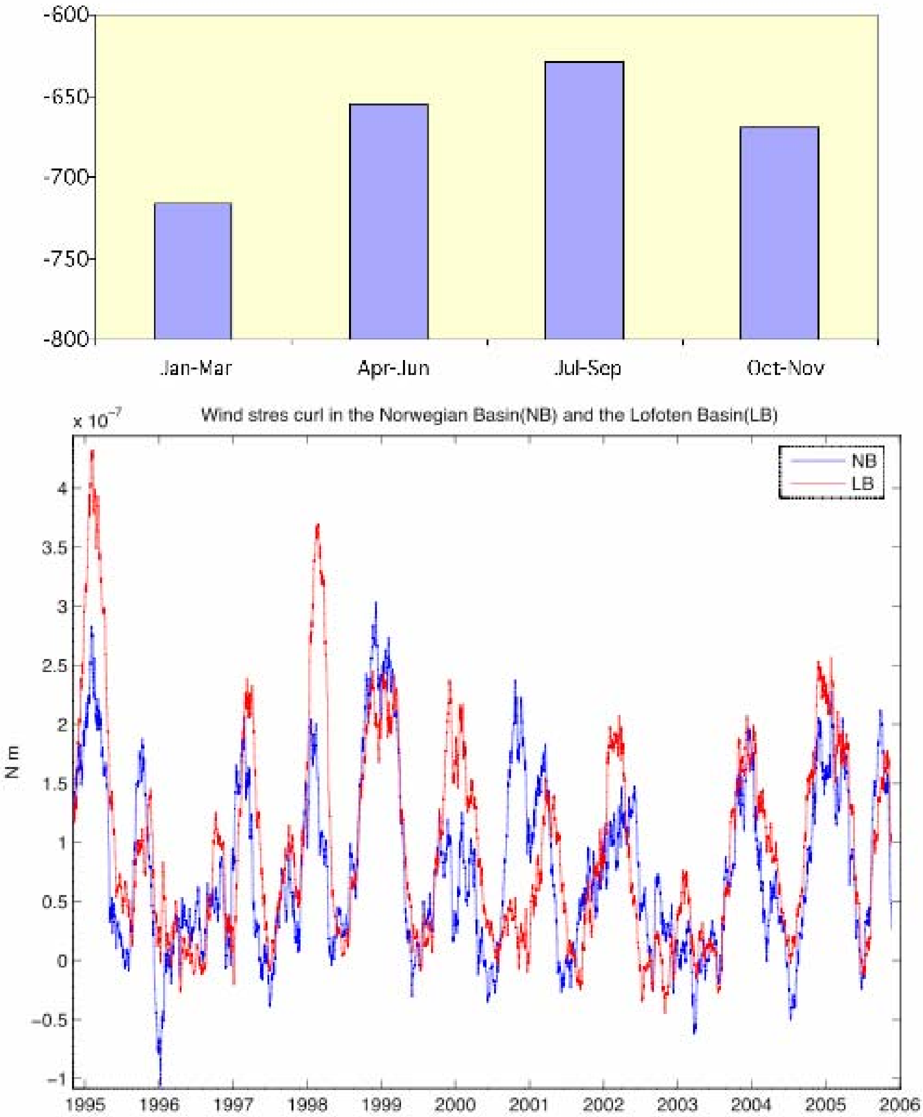

Figure 7. ***Top panel*: quarterly estimates of depth (of the 2.1e-7 surface) in the center of the Lofoten Basin: 69–71°N, 0–10°E; it clearly shoals between winter and summer and deepens thereafter. *Bottom panel*: windstress curl in the Lofoten and Norwegian Sea Basins; note the strong seasonal cycle.**

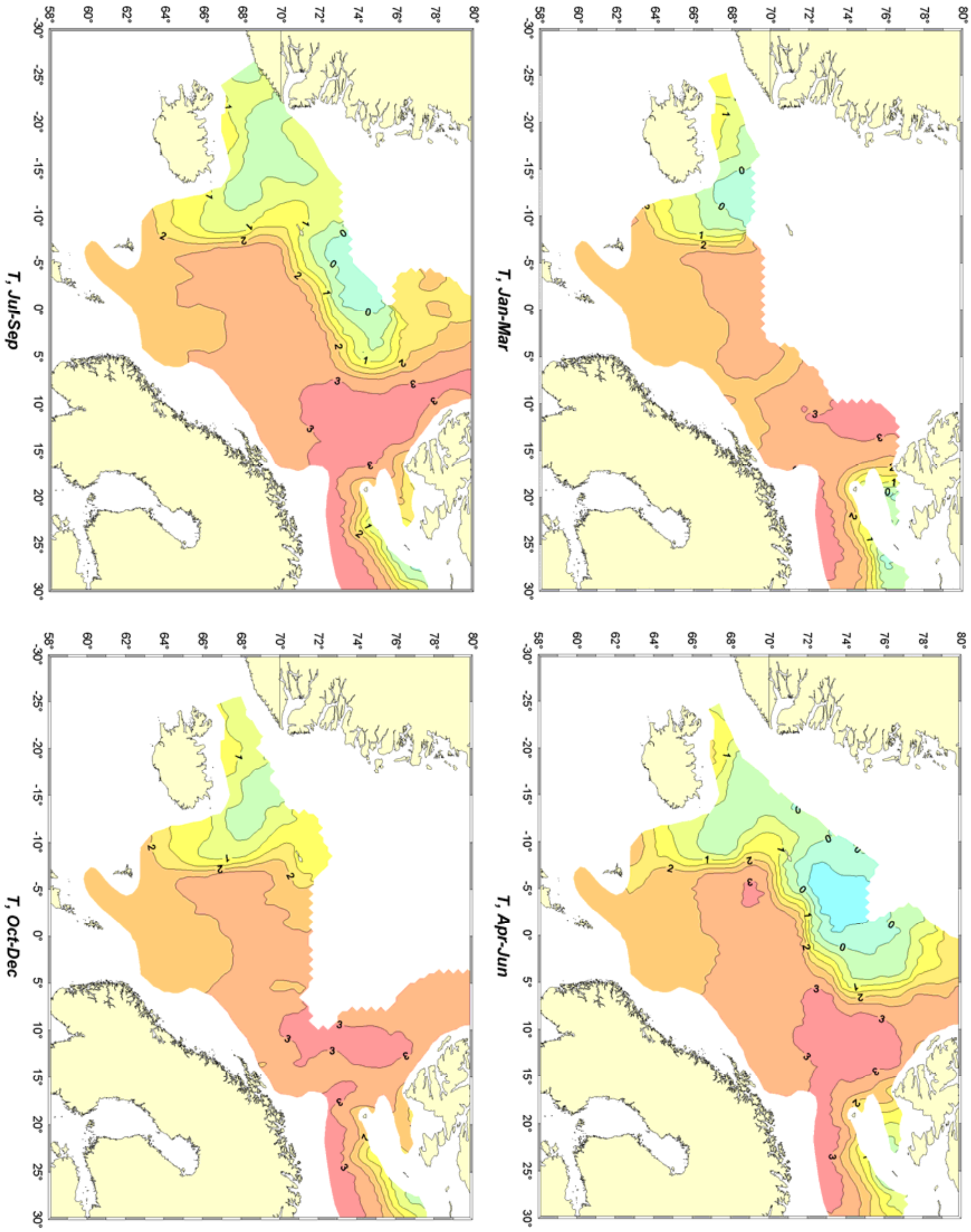

Figure 8. Quarterly fields of temperature on the 2.1e-7 surface. They are all quite similar with noticeable differences only along the wintertime edge of data availability, probably due to outcropping of the surface.

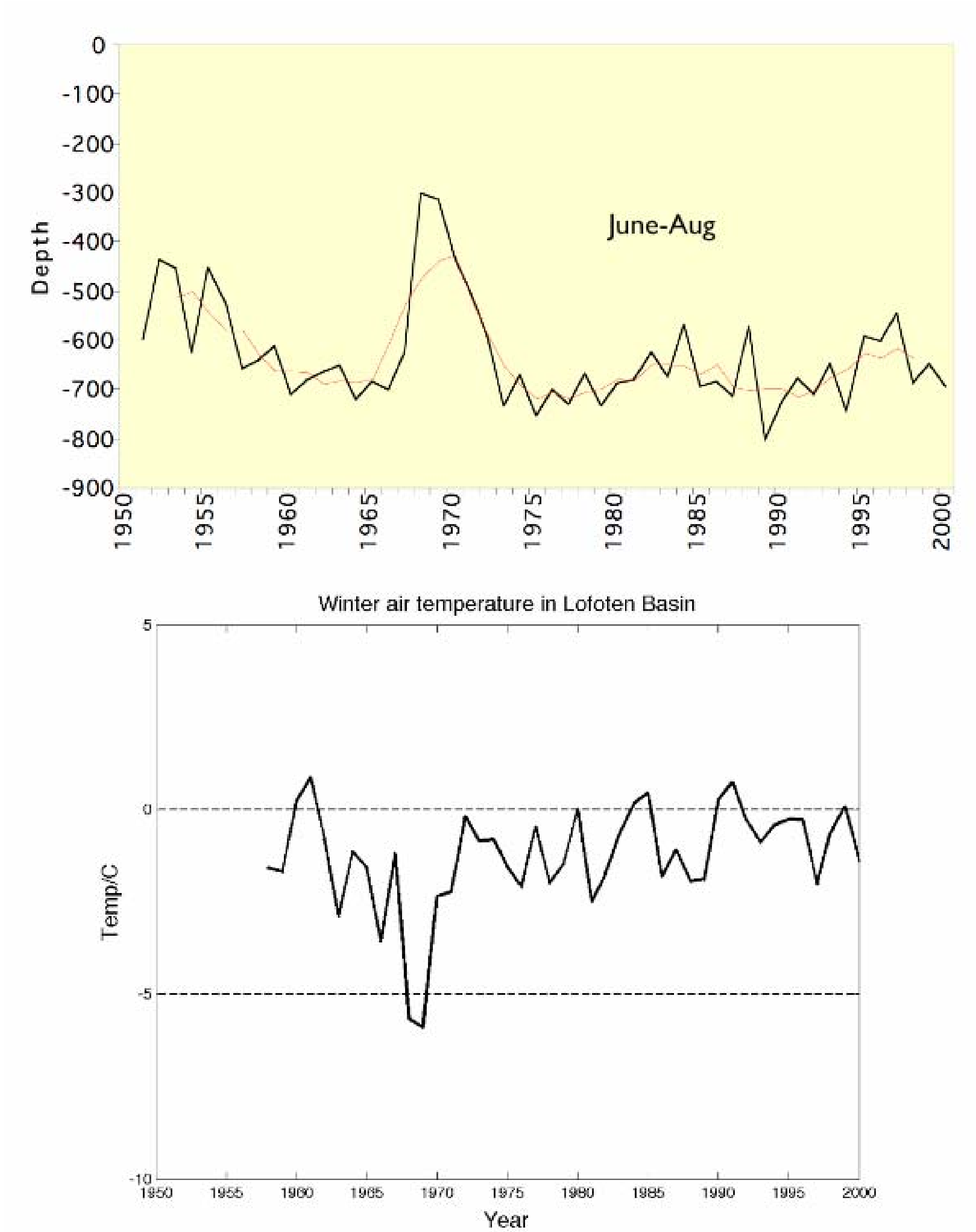

Figure 9. ***Top panel*****: depth of the delta surface as a function of year (black yearly; red 5-year running average).** ***Bottom panel*****: Dec-Jan-Feb air temperature at 2 m elevation in the Lofoten Basin.**

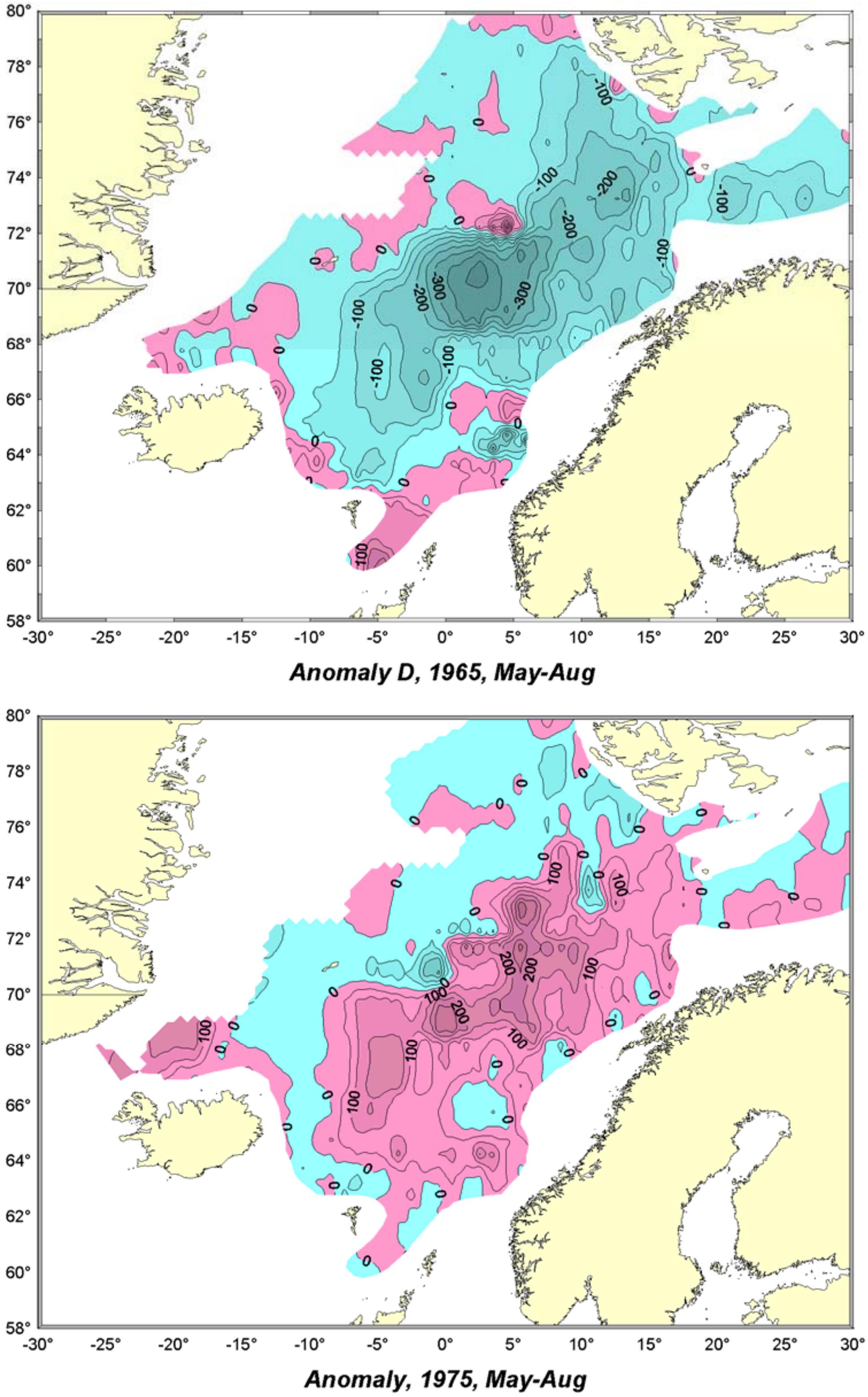

Figure 10. Depth anomaly for two extreme periods May-August 1969 and May-August 1975.

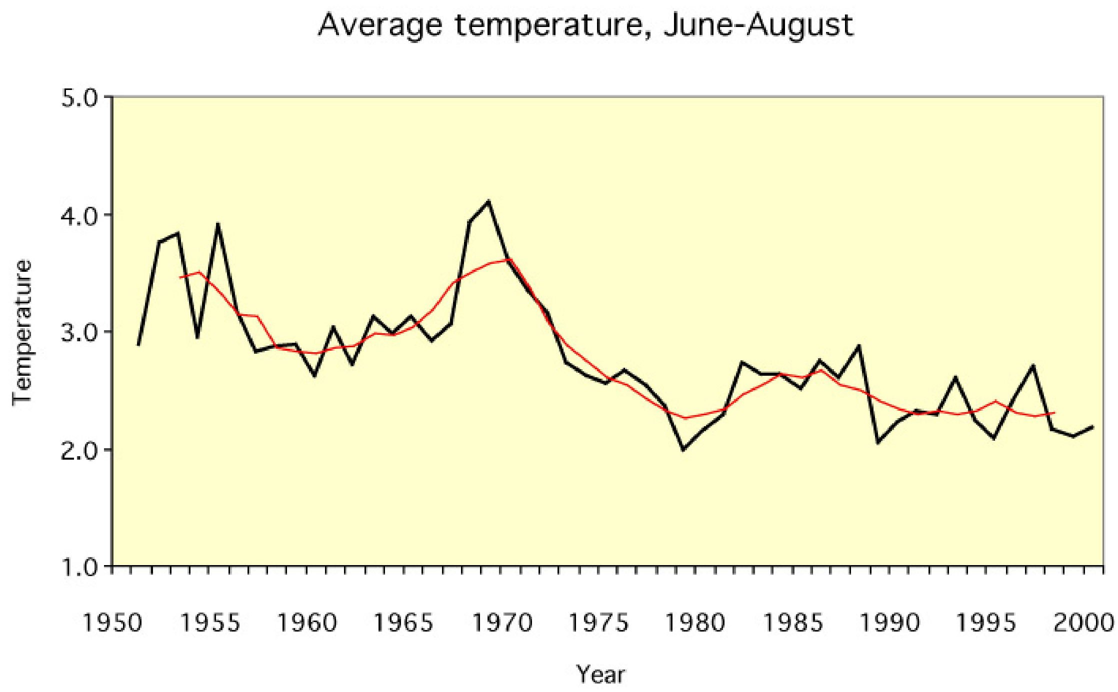

Figure 11. Temperature anomaly in the Lofoten Basin (69–71°N, 0–10°E) as a function of time.

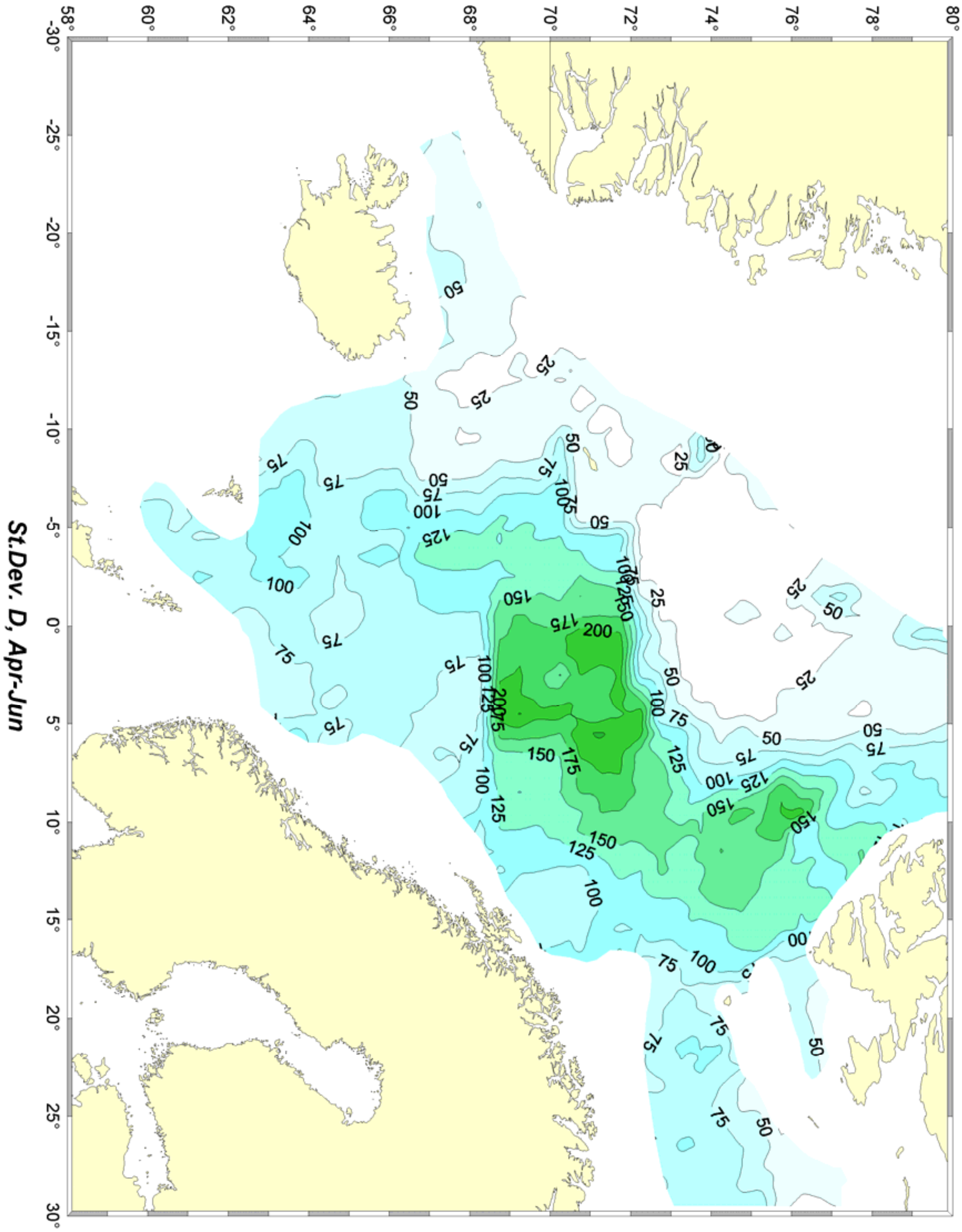

Figure 12. RMS depth variability of the delta surface for April-June – comparable in other seasons.

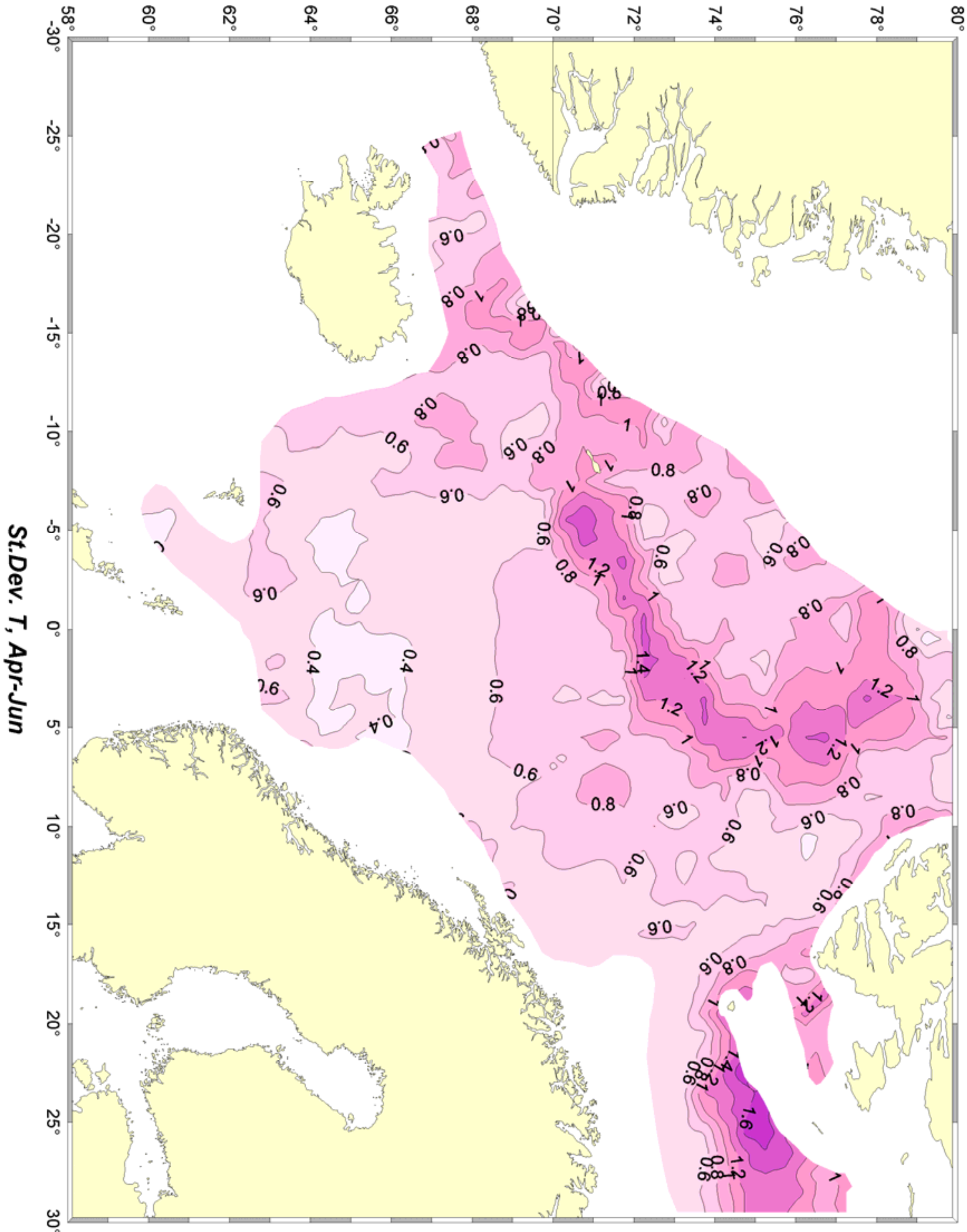

Figure 13. RMS temperature variability on the delta surface for April-June – comparable in other seasons.

Annex 6: Area 2b – Labrador Sea,

BY: Ross Hendry

The Labrador Sea is located between Greenland and the Labrador coast of eastern Canada. Cold, low salinity waters of polar origin circle the Labrador Sea in a counter-clockwise current system that includes both the north-flowing West Greenland Current on the eastern side and the south-flowing Labrador Current on the western side. Warm and saline waters from more southern latitudes flow northwards into the Labrador Sea on the Greenland side and become colder and fresher as they circulate.

Labrador Sea hydrographic conditions depend on a balance between heat lost to the atmosphere and heat gained from warm and saline Atlantic Waters. Severe winters under high NAO conditions lead to greater cooling: in exceptional cases, the resulting increases in the surface density can lead to convective mixing of the water column to depths up to 2 km. Milder winters under low NAO conditions lead to lower heat losses and an increased presence of the warm saline Atlantic Waters.

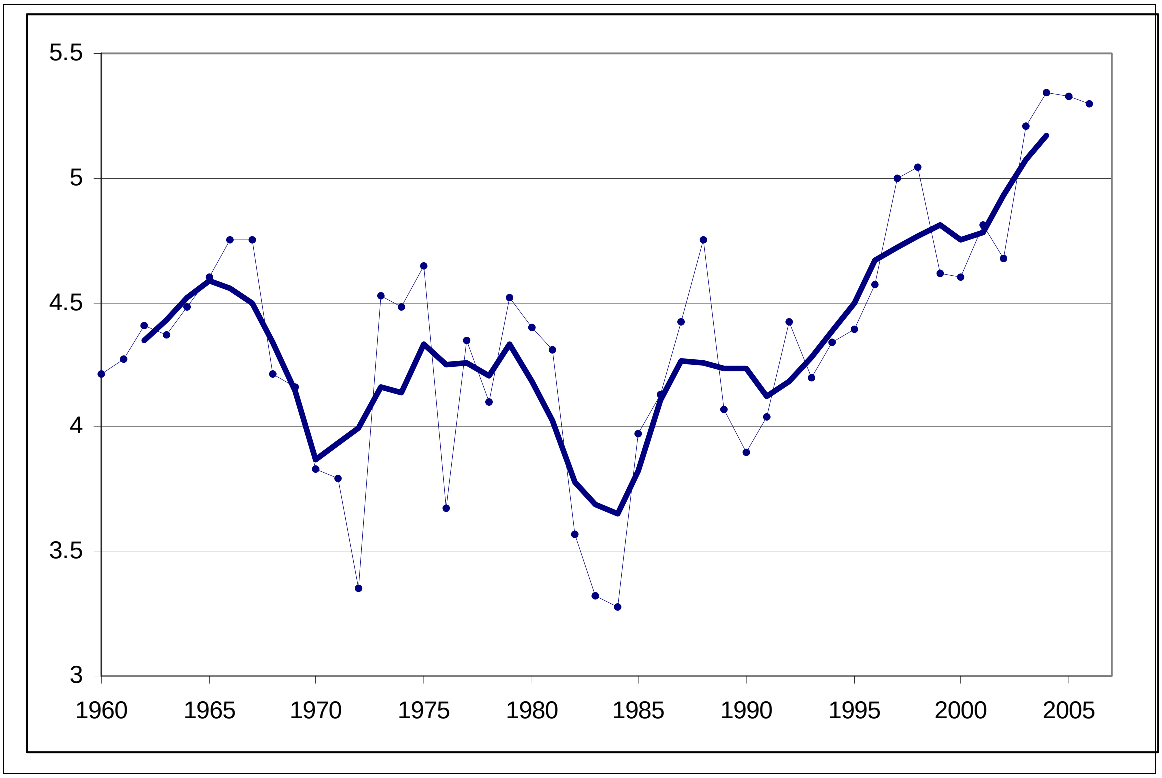

Figure 15. Area 2b – Labrador Sea. Annual mean Sea Surface Temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 Global Sea Surface Temperature data set, UK Meteorological Office, Hadley Centre.

A sequence of severe winters in the early 1990s led to the most recent period of deep convection that peaked in 1993–1994. Subsequent winters have generally been milder than normal, and the upper levels of the Labrador Sea have become warmer and more saline. The upper 150 m of the west-central Labrador Sea have warmed by more than 1°C and increased in salinity by more than 0.1 since the early 1990s. Conditions in 2006 were similarly warm and saline.

The 2006 annual mean sea surface temperature in the west-central Labrador Sea was warmer than normal for the 13th consecutive year. The last four years (2003–2006) have been exceptionally warm.

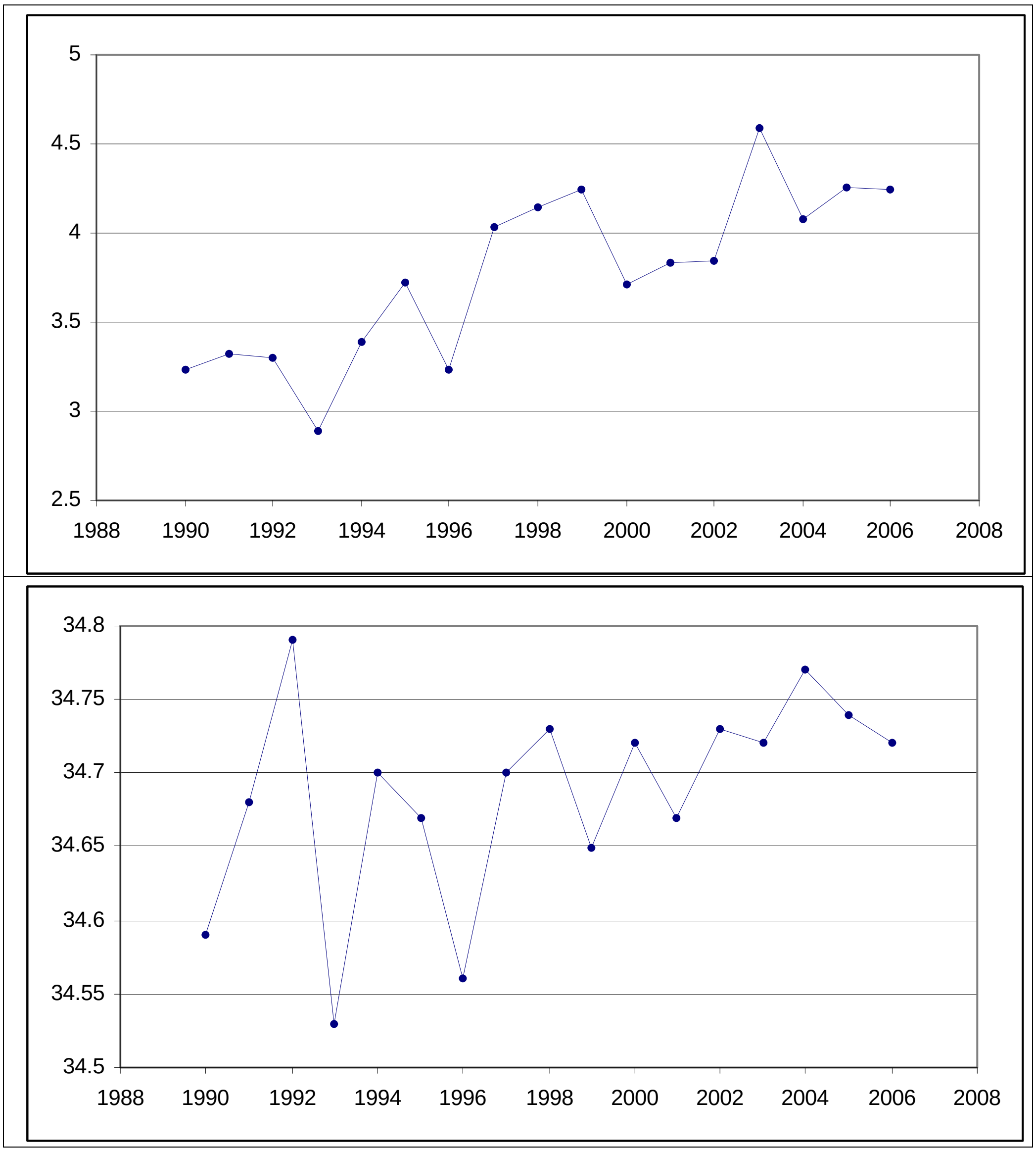

Figure 16. Area 2b – Labrador Sea. Spring/early summer potential temperature (upper panel) and salinity (lower panel) values for 0–150 m depth from four stations in the west-central Labrador Sea (centred at 56.7°N 52.5°W).

Annex 7: Area 3 – Icelandic waters

BY: Héðinn Valdimarsson, and Steingrímur Jónsson, 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.

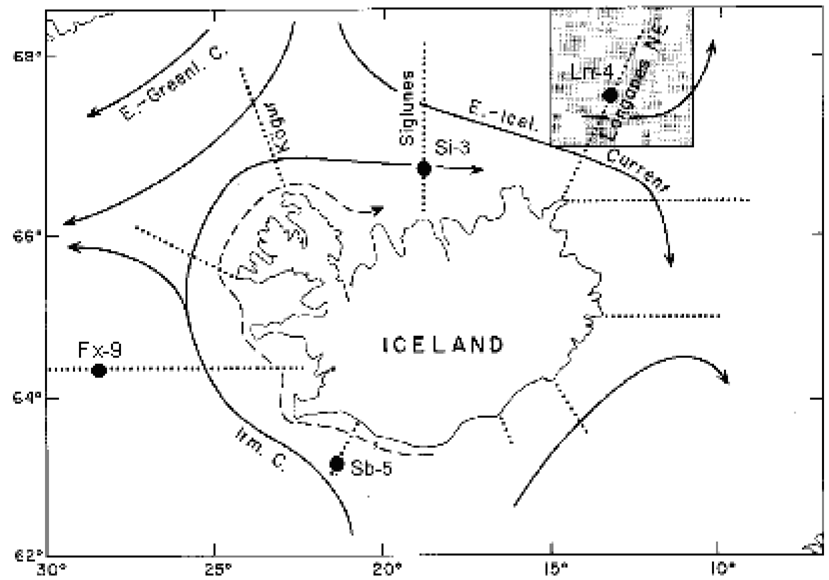

Figure 1. Main currents and location of standard hydro-biological sections in Icelandic waters. Selected areas and stations dealt with in this report are indicated.

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 2006 mean air temperature in the south (Reykjavik) and north (Akureyri) were above long time average (Figure 2a).

The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years (Figures 3.b, 5, and 7). The salinity in the East Icelandic Current in spring 2006 was about average but temperature was above long-term mean (Figures 3a, 6, and 7).

Extremely cold conditions in the northern area 1995, improving in 1996 and 1997, and continued to do so in 1998 and 1999 to 2001 mild but showed a slight decrease in 2002 (Figure 2b) and were then followed by the mild conditions for all seasons in 2003 and 2004. Slightly lower temperatures were seen in 2005. Spring of 2006 was having slightly warmer and more saline surface layers in north than 2005. In the area north of Iceland the latter half of the year surface layers were cooler and fresher and in autumn temperatures and salinities were among the lowest since 1998. This was linked to sea-ice in summer and autumn north- and northwest of Iceland. In February 2007 temperature and salinity were again above long time average in the northern area.

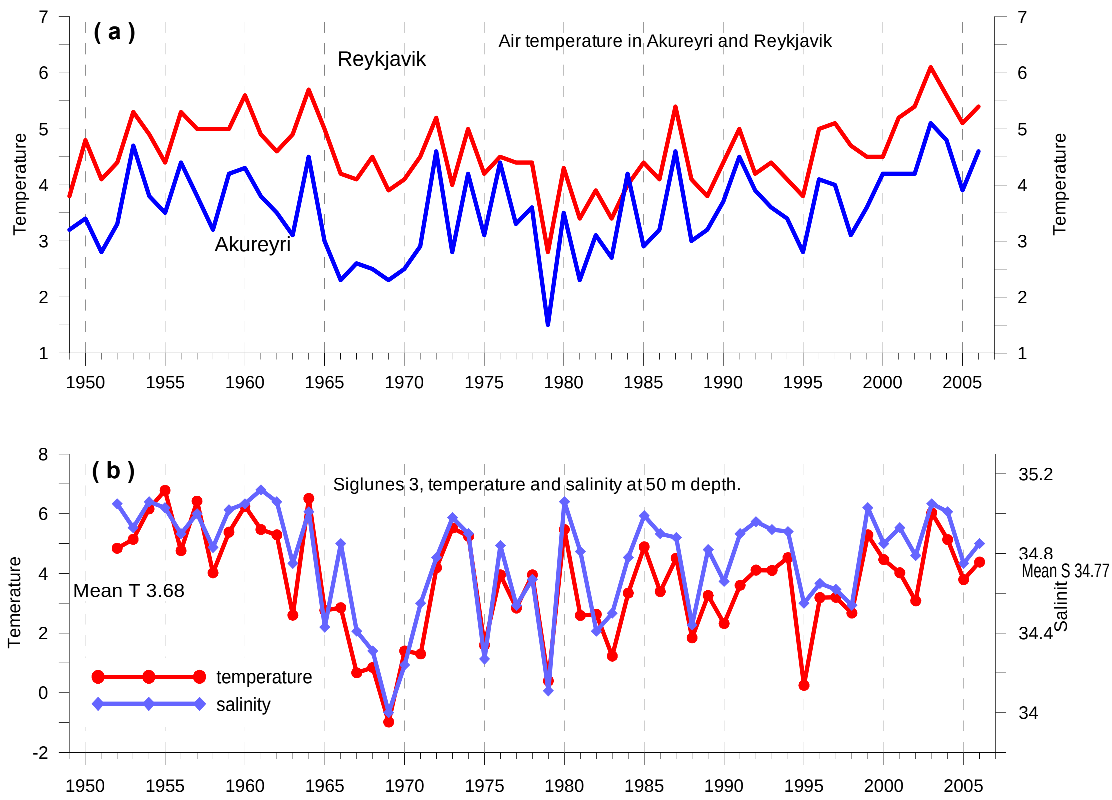

Figure 2. a. Mean annual air-temperatures in Reykjavík and Akureyri 1949–2006.

b. Temperature and salinity at 50 m depth in spring at Station Si-3 in North Icelandic waters 1952–2006.

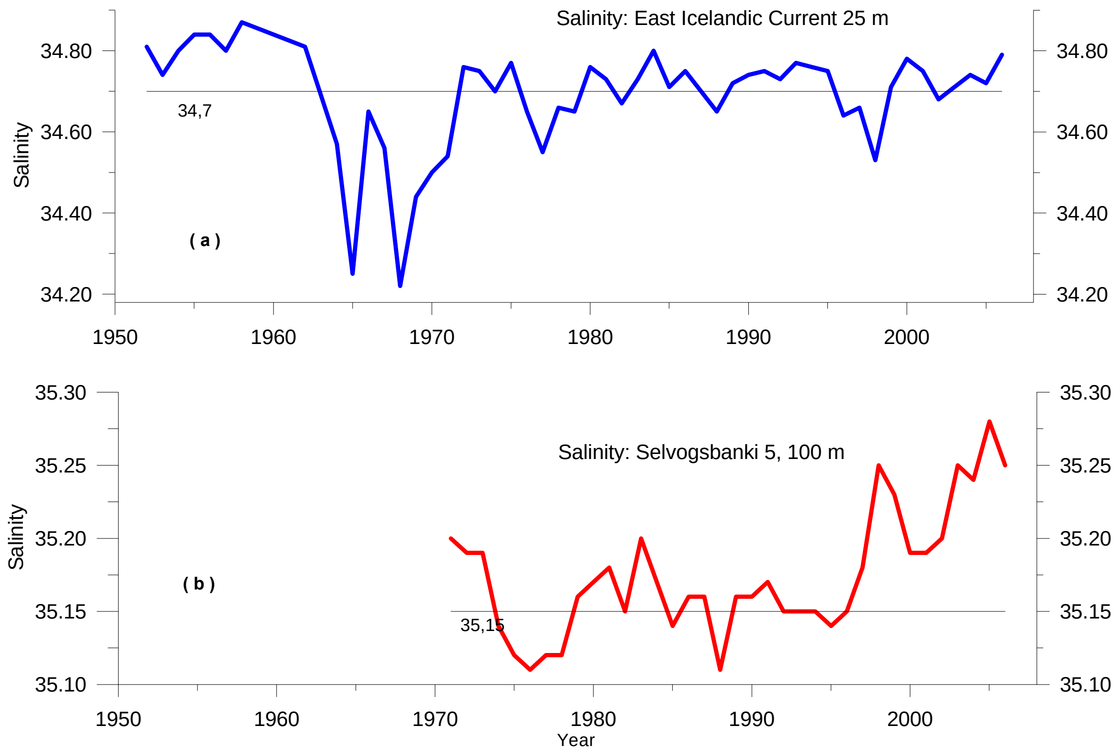

Figure 3. Salinity in spring at: a. 100 m depth in the Irminger Current south of Iceland (Sb-5) 1971–2006.

b. 25 m depth in the East Icelandic Current north-east of Iceland 1952–2006, mean from shaded area in Figure 1.

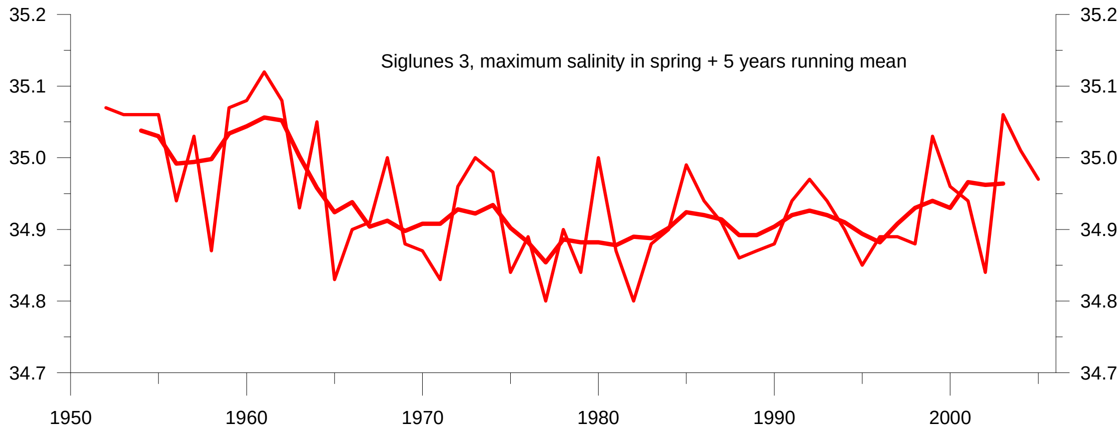

Figure 4. Maximum salinity in the upper 300 m in spring at station Si-3 in North Icelandic waters 1952–2006 and five years running mean.

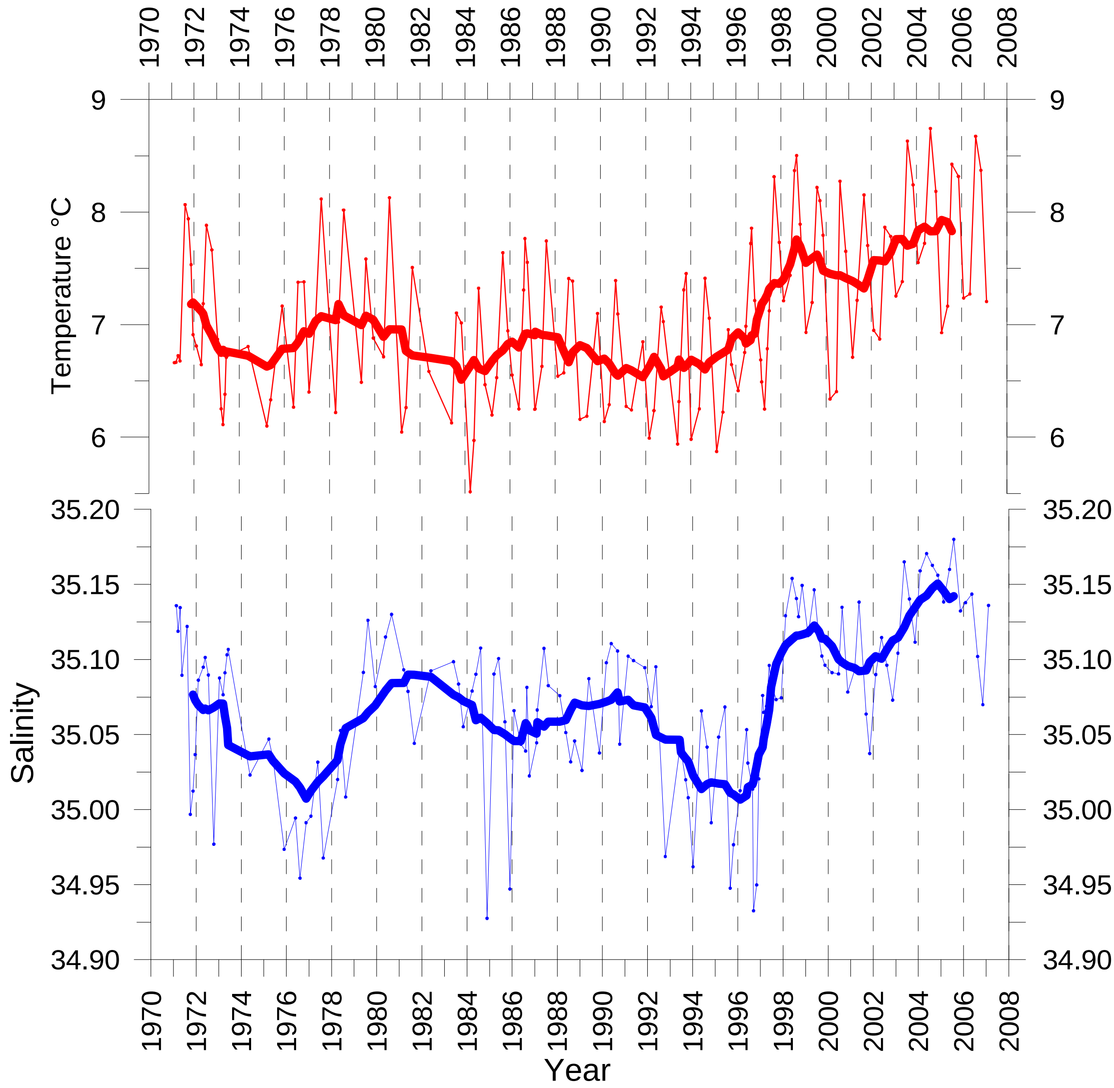

Figure 5. Mean temperature 0–200 m at the shelf brake west of Iceland, 1971–2007. Combined data from stations RE8 (1971–1984) and FX9 (1984–2007), 20 nm apart. Thick line is approx. 3 yrs running mean.

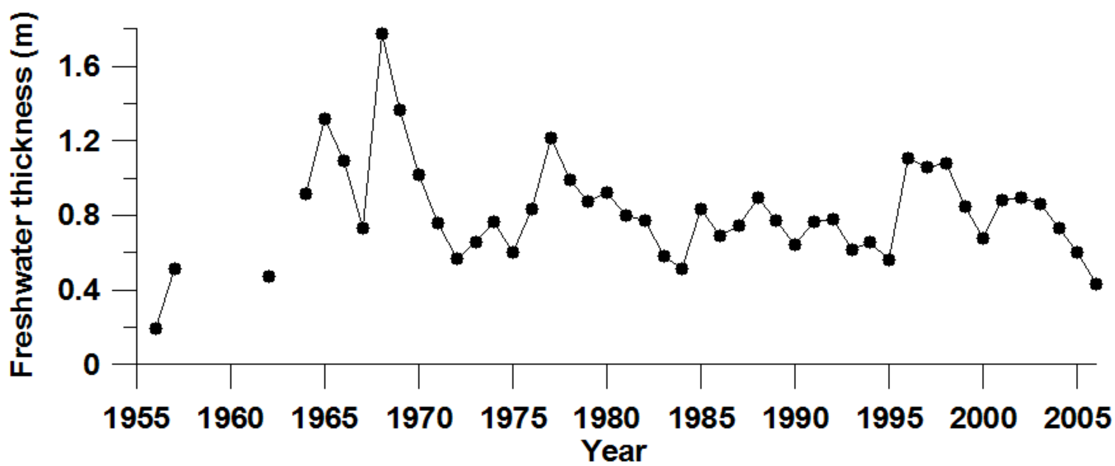

Figure 6. The fresh water thickness at Langanes NE 4 above 150 m, relative to salinity of 34.93 in May/June 1956–2006.

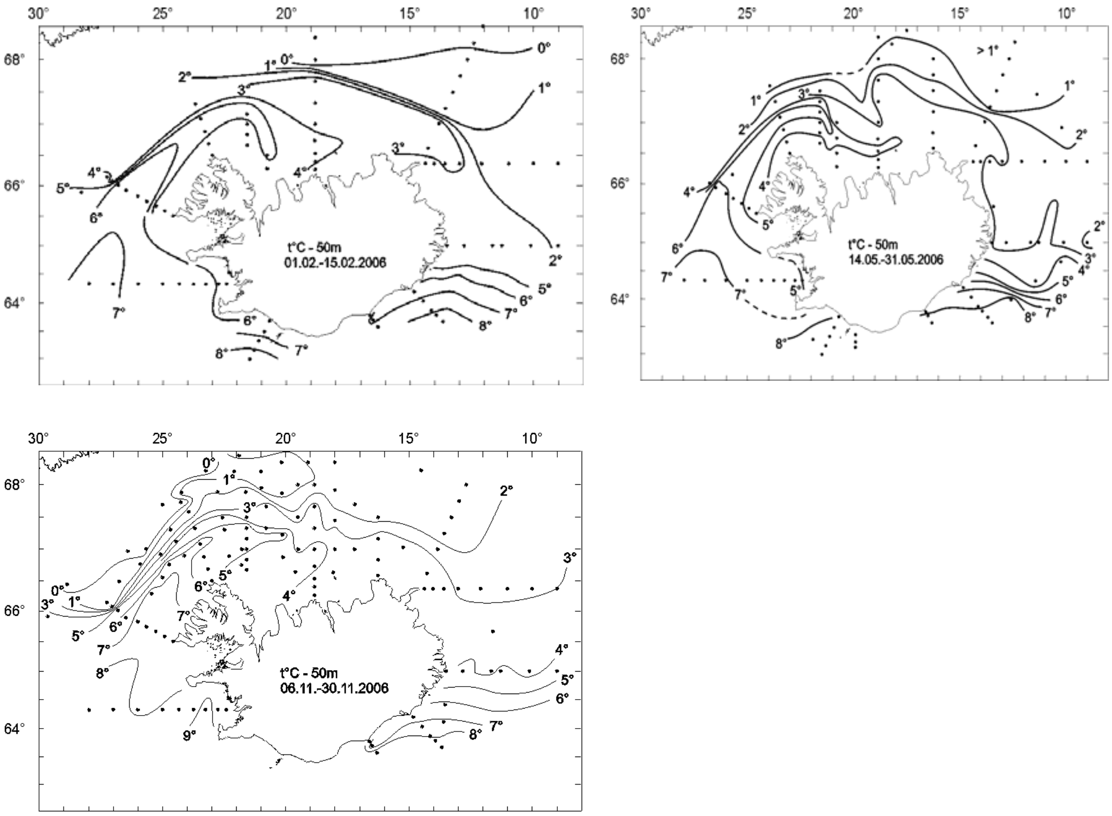

Figure 7. Temperature at 50 m depth in Icelandic waters in February, May and November 2006.

Annex 8: 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).

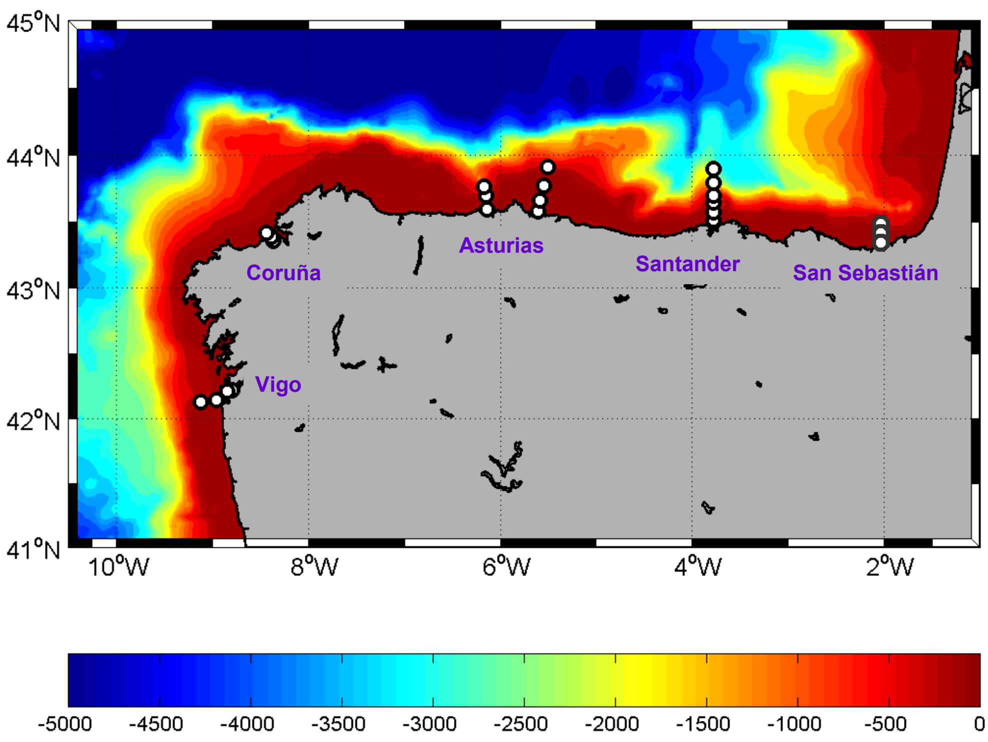


Figure 1. Spanish Standard Sections from the 'Instituto Español de Oceanografía' (Vigo, Coruña, Asturias, Santander) and from AZTI (San Sebastián).

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 $cm \cdot s^{-1}$). 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 2006 (source: Centro Meteorológico Zonal de Cantabria y Asturias and the Meteorological Observatory of Igeldo of the Instituto Nacional de Meteorología) indicate that, as a whole, it was a warm year resulting from a cold winter and positive temperature anomalies for the remainder seasons. The annual mean air temperature over the southern Bay of Biscay during 2006 has exceeded 15.5°C, more than 1ºC over the 1961–2005 average. Figure 2 shows the plot of the annual means and total average. 2006 has been the warmest year after 1988.

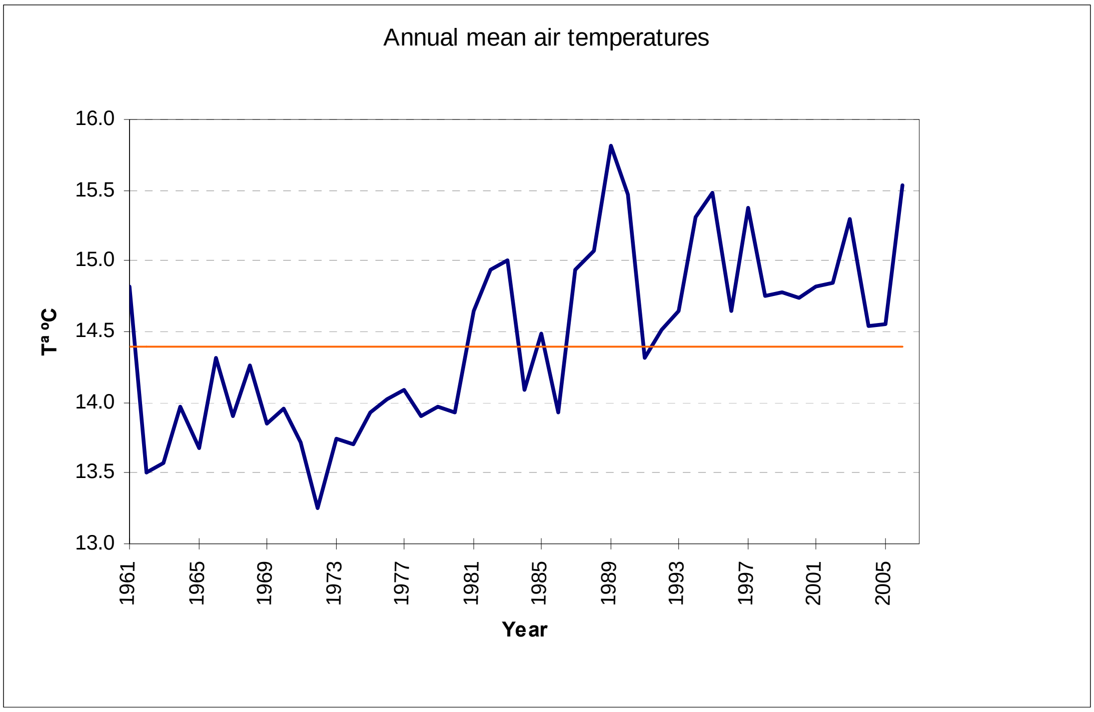


Figure 2. Annual mean temperatures in Santander (43.5ºN, 3.8ºW). Courtesy of the 'Instituto Nacional de Meteorología'.

In the annual cycle can be seen negative anomalies appearing in the winter (February), and positive anomalies for the rest of the year beginning in March and finishing in November. Especially important are the anomalies in February and July, 1.9ºC less than one standard deviation in the first case and 2.7ºC above two standard deviations in the second. The seasonal cycle amplitude was 13.6ºC from February (8.4ºC) to July (22ºC). This is a very large amplitude due to the cold February and hot July, greater than the maximum detected in 2003 with 13.2ºC of January (9.6) –August (22.8) and mainly due to the hot August 2003.

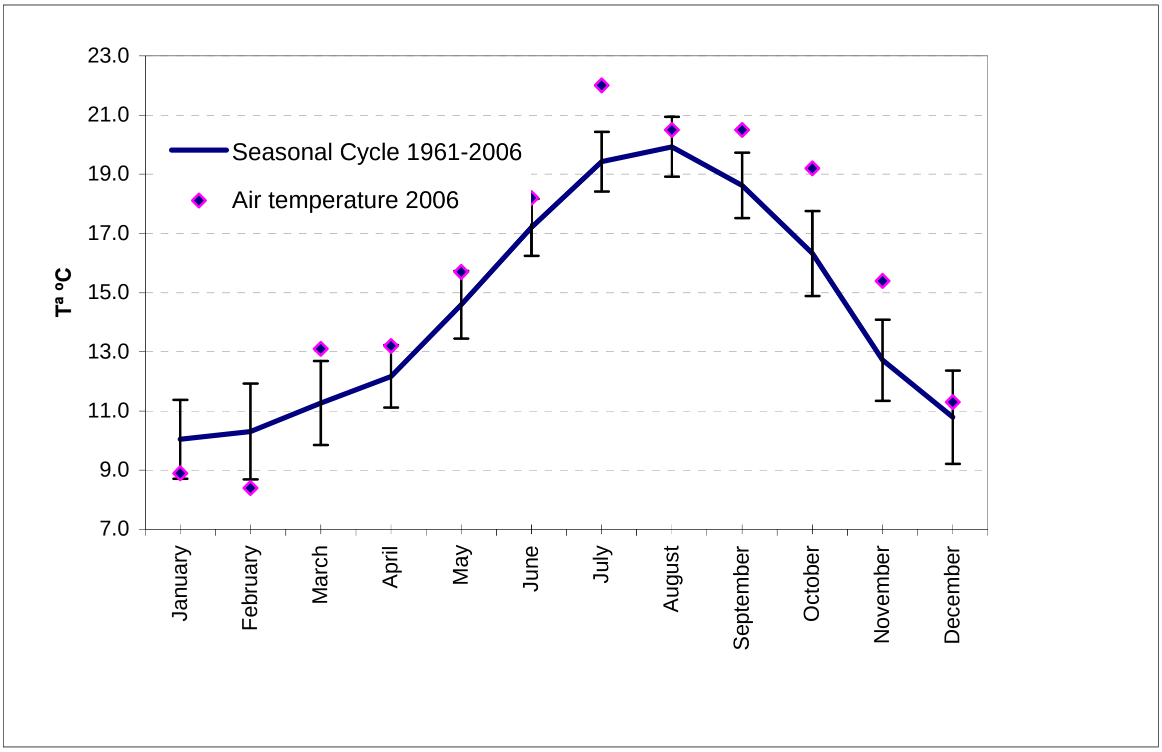


Figure 3a. Air temperatures in 2006 in Santander (43.5ºN, 3.8ºW) and mean value (1961–2005) and standard deviation. Courtesy of the 'Instituto Nacional de Meteorología'.

Meteorological conditions in the SE Bay of Biscay in 2006 (Observatorio Meteorológico de Igeldo, San Sebastián, Instituto Nacional de Meteorología) are characterized by a cold winter, with the exception of March (around the mean-standard deviation for 1986–2006), a warm spring and summer, excluding August (around the mean+standard deviation for 1986–2006) (Figure 3b), and a cold autumn, excluding December. The annual mean air temperature was 14.40ºC, 0.75ºC higher than the 1986–2006 average. This value is similar to those of 1989 (14.56ºC), 1997 (14.56ºC) and 2003 (14.48ºC).

