ICES Oceanography Committee
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Report of the Working Group on Oceanic Hydrography (WGOH)

29 March–1 April 2004
Southampton, UK

International Council for the Exploration of the Sea

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1 RECOMMENDATIONS AND FINDINGS

In most areas of the North Atlantic during 2003, temperature and salinity in the upper waters remained higher than the long-term average, with new records set in several regions.

Recognising that climate change is of international concern, the WGOH strongly recommends that the Oceanography Committee and ACME should support OSPAR to strengthen the measurements of standard physical oceanography parameters in the OSPAR's Co-ordinated Environmental Monitoring Programme (CEMP), and additionally physical oceanography monitoring as a basis for understanding of the ecosystem and climate change.

The WGOH consider that understanding the changes in the physical marine environment is indispensable for any ecosystem and fisheries assessment. The WGOH strongly recommends that they continue to meet and produce the IAOCSS on an annual basis. The WGOH wishes to ensure that the IAOCSS is more widely available than in the past and as such they strongly recommend that the IAOCSS have no restrictions for printing. To raise the profile, the WGOH will request a news item regarding the publication of the new IAOCSS on the front page of the ICES website.

The WGOH agree that for ecosystem assessment, a regional approach is necessary, but it is still necessary to understand regional climate in the context of the wider North Atlantic.

The WGOH request input from the new ICES database manager regarding the future direction of the ICES database.

The WGOH strongly recommends that the ICES website be improved.

2 SUMMARY OF WGOH 2004

A one-day mini-symposium on Climate was chaired by Sheldon Bacon from the Rennel Division of Southampton Oceanographic Centre on the first day of the meeting. Abstracts of talks are presented in Annex D.

National reports were presented on the second and third days of the meeting, the summaries of these were collected to form the 2003 ICES Annual Ocean Climate Status Summary (IAOCSS). The report was reviewed and approved by the WGOH. This will be made available on the ICES website and on the new WGOH website hosted by Southampton Oceanography Centre. (http://www.soc.soton.ac.uk/JRD/ICES_WGOH/index.php)

This year a summary table, with a colour index has been added to the IAOCSS, in order to allow comparison of changes over the whole region and make it more useful to non expert readers.

The WGOH reviewed the Proceedings of the ICES Symposium on 'Hydrobiological Variability in the ICES area 1990-1999', and found that intermediate steps such as nutrients, benthic and planktonic studies were the major gap in the symposium, work that is essential for a multidisciplinary approach.

The WGOH agreed that it would be beneficial to strengthen links with the CLIVAR programme. At present, the CLIVAR website does not contain any information about the WGOH or the ICES standard sections. This information would fill a significant gap in the CLIVAR field programme and research.

An isopycnal analysis method was discussed in the WGOH. This method has the potential to provide a unified framework for intercomparison of different datasets. Some WGOH members expressed an interest in further analysis and will explore the possibilities to use the method in other regions.

WGOH is keen to meet the challenge set by the ToRg (start preparations to summarise the ocean climate of the North Sea for the period 2000-2004, and any trends over recent decades in this climate; for input to the Regional Ecosystem Study Group for the North Sea in 2006). A sub-group has formed to take the work further.

The WGOH members are very keen to improve communications with the rest of ICES WGs and it was proposed that as a first step the IAOCSS should be advertised more widely within ICES. It is hoped that this will generate more interest in the product and will lead to a dialogue, which will eventually improve the product.

The WGOH has developed a new website hosted by Southampton Oceanography Centre. The IAOCSS and the working group reports will be made available for download from this site. The website will also provide a forum for suggestions about improvements to the IAOCSS. Whilst this is a useful interim measure, it would be more preferable for the ICES website to allow working groups to submit their own pages. A review of the website development has been proposed as ToR h for the 2005 meeting.

The view of the WGOH is that ICES should continue to support the physical database. However, it is essential that the database continues to be developed. There should be pro-active acquisition of data, generation of data products, involvement in international programmes to improve accessibility of data. The WGOH propose to invite an ICES database spokesperson to present the strategy for future direction of Data Management in ICES (ToR g).

Updates of ongoing and new Ferrybox type projects were presented to the WGOH. Details of the International Polar Year (IPY) planned for 2007/2008 was presented. The WGOH hope that the results from the IPY would be useful to the group.

The Working Group on Oceanic Hydrography wants to thank Harry Dooley, ICES hydrographer, for his help and dedication to the activities of the WG over the years.

The Working Group will meet next year in Rhode Island, USA, 11 April – 14 April 2005.

3 A MINI-SYMPOSIUM ON CLIMATE

To continue with the recommendations made at the 2001 Reykjavik WG meeting, a mini-symposium on the subject of climate was held. The mini-symposium was chaired by Sheldon Bacon from the Rennel Division of Southampton Oceanographic Centre on the first day of the meeting; abstracts of the talks are presented as Annex D.

This is the fourth year that the WGOH has commenced with a day of scientific presentations, jointly by members of the WGOH, and by scientists from the host organisation. The mini-symposium offers an opportunity for working group members to learn about the work of scientists in the host institute. The WG recommends that a mini-symposium be arranged for the 2005 meeting.

The Agenda of the symposium ran as follows:

Welcome by Prof. Howard Roe (Director, SOC)

Howard Cattle (Director, International CLIVAR Project Office, SOC):
Arctic environmental change -- promise or threat?

Richard Wood (Hadley Centre, Exeter):
Understanding past, current and future changes in the Atlantic.

Meric Srokosz (Rapid Climate Change Project Coordinator, SOC):
Rapid Climate Change -- what is happening?

Chris Reid (Director, SAHFOS, Plymouth):
Plankton and Climate Change: the Continuous Plankton Recorder (CPR) Survey.

Eugene Colbourne, J. Brattey, G. Lilly, G. A. Rose* (Northwest Atlantic Fisheries Centre, St. John's, Newfoundland; * Memorial University, St. John's, Newfoundland):
Impact of Extreme Ocean Climate Events on Marine Resources -- the Smith Sound Example.

Penny Holliday (SOC):
Largescale physical controls of phytoplankton growth in the Irminger Sea.

Harald Loeng (Institute of Marine Research, Bergen):
Some results from the Arctic Climate Impact Assessment (ACIA).

Yevgeny Aksenov, S. Bacon, A Coward (SOC):
Fram Strait fluxes and variability: a model study.

Agnieszka BeszczynskaMöller, E. Fahrbach, G. Rohardt, U. Schauer, A. Wisotzki (AWI, Bremerhaven):
ASOF--N: Heat and volume fluxes through Fram Strait -- results from an array of moorings.

Jan Piechura, W. Walczowski, R. Osinski (Institute of Oceanology, Sopot):

Structure of the West Spitsbergen Current and Atlantic Water transport estimation.

Hendrik van Aken (NIOZ, Texel):
Near inertial waves over the continental slope off Goban Spur.

Alicia Lavín, M. Ruiz, IEONorth (Instituto Español de Oceanografía, Santander):
Mediterranean Overflow Water eddies near Galician Bank.

Thomas Rossby (University of Rhode Island):
The Iceland-Faroe Front in the 1539 Carta marina by Olaus Magnus.

Sheldon Bacon (SOC):
The water planet.

Abstracts from the mini-symposium are included in Annex D of this report.

4 REVIEW OF MEMBERSHIP

The list of participants of the WGOH is in Annex B. Three new members attended the meeting, Bert Rudels from Finland, Victor Valencia from Spain and Glenn Nolan from Ireland. Also John Mortensen was nominated from Germany as new member. The following people attended the meeting to present national reports Agnieszka Beszczynska-Möller in replacement for Eberhard Fahrbach and Karin Margretha H. Larsen for Bogi Hansen.

Some work has been done with the France and Portugal ICES delegates to get participation from the national oceanographers and the WGOH wish their incorporation as soon as possible.

The list of members is presented as Annex C.

5 UPDATE AND REVIEW OF RESULTS FROM STANDARD SECTIONS AND STATIONS (TOR A)

Each member country/institute of the WGOH presents a national report to the group. All national reports are presented here in Annex E to X. This is a standard item of the WGOH, and is the basis for the main work of the Working Group, and its product the ICES Annual Ocean Climate Status Summary (IAOCSS).

This agenda item was covered by two days of presentations and discussion, in which an overview of North Atlantic ocean climate during 2003 emerged. The national contributions are summarised to provide input to the ICES Annual Ocean Climate Status Summary (IAOCSS) (ToR B) which is reproduced below.

Each national report is reproduced in full as an Annex to this report as follows:

ANNEX E: THE NAO IN WINTER 2003
S. Dye
The Centre for Environment Fisheries Aquaculture Sciences (CEFAS), Lowestoft, UK.

ANNEX F: OCEANOGRAPHIC INVESTIGATIONS OFF WEST GREENLAND 2002 (AREA 1)
E. Buch and M.H. Ribergaard
Division for Operational Oceanography, Danish Meteorological Institute, Denmark.

ANNEX G: CLIMATIC CONDITIONS OFF WEST GREENLAND – 2002 (AREA1)
M. Stein
Institute for Sea Fisheries, Hamburg, Federal Republic of Germany.

ANNEX H: LABRADOR SEA (AREA 2B).
R.M. Hendry, R.A. Clarke
Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, Canada.

ANNEX I: ENVIRONMENTAL CONDITIONS IN THE NORTHWEST ATLANTIC DURING 2003 (ICES AREA 2)
E. Colbourne
Fisheries and Ocean Canada, St. John's, Newfoundland, Canada.

ANNEX J: DECADAL VARIATIONS IN SURFACE PROPERTIES IN THE MID-ATLANTIC BIGHT.
T. Rossby
University of Rhode Island, USA.

ANNEX K: AREA 3: ICELANDIC WATERS.
H. Valdimarsson and S. Jónsson
Marine Research Institute, Reykjavík, Iceland

ANNEX L: HYDROGRAPHIC STATUS REPORT 2003: SPANISH STANDARD SECTIONS (AREA 4).
A: A. Lavín, C. González-Pola and J. M. Cabanas
Spanish Institute of Oceanography (IEO), Spain
B: V. Valencia, A. Fontán and A. Borja
Department of Oceanography and Marine Environment (AZTI Foundation, Spain).

ANNEX M: 2003 OCCUPATION OF THE ELLETT LINE – ROCKALL TROUGH (ICES AREA 5)
N.P. Holliday
Southampton Oceanography Centre, UK

ANNEX N: REPORT ON WOCE/CLIVAR SECTION A1E (NORTHERN NORTH ATLANTIC AREA 5B)
Hendrik van Aken
Institute for Sea Fisheries, Hamburg, Federal Republic of Germany.

ANNEX O: FAROESE WATERS (ICES AREA 6)
Bogi Hansen, Karin M. H. Larsen, Regin Kristiansen
Faroese Fisheries Laboratory, P.O. Box 3051, FO-110 Tórshavn, Faroe Islands

ANNEX P: 2002 RESULTS FROM THE SCOTTISH STANDARD SECTIONS, (AREA 7 AND 8)
S.L. Hughes and W.R. Turrell
FRS Marine Laboratory Aberdeen, Scotland, UK

ANNEX Q: THE NORTH SEA MISMASH CLIMATE (AREA 8 AND 9)
P. Loewe and G. Becker
Federal Maritime and Hydrographic Agency of Germany (BSH), Hamburg, Germany.

ANNEX R: SURFACE TEMPERATURE AND SALINITY IN THE SOUTHERN BIGHT OF THE NORTH SEA AND A COASTAL TEMPERATURE NETWORK (AREA 9)
Stephen Dye, Ken Medler, Sue Norris and Al Joyce
The Centre for Environment Fisheries Aquaculture Sciences (CEFAS), Lowestoft, UK.

ANNEX S: AREA 9B: SKAGERRAK, KATTEGAT AND THE BALTIC
K. Borenas
Swedish Meteorological and Hydrological Institute, Sweden

ANNEX T: AREA 9B: SKAGERRAK, KATTEGAT AND THE BALTIC
B. Rudels
Finnish Institute of Marine Research, Helsinki, Finland

ANNEX U: NORWEGIAN WATERS (AREA 8, 10 AND 11)
H. Loeng, K.A. Mork and E. Svendsen
Institute of Marine Research, Bergen, Norway

ANNEX V: RUSSIAN STANDARD SECTIONS IN THE BARENTS AND NORWEGIAN SEAS (ICES AREAS 10 AND 11)
V. Ozhigin
Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia

ANNEX W: POLISH NATIONAL REPORT (AREA 10, 11, 12)
W. Walczowski, J. Piechura,
Institute of Oceanology, Polish Academy of Sciences, 81-712 Sopot, Powstancow Warszawy 55.

ANNEX X: HYDROGRAPHIC CONDITIONS IN THE GREENLAND SEA AND FRAM STRAIT (AREA 12)
A. Beszczyńska-Möller, G. Budeus, E. Fahrbach, U. Schauer, A. Wisotzki
Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany.