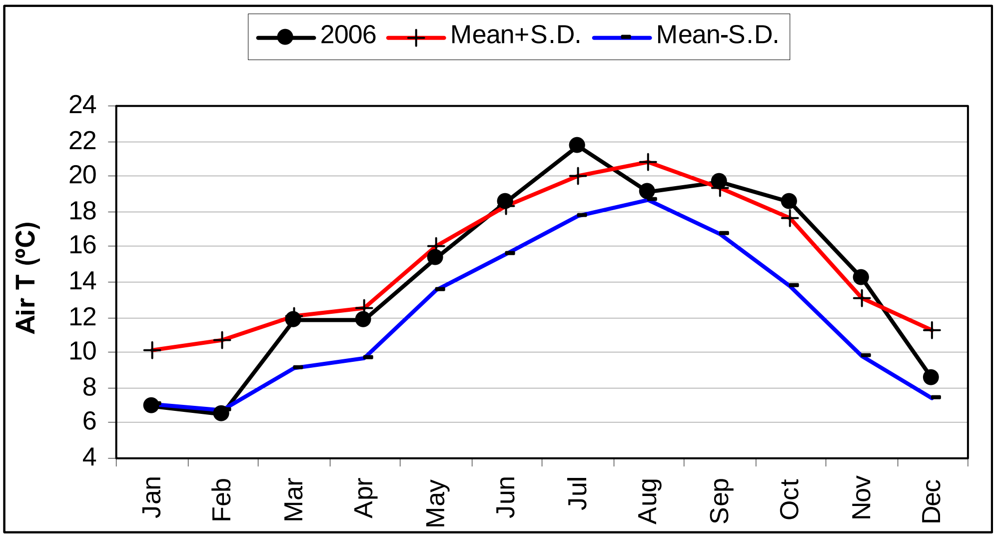


Figure 3b. Monthly mean air temperature (°C) in San Sebastián (43°18.5′N, 02°2.37′W) in 2006 compared with the mean ± standard deviation for the period 1986-2006. Courtesy of the 'Instituto Nacional de Meteorología'.

The peculiarities of the air temperature in 2006 can be observed in the context of the monthly mean temperatures of the period (1986–2006) and the evolution of the accumulated anomalies (Figure 4).

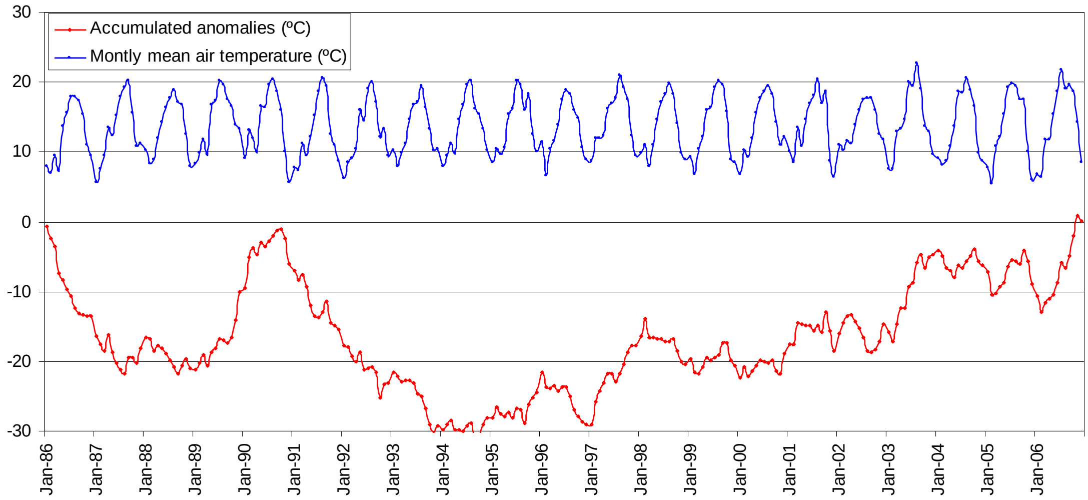


Figure 4. Monthly mean temperatures in San Sebastián (43°18.5′N, 02°2.37′W) in 1986–2006 and accumulated anomalies. Data Courtesy of the 'Instituto Nacional de Meteorología'.

Precipitation and evaporation

In San Sebastián, 2006 can be characterised for being a dry year, around the mean minus standard deviation for the period 1986–2006. Thus, only March and June were over the monthly mean; conversely, April and May were around the mean minus standard deviation for the period 1986–2006 (Figure 5).

With regard to water balance, the year 2006, within the context of the previous years, shows a decrease in the precipitation, in terms of accumulated anomalies (Figure 6). In addition, the precipitation minus evaporation balance shows that 2006 was characterised by dry weather, in terms of water balance (Figure 7).

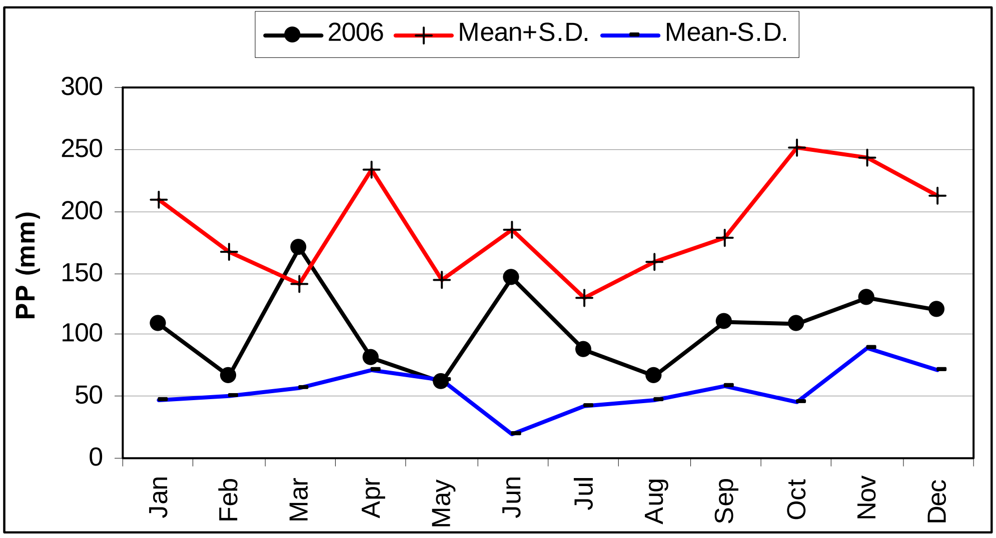


Figure 5. Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 2006 compared with the mean ± standard deviation for the period 1986–2006. Data Courtesy of the 'Instituto Nacional de Meteorología'

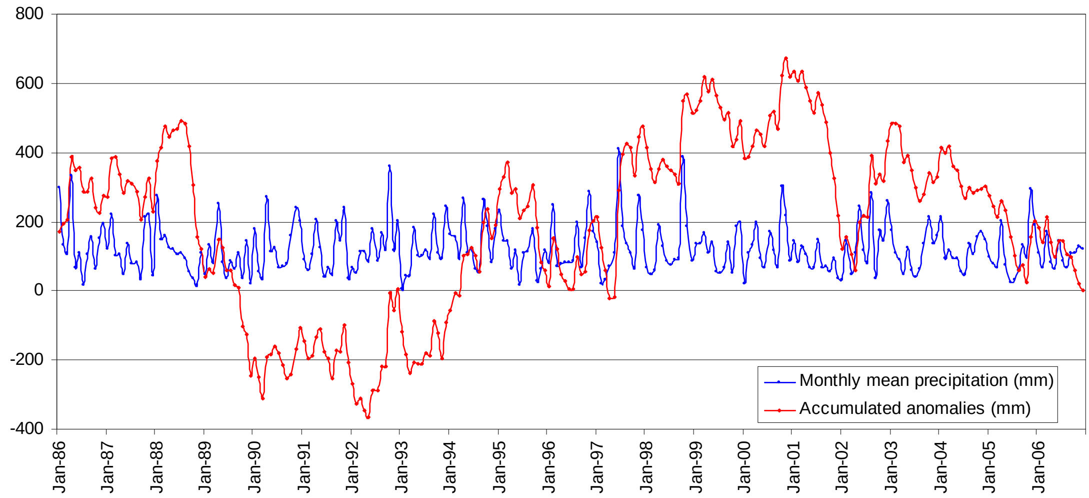


Figure 6. Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 1986–2006 and accumulated anomalies. Data Courtesy of the 'Instituto Nacional de Meteorología'.

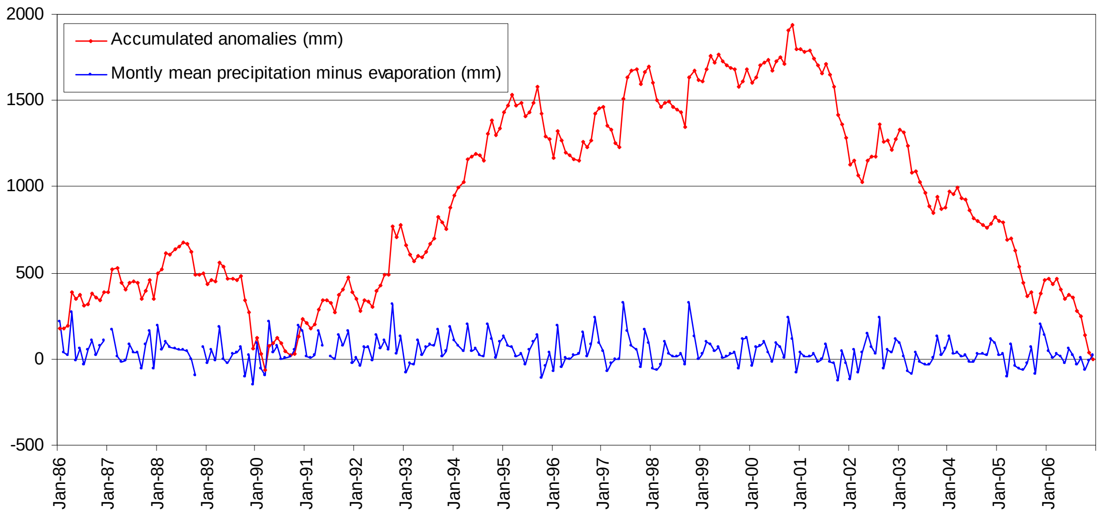


Figure 7. Monthly precipitation minus evaporation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 1986–2006 and accumulated anomalies. Data Courtesy of the 'Instituto Nacional de Meteorología'.

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. NS: not significant; *P=0.01; **P=0.005 ***P=0.001.

	FLOW WINTER	FLOW SPRING	FLOW SUMMER	FLOW AUTUMN
PP WINTER	0.75***			
PP-EV WINTER	0.72***			
PP SPRING		NS		
PP-EV SPRING		NS		
PP SUMMER			0.64**	
PP-EV SUMMER			0.59**	
PP AUTUMN				0.63**
PP-EV AUTUMN				0.67***

The Gironde River flow was low along 2006; the annual mean River flow was 679 $m^3 \cdot s^{-1}$, 166 $m^3 \cdot s^{-1}$ below the 1986–2006 average. Only March was over the monthly mean + the standard deviation for the period 1986–2006, in response to the increase of precipitations in March. September and October were around the monthly averages for the whole period. In this context, the Gironde River flow is in agreement with the precipitation in San Sebastián except for the local precipitation events during June (Figures 5 and 8).

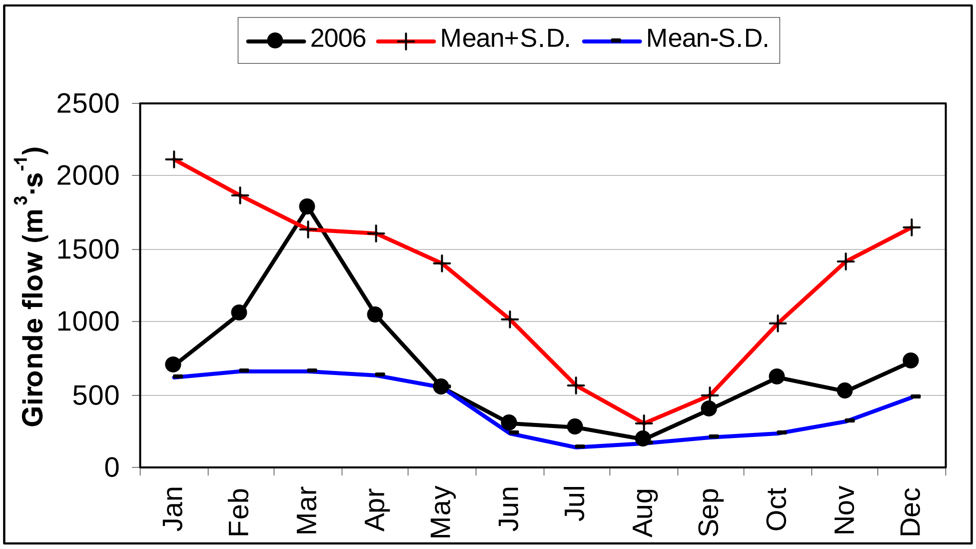


Figure 8. Monthly mean flow (m^3 s^{-1}) of the Gironde River in 2006 compared with the mean ± standard deviation for the period 1986–2006. Data Courtesy of the 'Bordeaux Harbour Authority'.

The peculiarities of the Gironde river flow in 2006 can be observed in the context of the monthly mean values of the reference period (1986–2006) and the evolution of the accumulated anomalies (Figure 9).

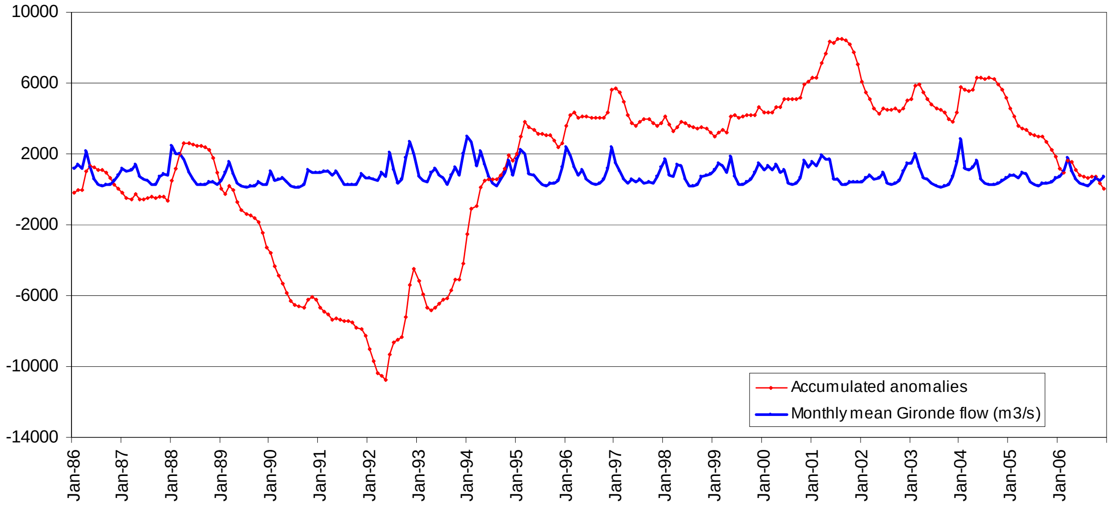


Figure 9. Monthly mean flow of the Gironde river ($m^3 \cdot s^{-1}$) in 1986–2006 period and accumulated anomalies. Data Courtesy of the 'Bordeaux Harbour Authority'.

Hydrography

Coastal and shelf waters

In order to obtain a first approximation of the hydrographic conditions in 2006, 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.

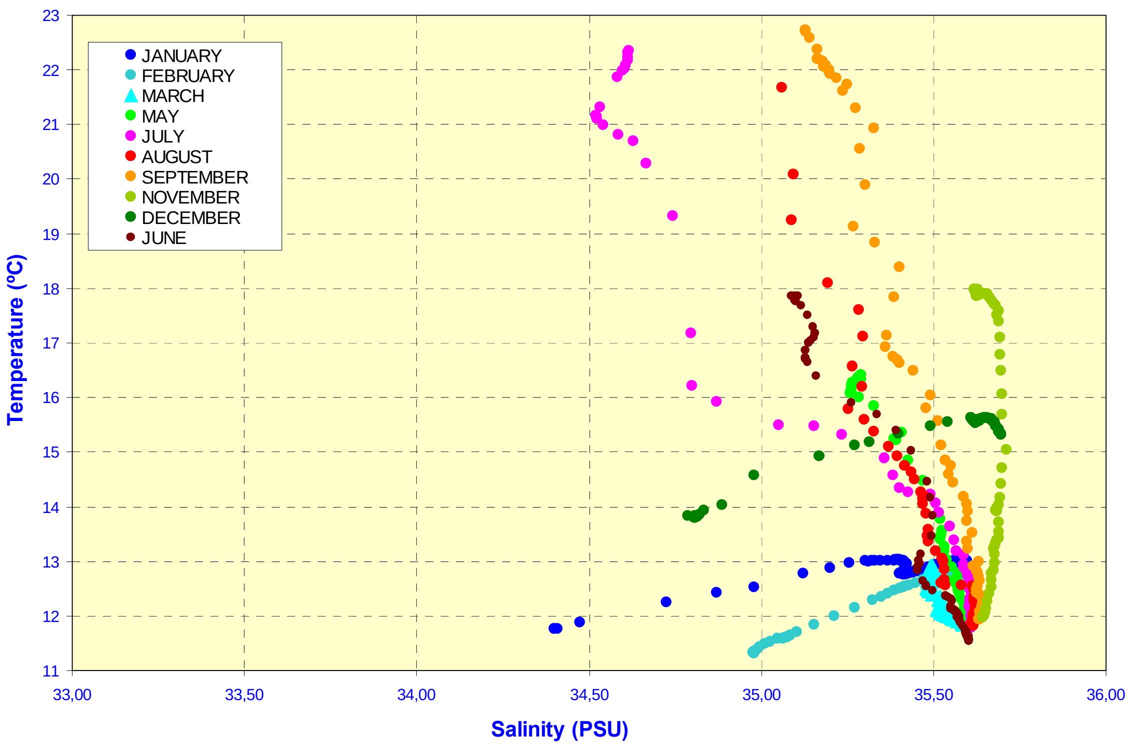


Figure 10. TS diagram of the waters over the continental shelf of the SE Bay of Biscay (43°30′N 02°00′W) in 2006.

The response of temperature and salinity of the upper layers to the meteorological factors described above is clearly observable in Figure 10. As a result of the low air temperatures in

January and February, thermal content of the water column was minimum in March. Moreover, despite relatively low precipitation and river runoff, the TS diagram is characterised by a thermal inversion in January and February; this is due to the presence of very cold water of continental origin. March is characterised by high precipitation, contributing to the development of haline stratification as well as to the beginning of the spring warming. Comparisons in deepest levels of the water column suggest a very homogeneous and deep winter mixed layer as result of a low modification of the mixed layer produced along the previous years.

Thermal stratification develops between May and September. Moreover, more or less extended haline stratification is present throughout almost all the year. 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. Nevertheless, a core of high salinity waters, corresponding to the upper ENACW remains all along the annual cycle.

Figure 11 shows the evolution of the monthly averaged sea surface temperature (SST) in 2006 (on the basis of a time-series obtained from the Aquarium of the Sociedad Oceanográfica de Gipuzkoa). In general, warm sea surface temperatures (above the mean plus standard deviation value) can be observed excluding wintertime period. The annual averaged SST in San Sebastián in 2006 (17.36°C) was higher than the 1986–2006 averaged temperature (16.14°C).

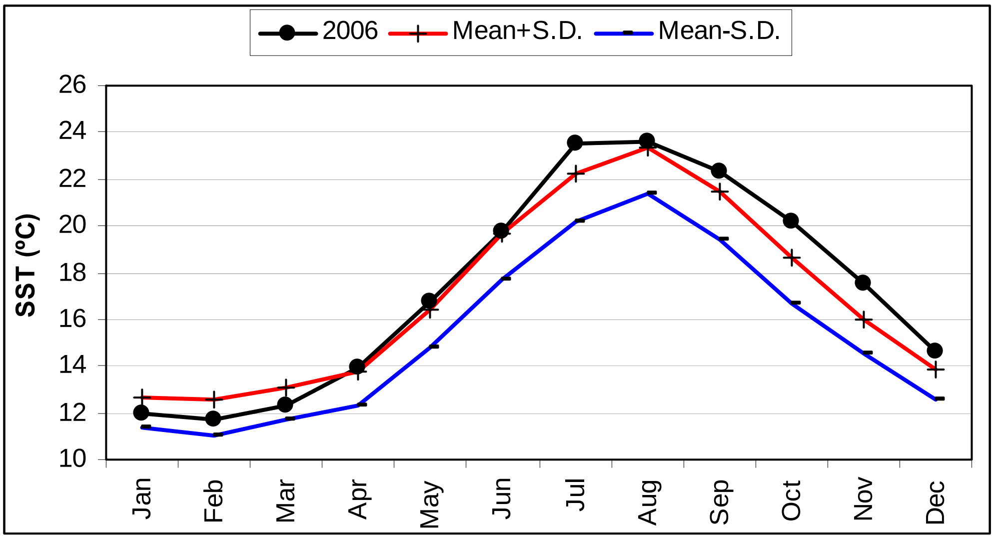


Figure 11. Monthly averaged sea surface temperature (°C) in San Sebastián (43°20′N 02°00′W) in 2006 in comparison with the mean ± standard deviation for the period 1986–2006 period. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.

The peculiarities of the SST in 2006 can be observed within the context of the monthly mean temperatures of the reference period (1986–2006) and the evolution of the accumulated anomalies (Figure 12).

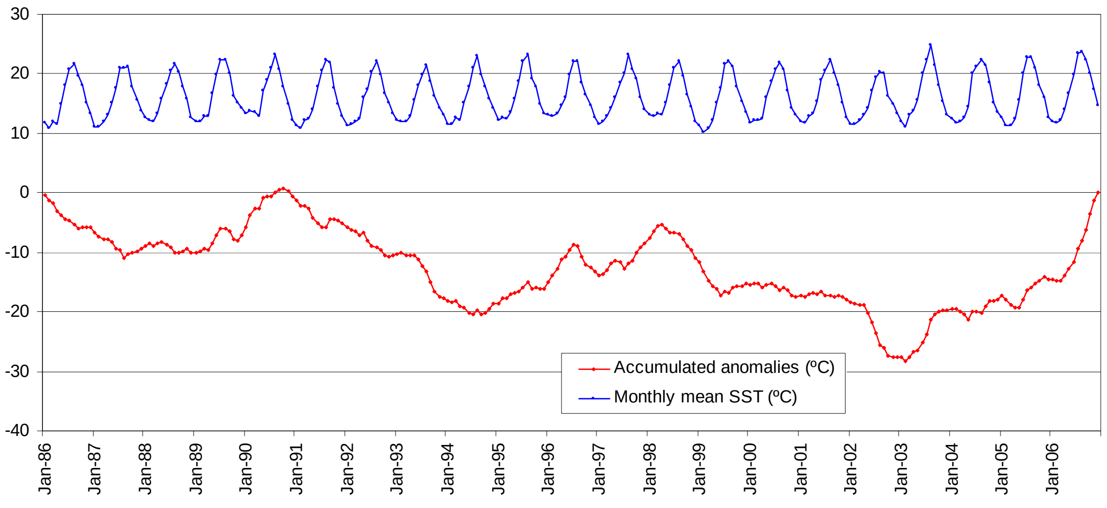


Figure 12. Monthly averaged SST (°C) in San Sebastián (43°20′N 02°00′W) during the 1986–2006 period, together with accumulated anomalies. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.

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.

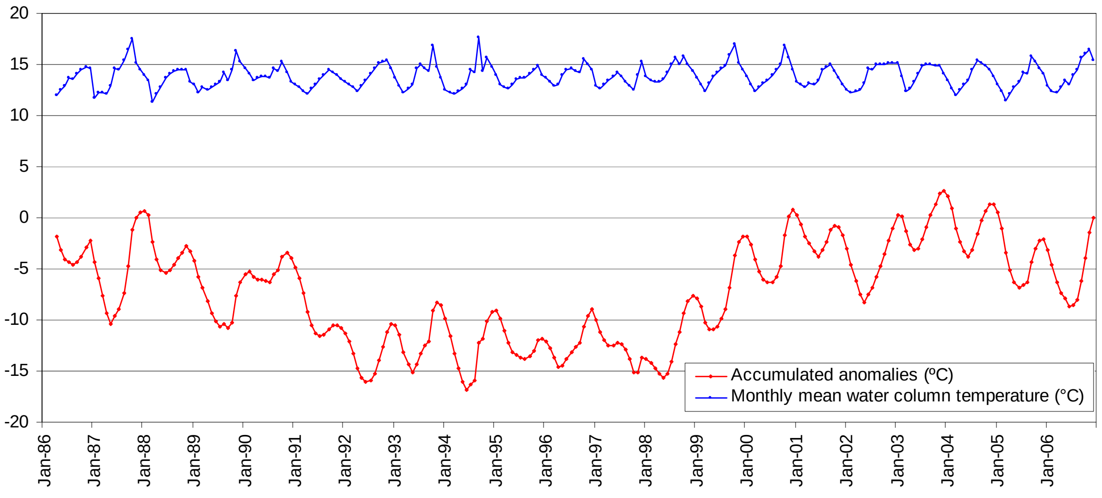


Figure 13. Monthly averaged water column temperature (°C) in San Sebastián (43°30′N 02°00′W) in the period 1986–2006, together with accumulated anomalies.

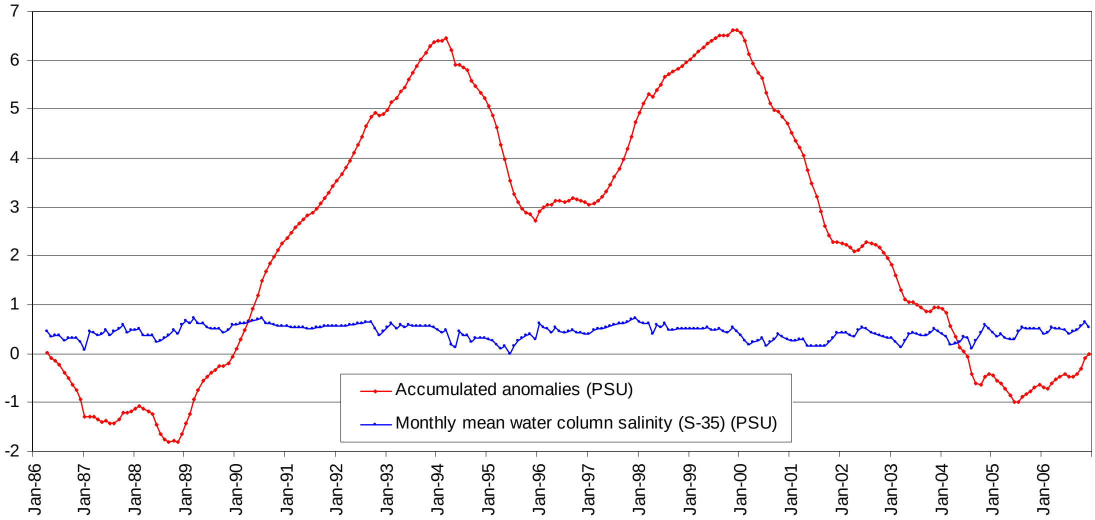


Figure 14. Monthly averaged corrected salinity (S-35) in 100 m water column in San Sebastián (43°30′N 02°00′W) in the period 1986–2006, together with accumulated anomalies.

Aspects related to the hydro-meteorological conditions during 2006, over the SE Bay of Biscay, are listed in Table 2. In spite of the very low air temperatures in December 2005 and January-February 2006, the SST in winter 2006 remains around the mean SST for the period 1986–2006 (Figure 11) due to the vertical mixing, with relatively warm sub-surface waters produced along summer and autumn of the previous year. This pattern changed from February to March-April, as a result of the sharp increase of the air temperature (Figure 3b) that compensates the precipitations and freshwater inputs (Figures 5 and 8). After the increase in air temperature in March and April, the warming of the sea surface and the water column began to be evident in May. For the summer season, haline stratification was perceptible in July but decreases progressively until December as result of the low precipitations and land runoff along the second half of the year. December is characterised by a thermal inversion, related to the conjunction of cooling and freshwater inputs.

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 31 m and, from June to September, this layer was placed at around 50 m. The intense fluctuations of the 14°C isotherm depth throughout the summer season, as well as the sequence of the TS values at 50 m water depth and within the bottom layers, indicates a relatively low dominance of downwelling processes until October. In December, unusually, with a strong thermal inversion, the 14°C isotherm represents more the cold than the warm surface waters (Table 2, Figure 10).

Table 2. Hydro-meteorological data in the shelf waters of San Sebastián (43°30′N 02°00′W) in 2006. Mean temperature and salinity calculated for 100 m water column.

2006	Air T (°C)	PP (mm)	Gironde flow ($m^3 s^{-1}$)	SST (°C)	SSS (PSU)	Mean temper-ature (°C)	Mean salinity (PSU)	Bottom temp. (°C)	Bottom salinity (PSU)	14 °C isotherm depth (m)
January	6.9	108	706	12.0	34.400	12.88	35.397	13.01	35.597	T<14
February	6.5	66	1055	11.7	34.978	12.35	35.414	12.54	35.598	T<14
March	11.8	170	1783	12.3	35.496	12.20	35.540	11.88	35.590	T<14
April	11.8	80	1043	13.9		12.78	35.519			
May	15.4	62	555	16.7	35.290	13.37	35.498	11.935	35.593	31
June	18.6	146	308	19.8	35.106	13.06	35.483	11.55	35.602	23
July	21.7	87	268	23.5	34.618	13.95	35.399	11.78	35.608	29
August	19.1	66	191	23.6	34.900	14.50	35.451	11.82	35.617	34
September	19.7	110	402	22.4	35.128	15.65	35.480	11.93	35.632	47
October	18.6	109	620	20.2		16.03	35.564			
November	14.2	130	524	17.5	35.619	16.41	35.648	11.973	35.641	75
December	8.5	120	721	14.6	34.787	15.34	35.529	15.315	35.695	11

In similar way, contours of temperature and salinity (over the shelf, 100 m depth) in the Santander section are shown in Figures 15a and 15b. 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. In 2006 it is recovered the summer warming intensity in the upper waters that was lost in 2005. The increase in temperature reaches deeper waters again, similar to the depths observed in previous years to 2005, around 25m. Salinity contours show high salinity at the beginning of the winter due to the poleward current and in spring and autumn due to seasonal upwelling events. In summer low salinity appeared in the upper layers due to the advection from the east of warm surface water from river discharges in the corner of the Bay of Biscay. The tendency observed in the last years since 2001 continues in 2006 and the advection and river discharges are low and decrease respect to the years before. In this station, close to shore, it is probably related with a decrease in the discharge of the Cantabrian Mountains rivers whereas in the station 6 (Figure 16a and b) it can be more related with the decrease in the advection of waters from the east.

Upwelling events detected by low SST in satellite measurements (www.teledeteccionoceanografica-ieo.net/afloramientos) indicated that during 2006 only an upwelling event occurred in June (from 1 to 6) with SST as low as 13ºC (Figure 17) reached the Santander Section. During July and August no low temperature upwelling indications. This reduction of upwelling episodes occurred after some ones in 2005 that reach Santander and some previous years without any as happened during 2003, that upwelling low SST signal never reach Santander and during 2004 when in August the signal reached 40 miles west of Santander.

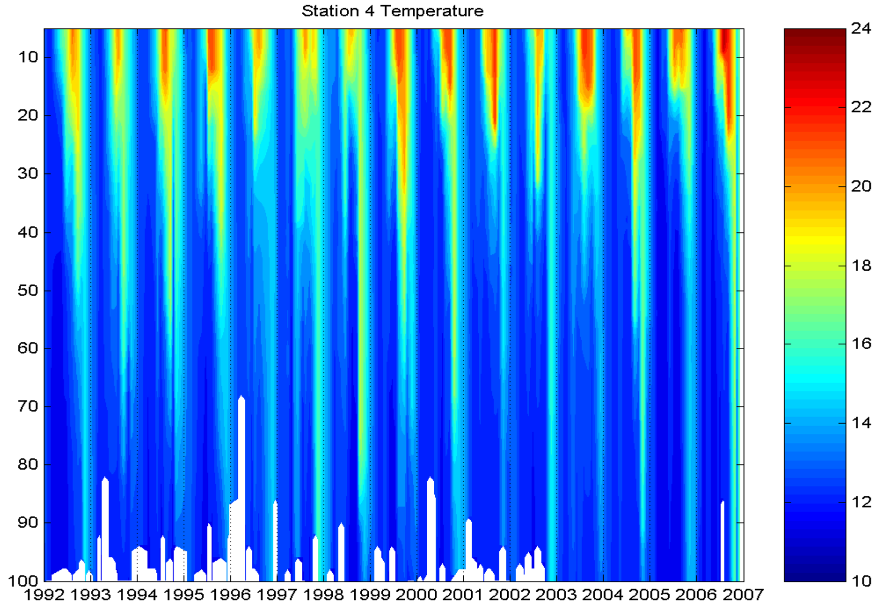


Figure 15a. Temperature evolution at Santander station 4 (shelf).

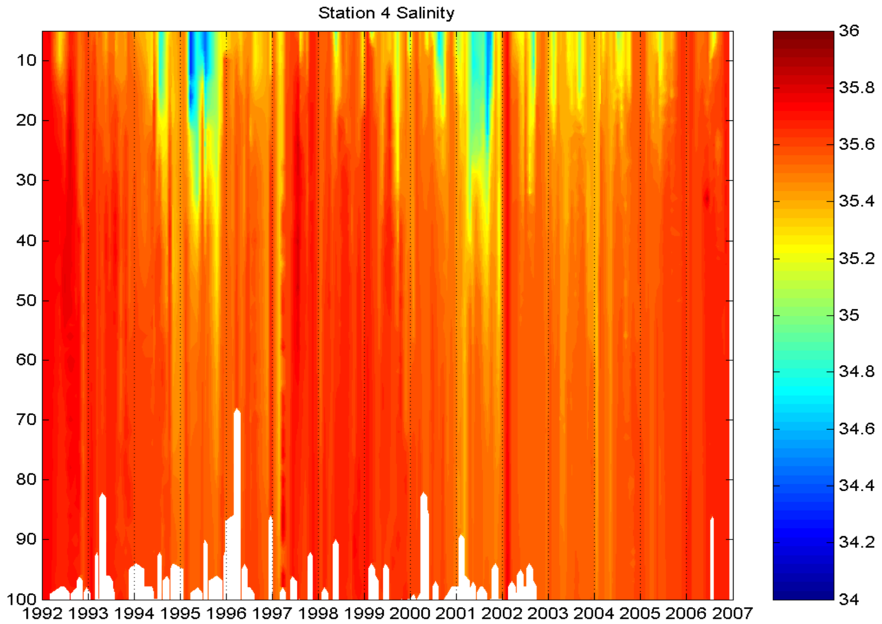


Figure 15b. Salinity evolution at Santander station 4 (shelf)

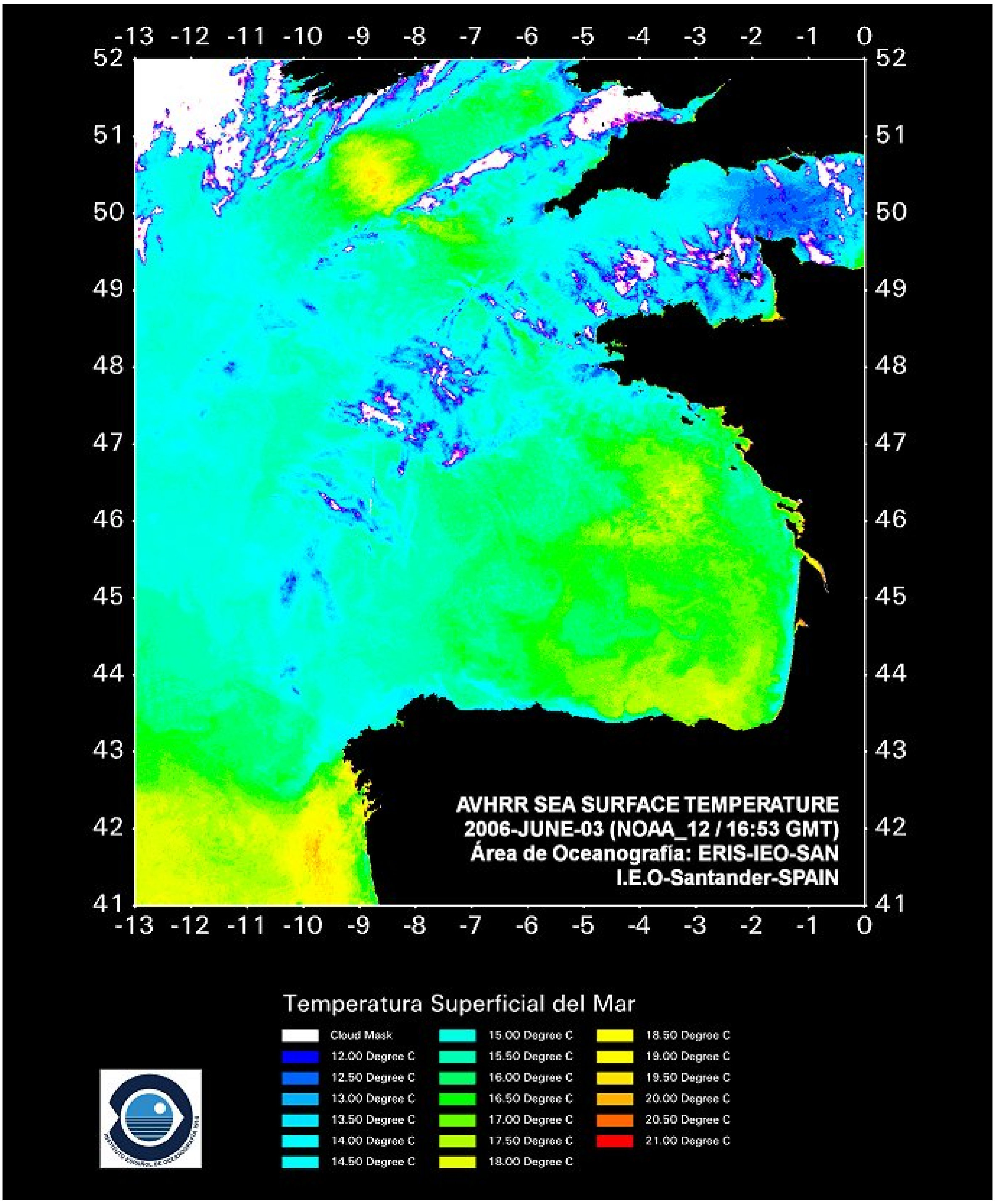


Figure 16. Sea Surface Temperature of the Eastern North Atlantic on June 3. Upwelling condition is showed by low temperature around the N/NW of the Iberian Peninsula, reaching 3º 47'W, position of the Santander Standard Section.

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 and fluorescence over the shelf in the Vigo section from 1994 to 2006 are presented in Figure 17. In summer cold waters were present at depth due to upwelling, while warm waters were at the surface in summer due to insolation. In autumn-winter there is a coastal poleward surface current that transports warm water. Salinity contours still continue show above normal values due to Eastern Atlantic general trend to salinity increase and also to the drought year until September.

The year 2006 with respect of the water thermohaline seasonal characteristics may be classified as normal. Regarding the fluorescence, related to chlorophyll, 2006 are the most productive since 1994 that also are noted in the zooplankton biomass.

At local scale, seems that the coastal processes: variability of the poleward current strength in winter and the upwelling in summer; in the west of Iberian peninsula have more influence that the general warming trend observed in some places of the eastern Atlantic.

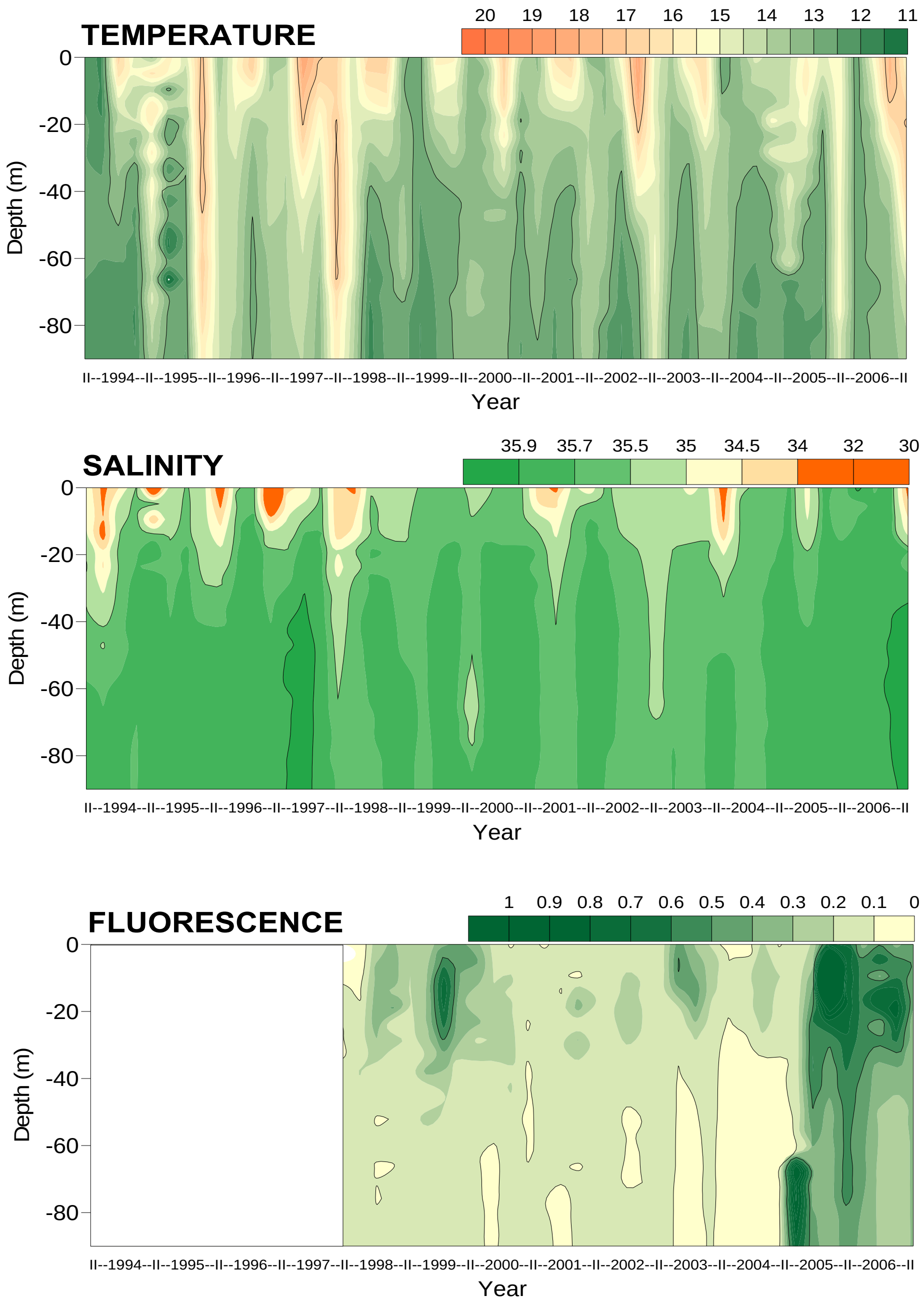


Figure 17a, b and c). Seawater evolution at Vigo (42.1ºN, 9.0ºW) station of Temperature, salinity and fluorescence.

Offshore and Slope waters

Contours of temperature and salinity over the shelf-break (600 m depth) in the Santander section are presented in Figure 18a and b. During the first period (1992–1994) only upper layers were sampled. 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) has been reduced in a greater extent from 2002 and practically disappearing in 2006.

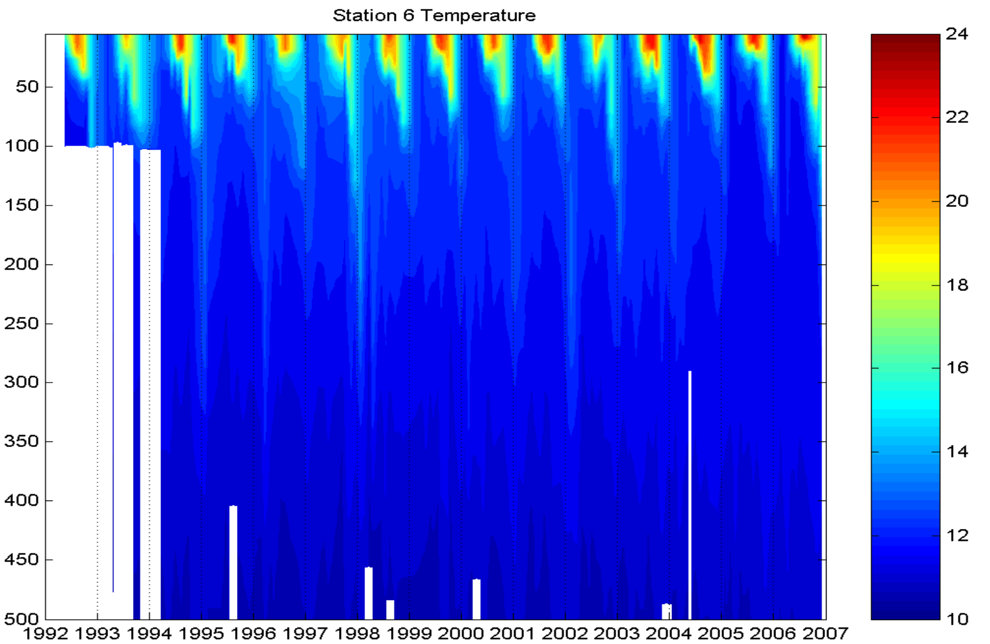


Figure 18a. Temperature evolution at Santander station 6 (shelf-break).

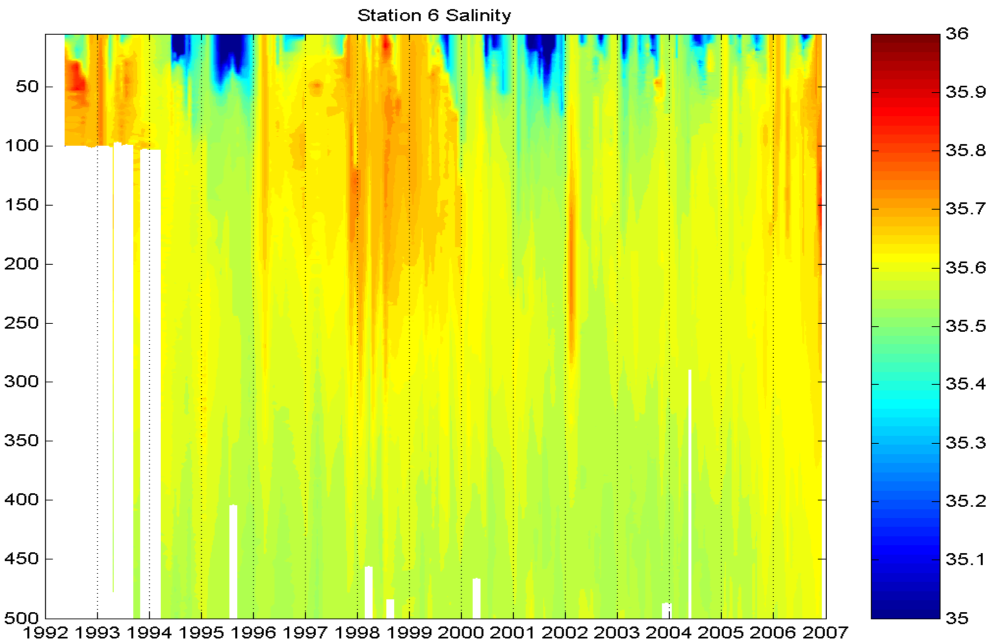


Figure 18b. Salinity evolution at Santander station 6 (shelf-break).

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. During the end of 2005 and 2006 the causes of the maintained salinity increase seem to be a combination of factors: a poleward current reaching the inner Cantabrian Sea in winter and the increase of salinity found in the East North Atlantic Central Water (ENACW) and related with the atmospheric forcing at the area of formation of this water mass specially during the extremely cold and dry 2005 winter (*Gonzalez Pola et al*., 2006).

Stratification develops between April-May and October-November, mainly reaching 100 m depth. During 2006 stratification was smaller in the first months (less than 50 meters) and high temperatures are only reached in the most superficial layer. At the end of the summer and during the autumn it was intensified reaching twice.

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 19). Taking this into account, we can compare the year 2006 with the climatological mean for surface waters. SST was under the mean value for the winter and the beginning of the spring. After that, a rapid increase in temperature it is produced and for the rest of the year SST was higher than the average, especially at the end of July when it is reached the highest value of the time series in SST.

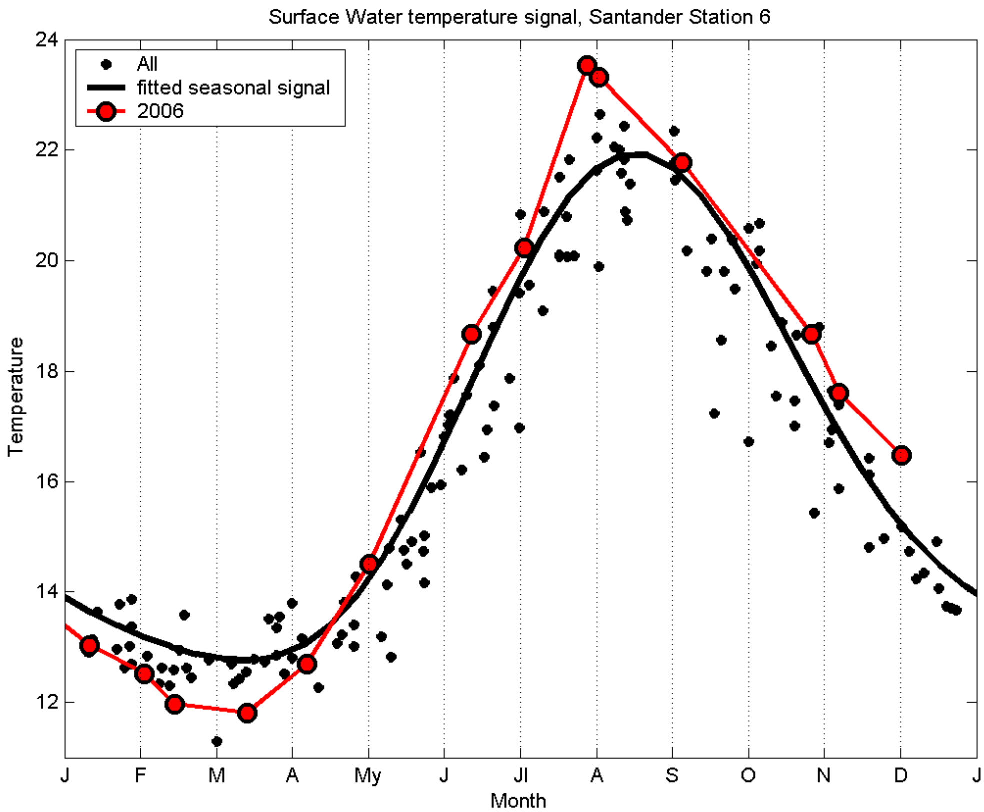


Figure 19. Seawater Surface Temperature at Santander station 6 (shelf-break).

The amplitude of the seasonal cycle of SST was of 11.8ºC, quite close to the air temperature seasonal cycle for the year (13.6ºC) and both of then larger than the long term mean 8.7 and 9.8ºC respectively.

As occurred in 2005 the anomalous cold winter and warm summer produced a yearly temperature close to the average (Figure 20). The consequences of the deep winter anomaly in the mixed layer and upper Central Waters in 2005 are still observed during the 2006 winter but this inertia seem to be lost during the summer, at least in the most superficial waters, when it is registered the highest positive anomaly in SST of the time series.

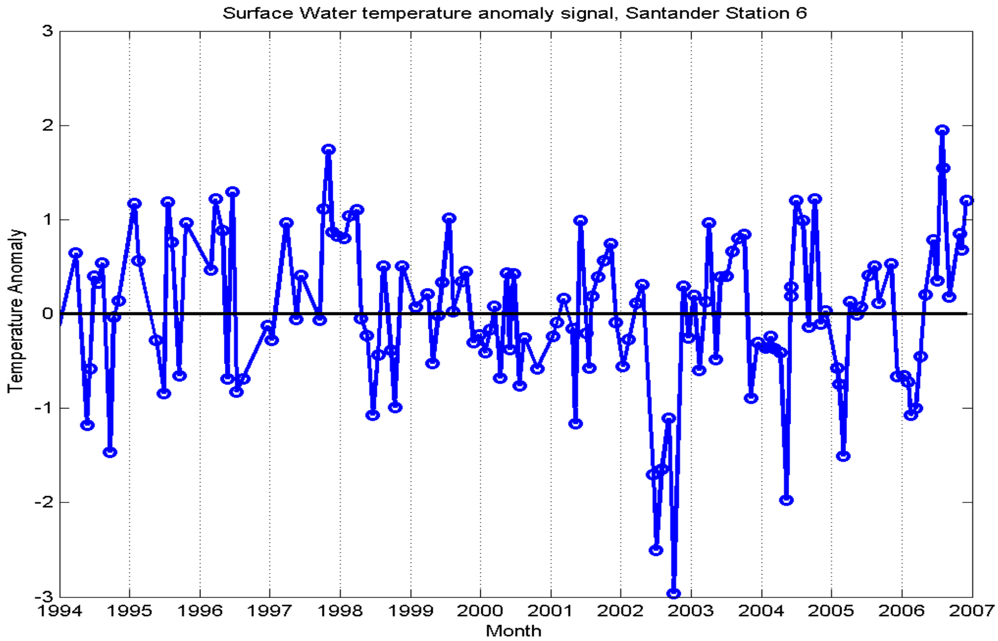


Figure 20. Seawater Surface Temperature anomalies at Santander station 6 (shelf-break).

When the analysis is produced all over the upper waters to 300m depth, 2006 due to the cool winter and warn summer temperatures present a very large range of variation (standard deviation). The mean temperature with value of 12.58ºC is lower than the time series average but inside the standard deviation of the time series (Figure 21).

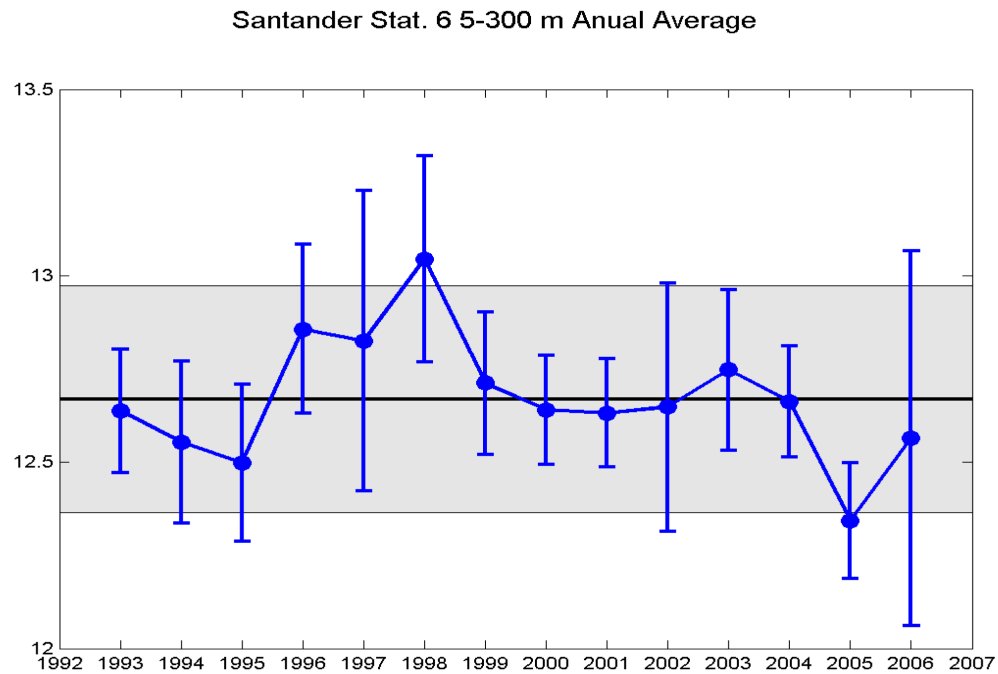


Figure 21. Annual average temperature (5–300m. at Santander station 6 (shelf-break).

A salinity average of this layer (5–300 m) is shown in Figure 22 for station 6. The 2006 mean value are in the limit of one standard deviation above the mean. 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 poleward episode at the beginning of the year. During 2006 an important increase in salinity has been observed in the upper 200 meters (Figure 6b). This increase keeps the trend started in 2003. 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 for the year 2005, and specifically with the difference between precipitation and evaporation. Down to this depth, salinity evolution does not have clear cycles (positive trends seem to appear at lower levels).

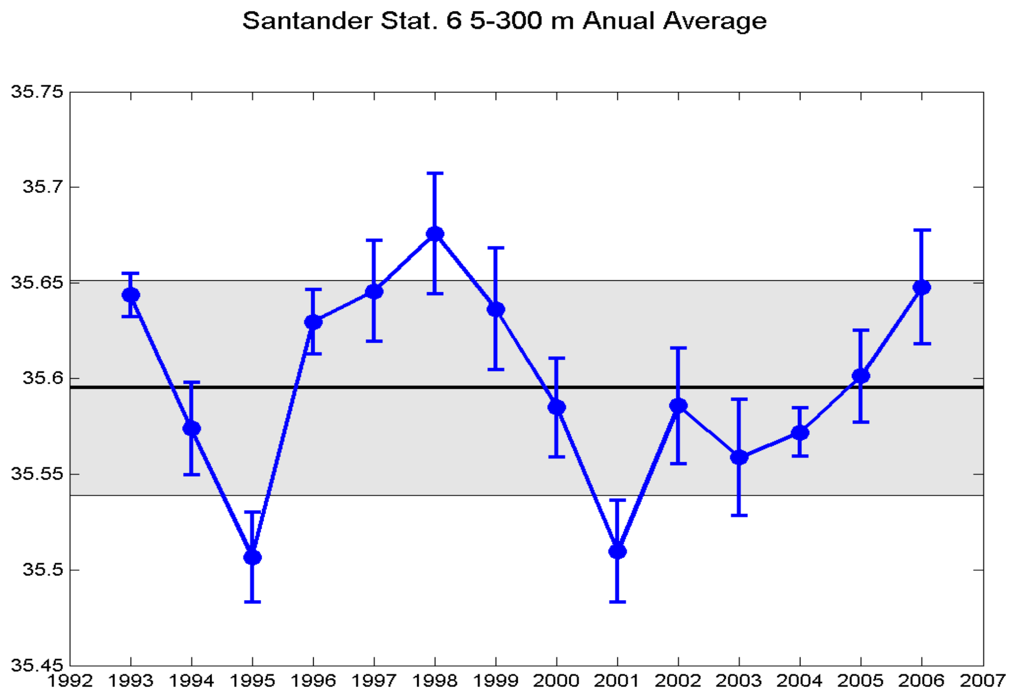


Figure 22. Annual average salinity (5–300m) at Santander station 6 (shelf-break).

In Figure 23 distributions of potential temperature and salinity at 300–600 meters and 600–950 meters corresponding to ENACW and MW (Mediterranean Water) respectively is presented at the over the slope (St 7). A warming trend is observed in ENACW and MW but beginning since the start of the time series in the case of MW and after in ENACW. A reduction on temperature is detected in 2004 and 2006 in ENACW but not so clearly in MW. The intense increase in salinity in ENACW for the years 2005 and 2006 it is observed in the figure whereas in MW the tendency of salt increase is kept since the beginning of the time series as in the case of temperature. The shallower level of MW it isn't represented here, but it seems to accelerate this processes maybe related for the first time in the series with mixing from above.

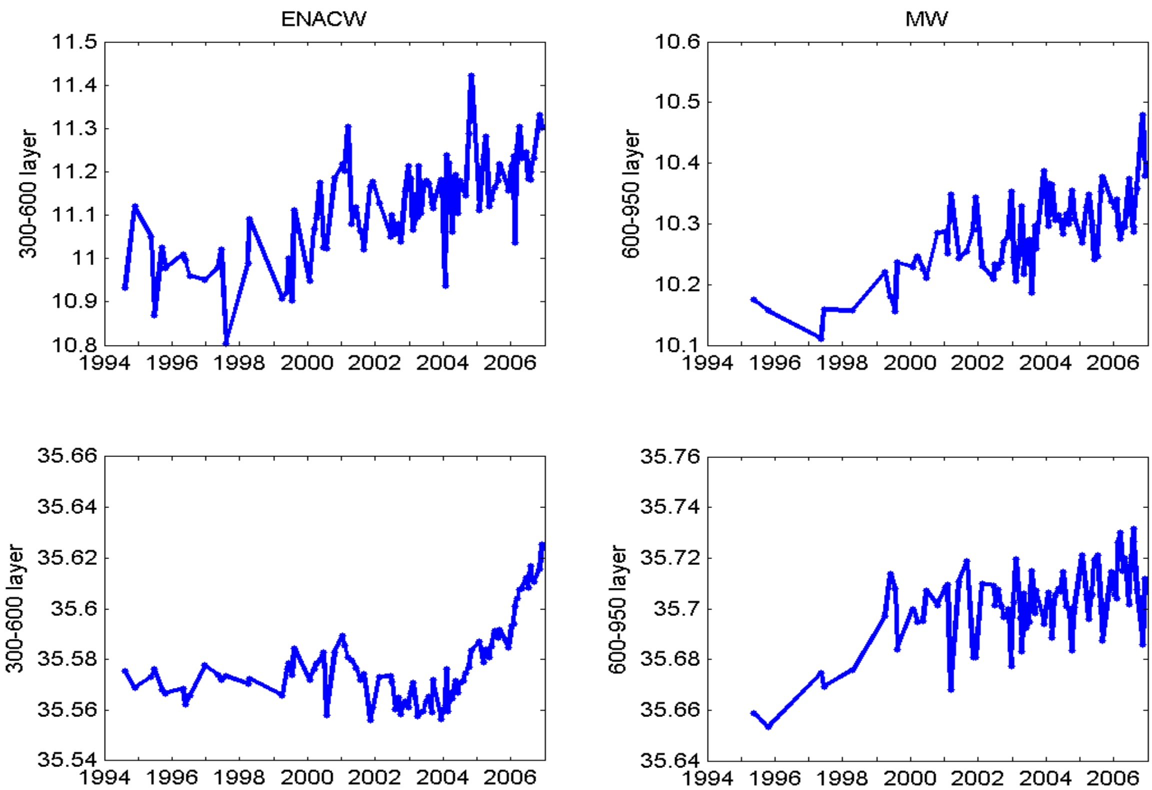


Figure 23. ENACW (300–600m) and MW (600–950m) water properties at Santander station 7(43º 48'N, 3º 47'W) (slope). Temperature in the upper panels and salinity in the lower panels.

Water Masses

The consequences of the deep winter anomaly in the mixed layer and upper Central Waters in 2005 are still observed during the 2006 winter. In 2005 the mixed layer depth was greater than 300 dbar and in winter 2006 the mixed layer reaches practically the same depth. The existence of a very low stratified water column below the seasonal thermocline, developed during the 2005 summer, has favoured the formation of a very deep mixed layer again in winter 2005–2006.

In the Figure 24 it can be seen the θS 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 less than 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 found progressively the Mediterranean Water (MW) which has its core about 1000 dbar the limit of our sampling. From the data set it can be observed that MW has increased its temperature and salinity compensating its density, whereas the variability in the ENACW is not so evident in the θS diagram. The main changes evident in ENACW are the increase in salinity since 2005 onwards and the interruption of the θS straight line below the 27:1 isopycnal level in the last years.

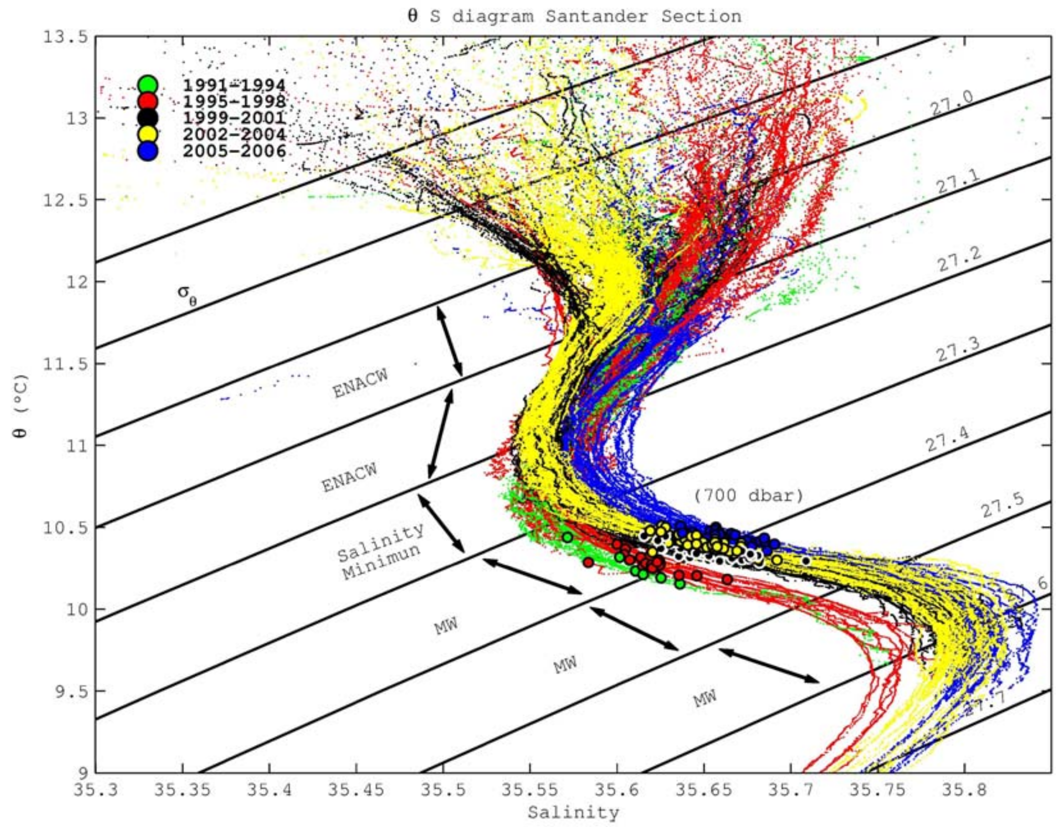


Figure 24. Water masses at Santander stations 6 and 7 presented in a TS diagram.

Annex 9: Area 5 – The Extended Ellett Line: Rockall Trough and Iceland Basin

BY: N.P. Holliday[1], J.F. Read[1], T. Sherwin[2], J. Allen[1]

[1]National Oceanography Centre, Southampton, UK. and [2]Scottish Association for Marine Science, Oban, UK.

The Extended Ellett line (Scotland to Iceland, Figure 1) was occupied in October 2006, another annual sampling of this repeat hydrographic section (Figure 2).

The updated time series of upper ocean conditions in the Rockall Trough (Figure 3) shows 2006 salinities a little down on peak in 2003, but still quite high. The relative freshening is consistent over 3 years now. The decrease in mean salinity this year is due to the presence of relatively cool/fresh water against the Rockall Bank. This is clear on the theta-S plot as a separate water mass, an occurrence not usually captured by the time series (Figure 4). This may represent a new influx of fresher water from the west (Western North Atlantic Water). In contrast the slope current and rest of the section still has very high salinity, higher than 2005 in shallow waters.

Temperatures are rising still if you take the mean of upper 800m across deep Rockall section. However the potential temperature anomaly on an isopycnal at around 500–600m (27.36) shows a decrease, the first time the two different ways of calculating an anomaly have significantly diverged (Figure 4) in the whole time series. This seems to be because temperature has increased more rapidly in the shallow water than the intermediate.

The time series of Labrador Sea Water (as represented by the properties at the deepest potential vorticity minimum) are relatively unchanged over the last 5–6 years (Figure 5). However since 2004 there has been evidence of 2 salinity and PV minima at the deepest station. The double salinity minima of the upper LSW and classic LSW feature was first seen in Labrador Sea in 2000, suggesting a possible transit time of only ~ 4 years. However, the salinity maximum in the core of the LSW might also be an interleaving effect with the water described next.

At the same time as the influx of shallow fresher water, there is also an interesting development in the deep T-S relationship. For the vast majority of the time series in the Rockall Trough, the T-S relationship in the deepest part of the basin has been tight and well mixed (LSW salinity minimum mixing down to lower deep water. But since 2003 there have been occasional stations with very different properties (more saline, more structure, Figure 4). The origin of this water is unclear; it lies beneath the cooler fresher upper ocean water in the west of the Trough and could have come from the southwest, but equally it could be Wyville-Thomson Ridge overflow water. This is being investigated.

In the Iceland Basin the salinity of the top 1000m has increased by up to 0.14, with a mean increase of 0.05 between 1997 and 2006 (north of 60°N) (Figures 6 and 7). Below 500m the increased salinity is a result of a reduction of fresh subarctic intermediate water. In the upper 500m it can be attributed to a change from fresher to more saline source water (Read, Allen, Griffiths, Holliday and Sherwin, submitted to GRL). Note however that in 2006 fresher water again returned to the region adjacent to the Hatton Bank.

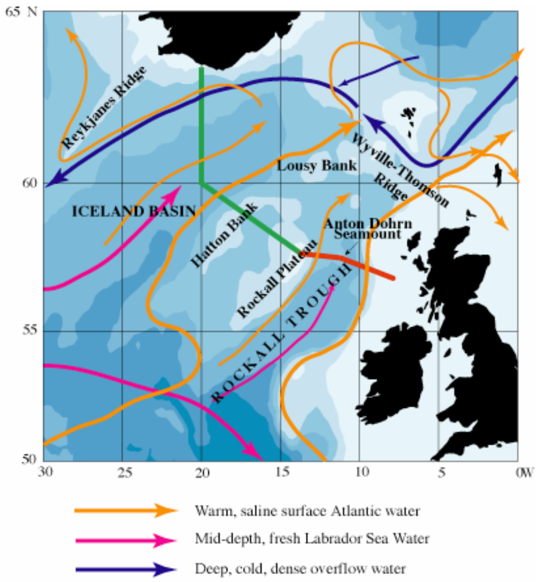


Figure 1. Location of the Extended Ellett Line within a schematic of currents.

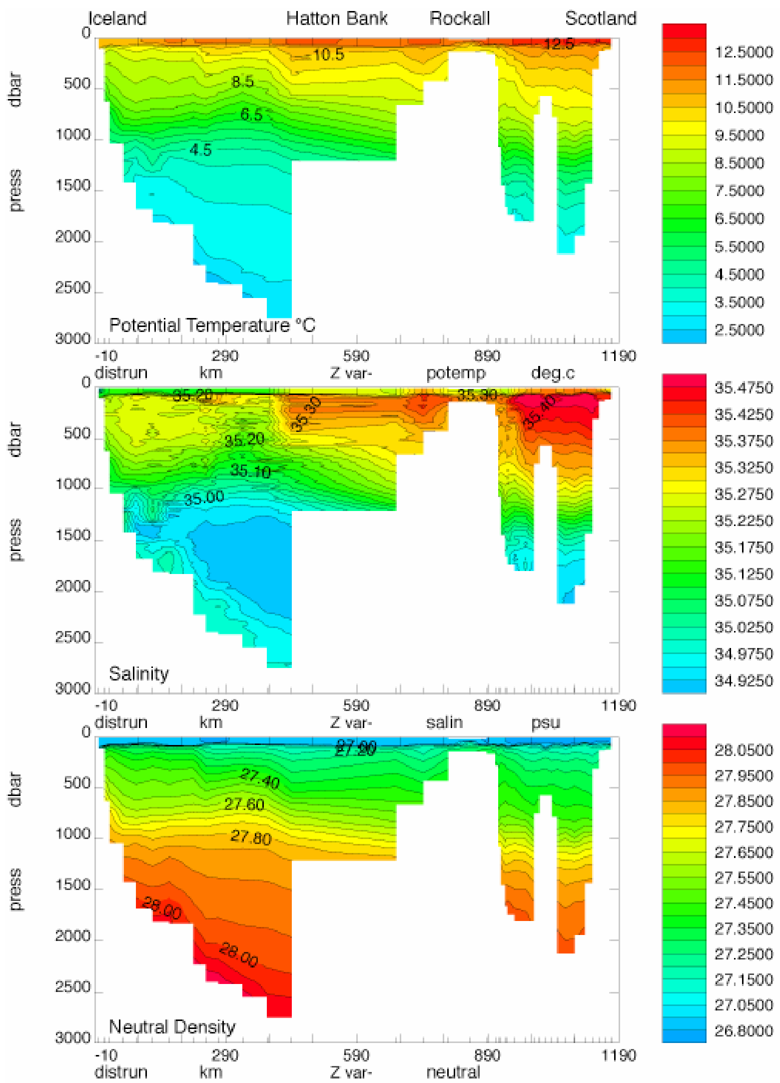


Figure 2. The Extended Ellett 2006 hydrographic section (temperature, salinity, density).

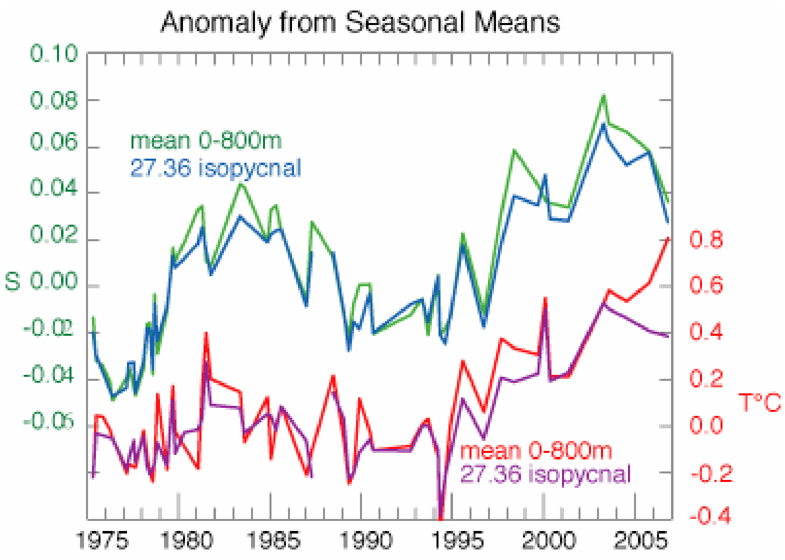


Figure 3. The Rockall Trough upper ocean time series of temperature (red and pink) and salinity (blue and green). The curves represents the average temperature and salinity of the upper 800m and on isopycnal 27.36 kg m^{-3} after a mean seasonal profile has been subtracted from the section-average profile.

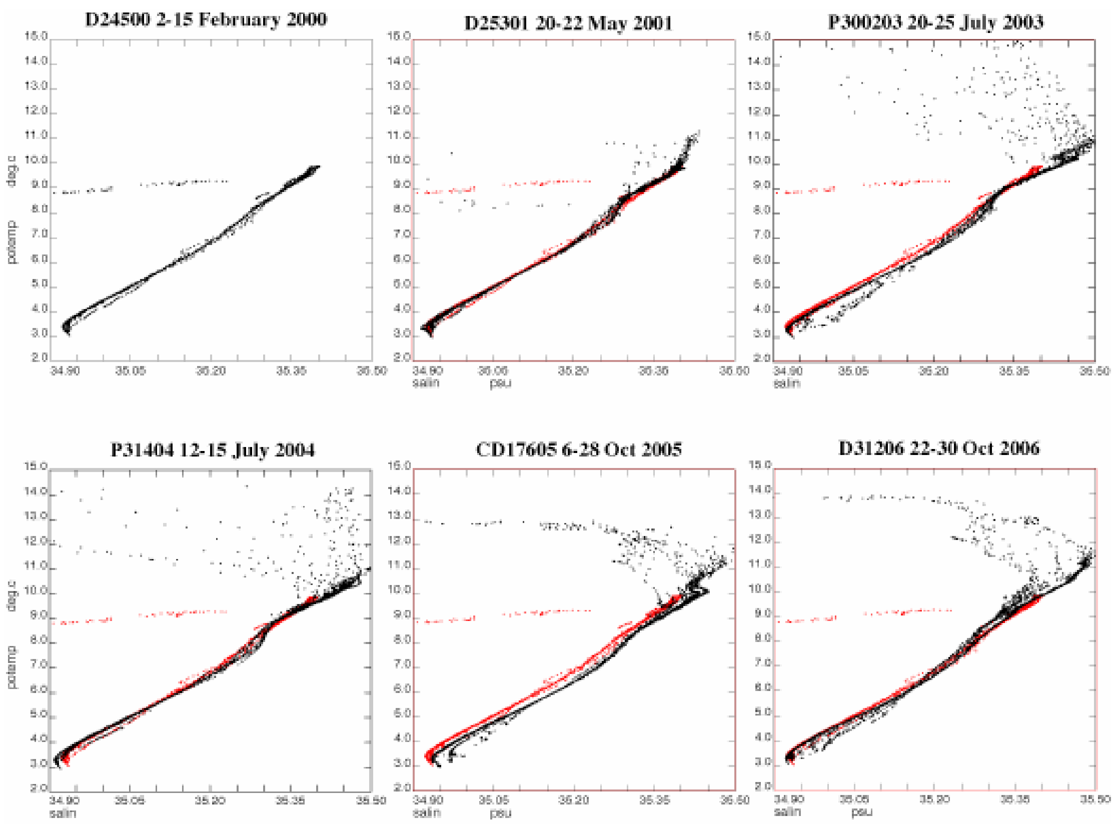


Figure 4. Potential temperature vs salinity for the Rockall Trough, 2000–2006. The 2000 data are shown in red in each of the panels.

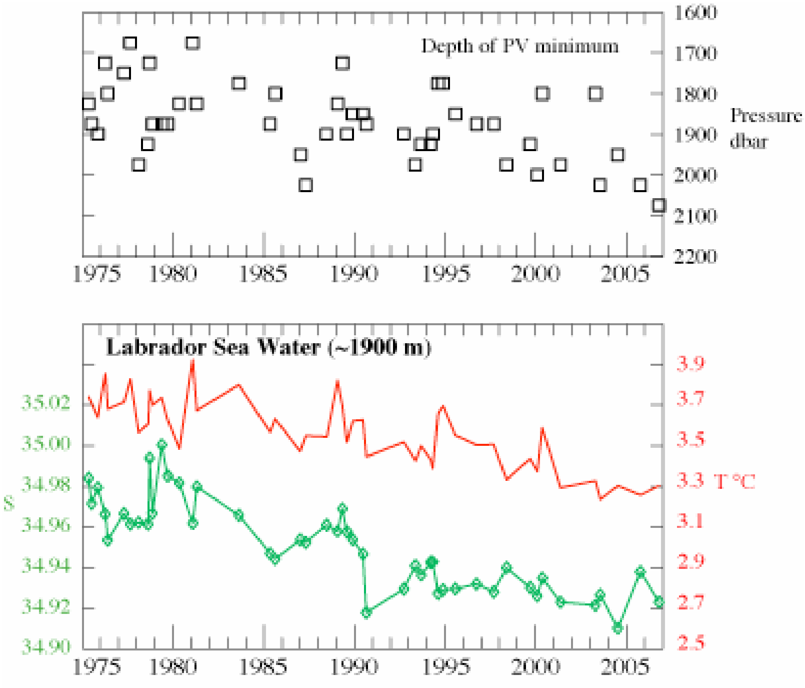


Figure 5. The Rockall Trough Labrador Sea Water Time Series (temperature and salinity at the deepest Potential Vorticity minimum).

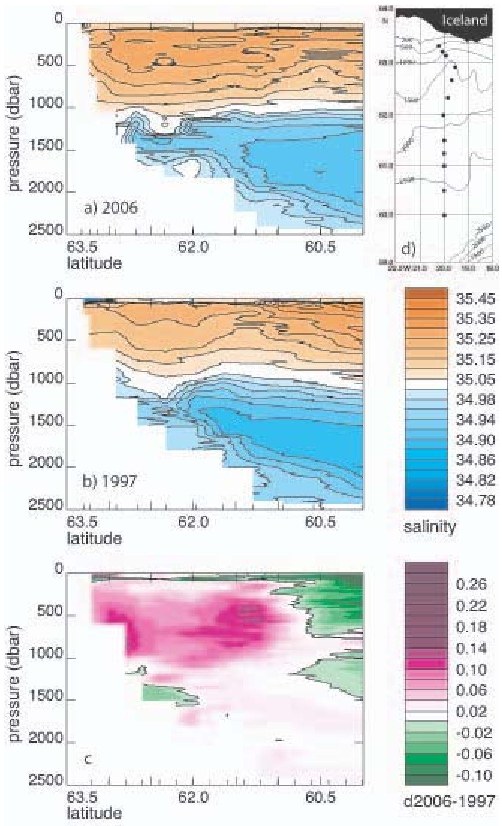


Figure 1. Sections along 20W of a) salinity in October 2006, b) salinity in September 1997, c) difference in salinity (2006-1997), d) map showing CTD station positions.

Figure 6 (Figure 1 from Read *et al.* submitted)

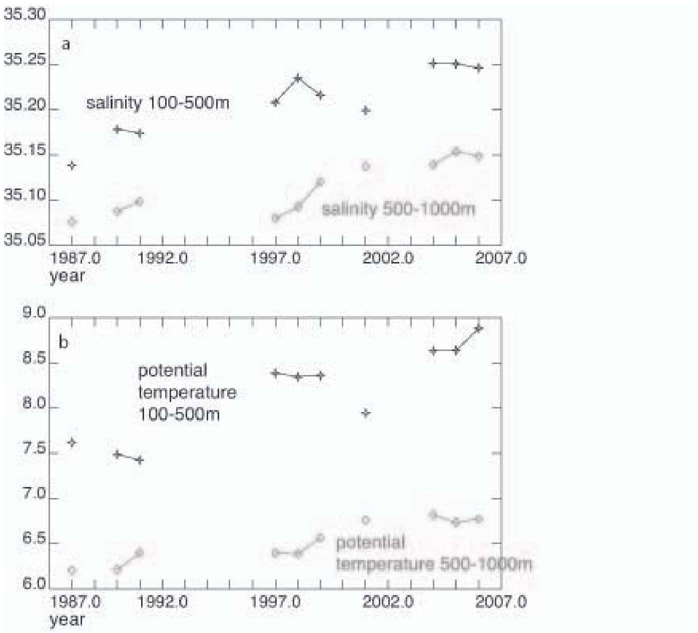


Figure 4. Time series of a) salinity and b) potential temperature averaged over 100-500m and 500-1000m for the section from Iceland to 60 °N, as plotted in Figs. 2 & 3.

Figure 7. (Figure 4 from Read *et al.* submitted)

Annex 10: National report The Netherlands, 2006

The Royal Netherlands Institute for sea Research (Royal NIOZ) used the British RSS Discovery (cruise DI309/310) to recover service and re-deploy the monitoring moorings in the Irminger Sea. Now 3 years of data from these moorings are available. They contain daily TS profiles, High frequency ADCP data from the upper 600 m and the lower 500 m of the water column, and TS data near the bottom. For 2006 the annual hydrographic survey of the former WOCE AR7E section was scheduled for the IfMH in Hamburg. Unfortunately the owner of the planned research vessel Gauss laid up this vessel in spring so that the annual survey between Europe and Greenland had to be cancelled. During the Cruise of RRS Discovery it appeared to be possible to spend some days to survey that part of the AR7E section in the Irminger Sea to obtain the data required for the time series from the Irminger Sea to be reported in the annual ICES Report on Ocean Climate (area 5b).

Annex 11: French National Report

BY: V. Thierry, F. Gaillard (LPO, Brest, France), G. Reverdin (LOCEAN, Paris, France), P. Morin (IUEM, Brest, France), F. Vandermeirsch (DYNECO/PHYSED- IFREMER, Brest, France), Nicole Degros (FRE ELICO – CNRS, Wimereux, France)

The Ovide section

The OVIDE project (LPO, France) aims at repeating a trans-oceanic hydrographic section across the North Atlantic every other year for 10 years since 2002 in order to monitor and understand low-frequency fluctuations of the oceanic Atlantic Meridional Overturning Cell, heat and tracer transports and water mass characteristics in the North Atlantic Ocean (Lherminier *et al*., 2007). The OVIDE section consists in full-water column hydrographic stations between Portugal and the southern tip of Greenland (Cape Farewell) (Figure 1). The western part of the section is coincident with the A01E/AR7E section between Cape Farewell and Ireland. The OVIDE section has been realised three times since 2002, in June-July 2002, June-July 2004 and in May-June 2006. High-quality hydrographic stations during the OVIDE sections include measurements of temperature, salinity and dissolved oxygen as a function of pressure using a Neil Brown Mark III CTD02 probe. The measurements satisfy the WOCE-standard accuracy. The rosette was equipped with 28 8-liter bottles for tracer measurements (macro-nutrients, inorganic and organic dissolved carbon, CFCs) and calibration purpose. Data collected during OVIDE also include currents from ship-based ADCP and lowered-ADCP.

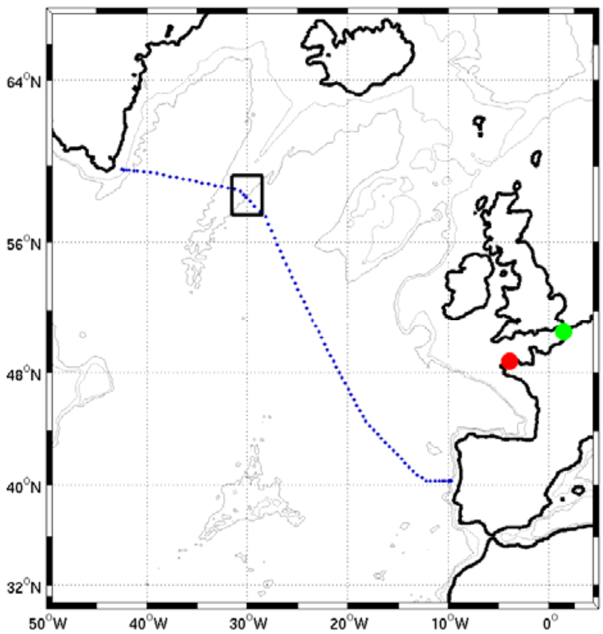


Figure 1. Position of the OVIDE stations. The black box indicates the localisation where the interannual variability of the the core property of a subpolar mode water variety is estimated. The red point indicates the position of the Astan and Estacade sites and the green point indicates the position of the Wimereux site (see Section 0).

Deep layers

In comparing the θ/S diagram of the deep layers of the three OVIDE realisations we observe a clear erosion of the lower-Labrador Sea Water (cLSW on Figure 2) with time. In addition, the properties of the upper-Labrador Sea Water differ from year to year. They are particularly distinguishable from surrounding water masses in 2004 suggesting a local formation of this water mass in the Irminger Sea during the 2003–2004 winter, whereas in 2006, the distinction is less visible with a shift to lighter and slightly more saline water. The most striking difference between 2006 and the earlier realisations of the Ovide section is in the shift of the properties of the Denmark strait Overflow Water (DSOW). Overflows water towards warmer and saltier waters in 2006.

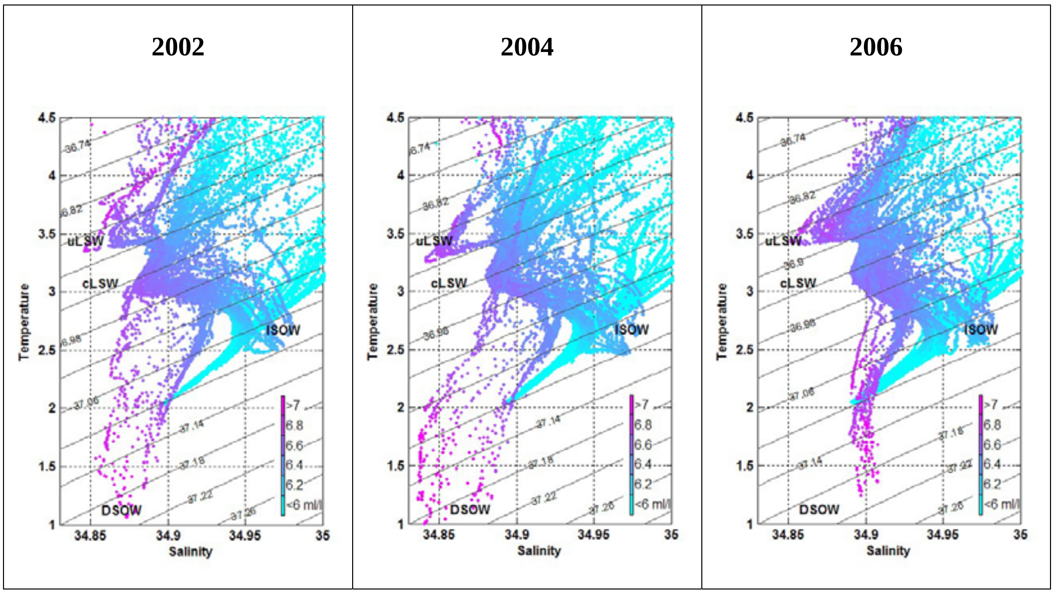


Figure 2. θ/S diagram of the deep water along the Ovide secion. The dots are colour-coded as a function of the oxygen content.

Subpolar mode water on the Reykjanes Ridge

In combining the OVIDE data with historical CTD data (mainly from earlier realisations of the A01E section) and Argo data, we have estimated the interannual variability of the core property of the Subpolar Mode Water observed on the Eastern Flank of the Reykjanes Ridge over the period 1990–2006 (Figure 1 and Figure 3). In this region, the density compensated tendency for cooling and freshening observed in the early 1990s was interrupted in 1996, with a later increase in both properties (and a decrease of density) until 2003 (but notice gap in data in 1998–2001). Since 2003, the data suggest a decrease of the temperature and salinity of the mode water core accompanied with an increase in density. Individual extreme values observed in 2002 (potential temperature and potential density greater than 8°C and less than 27.4, respectively) are due to an eddy sampled during the Ovide cruise. During that entire period, the data do not allow to identify significant modifications in the depth of the mode water core, except maybe in 2003–2004 when the mode water core is anomalously shallow.

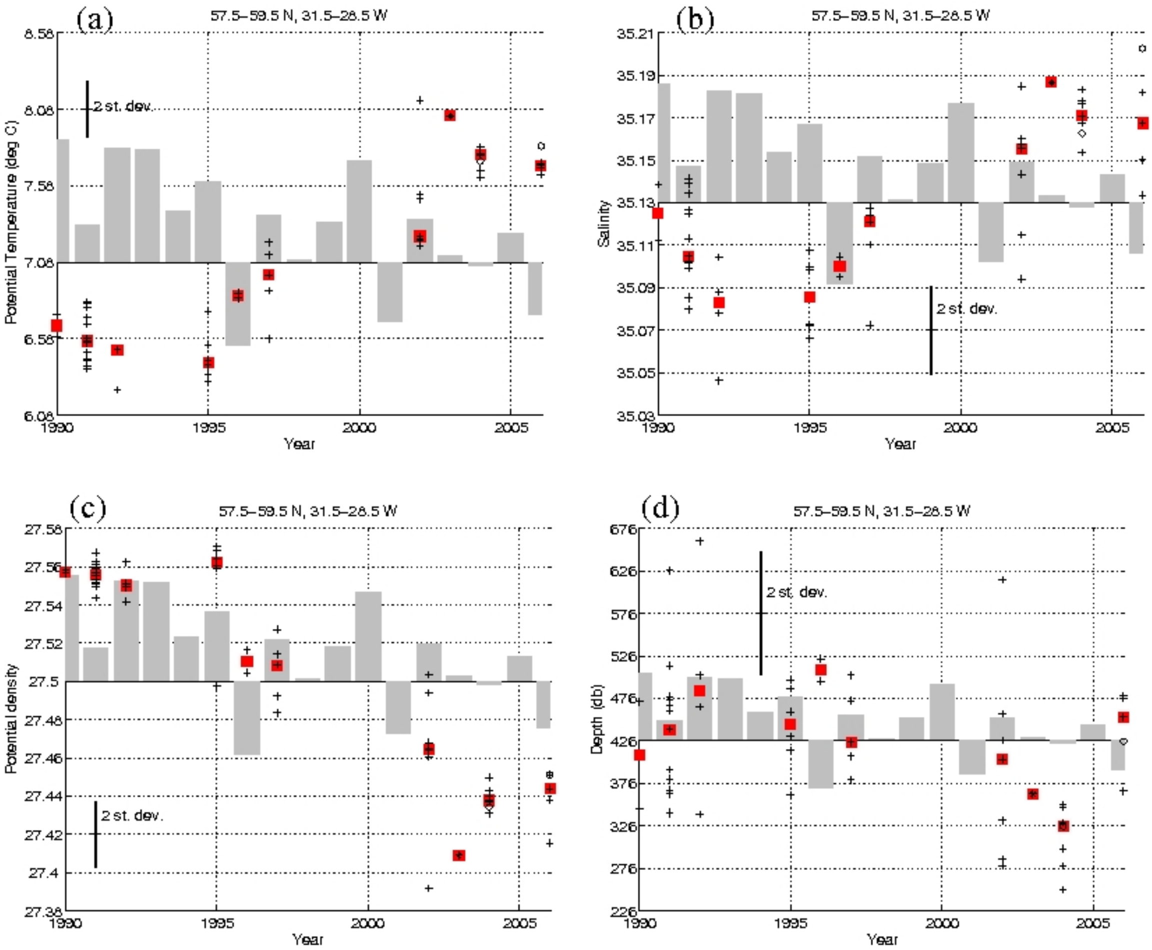


Figure 3. Time evolution of the properties of the Subpolar mode water found on the east flank of the Reykjanes Ridge (box on Figure 3). (a) potential temperature; (b) salinity, (c) potential density, (d) depth. Individual data are from CTDs (crosses) and from ARGO floats (circles for real time data and stars for delayed mode data). The median of the data for a given year is reported by a square. The vertical bars report the NAO index (Hurrell, 1995). Note that the temperature time series is very close to the February SST from Reynolds product at the same location (not shown).

Ships of opportunity

Here, we will report on near surface temperature and salinity measurements made from ships of opportunity in the North Atlantic. A few merchant vessels are equipped with thermosalinographs, contributing to the French ORE SSS (sea surface salinity research observatory). On some of the vessels, ancillary data are also obtained to study inorganic carbon in the upper ocean. These vessels include the Nuka Arctica, usually between Denmark and west Greenland (although no data have been obtained between January and mid-May 2006 on this line), the Skogafoss between Iceland and north-east North America (just the samples collected four times a year by an observer are now part of our effort, the TSG been now under the responsibility of NOAA), the Nokwanda between France and South Africa, a vessel between the Channel and eastern South America (currently, not implemented), and two vessels (Toucan and Colibri) on an irregular basis between the Channel, north-western Mediterranean and French Guyana. There is also one vessel between France, North America and Panama, 6 times each year (currently, Matisse). Data from the thermosalinographs should be validated by water samples collected on a regular basis (usually once a day), but quality control and correction of the salinity records has not yet been done for all those vessels. Here, I will report data from the Nuka Arctica TSG that is available since June 1997. The TSG was initially installed in the bow of the ship, but difficulties, in particular since it was coupled with a pCO2 equilibrator system (University of Bergen) and in 2005, have induced us to change it to a new location since early 2006 by mid-ship. The depth of intake is possibly a little deeper, but the intake is less prone to be in the air during bad weather. In 2006, despite different problems until mid-November 2006 (often insufficient flow through the TSG, in particular in the western part of the route near Greenland), useful salinity data can be recovered at times from the TSG. In situ temperature data is provided since 2005 by an intake sensor associated with the pCO2 system. Data are complemented by ancillary data in early 2006 (mostly from the Skogafoss or from profiling floats) to allow to construct a time series of anomalies with respect to a seasonal cycle based for salinity on data collected along the same route between 1896 and 1995.

Data (Figure 4) show that after fairly low salinities in mid-year 2005, during the winter of 2006, the positive salinity anomalies re-emerged, in particular west of the Reykjanes ridge, where positive anomalies were observed throughout 2006, although with slightly smaller values than in previous years (in particular in 2004). On the other hand, east of 25°W, positive anomalies are clearly much less positive in 2006 than in previous years. Note also that anomalies east of 5°W are often larger than further west, although they are mostly in phase with them. Close to the Greenland shelf, deviations from the seasonal cycle are very large and tended to be negative since mid-2003. However, this region is irregularly sampled and is prone to very large variability, which is not adequately resolved by the current sampling. In June 2006, clear inflow of freshwater (and ice) from the east Greenland shelf invaded the off-slope area in the southern Irminger Sea, which could have contributed to this fresh waters. Temperature anomalies are not presented, as they are mostly coherent with the SST maps produced by NOAA in 2006 (although these are independent data), and illustrate a continuation of the positive SST anomalies which have tended to be maximum along that latitude in 2006.

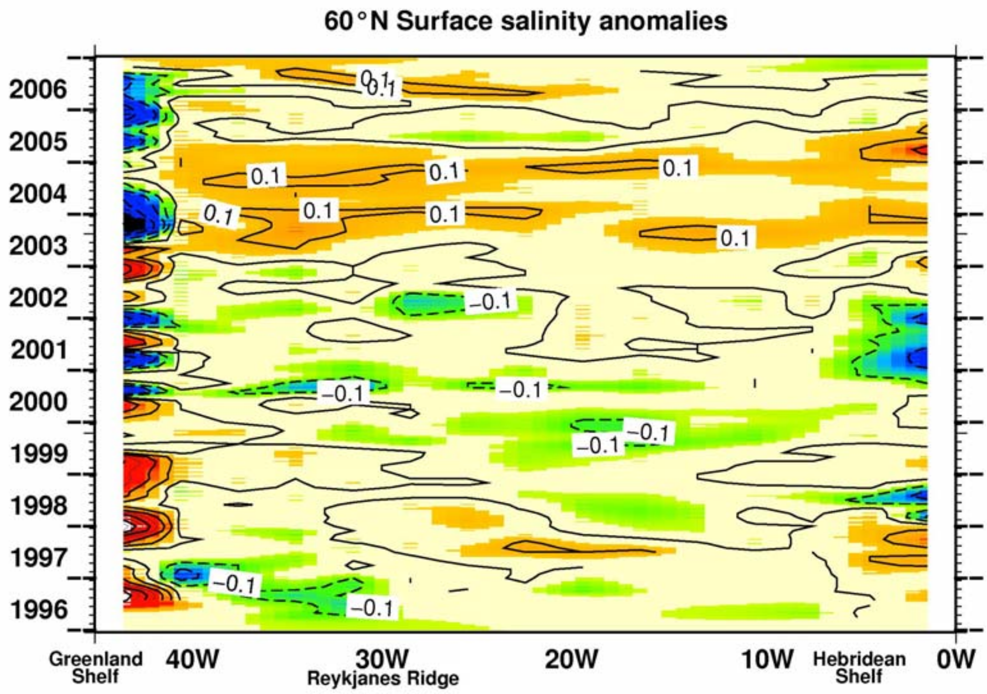


Figure 4. Time evolution of SSS along 60°N between the Greenland shelf break and 2W (on the Shetland shelf). The average seasonal cycle is based on the 1896–1995 surface data.

Temperature and salinity anomaly over the North-Atlantic

An analysis system has been developed by F. Gaillard and E. Autret and implemented at the Coriolis data center (Brest, France, www.coriolis.eu.org) to produce weekly analysis of temperature and salinity from all the data distributed by Coriolis (CTD, Argo, XBT, XCTD, moorings) since 2000. This tool produces gridded fields of temperature and salinity on a ½° horizontal grid and 59 levels from 0 to 2000 m depth over the global ocean. The system is univariate which means that temperature and salinity are estimated independently. It is based on optimal interpolation and the estimated quantity is the anomaly on depth levels relative to a reference climatology (Gaillard *et al*., 2007). The maps published on the Coriolis web site give an overview of the state of the ocean (http://www.coriolis.eu.org/english/map_of_the_day.htm). For a given year, monthly mean and annual mean are deduced from the average of the weekly analysis. The maps (Figures 4 and 5) display the 2006 annual temperature and salinity anomalies at different levels with respect to WOA05 (Antonov *et al*., 2006; Locarnini *et al*., 2006).

The 2006 anomalies clearly reveal a net warming and salinisation of the upper layers (Figure 5a). The tendency is reinforced compared to 2005 (not shown), except maybe near the Reykjanes Ridge (see Section 0 and ICES, 2006) but the analysis is not focused on those small horizontal scale changes.

At 1000m, the 2006 anomalies also show a net warming and salinisation of the Mediterranean Water overflow and a warming and freshening of the Irminger and Labrador Sea Water compared to the WOA05 climatology (Figure 5b). Between those areas, and more exactly on the path of the North Atlantic and Azores currents, a clear negative temperature anomaly is observed at 1000m with respect to the climatology. This tendency is more spread spatially at larger depths (at 1600 m on lower left panel of Figure 5b).

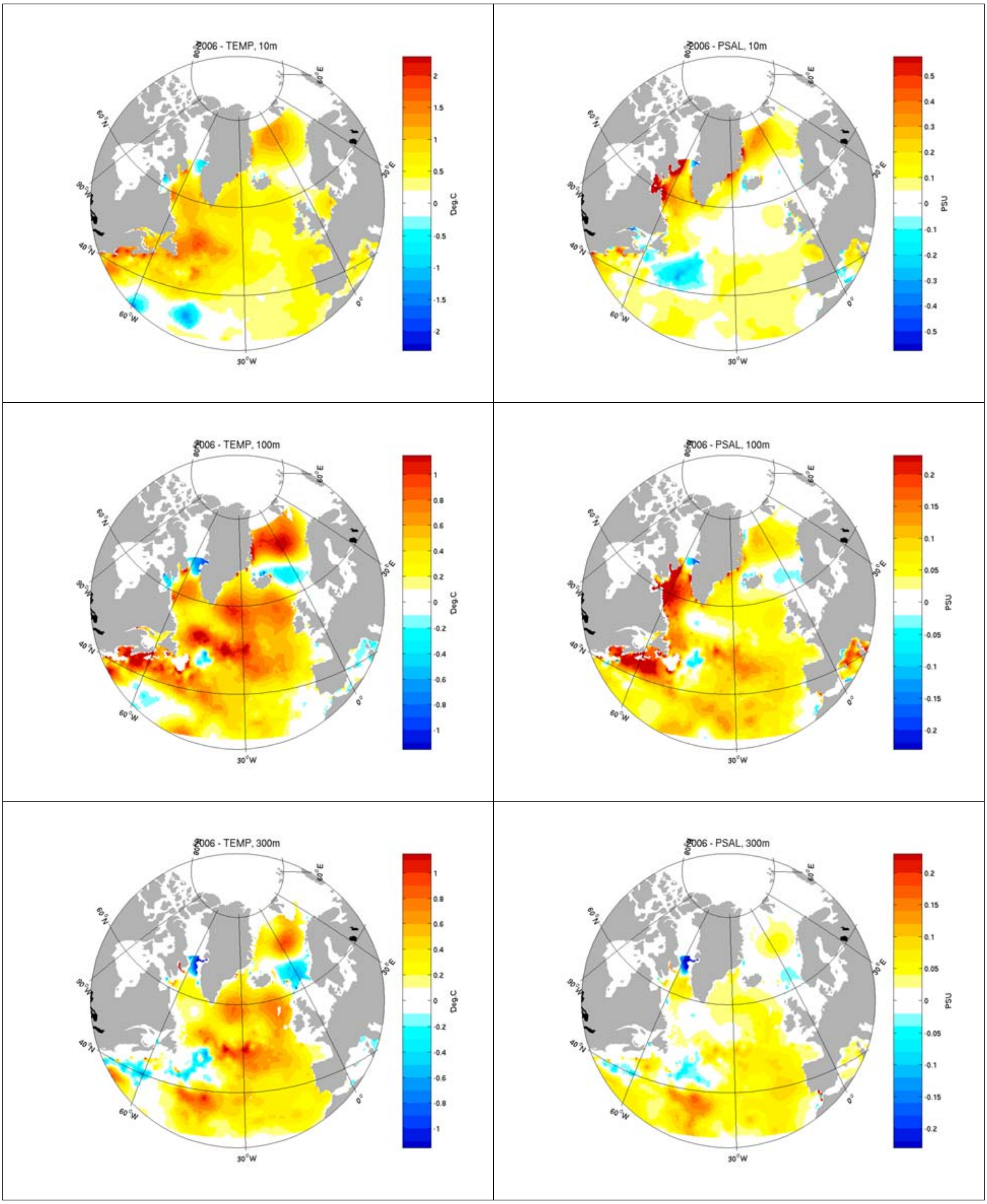


Figure 5a, Annual temperature (left panels) and salinity (right) anomaly for the year 2006 with respect to WOA 2001 (upper panels) at 10 m; (middle panels) at 100 m; (lower panels) at 300 m.

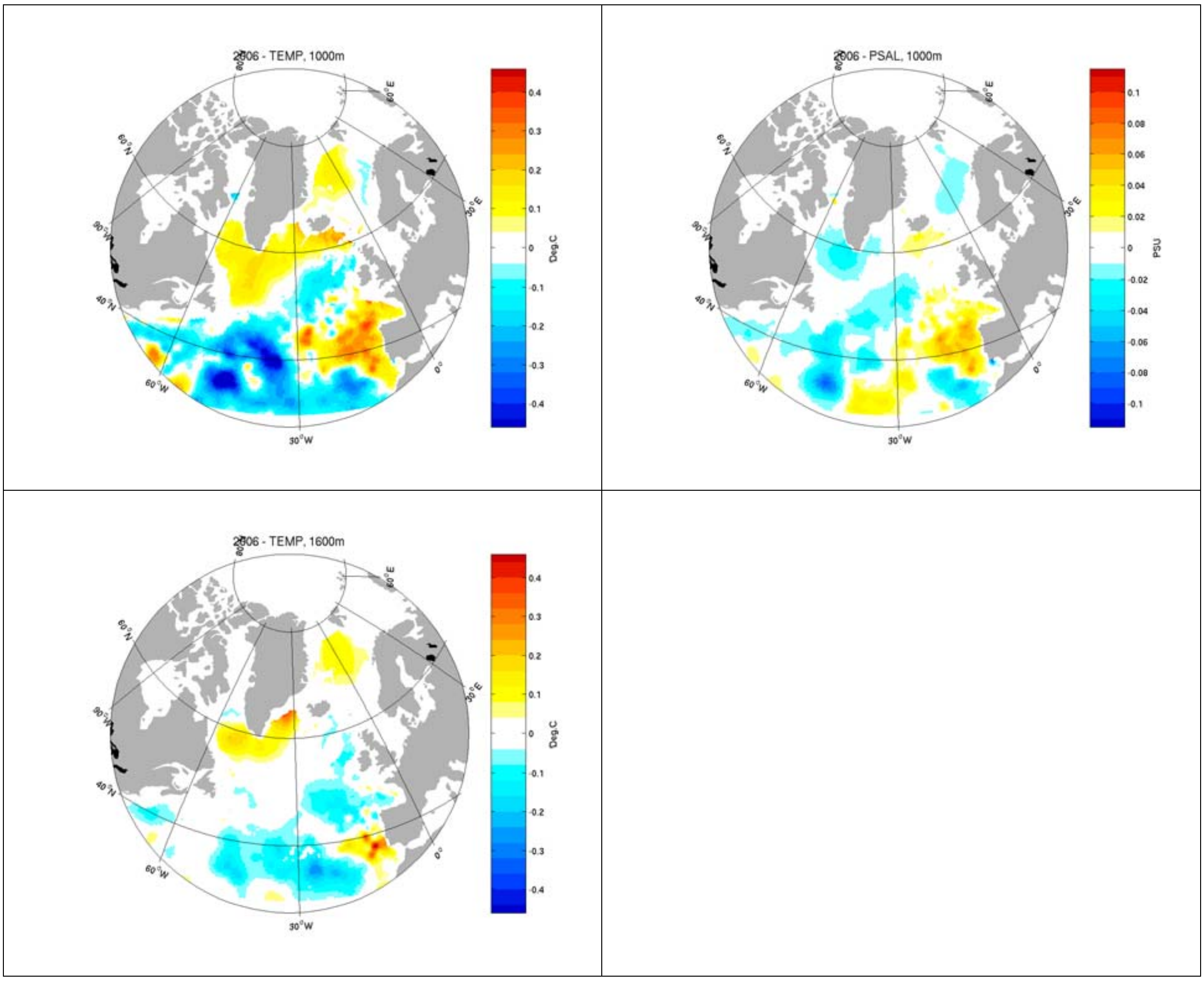


Figure 5b. Same as Figure but for the 2006 anomaly at 1000 m depth (upper panels) and at 1600 m depth (lower panels).

Bay of Biscay

In order to determine interannual variability of the water mass properties in the Bay of Biscay (eastward of 15°W), Ifremer has first constituted a unique data base of the Bay of Biscay in collecting all data available in the area from various international data centres over the period 1862–2006 from CTDs, bottles, XBTs/MBTs and profilers. Ifremer is currently working on the realisation of climatology of the area (from bi-monthly to annual products, see http://www.ifremer.fr/climatologie-gascogne/index.php). Figure shows the March mean temperature field at the surface and the annual salinity at 950 m in the Bay of Biscay estimated from this data base (the work is still in progress and some changes may occur in the future).

Ifremer is now working on the last step of the project which consists in computing anomalies with respect to the climatology. The 2006 anomaly is not yet available (a particular difficulty of the mapping for the shelf area is that oceanographic surveys are conducted mostly twice a year on the French part of the continental shelf, with large unresolved variability). Based on the data available, it is expected to illustrate large positive salinity anomalies, in particular in the first part of the year, and throughout the year in the southern part of the continental shelf, whereas temperature anomalies will likely be negative or near normal in the winter and early spring, and changing to positive in late spring-early summer and through the autumn 2006. The tool developed to produce gridded temperature and salinity fields in the Bay of Biscay is derived from the one presented in Section 0.

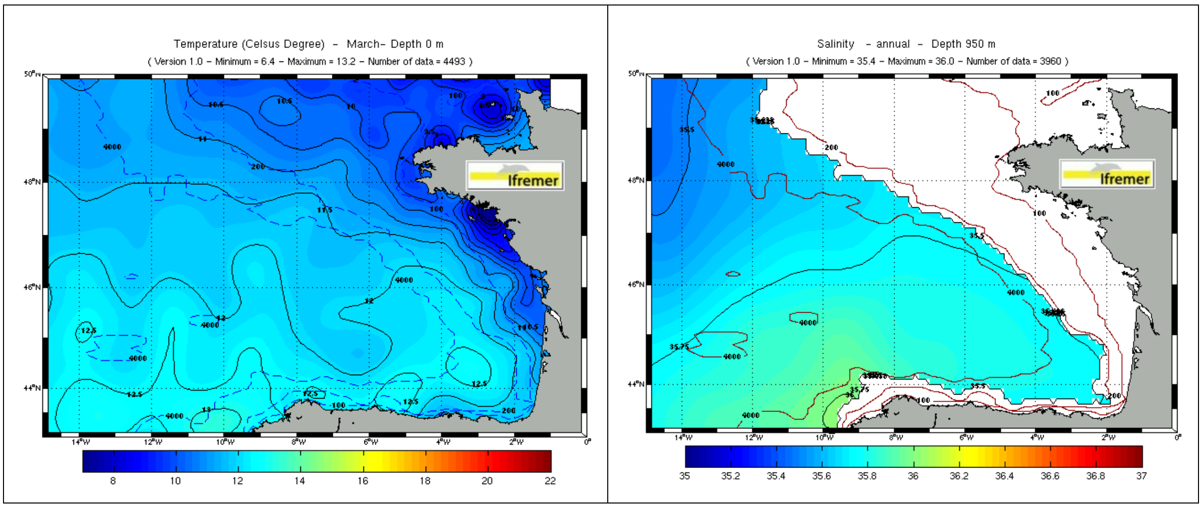


Figure 6. Climatological products in the Bay of Biscay. (Left panel) Temperature at the surface in March. (Right panels) Annual salinity at 950 m depth.

Coastal time series

Astan and Estacade sites (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 1). 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/.

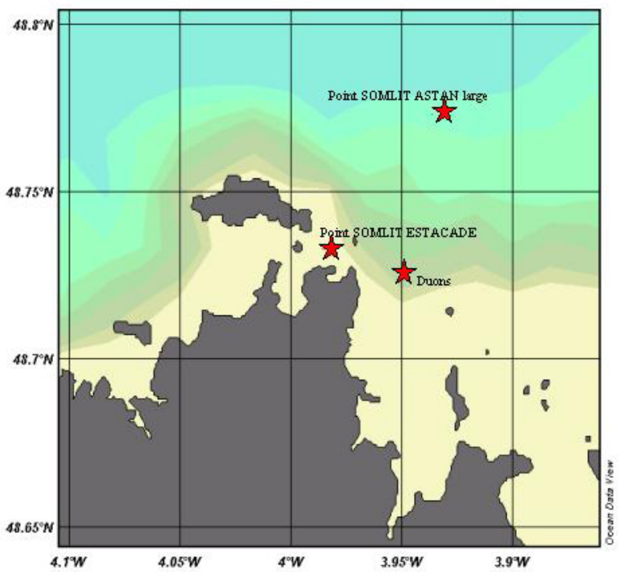


Figure 7. Localisation of the ESTACADE and ASTAN sites (see red point on Figure 1).

The first panels (Figure and Figure) present the 2006 cycle of temperature, salinity and nitrate compared to the mean annual cycle. Both stations show that winter 2006 has been colder than normal. Temperature remained below the averaged values until September. On the contrary, temperatures in autumn were above the averaged values. There are more differences in salinity and nitrates between the two sites, in particular in January-May. This is caused by the Estacade site station being more influenced by the fresh water enriched by nitrate than the coastal station (Astan site) with properties more characteristics of the western Channel properties (except in May 2006).

Figure show time series of temperature, salinity and nitrate at Astan over the period 2000–2006 and at Estacade over the period 1985–2006 with a large gap from 1992 through 2000. At the Astan site, winter 2006 is the coldest winter ever observed since 2000. In summer 2006, the maximum temperature is close to the average value, but the peak occurred later in time. The time series show that the warmest summer was 2003. Salinity is subject to large interannual variability (in particular in the winter-spring season), whereas nitrate concentration has decreased since 2000. Temperature time series at the Estacade site show that at the beginning of the 2000s, winter was warmer than at the end of the 80s. The 2005/2006 winter is the coldest over the period 2000–2006 but remains warmer than the 1985/1986 and 1986/1987 winters.

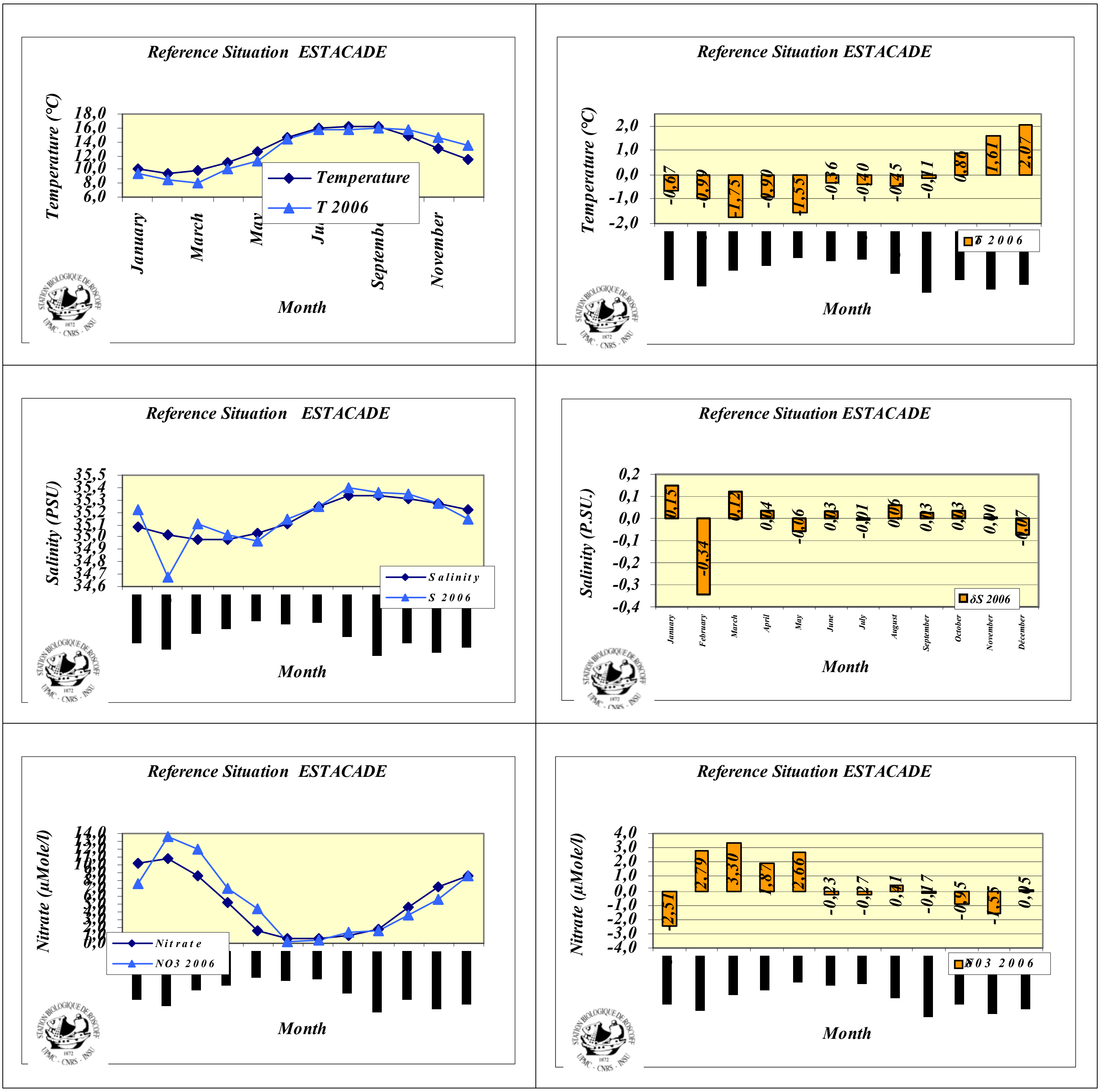


Figure 8. Comparison between times series of temperature (upper), salinity (middle) and nitrate (lower) at the Estacade site in 2006 with the climatological cycle. (Left panels) 2006 values. Dark blue line represents the mean annual cycle and light blue line represent 2006 data. (Right panels) 2006 anomalies.

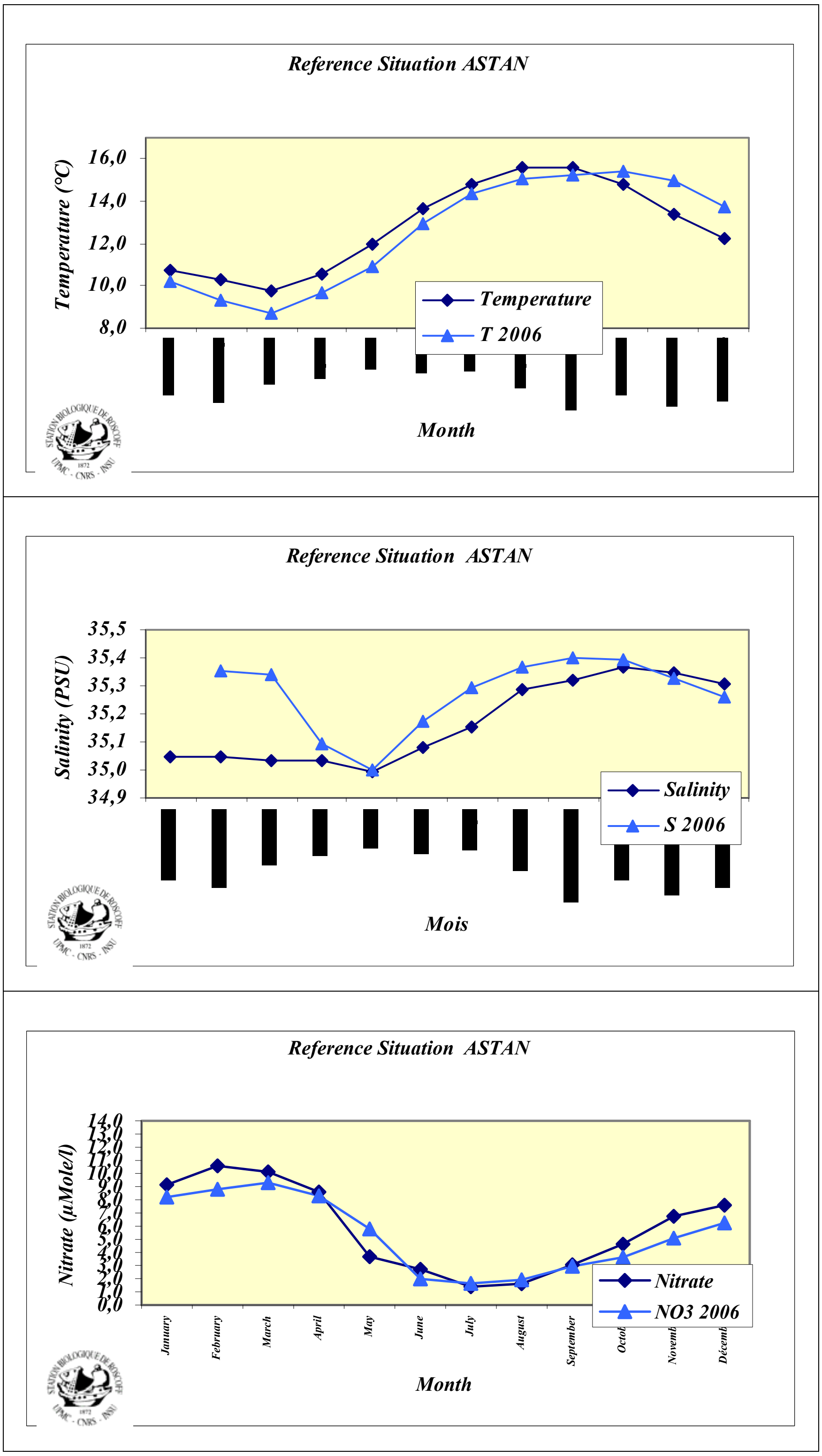


Figure9. Same as left panels of Figure but at the Astan site.

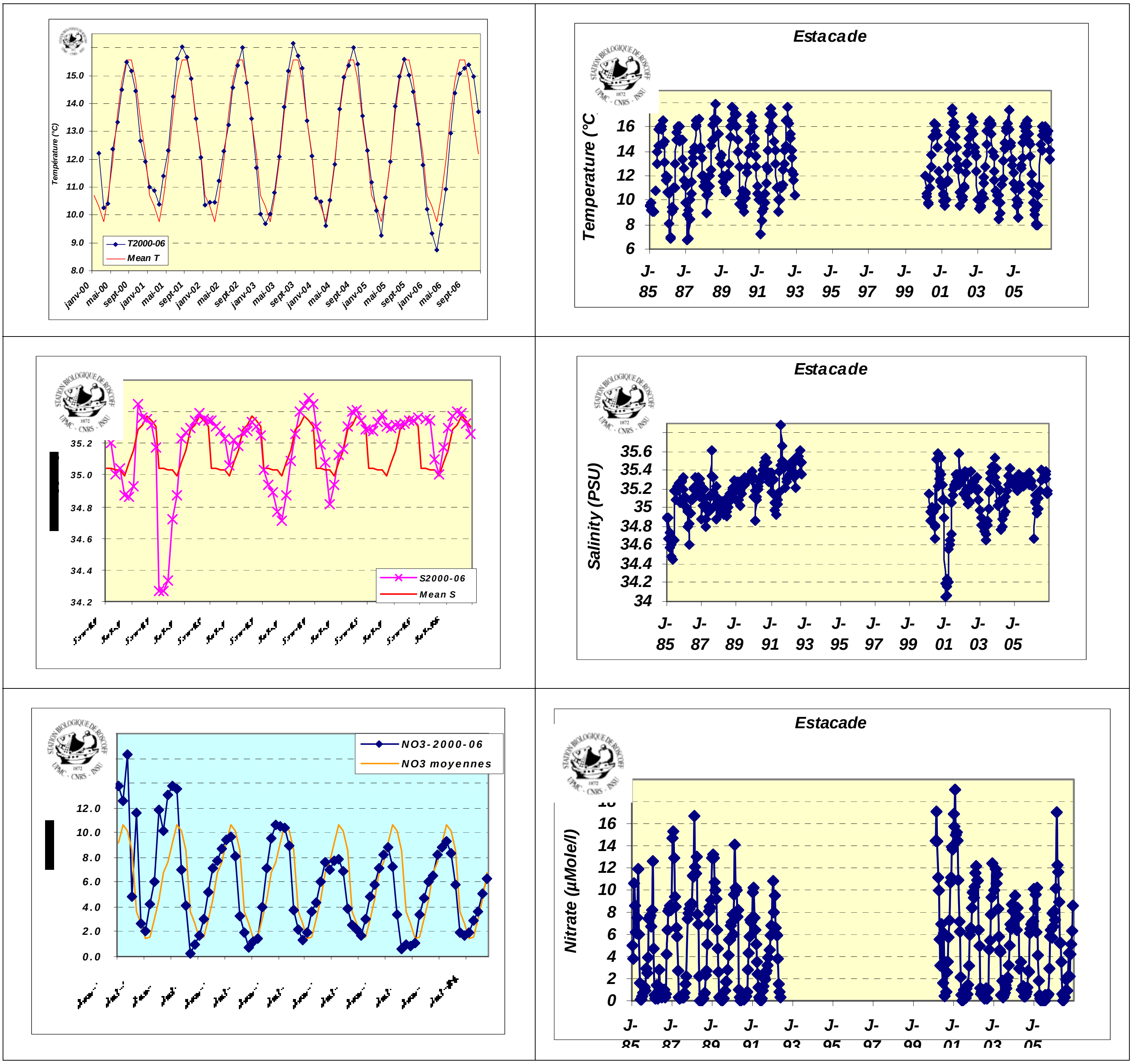


Figure 10. Interannual variability of the temperature, salinity and nitrate at the Astan site over 2000–2006 (left panels) and at the Estacade site over 1985–2006 (right panels).

Wimereux site

Measurements collected twice a month at two stations located on the coastal area of the north coast of France near Wimereux are presented here (green point on Figure 1, and stars on figure 11): station C (1°31’17E, 50°40’75N; near the shore – 1NM -; bottom depth at 26 m) and station L (1°24’60E, 50°40’75N; offshore 5 NM -; bottom depth at 53 m). The later station is less influenced by local continental inputs and is typical of the eastern Channel. Temperature and salinity measurements began in 1995, while measurements of other parameters started 2 years later (Figure and 13). More details can be found at http://www.domino.u-bordeaux.fr/somlit_national/.