6 CONSOLIDATION OF MEMBER COUNTRY INPUTS INTO THE ICES OCEAN CLIMATE STATUS SUMMARY (TOR B)

The draft ICES Annual Ocean Climate Status Summary (IAOCSS) was prepared and reviewed by the Working Group, and its contents agreed. Sarah Hughes (UK) must be thanked for helping prepare the 2003 IAOCSS. The text of the report is presented in Annex Y.

This year a summary table, with a colour index has been added to the report, in order to allow comparison of changes over the whole region and make it more useful to non expert readers. Working group members need to submit their data in good time before the 2005 meeting to allow this table to be prepared.

The 2003/2004 ICES Annual Ocean Climate Status Summary - Overview

In most areas of the North Atlantic during 2003, temperature and salinity in the upper layers remained higher than the long-term average, with new records set in several regions.

Following the strongly negative North Atlantic Oscillation (NAO) index during the winter preceding 2001, the winter NAO index values for 2002 and 2003 were both weak. The pattern of the sea level pressure anomaly for the winter of 2003 was meridional with an east-west dipole as opposed to the zonal pattern caused by the north-south dipole of the NAO. This led to increased southerly winds over the northern North Atlantic.

7 REVIEW NATIONAL MONITORING PROGRAMMES IN ORDER TO IMPROVE CLIMATE MONITORING ACTIVITIES (TOR C);

Most ICES countries have extensive monitoring activities, but these are not always very well coordinated between nations. The WGOH was supposed to evaluate the existing activities and look for improvement. It was agreed that all countries should sustain long-term national time-series. In a few areas, such as the North Sea and the Nordic Seas, several nations are operating different sections. To some extent a few standard sections are coordinated in the way that the same positions are occupied by different nations, but the field season overlaps, so there is difference in time between the occupations of sections. WGOH are presently developing a web-page that will include details of all standard hydrographic sections carried out by the member counties. This information will make it easier to review the monitoring activities, and it was suggested to revisit the TOR next year.

The WGOH noticed that the OSPAR monitoring programme for the North Sea contains no mandatory physical oceanography. Recognising that climate change is of international concern, the WGOH strongly recommends that the Oceanography Committee and ACME should support OSPAR to strengthen the measurements of standard physical oceanography parameters in the OSPAR's Co-ordinated Environmental Monitoring Programme (CEMP), and additionally physical oceanographic monitoring as a basis for understanding of the ecosystem and climate change. The WGOH will discuss the demands of OSPAR for physical oceanography information on the meeting next year.

Additionally information of a workshop to deal a question from OSPAR to ICES about assistance in developing criteria and guidelines for integrated biological effects and chemical monitoring was presented to the members.

8 REVIEW THE PROCEEDINGS OF THE ICES SYMPOSIUM ON HYDROBIOLOGICAL VARIABILITY IN THE ICES AREA, 1990-1999 (TOR D)

The 2nd ICES Decadal Symposium was held at the Royal College of Physicians, Edinburgh on August 8-10 2001 and was highly successful, attracting a full programme of 42 selected talks and 55 posters describing the variability of the plankton, fish, ocean and atmosphere of the ICES area during the 1990s. Active canvassing attracted a total of 17 corporate and institutional sponsors to allow the Symposia to be conducted within budget. Around 184 individuals participated overall, with 155 attending the decadal meeting.

It is suggested that by 2011, it might be appropriate to include a session specifically aimed at describing and testing the best of these relationships in stock assessment. The ICES website www.ices.dk/symposia/decadal3 will be made available to receive participants' comments on the success or otherwise of the present format and ideas for the design and content of a 3rd Decadal Symposium in 2011 (The WGOH have noticed that this website is not yet available)

The editorial panel formed by Ken Drinkwater (Canada), Alicia Lavín (Spain), Mike St Johns (Canada) and leading by Bill Turrell (U.K.) reviewed the posters and papers submitted. A total of 29 papers of four main subjects General climate (1), regional climate (15), plankton (6) and fisheries (7) were published. The volume of ICES Marine Science

Symposia nº 219 was entitled 'Hydrobiological Variability in the ICES area 1990-1999' and was published in September 2003. Also 43 short papers were included mainly from regional climate and fisheries to complete the 453 volume pages.

The book is a well-documented text of basic hydrography and multidisciplinary marine work on the ICES area during the 1990's. The better coverage was obtained in climate and less in fisheries and plankton. Ocean climate variability in all the areas covered by the WGOH was included. In the plankton studies, there were only papers covering work in Newfoundland, Faroe and the North and Baltic Seas.

To fully understand the links between physical environment and fisheries, the intermediate steps (nutrients, benthic, primary production, phytoplankton and zooplankton) also needs to be better understood. This subject strongly needs to be promoted if a multidisciplinary ecosystem approach has to be achieved.

9 REVIEW RELATIONS WITH INTERNATIONAL CLIMATE MONITORING PROGRAMMES (TOR E);

Katy Hill, (project scientist) from the CLIVAR office came to discuss possibilities for improved links between CLIVAR and the WGOH.

CLIVAR (**Cli**mate **Var**iability and Predictability) is an international research programme addressing many issues of natural climate variability and anthropogenic climate change (http://www.clivar.org/).

The specific objectives of CLIVAR are:

- To describe and understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal, and centennial time-scales, through the collection and analysis of observations and the development and application of models of the coupled climate system, in co-operation with other relevant climate-research and observing programmes.
- To extend the record of climate variability over the time-scales of interest through the assembly of quality-controlled paleoclimatic and instrumental data sets.
- To extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled predictive models.
- To understand and predict the response of the climate system to increases of radioactively active gases and aerosols and to compare these predictions to the observed climate record in order to detect the anthropogenic modification of the natural climate signal.

The WGOH agreed that it would be beneficial to strengthen links with the CLIVAR programme. At present, the CLIVAR website does not contain any information about the WGOH or the ICES standard sections. This information would fill a significant gap in the CLIVAR field programme and research.

The following actions were agreed:

- Sheldon Bacon (UK) and Tom Rossby (USA) will present a review of the activities of the WGOH to the CLIVAR Atlantic Panel meeting in June 2004.
- Members of the WGOH should consider attending the CLIVAR workshop on the North Atlantic Thermohaline Circulation (13-16 September, Kiel Germany)
- Members of the WGOH will submit articles to a special issue of the CLIVAR newsletter 'Exchanges'. Sheldon Bacon (UK) and Penny Holliday (UK) will liaise with the CLIVAR office an appropriate timeline for publication of this issue.

The main contact for WGOH at CLIVAR should be Roberta Boscolo, who is also staff support for the ASOF project.

10 REVIEW TWO PROPOSALS FOR NEW WORK (TOR F):

10.1 Undertake long-term storage of water samples

Karin Larsen (Faroe) described the long term storage project started by the Faroese Fisheries Laboratory (FFL). Based on the idea, that future technical development may allow determination of parameters that today cannot be routinely monitored for analytical or economical reasons, the FFL determined in 2001 to establish long-term storage of water samples from selected stations and depths. The samples are mainly from one station on section N and one from section V (Annex O) and depths have been chosen to represent different water masses. The samples are stored in glass bottles similar to salinity samples and for each bottle stored, two other samples have been acquired from the same rosette bottle and have been analysed for salinity. Temperature and salinity for each bottle are recorded. Since this program was initiated, 8 bottles were stored in 2001, 56 bottles in 2002, and 44 bottles in 2003.

Paul Ridout from OSIL was invited to discuss developments in water bottles for sample storage. He concluded that for long term storage, that the highest quality bottles should be used. The bottles in which Ocean Scientific (OSIL) sell their standard seawater are of very high quality glass. It is possible to reuse empty standard seawater bottles and OSIL can provide the caps and crimping equipment needed to reseal the bottles. Using these high quality bottles, salinity samples stored for a long period should drift by no more than 0.001 per year. It is also recommended that samples are stored at ~5°C and in the dark.

The WGOH feel that it is the choice of individual institutes to decide if they wish to undertake long term storage of samples and suggest that they take account of the recommendations made by OSIL.

10.2 Undertake an isopycnal analysis of *in situ* data

Tom Rossby (USA) presented a report from Vladimir Ozhigin (Russia) showing the results of isopycnal analysis of PINRO data in the Norwegian Sea. The isopycnal analysis is a method that allows for the consistent presentation and intercomparison of observations wherever they come from. A summary of the methodology is included as Annex Z of this report.

Some WGOH members expressed an interest in further work in this area and will explore the possibilities to use the method in other regions.

11 START PREPARATIONS TO SUMMARISE THE OCEAN CLIMATE OF THE NORTH SEA FOR THE PERIOD 2000-2004, AND ANY TRENDS OVER RECENT DECADES IN THIS CLIMATE; FOR INPUT TO THE REGIONAL ECOSYSTEM STUDY GROUP FOR THE NORTH SEA IN 2006 (TORG).

Bill Turrell, Chair of SG-GOOS, presented the background to this new term of reference. He explained the work of the ICES Regional Ecosystem Group for the North Sea (REGNS) and the plan to implement regional integrated ecosystem assessment, starting with the North Sea. REGNS are preparing for a regional ecosystem assessment of the North Sea in 2006, with a timetable as follows:

<u>WG meetings in 2004</u>
consider this request
provide feedback on how sensible it is
start specifying and collecting the various data you will need to do the task
nominate contact person

<u>ICES ASC 2004</u>
meeting of all the nominated contact people
start the integration process.

<u>WG meetings 2005</u>
produce a first draft of your contribution to the themed "Chapter" or paper

<u>ICES ASC 2005</u>
integrating panels assess the draft papers
produce a draft assessment

<u>WG meetings 2006</u>
final chance to review papers ready for the Theme Session in September 2006

Many WGOH members can relate experiences of difficulties in the past that has left them frustrated by the lack of understanding and interaction between disciplines, but despite these initial reactions the WGOH is keen to meet the challenge set by the ToRg.

A sub-group has formed to take the work further. This group consists of Gerd Becker (Germany), Hendrik van Aken (the Netherlands), Harald Loeng (Norway), Stephen Dye (UK) and Sarah Hughes (UK).

Stephen Dye (UK) has been nominated as the contact person for the sub-group and he will attend the next REGNS meeting to report on the sub-groups plans. Sarah Hughes (UK) will attend the meeting at the ICES ASC in Vigo.

The WGOH discussed the proposal at length and have the following feedback to give:

- The WGOH consider that understanding the changes in the physical marine environment is indispensable for any ecosystem and fisheries assessment, therefore the WGOH wishes to ensure that the IAOCSS is more widely available to the wider scientific community. The WGOH will take steps to ensure that the IAOCSS is distributed more widely than it has in the past.
- The WGOH agree that for ecosystem assessment, a regional approach is necessary but would add that it is also necessary for the WGOH to continue to meet and prepare an overall summary of climate in the wider North Atlantic area. There was some concern that the move to regional assessments might mean that the WGOH would be disbanded.
- The WGOH wishes to meet and produce the IAOCSS on an annual basis. The WGOH recognises that the IAOCSS could be improved with the addition of other information, such as comprehensive area datasets, satellite data, model data and will aim to include these in future reports. It would be useful if other groups could provide feedback to the WGOH on the IAOCSS.
- The WGOH wishes to amend the wording of ToRg for 2005 as follows:
- Summarise the ocean climate of the North Sea, **in the context of the wider North Atlantic**, for the period 2000-2004, and any trends over recent decades in this climate; for input to the Regional Ecosystem Study Group for the North Sea in 2006.
- The WGOH hopes that the report produced by REGNS would not simply end up being another bureaucratic exercise. The WGOH wishes to see a positive outcome resulting in new and exciting science. To do this it will be necessary to improve communication between scientific disciplines, with this aim the WGOH suggests that ICES also encourage more interdisciplinary theme sessions at the annual science conference.

12 ANY OTHER BUSINESS

12.1 Ferrybox presentation

David Hyde (SOC) presented an overview of the European funded FerryBox project. The project is running well and receiving regular data from ferries running on a number of routes. David commented that ferries operate in weather that would not be possible for smaller research ships. There have been some problems with data transmission by the Orbcomm network on the Portsmouth-Bilbao route, and the Ferrybox project will move to the Iridium system on this route (http://www.ferrybox.de). Ferryboxes are now operating on the following routes, collection temperature, salinity, chlorophyll:

Helsinki (Finland) –Tallin (Estonia)
Helsinki (Finland) –Travemünde (Germany)
Portsmouth (UK) –Bilbao (Spain)
Oslo (Norway) –Hirtshals (Denmark)
Cuxhaven (Germany) – Harwich (UK)
Southampton (UK) - Isle of Wight (UK)
Liverpool(UK) -Belfast (UK)
Den Helder (NL) – Texel Island (NL) (ADCP data)
Athens(Greece) – Crete (Greece)

The data from the FERRYBOX project is available from the via the project website: (http://www.soc.soton.ac.uk/ops/ferrybox_index.php)

12.2 ICES publications, database and website

WGOH members discussed various aspects of ICES, including the publications, the ICES database and the ICES website. Recommendations and actions arising from these discussions are as follows:

The WG are very keen to improve communications with the rest of ICES and it was proposed that as a first step the IAOCSS should be advertised more widely within ICES. It is hoped that this will generate more interest in the product and will lead to a dialogue which will eventually improve the product.