Figure 11. Localisation of the two stations (Wimereux-C near the shore and Wimereux-L offshore) of WIMEREUX site (sea green point on Figure 1).

The two temperature records show the same evolution in 2006 (Figures 12, 13). After a very cold winter (coldest on record in these time series), temperature reached near average summer values and is anomalously warm since then. The salinity records show some rather coherent low-frequency variability at the two sites (except in late 1996-early 1997) with low values in 2000 and 2001, followed by an increase in 2002–2003 and usually larger values since then. For instance, at station L, most surface values in 2006 are between 34.5 and 35 pss-78, with a few values exceeding 35 pss-78 (maxima close to 35.25 pss-78). Nitrate records at both stations exhibit usually below average values in the first part of the year, and near normal values later in 2006 (same tendency for silicates, although with a different timing). At L, there was no large spring blooms in 2006 (based on CHla measurements), whereas C exhibited much larger values than at L, although at both stations values were less than in other years during the first part of the year. There is a secondary Chl-a peak at L in the autumn in September-early October.

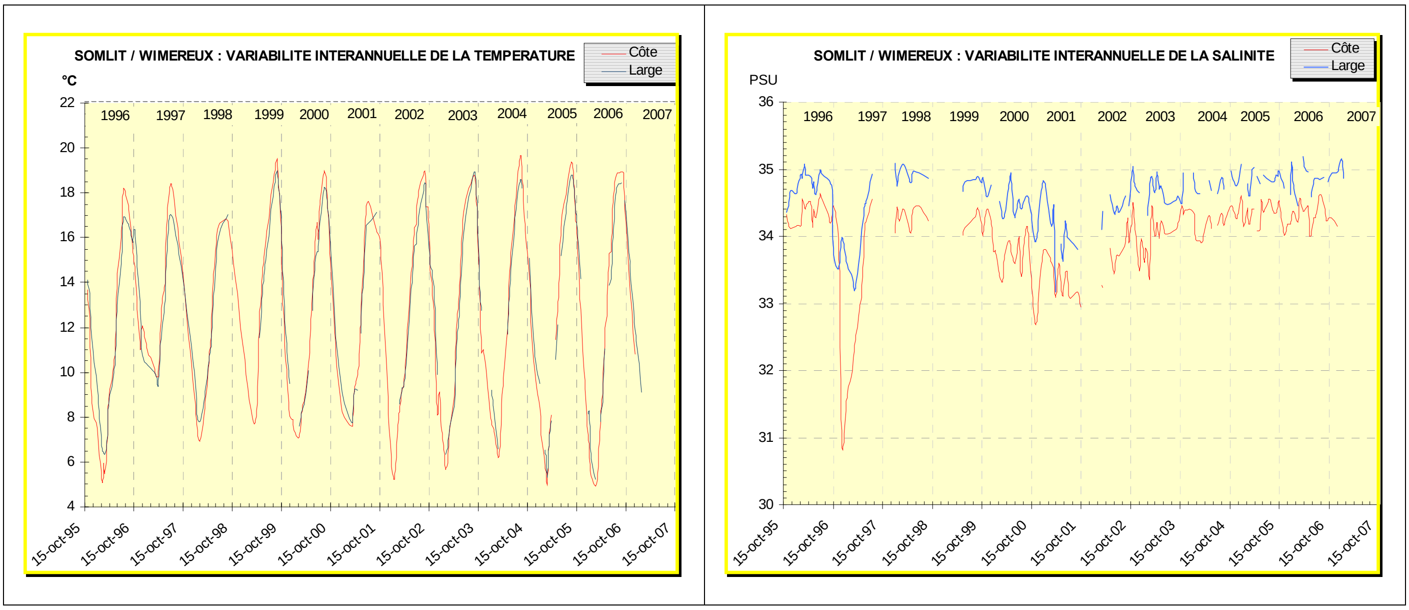
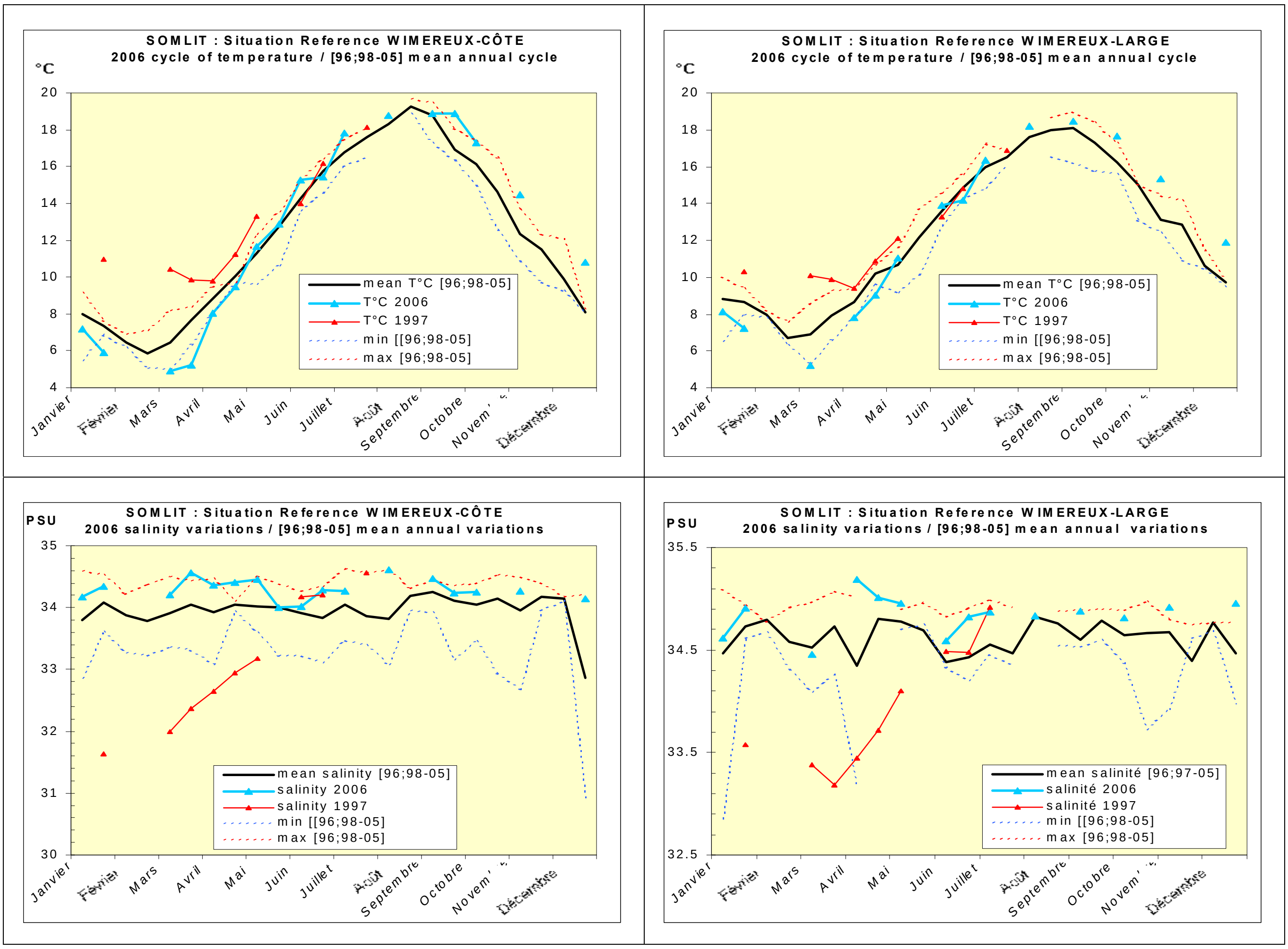


Figure 12. Times series of temperature (left panel) and salinity (right panel) at station C (red curves) and station L (blue curve).



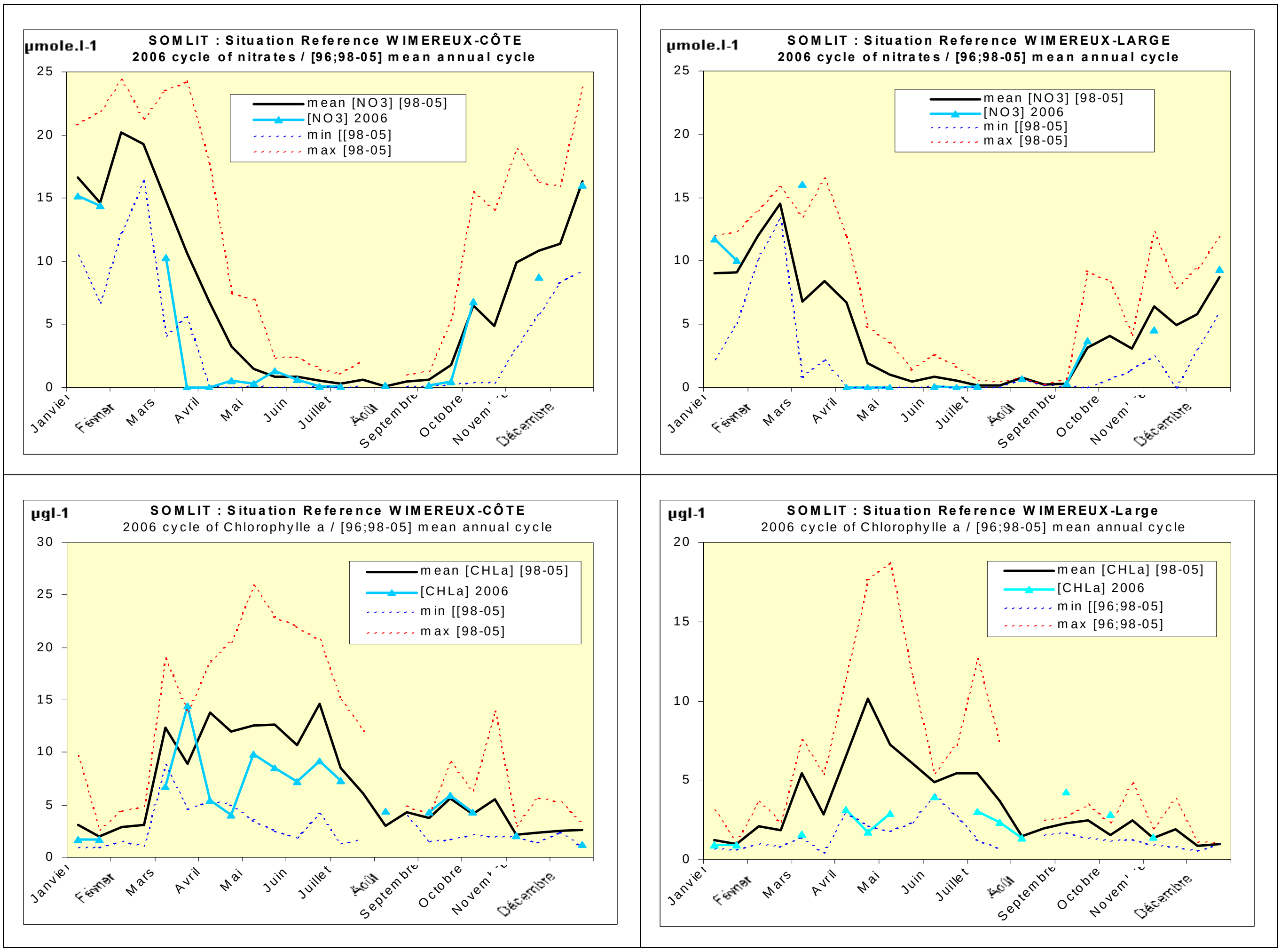


Figure 13. 2006 cycle of temperature (upper), salinity (middle-up), nitrates (middle-down) and chlorophylle a (lower) with the corresponding mean annual cycles at Wimereux-Côte (left panels) and Wimereux-Large (right panels) sites.

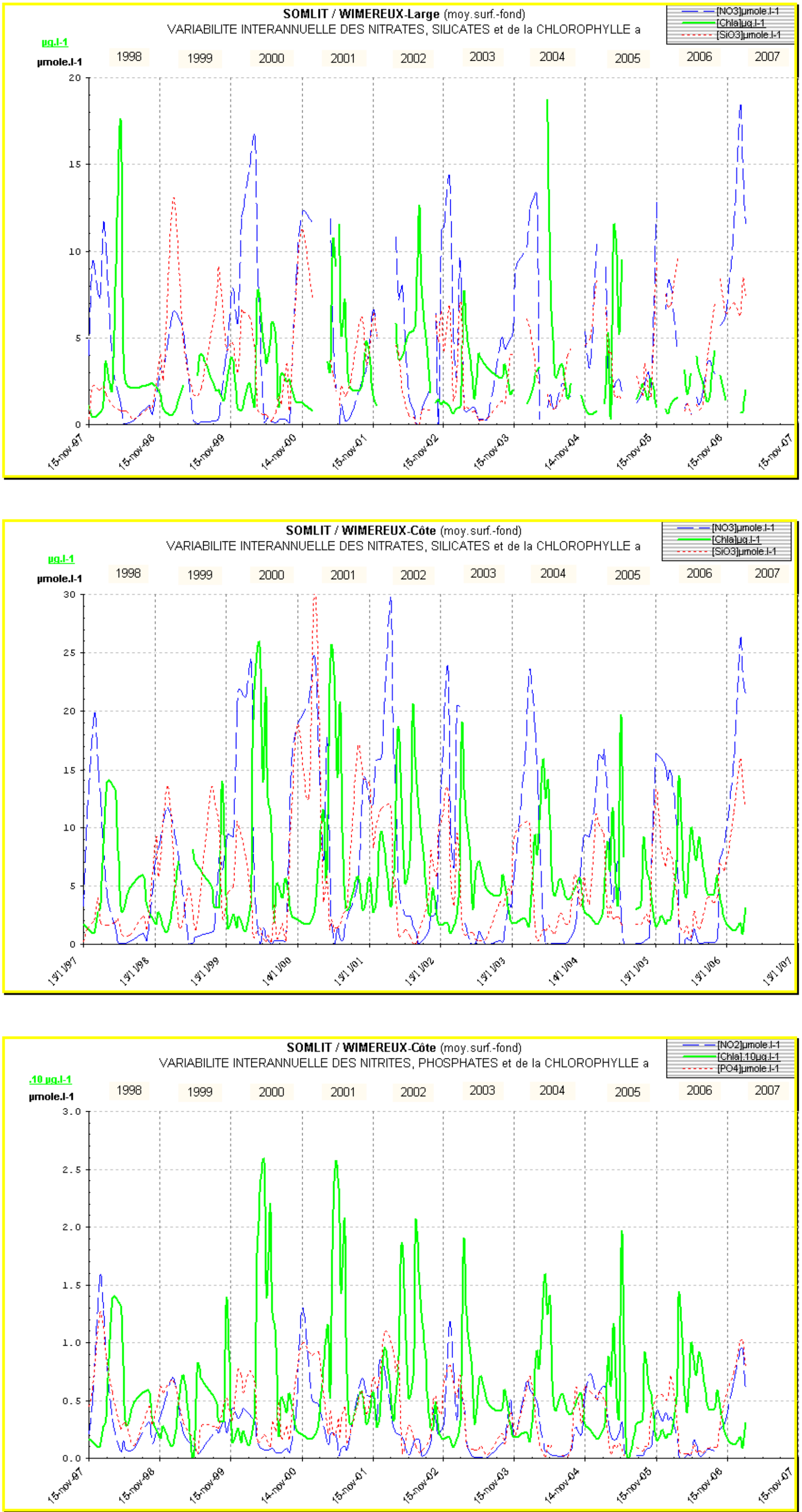


Figure 14. (Upper panel) Time series of nitrate, silicates and chlorophyll at station L (offshore). (Middle panel) Time series of nitrate, silicates and chlorophyll at station C. (Lower panel) Time series of nitrites, phosphates and chlorophyll at station C.

References

Antonov, J. I., Locarnini, R. A., Boyer, T. P., Mishonov, A. V., and Garcia, H. E. 2006. World Ocean Atlas 2005, Volume 2: Salinity. S. Levitus, Ed. NOAA Atlas NESDIS 62, U.S. Government Printing Office, Washington, D.C., 182 pp.

Gaillard, F., Autret, E., Thierry, V., Galaup, P., and Coatanan, C. 2007. An operational system for real time and delayed mode quality control of Argo profiles. Submitted to Journal of Atmospheric and Ocean Technology.

ICES. 2006. Report of the Working group on Oceanic Hydrography (WGOH), 19–22 April 2006, Galway, Ireland. ICES CM 2006/OCC:08., 156 pp.

Lherminier, P., Mercier, H., Gourcuff, C., Alvarez, M., Bacon, S., and Kermabon, C. 2007. Transports across the 2002 Greenland-Portugal OVIDE section and comparison with 1997. In press in Journal of Geophysical Research.

Locarnini, R. A., Mishonov, A., Antonov, V. J. I., Boyer, T. P., and Garcia, H. E. 2006. World Ocean Atlas 2005, Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 61, U.S.

Annex 12: Oceanographic Status Report, North Sea 2006

Working Group on Oceanic Hydrography

Göteborg, March 2007

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

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Content:

- Global Radiation
- Elbe River Run-Off
- North Sea SST and Helgoland Roads Data
- Temperature and Total Heat Content
- Salinity and Total Salt Content
- Secci Depth and Near-Bottom Oxygen
- Monthly averaged Chlorophyll A distributions

Global Radiation

In 2006 the monthly means of global radiation at the East Frisian Island Norderney (Figure 1) was during the first six months very close to the long-term means. The July average exceeded the long-term mean significantly, while in August the global radiation was below the long-term mean due to extensive cloud coverage. From September to December global radiation was again close to the long-term mean.

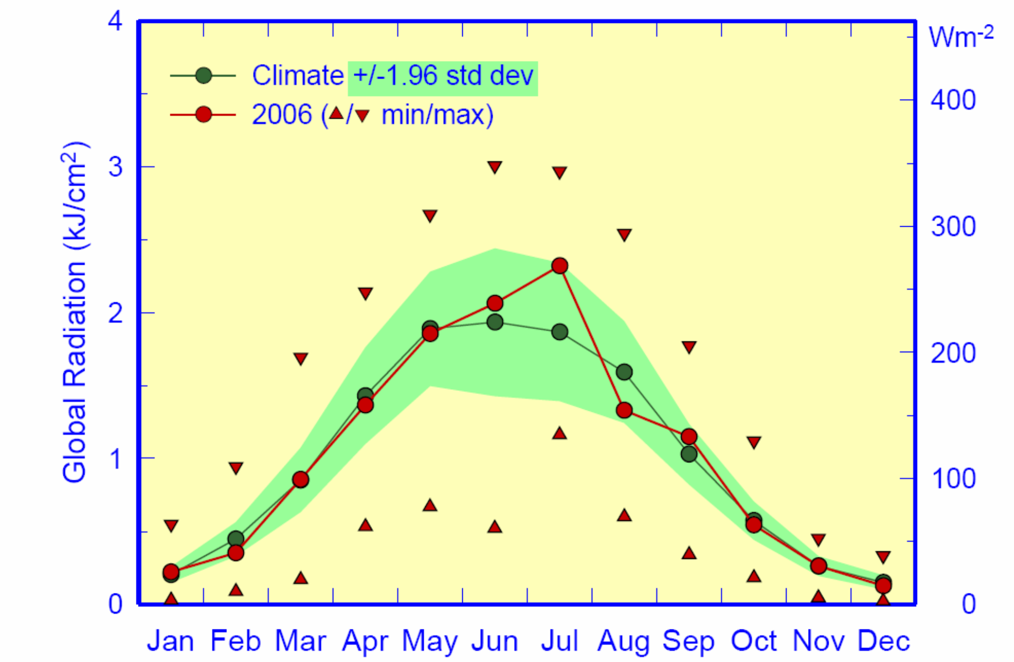


Figure 1. Monthly averaged global radiation at Norderney in 2005 [kJ/cm²]. Data kindly provided by DWD (German Weather Service).

Elbe River Run-Off

During the first three month of 2006 the monthly Elbe river run-off was below the long-term mean (Figure 2). In April the run-off was significantly above the climatology due extraordinary snow falls in winter 2005/2006. In May and June the run-off was still slightly above the long-term mean but below from September until December. The annual mean run-off of the Elbe river in 2006 (Figure 3) was 22.2 km³/year which is very close to the long-term mean of about 22 km³/year. The data were kindly provided by the WSA Lauenburg.

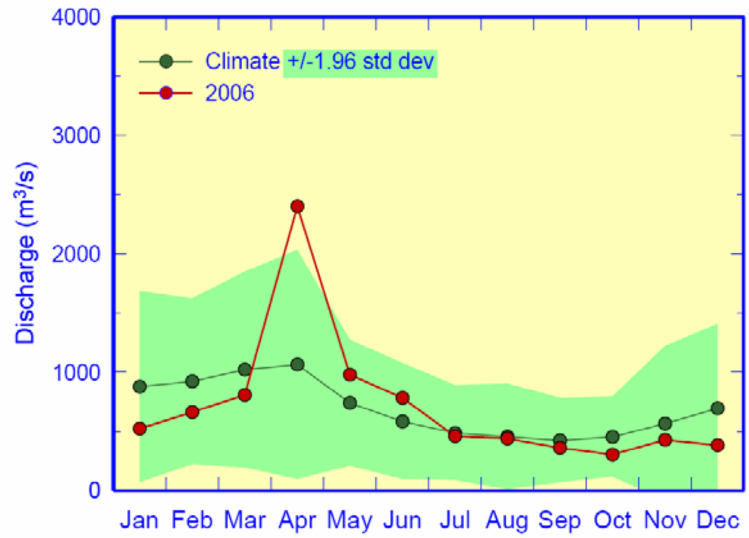


Figure 2. Monthly means of Elbe discharge in 2006.

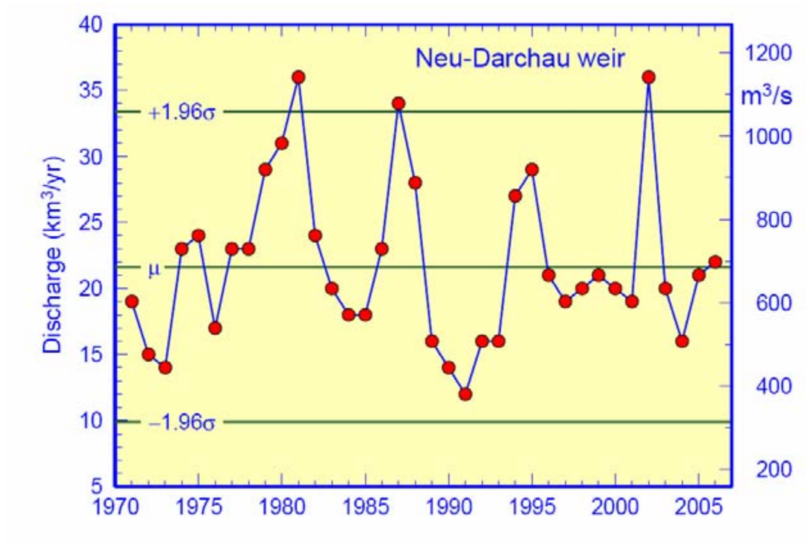


Figure 3. Yearly averaged Elbe run-off 1970–2006.

North Sea SST and Helgoland Roads Data

During the first two month of 2006 the area averaged North Sea SSTs exceeded the long term mean (climatology 1971–1993) distinctively due to the warm temperatures during the last months in 2005 (Figure 4). Between March and June the values were comparable to the climatological means. From July on the SSTs exceeded the climatology significantly with October and December being the warmest since the beginning of these observations in 1971.

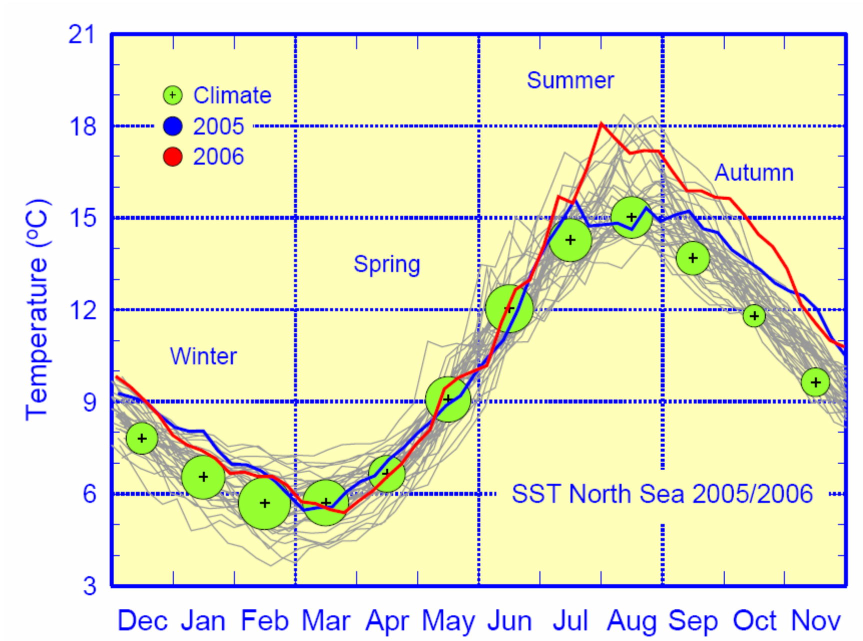


Figure 4. Weekly means of averaged North Sea SST from December 2005 until November 2006 (red line) and from December 2004 until November 2005 (blue line). The black lines are the annual cycles back to 1968. The green circles give the long-term mean, the radius gives the interannual standard deviation for the period 1971–1993.

Table 1 summarises the values for monthly anomalies from January 2005 to December 2006. In both years the temperatures during the late summer and fall have been significantly above the long-term mean.

Table 1. North Sea SST anomalies relative to the climatology 1971–1993.

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	0.6	1.0	0.8	0.5	1.3	-0.3	-0.9	0.3	0.8	0.9	0.7	0.9
2001	0.6	0.5	0.1	0.0	0.2	-0.3	1.0	0.8	0.8	1.3	1.3	0.8
2002	0.5	1.5	1.2	1.1	0.6	0.9	0.7	2.4	2.5	1.2	0.4	0.1
2003	0.3	0.4	0.5	0.7	0.9	1.7	1.7	2.5	2.1	1.1	0.9	1.3
2004	0.8	0.9	0.6	0.8	0.6	0.5	0.3	2.1	1.5	0.6	0.9	1.2
2005	1.2	0.8	0.0	0.5	0.0	-0.3	0.5	-0.1	1.2	1.5	1.9	1.2
2006	0.7	0.8	-0.1	-0.1	0.2	-0.2	1.7	2.2	2.2	2.4	1.7	1.7
2007	1.7											

North Sea SST anomaly: <0°C, >1.5°C, >2.0°C

This is also evident in the Helgoland Roads data (Figure 5): The warm period starting in 1988 is still holding up. The summer periods became longer and warmer and the winters became less cold. The amplitude-decrease of the annual cycle of sea surface salinity, beginning in the mid-nineties, could still be observed in 2006.

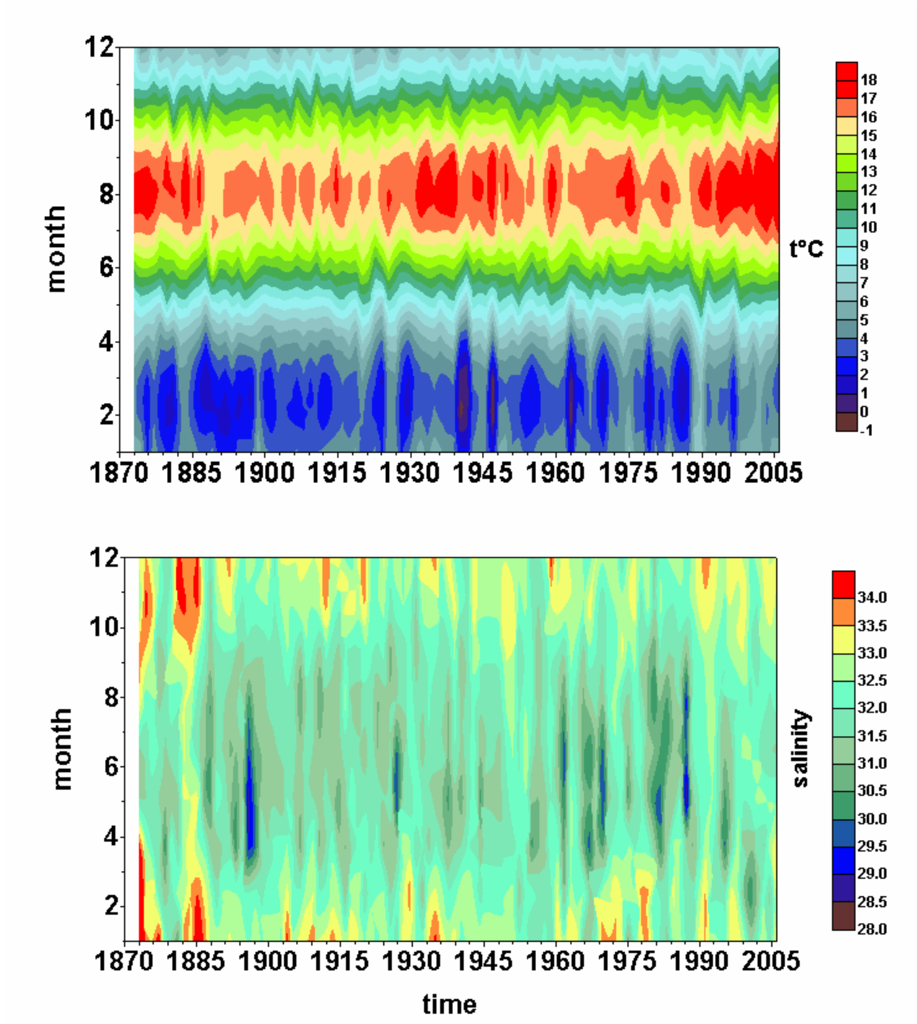


Figure 5. Helgoland Roads temperature and salinity time series. Gaps in the time series are closed by correlation and substitution with light vessel data. Data: P.Mangelsdorf / Karen WiltshireAlfred-Wegener-Institut für Polar- und Meeresforschung (AWI), Biologische Anstalt Helgoland.

Temperature and Total Heat Content (GAUSS summer cruise)

Temperature and heat content data discussed in this section are based upon vertical CTD profiles (stations) and *Delphin* data, a towed CTD-system which is oscillating between near-surface and near-bottom depths during the transits between CTD stations.

The near-surface temperature in Figure 6 exhibits the typical gradient with increasing temperatures from the open northern boundary towards the inner German Bight. The spatial pattern is comparable to 2005 but the temperatures are about 1°C warmer at the northern boundary and about 3°C warmer at the southern coast. The monthly averaged SST for August 2006 has a positive anomaly of 2.2°C but a negative anomaly of –0.1°C in August 2005 due to extensive cloud coverage.

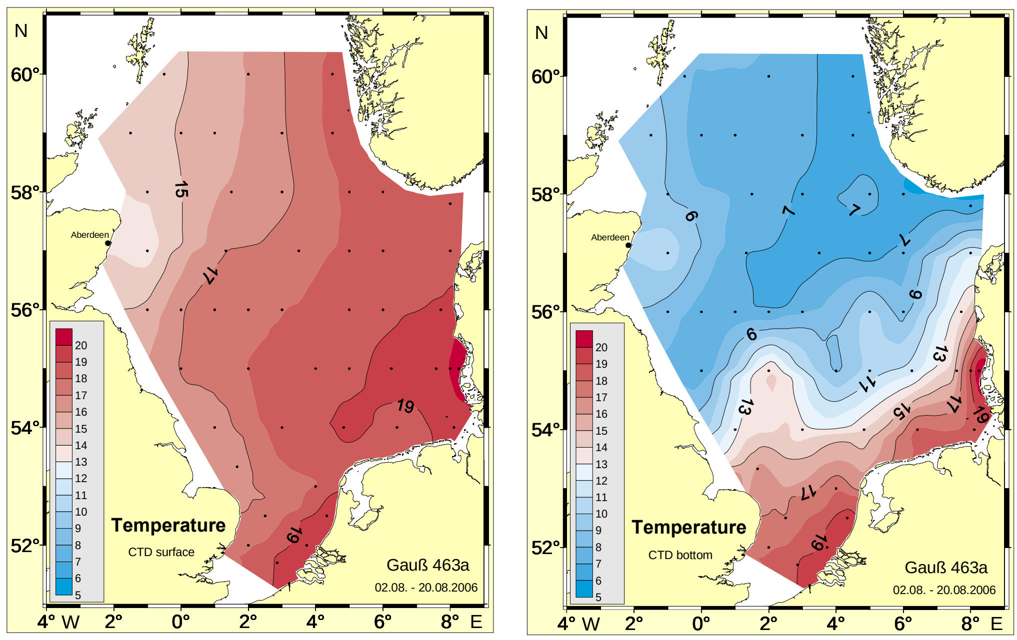


Figure 6. Horizontal temperature distribution near the surface (left) and bottom (right) [°C], GAUSS cruise 463a, 2–j20 August 2006.

The near-bottom temperature in 2006 (Figure 6, right) show higher values compared to 2005 close to the southern coast, here the water column is vertically mixed, but colder water in the central and northern North Sea. However, the near-bottom temperatures are generally still above the long-term mean.

Figure 7 shows the heat content per unit volume for the last four GAUSS summer cruises, related to the masked area. Table 2 gives the total North Sea heat content for the last eight years which is steadily decreasing since 2003, though the SSTs are still increasing and setting new records (compare Table 1).

Table 2. Total heat content during Gauss summer cruises from 1999–2006.

time	total heat content [J]	cruise	rank
09. July 1999	1.359×10^{21}	G335	8
16. Aug 2000	1.497×10^{21}	G353	6
27. July 2001	1.364×10^{21}	G370	7
25. July 2002	1.517×10^{21}	G385	5
04. Aug 2003	1.625×10^{21}	G405	1
12. Aug 2004	1.594×10^{21}	G425	2
23. Aug 2005	1.550×10^{21}	G446	3
11. Aug 2006	1.520×10^{21}	G463	4

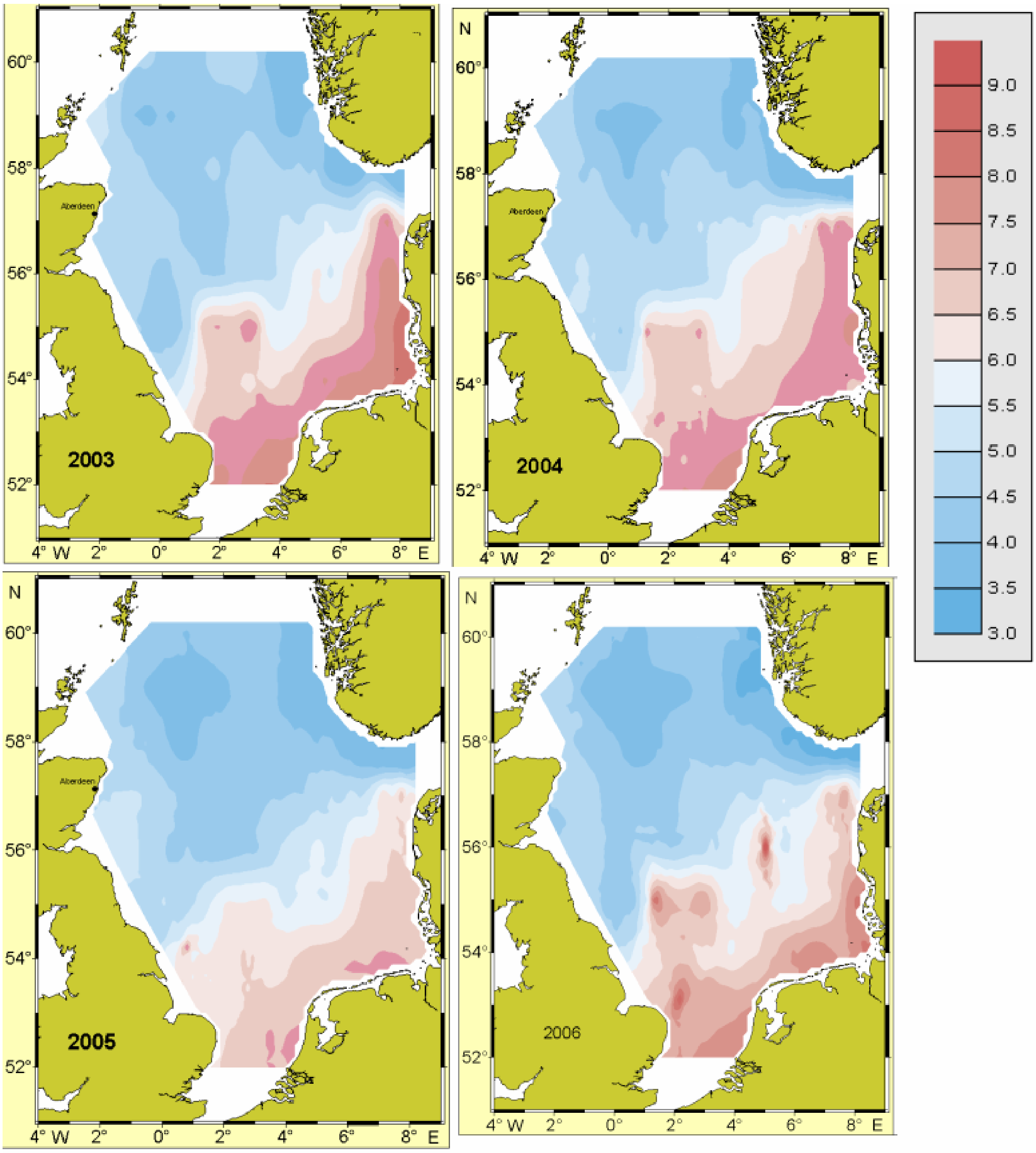


Figure 7. Heat content per unit volume in J x 10^7/m³, evaluated from GAUSS summer cruises 2003–2006.

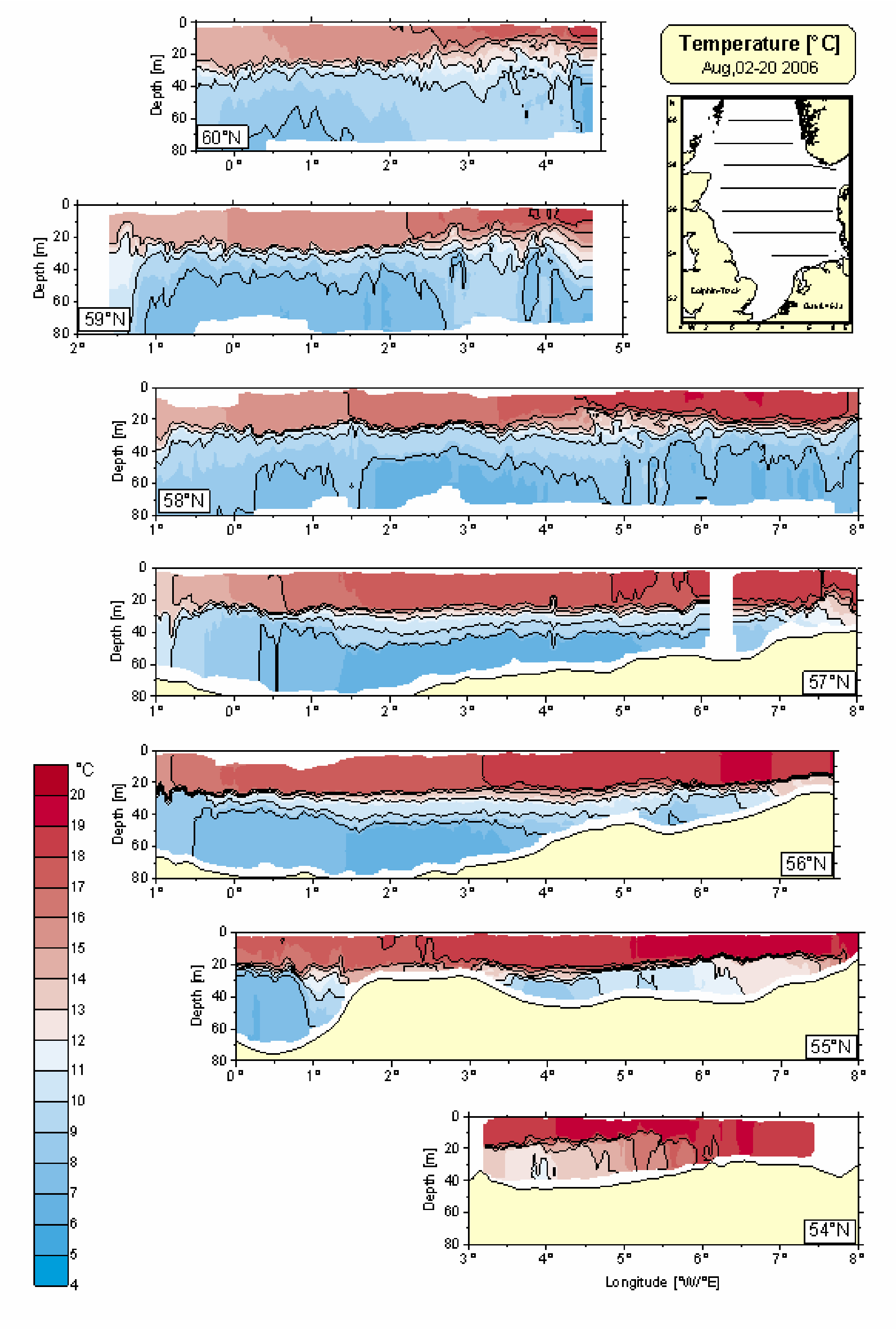


Figure 8. Temperature section from GAUSS cruise 463a, 2–20 August 2006.

The zonal (east-west) temperature sections shown in Figure 8 exhibit a distinctive thermocline between 54 and 58° N with unusual high temperatures in the upper mixed layer of the central North Sea. However, compared to previous years the upper mixed layer is thinner. At the 54 and 55° N section the water column is vertically mixed down to the bottom close to the eastern coast and above the Dogger Bank. At the northern section (59 and 60° N) the thermocline is less distinctive and surface temperatures are decreasing.

A comparison of all 58°N temperature sections from 1998 to 2006 is given in Figure 9. Obvious is a great year to year variation concerning the sharpness of the thermocline and the thickness of the upper mixed layer. Striking is the 2003 section with a mighty and very warm mixed layer and with high temperatures extending far to the west compared to other years.

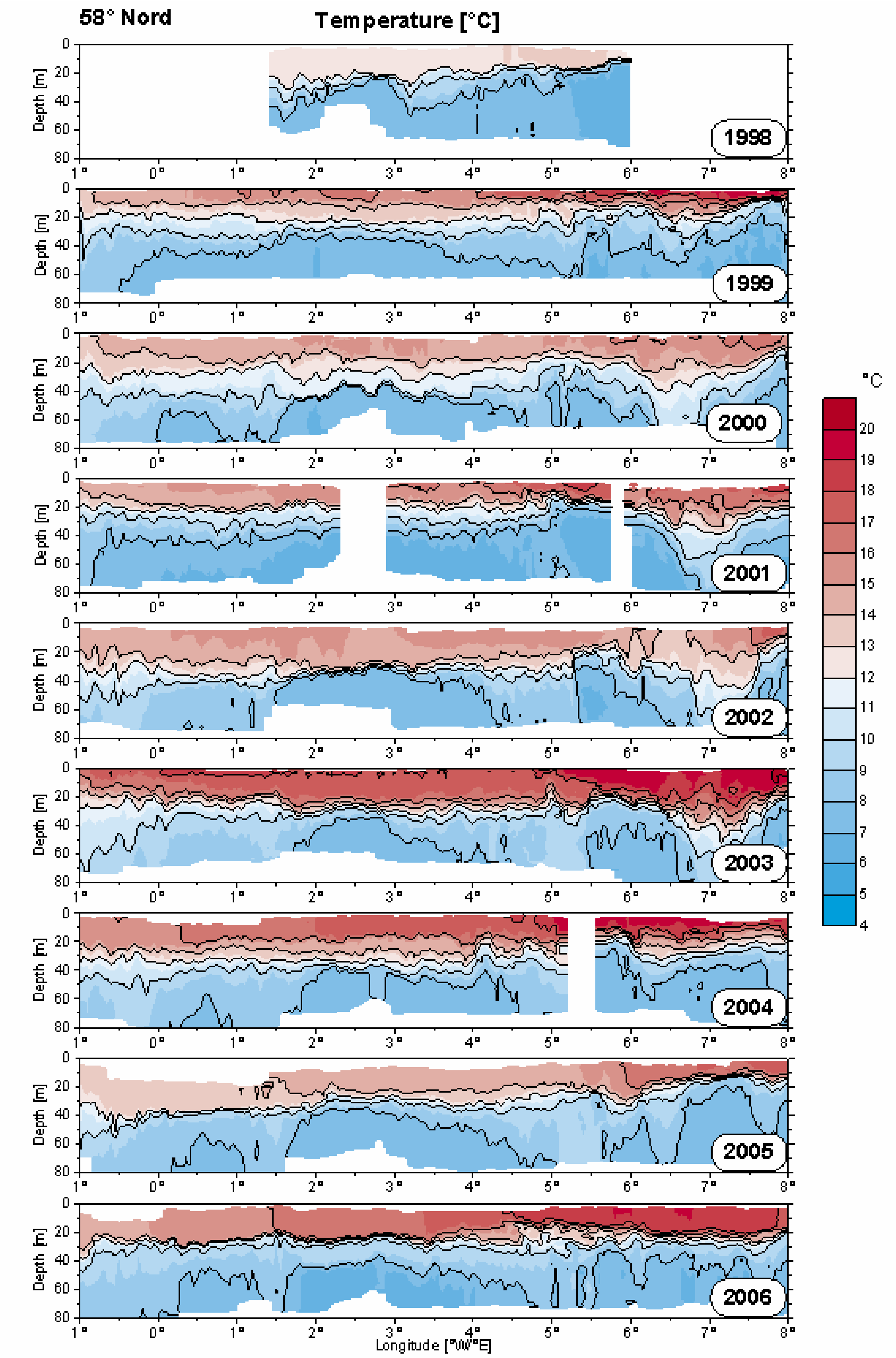


Figure 9. Temperature sections along 58°N from 1998 until 2006.

Salinity Distribution and Total Salt Content (GAUSS summer cruise)

The salinity distributions and total salt contents shown in this section are also based upon vertical CTD profiles (stations) and *Delphin* data.

Compared to 2005 the near-surface salinity distribution (Figure 10, left) shows a strong tongue of Atlantic water with salinity above 35 expanding far into the central North Sea. The ribbon of less saline water (S<34) generated by continental river run-off and the Baltic outflow is smaller than in 2005.

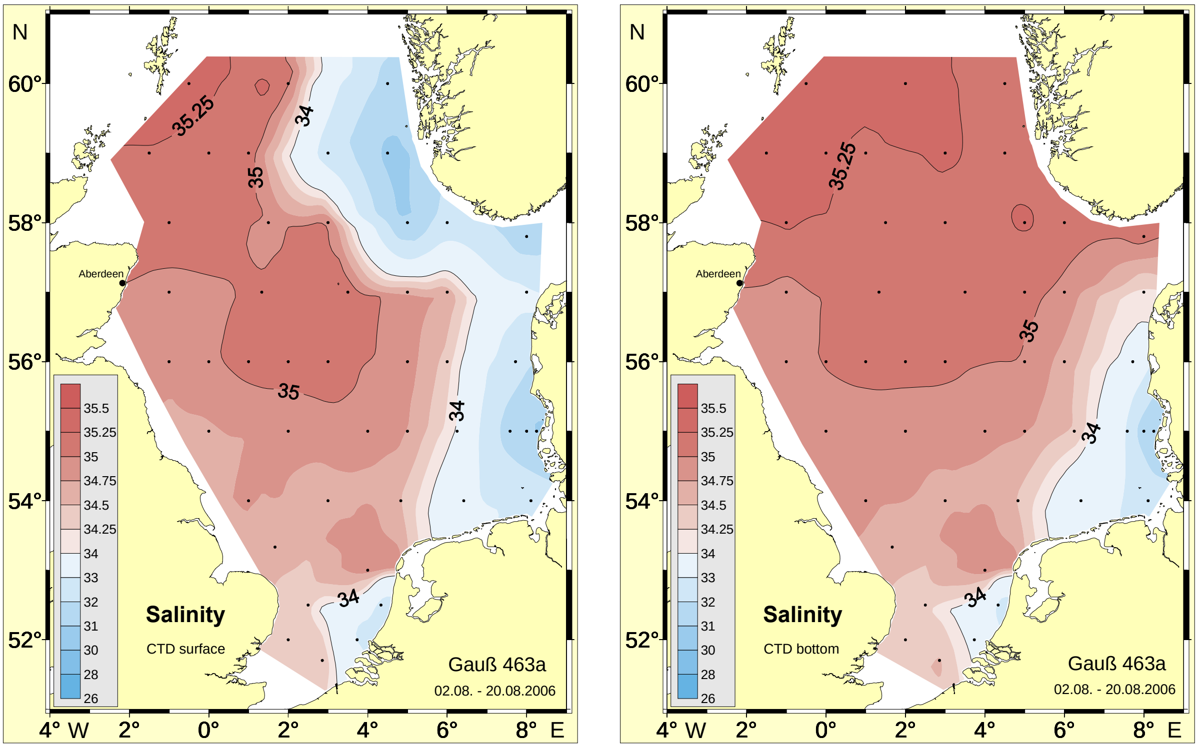


Figure 10. Horizontal salinity distribution near the surface (left) and bottom (right), GAUSS cruise 463a, 2–20 August 2006.

Near the bottom (Figure 10, right) the water in the northern and central North Sea is fresher in 2006 while the salinity along the German and Danish coast is comparable in both years. Table 3 shows that the salt content is gradually increasing from 2002 until 2005, indicating an increasing influence of the Atlantic during these years. However, from 2005 to 2006 the salt content decreased to its 2003 value.

Table 3. Total salt content during Gauss summer cruises from 2002–2006.

time	total salt content [t]	cruise	rank
25. July 2002	1.135×10^{12}	G385	4
04. Aug 2003	1.138×10^{12}	G405	3
12. Aug 2004	1.148×10^{12}	G425	2
23. Aug 2005	1.153×10^{12}	G446	1
11. Aug 2006	1.138×10^{12}	G463	3

The zonal (east-west) salinity sections of Figure 12 show a distinctive stratification between the fresher Baltic outflow (S<34, 58–60°N) and North Sea water. Along 58° N its western expansion reaches towards 4.5° E only compared to 2° E in 2005.

Figure 13 shows salinity sections along 58°N from the summer cruises for the years 1998–2006. The increasing salinity concentrations along the Scottish coast and at the eastern part of the sections below the fresher Baltic Sea run-off observed during the last years could not be observed in 2006 and is only noticeable in a small ribbon close to the Scottish Coast

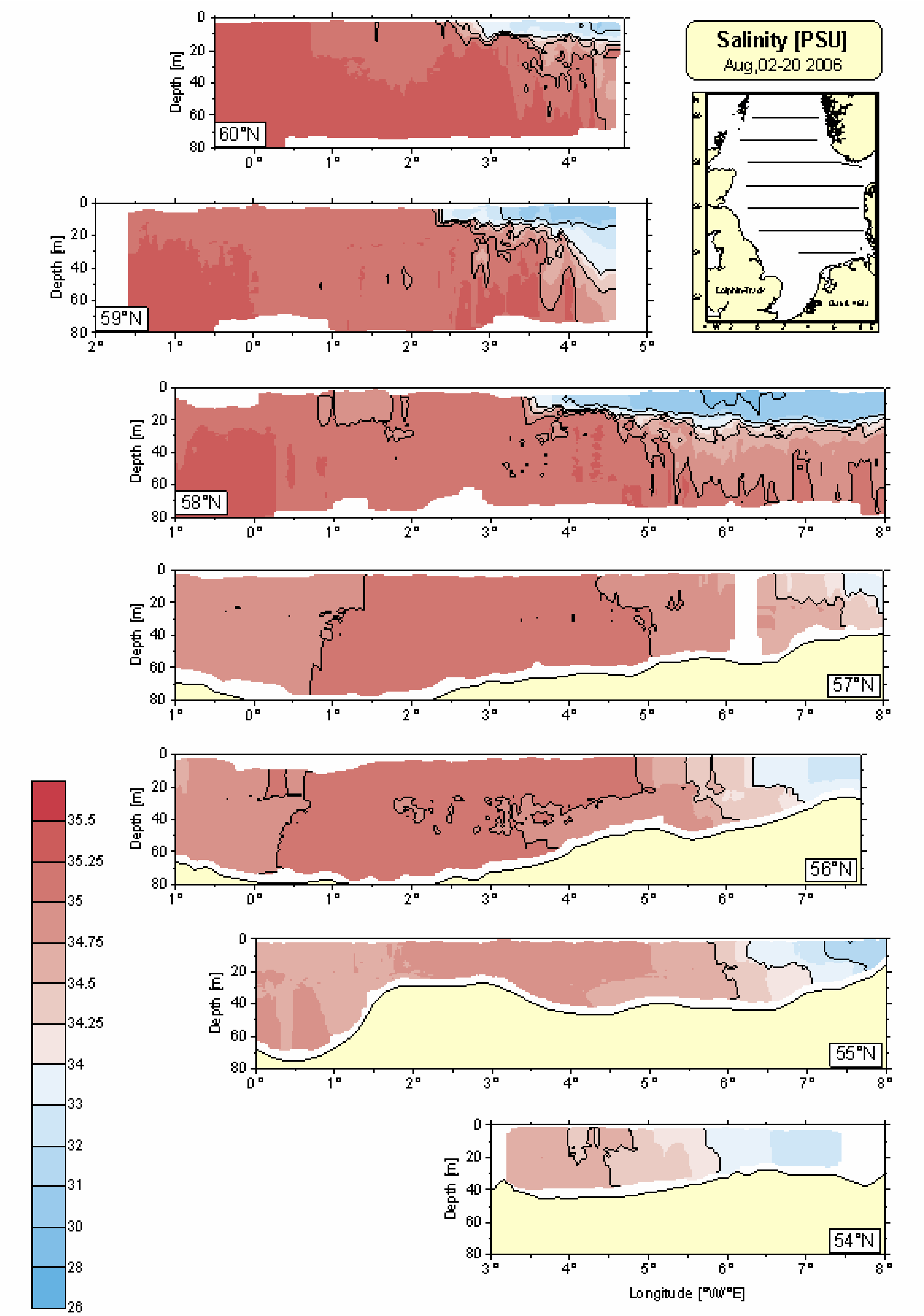


Figure 12. Salinity sections from GAUSS cruise 463a, 2–20 August 2006.

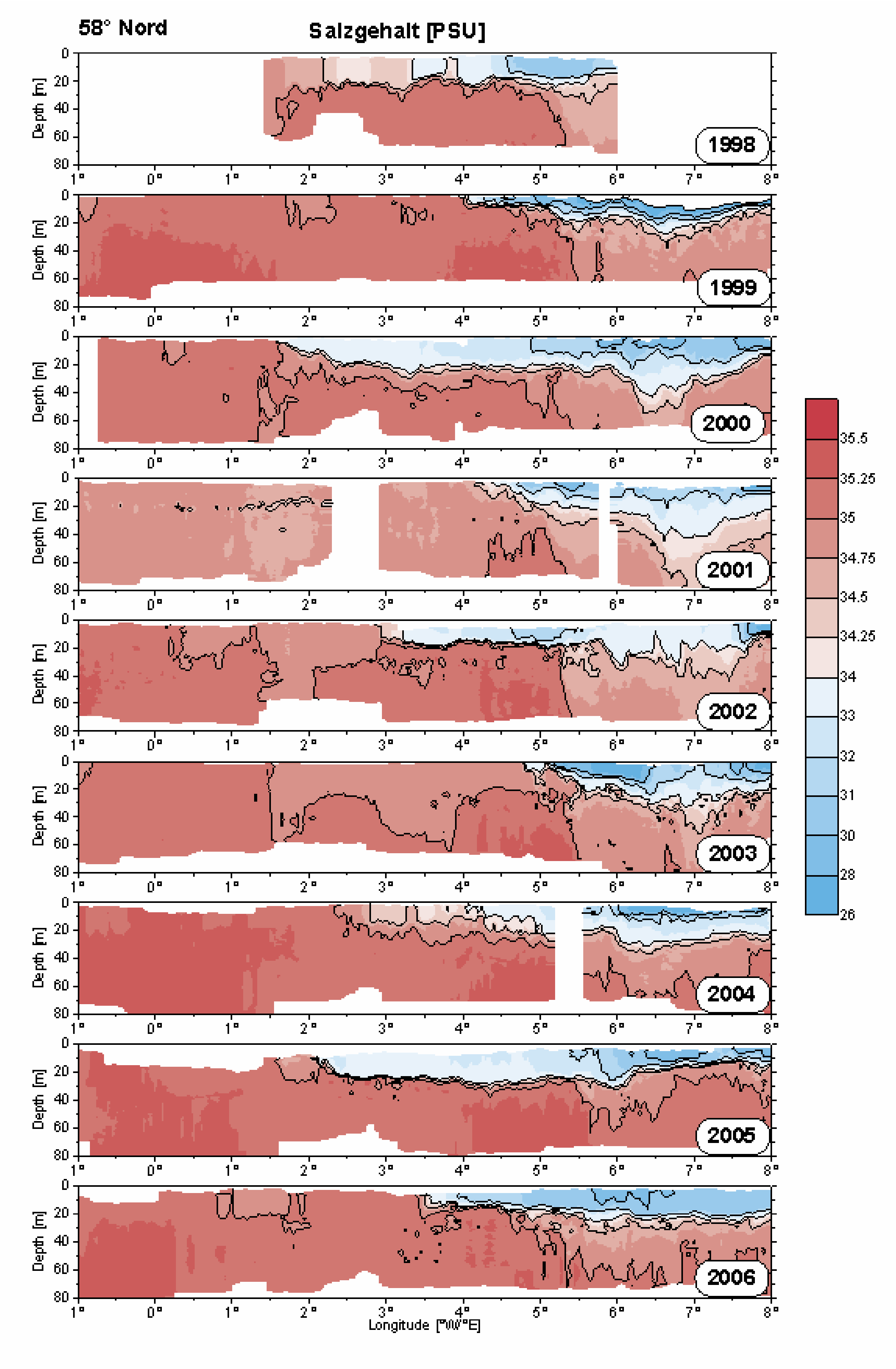


Figure 13. Salinity sections along 58°N from 1998 until 2006.

Secci-Depth and Near-Bottom Oxygen Distribution

Figure 14 shows the Secchi-depth during the GAUSS summer cruise. The maxima of Secchi depths coincide with regions of high saline – and obviously clearer - Atlantic water.

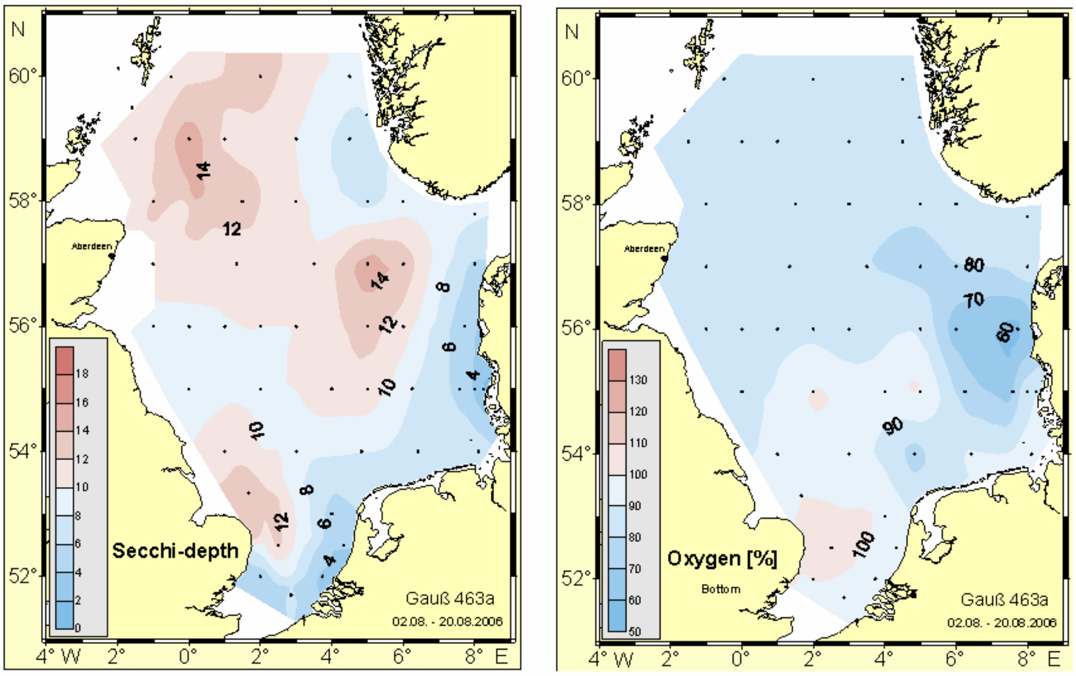


Figure 14. Left: Secchi-depth [m], right: near-bottom oxygen distribution [%], GAUSS cruise 463a, 2–20 August 2006.

The oxygen saturation below the thermocline was unusually high for August. Only in a small area west off Jutland the saturation fell below 80% with a local minimum of 54%. Not until oxygen saturation falls below 40% marine life experience substantial stress.

Monthly Averaged Chlorophyll A Distribution

The monthly averaged chlorophyll A distributions of the North Sea are show in Figures 15 – 17. The data are from the MEdium Resolution Imaging Spectrometer Instrument (MERIS) of the ENVISAT satellite. To improve the resolution a logarithmic scale is used.

There are no data in January and December due to cloud coverage and there are greater spatial gaps due to clouds in February and November. A noticeable chlorophyll production starts in February along the coast of the southern North Sea and in the German Bight. The maximum chlorophyll extension occurs in Mai with a bloom covering the whole German Bight. During spring and autumn there are high concentrations in association with the East Anglia sediment plume and around the Dogger Bank (March and April).

Due to the extraordinary high temperatures during autumn 2006 with SST anomalies between 1.7–2.4 °C there are still high chlorophyll concentrations in the German Bight and along the East Anglia coast in November.