The WG agreed that a pdf of the report, and/or the WGOH website address should be sent to all the chairs of ICES WGs and Committees as soon as it is complete (Chair). The e-mail should ask recipients for feedback on the content of the report and suggestions for improvements. Members were also encouraged to email the document to colleagues and students. It was also suggested that the IAOCSS be featured as a news item on the ICES website each year (Secretariat).

Previous versions of the IAOCSS have been issued in 'pdf' format with restrictions set on printing of the document. In order to facilitate the wider distribution of the report the WGOH will request that printing restrictions are removed from the document. The WGOH consider that understanding the changes in the physical marine environment is indispensable for any ecosystem and fisheries assessment.

The WGOH have developed a new website hosted by Southampton Oceanography Centre. The IAOCSS and the working group reports will be made available for download from this site. The new website will be used to provide information about WGOH meetings and will collect information about standards sections included in the IAOCSS. The website will also provide a forum for suggestions about improvements to the IAOCSS. Whilst this is a useful interim measure, it would be more preferable for the ICES website to allow working groups to submit their own pages.

The WG is concerned about the apparent declining support for the physical database within the ICES data centre. Although the WGOH does not use the database directly for its annual reports, many members use it as a permanent archive for their data, and as a valuable data resource for their research. The view of the WG is that ICES should continue to support the physical database. However it is essential that the database continue to be developed. There should be pro-active acquisition of data, generation of data products, involvement in international programmes to improve accessibility of data, etc. It was suggested that these views should be expressed to the WG on Data Management, but in addition the WG felt it was important to discuss this issue with a senior ICES representative, both in order to make our views known, as well as to hear in detail the ICES policy and strategy regarding the database.

12.3 International Polar Year 2007/2008

Harald Loeng (Norway) presented details of the International Polar Year (IPY) being planned for 2007/2008.

The International Polar Year (IPY) 2007-2008 is envisioned as an intense, internationally coordinated campaign of research that will initiate the dawn of a new era in polar science. IPY 2007-2008 will include research in both polar regions and involve strong links to the rest of the globe. It will be multi- and interdisciplinary in scope and truly international in participation. It will educate and excite the public, and help train the next generation of engineers, scientists, and leaders. It will include elements from a wide range of scientific disciplines, including issues related to human populations.

The WGOH recommends a wider participation and hope that the results from IPY would be useful for the group.

12.4 Tom Rossby – Iceland_Faroes Ferry

Tom Rossby described the proposal for instrumenting a vessel running between Denmark, Faroe and Iceland.

A key link in the global thermohaline circulation consists of the exchange of waters between the North Atlantic and the Nordic Seas. The warm saline waters flowing north are cooled off and flow back into the North Atlantic as a deep overflow, in part as Greenland Sea Deep water and in part as Arctic Intermediate water. By monitoring the flows both north and south one can provide a very accurate and quick measure of the rate of exchange between the basins and hence keep a finger on the pulse of the larger thermohaline circulation system. The bottom-sited ADCPs in the Faroe-Shetland Channel provide good coverage of the outflow there. However, evidence suggests there is substantial overflow between the Faroes and Iceland as well, but this flux appears to be quite variable in both space and time. Without accurate knowledge of the relationship between this overflow and the FSC overflow it becomes difficult to establish accurately the magnitude and temporal characteristics of these fluxes. But this need not be so.

Recently, a new car-ferry has started operation on a weekly schedule from the Faroes to Iceland in the west and Shetland and Denmark in the east. This route cuts across all warm water inflows between Iceland, the Faroes and Scotland. It is proposed to explore the possibility of equipping this vessel with a phased-array acoustic Doppler current profiler (ADCP). A 75 kHz ADCP would be able to operate in the bottom-track mode everywhere except in the central part of the Shetland Channel and a 38 kHz unit should reach the bottom everywhere. Equipped with either instrument such an operation would be able to monitor all inflow between Europe and Iceland and almost all outflows with a biweekly sampling rate and with excellent horizontal and vertical resolution.

The ICES WGOH endorses the concept in principle and encourages further evaluation and development of such a program.

12.5 Session on the 2004 ASC. Presentation and call for papers

The WGOH members were reminded of the deadline for submission of papers to the theme session (Session N) on 'Oceanographic Processes related to the continental slopes of the North Atlantic' at the 2004 Annual Science Conference in Vigo, Spain (Co-Convernors: Alicia Lavin (Spain), Denis Gilbert (Canada) and Xavier Carton (France)). Abstracts must be submitted by 3 May 2004.

The western continental slope of the Atlantic Ocean is well known for its intense boundary currents at surface and subsurface levels. At the eastern (European) continental slope energy levels are much lower. Processes there, however, may strongly affect marine circulation and production. Papers and posters are invited which address physical, chemical, and biological processes at both of these boundaries, in particular:

- The role of the eastern North Atlantic slope current in providing a source of heat and salt and in forming a meridional link between different populations of marine species.
- The influence of the Mediterranean outflow on the properties of the eastern North Atlantic slope current.
- The role of filaments arising from slope current processes in transporting water from the continental shelf into the ocean basins.
- A description of slope processes in the Northwest Atlantic related to the Labrador Current, Gulf Stream eddies, exchanges with the continental shelf at trenches, and the deep western boundary current.
- Analyses of how the energy transported laterally by internal waves and internal tides, generated and reflected at the continental slopes, becomes available for boundary-intensified turbulent diapycnal mixing.
- The role of the slope currents of the North Atlantic in the global thermohaline circulation.
- The influence of climate variability on slope currents.
- The impact of slope current variability on processes in adjacent marginal seas.
- An evaluation of processes on continental slope dynamics arising from modelling and observational studies.
- General processes on continental slopes.

12.6 Session for 2005 Annual Science Conference, Aberdeen

The Working Group proposes for 2005 ICES Annual Science Conference (ASC) in Aberdeen (UK) a special theme session on the subject "Recent advances in our understanding of marine turbulence in an ecological and climatological context'. Co-convenors: Hendrik van-Aken (Netherlands) and Tom Osborn (USA).

The Working Group on Modelling of Physical/Biological Interactions (WGPBI) were also interested in this theme session and decided to suggest Tom Osborn as co-convenor.

'The Working Group on Ocean Hydrography considers turbulence and turbulence mixing to be key factors in understanding the ocean physics and ecosystem Turbulence can be shear driven, convectively driven or driven by double diffusive processes.

- Turbulent mixing maintains vertical (diapycnal) fluxes of heat, freshwater (salt) and dissolved substances like nutrients or oxygen. Knowledge of these fluxes is required for the understanding of climatological and ecological processes.
- Turbulence with its related variations in velocity and shear represents an ecological stress factor for small organisms including fish larvae. It may influence exchange of substances between organisms and its surroundings as well as prey-predator relationship.

- The correct parameterization of turbulent fluxes is a key factor for the success of both ecological and circulation models.'

12.7 Thanks to Harry Dooley

The WGOH would like to thank Harry Dooley, the ICES Hydrographer, for all of his help and dedication to the activities of the group. Since his arrival from FRS Marine Laboratory in Aberdeen, Harry has seen many changes at ICES and has helped to move oceanographic data management through many advances in technology. Harry, we will miss you.

13 DATE AND PLACE OF NEXT MEETING

Professor Tom Rossby (USA) kindly extended to the Working Group an invitation to Rhode Island in 2005. The Working Group will meet there during 11 April – 14 April 2005. It is proposed that a one-day mini-symposium be held to inform about the work of scientists at the host institute of relevance to WGOH.

WGOH members are reminded that the work of the group requires 4 full days and are asked, where possible, to arrange their travel after the fourth day.

14 RECOMMENDATIONS

The **Working Group on Oceanic Hydrography** [WGOH] (Chair: A. Lavín, Spain) will meet in Rhode Island USA, from 11–14 April 2005:

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

b) consolidate inputs from Member Countries and NORSEPP into the ICES Annual Ocean Climate Status Summary (IAOCSS);

c) review national monitoring programmes and OSPAR's Coordinated Environmental Monitoring Programme (CEMP), in order to improve climate monitoring activities. (Harald Leong, Gerd Becker)

d) review and improve relations with international climate monitoring programmes. (Sheldon Bacon).

e) undertake an isopycnal analysis of *in situ* data. (Tom Rossby)

f) summarise the ocean climate of the North Sea, in the context of the North Atlantic, for the period 2000-2004, and any trends over recent decades in this climate; for input to the Regional Ecosystem Study Group for the North Sea in 2006. (Stephen Dye)

g) Invite the new ICES databank manager to present the strategy for future direction of Data Management in ICES (Penny)

h) Review website developments. (Sheldon Bacon).

Supporting Information

Priority:	The activities of this group are fundamental to the fulfilment of the oceanography committee's action plan.
Scientific Justification:	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 2004. b) The Working Group recognises the need for disseminating climate information in a timely and appropriate manner. The Steering Group on ICES-GOOS has also identified the climate summary as an essential contribution from Working Group on Oceanic Hydrography. This agenda item will allow Working Group OH members to prepare the document during the meeting, thus avoiding delays in the dissemination of the information. c) Most ICES countries have an extensive monitoring activity, but there is no or little co-ordination between nations. This agenda item will therefore critical evaluate the existing activities and look for improvement and better co-ordination efforts. Also OSPAR's Coodinated Environmental Monitoring Programme (CEMP), will be reviewed.

	d) Links have been made with the CLIVAR programme, it would be of benefit both to ICES an the international programmes to enhance internal information exchange. e) To develop a method for consistent presentation and inter-comparison of datasets to help improve understanding of changes. f) This is required as the working groups input to the thematic writing panels working under the co-ordination of REGNS to develop an integrated assessment of the North Sea. Where possible outline the causes of these trends. For the purposes of this study the North Sea comprises ICES Area IV and IIIa and does not include intertidal areas. As far as possible, significant seasonal variation should be described. g) The WG is concerned about the declining support for the ICES physical database. The view of the WG is that ICES should continue to support the development of the physical database and would like the opportunity to discuss the issue with an ICES representative. h) The work of the WGOH needs to be publicised more widely, both to the general public, to the wider scientific community, and to other scientists within ICES. Therefore we have established and are developing a dedicated WGOH website (located at SOC) to that end.
Relation to Strategic Plan:	The WGOH supports various elements of Goals 1, 4 and 5.
Resource Requirements:	No extraordinary additional resources
Participants:	The Group normally is well attended but lacks participation from a number of countries committed to physical oceanographic programmes in the Atlantic, in particular France
Secretariat Facilities:	N/a
Financial:	None apart from b) Publication / reproduction costs
Linkages to Advisory Committees:	ICES Annual Ocean Climate Status Summary available to the Advisory Committee on Fishery Management and Advisory Committee on the Marine Environment
Linkages to Other Committees or Groups	Publications Committee; Consultative Committee; ICES/IOC Steering Group on GOOS
Linkages to Other Organisations:	IOC, JCOMM, CLIVAR

15 ANNEXES

Annex A: Agenda and Terms of Reference for 2004 WGOH Meeting

2C06 The **Working Group on Oceanic Hydrography** [WGOH] (Chair: A. Lavín, Spain) will meet in Southampton, UK, from 29 March–1 April 2004 to:

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

b) consolidate inputs from Member Countries and NORSEPP into the ICES Annual Ocean Climate Status Summary (IAOCSS);

c) review national monitoring programmes in order to improve climate monitoring activities;

d) review Proceedings of the ICES Symposium on Hydrobiological Variability in the ICES Area, 1990–1999 in order to evaluate gaps in knowledge;

e) review relations with international climate monitoring programmes;

f) review two proposals for new work, viz:

i) discuss the possibility to undertake long-term storage of water samples of key locations for future analysis
ii) undertake an isopycnal analysis of *in situ* data.

g) start preparations to summarise the ocean climate of the North Sea for the period 2000-2004, and any trends over recent decades in this climate; for input to the Regional Ecosystem Study Group for the North Sea in 2006.

WGOH will report by 30 April 2004 for the attention of the Oceanography Committee and ACME.

Scientific Justification:	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 2000. b) The Working Group recognises the need for disseminating climate information in a timely and appropriate manner. The Steering Group on ICES-GOOS has also identified the climate summary as an essential contribution from Working Group on Oceanic Hydrography. This agenda item will allow Working Group OH members to prepare the document during the meeting, thus avoiding delays in the dissemination of the information. c) Most ICES countries have an extensive monitoring activity, but there is no or little co-ordination between nations. This agenda item will therefore critical evaluate the existing activities and look for improvement and better co-ordination efforts d) The WGOH will review the proceedings of the ICES Symposium on Hydrobiological Variability in the ICES area, 1990-1999 in order to identify any potential gaps and provide advice intended for the third Decadal Symposium. e) The visit of the ICES WGOH to Southampton Oceanography Centre provides an opportunity for the WGOH to interact directly with the representatives of several international climate monitoring programmes (e.g. CLIVAR, GOOS, Argo), and it would be of benefit both to ICES an the international programmes to enhance internal information change f) These two new business items were proposed by Prof. Hansen (Faroe Islands) and Prof. Rossby (USA) for further discussion by the group (see Annex Y and Z of 2002 report). g) This is required as the working groups input to the thematic writing panels working under the co-ordination of REGNS to develop an integrated assessment of the North Sea. Where possible outline the causes of these trends. For the purposes of this study the North Sea comprises ICES Area IV and IIIa and does not include intertidal areas. As far as possible, significant seasonal variation should be described.

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Annex D: Mini-Symposium on Climate, Southampton 2003

Arctic Environmental Change: Promise or Threat

Howard Cattle

International CLIVAR Project Office, Southampton Oceanography Centre, University of Southampton

This paper will firstly provide an overview of changes in Arctic climate observed over recent decades. In particular the changes to surface temperature, permafrost temperatures, river runoff, northern hemisphere snow extent and Arctic Sea ice extent and thickness will be illustrated. Many of these changes have been attributed to the positive phase of the North Atlantic Oscillation over the period, though recent model simulations from the Hadley Centre indicate that positive heat flux anomalies into the Arctic may also play a role. Climate model simulations also show the Arctic to be the globally most sensitive region in terms of the response of climate to greenhouse gas-induced climate change. This presentation will also provide an overview of the likely changes in Arctic climate through the 21st century as revealed by climate model simulations. Uncertainties in model simulations will be discussed. Changes in the Arctic due to greenhouse gas-induced change are likely to be of significant societal importance affecting indigenous peoples and with economic and ecological consequences. The likely impacts will be discussed with particular reference to the outputs from the IPCC's Third Assessment Report.

Rapid Climate Change – what is happening?

M. A. Srokosz

Southampton Oceanography Centre

The possibility of rapid climate change (that is, significant change over a period of the order of a decade) is of interest to both scientists and policy makers. Evidence from palaeo data (for example, Greenland ice cores and marine sediments) shows that over the last 11,000 years (the Holocene) the climate has been relatively stable. However, prior to that rapid changes in temperature of the order of 5-10 degrees have occurred in perhaps as short a time as 5-10 years. The palaeo data suggest that the oceanic thermohaline circulation (THC) is implicated in these changes. Computer models indicate that under global warming similar rapid changes might occur in the future, with a slowdown or shutdown of the N. Atlantic THC. Such rapid changes could have major climatic impacts particularly in NW Europe. The UK Natural Environment Council (NERC) has funded the Rapid Climate Change (RAPID) programme (£20M over 6 years), which is using a combination of palaeo data, observations in the N. Atlantic and models to study rapid climate change, with the aim of reducing uncertainties and improving predictions. NERC is working with NSF and NOAA in the USA, and with the Netherlands Organisation for Scientific Research and the Research Council of Norway in Europe. At the present time a major observational array is being deployed in the N. Atlantic to measure changes in the meridional overturning circulation (of which the THC is the dominant component). In addition, improved palaeo data on past rapid changes are being acquired. Both the palaeo data and observations will be used to test and so improve climate models so that the possibility of future rapid climate change may be better assessed. For more information on RAPID e-mail M.Srokosz@soc.soton.ac.uk or see the web page http://rapid.nerc.ac.uk/

Plankton and Climate Change: the Continuous Plankton Recorder (CPR) survey

Philip C. Reid

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Evidence from the Continuous Plankton Recorder (CPR) survey suggests that the plankton can integrate hydro-meteorological signals and may be used as a possible index of climate change. As many species undergo strong seasonal vertical migrations and spend much of their year in waters down to 2000m, they may reflect changes in intermediate and deep layers as well as the surface of the ocean. Strong links have been demonstrated between the plankton and Northern Hemisphere temperatures, the North Atlantic Oscillation (NAO) and sea surface temperatures. The colour index of the CPR survey has shown a substantial increase in season length and intensity and implies increases in chlorophyll and primary production in a wide belt across the North Atlantic and especially in shelf seas. Parallel increases in the benthos imply that sedimentation from the plankton has also increased in the last decade. These events are part of what has been termed a regime shift in the North Sea after 1987. Part of the cause of the change appears to be linked to varying oceanic advection into shelf seas. The source, characteristics and volume flow of these inputs appears to have a major impact on the biological productivity of shelf seas with associated changes to fish stocks. This was demonstrated recently when a reduction in the size and biomass and changes in timing of plankton were shown to be the cause of large reductions in cod recruitment in the North Sea. Superimposed on the changes associated with the regime shift has been a northerly movement of warmer water plankton on the eastern side of the Atlantic and a southerly movement of colder plankton in the western Atlantic. The rate of change has been substantial, 10° of latitude in only forty years in the eastern Atlantic.

The third report of the international panel on Climate Change (IPCC) has shown that the rapid rise in mean global temperature seen in the last century was exceptional in the context of the last millennium. Mean surface (land and sea) global temperatures increased by 0.6□C □ 0.2□C in the twentieth century. There is now a scientific consensus that these increases are attributable to the even greater rate of increase seen in greenhouse gases. Concentrations of CO2 for example have increased by 30% since 1750 at a rate that has been unprecedented in the last 20 000 years. Greenhouse gases are expected to continue to rise at a rapid rate over the next 100 years. Modelled projections for CO2 suggest increases of 540 to 970ppm in the next hundred years compared to ~380ppm in 2000 and ~280ppm in 1800. On the basis of these greenhouse gas projections surface temperatures are expected to increase by a further 1.4 to 5.8□C by 2100. It is likely that changes in temperature at this scale and rate are likely to have a pronounced effect on northern latitudes in the Arctic and in turn on the circulation of the North Atlantic which plays such a key role in the ‘Global Conveyor Belt’. The extent to which climatic variability may be contributing to the marked changes observed in the plankton over the last five decades will be assessed with a forecast of potential future ecosystem effects in a climate change scenario. The scale of the changes seen over five decades emphasises the importance of maintaining existing and establishing new, long term and wide scale monitoring programmes of the world’s oceans under the flag of the Global Ocean observing System (GOOS).

Impact of Extreme Ocean Climate Events on Marine Resources –the Smith Sound Example

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Smith Sound located on the East Coast of Newfoundland is about 20 km in length and about 1-2 km wide with water depths to 210 m and a sill depth of 155 m. During April 1995, a large and dense aggregation of cod (Gadus morhua) was discovered in the Sound. Subsequent hydro-acoustic surveys of the aggregation estimated the biomass to range from about 10,000 metric tons during the mid-1990s to about 25,000 metric tons during the early 2000s. This group of fish now represents the largest known single spawning aggregation of the once abundant northern cod stock. Recaptures from tagging studies determined that during late spring and early summer most of these fish move out of Smith Sound and migrate north along the east and northeast coast of Newfoundland remaining in the inshore regions. They return to Smith Sound in late autumn to over-winter. In early April of 2003, residents of the Sound discovered a significant number of cod and redfish floating on the surface and washing onto the shoreline. Dead cod were subsequently harvested from the surface by fishers during a three-week period and approximately 800 metric tons, representing nearly 4% of the estimated biomass of the aggregation was processed by local fish plants. An examination determined that the fish were either frozen or contained ice crystals. This event was the largest documented natural mortality of cod in Newfoundland and Labrador waters.

Climate conditions in Atlantic Canada during this period were among the coldest observed in about a decade. This followed a period of intense cyclonic atmospheric circulation over the Labrador Sea, resulting in an unusually cold winter that brought the heaviest sea-ice cover to the region since the early 1990s. Oceanographic measurements made during the mass mortality incident in early April revealed that the water column within the Sound had cooled significantly compared to January and indeed to the past 10 years. It was discovered that the entire Sound was flooded by extremely cold water, with minimum temperatures of -1.73°C at mid-depth and about -1.6°C near bottom at 200-m depth. The near-freezing sub-surface water within Smith Sound during the spring was the result of intense winter convection on the Newfoundland and Labrador Shelf. These cold sub-surface waters which are continuously advected southward by the Labrador Current penetrated to the inner reaches of Smith Sound by early April. The reason why so many fish in Smith Sound during the spring of 2003 did not adapt to the ambient temperature of the surrounding water is not clear. It is clear however, from existing data that the 2003 temperatures were near critical values, substantially colder than the previous 8-10 years. It is possible therefore, that this may have been the first time that this body of fish was exposed to near freezing water. Furthermore, the rate of decrease in temperatures at 200-m depth from near 0.5ºC in late January 2003, to a minimum of -1.73ºC by early April 2003, is anomalous and may be a significant factor that led to the mass mortality. There are numerous other observations that are currently being compiled surrounding this incident. Further research to determine the full circumstances that led to perhaps the largest documented natural mortality of cod in Newfoundland and Labrador waters is currently being carried out both at Memorial University and by Fisheries and Oceans Canada.

Some results from the Arctic Climate Impact Assessment (ACIA)

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Approximately 2/3 of the Arctic Region in the ACIA context is comprised of ocean. The Marine Arctic includes the Arctic Ocean and its adjacent shelf seas, as well as the Nordic Seas, the Labrador Sea and the Bering Sea. From a climate change perspective these areas are very important since processes occurring in the Arctic affect the rate of deep-water formation in the convective regions of the North Atlantic, thereby influencing the ocean circulation across the globe. In addition, global climate modelling studies consistently show the Arctic to be one of the most sensitive regions to climate change.

Not surprisingly, many Arctic life forms, including humans, are directly or indirectly dependent on productivity from the sea. Several physical factors make Arctic marine systems unique from other oceanic regions including: a very high proportion of continental shelves and shallow water; a dramatic seasonality and overall low level of sunlight; extremely low water temperatures; presence of extensive permanent and seasonal ice-cover; and a strong influence from freshwater, coming from rivers and ice melt. Some of these factors represent harsh conditions for many types of marine life. Arctic fauna is young, geologically speaking. Recent glaciations resulted in major losses of biodiversity, and re-colonisation has been slow because of the extreme environmental conditions and overall low productivity of the Arctic system. This results in Arctic ecosystems, in a global sense, being "simple". They are composed largely of specialists that have been able to adapt to the extreme conditions and overall species diversity is low. The high seasonal pulse of summer production in the Arctic, during the period of 24 hours light is particularly pronounced near the ice edge and in shallow seas such as the Barents and Bering Sea. This production attracts seasonal migrants that travel long distances to take advantage of Arctic summers and return to the south to overwinter.

Some of the main conclusions are:

- Large uncertainties in the response of the Arctic climate system to climate variability arise through poorly quantified feedbacks and thresholds associated with the albedo, the thermohaline circulation and the absorption of greenhouse gases by the ocean. Since available climate models cannot agree on future changes in the pressure fields and hence their associated winds, much uncertainty remains in the extent of the changes in stratification, mixing and ocean circulation.
- The Arctic THC is a critical component of the Atlantic THC. The IPCC 2001 assessment considers a reduction of the Atlantic THC likely, while a complete shutdown is considered unlikely but not impossible. If the Arctic THC is reduced, it will affect the global thermohaline circulation and thus the long-term development of the global climate system. Reduction of the THC may also result in a lower oceanic heat flux to the Arctic. If the THC is reduced, localised regions of the Arctic will likely experience cooling rather than warming and the location of ocean fronts may change. ACIA climate models cannot assess the likelihood of these occurrences.
- Most of the present ice-covered Arctic areas will very likely experience reductions in sea ice extent and thickness, especially in summer. Equally important there will be earlier ice melt and later freeze up. This will likely lead to an opening of navigation routes through the Northwest and Northeast passages for greater periods of the year and increased oil and gas and mineral exploration.
- Decreases in sea-ice cover will reduce the over-all albedo of the region, which very likely will act as a positive feedback mechanism for global warming.
- Upper layer sea temperatures will very likely increase, especially where sea ice coverage is reduced.
- In areas of reduced ice-cover, primary production is very likely to increase, which in turn will likely increase zooplankton and possibly fish production. Increased cloud cover will likely have the opposite effect on phytoplankton production in areas that are currently ice free
- Increased sea temperatures will very likely lead to a northward shift of many fish species, changes in the timing of their migration, possible extension of their feeding areas and increased growth rates. It is also likely to lead to the introduction of new species to the Arctic but it is unlikely lead to the extinction of any present Arctic fish species. Changes in timing of biological processes may affect the overlap of spawning of predators and their prey (match-mismatch hypothesis
- Stratification in the upper layers will likely increase the present day ice-free areas of the Arctic assuming that there is no marked increase in winds

ASOF-N: Heat and volume fluxes through Fram Strait - results from an array of moorings.