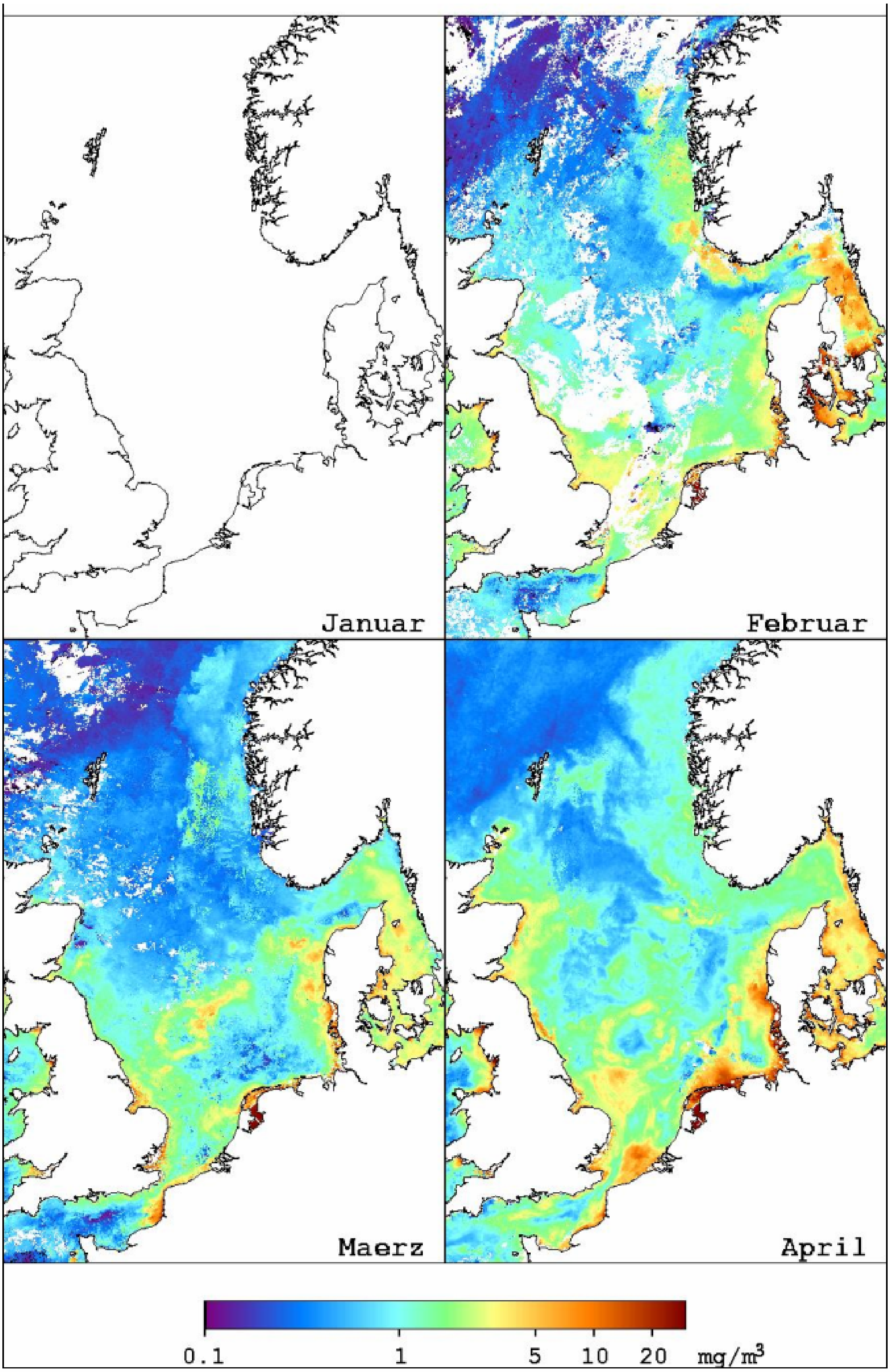


Figure 15. Monthly averaged Chlorphyll A distribution (MERIS) for January, February, March, and April, 2006.

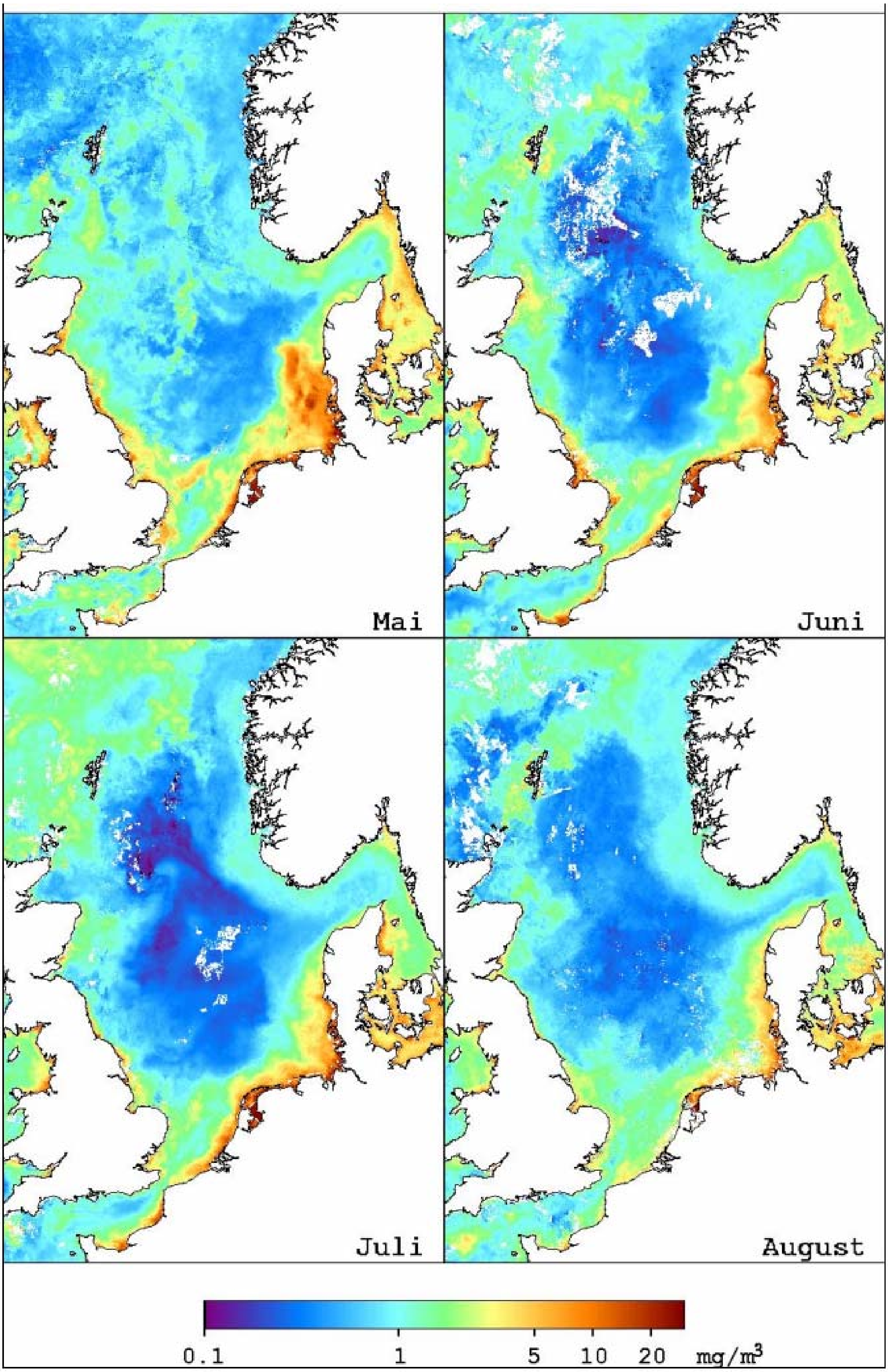


Figure 16. Monthly averaged Chlorphyll A distribution (MERIS) for May, June, July, and August, 2006.

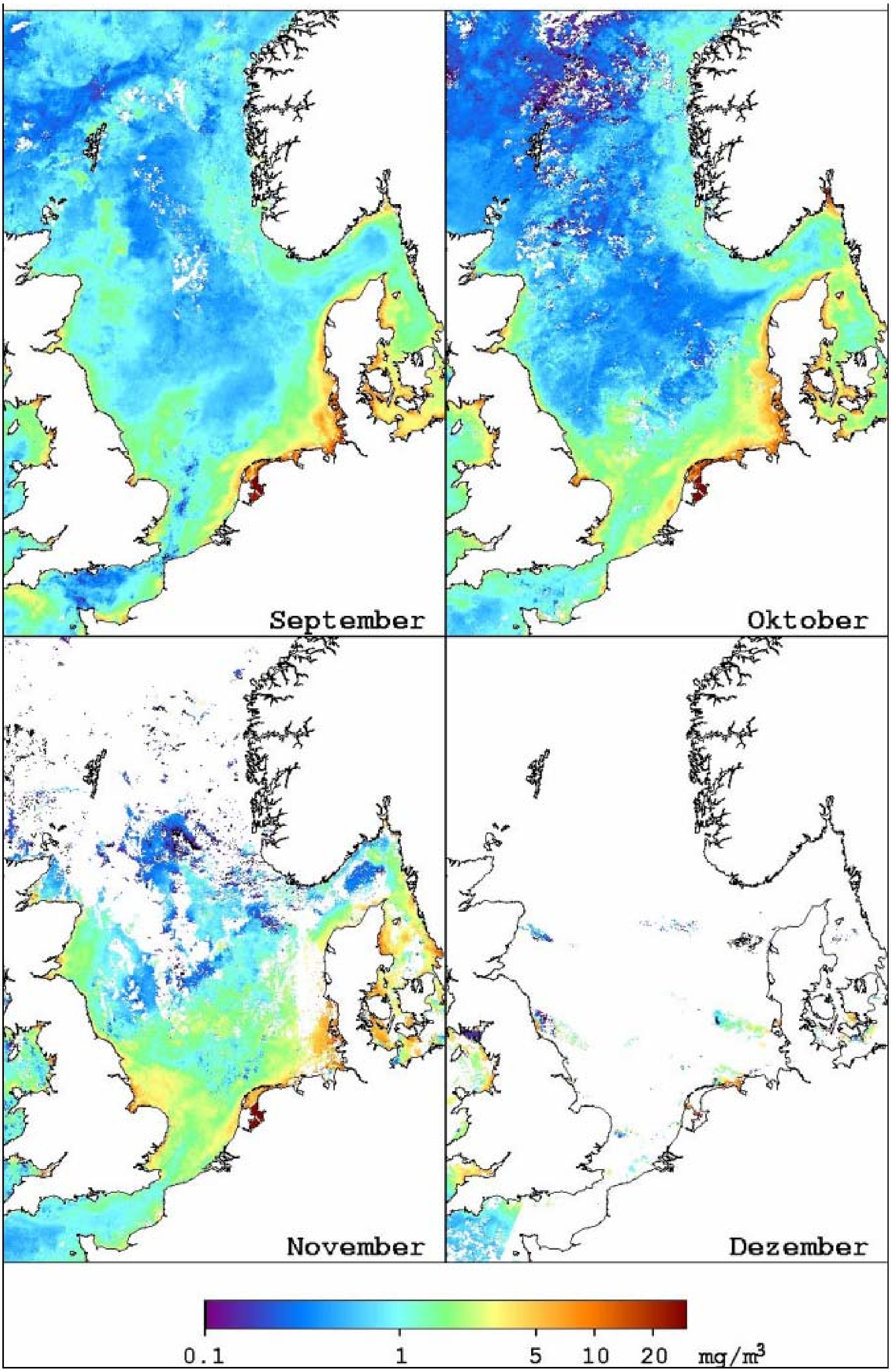


Figure 17. Monthly averaged Chlorphyll A distribution (MERIS) for September, October, November, and December, 2006.

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

By: Karin Borenäs

The mean atmospheric temperature was higher than normal for the year 2006, due to an unusually warm second half of the year. The winter was cold and prolonged in the south, but milder in the north. March was in general colder than normal. The summer and fall was warm with many temperature records set in September. A short period of cold weather around the turn of the month October/November was followed by a much warmer than normal December. The precipitation over Sweden was above mean during the fall, especially on the west-coast where flooding took place.

Annual cycles of temperature and salinity

A large number of hydrographic stations are regularly visited in the Baltic Sea, the Kattegat and the Skagerrak, as exemplified in Figures 1 and 2. Sea-surface temperatures were close to normal in the beginning of the year but the cold period in March in the southern parts of the area lowered the temperatures below normal in Skagerrak, Kattegat and the southern Baltic Sea (see i.e. Å17 in Figure 3). Summer temperatures were above normal in the whole region. The beginning of the fall was close to normal while in October the sea-surface temperatures were higher than normal, especially in the Baltic Sea. In the Archipelago Sea and the Northern Quark the values were record high for the last 30 years (see Figure 4). After a normal November, December was again above mean, but mainly so in Skagerrak and Kattegat. This feature is clearly shown in Figure 4, showing the SST anomaly for December 1 relative to the 15-year period 1990–2004.

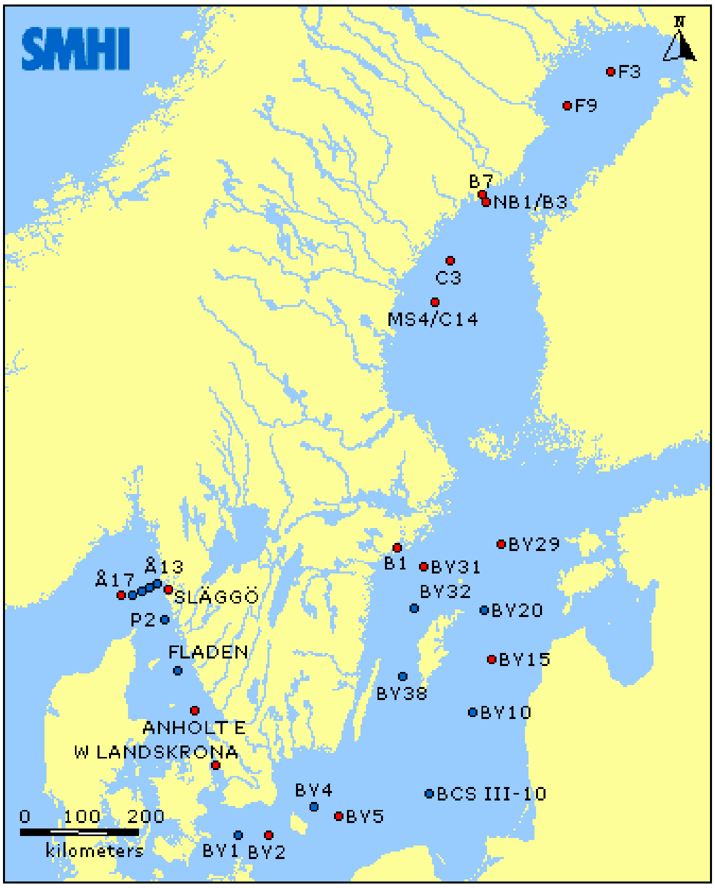


Figure 1. Position of stations visited on a regular basis. Stations marked with red pertain to the Swedish National Monitoring Programme while stations in blue are additional stations sampled by SMHI.

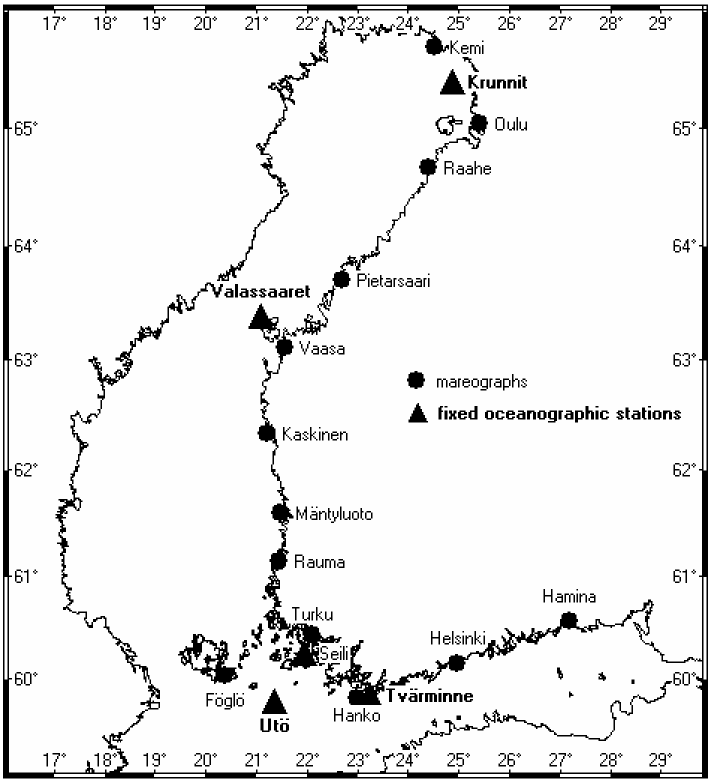
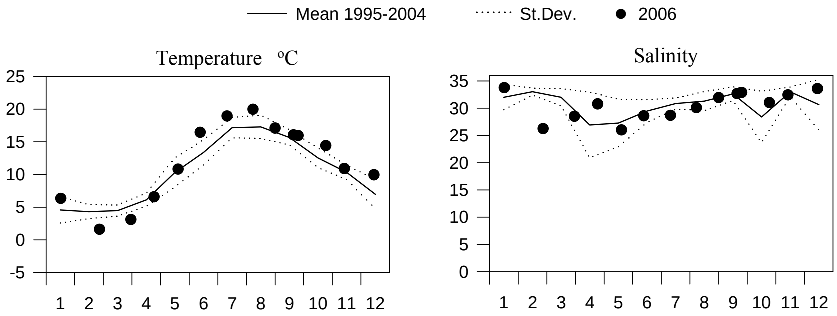


Figure 2. Finnish fixed oceanographic stations and sea level stations (mareographs).

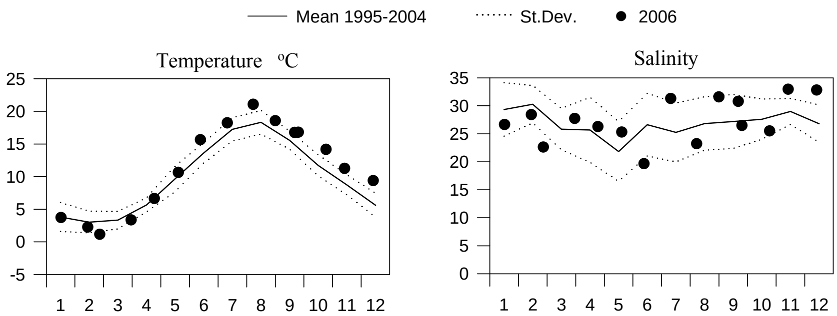
STATION Å17 SURFACE WATER

Annual Cycles



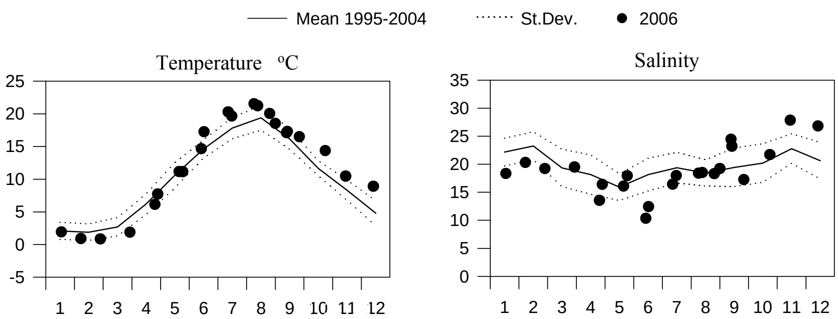
STATION P2 SURFACE WATER

Annual Cycles



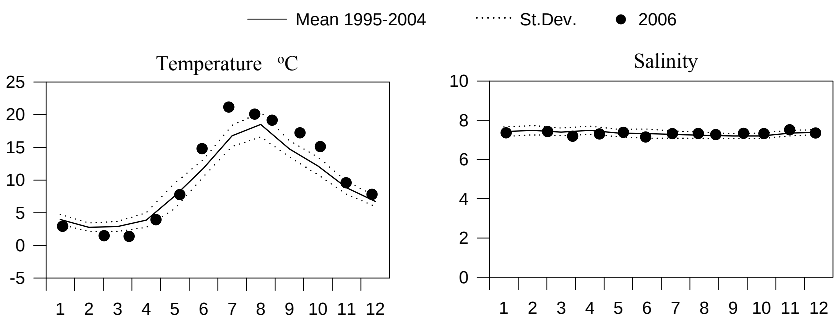
STATION ANHOLT E SURFACE WATER

Annual Cycles



STATION BY5 SURFACE WATER

Annual Cycles



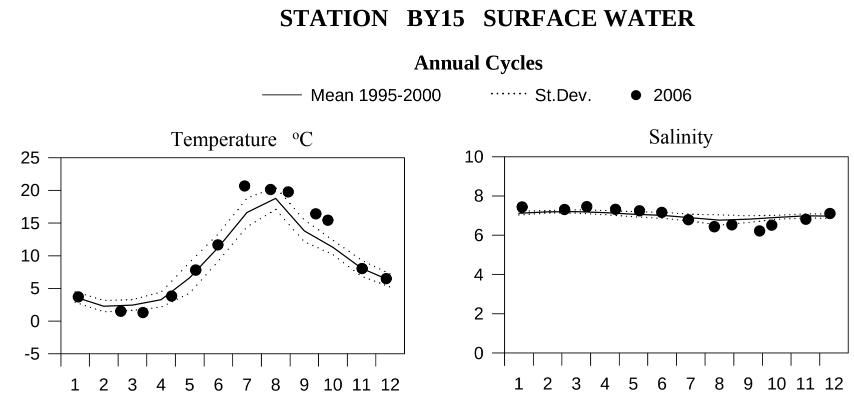


Figure 3. Annual cycles of temperature and salinity, see Fig.1 for station positions.

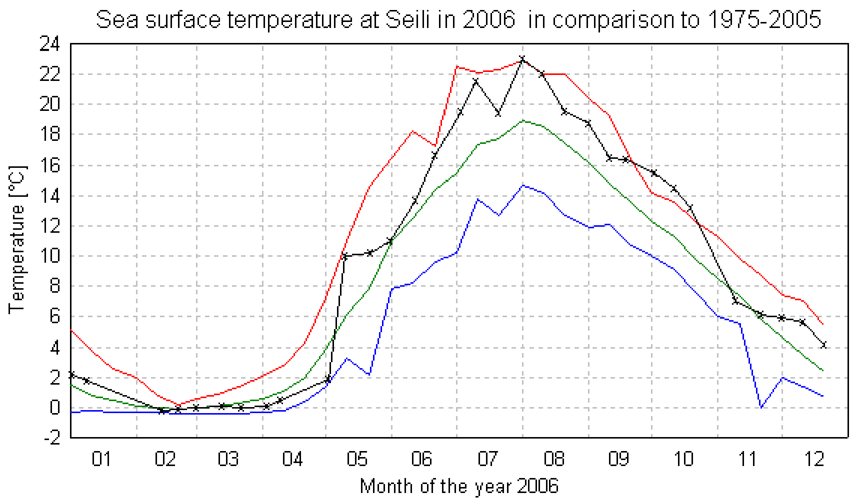


Figure 4. Sea surface temperature at Seili in 2006 (black line) compared to the average (green) and extreme values (red maximum, blue minimum) of the period 1975–2005.

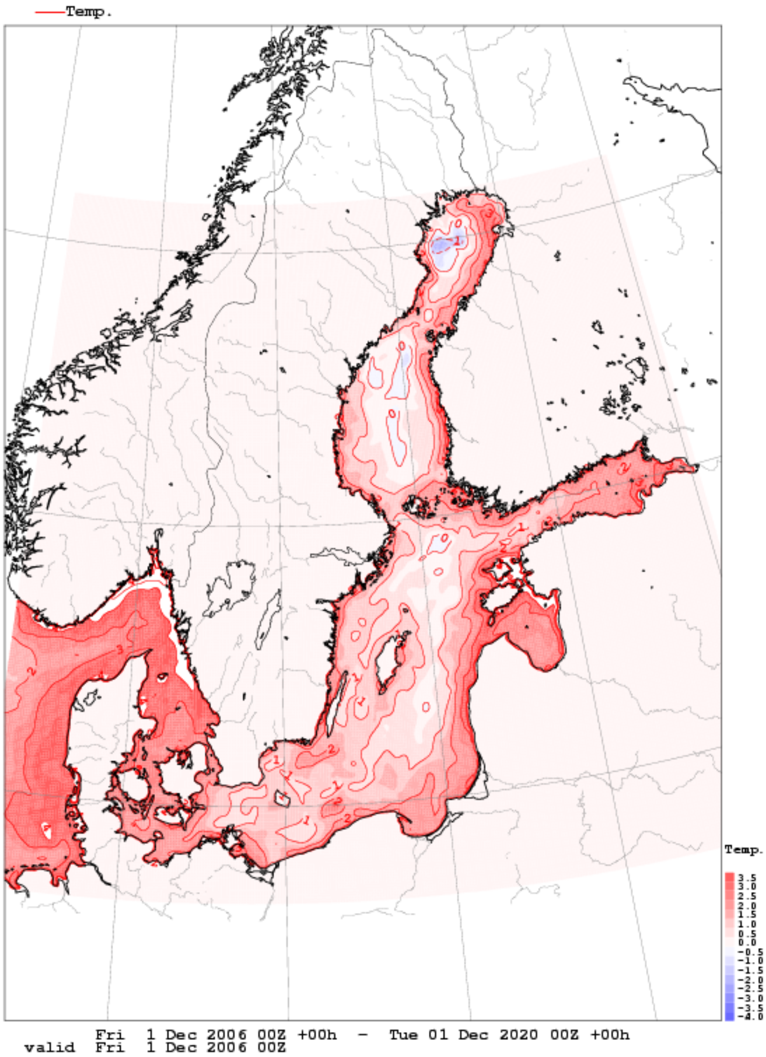


Figure 5. SST-anomaly on December 1 relative to the 15-year period 1990–2004 (from www.smhi.se/polarview)

Long term observations

The slight increase in the yearly mean surface salinity at station BY15 came to an end and the 5-year running mean has levelled out (Figure 6).

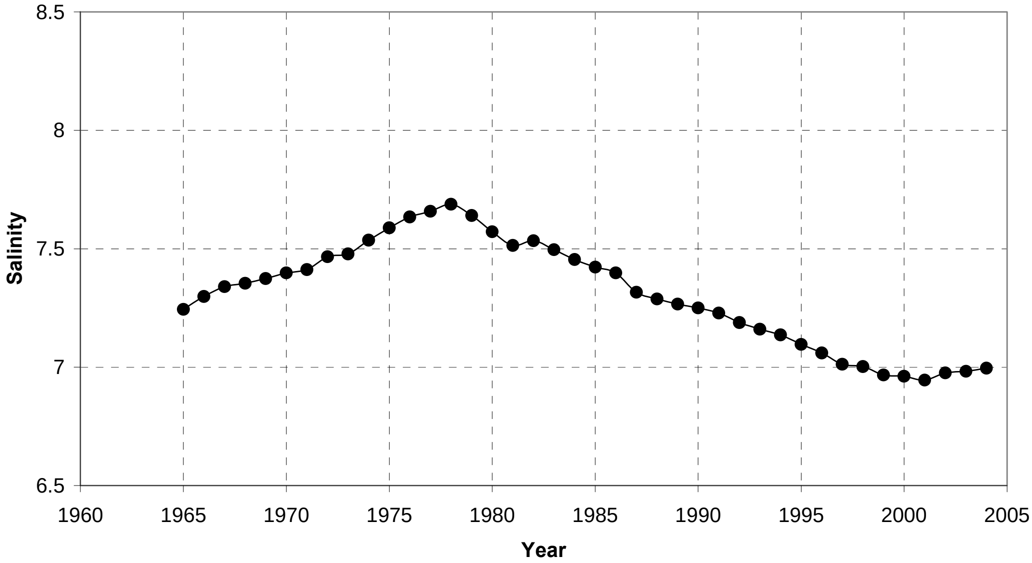


Figure 6. Surface salinity at BY15 (see Figure 1) in the Baltic proper (5-year running mean).

Water exchange

There were several inflows to the Baltic during the fall 2006 (Figure 7). The first one, lasting from October 20 to November 15, transported an amount of about 40 km^3 through Öresund. During the first half of December another 30 km^3 entered the Baltic this way. There was no renewal of the bottom water, however. The reason for this is that the Kattegat water was unusually warm and, consequently, the inflowing water was not dense enough to reach the deeper parts of the Baltic. Later expeditions revealed a slight increase in the oxygen values at intermediate levels at station BY15 and BY20 (see Figure 1).

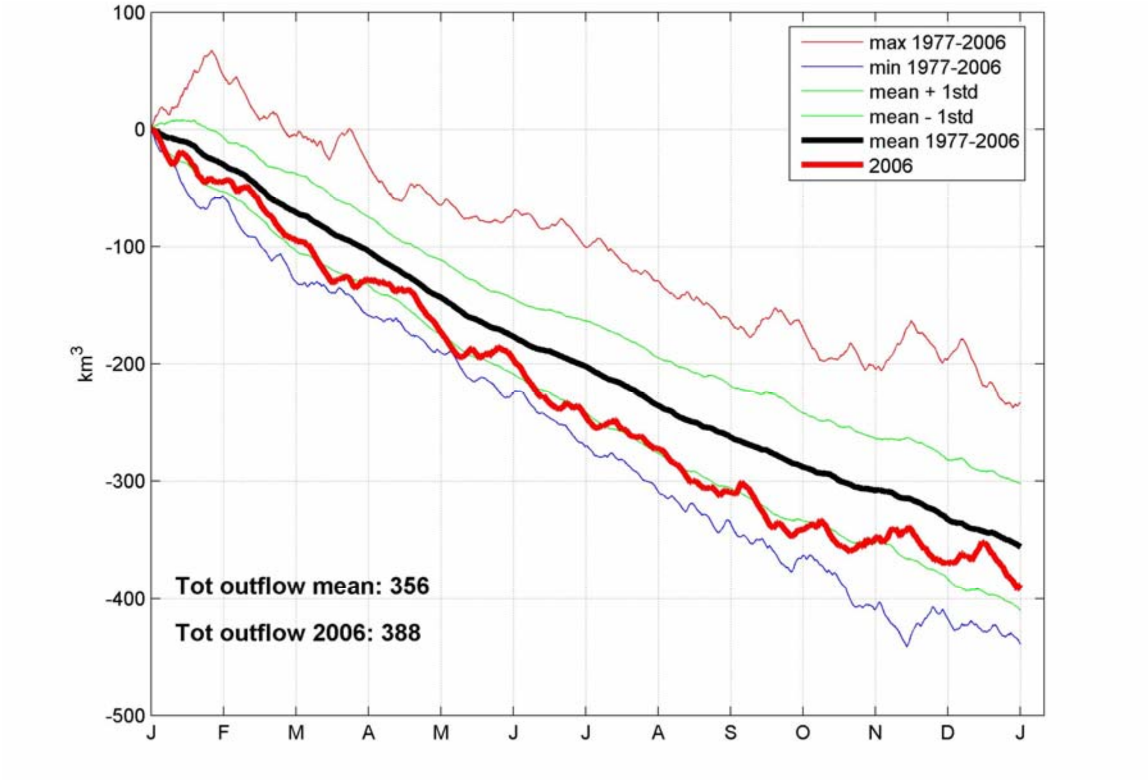


Figure 7. Accumulated flow through the Öresund to the Baltic in 2006 (SMHI).

Ice conditions

The freeze-up was quite late during the winter 2005/2006 but the ice extent was yet much larger than the previous year and the ice winter was classified as normal/sever. The maximum ice extent was reached on March 15 as illustrated in Figure 8. In Figure 9 the ice extent is shown for a period starting in 1961.

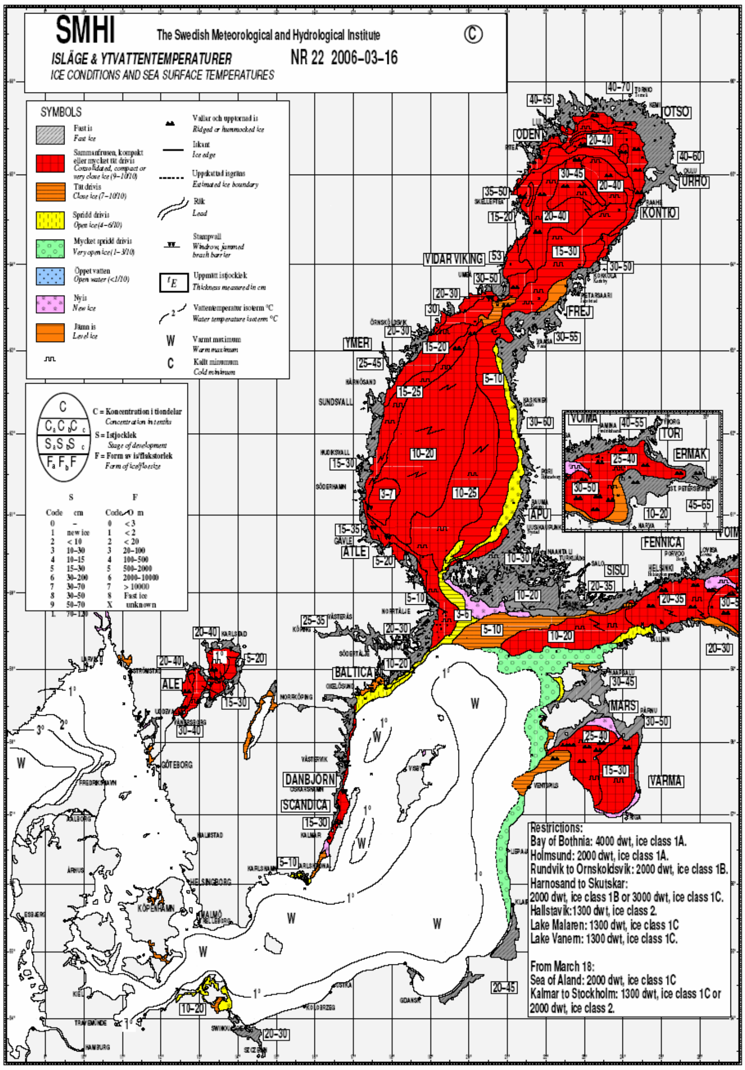


Figure 8. The maximum ice extent in the Baltic Sea during the winter 2005/2006. The map was constructed by the Ice Service at SMHI.

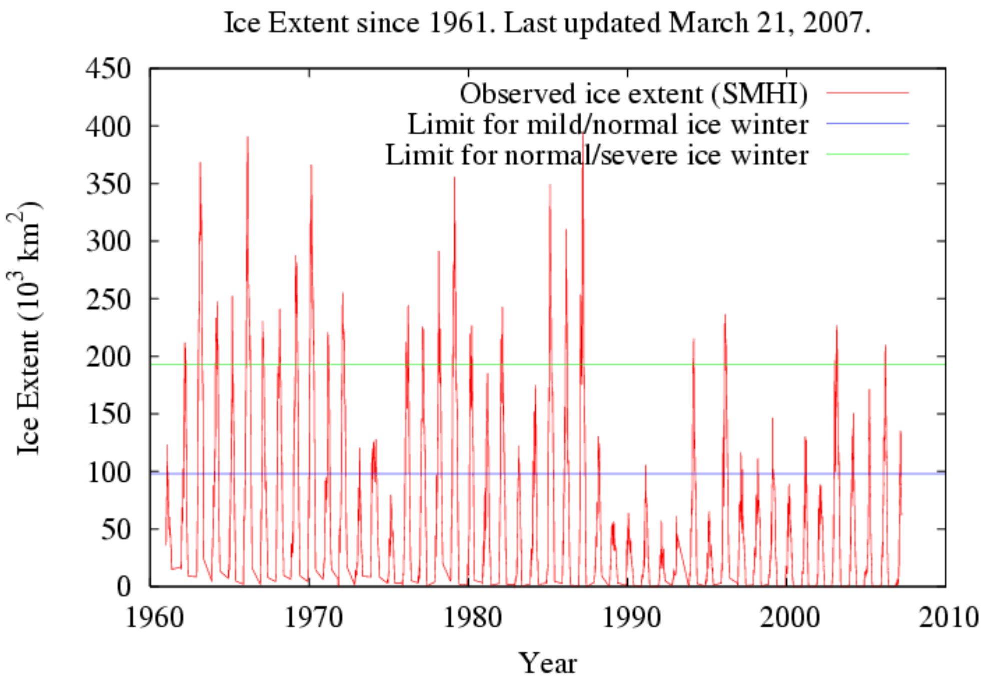


Figure 8. The ice extent in the Baltic starting from 1961. The last value is from 21 March 2007. Graph constructed by Lars Axell (SMHI).

Annex 14: Norwegian Waters

Working Document **ICES 2007**

Working Group on Oceanographic Hydrography

Gothenburg, 27–30 March 2007

BY: Randi Ingvaldsen, Kjell Arne Mork, Einar Svendsen, Paul Budgell, and Harald Loeng, Institute of Marine Research ,P.O. Box 1870 Nordnes, 5817 Bergen, Norway

Summary

The temperature in the southern Barents Sea was approximately 1–1.5°C higher than average during 2006 and there was a record-low sea-ice cover. In 2006 the Atlantic water in the Norwegian Sea was 0.8–1.1°C warmer than normal with highest anomaly to the north. In the North Sea, the temperature by the end of 2006 was about 2-4°C above the long-term mean.

Figure 1 shows all Norwegian standard sections and fixed oceanographic stations.

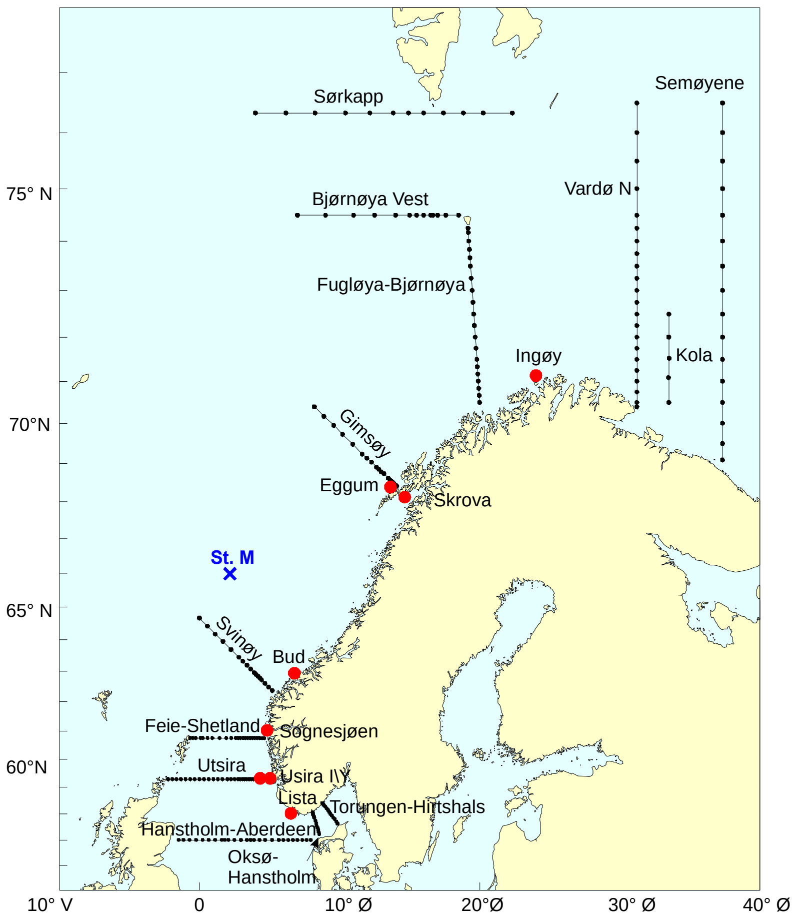


Figure 1. Standard sections and fixed oceanographic station worked by Institute of Marine Research, Bergen. The University of Bergen is responsible for station M, while the Kola section is operated by PINRO, Murmansk (ANON, 2002)

The Norwegian Sea

The five last years the northward flowing Atlantic water in the eastern Norwegian Sea have been extraordinary warm and salt. Along the Norwegian continental slope the core of Atlantic Water was in 2006 0.8–1.1 °C warmer than normal with highest anomaly in the north. The Norwegian Sea was also warmer than normal further offshore at 100 m depth in 2006.

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 present. During 2002–2006, the temperature in the Svinøy section had the four largest values in the time series. As Atlantic water flows northward the temperature increase can now also be observed further north, in the Sørkapp section. In 2006, the temperature was 0.8°C, 1.0°C and 1.1°C above the long-term-mean for the time series in Svinøy, Gimsøy and Sørkapp sections, respectively. The salinity has the last years increased remarkable in all three sections. In the Svinøy section the last four years (2003-2006) have the largest values in the time series and in the Gimsøy section 2005 and 2006 have the largest values in the time series. In the Sørkapp section only in 1983 has the salinity larger values than in 2005 and 2006. The salinity in 2006 was respective 0.08, 0.09, and 0.09 above the long-term-mean. The large salinity values that are observed in the sections are a result of a saltier inflow of AW to the Norwegian Sea through the Faroe-Shetland Channel.

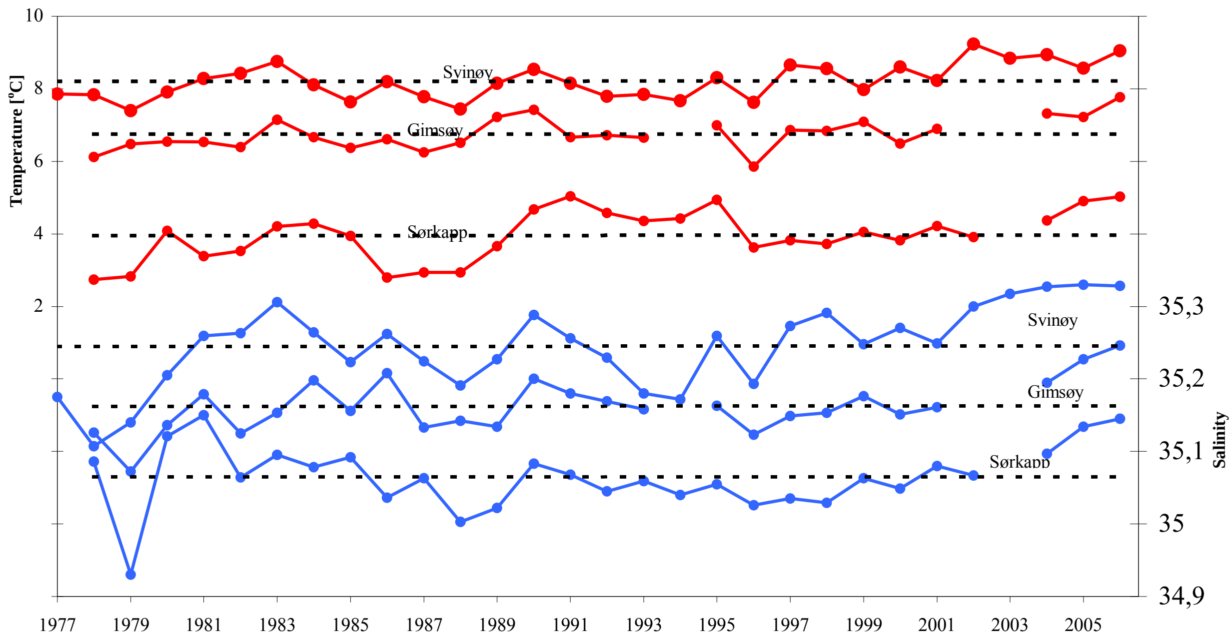


Figure 2. Temperature and salinity, observed in July/August in the core of Atlantic water in the sections Svinøy-NW, Gimsøy-NW and Sørkapp-W, averaged between 50 and 200 m depth.

The area of Atlantic water (defined with S>35.0) in the Svinøy-section has been calculated. The mean temperature within the limited area has also been calculated, and the results for spring and summer are shown in Figure 3. Large values in the area are due to larger distribution of Atlantic water in the section. This is due to a more westerly or/and vertical distribution of Atlantic water. There are considerable variations both in the area of Atlantic water distribution and its temperature. The distribution area of Atlantic water decreased since the beginning of 1980s to mid 1990s and increased from there to present. The temperature has shown a steady increase. Since 1978 the Atlantic water has been about 0.8°C warmer. In 2002, the temperature increased considerable and had in 2003 the largest value in the time series. The temperature has the last two years decreased and was in 2005 close to the long-term-mean. However in 2006 the temperature increased again to the similar record-high value as in 2003. It was then 0.7°C higher than the long-term-mean. The area of Atlantic water was in 2006 somewhat larger than the long-term-mean.

Hydrographic data from an ecosystem cruise in May 2006 (figure not shown) show that the temperature at 100 m depth is above normal for most of the Norwegian Sea and not only in the east along the continental slope. Typically the temperature was between 0.25°C and 1.25°C above normal (averaged over 1995–2006).

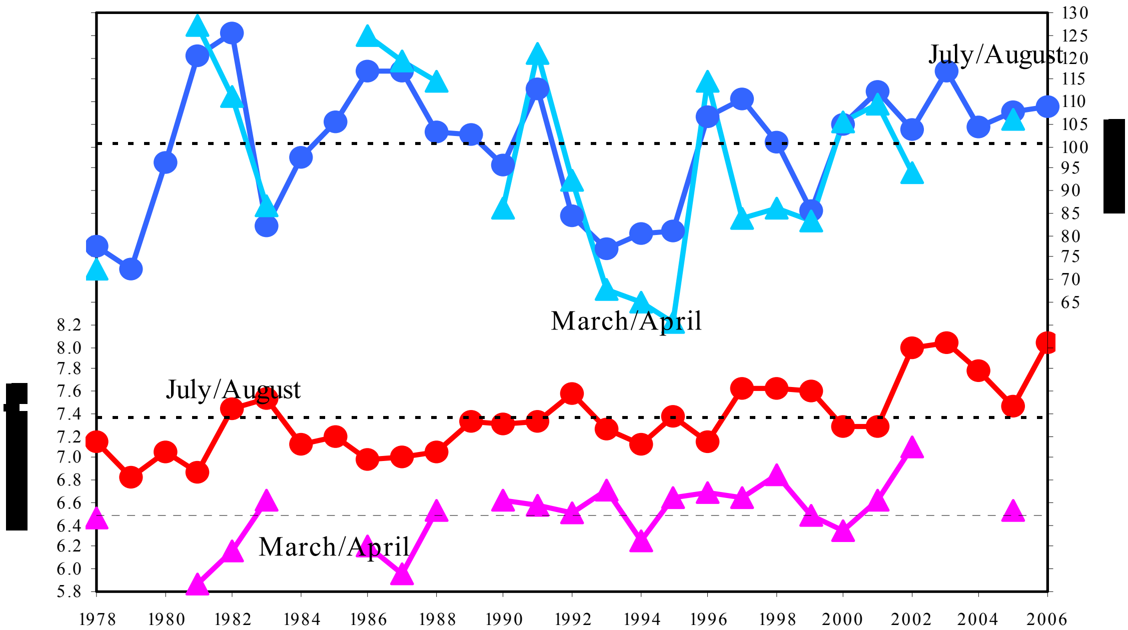


Figure 3. Time series of area (in km²) and averaged temperature (red) of Atlantic water in the Svinøy section, observed in March/April and July/August, 1978–2006.

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.

The hydrographic observations were carried out according to the plan. Figure 4 shows the temperature and salinity anomalies in the Fugløya-Bear Island section in the period from 1977 to January 2007. In the period 1977–1997 there was distinct warm and cold period alternating with a period of 3–5 years. After that the temperatures has stayed above the long-term mean, and since 1997 the temperature has increased with 1°C. The period 2001–2005 was in fact the warmest 5-year period since the beginning of last century.

In January 2006, a positive temperature anomaly of 1.44°C was observed, which is all time high. The temperature stayed high throughout 2006, and all observations except October were all time high since the time series started in 1977. In January 2007 the temperature anomaly was 1.55°C, a new all time high for this section. The salinity variations are similar to those in temperature, and there has been a high salinity in the last 6 years.

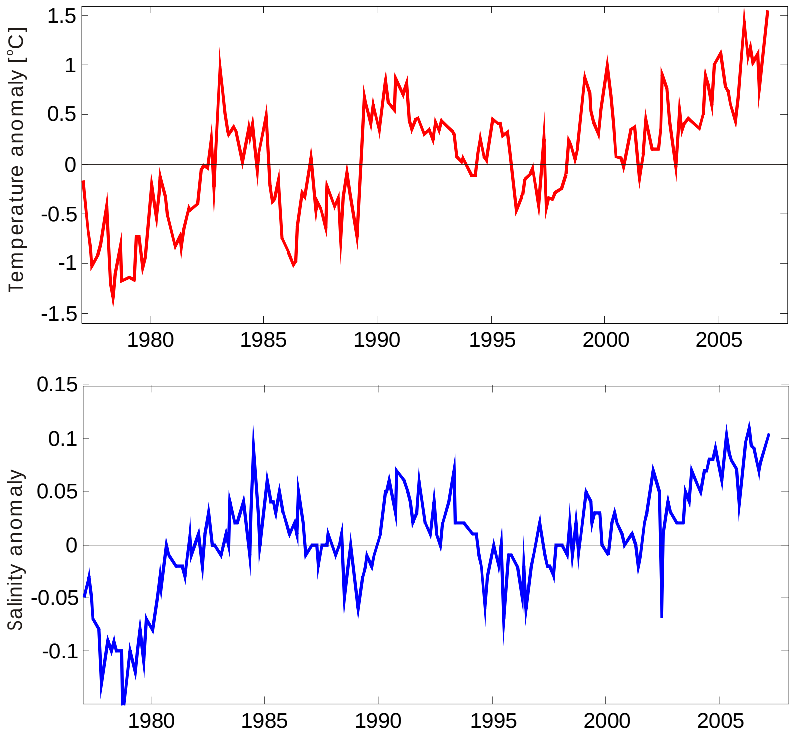


Figure 4. Temperature anomalies (upper panel) and salinity anomalies (lower panel) in the section Fugløya – Bear Island section including January 2007.

Figure 5 shows the ice index for the Barents Sea. The variability in the ice coverage is closely linked to the temperature of the inflowing Atlantic water. The ice has a relatively short response time on temperature change (about one year), but usually the sea ice distribution in the eastern Barents Sea respond a bit later than in the western part. Due to the high temperatures there has been little ice in the last years, and that was also the case in 2006. Since 1970 there has never been less ice in this area, and 2006 was the first time there was no ice south of 76°N throughout the winter.

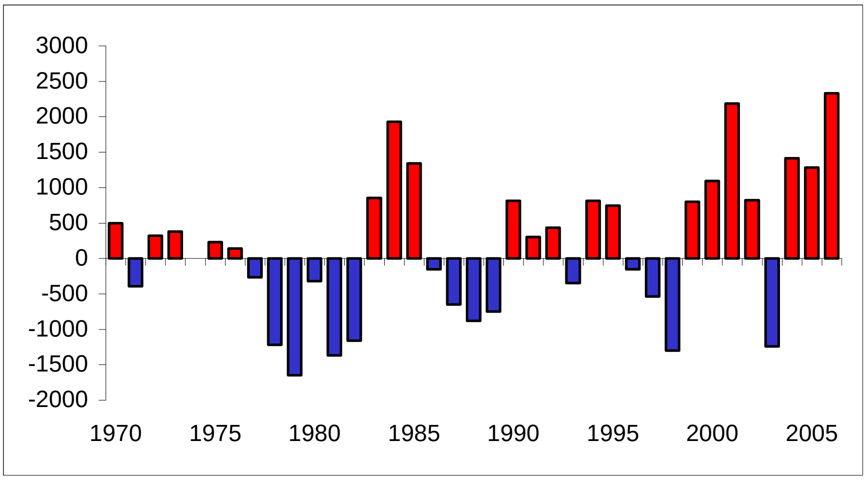


Figure 5. Ice index for the period 1970–2006. Positive values means less ice than average, while negative values show more severe ice conditions.

The current measurements that started in August 1997 as part of the EU-VEINS project showed that the observed current in the section Fugløya-Bjørnøya is predominantly barotropic, and reveals large fluctuations in both current speed and lateral structure (Ingvaldsen *et al.,* 2002, 2004). The inflow of Atlantic water may take place in a wide core located in the area 72°30'–73°N with outflow further north, but it may also be split in several cores. Between the cores there might be a weaker inflow or a return flow. The outflow area may at times be much wider than earlier believed, stretching from 73°30'N south to 72°N. This phenomenon is not only a short time feature; it might be present for a whole month. These patterns are most likely caused by horizontal pressure gradients caused by a change in sea-level between the Barents Sea and the Arctic or the Norwegian Sea by accumulation of water and/or by an atmospheric low or high.

There seems to be seasonality in the structure of the current. During winter the frequent passing of atmospheric lows, probably in combination with the weaker stratification, intensify the currents producing a structure with strong lateral velocity-gradients and a distinct, surface-intensified, relatively high-velocity, core of inflow. During the summer, when the winds are weaker and the stratification stronger, the inflowing area is wider, and the horizontal shear and the velocities are lower. In the summer season there is in inflow in the upper 200 m in the deepest part of the Bear Island Trough.

The time series of volume transport reveals fluxes with strong variability on time scales ranging from one to several months (Figure 6). 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 time series of volume transports shows a relatively high inflow during 1997 and 1998, before the transport decreased and reached a minimum in end of 2000. Then there was a strong increase in the transport until beginning of 2003. The inflow was low in 2004, but increased substantially towards the summer of 2006. There is a significant increasing trend in the volume flux from 1997 to present, and the calculated trend indicates that the mean Atlantic flux increased by almost 50%. The measurements started in a period with generally low inflow, but the increase is still stronger than expected.

Although both temperature and volume flux has increased since 1997, these two parameters do not have to vary in phase (Figure 6). This is because the temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea, while the volume flux depends mainly on the local wind field.

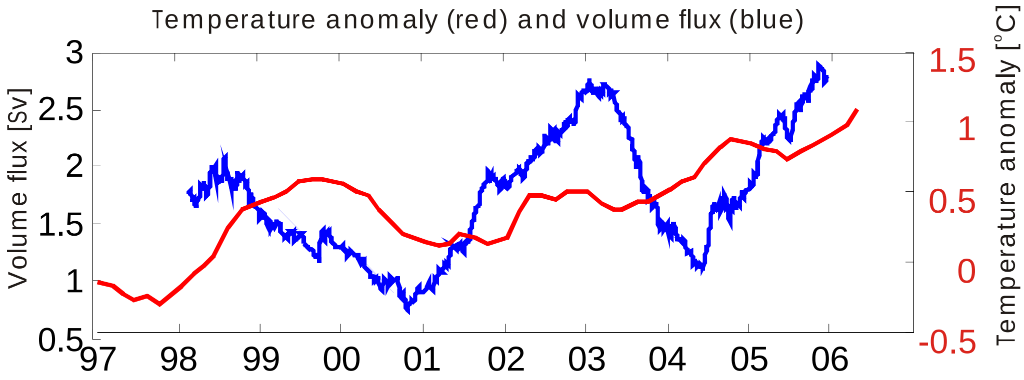


Figure 6. The blue line show Atlantic Water volume flux across the section Norway-Bear Island and the red line show temperature anomalies the Fugløya – Bear Island section. Time series are 12 months running means.

A dynamic-thermodynamic sea ice model has been coupled to a three-dimensional ocean circulation model for the Barents Sea region (Budgell, 2004). The ocean model component is based on ROMS (Regional Ocean Modelling System) version 2.1. ROMS is a three-dimensional baroclinic general ocean model. It uses a topography-following coordinate system in the vertical, with 32 s-coordinate levels. Orthogonal curvilinear coordinates are used in the horizontal. The average horizontal grid size is 9.3 km. The present model forcing includes surface forcing (wind and radiation) from the NCEP/NCAR Reanalysis and open boundary conditions from a large-scale implementation of ROMS covering the area from the southern Atlantic to the Polar Ocean.

The model performs well (Budgell, 2005) with the most apparent discrepancies with observations mainly being due to uncertainties in the prescribed forcing fields.

A comparison of modelled and observed sea surface temperature (SST) with data from the Pathfinder AVHRR satellite, show that in March, the model produces a realistic transport of warm water northward west of Spitzbergen and the region encompassed by the 2 degree isotherm matches the satellite SST distribution. The model results for September also show good agreement with the satellite SST field (Figure 7).

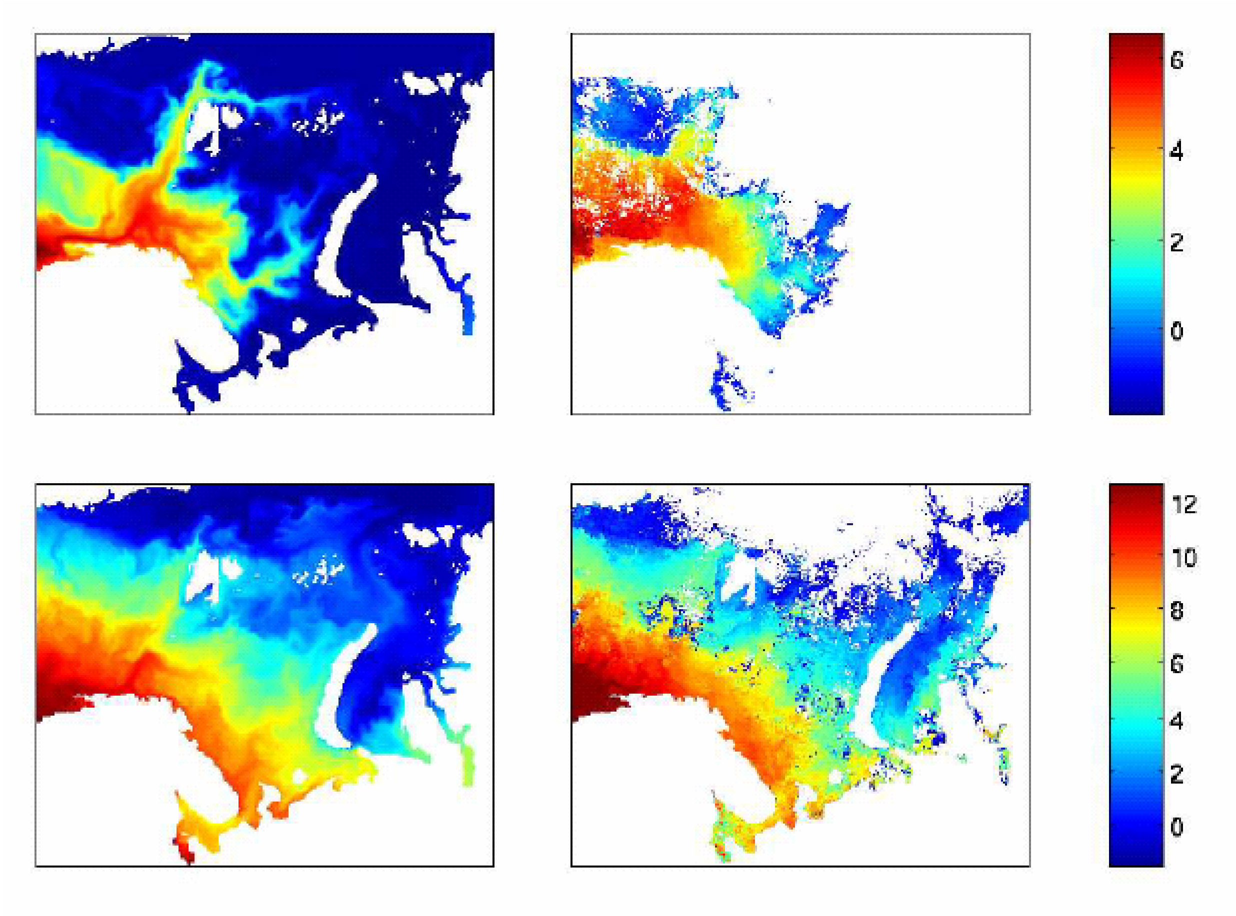


Figure 7. Modelled vs. Pathfinder AVHRR monthly-mean SST. The top row is from March, 1993, the lower row is from September, 1993. The left-handed column contains the ROMS model fields, the right-hand column contains the Pathfinder AVHRR fields.

The sea ice concentration in the Barents Sea can exhibit considerable variation both seasonally and inter-annually, and a comparison with an integral estimate of monthly-mean total area ice cover with observations from the SSM/I satellite show excellent agreement for the winter and an excessive ice melting in the model during summer (Figure 8). This melting is most likely due to poor surface forcing during summer.

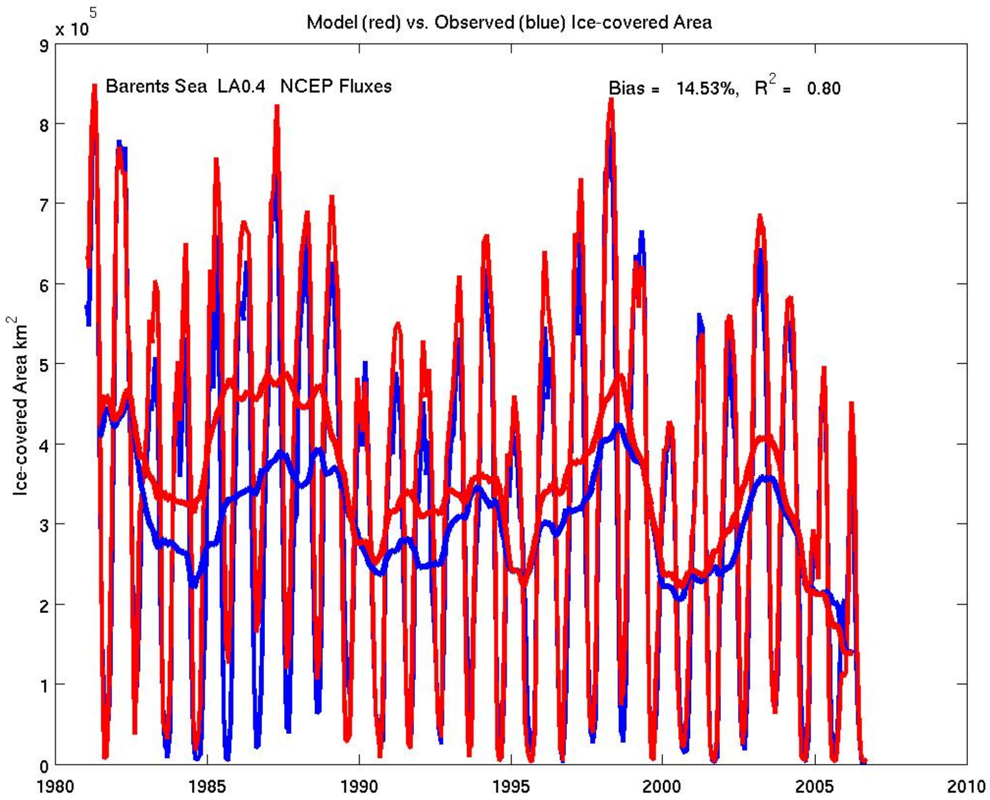


Figure 8. Monthly mean modelled (red) and SSM/I (blue) time series of the ice-covered area in the Barents Sea model domain 1980–2006.

Budgell, W.P., 2005, Numerical simulation of ice-ocean variability in the Barents Sea region: Towards dynamical downscaling, *Ocean Dynamics*, 55: 370-387, DOI 0.1007/s10236-005-0008-3.

The North Sea

At the beginning of 2006 the temperatures of the North Sea were extremely high, about one to two degrees warmer than normal. Due to a relatively cold winter the temperatures were relatively rapidly reduced to the norm. Towards the end of 2006 and the beginning of 2007, after a very warm summer and mild autumn, the temperatures again became extremely high, from 2–4 degrees above the norm. This is a clear record since the measurements started about 100 years ago.