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Since 1997 the volume and heat fluxes in Fram Strait have been monitored under the VEINS and ASOF-N projects. 14 current meter moorings with additional TS sensors and bottom pressure recorders were deployed at 78°55'N/79°N to monitor the heat and mass exchange through the only deep passage between the Nordic Seas and the Arctic Ocean. Since 2002 the array has been augmented with two additional moorings in the recirculation area. The high resolution hydrographic section was carried out once per year to supplement the results from moored instruments. The flow in the eastern part of the strait is mostly barotropic with a weaker baroclinic component. The West Spitsbergen Current carrying the Atlantic water northward has a complex spatial structure with the main core over the upper continental slope and a weaker stream shifted offshore. The volume and heat fluxes reveal a seasonal signal with the maximum northward transport in winter. The interannual variations in the velocity and temperature fields resulted in two most prominent features in the observed period: a significant increase of the northward heat flux and a shift of the net volume transport from southward during first three years to northward in the following years. The variations in the structure of the Return Atlantic Current, recirculating Atlantic water in the central Fram Strait, were coupled with an increase and widening of the northward flow in its eastern part. The current field in the eastern part of the strait was also found to be correlated with the atmospheric pressure gradient across Fram Strait.

Observations of inertial wave events near the continental slope off Goban Spur

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Analysis of public current meter data from the OMEX-I research programme, carried out near Goban Spur at the northwestern end of the Bay of Biscay, showed a near bottom maximum of near-inertial kinetic energy over the continental slope 50 m above the bottom near the 1000 m isobath. Most kinetic energy at near-inertial frequencies was observed during a few short-term events, where inertial velocities well over 10 cm/s were observed. Coherence between inertial peaks at neighbouring current meters suggested westward and upward transport of inertial energy from the 1000 isobath in relatively narrow beams. The co-occurrence of inertial wave events and strong changes in the background temperature field suggest that sudden changes and geostrophic adjustment of the sub-surface eastern boundary current, which transports warm and saline water northwards, is the main source of energy for the near inertial waves. Since the near inertial spectral peak was located 1.7% above the inertial frequency, the near inertial waves have a slight gravity wave character. This allows both vertical wave propagation and vertical orbital motion, parallel to the sloping bottom. While the first allows with the derived vertical and horizontal transport of near inertial energy, the latter will cause a near inertial spectral peak in the temperature spectrum. That peak indeed was observed and its magnitude agreed quantitatively with vertical slightly super-inertial motion parallel to the bottom in the observed mean temperature stratification.

Mediterranean Overflow Water eddies near Galician Bank.

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The Mediterranean water spreading is a major fact in the high salinity of the North Atlantic Water and an important contribution to the conditions of the high latitude convection that produces the thermohaline circulation. Recent studies of the MOW indicate that an important contribution of this flux of salinity to the interior of the North Atlantic is carried by lens or Meddies of Mediterranean Overflow water. These elements detach from the main vein that fluxes along the Iberian coast and slope eastern boundary current from the Gibraltar Strait near some topographic features as Extremadura promontory, Cape Saint Vincent, and so on. Lately, new 'northern meddies' have been described as north as the Western Bay or Biscay or the Goban Spur. Here we present observations of eddy activity at MOW level in the vicinity of the Bank of Galicia. The observations do not allow us to determine the source of these meddies, but the TS characteristics and the detachment of the described formation regions suggest the possibility of a northern source of Mediterranean water 'Meddies' or anomalous high salinity lenses that spread around the area. Recent reports of “northern meddies” near Charcot seamount suggest Finisterre-Ortegal area as a meddy source. However, since other seamounts have been recognised as meddy sources, the Galicia Bank could also be a candidate.

Annex E: The NAO in winter 2003

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1 Background

The North Atlantic Oscillation (NAO) is the dominant mode of atmospheric variability in the North Atlantic, accounting for 44% of the variance in winter (December-March, DJFM, is defined as the winter season and the year given by January) sea-level pressure (SLP) in the last century (Hurrell, 1995). The classical dipole is shown in the Figure 1 as the first EOF of sea level pressure (SLP) anomaly (Hurrell, pers. comm.), the next two modes of variability account for 12% and 11% of the variance respectively.

It is conventional to use an index of the winter NAO (NAO_{DJFM}) defined by the pressure difference between the two cells of the dipole, as measured at land stations. Hurrell (1995; 1996; Hurrell *et al.* 2003) constructs a time-series of the winter NAO_{DJFM} index of Lisbon–Stykkisholmur SLP, whilst Jones *et al.* (1997) use the SLP difference Gibraltar–Reykjavik. These indices have the benefit that they can be extended back to 1864 (Hurrell, 1995) and 1821 (Jones *et al.* 1997). Whilst these indices of the NAO_{DJFM} are normalised to the standard deviation over a base period, it remains a measure of SLP difference between two particular land stations and a diagnostic of the NAO_{DJFM} SLP distribution. An alternate index of the NAO can be made using the Azores as the southern node (Rogers, 1984). In winter the Azores High retracts eastward placing Lisbon or Gibraltar closer to the southern centre of action. However, the Rogers winter NAO_{DJF} index simply uses the SLP difference between the Azores and Iceland without a normalisation routine so is applicable as an indicator of westerly and north-westerly winds over the Northwest Atlantic (Colbourne, 2003).

The characteristics of the NAO_{DJFM} and aspects of the relationship to the ocean were discussed in the prior reports to the WGOH (Dickson and Meincke, 1999, 2000; Dickson *et al.* 2001) and recently by Visbeck *et al.* (2003). In Figure 2 we show the correlation between the NAO_{DJFM} index and the sea surface temperature (pers comm., B. Planque). The SST pattern is produced by the surface heat flux anomalies associated with NAO correlated wind speed and source of airflow changes. The amplification of the NAO_{DJFM} index from the extremes of negative to positive between the 1960's and the late-1980's/early-1990's underwent a sharp decrease in winter 1996. Following the 1996 winter extreme, subsequent winters showed a return to positive NAO conditions apart from the winter of 2001 when the Hurrell NAO_{DJFM} index was –1.89 and the Jones NAO_{DJFM} index was –0.5 (see data sources below). At the time of the last report early indications were that the NAO_{DJFM} index for winter 2003 could become negative but without a strong NAO pattern (Dye *et al.* 2003).

Here we briefly report on the conclusion from winter 2003 and early indications for winter 2004. Additionally we show seasonal air temperature and wind-speed anomalies for the other seasons of 2003, where the atmosphere over much of the ICES WGOH region exhibited warm and low wind-speed conditions throughout the year.

2 Winter NAO in 2003

The Jones NAO_{DJFM} index (www.cru.uea.ac.uk) for the winter of 2003 was 0.40 and the Hurrell NAO_{DJFM} index (www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html) was 0.20, part of a general diminishing trend of the NAO_{DJFM} index since the extreme and persistent positive index of the early 1990s (Figure 2). Both indices are based upon the pressure difference between Iceland and the southern Iberian Peninsula. Figure 3 shows the SLP anomaly field in the North Atlantic for the composite of the 4 winter months (NCEP/NCAR Reanalysis data, Kalnay *et al.*, 1996) with none of the typical NAO pattern. The cause of the overall weak positive NAO_{DJFM} index is the small difference in SLP anomaly between Iceland and Lisbon/Gibraltar. The Rogers NAO index using the Azores as the southern node was (as 2002) weak and negative. Overall, it appears that the NAO pattern was not a strong influence upon the SLP anomaly over the North Atlantic during the winter of 2003.

The east-west dipole evident in the winter SLP anomaly for 2003 suggests anomalous southerly airflow over much of the north Atlantic, resulting in warmer than usual air temperatures over most of the north Atlantic, particularly north of 55°N (Figure 4a). At the eastern edge of the Scandinavian anticyclonic anomaly air temperatures were generally colder than usual as the geostrophic wind anomaly came from the north and west. Some indication of indication of cooler than usual temperatures is evident south of Newfoundland where the airflow is likely have been more north-westerly in origin than average. The winter of 2003 can also be characterised (Figure 4b) as one of low wind speed. In combination with warm air this is likely to have reduced the liberation of stored heat from the upper ocean over the winter preparing the way for warm SST for the rest of the year.

3 Early indications for 2004

The NAO_{DJFM} indices for 2004 have yet to be published and the March reanalysis data is not yet available. The December to February composite of SLP anomaly from the NCEP/NCAR model (Figure 5) shows a 6 to 8 mb high pressure anomaly west of Iceland and a small pressure anomaly at Lisbon/Gibraltar. As the Jones and Hurrell NAO_{DJFM} indices both normalise the local data before taking the south-north difference it is not entirely clear that this SLP anomaly distribution would necessarily lead to a negative index however this seems the most likely outcome for winter 2004. The Rogers NAO Azores-Iceland index uses only the months December to January and raw SLP so Figure 5 allows us to make a rough estimate of Rogers NAO index for 2004 at –6 to –10 mb. The SLP anomaly field suggests that south of Iceland and west of about 10°W a south-easterly wind anomaly will have been present, as expected in an NAO negative winter. The Nordic and North Seas will have been subjected to northerly airflow caused by the east west dipole in SLP anomaly here.

In summary the NAO north-south dipole pattern appears to be present in the west of the region over the winter 2004, but in the eastern part of the ICES WGOH region the SLP anomaly is dominated by an east-west pattern. Early indications suggest a weak NAO negative that is more evident in the west.

4 Other Seasons of 2003

In Figure 6a-c we show the atmospheric conditions over the region in the other seasons of 2003 (NCEP/NCAR Reanalysis data, Kalnay *et al.*, 1996), wind speed and air temperature were chosen because of their importance to the surface heat flux and mixed layer characteristics. Spring (March-May) over Newfoundland highlights the western Atlantic cold anomaly identified in the winter (DJFM) analysis. Over the Labrador Sea conditions remained up to 3 degrees warmer than usual. A band of particularly warm conditions lay between Greenland and the southern North Sea. In spring the general pattern of wind speed anomaly was towards slower conditions over the whole region. Of note is the paired negative-positive wind speed anomaly pattern shown between the Rockall Trough region and an area south and west of Iceland, where a northward shift in the atmospheric circulation appears to have brought particularly timid conditions to Rockall.

Summer air temperature conditions were warm everywhere, again centred on an axis running from Greenland towards the North Sea and particularly evident in France. In autumn the entire area remained warmer than usual but the reanalysis data suggests this was now strongest over the region north and west of the line between Newfoundland and Svalbard. Wind speeds in the summer were near normal in a band running to the north and east over Scotland and into the Baltic, but north of this were up to 2 m/s weaker than average. Low wind speed conditions persisted through the autumn over the whole region.

In summary, the dominant features of the surface atmosphere over the ICES WGOH region in 2003 were low wind speeds and warmer than average temperatures.

5 NAO information and Data sources

Hurrell (1995) instrumental NAO_{DJFM} index www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html
Jones (1997) instrumental NAO index from www.cru.uea.ac.uk/cru/data/nao.htm
SLP Anomaly data NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center (Kalnay *et al.*, 1996) www.cdc.noaa.gov/Composites
NCEP-CPC 700 mbar principal component NAO index plus other N. Hemisphere teleconnections www.cpc.ncep.noaa.gov/data/teledoc/telecontents.html
NCEP-CPC 500 mb daily principal component NAO index and forecasts www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao_index.html
Further NAO information and comparison between instruments and principal component indices and alternate seasons www.cgd.ucar.edu/~jhurrell/nao.html

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Kalnay, E. and Coauthors, 1996: The NCEP/NCAR Reanalysis 40-year Project. Bull. Amer. Meteor. Soc., 77, 437-471.

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Figure Captions

Figure 1: a) The first EOF of winter SLP anomaly over the Atlantic sector describes 44% of the variance. Figure courtesy of J. Hurrell, NCAR. **b)** The correlation co-efficient between the Hurrell Lisbon-Iceland instrumental NAO_{DJFM} and winter SST in the North Atlantic. Figure courtesy of B. Planque IFREMER.

Figure 2: The Hurrell95 instrumental NAO_{DJFM} index over the last 50 years in standard deviation normalised units. The red curve shows the 7-point low-pass filtered version (filter run includes data prior to 1950).