In January 2006 the upper water-masses were about 0.5–1.0 ^{0}C warmer than normal basically over the whole North Sea. Mild southwesterly winds during autumn 2005 were followed by a relatively cold weather during winter, dropping the sea temperature approximately to the norm, and it stayed near the norm up until the summer. Very warm weather from mid summer and during autumn caused the temperature of the water during the last half year of 2006 to be about 2–4 ^{0}C warmer than normal. The highest deviations were found in the southerly and easterly (Norwegian) parts of the North Sea, being the most extreme ever observed.

Figure 9 shows the development of temperature and salinity at two positions, one (A) near bottom in the north-western part of the North Sea and the second (B) in the core of Atlantic water at the western shelf edge of the Norwegian Trench. The measurements are carried out during summer and represent the last winter situation. The average temperature at the plateau is 1–2°C lower than in the core of the inflowing Atlantic water (Figure 9). Also the salinity is slightly lower at the plateau. In both places there was extremely high temperature and salinities in 2004. This is a result of very high salinity in the inflowing Atlantic water and the effect of a mild winter. The relatively cold winters and springs of 2005 and 2006 has lead to quite normal temperatures in the deep layers of the North Sea, while the salinities still are quite high due to high salinities of the inflowing Atlantic water.

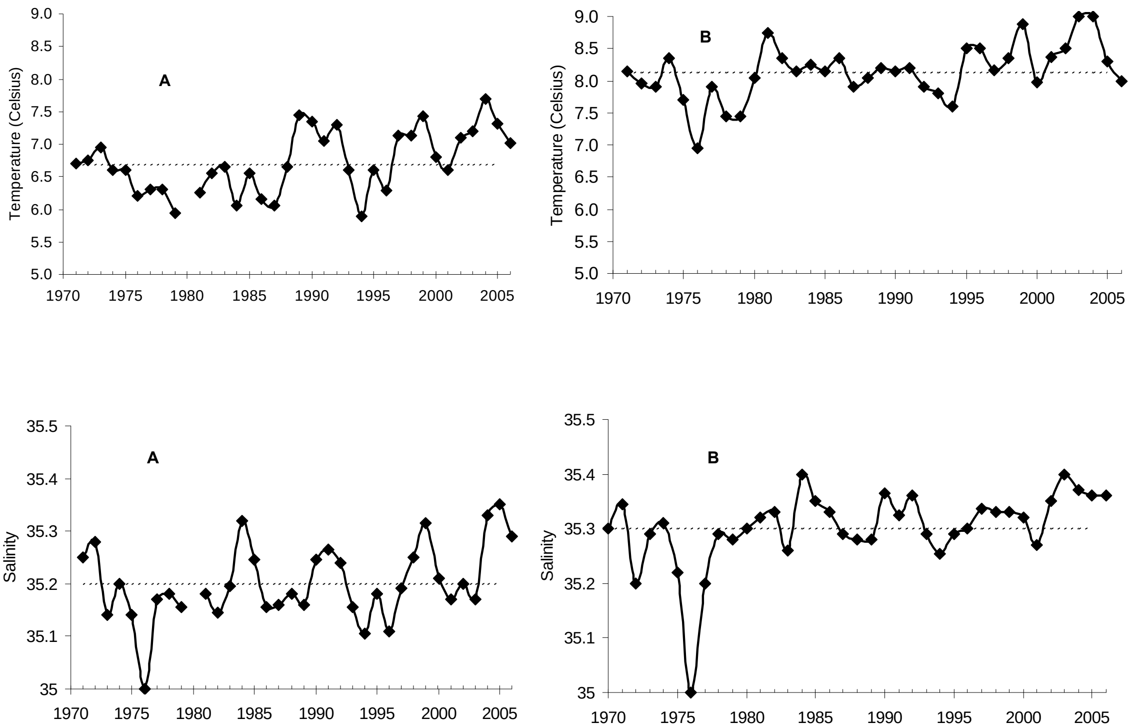


Figure 9. Temperature and salinity near bottom in the northwestern part of the North Sea (A) and in the core of Atlantic water (B) at the western shelf edge of the Norwegian Trench during the summers of 1970–2006 (Anon, 2007).

Estimates from a numerical ocean circulation model (NORWECOM) shows that the circulation in the North Sea was quite normal in 2006. After a strong inflow of Atlantic water to the northern and central North Sea in January 2006, the inflow during the rest of the winter, spring and summer was quite normal (Figure 10). During the fourth quarter a new relatively (to the season) strong inflow occurred, particularly in November and December. The inflow through the English Channel was also quite strong during the fourth quarter, and the rest of the year quite normal.

The catches of horse mackerel during the autumn in the North Sea have for many years been strongly linked with the northern modelled inflow of Atlantic water during winter (1. quarter) approximately half a year earlier. In 2006 the model prognosis was near identical to the following reported catches of 29 000 tonnes.

As predicted in 2005 there was in the Skagerrak no renewal of the deep water in 2006, and also for 2007 we do not expect a new renewal to occur.

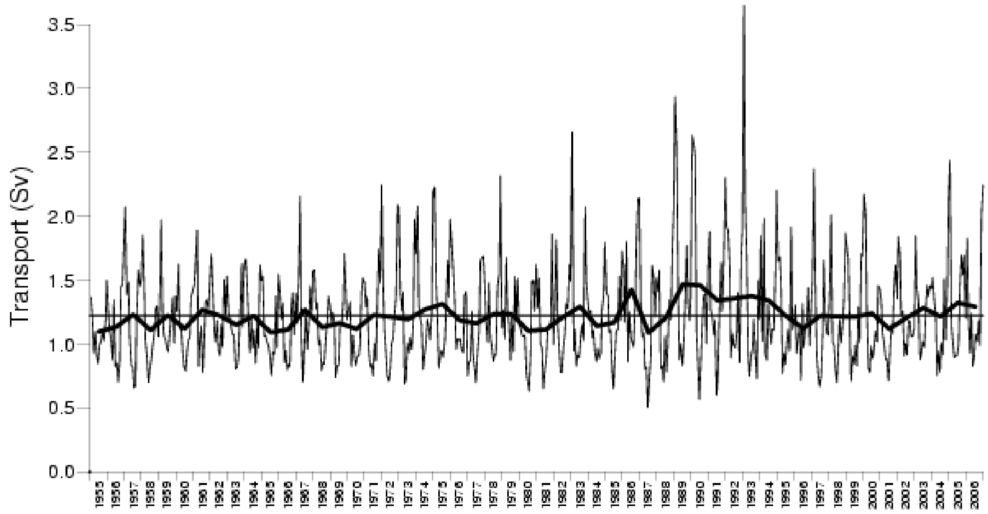


Figure 10. Time series (1955–2006) of modelled annual mean (bold) and monthly mean volume transport of Atlantic water into the northern and central North Sea southward between the Orkney Islands and Utsira Norway. 1 Sv = $10^6 m^3 s^{-1}$. (Anon, 2006).

Annex 15: Hydrographic conditions in Atlantic Domain of the Nordic Seas – Areas 8, 10, 11 – Summer 2006

BY: Waldemar Walczowski, and Jan Piechura, Institute of Oceanology Polish Academy of Sciences, Sopot, Poland

1. Observations 2006

AREX2006 cruise of Institute of Oceanology Polish Academy of Sciences vessel RV "Oceania" was performed in period of 8 June 2006 – 19 July 2006. 188 CTD casts along 12 sections were done (Figure 1). The SBE 9/11 device was used. Measurements of currents were performed by means of Lowered Acoustic Doppler Current Profiler. The self-recording 300 kHz RDI device was used to profile entire water column during the standard CTD casts. During the whole cruise continuous currents measurements by the ship-mounted ADCP, RDI 150 kHz were conducted.

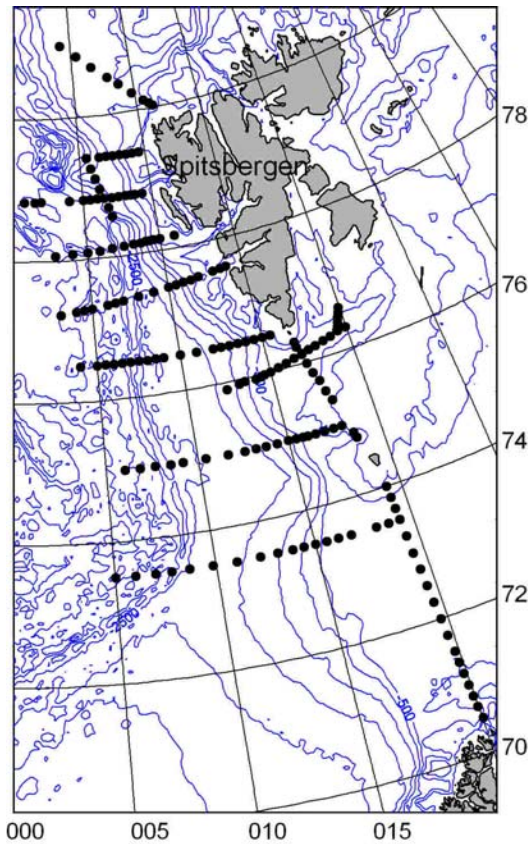


Figure 1. Stations grid performed during RV 'Oceania' cruise, summer 2006.

2. Hydrographic conditions

In June/July 2006 temperature and salinity in the upper layer of investigated region (Figure 2) was higher than observed in summer 2005 and higher than mean properties for summers 2000–2006 (Figure 3). At 100 dbar the 5°C isotherm shifted northward more than 180 Nm (2° latitude), passing the 79° parallel. The expansion of warm Atlantic Water over the Spitsbergen shelf has been observed (Figure 2, and Figure 4).

Also measurements at standard sections show much higher then usually temperature and salinity of the Atlantic Water. At the section 'N' along the 76°30', between latitudes 009–012°E mean temperature and salinity at 200 dbar was in 2006 respectively 4.50°C and 35.13 in comparison to 3.81°C and 35.10 in 2005 (Figure 5). The Atlantic Water core temperature was higher than in summers 2004 and 2005. Also in the central part of section, the AW temperature was higher then observed earlier.

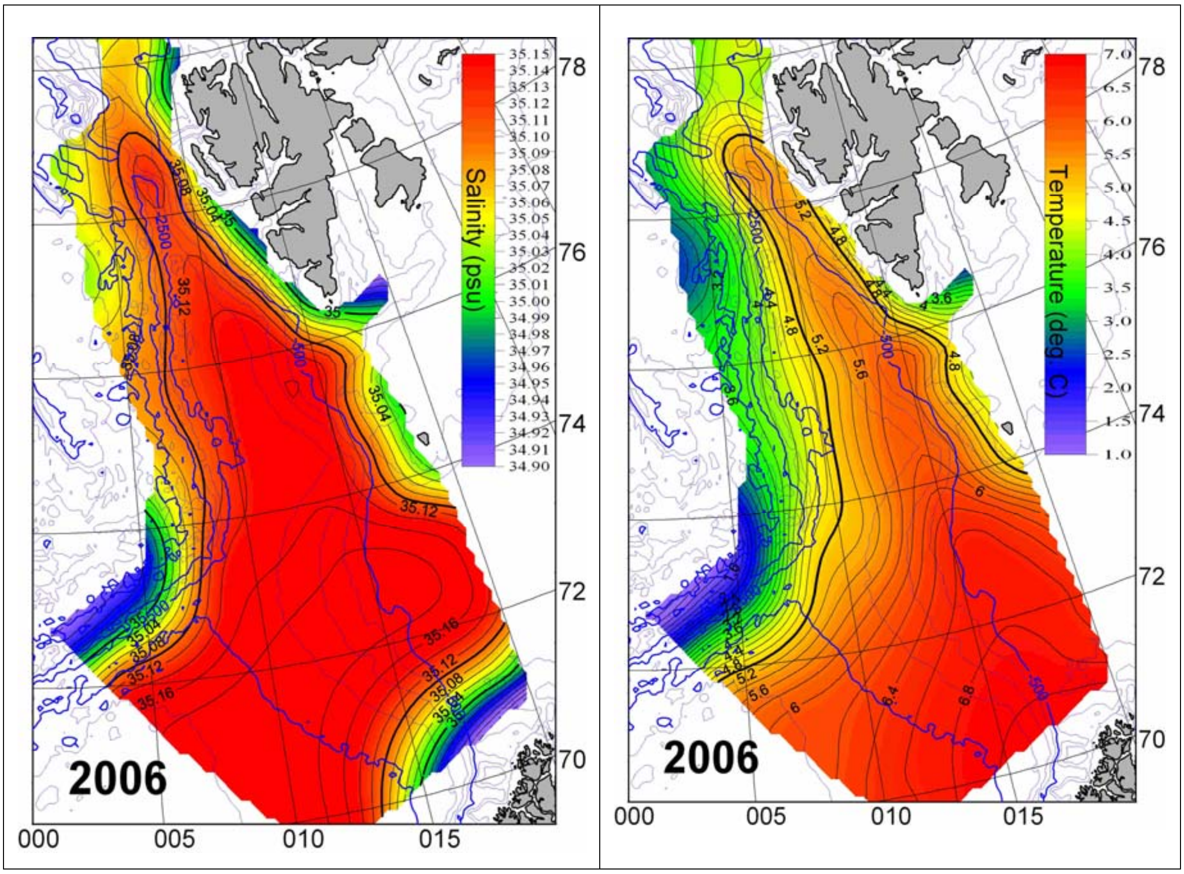


Figure 2. June–July 2006. Salinity (left panel) and temperature at 100 dbar.

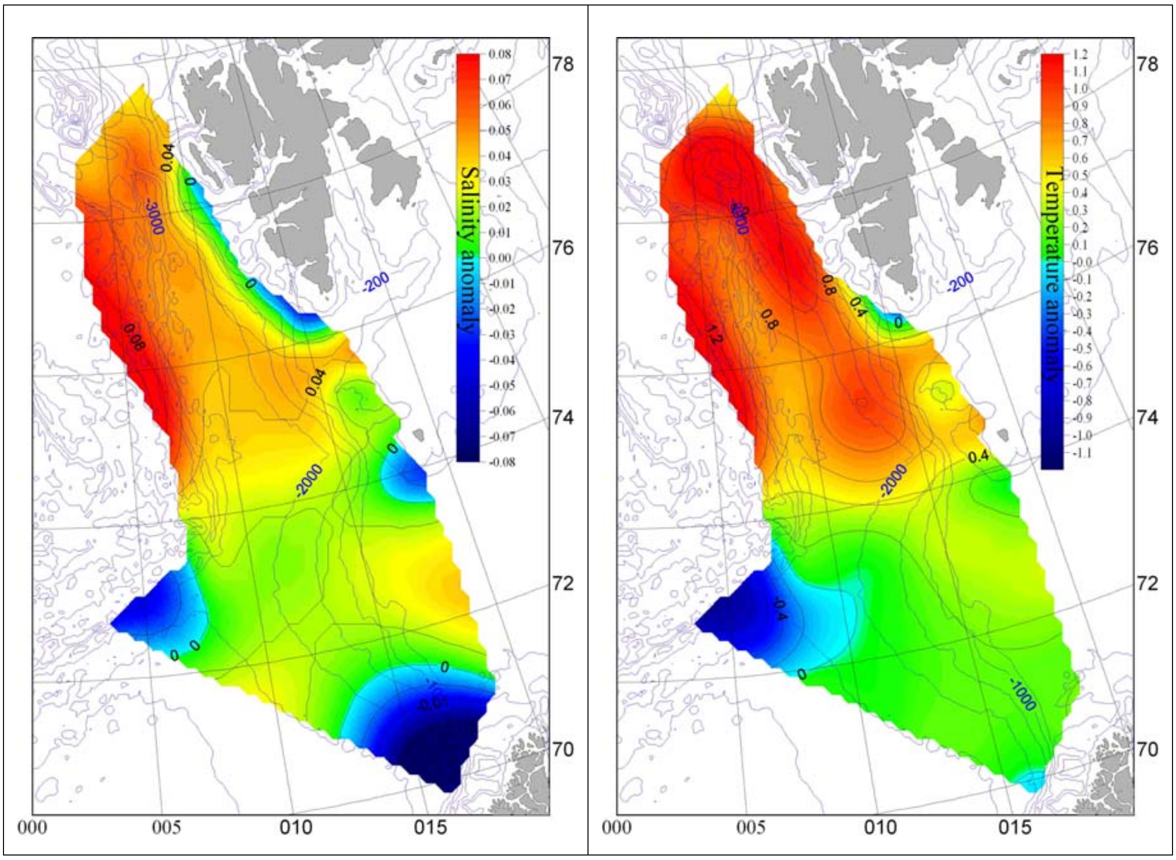


Figure 3. June-July 2006. Anomaly of salinity (left panel) and temperature at 100 dbar. All anomalies were calculated in reference to summer 2000–2006 mean.

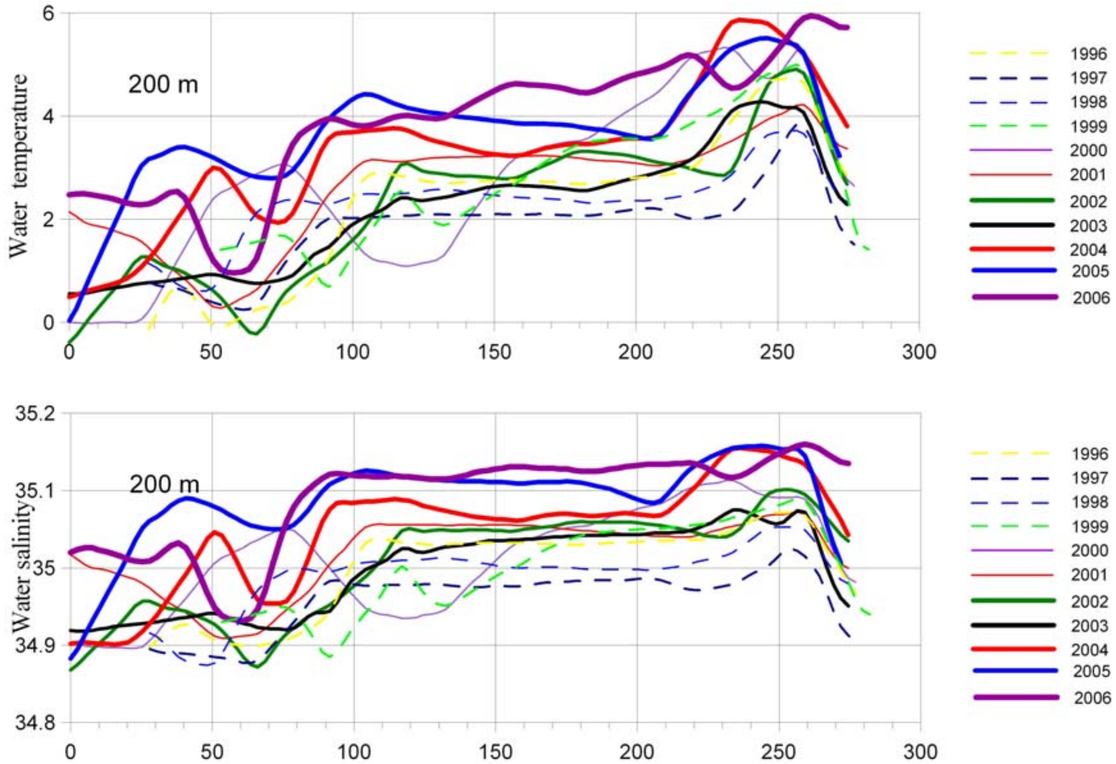


Figure 4. Temperature (upper panel) and salinity curves at section 'N' along 76°30' N parallel, from latitude 004°E to 015°E at 200 m. Years 1996–2006.

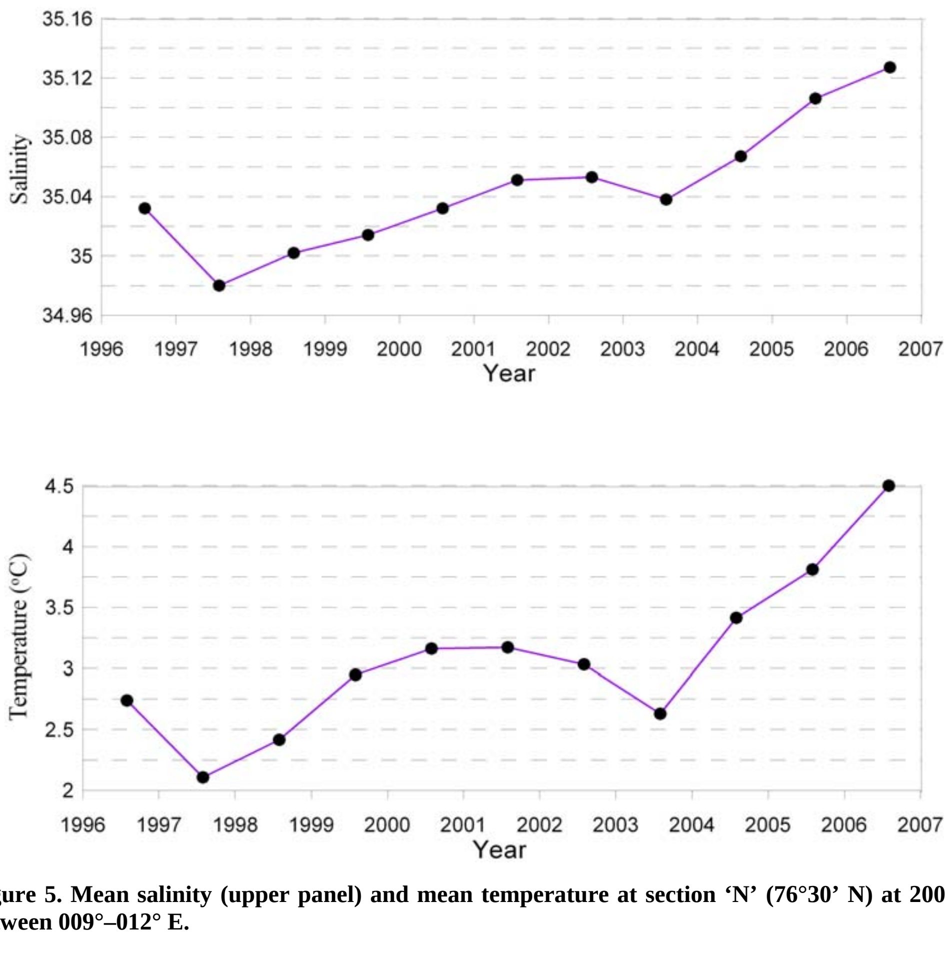


Figure 5. Mean salinity (upper panel) and mean temperature at section 'N' (76°30' N) at 200 m, between 009°–012° E.

3. Dynamics

Figure 6 presents the distribution of baroclinic currents kinetic energy and baroclinic currents at 100 dbar (currents calculated in reference to level of 1000 m.) during summer 2006. Considerable part of AW inflowing the study area carried by the western branch of the Norwegian Atlantic Current splits at 72° N into two branches. One stream continues over the underwater ridges, while the second one flows along the Barents Sea shelf brake. Convergence of all West Spitsbergen Current branches occurred at latitude 78° N, then current diverges again downstream, forming a multi-path flow structure in the Fram Strait.

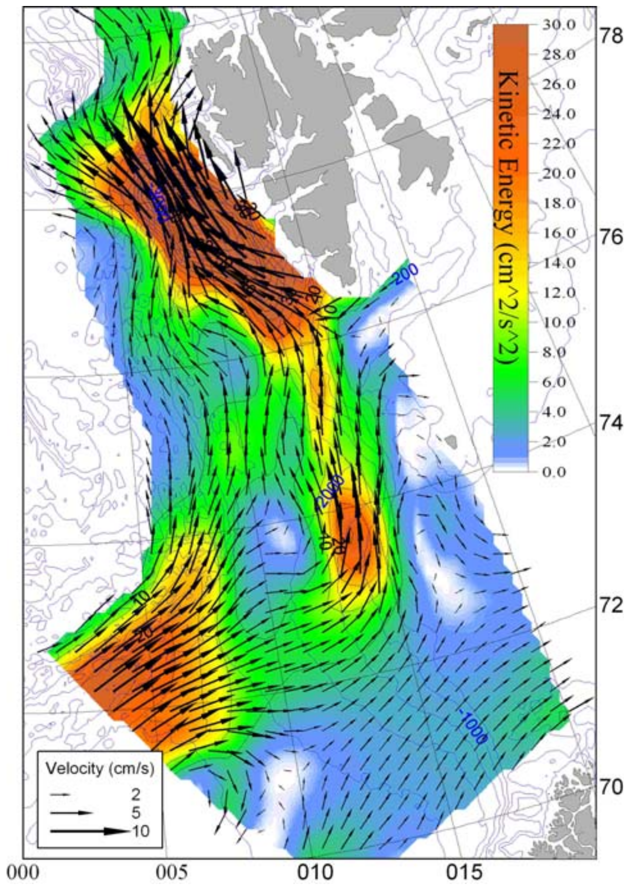


Figure 6. June-July 2006. Baroclinic flow kinetic energy distribution (colour scale), and baroclinic currents at 100 dbar. Reference level 1000 m.

Annex 16: Barents Sea: Russian standard sections, 2006 (Area 11)

BY: A.L. Karsakov, A.P. Pedchenko, and V. Ozhigin: Polar Research Institute of Marine Fisheries and Oceanography (PINRO), 6, Knipovich Str., Murmansk, 183763, Russia [Tel./Fax: +7 8152 472532, e-mail: inter@pinro.ru]

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 2006 was 1,214 including 297 stations at the standard sections.

Figure 1 presents the main Russian standard sections in the Barents Sea the data from which will be discussed further.

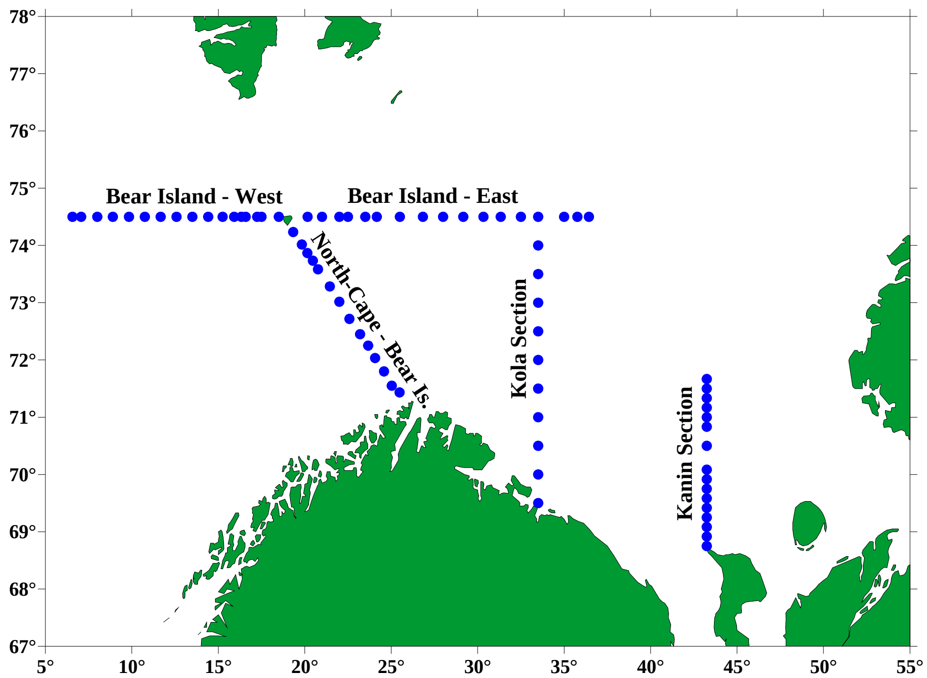


Figure 1. Main Russian standard sections in the Barents Sea.

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 – the 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 1,100 times by now.

Published time series from the main standard sections (Bochkov, 1982; Tereshchenko, 1997, 1999; Antsiferov, Guzenko, 2002) were also used in this analysis.

Results

During the year, the weather over the sea was influenced by the cyclonic activity caused by the development of Icelandic Low in the beginning and end of the year. In January, April, June-July and November-December, prevailing were southerly winds, in February-March, May and September-October, – northeasterly and easterly winds dominated, and, in August, the westerlies predominated.

Air temperature dada were taken at http://nomad2.ncep.noaa.gov and averaged over western (70–76°N, 15–35°E) and eastern (69–77ºN, 35–55ºE) parts of the sea. In the early 2006, the air temperature over the Barents Sea was well above normal, with maximal values of positive anomalies (4.0–5.0ºC) in the eastern sea. In summer and autumn temperature anomalies decreased. Insignificant positive anomalies of air temperature were registered in the western Barents Sea and, in the eastern part of the sea, negative anomalies (0.4–0.7ºC) were observed in June-July and October. In November-December, over the most of sea, air temperature was, on average, 2.0–3.0ºC higher than the long-term mean.

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), central (71–74ºN, 20–40ºE) and southeastern Barents Sea (69–73ºN, 42–55ºE). In 2006, over most of the Barents Sea area, SST was higher than normal, with maximum anomalies of 0.6–1.1ºC in the central and eastern areas. In May-June, the weakened radiation warming of the surface layer became a reason of decrease in SST anomalies. As a result, there was a transition from positive to negative SST anomalies in the western and eastern parts of the sea in July and in the central part – in August. In autumn-winter period, SST anomalies increased again to well above normal values. In that period, the maximum positive anomalies (1.0–1.3 ºC) were observed in the southern sea and reached.

During the year, the sea ice extent was much less than the long-term mean, and, in January, May-July and December, it was the lowest for corresponding months since 1951. In 2006, the greatest ice coverage was observed in March and amounted to 44% that was 17% less than normal and the least – in August when there was no ice in the sea. In the late September and in October, with the prevalence of northerly and northeasterly winds and the decrease in air temperature the ice formation and shift southward became active. In that period, the total ice extent increased to 10% (however, it remained being 7% lower than the long-term mean). In November-December, with the increase in the southerly wind occurrence and higher than normal air temperature, the ice coverage again was at the level of significantly less than normal (Figure 2).

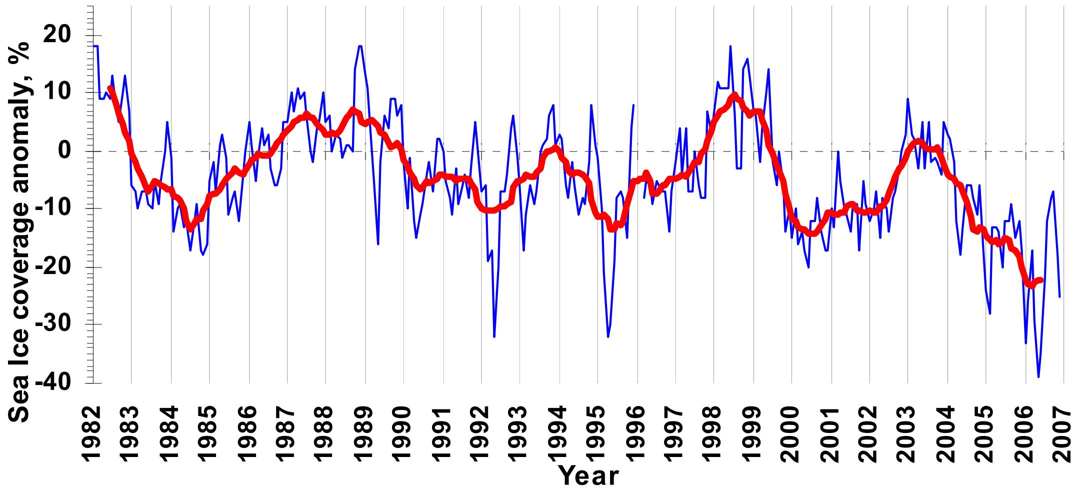


Figure 2. Anomalies of mean monthly ice extent in the Barents Sea in 1982–2006. A blue line shows monthly values, the red one – 11-month moving average values (Anon., 2007)

According to the observations along the Kola Section, which was made 9 times, sea temperature in the active layer (0–200 m) of the southern Barents Sea, was significantly higher than the long-term mean throughout the year, therefore 2006 can be considered as an anomalous warm year. From January to May, the temperature of the coastal waters (St. 1–3 of the Kola section) in all the layers was maximal during the whole period of observations since 1951, and in the Murman Current (St.3–7 of the Kola section), in 0–200 m and 50–200 m layers, the extremely high water temperatures were registered in the period from May to October (Figure 3). Since May, in the coastal waters, the positive anomalies were gradually decreasing. In 0–200 m layer, they decreased from 1.4 ºC to 0.6 ºC. In the Murman Current, some decrease of temperature anomaly was recorded from August to December, however throughout the year, it exceeded 1.0ºC. (Figure 3).

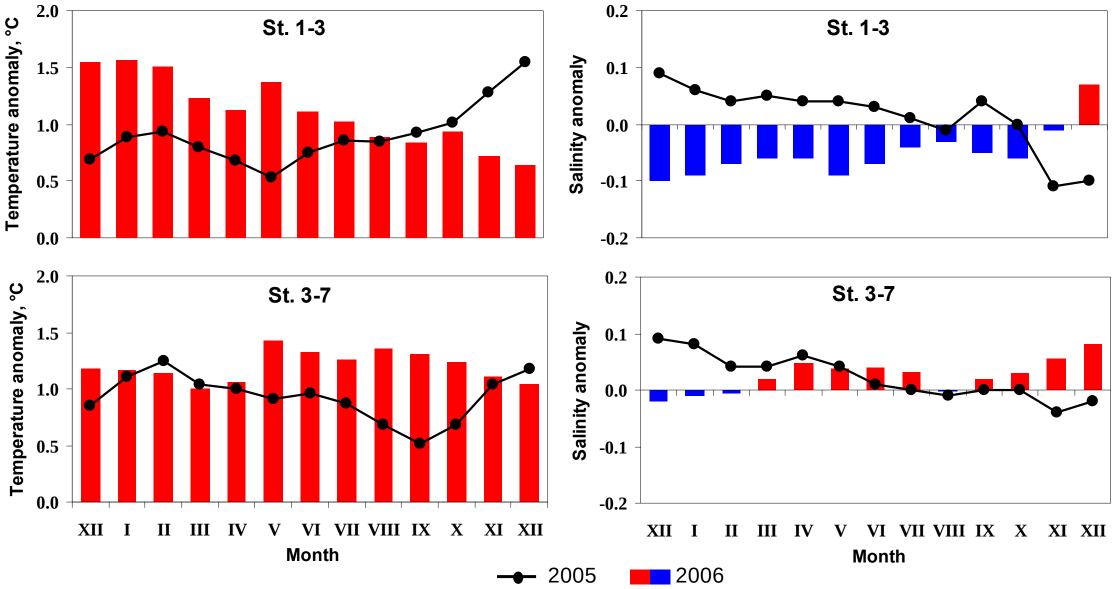


Figure 3. Monthly mean temperature (on the left) and salinity (on the right) anomalies in the 0–200 m layer of the Kola section in 2005 and 2006. St.1–3 – coastal waters. St.3–7 – Murman Current (Anon., 2007)

In the southern Barents Sea, water salinity was typical for warm years. In the coastal waters, the decrease in salinity relative to both the long-term mean and the last year levels was observed. In the Murman Current, on the contrary, since March, some increase in salinity with reference to the long-term mean level and 2005 was recorded (Figure 3).

On the whole, in 2006, in the 0–200 m layer of the Kola section, the mean annual water temperature was highest on record for more than 100 year history of observations in the section. In the 0–200 m layer of the Murman Current, salinity remained at the last year level, and, in the coastal waters, it was lower than normal and 2005 level (Figure 4).

In the North Cape-Bear Island Section, the observations were made in May and September. Temperature of the North Cape Current, in the 0–200 m layer, was characterized by significant positive anomalies: 1.3 ºC in May and 0.9 ºC in September.

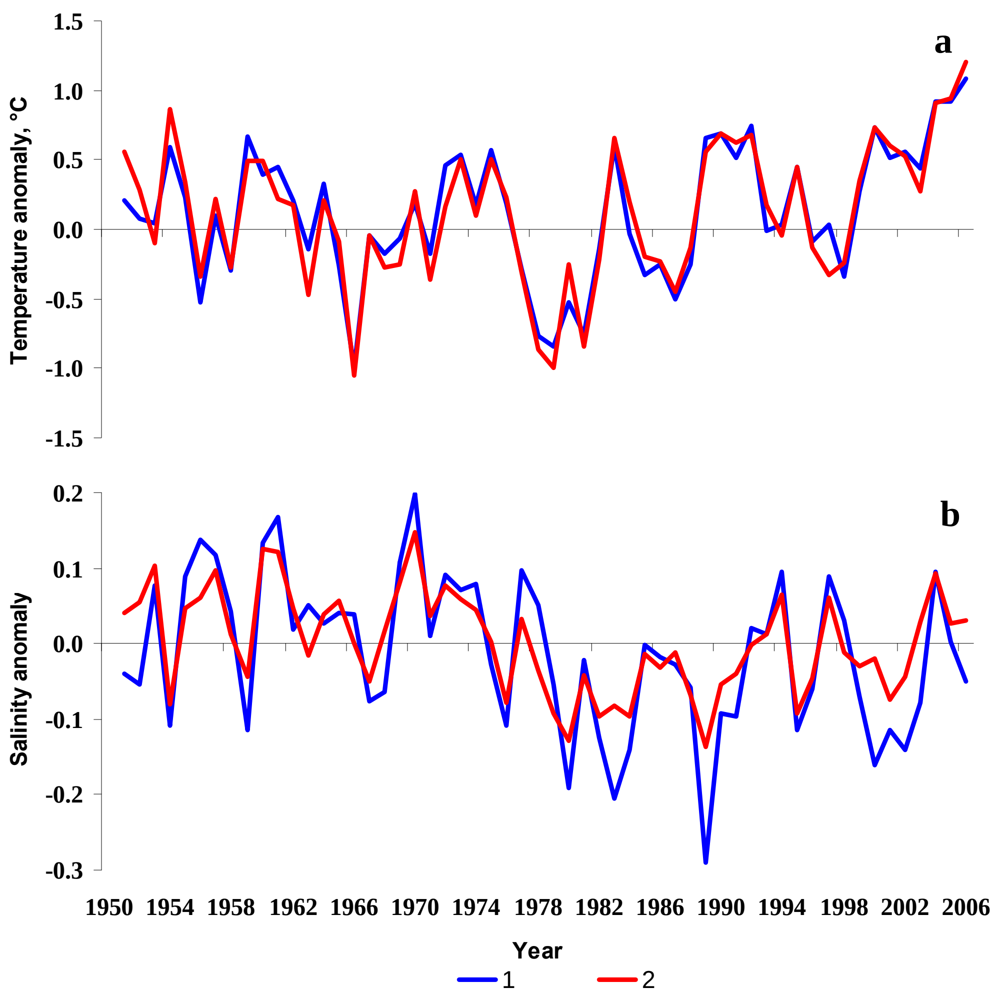


Figure 4. Mean annual temperature (a) and salinity (b) anomalies in the 0–200 m of the Kola section in 1951–2006. 1 – coastal waters, 2 – Murman Current (Anon., 2007).

In 2006, the section Bear Island – West (along 74º30'N) was occupied 5 times. During the year, temperature in the eastern branch of the Norwegian Current (74º30'N, 13º30'–15º55'E), in the 0–200 m layer, was significantly warmer than normal. The positive anomalies increased from 0.8ºC in April to 1.3ºC in October.

During 2006, the section Bear Island – East (along 74º30'N) was made 6 times. Temperature in the 0–200 m layer of the northern branch of the North Cape Current (74º30'N, 26º50'–

31º20'E), significantly exceeded the long-term mean level, with the maximum positive anomaly (1.4 ºC) registered in May and June. In August, the temperature of Atlantic waters remained high and, by October, positive anomalies of temperature decreased to 0.8 ºC.

In the eastern Barents Sea, in the Kanin section (along 43º15'E), the observations were made in August and October. In the Novaya Zemlya Current (71º00'– 71º40'N, 43º15'E), in the 0–200 m layer, water temperature was warmer than normal by 1.3 ºC in August and by 1.0 ºC in October.

In August-September 2006, in the bottom layer of the Barents Sea, water temperature, on the whole, corresponded to that one in anomalous warm years. Waters with positive anomaly of bottom temperature occupied more than 80% of the surveyed area (Figure 5), and at about 30% of it, the anomalies were maximal for the period since 1951. The highest anomalies of temperature in bottom layer (over 3ºC) were observed in the Spitsbergen Bank area. In the North Cape and Murman Currents, the positive anomalies of bottom temperature were 1.0–2.0ºC. In the northeastern sea, the negative anomalies to 0.5ºC were registered that was about 1ºC lower than 2005 (Figure 5).

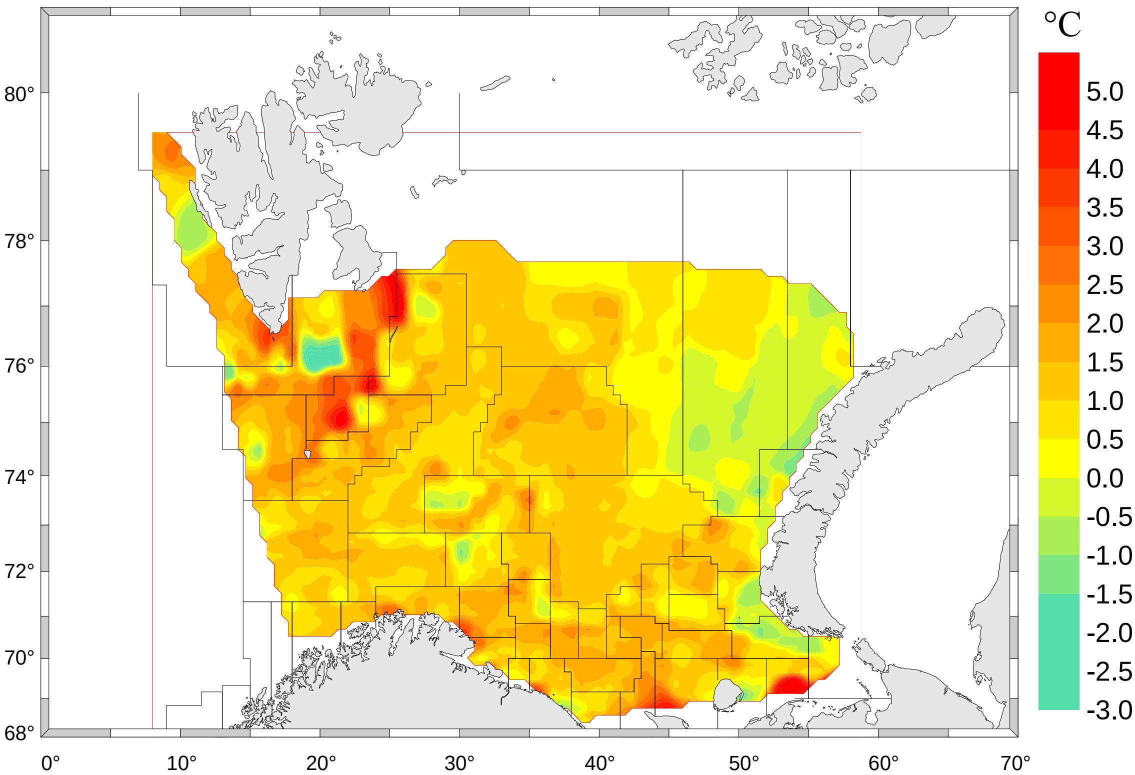


Figure 5. Bottom temperature anomalies in the Barents Sea in August-September 2006 (Anon., 2007).

Conclusion

According to temperature of air and sea water, 2006 can be classified as an anomalous warm year (Anon., 2007).

As a whole, in 2006, temperature in the main currents in the Barents Sea was significantly higher than the long-term mean value. In the Kola Section, the mean annual temperature in the 0–200 m layer was highest on record since 1900. The salinity of the Murman Current in the 0–200 m layer stayed at the last year level and, in the coastal waters, it was lower than normal and 2005 level.

During the year, the total ice extent was considerably less than the long-term mean, and, in January, May-July and December, it was the lowest for corresponding months since 1951.

References

Anon. 2007. Status of biological resources in the Barents Sea and North Atlantic for 2007. Ed by Yu. M. Lepesevich. Collected Papers. PINRO Press, Murmansk: 99 p. (in Russian)

Antsiferov, M. Yu., and Guzenko, V.V. 2002. Distribution of hydrometeorological characteristics in the eastern part of the Barents Sea in August and September 1972–2001. Murmansk, PINRO Press, 2002. 73 pp. (in Russian)

Bochkov, Yu. A. 1982. Historic data on water temperature in 0–200 m layer on the Kola Section in the Barents Sea (1900–1981). Trudy PINRO. 1982. p.113–122 (in Russian)

Terescchenko, V.V. 1997. Seasonal and year-to-year variations of water temperature and salinity in the main currents on the Kola Section in the Barents Sea. Murmansk: PINRO Press. 1997. 71 pp. (in Russian)

Tereshchenko, V.V. 1999. Hydrometeorological conditions in the Barents Sea in 1985–1998. Murmansk: PINRO Press. 1999, 176 p. (in Russian)

Annex 17: Hydrographic Conditions in the Greenland Sea and Fram Strait (ICES Area 12)

BY: A. Beszczynska-Möller, G. Budeus, E. Fahrbach, and A. Wisotzki: Alfred Wegener Institute for Polar and Marine Research, Postfach 120161, 27515 Bremerhaven, Germany

In summer 2006 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 onboard the new research vessel 'Maria S. Merian'. These two sections allow monitoring 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 essentially 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 oceanic fluxes enter the Arctic Ocean either through the Barents Sea or through Fram Strait. However, the Fram Strait represents the only deep connection between the Arctic Ocean and Nordic Seas. The transfer of heat and freshwater is affected by the different ocean-atmosphere interaction over the deep passage of Fram Strait and shallow Barents Sea and the spreading of Atlantic water into 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 only 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. This branch has to cross the Yermak Plateau, passing over the sill with a depth of approximately 700 m. 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 July 2006 with a regular station spacing of 10 Nm. In August/September 2006 a hydrographic section with a high spatial resolution was carried out across Fram Strait at 78°50'N. The CTD stations (Figure 1) were combined with recovery and redeployment of 12 moorings in the eastern and central part of the strait. Due to ice conditions (the sea ice tongue which developed in the central part of the strait during the cruise) the standard Fram Strait section was accomplished only to 2°W and further deviated to south-west, following the ice edge.

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 12 moorings, deployed in autumn 2005. 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 and since 2006 it has been continued in a frame of the EU DAMOCLES 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 maintained by AWI. The Norwegian Polar Institute operates the remaining 6 moorings in the western part of the strait. The standard measurement depths include the subsurface layer (ca. 50 m), the AW layer (ca. 250 m), the deep water (ca. 1500 m) and the near-bottom layer. Since 2003 the measurements at the array augmented with two new moorings in the recirculation area and an additional level of instruments at the AW lower boundary (ca. 750 m) have been continued.

The general situation at the section in the Greenland Sea at 75°N in 2006 was characterized by summer conditions with a low salinity surface layer. The subsurface layer in the central Greenland Gyre was strongly influenced by Atlantic Water as compared to previous years. Patches of warm and salty AW were found across the whole section (Figure 2a, b). Due to summer heating the warm surface water with T>0°C occupied ca. upper 100 m, while in areas with patches of AW isotherm 0°C deepened to 200–300 m (Figure 3a). These AW patches were also characterized by high salinity exceeding 34.9 (Figure 2b). The AW layer at the eastern rim of the Greenland Basin spread deeper had higher maximum salinity than in 2005. Also the area occupied by the Return Atlantic Water (RAW) at the western edge of the section has increased since 2005.

The averaged properties of the Atlantic Water and Return Atlantic Water observed at the Greenland Sea section at 75°N (Figure 3) were similar as last year and remained high, after recovery from the extremely low values in 2003. The properties of the Atlantic Water 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 is characterized by the temperature and salinity maximum below 50 m averaged over 3 stations west of 11.5°W. In AW domain temperature was close to observed in 2005, in the RAW domain further increase of temperature was found. In both domains temperature exceeded the long term mean. Temperature of the AW reached the maximum for the whole time series (5.65°C) while temperature of the RAW was the second highest (2.9°C after maximum 3.5°C in 1995). A significant rise of mean salinity was also found RAW resulting in highest values since the beginning of observations, 35.106. In the AW domain salinity slightly decreased as compared with 2005 but still remained high (the second highest 35.156 after last year maximum 35.16).

Time development of temperature and salinity in the central Greenland Basin, within the Greenland Gyre is shown on Figure 4. 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. Salinity development shows several periods of salinity increase, the strongest signal found in last 2 years. Freshening/salinification of the upper layer are related to two different type of the winter convection and the mixed layer type ventilation is favourable for the deepening of AW and salinity increase (Ronski and Budeus, 2005). The absence of a steady trend is visible in the temperature development where periods of cooling and warming alternate. However, the last 3 years are characterized by significantly higher temperatures and a deeper warm layer. 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 winter convection depths (Figure 5) 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. In winter 2005/2006 the winter convection depth was estimated on 1200m, which was significantly deeper than during the previous winter (700m) but still less the maximum depths in period from winter 1999/2000 to 2002/2003 (between 1400 and 1600 m). Mean properties of the deep water (3000m) in the center of the Greenland Gyre shown on Figure 6 reveal steady increase both in temperature (from -1.18°C to -1.015°C) and salinity (from 34.9013 to 34.9125) over last 14 years.

In 2006 warming and salinification continued in the entire Fram Strait and especially in the WSC domain. The Atlantic layer in the WSC was warmer than in 2005 and significantly deeper (Fig.7a). The lower boundary of AW warmer than 0°C was shifted down to ca. 1000 m. The cold Polar Water (PW) in the western part of the section retreated westward as compared to 2005 and clear westward shift of the Polar Front between AW and PW is visible in last 3 years. The thicker AW layer in the WSC had also higher salinity than the year before (Figure 7b). The westward range of the AW in the recirculation area in the deep part of the strait was similar as in 2005. The surface layer of low salinity water was confined to the western part of the section with only small patches present above the AW in the middle part. This was different than in 2004 and 2005 when the low salinity surface water was nearly continuous across the whole section. Difference of temperature between 2006 and 2005 (Figure 7c) shows also noticeable warming in deep waters in the whole Fram Strait (up to 0.1°C).

Time series of mean temperature and salinity in Fram Strait 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 8). Mean temperature and salinity in the layer 50–500m in three domains (WSC, RAC, and EGC) were all higher than the long period average and continued the increase observed already in 2003. Mean temperature and salinity in the WSC reached their maxima since the beginning of measurements (4.75°C and 35.10 respectively). A slight decrease was found in mean temperature in the RAC as compared to 2005 but it still remained high, while mean salinity in the RAC was close to the last year value. In the EGC both mean temperature and salinity were comparable to observed in 2005.

Hydrographic properties of the Atlantic water in Fram Strait (defined as water mass with T>2°C and S>34.92) reveal the clear trend for last 10 years (Figure 9). While the spatial coverage of the AW varied strongly year-to-year within a first half of measurement period, it has been steadily increasing since its local minimum in 2002. Also the mean temperature and salinity of Atlantic Water have continued to increase since 2003. In 2006 both mean temperature and salinity of the AW reached their maxima for the whole time series (3.84°C and 35.06 respectively). In addition to high temperature and salinity, the AW occupied exceptionally big area of the section what resulted in the largest heat content since the beginning of time series.

Time series of temperature and current velocities, recorded at the array of moorings since 1997 were used to calculate volume and heat fluxes through Fram Strait. A time-space diagram of temperature and cross-section current velocity at the depth of 250m, representative for the AW layer (Figure 10) confirms tendencies found from summer hydrographic sections. In late autumn and winter 2005/2006 significantly higher temperatures were observed not only in the WSC but especially in the middle part of Fram Strait, in recirculation area. A seasonal signal characterized by lower temperatures in late winter and spring was strongly dumped and seasonal differences in temperature were much smaller then in previous years. In the WSC the cross-section current velocity was lower in 2005–2006 than in 2004–2005 and winter maximum of the northward flow was also much weaker. In the recirculation area the cross-section flow was variable, similar as in previous years while in the EGC a stronger southward flow was observed during the last deployment period.

The weaker flow in the WSC resulted in a decreased volume transport with the much lower winter maximum in 2006 than in 2005 (Figure 11a). Despite of the lower volume transport, the heat transport in the WSC (Figure 11b) remained high, on interannual time scale close to values observed one year before. However the usual winter maximum in the heat transport was hardly visible. A significant increase of temperature in the WSC balanced a decrease in volume transport, resulting in the relatively high heat transport. The annual averages of volume and heat transports across the whole Fram Strait (Figure 12) show a relatively high net volume transport to the south and lower net heat transport than in last 2 years. The latter is mostly due to the increased southward heat transport in the EGC, which can be a joint effect of the stronger southward volume transport of the warmer water in this area. The net volume transport through the recirculation area was rather low and on the annual scale the heat transport remained practically balanced to zero in this domain.

The general conclusion for 2006 is that temperature and salinity in the Greenland Sea and Fram Strait were higher than in 2005 and higher than their long term averages. An increase of the AW spatial coverage was observed at both sections and this AW was warmer and more saline than before. Higher temperatures and salinities were also found in the recirculating AW (return AW flow to the south). Deep waters in the Greenland Basin steadily change towards the warmer and more saline conditions and in 2006 an arisen temperature in the deep layer was also observed in Fram Strait.

List of figures:

Figure 2 Location of CTD stations in 2006 (black dots – in the Greenland Sea during MSM02/2, red dots – in Fram Strait during MSM02/4).

Figure 2 Distributions of potential temperature (upper fig.) and salinity (lower fig.) at the section
across the Greenland Sea measured in summer 2006 (G. Budeus, S. Ronski).

Figure 3 Time series of mean properties of the Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea observed at the section along 75°N (G. Budeus, S. Ronski). Anomalies from the long term averages (1989–2000) shown at the bottom plots.

Figure 4 Time development of temperature (left panel) and salinity (right panel) in the central Greenland Gyre in 1993–2006 (G. Budeus, S. Ronski).

Figure 5 Time series of the winter convection depths in the Greenland Sea in 1993–2006, obtained with the multiparameter method by Ronski and Budeus (2005)

Figure 6 Time series of temperature (left panel) and salinity (right panel) of the deep water (3000 m) in the central Greenland Sea in 1993–2006 (G. Budeus, S. Ronski)

Figure 7 Vertical distributions of (a) potential temperature and (b) salinity at the section through Fram Strait at 78°50’N measured in 2006 and (c) temperature difference between 2006 and 2005.

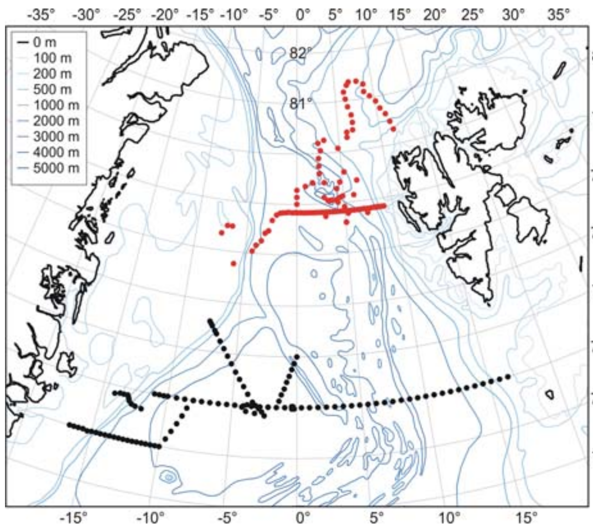
Figure 8 Time series of the mean temperatures and salinities in Fram Strait in the West Spitsbergen Current (WSC), Return Atlantic Current (RAW) and East Greenland Current (EGC) in the layer 50–500m. Anomalies from the long term averages (1980–2000) shown at the bottom plots.

Figure 9 Mean properties of Atlantic Water (T>2°C, S>34.92) based on CTD sections in 1997–2006.

Figure 10 Hovmöller diagrams of temperature (upper fig.) and meridional component of current (lower fig.) in the AW layer at the depth 250m in 1997–2006. Monthly means of the measured values used.

Figure 11 Monthly means of the northward, southward and net volume (Figure a) and heat (Figure b) fluxes in the West Spitsbergen Current based on results from the array of moorings in 1997–2006.

Figure 12 Annual averages of net volume and heat fluxes through Fram Strait (upper left fig.) and separately in three domains: WSC (lower left fig.), RAC (upper right fig.) and EGC (lower right fig.) based on results from the array of moorings in 1997–2006.



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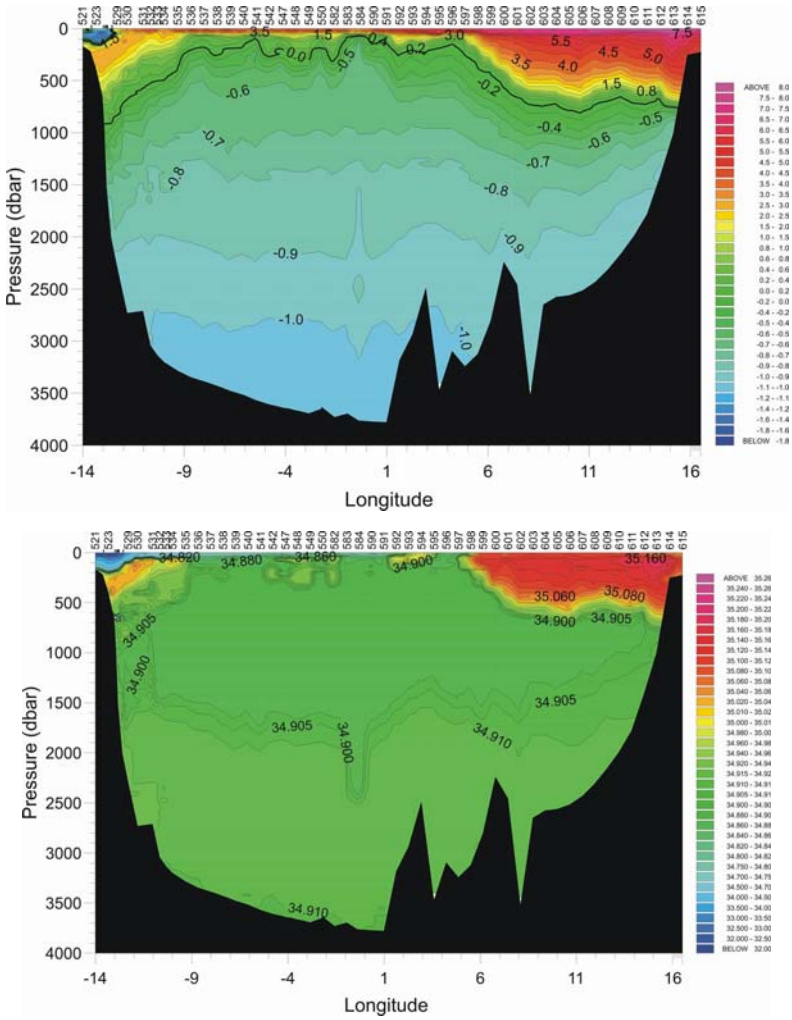

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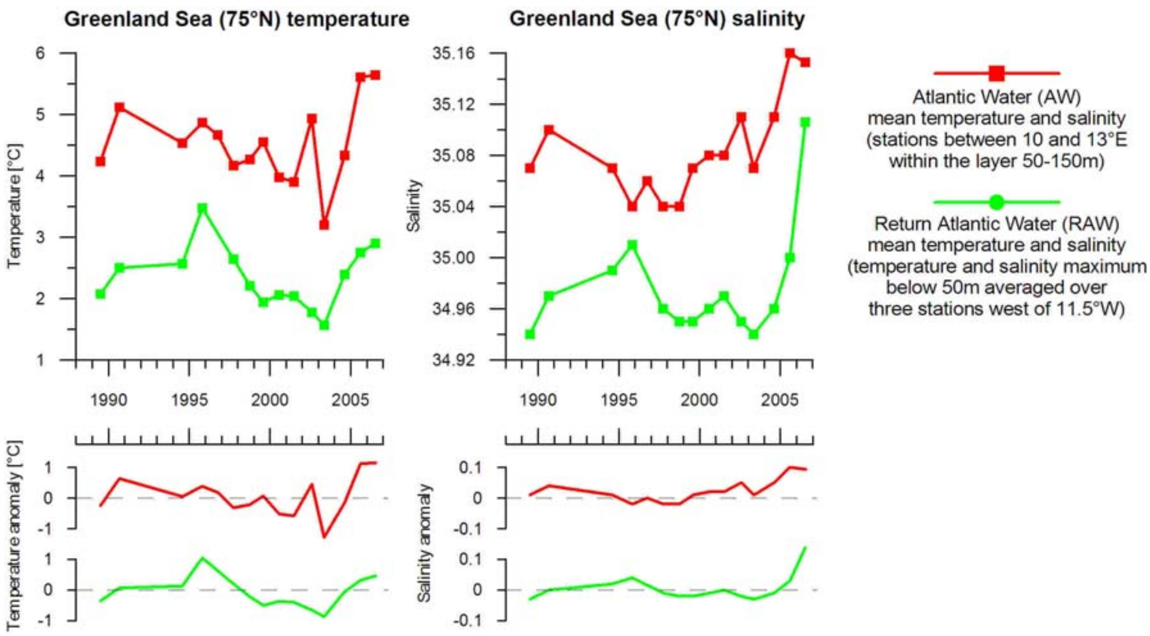

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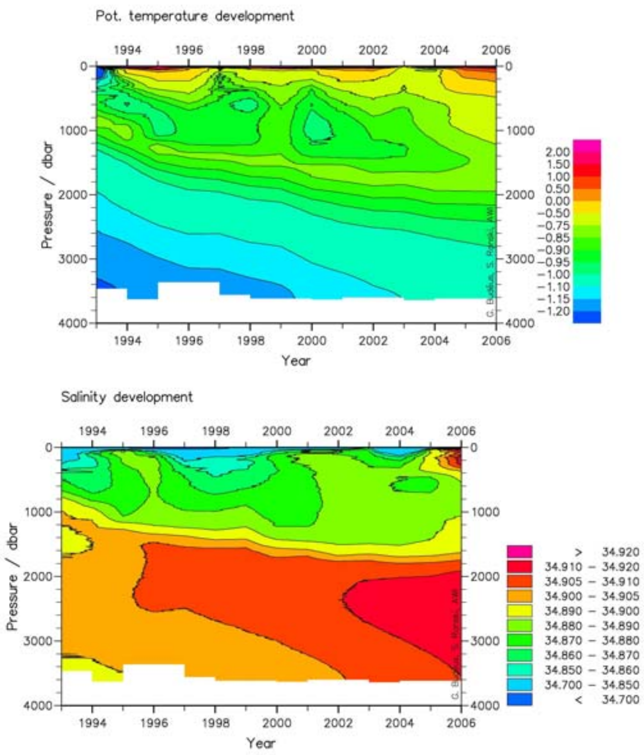
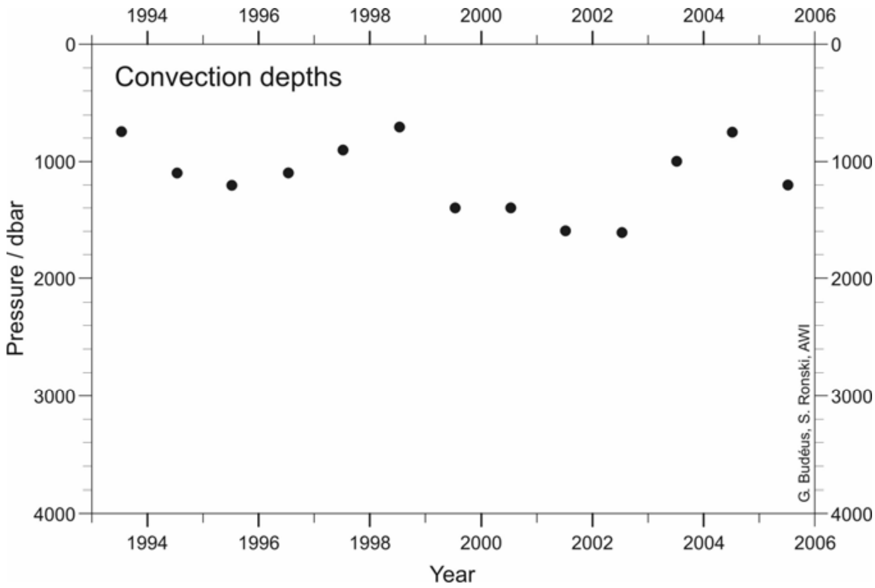


Figure 4. Time development of temperature (left panel) and salinity (right panel) in the central Greenland Gyre in 1993–2006 (G. Budeus, S. Ronski).