Figure 3: The North Atlantic distribution of SLP anomaly (mbar) for the composite of December 2002 to March 2003 relative to the period 1968-1996. (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

Figure 4: December 2002 to March 2003 composites of the North Atlantic distribution of **a)** Air Temperature anomaly (°C), **b)** scalar wind speed anomaly (m/s). (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

Figure 5: The North Atlantic distribution of SLP anomaly (mbar) for the composite of December 2003 to February 2004 relative to the period 1968-1996. (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

Figure 6: Seasonal anomaly composite for **a)** spring MAM **b)** summer JJA **c)** autumn SON. Left-hand panels show the Air Temperature anomaly (°C), right-hand panels show the scalar wind-speed anomaly (m/s). (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

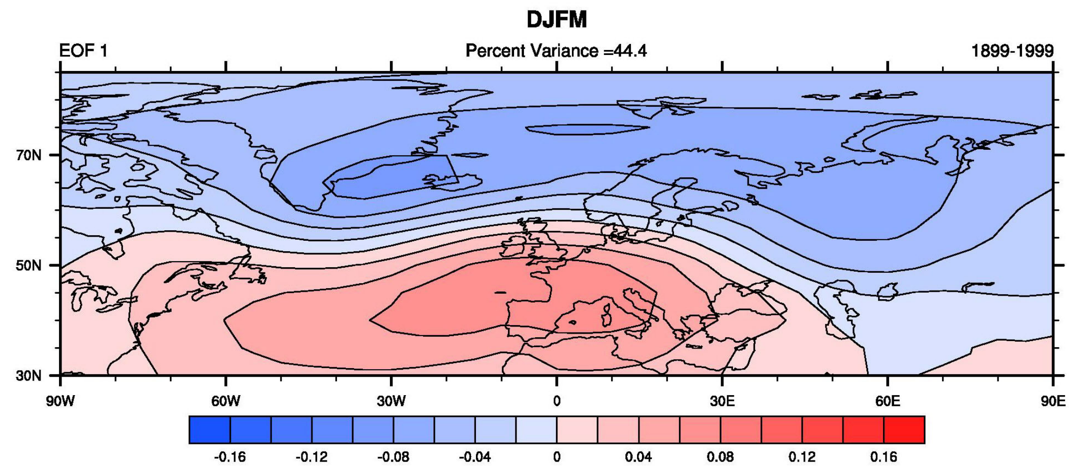


Figure 1a.

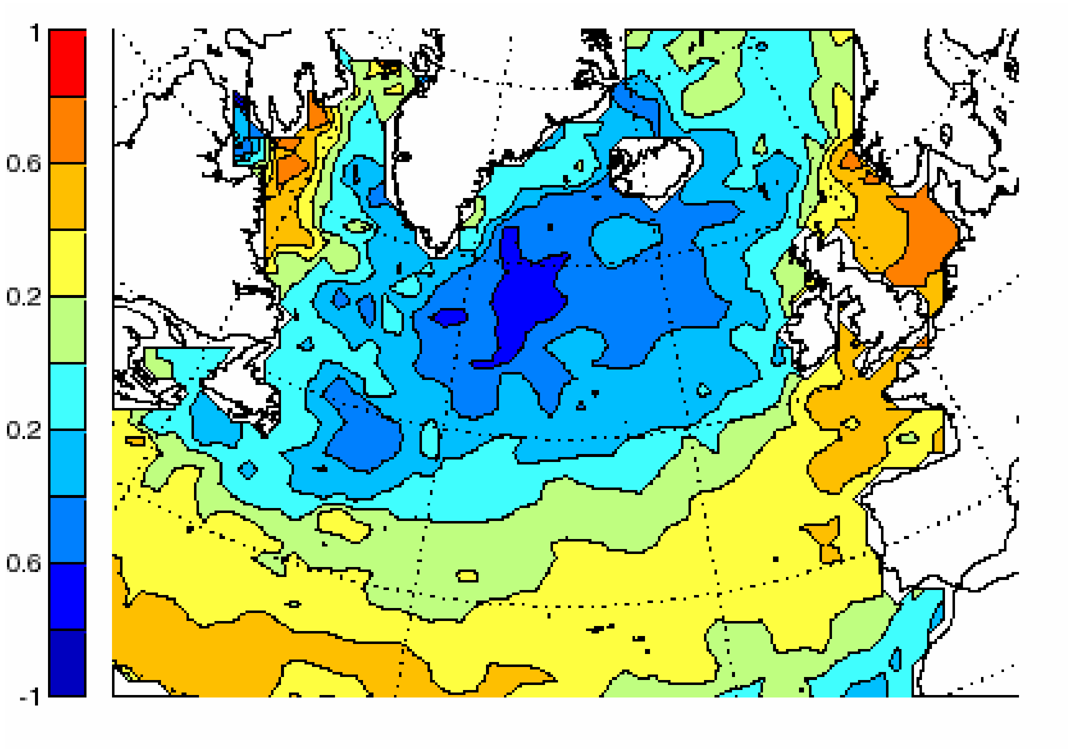


Figure 1b.

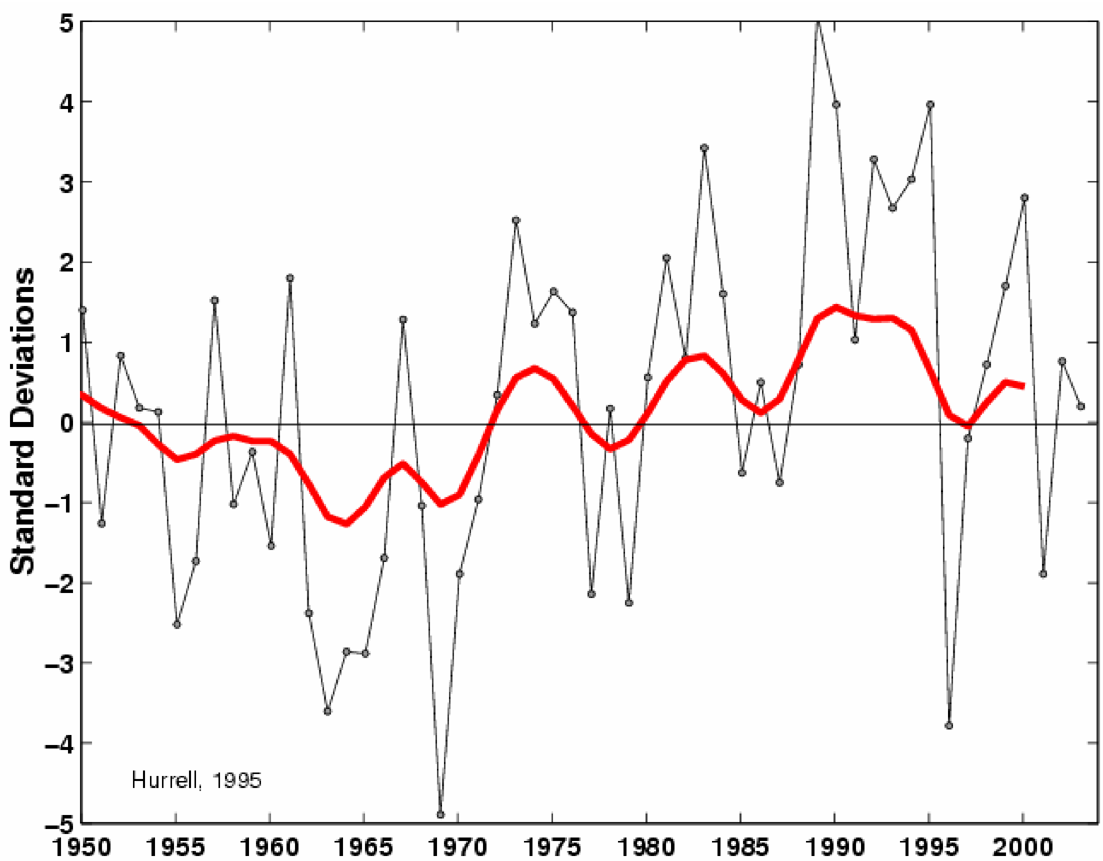


Figure 2.

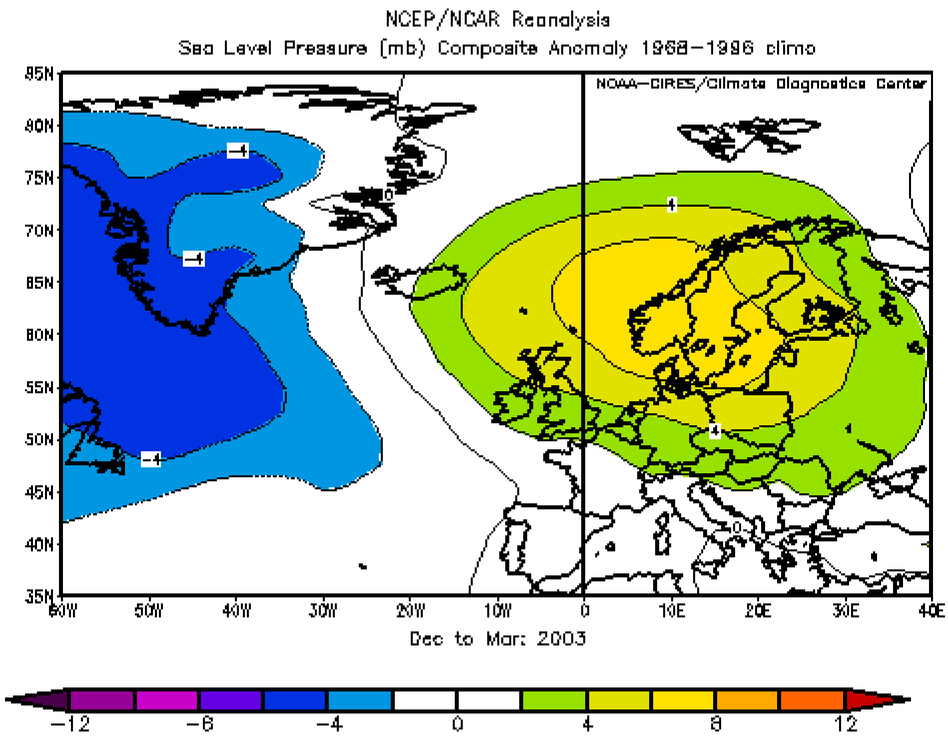


Figure 3.

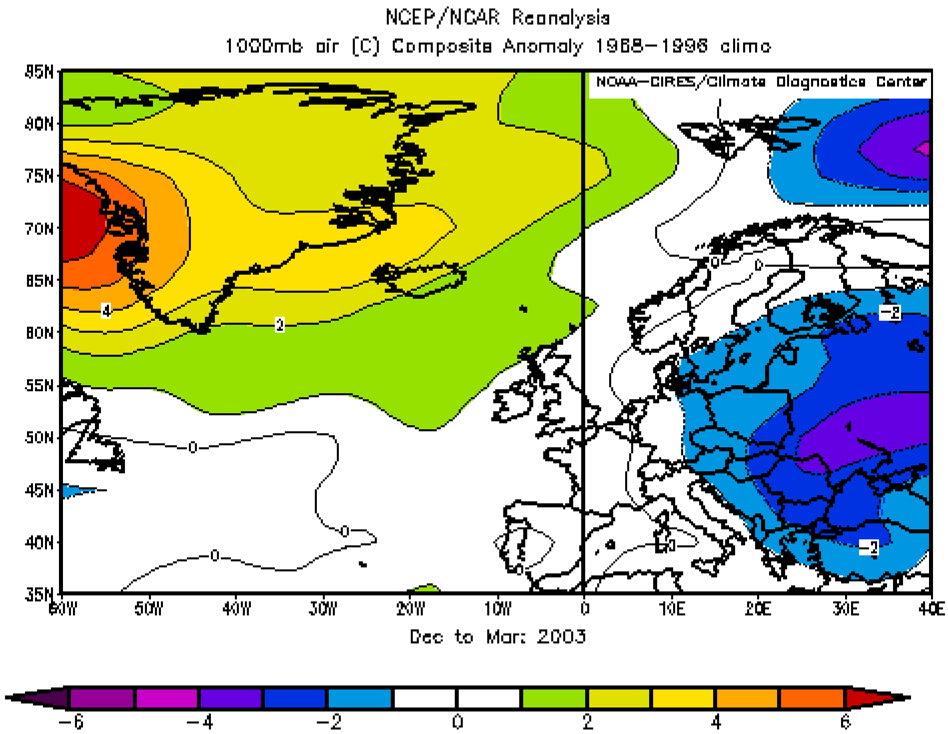


Figure 4a) Air temperature anomaly

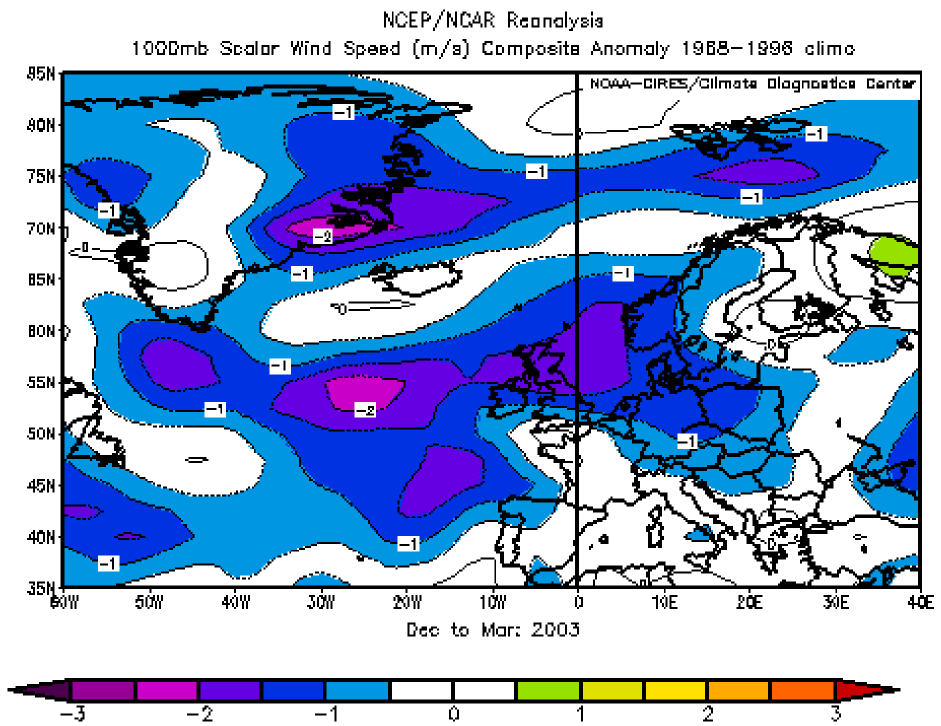
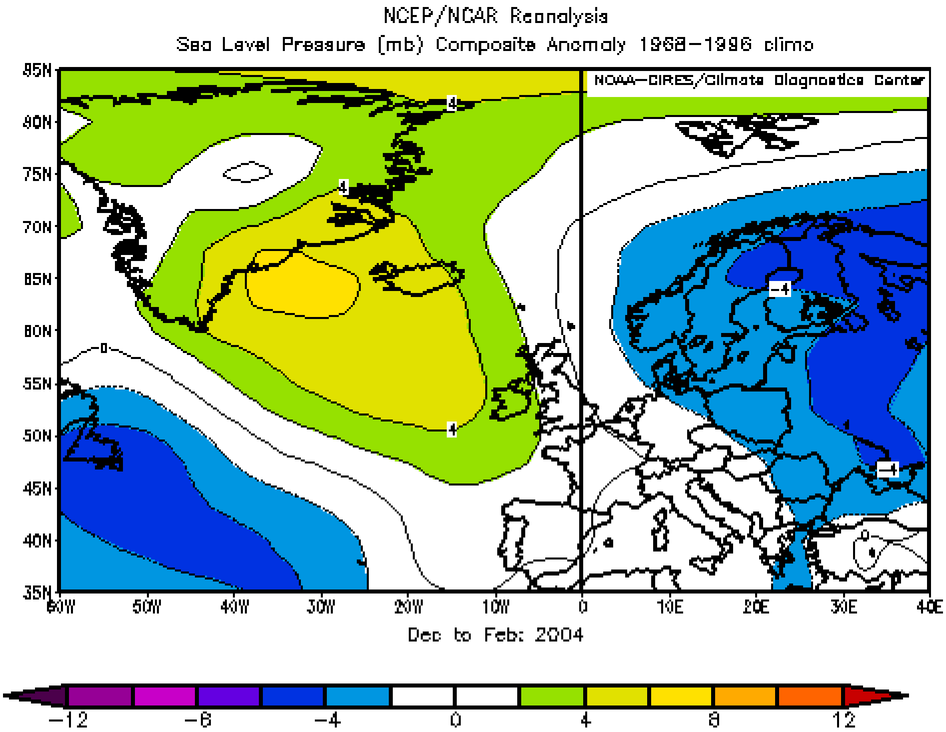


Figure 4b) Scalar wind speed anomaly.


NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Anomaly 1968–1996 climo
NOAA–CIRES/Climate Diagnostics Center
85N
80N
75N
70N
65N
60N
55N
50N
45N
40N
35N
60W
50W
40W
30W
20W
10W
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30E
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Dec to Feb: 2004
−12
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12

Figure 5.

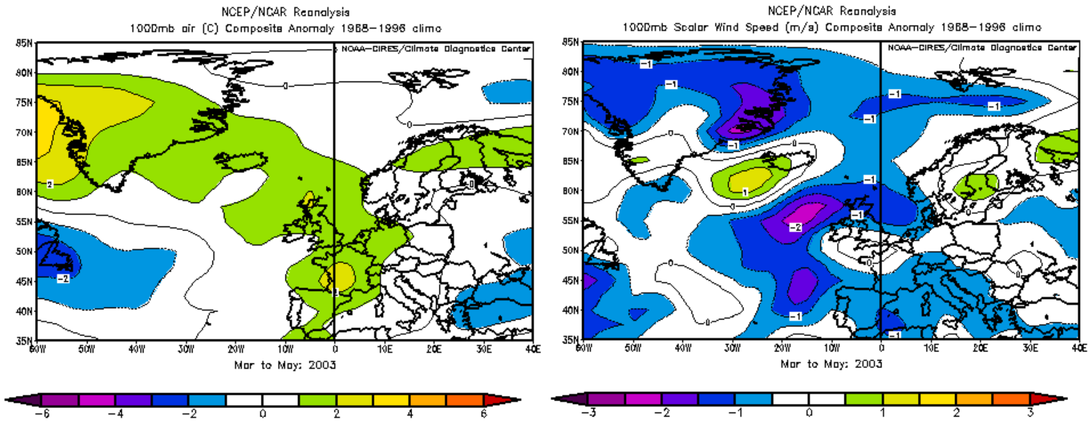


Figure 6a) Spring MAM.

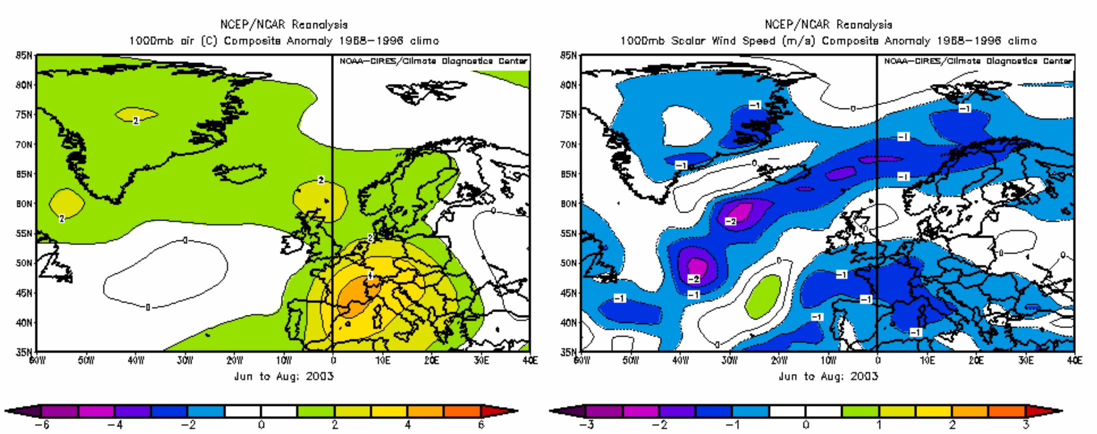


Figure 6b) Summer JJA.

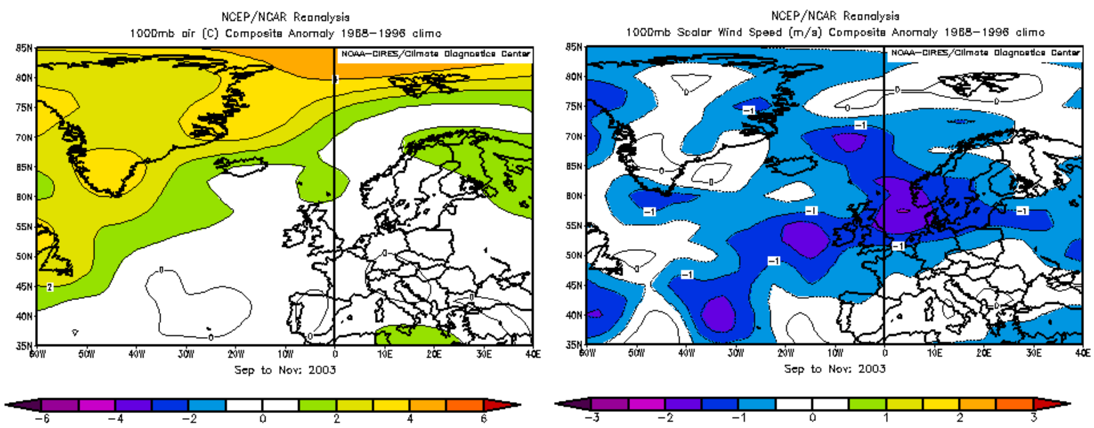
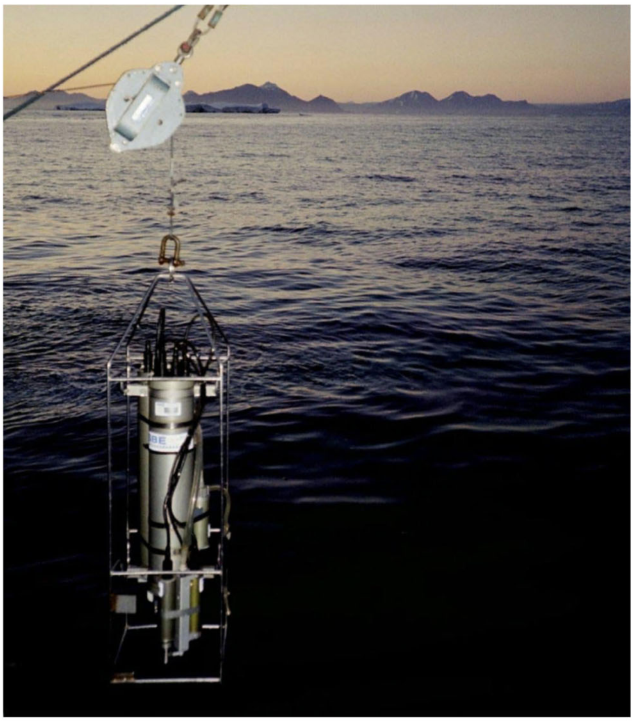


Figure 6c) Autumn SON.

Annex F: Oceanographic Investigations off West Greenland 2003 (Area 1)

Oceanographic Investigations Off West Greenland 2003



By

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NOVEMBER 2003

Abstract

Results of the summer 2003 standard section cruise along the west coast of Greenland are presented together with CTD data gathered during trawl surveys.

The NAO index was close to zero, but the Icelandic Low had moved towards southwest while the Azores high had moved north-eastward. As a consequence the wind anomaly in large part of the North Atlantic including the Denmark Strait was southwest-ward, reducing the strength of the East Greenland Current while strengthen the Irminger Current.

The time series of mid-June temperatures on top of Fylla Bank was about one degree above average conditions, while the salinity was slightly higher than normal.

The temperature of the Polar Water was high compared to normal years and the front between Polar Water and Irminger Water week indicating a reduced inflow of Polar Water to the West Greenland area in 2003. Pure Irminger Water was observed from Cape Farewell to the Fylla Bank section, and Modified Irminger Water could be traced as far north as the Maniitsoq (Sukkertoppen) section. The inflow of Irminger Water seems to be much higher than the last couple of years, which most likely can be a consequence of reduced inflow of Polar Water.

Two very different kinds of fjords systems were measured around Sisimiut. Two fjords have deep sills allowing relative warm and saline water of Atlantic origin to enter at the bottom. The density of this bottom water is higher than the surface Polar Water at its freezing point preventing winter convection to the bottom. The other type of fjord have a shallow sill preventing the warm Atlantic water to enter at the bottom. Therefore cold and fresh bottom water was measured below sill depth, which is surface water transformed by convection during winter, as the salinity of the whole fjord system was very homogeneous. At the surface of both fjord systems solar heated Polar Water was found.

1. Introduction

The North Atlantic marine climate is largely controlled by the so-called North Atlantic Oscillation (NAO), which is driven by the pressure difference between the Azores High and the Iceland Low pressure cells. We use wintertime (December–March) sea level pressure (SLP) difference between Ponta Delgada, Azores, and Reykjavik, Iceland, and subtract the mean SLP difference for the period 1961–1990 to construct the NAO anomaly. The winter NAO index during winter 2002/2003 was approximately zero (Figure 1). However, the Icelandic low was during the winter months (December–Marts) displaced towards southwest and the Azores high was deflected towards central Europe (Figure 2). The center of the low was just south of Cape Farewell. This has the effect that the wind anomaly (difference from normal conditions) over the eastern part of the Irminger Basin, the Iceland Basin and in the Denmark Strait was northwest-ward reducing the strength of the East Greenland Current through Denmark Strait and intensifying the Irminger Current as explained further in chapter 4.