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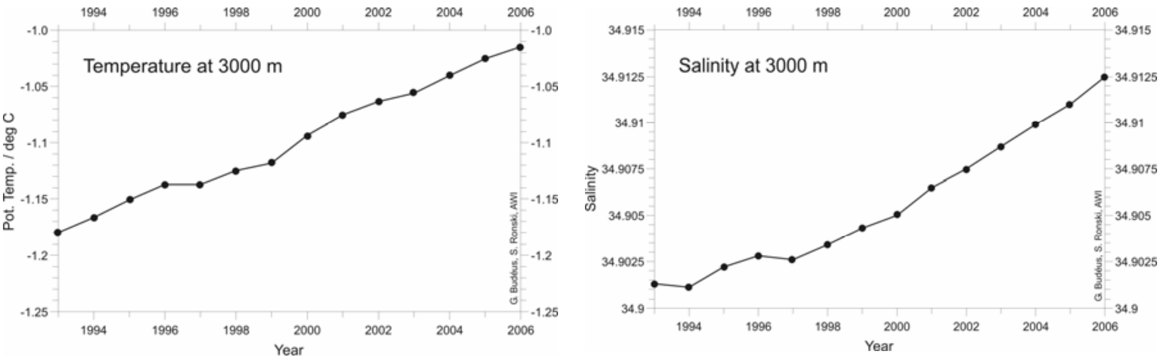

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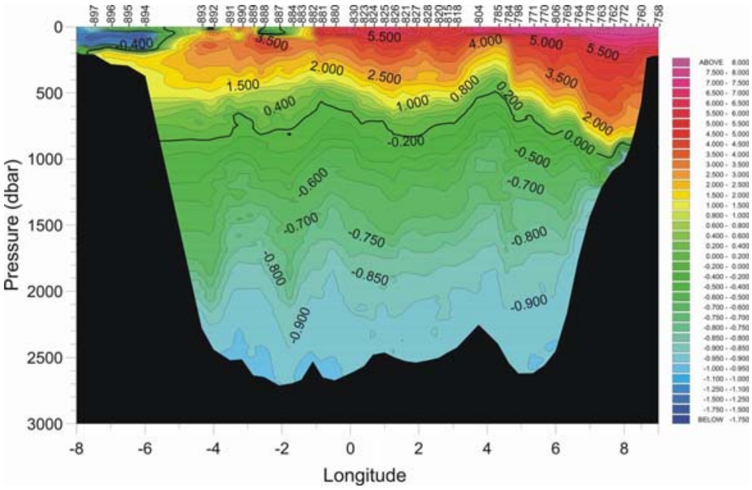

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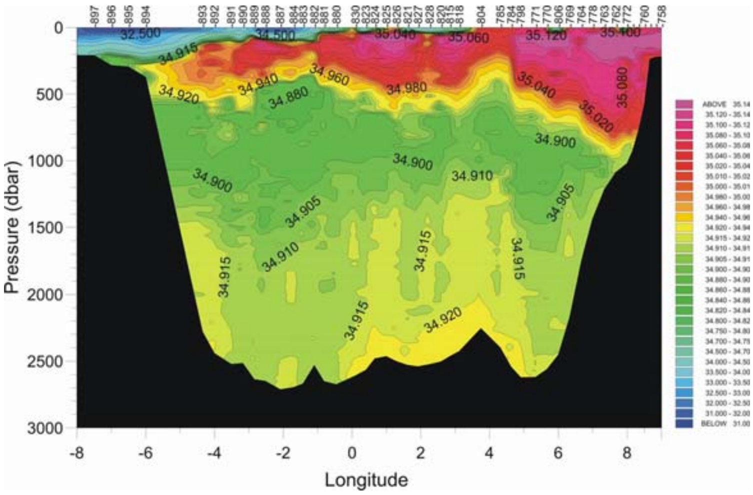

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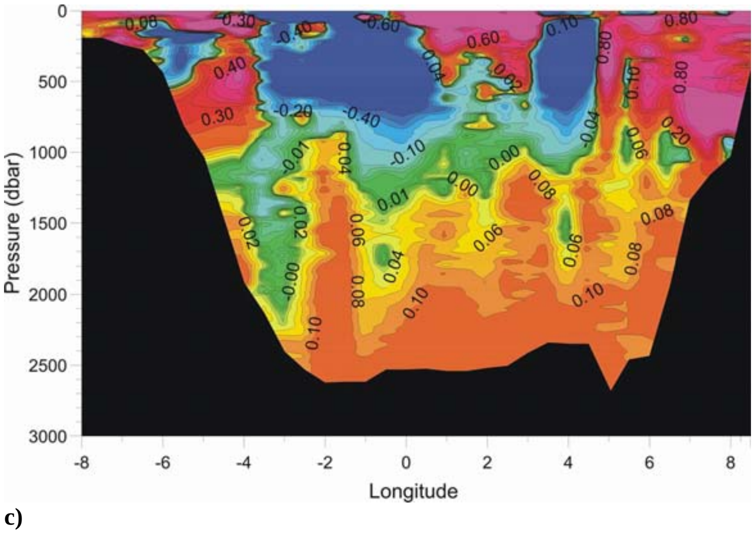
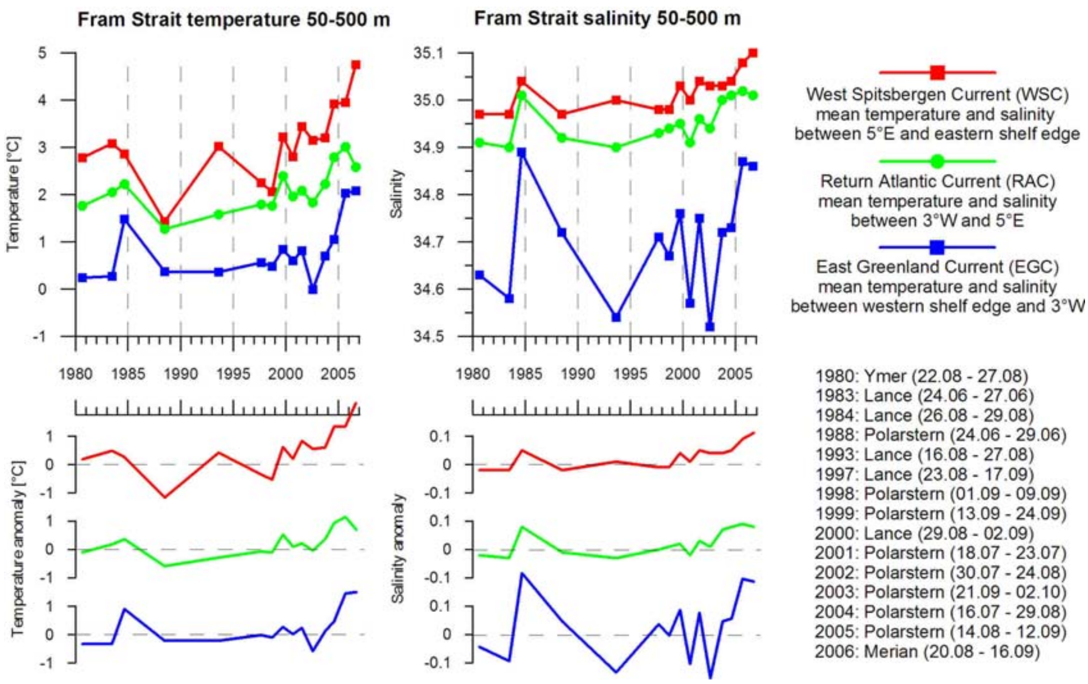


c)

Figure 7 Vertical distribution of (a) potential temperature and (b) salinity at the section through Fram Strait at 78°50'N measured in 2006 and (c) temperature difference between 2006 and 2005.



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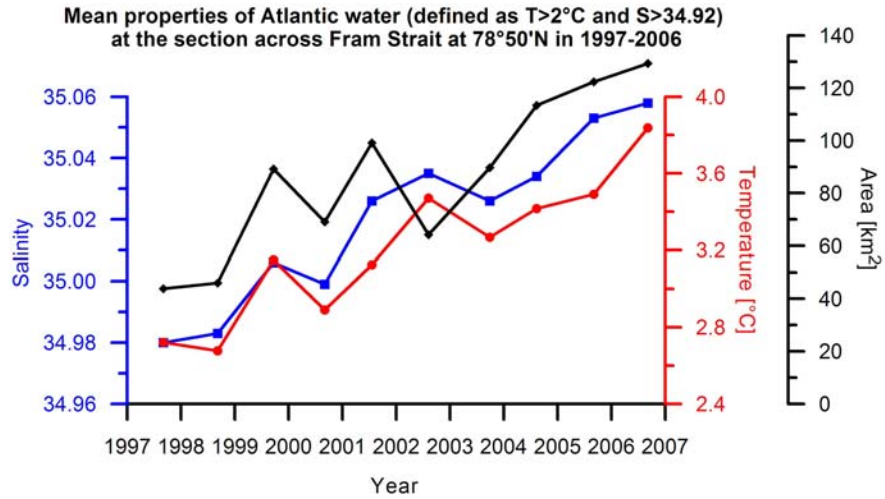


Figure 9. Mean properties of Atlantic Water (T>2°C, S>34.92) based on CTD sections in 1997–2006.

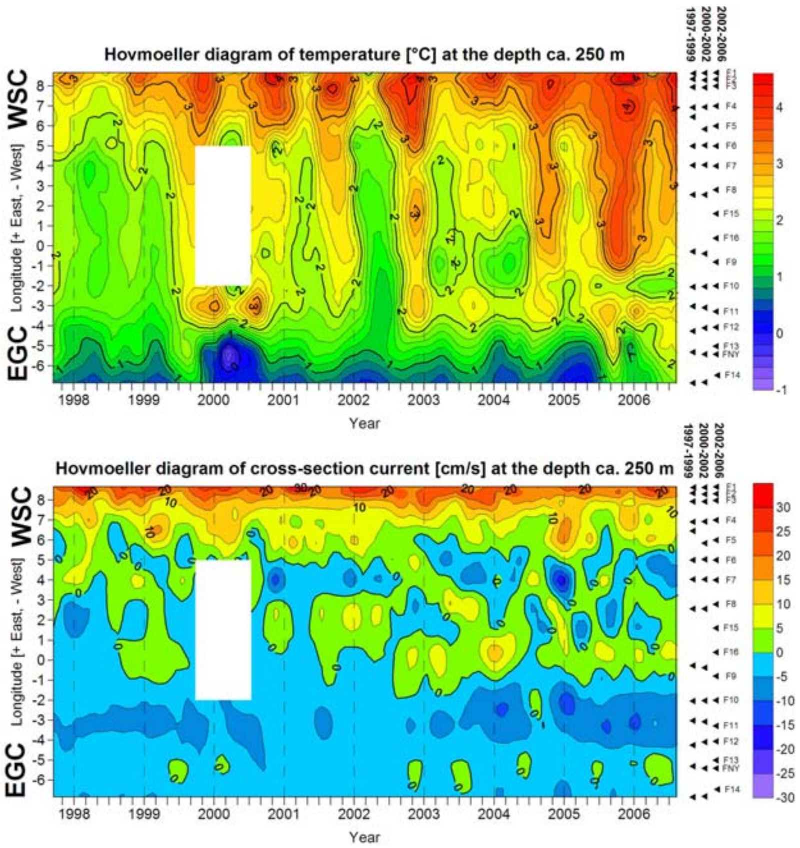
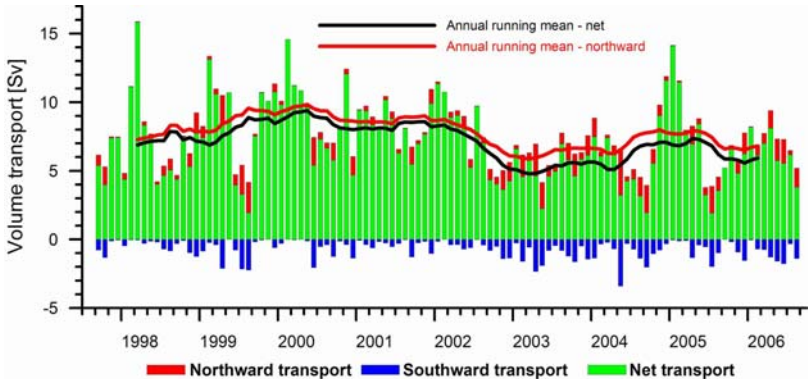
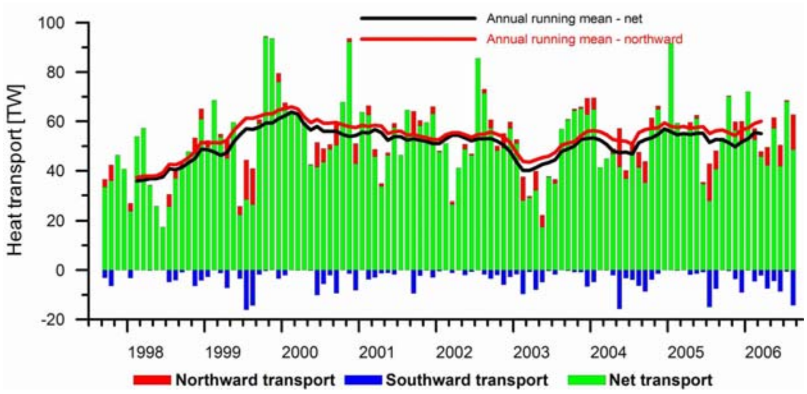


Figure 10. Hovmöller diagrams of temperature (upper figure) and cross-section current (lower figure) in the AW layer at the depth 250m in 1997–2006. Monthly means of the measured values used.



a)



b)

Figure 11. Monthly means of the northward, southward and net volume (figure a) and heat (figure b) fluxes in the West Spitsbergen Current based on results from the array of moorings in 1997–2006.

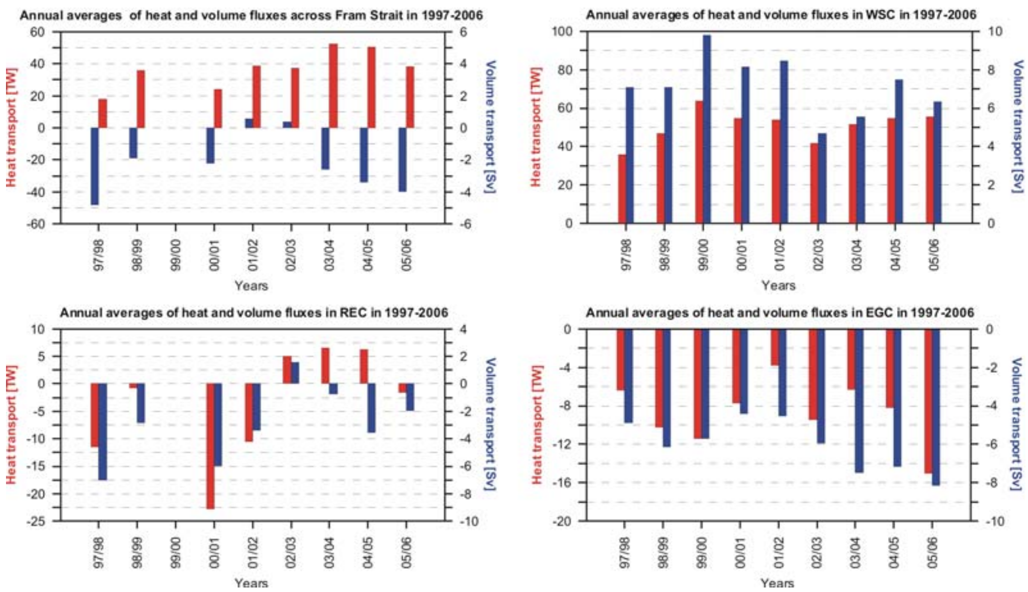


Figure 12. Annual averages of net volume and heat fluxes through Fram Strait (upper left fig.) and separately in three domains: WSC (upper right fig.), RAC (lower left right fig.) and EGC (lower right fig.) based on results from the array of moorings in 1997–2006.

Annex 18: Ireland Area report

BY: Glenn Nolan, Kieran Lyons and Sheena Fennell, Oceanographic Services, Marine Institute

Coastal time series

Several coastal time series are maintained around the Irish coast. These include a standard oceanographic section at 53° North, SST measurements at the M1 weather buoy (west of Galway) and a longer-term SST record at Malin Head. The locations of these measurements are shown in Figure 1.

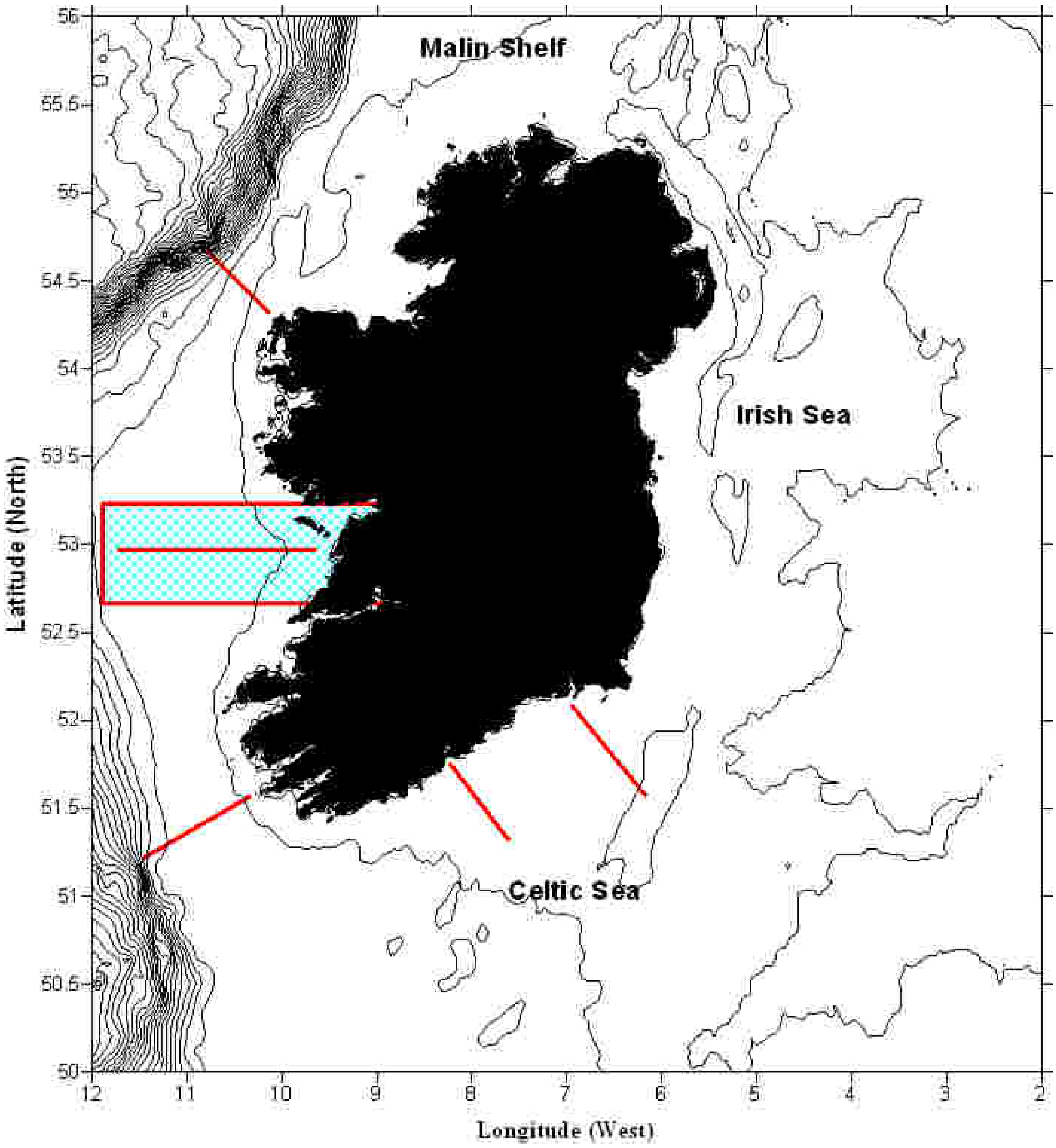


Figure 1. The Sea area west of Ireland. 53North line shown within blue shaded box. Malin Head SST location shown as a red dot. The M1 weather buoy is located in the blue shaded box at ca. 53N, 11W.

53° North hydrographic section

The 53° North section has been occupied annually since 1999 by the RV Celtic Voyager. Anomalies on the section are calculated relative to the World ocean Atlas climatology. Figure 2 shows the temperature anomaly along this section. Since 1999 the temperature anomaly has been positive (with the exception of 2001 where the value matched the climatological mean). Years of weaker positive temperature anomalies seem to co-occur with years of negative salinity anomalies (Figure 3).

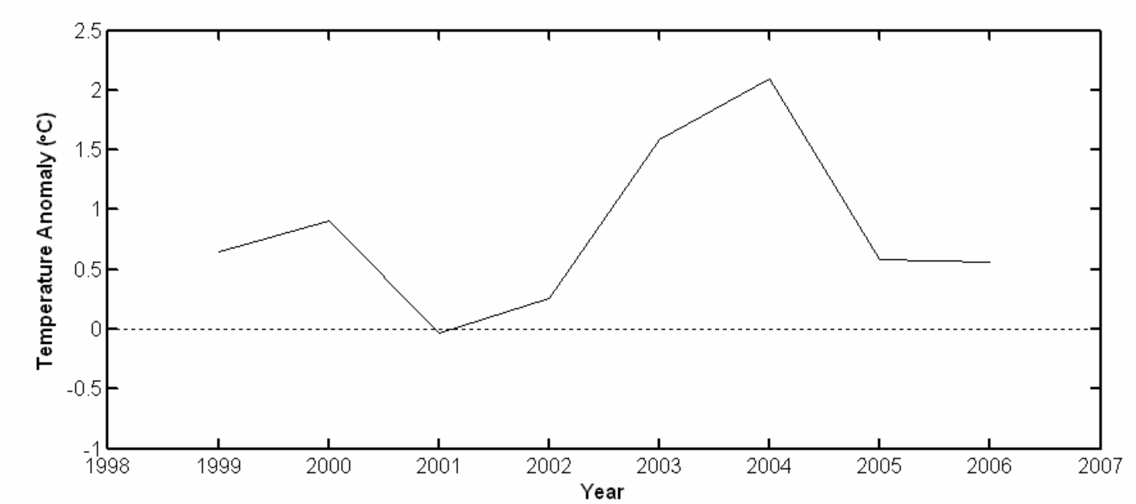


Figure 2. Temperature anomalies along the 53° North section (1999–2006). Climatological values are calculated from the World Ocean Atlas.

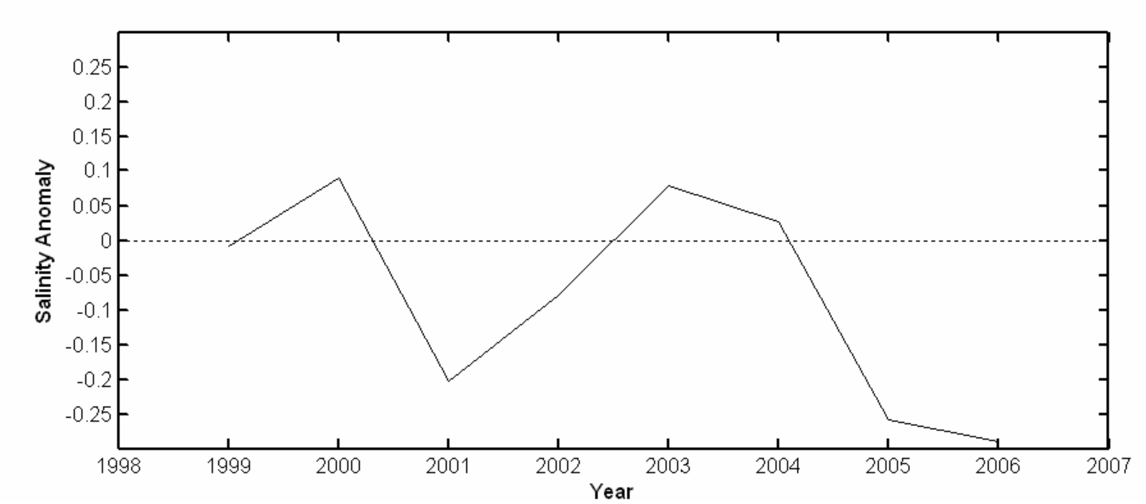


Figure 3. Salinity anomalies along the 53° North section (1999–2006). Climatological values are calculated from the World Ocean Atlas.

M1 Buoy

An offshore weather buoy is maintained at 53° N, 11° 12’ W on the western Irish shelf. Sea surface temperature data are measured hourly at this location and archived after quality control procedures have been completed. Figure 4 below shows the SST anomaly from both the WOA mean and from the mean values for the M1 buoy since late 2001. The anomaly compared to the buoy’s mean is the lower of the two curves. Compared to WOA the buoy SST anomaly is positive for the duration of the time series. The anomaly exceeds 1°C in 2003.

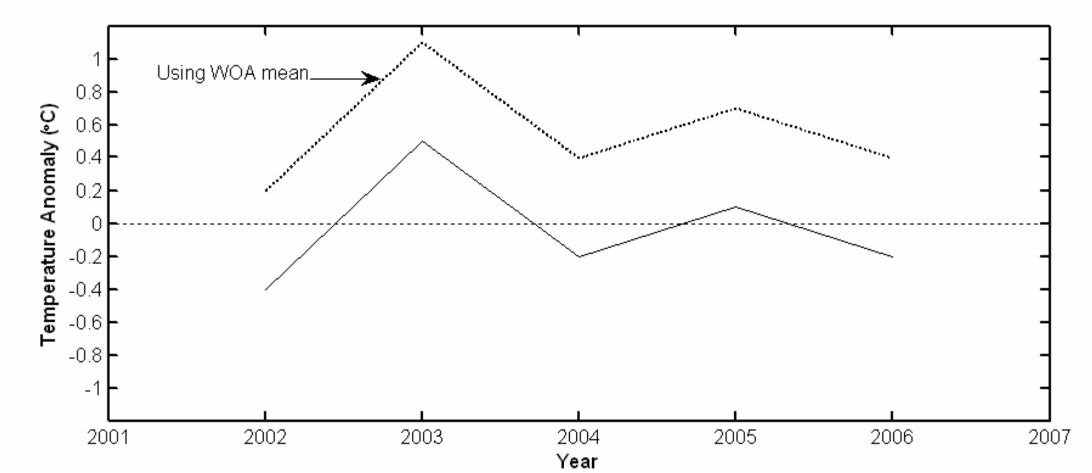


Figure 4. SST anomaly at the M1 weather buoy since its deployment in 2001.

Considering the M1 SST data as a Hovmoller plot (Figure 5) the intense warming during summer is evident in 2003, 2004 and to a lesser extent in 2005 (around day 225). The length of the summer heating season is longer in 2005 and 2006 most likely related to calmer weather conditions.

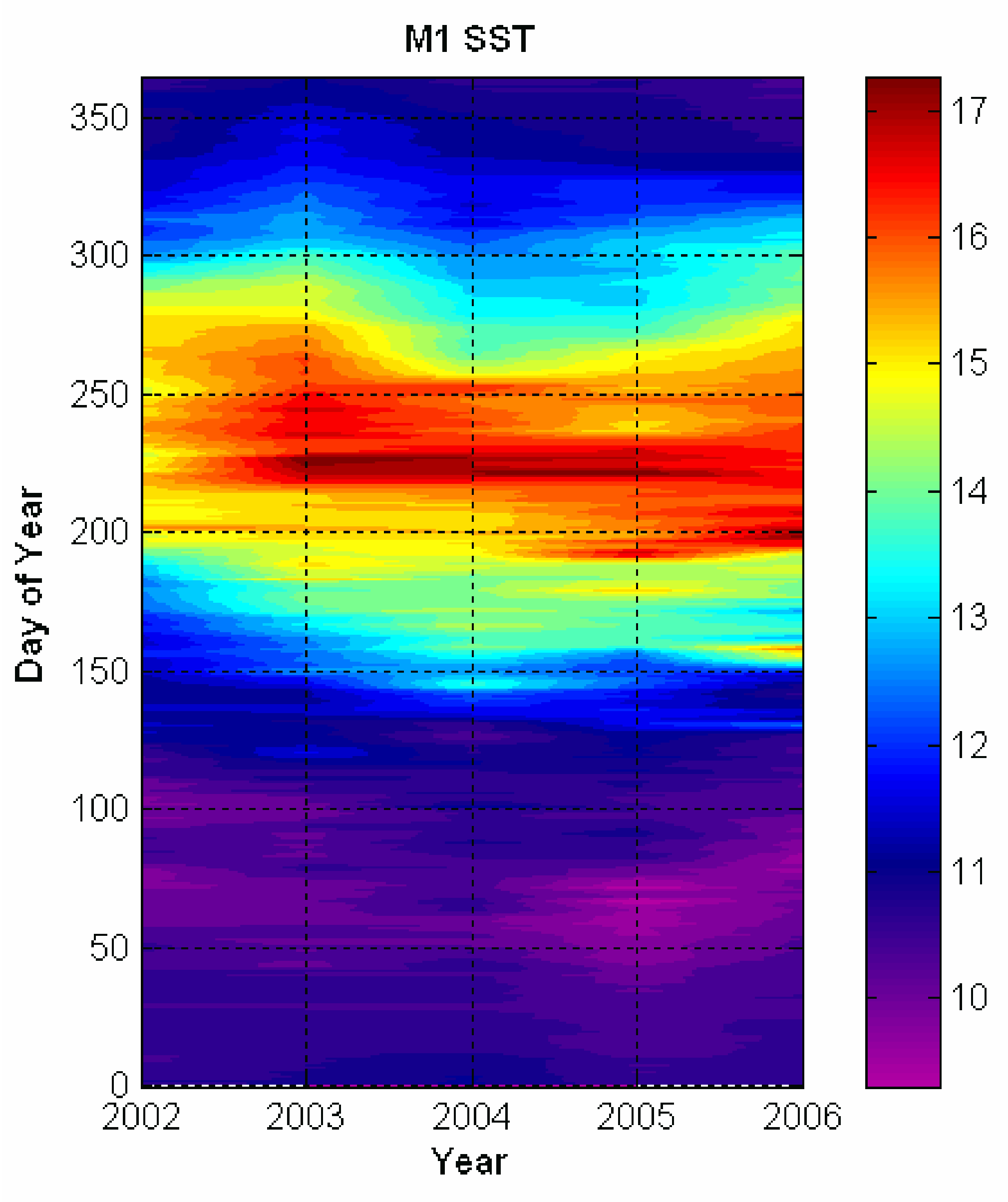


Figure 5. SST Hovmoller diagram at M1 weather buoy.

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. The results presented herein are daily averages of sea surface temperature at the station (Figure 6).

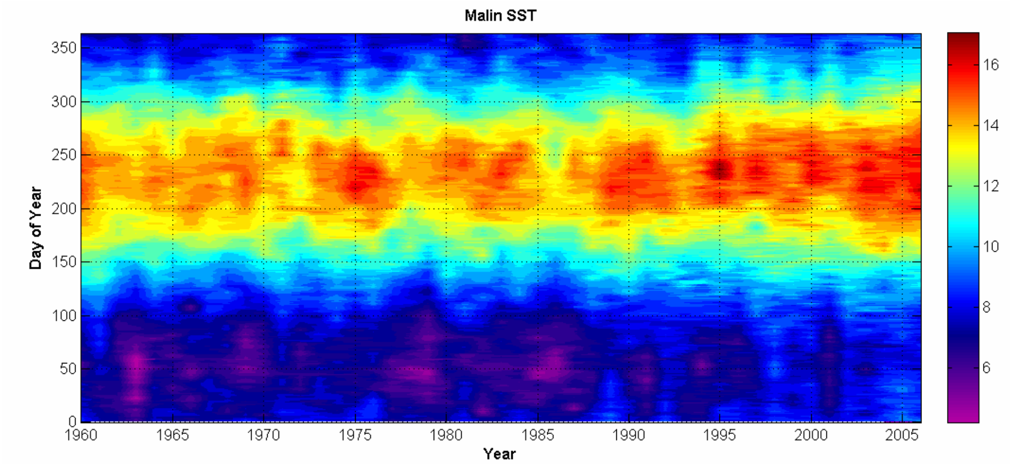


Figure 6. Sea surface temperature from Malin Head (Ireland) 1960–2005, x axis is year while y axis is year day (0–365).

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 considered in relation to storminess over the period of the record. Figure 7 depicts the wind speeds over the northern part of Ireland since 1960. Red colours relate to wind speeds exceeding 30 knots while weak wind speeds are coloured blue and purple. Stormy conditions in February and March are apparent in 1963, 1978 and 1985–1986 concurrent with the lower winter SST values.

Winter temperatures are typically >6°C since 1990 and summer temperatures are more pronounced in that period also. This seems to correspond with a period of decreased storminess in this data since 1990.

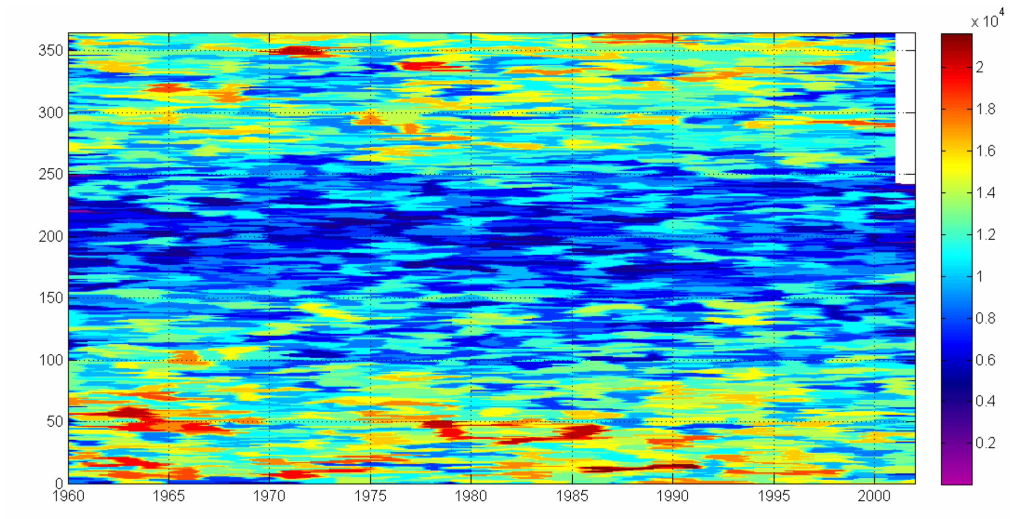


Figure 7. Wind speed for a grid covering the northern part of Ireland (1960–2002). Red colours indicate stormy conditions, blue colours indicate calm conditions.

Consideration has been given to the sea surface temperature anomaly at Malin Head over the 1960–2006 period. The anomaly is expressed relative to the 1961–1990 average and is shown in Figure 8 below.

There is considerable variability in the anomaly both on a monthly and yearly basis but a trend towards sustained positive temperature anomalies from 1990 is apparent. Interestingly the temperature anomaly record at Malin seems to mirror that observed at 53°N in the period between 1999 and 2006 with both records showing smaller temperature anomalies in 2002 and post 2005.

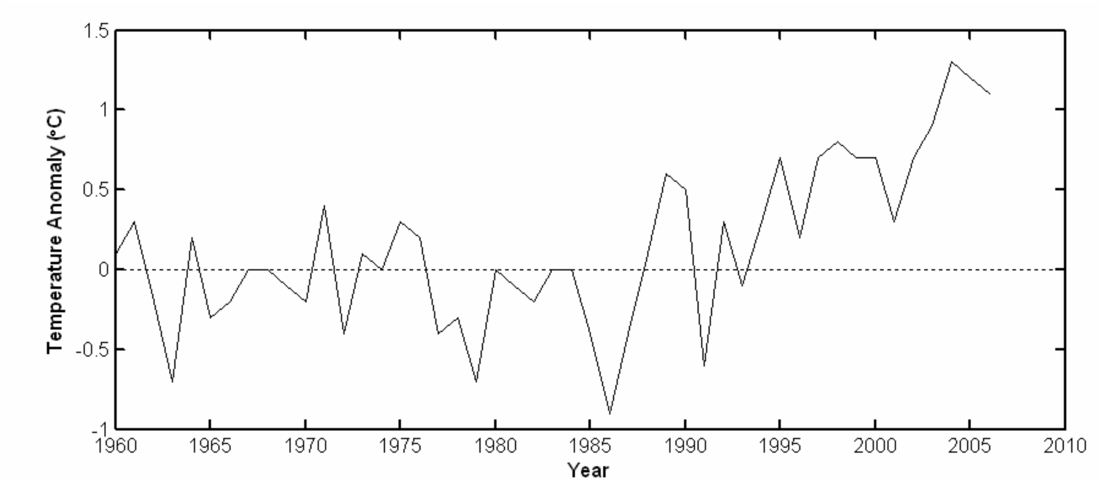


Figure 8. Sea surface temperature anomaly at Malin Head (1960–2005).

Offshore cruise activity

Celtic Explorer cruise CE0702 was conducted in January 2007 to examine hydrographic conditions in Rockall Trough. A total of 69 stations were occupied for a variety of parameters including CTDs, grab samples and cores, nutrients, salinity and phytoplankton. A coastal buoy was also deployed in Galway Bay at the end of this cruise (station 70 in log).

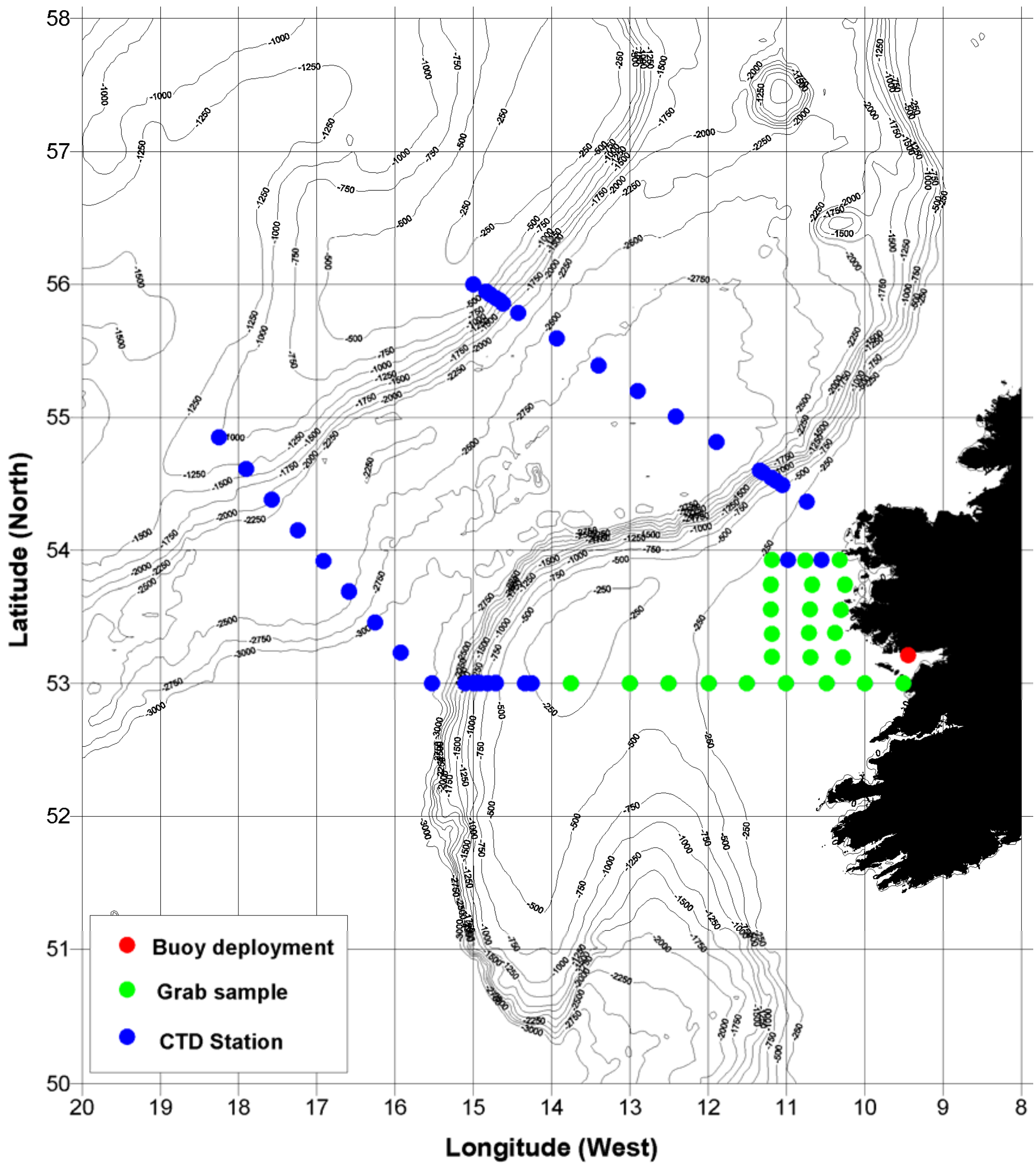
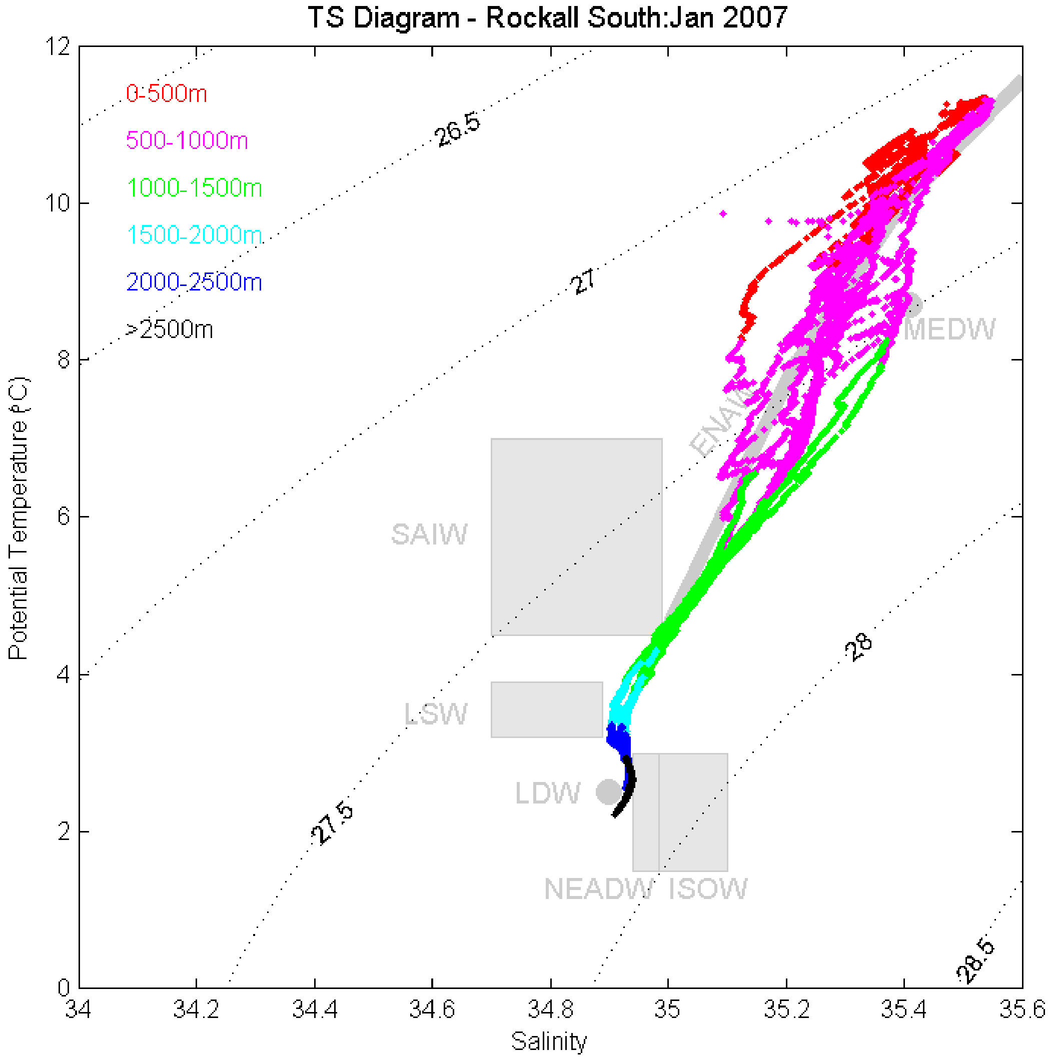


Figure 9. Offshore cruise station locations, January 2007.

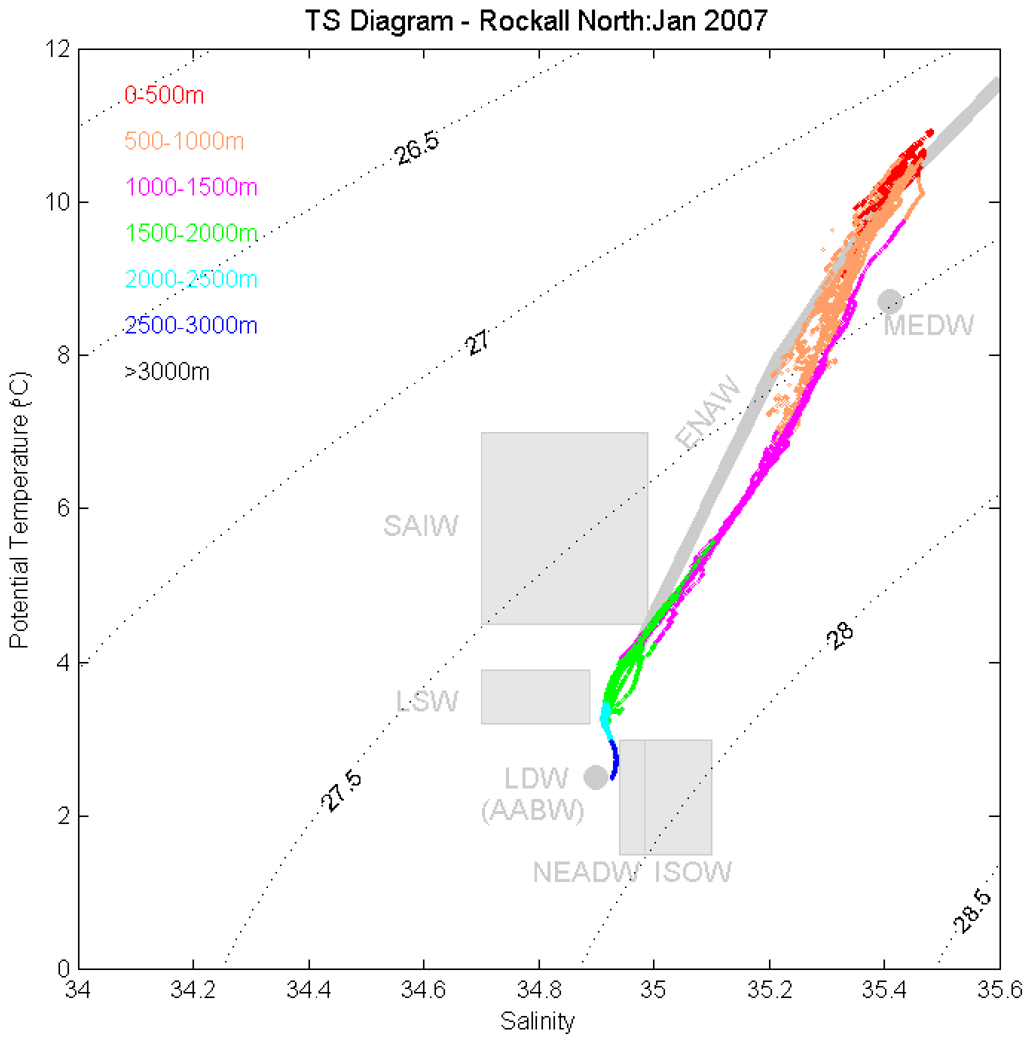
South Rockall line

Two transects across the Rockall Trough were completed on cruise CE0702. The first was the South Rockall Line which runs from Porcupine Bank to Southern Rockall Bank. Some stations on this transect exceed 3000m 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 deeper on the eastern side of the trough also and shoals up as one progresses westward along the section. A pool of low salinity water is evident at ca. 17W. This signal is evident in the low dissolved oxygen signal at the same location. 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. There was limited evidence of overflow water from the Nordic Seas on this section.



North Rockall line

The second traverse of the Rockall Trough conducted is the North Rockall line which traverses from Rockall Bank to Erris Head. Again a shoaling of the permanent thermocline is evident from east to west on this section. The picture is complicated by the presence of an eddy at ca. 12 30'W evident in the temperature, salinity, density and dissolved oxygen measurements. Because this section is further north than the previous section, Med Water is not observed on the North Rockall line.


TS Diagram - Rockall North:Jan 2007
0-500m
500-1000m
1000-1500m
1500-2000m
2000-2500m
2500-3000m
>3000m
26.5
27
27.5
28
28.5
SAIW
LSW
LDW
(AABW)
NEADW
ISOW
ENAW
MEDW
Potential Temperature (°C)
Salinity
0
2
4
6
8
10
12
34
34.2
34.4
34.6
34.8
35
35.2
35.4
35.6

Annex 19: Environment Conditions on the Newfoundland and Labrador Shelf during 2006 – ICES Area 2

BY: E. B. Colbourne, J. Craig, C. Fitzpatrick, D. Senciall, P. Stead, and W. Bailey: Fisheries and Oceans, Canada, P. O. Box 5667, St. John's Newfoundland, Canada A1C 5X1

ABSTRACT

Oceanographic observations on the Newfoundland and Labrador Shelf during 2006 are presented in relation to their long-term (1971–2000) means. At Station 27 off St. John's, the depth-averaged annual water temperature increased over 2005 setting a new record high of nearly 1°C above normal. Annual surface temperatures at Station 27 were also the highest in 61-years at 1.7°C above normal. Bottom temperatures were also above normal by 0.8°C, the 3rd highest in the 61-year record. Annual surface temperatures on Hamilton Bank were 1°C above normal, the 10th highest on record, on the Flemish Cap they were 2.5°C above normal, the 3rd highest in 57 years. Upper-layer salinities at Station 27 were above normal for the 5th consecutive year. The area of the Cold-Intermediate-Layer (CIL) water mass on the eastern Newfoundland Shelf during 2006 was below normal for the 12th consecutive year and the 3rd lowest since 1948. The near-bottom thermal habitat on the Newfoundland and Labrador Shelf continued warmer than normal in 2006, with bottom temperatures remaining >2°C, about 0.5°C above normal on Hamilton Bank off southern Labrador during the fall. Bottom temperatures during the fall however decreased substantially from 2005, particularly in northern areas. The area of bottom habitat on the Grand Banks covered by sub-zero water has decreased from >50% during the first half of the 1990s to near 15% during the past 2 years, ranking the 3rd lowest in 2006. In general, except for late fall values, water temperatures on the Newfoundland and Labrador Shelf increased from 2005 values, continuing the warm trend experienced since the mid to late 1990s. Newfoundland and Labrador Shelf water salinities, which were lower than normal throughout most of the 1990s, increased to the highest observed in over a decade during 2002 and have remained above normal in most areas during 2006.

INTRODUCTION

Meteorological and oceanographic conditions during 2006 are presented referenced to a standardised base period from 1971–2000. The data were collected by a number of researchers in Canada and compiled into time series for the standard sections and stations. Recognising the usefulness of standard oceanographic indices for monitoring ocean climate variability the Canadian Department of Fisheries and Oceans started occupying a series of cross-shelf hydrographic sections and stations beginning in the late 1940s. In 1976 the International Commission for the Northwest Atlantic Fisheries (ICNAF) adopted a suite of standard oceanographic stations along sections in the Northwest Atlantic from Cape Cod (USA) to Egedesminde (West Greenland) (Anon. 1978). Several of these sections are occupied seasonally on oceanographic surveys conducted by the Canadian Department of Fisheries and Oceans (Figure 1a).

Climate conditions in the northwest Atlantic are largely determined by the strength of the winter atmospheric circulation (Colbourne *et al*., 1994; Drinkwater, 1996). In general, when the normal cyclonic circulation is weak during the winter months, usually corresponding to a negative NAO index, warm-saline ocean conditions predominate and conversely when the NAO is positive. Water properties on the Newfoundland and Labrador Shelf are influenced by several factors including the Labrador Current (Figure 1b), cross-shelf exchange with warmer continental slope water and bottom topography. Superimposed on these oceanic processes are large seasonal and inter-annual variations in solar heat input, ice cover and storm-forced mixing. The resulting water mass on the shelf is characterised by large annual cycles with strong horizontal and vertical temperature and salinity gradients that exhibit significant inter-annual variations.

This manuscript presents an overview of the physical oceanographic environment in the Newfoundland and Labrador (NL) Region during 2006, in relation to long-term average conditions based on historical data. The information presented for 2006 is derived from three principal sources; (1) observations made at the fixed AZMP site (Station 27, Figure 1a) throughout the year from all research and assessment surveys, (2) measurements made along standard NAFO and AZMP cross-shelf sections from seasonal oceanographic surveys and (3) oceanographic observations made during spring and fall multi-species resource assessment surveys (Figure 1a). Data from other research surveys and ships of opportunity are also used to help define the long-term means and conditions during 2006. These data are available from archives at the Fisheries and Oceans Integrated Scientific Data Management (ISDM) Branch in Ottawa and maintained in regional databases at the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia and at the Northwest Atlantic Fisheries Centre (NAFC) in St. John’s Newfoundland.

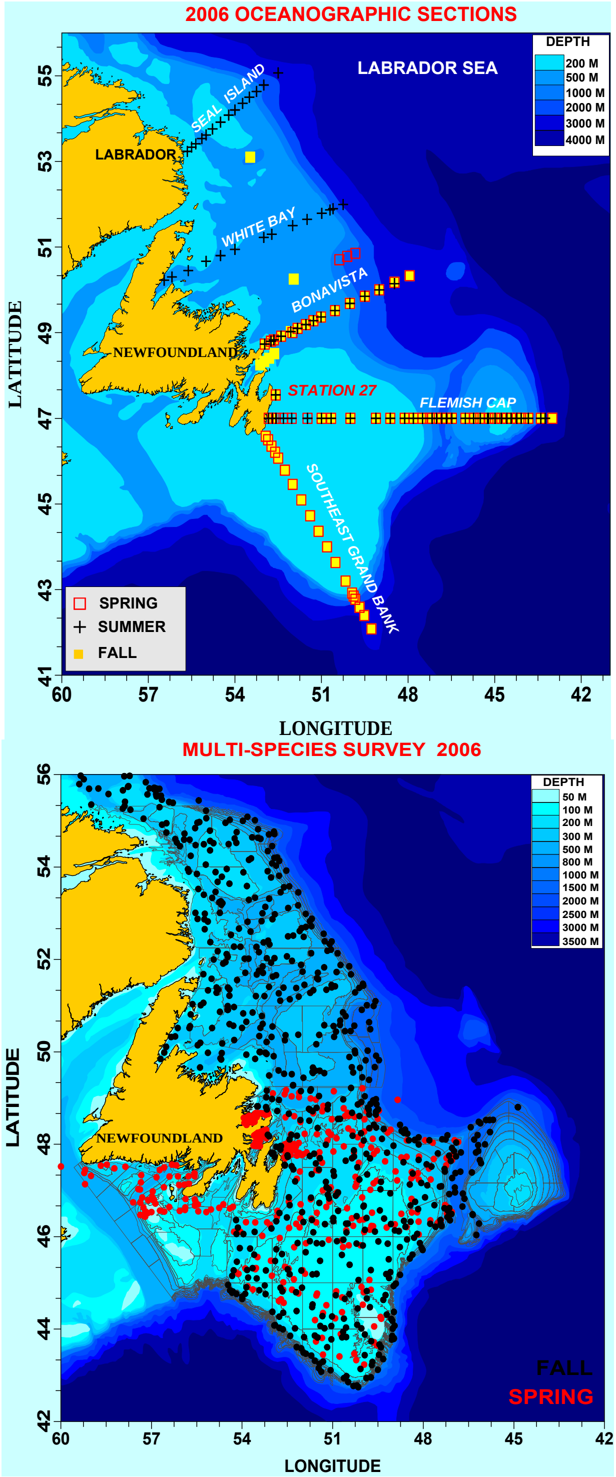


Figure 1a. Maps showing sections sampled on the NL Shelf during 2006, the location of Station 27 and the positions of trawl-mounted CTD profiles obtained from the spring and fall multi-species assessment surveys during 2006.

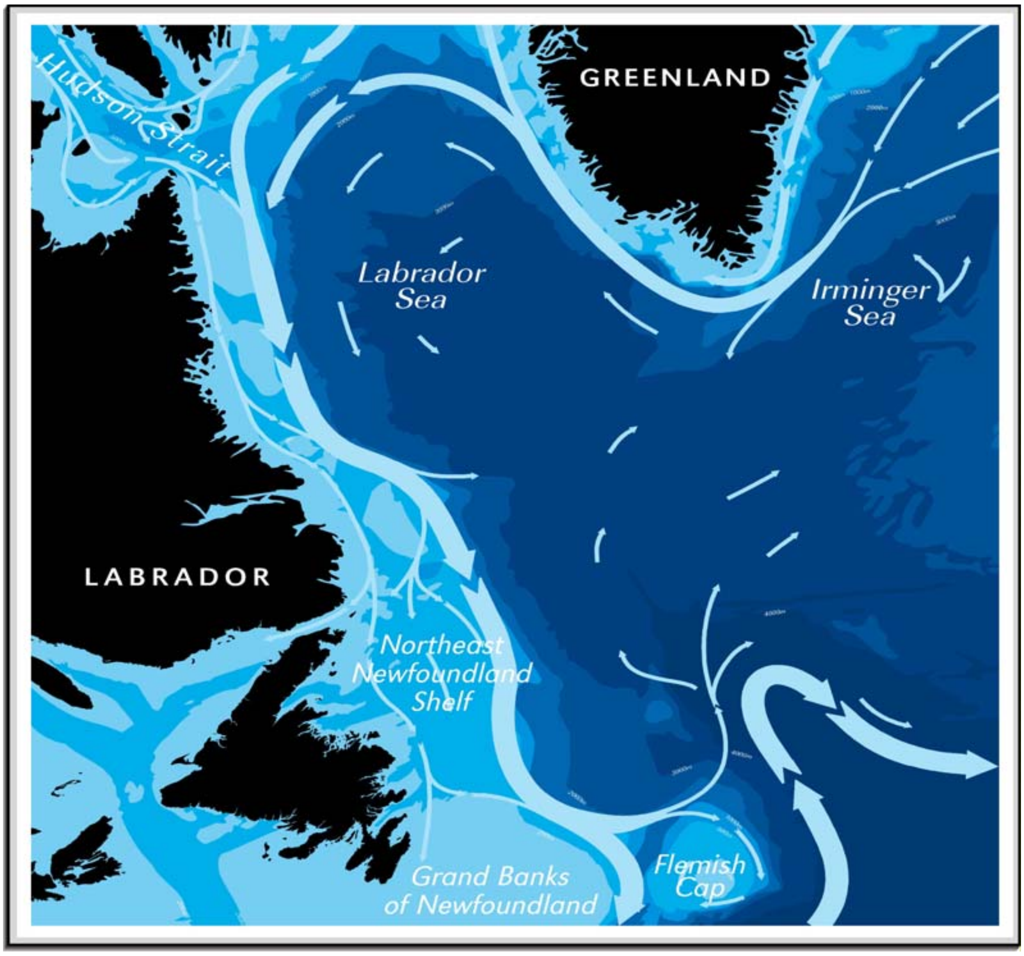


Figure 1b. Map showing the general circulation features of the Northwest Atlantic. The Labrador Current is shown as two separate branches, the strongest flowing south eastward along the Labrador and Newfoundland Shelf and a weaker inshore component.

Time series of temperature and salinity anomalies and other derived climate indices were constructed by removing the annual cycle computed over the standard base period. It is recognized that monthly and annual estimates of anomalies that are based on a varying number of observations may only approximate actual conditions; caution therefore should be used when interpreting short time scale features of many of these indices. Annual or seasonal anomalies were normalized by dividing the values by the standard deviation of the data time series over the indicated base periods, usually 1971–2000 if the data permit. A value of 2 for example indicates that the index was 2 standard deviations higher than its long-term average. As a general guide anomalies within ±0.5 standard deviations in most cases are probably not significantly different from the long-term mean. Water property time series and derived ocean climate indices from fixed locations and standard sections sampled in the Newfoundland and Labrador region during 2005 are presented as normalized anomalies in 0.5 standard deviation (SD) units and summarized in tables. The anomalies are colour coded with blues representing cold-fresh environmental conditions and reds warm-salty conditions (Table 1). In some instances (NAO, ice and water mass areas or volumes for example) negative anomalies indicate warm conditions and hence are coloured red. More details on oceanographic monitoring programs, data analysis and long-term trends in the environment are presented in Colbourne *et al.* (2005).

Table 1. Standardized anomalies colour coding scale in units of 0.5 standard deviations.

				COLD/FRESH		WARM/SALTY					
<-2.5	-2.5 to -2.0	-2 to -1.5	-1.5 to -1.0	-1.0 to -0.5	-0.5 to 0.0	0.0 to 0.5	0.5 to 1.0	1.0 to 1.5	1.5 to 2	2.0 to 2.5	>2.5

Meteorological and Sea-Ice Conditions

The North Atlantic Oscillation (NAO) Index as defined by Rogers (1984) is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is a measure of the strength of the winter westerly and northwesterly winds over the Northwest Atlantic. A high NAO index corresponds to an intensification of the Icelandic Low and Azores High, which in most years creates strong northwest winds, cold air and sea temperatures and heavy ice conditions on the NL Shelf regions. During both 1999 and 2000 the NAO was well above normal, however, the colder-than-normal winter conditions usually associated with high NAO values did not extend into this region due to shifting anomalies in the sea level pressure (SLP) fields. The NAO index for 2001 to 2004 was below normal indicating a reduced Arctic outflow to the Northwest Atlantic during the winter months. In 2005, the index was slightly above normal whereas in 2006, it was slightly below normal and in both cases, the spatial patterns in the SLP fields during the winter months resulted in very weak northwesterly winds over the Newfoundland and Labrador area. The difference in SLP between Nuuk in West Greenland and Gander NL show similar patterns and correlation with local ocean conditions on the NL Shelf (Table 2).

Table 2. Atmospheric and ice anomalies from several locations in the Northwest Atlantic during 1990 to 2006. The anomalies are normalized with respect to their standard deviations over the indicated base period.

STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (METEOROLOGICAL AND SEA-ICE)

INDEX	LOCATION	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
SEA-LEVEL PRESSURE	SLP (ICELAND-AZORES) NAO	1971-2000	1.05	0.33	0.23	0.87	0.38	1.27	-1.42	-0.64	-0.34	1.18	1.10	-0.96	-0.37	-0.39	-1.05	0.47	-0.39
	SLP (GREENLAND-GANDER)	1971-2000	0.49	1.45	0.79	0.98	0.04	-1.26	-0.83	0.57	-0.24	0.57	0.74	-1.90	-0.30	-1.07	-1.60	0.25	-1.35
AIR TEMPERATURES	NUUK (WINTER)	1971-2000	-0.45	-0.06	-0.72	-1.84	-0.28	-0.77	0.88	-0.05	0.12	-0.04	0.20	0.73	-0.04	1.11	0.86	1.40	1.15
	NUUK (ANNUAL)	1971-2000	-0.54	-0.11	-1.47	-1.68	-0.47	0.03	0.77	0.42	0.61	0.06	0.82	1.33	0.56	1.91	1.10	1.67	1.26
	IQALUIT (WINTER)	1971-2000	-0.60	-0.55	-0.80	-1.59	-0.12	0.14	0.62	0.13	-0.76	0.36	0.12	0.49	-0.65	0.25	0.37	0.84	1.45
	IQALUIT (ANNUAL)	1971-2000	-0.91	-0.15	-1.48	-1.54	0.01	1.02	1.00	0.72	0.58	0.53	0.91	1.05	0.29	1.31	0.54	1.40	1.98
	CARTWRIGHT (WINTER)	1971-2000	-1.38	-0.52	-0.59	-1.46	-1.00	-0.86	0.99	-0.40	0.97	1.61	0.70	0.55	-0.10	-0.20	1.59	0.50	1.46
	CARTWRIGHT (ANNUAL)	1971-2000	-0.94	-1.30	-1.05	-1.01	-0.17	0.20	1.12	0.12	1.23	1.82	1.13	1.22	0.18	1.01	1.79	1.59	2.56
	BONAVISTA (WINTER)	1971-2000	-1.51	-0.58	-0.84	-1.48	-1.46	-0.20	1.19	-0.62	0.84	2.12	1.41	0.50	0.29	-0.84	1.00	0.55	1.75
	BONAVISTA (ANNUAL)	1971-2000	-0.12	-1.42	-1.37	-1.37	-0.16	-0.25	1.21	-0.39	1.23	2.17	1.49	1.26	0.41	1.15	1.64	1.84	2.47
	ST. JOHN'S (WINTER)	1971-2000	-1.38	-0.63	-0.88	-0.97	-1.11	-0.22	0.87	-0.84	0.73	2.28	1.69	-0.11	-0.11	-0.81	0.48	0.39	1.26
	ST. JOHN'S (ANNUAL)	1971-2000	-0.07	-1.02	-1.39	-1.14	-0.03	-0.33	0.78	-0.69	1.13	2.51	1.55	0.78	0.07	0.88	1.11	1.26	2.19
SEA ICE COVERAGE	NL SEA-ICE EXTENT (Annual)	1971-2000	0.93	1.36	1.07	1.39	0.85	-0.29	-1.35	-0.58	-0.99	-1.21	-0.88	-1.41	-1.01	-0.61	-1.98	-1.40	-1.95
	NL SEA-ICE EXTENT (Winter)	1971-2000	0.86	0.87	1.02	1.52	1.02	-0.05	-1.08	-0.37	-1.33	-1.09	-0.77	-1.48	-1.13	-0.70	-2.45	-1.25	-1.95
	NL SEA-ICE EXTENT (Spring)	1971-2000	0.67	1.63	0.90	1.27	0.70	-0.45	-1.53	-0.70	-0.42	-1.23	-0.87	-1.13	-0.77	-0.30	-1.17	-1.50	-1.77
ICE BERG COUNT	GRAND BANKS	1971-2000	0.05	1.77	0.17	1.45	1.47	0.98	-0.22	0.37	0.91	-1.07	0.12	-0.98	0.17	0.25	-0.72	-1.09	-1.11

Air temperature anomalies at five sites in the northwest Atlantic, Nuuk Greenland, Iqaluit on Baffin Island, Cartwright Labrador, Bonavista and St. John's Newfoundland are also shown in Table 2. The predominance of warmer-than-normal annual air temperatures at all sites from the mid-1990s to 2006 is evident, with 2006 annual and seasonal values ranging from 1–2 standard deviations (SD) above normal. Annual temperature at Cartwright on the mid-Labrador Coast broke a 73-year record at 2.56 SD above normal. Other recent extremes included 1999 which saw the second highest air temperatures at Cartwright (1.82 SD above normal) and a 126 year record at St. John's (2.51 SD above normal). The coldest overall air temperatures in the Northwest Atlantic since the 1990s occurred in 1993, when the annual anomalies were all at least 1 SD below normal.

The spatial extent and concentration of sea ice are available from the daily ice charts published by the Canadian Ice Services of Environment Canada in Ottawa. The time series of the areal extent (defined by 1/10 coverage) of sea ice on the NL Shelf (between 45°–55°N) show lower than normal amounts of ice during 2006 for the 12th consecutive year (Table 2). The spring of 2006 had the lowest extent of sea-ice on the NL Shelf since record keeping began in 1963. In general, during the past several years, the sea ice season was shorter than normal in most areas of the NL Shelf. Iceberg counts obtained from the International Ice Patrol of the US Coast Guard indicate that 11 icebergs drifted south of 48°N onto the Northern Grand Bank during 2005 and none in 2006, the lowest numbers since 1966 and well below the 106-year average of 477. In 2004 there were 262 icebergs observed on the Northern Grand Bank and in some years of the early 1990s, over 1500 icebergs drifted onto the northern Grand Bank. Years with low iceberg numbers on the Grand Banks generally correspond to warmer than normal meteorological and oceanographic conditions on the NL Shelf.

A more extensive analysis of meteorological, sea ice and sea-surface temperature data in the Northwest Atlantic, including the Newfoundland and Labrador Shelf, are presented by Petrie *et al*. (2007).

Time trends in temperature and salinity

Station 27, located in the Avalon Channel off Cape Spear NL (Figure 1a), was sampled 46 times (40 CTD profiles, 6 XBT profiles) during 2006. Depth versus time contours of the annual temperature cycle for 2006 are displayed in Figure 2. The cold, near-isothermal water column during late January to early May has temperatures ranging from near 0° to –1°C. These temperatures persisted throughout the year below 120 m. Upper layer temperatures warmed to >1°C by late-April and to >15°C by August, after which the fall cooling commenced with values decreasing to 2°C by the end of December. The seasonally heated upper-layer penetrated to about 75 m depth by October and then began to cool down to 2°–3°C by December.

Annual surface temperatures at Station 27 have been increasing since 2002, reaching a 61-year high of 3.22 SD above their long-term means in 2006. Bottom temperatures were the 3rd highest at 2.7 SD, similar to 2004 and 2005 values. Vertically averaged values over various depths also set record highs >3 SD above normal. In general, Station 27 temperatures were below normal from 1990–1995, reaching minimum values in 1991 when they dipped to 2–3 SD below normal. Temperatures warmed during the mid-1990s and have remained, for the most part, above normal for the past 11 years (Table 3). At other locations, (Hamilton Bank, Flemish Cap and St. Pierre Bank) temperatures remained significantly above normal during both 2004 and 2005 with anomalies reaching a record 2.7 SD above normal on Hamilton Bank. During 2006, Hamilton Bank temperatures decreased compared to 2005 values while Flemish Cap values increased. Temperature data obtained from thermographs deployed at inshore sites showed considerable variability about the mean due to local wind driven upwelling. In general however, they show similar patterns, with mostly below normal anomalies during the first half of the 1990s and above normal during the latter half and up to 2006 (Table 3).

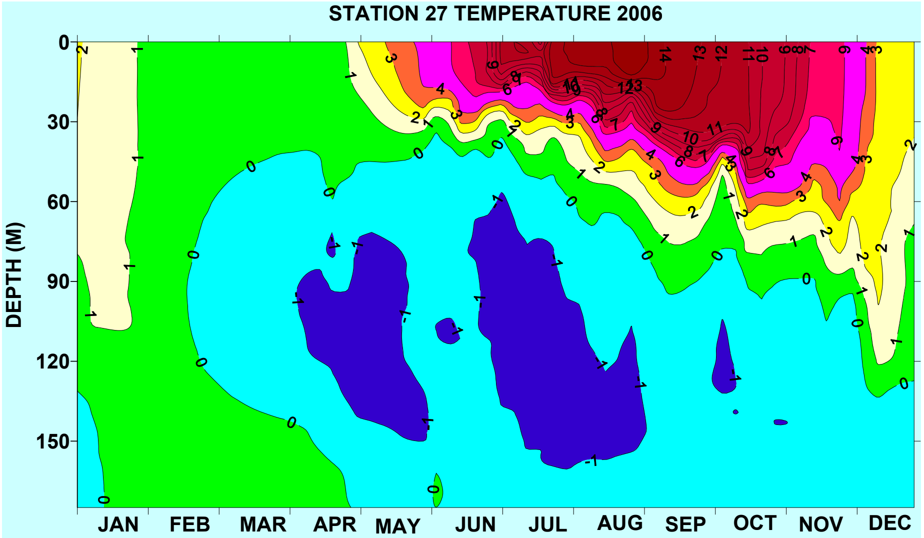


Figure 2. Contours of temperature observations (in °C) as a function of depth at Station 27 for 2006.

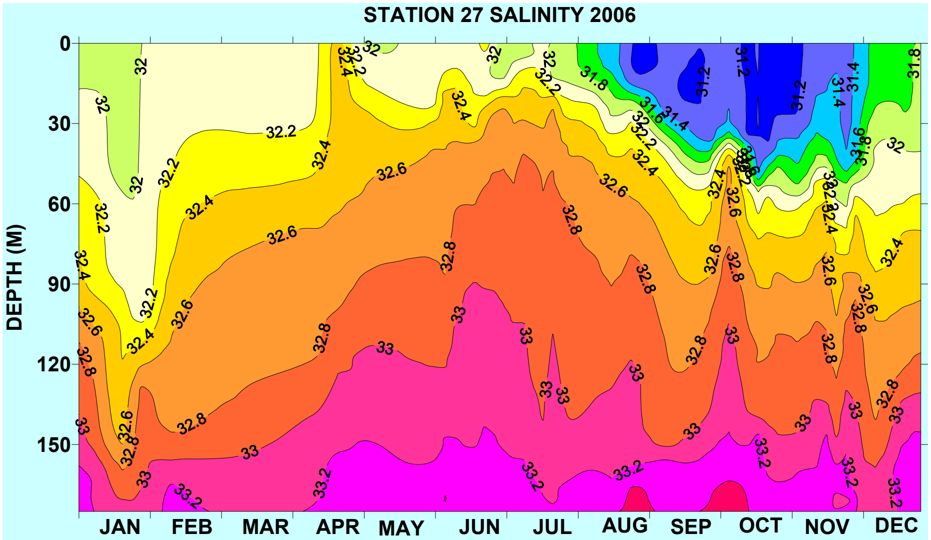


Figure 3. Contours of salinities observations as a function of depth at Station 27 for 2006.

Depth versus time contours of the annual salinity cycle for 2006 are displayed in Figure 3. Surface salinities reached maximum values in early spring (>32) and decreased to minimum values by late summer and into the fall months (<31.2). In the depth range from 50–100-m, salinities ranged from 32.2 to 32.8 and near bottom they varied throughout the year between 33 and 33.4. The period of low salinity values at shallow depths occurred from late summer to late fall This prominent feature of the salinity cycle on the Newfoundland Shelf is due largely to melting sea-ice off Labrador earlier in the year followed by advection southward onto the Grand Banks. Annual surface salinities at Station 27 increased from 2005 values and were above normal during 2006 by 0.65 SD. Depth averaged values also increased over 2005 values to 0.61–0.77 SD above normal. Upper-layer salinities during the past 5 years have ranged from near-normal to saltier than normal in contrast to the mainly fresher-than-normal values that dominated most of the 1990s (Table 3).

On the Flemish Cap, surface salinities were also higher than normal during 2006, while on Hamilton Bank they were about normal. Salinities on the Flemish Cap have been above normal from 2001 to 2006. During the past several decades, cold ocean temperatures and fresher-than-normal waters were associated with strong positive NAO anomalies, colder-than-normal winter air temperatures, and heavy sea-ice conditions on the continental shelf (Colbourne *et al*., 1994; Drinkwater 1996). The magnitude of negative salinity anomalies (up to 1.8 SD) on the inner Newfoundland Shelf during most of the early 1990s is comparable to that experienced during the 'Great Salinity Anomaly' of the early 1970s (Dickson *et al*., 1988), however, the spatial extent of the fresh water was mainly restricted to the inner Newfoundland Shelf.

Table 3. Water property anomalies and ocean climate indices derived from temperature and salinity data collected on the Newfoundland and Labrador Shelf. The anomalies are normalized with respect to their standard deviations over the indicated base period. The grey shaded cells indicate no data.

STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (FIXED SITES)

INDEX	LOCATION	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
SURFACE TEMPERATURE	HAMILTON BANK	1971-2000	0.38	-0.87	-0.56	0.34	0.15	-0.19	-0.52	0.12	2.82	-0.01	1.75	0.05	-0.23	2.50	2.03	2.73	1.43
	FLEMISH CAP	1971-2000	-0.51	-1.30	-1.54	-1.66	-0.73	0.01	0.17	0.32	2.50	0.13	0.85	0.48	-0.66	0.20	0.53	1.97	2.29
	STATION 27	1971-2000	0.05	-2.49	-1.40	-1.37	0.32	-0.60	0.32	-0.39	0.86	1.81	1.15	0.92	-0.08	1.34	2.00	2.00	3.22
	ST. PIERRE BANK	1971-2000	-1.81	-0.01	-1.24	-0.40	-0.72	0.74	0.39	-0.41	1.13	1.21	1.51	-0.82	-0.08	-0.43	0.44	2.18	
SURFACE SALINITY	HAMILTON BANK	1971-2000	-0.40	0.07	-0.29	-1.06	-1.01	0.74	0.56	1.04	-0.21	-0.46	-0.06	0.13	-0.51	-0.35	-0.09	0.73	0.02
	FLEMISH CAP	1971-2000	0.75	0.47		0.00	-1.38	0.80	0.60	1.14	-0.06	0.82	-0.29	1.26	1.49	2.27	1.46	1.20	0.56
	STATION 27	1971-2000	1.48	-1.85	-0.96	-0.04	-0.33	-1.82	0.22	-0.26	-0.29	-0.37	-0.23	-0.56	1.06	1.01	0.58	0.44	0.65
BOTTOM TEMPERATURE	STATION 27	1971-2000	-0.76	-1.42	-0.95	-1.37	-1.16	-0.38	1.24	0.83	1.36	1.43	1.31	1.50	0.60	0.63	2.95	2.65	2.70
	FLEMISH CAP	1971-2000	-2.30	-1.02	-0.66	-0.41	-2.59	-0.51	-0.48	-0.11	0.82	1.78	0.36	-0.16	0.11	0.84	1.08	2.12	1.40
	HAMILTON BANK	1971-2000	-1.19	-0.45	-0.96	-1.29	-0.64	0.49	0.67	1.71	0.65	1.56	0.28	1.79	1.72	1.19	2.25	1.86	0.66
	ST. PIERRE BANK	1971-2000	-1.26	0.20	-0.47	-0.69	-1.78	-1.07	-0.21	-0.21	-0.61	0.67	0.70	-0.53	-0.62	-1.11	1.29	2.91	
VERTICALLY AVERAGED TEMPERATURE	STATION 27 (0-20 M)	1971-2000	0.26	-2.40	-1.10	-1.22	0.62	-0.31	0.67	-0.10	1.00	2.10	1.00	1.25	0.18	1.53	2.11	1.97	3.46
	STATION 27 (0-50 M)	1971-2000	-0.18	-3.04	-0.57	-0.54	0.63	-0.13	1.62	0.03	0.18	1.26	0.95	1.73	-0.11	1.48	1.96	1.94	3.91
	STATION 27 (0-100 M)	1971-2000	0.20	-2.71	-0.59	-0.89	0.59	-0.34	2.24	-0.33	-0.28	1.23	0.87	1.12	0.56	1.30	2.61	1.89	3.21
	STATION 27 (0-175 M)	1971-2000	-0.13	-2.46	-0.69	-1.04	0.16	-0.40	2.47	-0.05	-0.05	1.18	1.14	1.25	0.68	1.18	2.95	1.98	3.27
	ST. PIERRE BANK (0-75 M)	1971-2000	-2.46	0.45	-0.26	-0.87	-1.47	-1.27	-0.49	-1.01	-0.36	1.94	0.75	-0.65	-0.14	-0.59	0.31	0.84	
VERTICALLY AVERAGED SALINITY	STATION 27 (0-20 M)	1971-2000	1.57	-1.81	-0.95	0.02	-0.26	-1.77	0.17	-0.31	-0.24	-0.35	-0.19	-0.62	1.10	1.08	0.61	0.48	0.66
	STATION 27 (0-50 M)	1971-2000	1.90	-1.63	-1.46	-0.17	-0.31	-1.35	-0.17	-0.20	-0.03	-0.17	-0.44	-0.79	1.10	1.16	0.43	0.47	0.61
	STATION 27 (0-100 M)	1971-2000	1.91	-1.37	-1.57	-0.07	-0.63	-1.00	-0.74	0.16	0.08	-0.32	-0.71	-0.78	0.77	0.85	-0.31	0.01	0.77
	STATION 27 (0-175 M)	1971-2000	1.61	-1.41	-1.54	0.15	-0.63	-0.65	-1.07	0.08	0.16	-0.32	-0.50	-0.90	0.49	0.29	-0.49	-0.10	0.77
MIXED-LAYER	STATION 27 (WINTER)	1990-2004	-0.76	-1.11	-0.83	-0.92	1.39	-0.86	0.88	0.69	-0.78	-0.13	-0.90	0.72	0.94	-0.29	1.95	0.79	2.14
MIXED-LAYER	STATION 27 (ANNUAL)	1990-2004	-0.95	-1.34	0.11	-0.04	1.13	-1.60	0.60	-0.60	-0.27	-0.17	-0.50	0.45	1.18	-0.27	2.18	0.09	0.58
MIXED-LAYER	STATION 27 (SPRING)	1990-2004	-0.72	-0.79	-0.13	-0.13	0.38	-1.21	-0.45	-1.20	1.55	-1.11	-0.13	0.98	0.91	0.02	2.03	-0.64	-0.07
STRATIFICATION	STATION 27 (ANNUAL)	1971-2000	-0.92	0.07	-0.11	-0.79	-0.12	1.55	-1.09	0.56	1.22	1.44	0.68	1.44	-0.17	0.03	-0.35	0.27	1.36
STRATIFICATION	STATION 27 (SPRING)	1971-2000	-1.31	-0.63	-0.93	-0.22	-0.51	1.60	-0.75	0.05	0.92	0.73	-0.22	0.02	-0.91	-0.89	-0.28	0.21	0.57
STRAT ONSET	ONSET (25% OF MAX)	1993-2004				-0.46	0.77	-2.10	0.50	-1.01	-1.01	-0.46	0.63	0.22	0.91	0.91	1.09	0.36	0.04
STRAT PHASE	TIME OF MAX AMPLITUDE	1993-2004				0.48	0.23	-1.35	1.72	-0.43	-1.10	-1.35	0.56	-0.60	0.39	1.39	0.06	0.64	0.64
10 M TEMPERATURE	STOCK COVE BB	1971-2000	0.44	-1.73	-0.36	-1.76	0.98	0.09	0.53	-0.70	0.96	0.90	1.18	1.33	1.08	1.32	1.05	1.44	1.81
10 M TEMPERATURE	COMFORT COVE NDB	1982-2004	1.14	-1.98	-0.73	-1.75	0.11	-1.07	0.77	-0.62	-0.11	0.92	1.08		0.70	0.82		0.38	-0.02
10 M TEMPERATURE	ARNOLDS COVE PB	1981-2004	0.81	-1.86	-1.23	-1.42	0.56	-0.68	0.72	-0.26	0.56	2.33	1.03	0.52	0.59	1.10	-0.12	0.44	1.18
5 M TEMPERATURE	BRISTOL'S HOPE	1989-2004	-0.57	-2.81		-0.52	0.64	0.14	0.22	0.06	-0.54	1.15	0.83	0.78	0.18	1.03	0.37	0.98	1.07
9 M TEMPERATURE	HAMPDEN WB	1992-2004			-0.24	0.37	-1.32	-2.01	-0.20	-0.72	0.60	0.37	1.61	-0.73	0.75	0.50	1.02	1.11	1.63
10 M TEMPERATURE	OLD BONAVENTURE	1991-2004		-1.76	-1.11	-0.98	2.05	0.17	0.62	-0.01		-0.46	0.09	1.25	0.36	0.20	-0.41	0.63	1.20
10 M TEMPERATURE	UPPER GULLIES CB	1990-2004	-1.44	-1.57	1.13	-0.38	0.39	0.50	-1.03	0.00	-1.23	1.78	-0.15	0.22	0.50	1.26	0.02	1.85	1.93

The stratification of the water column (defined as the density difference between 0 and 50 m divided by 50) was computed from temperature and salinity data collected at Station 27. The annual stratification was generally below normal in the early 1990s, increased to above normal from 1997–2001, varied about the mean from 2002–2005 and increased to 1.36 SD above normal in 2006. The spring values show similar patterns, however they were significantly below normal in 2002 and 2003. Before 1997 (except 1995) stratification was mostly below normal. The time of the spring onset of stratification and of maximum amplitude are highly variable; the initial onset was slightly later than normal from 2000–2006, although were not significant during the past 2-years. The mixed layer depth (MLD), estimated as the depth of maximum density gradient, is also highly variable on the inner NL Shelf. During 2004 the MLD was significantly (>2 SD) deeper than normal but shoaled to near normal depths during 2005 and deepened again in 2006. Spring values were slightly shallower than normal in 2005 and 2006 (Table 3).

Standard Sections

Beginning in the early 1950s several countries of the International Commission for the Northwest Atlantic Fisheries (ICNAF) carried out systematic monitoring along sections in Newfoundland and Labrador Waters. In 1976, ICNAF standardized a suite of oceanographic monitoring stations along sections in the Northwest Atlantic Ocean from Cape Cod (USA) to Egedesminde (West Greenland) (ICNAF, 1978). Beginning in 1998 under the AZMP program, the Bonavista and Flemish Cap sections are occupied during the spring, summer and fall and a section crossing the Southeast Grand Bank was added to the spring and fall monitoring surveys. In 2006 the Southeast Grand Bank section was sampled during April and November, the Flemish Cap section during April, July and December, the Bonavista section during late April to early-May, July and December and the White Bay and Seal Island sections during early August (Figure 1a).

The water mass characteristics observed along the standard sections crossing the Newfoundland and Labrador Shelf (Figure 1b) are typical of sub-polar waters with a sub-surface temperature range on the shelf of -1° to 2°C and salinities of 32 to 33.5. Labrador Slope Water flows southward along the shelf edge and into the Flemish Pass region, this water mass is generally warmer and saltier than the sub-polar shelf waters with a temperature range of 3° to 4°C and salinities in the range of 34 to 34.75. Surface temperatures normally warm to 10° to 12°C during late summer, while bottom temperatures remain <0°C over the Grand Banks but increase to 1° to 3.5°C near the shelf edge below 200 m and in the deep troughs between the banks. In the deeper waters of the Flemish Pass and across the Flemish Cap, bottom temperatures generally range from 3° to 4°C. In general, the water mass characteristics encountered along the standard sections undergo seasonal modification due to the seasonal cycles of air-sea heat flux, wind forced mixing and ice formation and melt which leads to intense vertical and horizontal gradients, particularly along the frontal boundaries separating the shelf and slope water masses.

Throughout most of the year, the cold, relatively fresh water overlying the shelf is separated from the warmer higher density water of the continental slope region by a strong temperature and density front (Figure 4). This winter formed water mass is commonly referred to as the cold intermediate layer or CIL (Petrie *et al.*, 1988) and it's area or volume is generally regarded as a robust index of ocean climate conditions off the eastern Canadian continental shelf. While the area of the CIL water mass undergoes significant annual variability, the changes are highly coherent from the Labrador Shelf to the Grand Banks. This shelf water mass remains present throughout most of the year as summer heating and salinity changes increases the stratification in the upper layers to a point where heat transfer to the lower layers is inhibited, although it continues to undergo a gradual decay during late summer reaching a minimum in late fall, due mainly to wind forced mixing. The seasonal extent of this winter-chilled water mass is evident in the contour plots of the temperature along the Bonavista section in 2006 (Figure 4). The water mass extended to near the surface during spring, was the 3rd smallest since 1948 in the summer and was still present at mid-depths by late November of 2006. Seasonal cross sections of salinity for 2006 show remarkable similarities from spring to fall with slightly fresher upper-layer shelf values occurring during the summer (Figure 4).

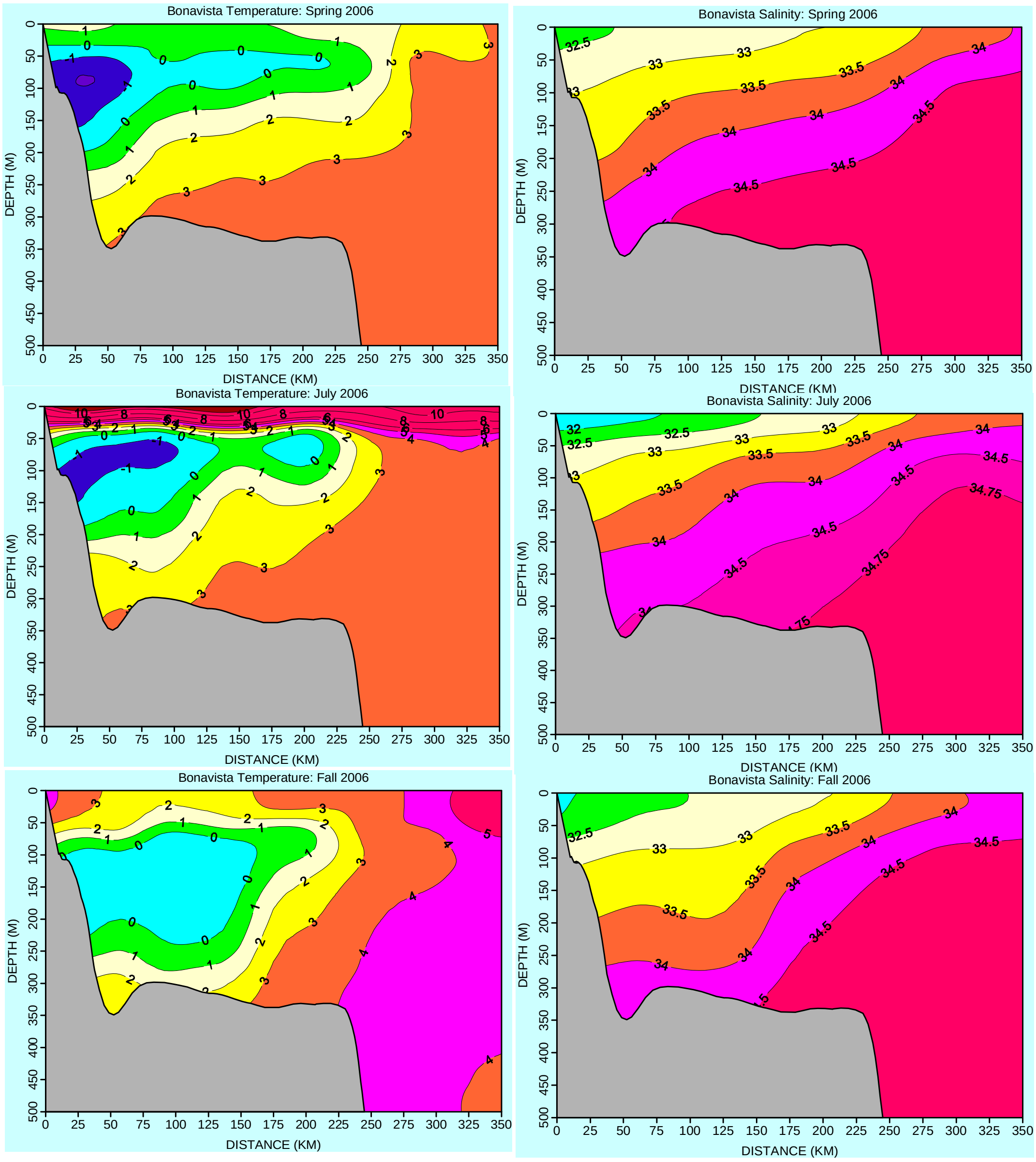


Figure 4. Contours of temperature (°C) and salinity across the Newfoundland Shelf along the Bonavista Section (Figure 1a) during the spring, summer and fall of 2006.

Climate indices based on temperature and salinity data collected along sections from southern Labrador to southern Newfoundland are displayed in Table 4 for the years 1990–2006. On the southern Labrador Shelf south to eastern Newfoundland temperature and salinity have been increasing since the near-normal year of 2000 reaching near-record high values in 2004 and continuing warm and salty during 2005 and 2006. From 1990 to 1994 conditions were significantly below normal in these areas. Farther south on the Grand Bank and St. Pierre Bank, conditions have been more variable with near-record cold conditions during the spring of 2003. During 2004 to 2006 however, ocean conditions in this area have also become generally warmer and saltier than normal, although the magnitude of the anomalies are lower than those observed farther north. Insufficient data were available for the spring of 2006 along the St. Pierre Bank section to construct T/S cross-sections.

Table 4. Temperature and salinity anomalies and ocean climate indices derived from data collected along standard sections from southern Labrador to southern Newfoundland. The anomalies are normalized with respect to their standard deviations over the indicated base period.

STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (AZMP STANDARD SECTIONS)

REGION/SECTION	INDEX	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
SOUTHERN LABRADOR SEAL ISLAND SECTION (SUMMER)	COLD-INTERMEDIATE-LAYER AREA	1971-2000	1.26	1.36	0.55	0.71	0.61	-1.22	-0.51	-1.46	-0.63	-1.91	0.26	-0.52	-1.07	-0.43	-1.41	-1.09	-0.65
	MEAN CIL TEMPERATURE	1971-2000	-1.42	-0.87	-1.11	-1.30	-0.79	1.25	0.27	0.31	0.11	1.13	-0.48	0.62	0.54	-0.09	0.58	1.01	0.42
	MINIMUM CIL TEMPERATURE	1971-2000	-0.45	-0.71	-0.46	-0.82	-0.18	2.39	0.11	-0.16	0.06	1.48	-0.06	1.42	-0.13	1.08	2.68	1.42	1.53
	MEAN SECTION TEMPERATURE	1971-2000	-1.74	-1.64	-1.39	-1.32	-0.76	0.66	0.32	1.10	0.95	1.39	0.29	0.54	0.86	1.22	2.32	1.59	1.74
	MEAN SECTION SALINITY	1971-2000	-0.90	-1.03	1.12	-0.32	-0.58	0.86	-0.32	0.92	0.40	0.99	-0.58	0.40	1.31	0.21	1.51	0.86	0.66
	INSHORE SHELF SALINITY	1971-2000	0.07	-0.77	0.98	1.05	-0.54	0.71	-0.54	0.67	0.48	1.05	-1.11	0.29	0.67	0.18	0.22	1.21	0.33
	LABRADOR CURRENT TRANSPORT	1971-2000	0.64	0.84	1.32	-1.54	-0.52	0.43	0.84	0.50	1.18	-0.11	0.98	1.18	1.59	1.46	1.05	1.59	0.98
NORTHEAST NEWFOUNDLAND WHITE BAY SECTION (SUMMER)	COLD-INTERMEDIATE-LAYER AREA	1977-2000	1.69	0.95	1.02	0.83	0.96	-0.69	-0.10	-0.50	-1.03	-1.10	0.10	-0.64	-0.98	-0.54	-1.90	-1.29	-1.81
	MEAN CIL TEMPERATURE	1977-2000	-1.14	-0.54	-0.66	-1.08	-0.42	0.42	0.42	-0.24	0.42	1.55	-0.18	0.66	0.95	0.06	2.45	1.13	1.25
	MINIMUM CIL TEMPERATURE	1977-2000	-0.41	-0.68	-0.66	-0.94	-0.34	-0.16	0.80	-0.24	-0.20	1.20	0.29	0.15	0.22	0.37	4.65	0.75	2.25
	MEAN SECTION TEMPERATURE	1977-2000	-1.46	-0.84	-1.65	-1.29	-1.31	0.01	-0.11	1.00	1.22	1.50	0.55	0.53	0.60	1.00	1.92	2.00	2.11
	MEAN SECTION SALINITY	1977-2000	-1.07	-0.77	-0.66	-0.15	-0.77	0.57	-1.38	1.49	0.77	-0.25	-0.46	0.36	1.49	0.46	1.59	0.98	1.28
	MEAN SHELF SALINITY	1977-2000	0.17	-0.65	-1.21	0.98	-0.75	0.17	-0.90	1.59	0.07	-1.67	-0.60	0.07	1.19	-0.34	0.88	-0.09	0.93
EASTERN NEWFOUNDLAND BONAVISTA SECTION	CIL AREA (SPRING)	1977-2000	1.90	1.11	0.55	0.53	1.05	-0.74	-0.44	-0.44	0.14	-0.94	-0.14	-0.90	-0.34	-0.01	-1.02	-1.41	-1.44
	CIL AREA (SUMMER)	1971-2000	1.66	1.78	-0.01	0.55	-0.03	-0.99	-0.49	-1.03	-0.35	-0.93	-0.17	-1.24	-0.98	-0.58	-1.72	-1.41	-1.67
	CIL AREA (FALL)	1979-2000	1.46	0.45	0.84	1.33	0.92	-0.63	-0.45	-1.17	-0.76	-1.43	-0.19	-0.53	-0.93	-1.17	-1.43	-1.40	0.24
	MEAN CIL TEMPERATURE (SUMMER)	1971-2000	-0.95	-1.51	-0.40	-1.09	-0.47	0.71	1.41	-0.40	-1.02	-0.19	0.09	1.34	-0.26	-0.26	1.62	1.48	1.89
	MINIMUM CIL TEMPERATURE (SUMMER)	1971-2000	-0.41	-0.79	-0.25	-0.78	-0.48	0.19	0.88	-0.06	-0.09	0.62	0.34	1.22	0.54	0.28	2.78	1.73	3.02
	MEAN SECTION TEMPERATURE (SUMMER)	1971-2000	-1.68	-1.61	-1.30	-0.97	-0.83	0.30	-0.10	1.01	0.87	1.41	0.75	0.56	0.66	0.99	2.48	2.05	2.33
	MEAN SECTION SALINITY (SUMMER)	1971-2000	-1.18	-1.18	-0.32	0.04	0.53	1.63	-1.54	1.51	0.04	0.41	0.41	0.29	2.61	1.14	2.49	1.51	2.49
	INSHORE SHELF SALINITY (SUMMER)	1971-2000	0.74	-1.19	-1.10	0.30	0.56	-1.19	0.13	0.13	-0.31	-1.81	0.74	-0.40	2.32	0.04	1.00	1.09	1.80
	LABRADOR CURRENT TRANSPORT (SUMMER)	1971-2000	-0.16	1.49	1.49	0.39	-0.24	-0.24	0.47	0.08	-0.32	1.73	0.63	-1.02	0.39	0.70	-0.16	0.23	-0.95
GRAND BANK FLEMISH PASS FLEMISH CAP 47 °N SECTION	CIL AREA (SPRING)	1971-2000	0.95	0.90	0.77	1.02	0.87	0.42	-0.50	-0.10	-0.94	-2.17	-0.36	0.05	1.22	1.44	-1.57	-1.14	-1.77
	CIL AREA (SUMMER)	1971-2000	-0.03	1.68	0.62	1.26	-0.01	0.26	-0.80	0.26	-0.72	-1.37	-1.25	-0.54	-0.80	-0.41	-2.72	-1.06	-2.70
	CIL AREA (FALL)	1973-2000	0.47	0.66	0.02	0.09	0.76	-0.36	-0.28	-0.33	0.04	-1.37	0.01	-0.17	-0.62	-0.54	-1.50	-0.57	-0.69
	MEAN CIL TEMPERATURE (SUMMER)	1971-2000	-1.07	-1.83	-1.30	-1.70	-0.22	-0.85	0.86	0.27	0.59	1.39	0.99	0.90	0.14	-0.40	1.30	0.86	1.62
	MINIMUM CIL TEMPERATURE (SUMMER)	1971-2000	-0.11	-0.86	-0.25	-0.79	-0.55	-0.05	1.97	0.69	-0.08	1.06	0.93	2.34	-0.42	0.39	0.66	1.13	1.33
	MEAN SECTION TEMPERATURE (SUMMER)	1971-2000	-0.64	-1.31	-1.58	-2.47		-0.67	0.18	-0.12	0.82	1.59	0.45		-0.20	2.41	1.29	1.19	2.60
	MEAN SECTION SALINITY (SUMMER)	1971-2000		-0.15	0.05	0.15		0.54	0.34	1.12	0.73	0.83	-0.05		1.32	2.29	1.12	-0.44	1.61
	INSHORE SHELF SALINITY (SUMMER)	1971-2000		-0.54	-0.83	-0.42	-0.18	-0.42	-0.71	0.12	0.18	-0.06	-0.83	-0.83	0.47	0.06	-0.12	-0.30	0.95
	LABRADOR CURRENT TRANSPORT (SUMMER)	1971-2000		0.18	1.45	0.81		1.13	0.07	0.39	1.24	-0.14	1.13	1.24	1.45	2.51	1.13	1.13	0.18
SOUTHEAST GRAND BANK SECTION	CIL AREA (SPRING)	1972-2000	1.54	1.78	0.40	-0.21	-0.36	-0.83	-0.81	-0.19	-0.55	-0.87	-0.73	-0.21	0.79	2.98	-0.85	-0.94	-1.40
	MEAN CIL TEMPERATURE (SPRING)	1972-2000	-0.08	-0.38	-0.38	-1.81	-0.94	-1.50	0.40	0.09	0.65	-0.60	0.70	1.39	0.74	0.09	2.38	0.78	2.90
	MEAN TEMPERATURE (SPRING)	1972-2000	-1.77	-1.40	-0.89	-0.48	-0.29	-0.47	0.03	-0.17	0.29	1.46	0.20	-1.21	-1.61	-2.34	-0.07	-0.26	-0.07
	CIL AREA (FALL)	1990-2004	-0.51	1.47	-0.41	0.68	2.18	1.21	-0.54	-0.50	-0.38	-0.59	-0.38	-0.45	-0.57	-0.50	-0.70	-0.44	-0.44
	MEAN CIL TEMPERATURE (FALL)	1990-2004	-1.28	0.79	-0.77	0.42	-0.17	1.98	0.64	-1.14	-0.99	0.57	0.20	0.05	-1.06	-1.28	2.05	1.38	1.38
	MEAN SECTION TEMPERATURE (FALL)	1990-2004	-0.95	-0.46	-1.27	-0.43	-0.67	0.92	-0.64	-0.10	1.44	1.52	0.99	0.35	-0.44	-0.48	0.22	-0.39	0.93
ST. PIERRE BANK SECTION (SPRING)	CIL AREA	1993-2004				1.16	0.95	0.40	-1.03	1.09	-0.84	-1.16	-1.16	0.55	-0.09	1.20	-1.09	-1.16	
	MEAN TEMPERATURE (< 100 M)	1993-2004				-1.00	-0.82	-0.22	0.29	-0.96	0.80	1.81	1.45	-0.43	-0.16	-1.31	0.55	1.16	
	MEAN SECTION TEMPERATURE	1993-2004				-0.81	-1.45	0.47	0.16	-0.74	0.54	1.88	1.42	-0.81	0.10	-0.96	0.19	1.36	
	MEAN SALINITY < 100 M	1993-2004				0.99	-1.64	0.48	-0.68	-0.42	1.12	0.60	-1.64	1.12	-0.74	0.48	0.35	-0.55	
	MEAN SECTION SALINITY	1993-2004				1.60	-2.00	0.97	-0.92	-0.47	0.43	1.15	-0.47	-0.11	-0.65	-0.02	0.52	0.07	

In 2006 the CIL areas along most sections during spring, summer and fall were below normal, implying warmer-than-normal water temperatures on the continental shelf. Along the Bonavista section, the summer CIL area was below normal for the 12th consecutive year ranking the third warmest year in the 58 year time series. This represents only a slight cooling from 2004 when it was the second lowest on record. The overall average temperature along the Bonavista section was the third highest on record in 2006, surpassed only by 2004 and 1965.

On the Grand Bank along the 47°N section, the summer CIL area was below normal for the 9th consecutive year and along the southeast Grand Bank section it was below normal for the 6th consecutive year with the spring of 2006 the lowest and 2003 the highest since 1972. On St. Pierre Bank the CIL area decreased sharply from the record high value during the cold spring of 2003. In this area, 1999 appears to be the warmest year in the time series. Again no data were available for 2006. Salinities continued above normal along all sections sampled in 2006. The baroclinic transport in the offshore branch of the Labrador Current was above normal during 2006 off southern Labrador and off the Grand Bank through the Flemish Pass, continuing a 7-year trend. Along the Bonavista Section however, where a significant component of the flow is in the offshore direction, there are no apparent patterns in the estimates of transport in recent years with 2006 showing a below normal estimate.

Multi-Species Survey Results

Canada has been conducting stratified random bottom trawl surveys in NAFO Sub-areas 2 and 3 on the NL Shelf since 1971. Areas within each division, with a selected depth range, were divided into strata and the number of fishing stations in an individual stratum was based on an area-weighted proportional allocation (Doubleday 1981). Temperature profiles are available for fishing sets in each stratum and since 1989 trawl-mounted CTDs have provided profiles of salinity. These surveys provide 2 large spatial-scale oceanographic data sets on an annual basis for the Newfoundland Shelf, one during the spring from 3Pn in the west to 3LNO on the Grand Bank and one during the fall from 2J in the north, to 3NO in the south. The hydrographic data collected on the surveys are now routinely used to provide an assessment of the spatial and temporal variability in the thermal habitat of several fish and invertebrate species. A number of data products based on these data is used to characterize the oceanographic habitat. Among these are contoured maps of the bottom temperatures and their anomalies, a thermal habitat areal index, spatial variability in the volume of the cold intermediate layer and water-column stratification and mixed-layer depth spatial maps. In this section an analysis of the near-bottom temperature fields and their anomalies based on these data sets are presented for the spring and fall surveys.

Spring Conditions

Maps of bottom temperatures and their anomalies for NAFO Divisions 3LNO during the spring of 2006 are displayed in Figure 5. Spring bottom temperatures in Div. 3L ranged from $<0^{o}$C to 1^{o}C in the inshore regions of the Avalon Channel and parts of the Grand Bank and from 1^{o} to $>3^{o}$C at the shelf edge. Over the central and southern areas bottom temperatures ranged from 1^{o}C to 3^{o}C. The spring of 2006 had the 3rd lowest area of $<0^{o}$C near-bottom water in Division 3L since the surveys began in the early 1970s (Figure 5). Bottom temperature anomalies ranged from 0.75^{o} to 1^{o}C above normal over most of the 3L region and in southern areas of 3NO they were more variable, but again, mostly above normal. The apparent negative anomalies along the slopes of 3O are most likely due to gridding extrapolations into areas of no data.

Climate indices based on the temperature data collected on the spring and fall multi-species surveys for the years 1990–2006 are displayed in Table 5 as normalized anomalies. In both 3Ps and 3LNO bottom temperatures were generally lower than normal from 1990–1995 with anomalies often exceeding 1 SD below the mean. By 1996 conditions had moderated to near-normal values but decreased again in the spring of 1997 to colder than normal in both 3Ps and 3LNO. In 3LNO from 1998 to 2006 with the exception of 2003 temperatures were above normal with 1999 and 2004 among the warmest years on record. The spring of 2004 had the lowest area of <0oC water in Division 3L since the surveys began in the early 1970s at 2.13 SD below normal and in 2006 this area increased slightly to 1.81 SD below normal (Table 5).

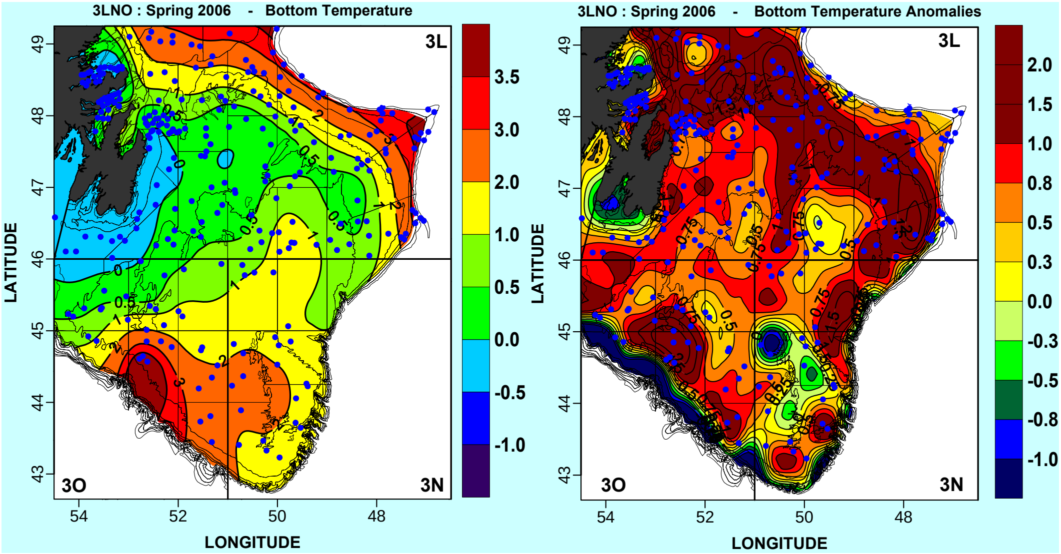


Figure 5. Contour maps of bottom temperature and their anomalies (in °C), during the spring of 2006 in NAFO Divisions 3PLNO. The blue dots indicate sampling positions.

In 3P bottom temperatures were below normal from 1990–1995, moderated in 1996, decreased again in 1997 but increased to above normal values by 1999 and 2000. Beginning in 2001 temperatures again decreased, reaching near-record cold conditions in 2003 with bottom temperatures on St. Pierre Bank (depths <100 m) reaching 1.57 SD below normal, the coldest since 1990. During 2004 and 2005 temperatures have again increased to above normal values with 2005 the highest on St. Pierre Bank since 2000, ranking the 6th highest in the 36 year time series (Table 5).

Fall Conditions

Bottom temperature and temperature anomaly maps for the fall of 2006 in NAFO Divisions 2J, 3K and 3LNO are displayed in Figure 6. Bottom temperatures during the fall of 2006 in Div. 2J ranged from <0oC inshore, to >3.5oC offshore at the shelf break. Over Hamilton Bank they ranged from 0oC to 2oC which represent a significant cooling over 2005 values. Most of the 3K region is deeper than 200-m, as a result relatively warm slope water floods through the deep troughs between the northern Grand Bank and southern Funk Island Bank and between northern Funk Island Bank and southern Belle Isle Bank. Bottom temperatures on these banks during the fall of 2006 ranged between 2o to 3oC. In the near-shore areas, temperatures were generally below 1oC. Near the edge of the continental shelf in water depths >500 m, temperatures were near normal around 3.5oC. Fall bottom temperatures in Divs. 3LNO generally ranged from <0oC on the northern Grand Bank and in the Avalon Channel to 3.5oC along the shelf edge. Over the southern areas, bottom temperatures ranged from 1o to 3.5oC during 2006 and to >3.5oC along the edge of the Grand Bank. During 2006, bottom temperatures were predominately above normal on the northern Grand Bank but varied about the mean in southern areas with an area of below normal values in the shallow waters of the southeast shoal of the Grand Bank (Figure 6). The isolated areas of below normal values near the coast and within some bays are likely due to extrapolation by the gridding algorithm into areas of no data coverage and hence are not reliable. Overall bottom temperatures decreased from 2005 values however, the area of <0oC bottom water on the Grand Banks during the fall of 2006 spring was the 3rd lowest on record with 2004 the lowest.

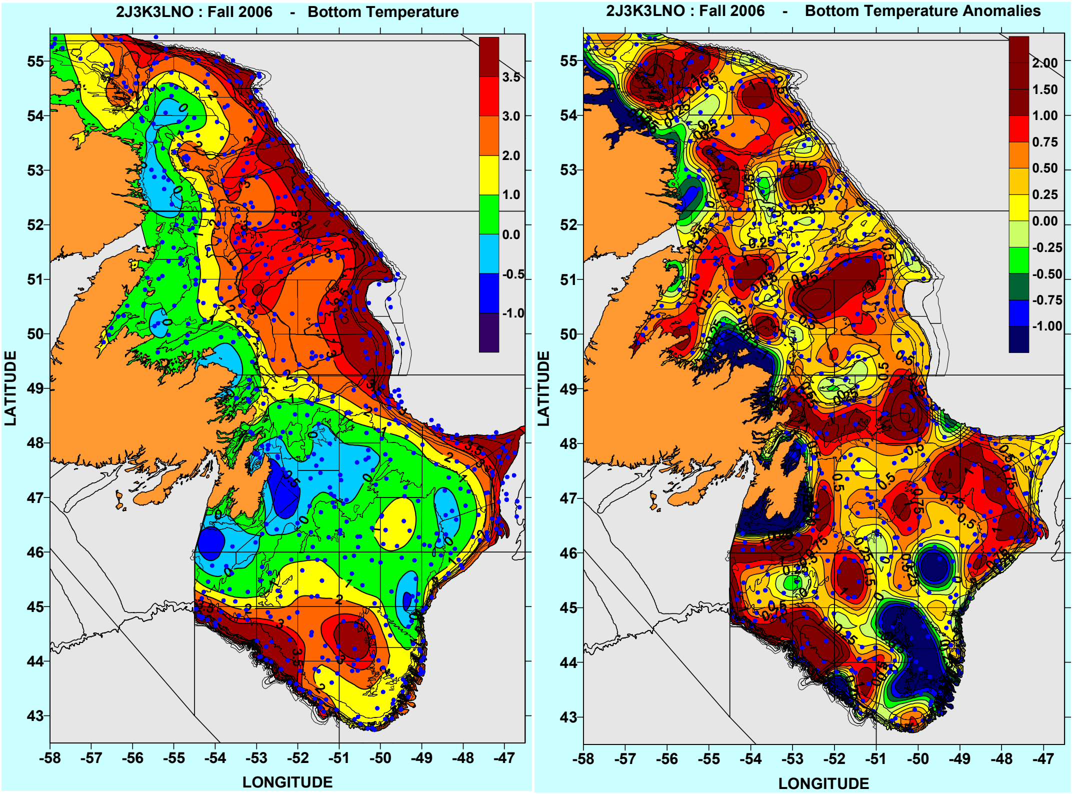


Figure 6. Contour maps of bottom temperature and temperature anomalies (in °C) during the fall of 2006 in NAFO Divisions 2J, 3KLNO. The blue dots indicate sampling locations.

The normalized temperature anomalies and derived indices based on data collected on the fall multi-species surveys for the years 1990–2006 are displayed in Table 5. In 2J, bottom temperatures were generally colder than normal from 1990–1995, with the coldest anomalies observed in 1992 when they reached >1.7 SD below normal on Hamilton Bank (<200 m depth). From 1996 to 2006 bottom temperatures were above normal reaching record high values in 2004 and 2005 (2.5 SD above normal). From 1998 to 2005 near-bottom water with temperatures <0°C disappeared from the Hamilton Bank during the fall with a corresponding increase in the area covered by water >2°C. During the fall of 2006 however, a small area of <0°C water was present on Hamilton Bank. In 3K, conditions were very similar with the 3 warmest years on record occurring in 1999, 2004 and 2005. In 3LNO during the fall bottom temperatures were somewhat cooler than those farther north in 2J and 3K with record high values in 1999, near normal values in 2000–2003 and above normal temperatures during 2004 to 2006, with 2005 being the 2nd highest in the time series. The total volume of CIL water remaining on the shelf during the fall was the lowest in the 26-year record during 1999 (1.81 SD), followed by 2004 and 2005. The 2006 value was at 0.5 SD below the long-term mean (Table 5).

Table 5. Temperature anomalies and derived indices from data collected during spring and fall multi-species surveys on the Newfoundland and Labrador Shelf. The anomalies are normalized with respect to their standard deviations over the indicated base period.

STANDARIZED PHYSICAL ENVIRONMENTAL ANOMALIES (MULTI-SPECIES SURVEYS)																			
REGION	INDEX	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
NAFO DIV. 2J FALL	BOTTOM TEMPERATURES	1978-2000	-0.40	-0.04	-1.11	-0.61	-0.47	-0.39	1.38	0.74	1.05	1.91	1.25	1.74	1.43	2.28	2.56	2.51	1.54
	BOTTOM TEMPERATURES < 200 M	1978-2000	0.08	-0.32	-1.68	-1.71	-0.71	-0.45	1.01	0.39	0.32	1.36	0.47	1.78	0.81	1.44	2.28	2.35	1.09
	THERMAL HABITAT AREA >2°C	1978-2000	-0.76	-0.37	-0.96	-0.50	-0.28	0.45	0.92	1.01	0.73	1.28	0.54	1.53	1.14	1.57	2.17	2.70	0.65
	THERMAL HABITAT AREA <0°C	1978-2000	0.05	-0.32	1.15	0.80	-0.14	0.59		-0.58									-0.51
NAFO DIV. 3K FALL	BOTTOM TEMPERATURES	1979-2000	-0.67	-0.34	-1.51	-1.32	-0.83	0.43	0.52	1.17	0.80	1.96	0.64	0.86	1.11	1.35	1.91	1.82	0.86
	BOTTOM TEMPERATURES < 300 M	1979-2000	-0.69	-0.38	-1.27	-1.80	-1.39	0.42	0.46	1.04	1.17	1.47	0.32	0.51	0.94	1.31	1.74	1.60	0.37
	THERMAL HABITAT >2°C	1979-2000	-1.19	-0.23	-1.34	-1.26	-0.79	0.37	0.53	1.17	1.10	1.87	0.79	0.62	1.21	1.29	1.32	1.67	0.74
	THERMAL HABITAT AREA <0°C	1979-2000	0.33	0.70	1.28	0.93	0.56	-1.11	-1.07		-0.38		-0.78	-0.99		-1.04			-1.09
NAFO DIV. 3LNO FALL	BOTTOM TEMPERATURES	1990-2004	-0.38	-0.08	-1.26	-1.69	-1.58	0.08	0.12	0.30	0.51	2.32	0.06	0.29	0.11	0.19	1.01	1.98	0.19
	BOTTOM TEMPERATURES <100 M	1990-2004	0.02	-0.96	-0.87	-1.28	-1.46	0.37	0.71	0.49	0.71	2.56	0.09	-0.31	-0.50	-0.08	0.50	1.54	-0.24
	THERMAL HABITAT AREA >2°C	1990-2004	-1.09	-0.40	-0.88	-1.73	-0.83	-0.08	0.32	0.24	0.78	2.77	0.15	0.22	-0.38	-0.05	0.51	0.49	-0.07
	THERMAL HABITAT AREA <0°C	1990-2004	0.21	1.15	1.21	1.55	1.46	-0.90	-0.32	0.14	-0.69	-1.47	0.35	-0.27	-0.74	-0.17	-1.51	-1.25	-1.44
NAFO DIV 2J3KL	CIL VOLUME (SUMMER)	1980-1999	1.90	1.16		0.74	0.32	-1.23	-0.61	-0.81	-0.70	-1.28							
	CIL VOLUME (FALL)	1980-2004	0.94	1.05	1.46	1.55	0.74	-0.34	-0.85	-0.85	-0.58	-1.81	-0.45	-0.76	-0.57	-0.78	-1.47	-0.86	-0.50
NAFO DIV. 3LNO SPRING	BOTTOM TEMPERATURES	1976-2000	-1.66	-1.49	-1.11	-0.72	-0.71	-0.70	-0.24	-0.53	0.23	0.60	0.58	0.05	0.00	-0.50	0.99	0.43	
	BOTTOM TEMPERATURES <100 M	1976-2000	-1.17	-1.54	-1.22	-0.42	-0.99	-0.26	0.12	-0.81	0.98	1.82	0.57	-0.14	0.20	-0.98	1.25	0.75	0.58
	THERMAL HABITAT AREA >2°C	1976-2000	-1.54	-1.39	-1.13	-0.44	-0.46	-0.27	0.06	-0.17	0.82	2.00	0.90	-0.08	0.04	-0.10	2.05	1.18	
	THERMAL HABITAT AREA <0°C	1976-2000	1.02	1.46	1.01	1.11	0.76	0.44	-0.44	0.58	-1.10	-1.65	-0.80	-0.66	-0.41	0.43	-2.13	-1.38	-1.81
NAFO DIV. 3PS SPRING	BOTTOM TEMPERATURES	1971-2000	-1.56	-0.93	-0.94	-0.56	-0.42	-0.93	-0.03	-0.58	-0.30	0.46	0.65	-0.69	-0.19	-1.34	-0.25	0.38	
	BOTTOM TEMPERATURES <100 M	1971-2000	-1.65	-0.94	-1.07	-1.01	-0.73	-0.60	0.40	-0.46	0.45	1.29	1.58	-0.53	-0.30	-1.57	0.40	1.14	
	THERMAL HABITAT AREA >2°C	1971-2000	-1.49	-1.02	-0.72	-0.79	-0.96	-0.86	-0.21	-0.61	-0.06	0.77	1.15	-0.62	-0.50	-0.85	-0.48	0.17	
	THERMAL HABITAT AREA <0°C	1971-2000	1.66	0.95	1.20	1.27	0.77	1.02	-0.38	0.75	-0.03	-0.52	-0.88	0.67	0.47	1.48	-0.98	-0.88	

Summary

The North Atlantic Oscillation winter index for 2006 was slightly below normal at 0.4 SD, while the sea-level pressure difference between Greenland and Newfoundland was significantly below normal. As a result, arctic outflow to the Northwest Atlantic was weaker-than-normal resulting in record high annual air temperatures in some locations and above normal values throughout the Northwest Atlantic from West Greenland to Baffin Island to Labrador and Newfoundland. Sea-ice extent and duration on the Newfoundland and Labrador Shelf remained below average for the 12th consecutive year. Consequently, water temperatures on the Newfoundland and Labrador Shelf remained well above normal in 2006, continuing the warm trend experienced since the mid-to-late 1990s. The annual values for 2006 increased over 2005 values even surpassing the record highs of 2004. However, data from late fall surveys show a decrease in sub-surface temperatures as slightly colder water moved southward over the area. Salinities on the NL Shelf, which were lower than normal throughout most of the 1990s, increased to the highest observed in over a decade during 2002 and have remained above normal during the past 4 years.

Highlights for 2006:

- Annual air temperatures were above normal in Newfoundland and Labrador by 2.9°C (record high) at Cartwright, 2°C (record high) at Bonavista and by nearly 1°C at St. John's.
- Annually, sea ice extent remained below normal for the 12th consecutive year on the Newfoundland and Labrador Shelf. The ice extent was the 4th lowest in winter and the lowest during spring since 1963.
- No icebergs were detected south of 48oN on the Northern Grand Bank and only 11 during 2005, the lowest numbers since 1966, well below the 106-year average of 477.
- The Station 27 depth-averaged annual water temperature increased to 0.9°C above normal, the highest on record.
- Annual surface temperatures at Station 27 reached 1.7°C above normal, also the highest in 61 years.

- Bottom temperatures at Station 27 have been above normal for the past 11 years. In both 2005 and 2006 they were 0.8°C (2.65 SD) above normal, the 3rd highest in the 61-year record.
- Annual surface temperatures on Hamilton Bank were 1°C above normal, the 10th highest on record. On the Flemish Cap they were 2.5°C above normal, the 3rd highest in 57 years.
- Near surface salinities at Station 27 were above normal for the 5th consecutive year. The average salinity along the Bonavista section has remained above normal since 2002.
- The area of <0°C (CIL) water mass on the eastern Newfoundland Shelf was below normal for the 12th consecutive year and the 3rd lowest since 1948.
- The density driven component of the shelf-slope Labrador Current volume transport shows an increasing trend off southern Labrador and through the Flemish Pass from 2000–2006.
- Bottom temperatures during the fall of 2006 on the Newfoundland and Labrador Shelf were above normal in most all areas but decreased substantially from 2005, particularly off Southern Labrador.
- The area of bottom habitat on the Grand Banks covered by sub-zero water has decreased from >50% during the first half of the 1990s to near 15% during the past 3 years, ranking the 3rd lowest in 2006.

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References

Colbourne, E. B., Fitzpatrick, C., Senciall, D., Stead, P., Bailey, W., Craig, J., Bromley, C. 2005. An assessment of the physical oceanographic environment on the Newfoundland and Labrador Shelf during 2004. DFO Can. Sci. Advis. Sec. Res. Doc. 2005/14, 36 p.

Colbourne, E. B., S. Narayanan, and S. Prinsenberg. 1994. Climatic change and environmental conditions in the Northwest Atlantic during the period 1970–1993. ICES Mar. Sci. Symp., 198:311–322.

Dickson, R.R., Meincke, J., Malmberg, S. A., and Lee, A. J. 1988. The "Great Salinity Anomaly" in the northern North Atlantic 1968–1982. Progr. Oceanogr., 20: 103–151.

Doubleday, W. G., Editor. 1981. Manual on groundfish surveys in the Northwest Atlantic. NAFC. Sco. Coun. Studies, 2: 56p.

Drinkwater, K.F. 1996. Climate and oceanographic variability in the Northwest Atlantic during the 1980s and early-1990s. J. Northw. Atl. Fish. Sci., 18: 77–97.

ICNAF. 1978. List of ICNAF standard oceanographic sections and stations. ICNAF selected papers #3.

Petrie, B., R.G. Pettipas, and W.M. Petrie. 2007. An overview of meteorological, sea ice and sea surface temperature conditions off eastern Canada during 2005. DFO Can. Sci. Advis. Sec. Res. Doc. 2007. In Press.

Petrie, B., S. Akenhead, J. Lazier and J. Loder. 1988. The cold intermediate layer on the Labrador and Northeast Newfoundland Shelves, 1978–1986. NAFO Sci. Coun. Studies, 12: 57–69.

Rogers, J.C. 1984. The association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. Mon. Wea. Rev., 112: 1999–2015.