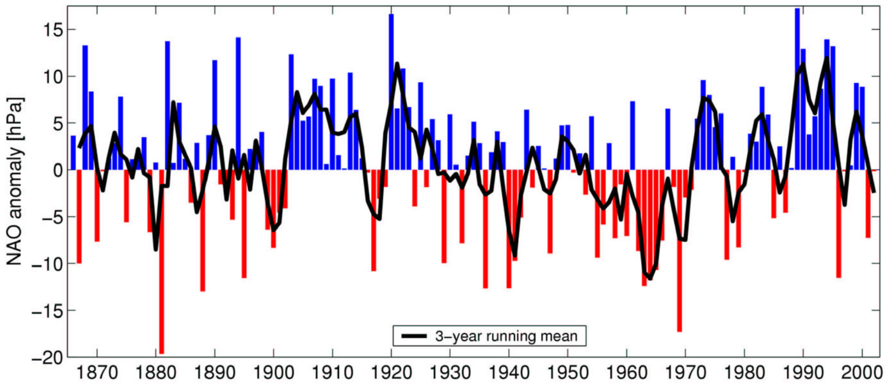

Figure 1. Time series of winter (December–March) index of the NAO from 1865–2003. The heavy solid line represents the meridional pressure gradient smoothed with a 3-year running mean filter to remove fluctuations with periods less than 3 years. Note that values for both 2001/2002 and 2002/2003 were very close to zero. (Pressure data updated from http://www.cru.uea.ac.uk/cru/data/nao.htm, as described in Buch et al., 2003).

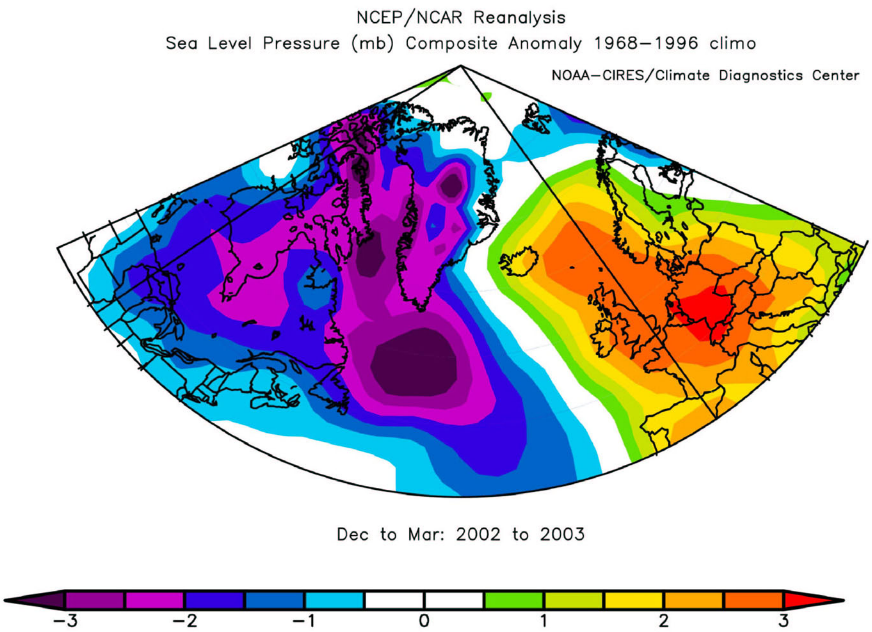

Figure 2. Winter (DJFM) sea level pressure anomaly for 2002/2003 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

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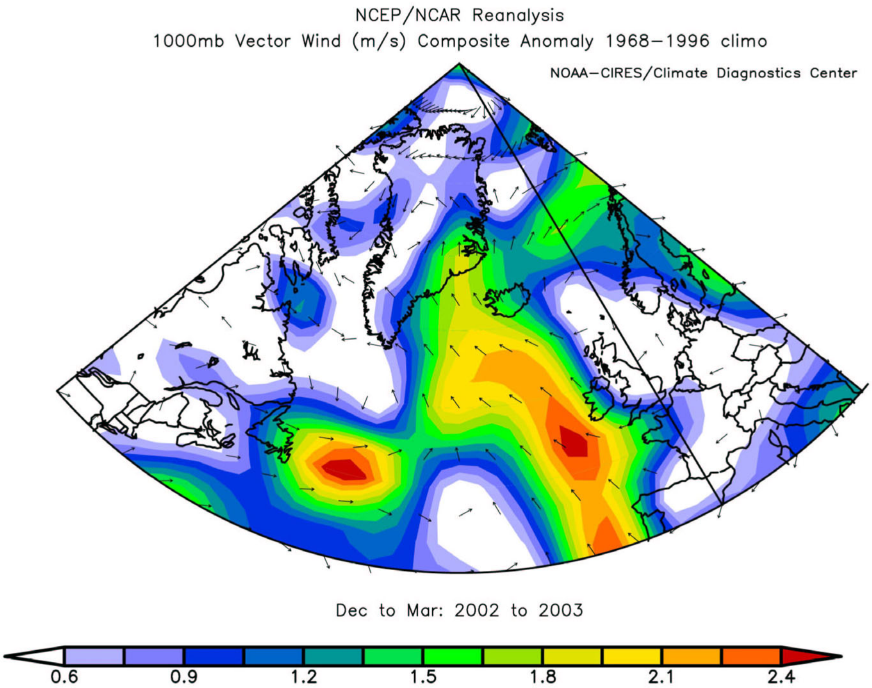

Figure 3. Winter (DJFM) wind anomaly for 2002/2003 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

West Greenland lies within the area which normally experiences warm conditions when the NAO index is negative. As can be seen from Figure 4 the annual mean air temperature for 2003[1] in Nuuk was minus 1.7°C which is close to the mean value, reflecting well the NAO value close to zero. The mean annual air temperature for November 2002–October 2003 was however above normal for most of the North Atlantic region, Figure 5.

Changes in the ocean climate in the waters off West Greenland generally follow those of the air temperatures, exceptions are years with great salinity anomalies i.e. years with extraordinary inflow of Polar Water or water of Atlantic origin. In 2003 the mean temperature on top of Fylla Bank in the middle of June was 2.69°C which is about one degree above the average value of 1.67°C for the whole 53 year period and the forth highest value, whereas the mean salinity value, 33.57, was about equal to the average value for the entire period (Figure 6). This does *not* correlate with the NAO, but can be explained by the displacement of the centers of the North Atlantic pressure system, see chapter 4.

[1] As the mean temperature was made in November 2003, November and December values was taken as the mean values for the whole time series for these months.

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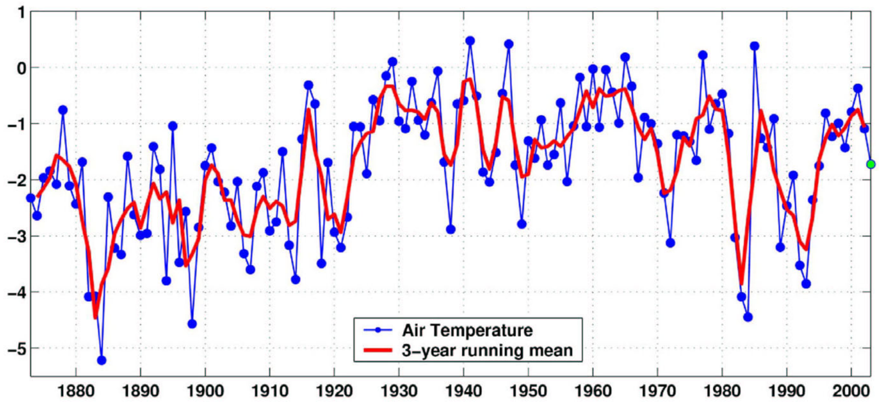

Figure 4. Annual mean air temperature observed at Nuuk for the period 1873 to 2003. In 2003 (green) the values from November and December are taken as the mean value for these month for the rest of the period, as the plot was constructed in November 2003.

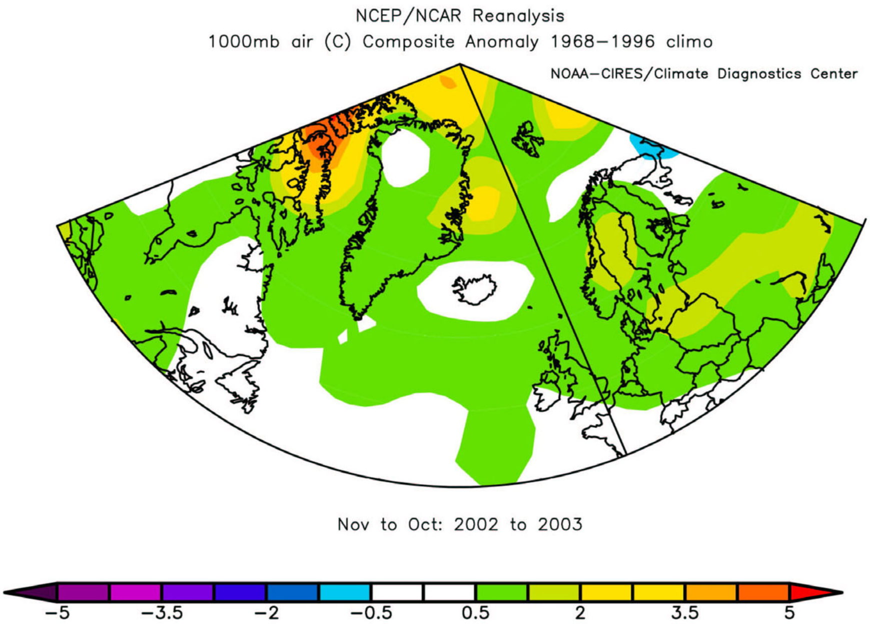

Figure 5. Anomalies of the annual mean air temperature (taken as November–October) for 2002/2003 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

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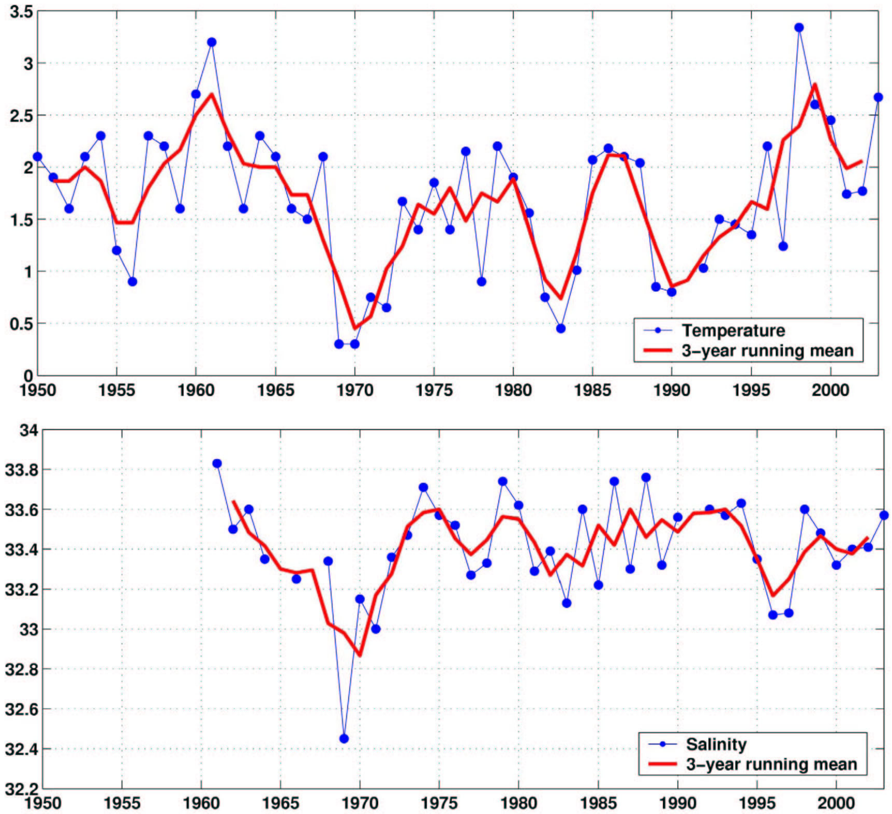

Figure 6. Time series of mean temperature (top) and mean salinity (bottom) on top of Fylla Bank (0–40 m) in the middle of June for the period 1950 to 2003. The red curve is the 3 year running mean value.

2. Measurements

The 2003 cruise was carried out according to the agreement between the Greenland Institute for Natural Resources and Danish Meteorological Institute during the period June 29 to July 6, 2003 onboard the Danish naval ship **"AGPA".** Observations were performed on the following stations (Figure 7 and Figure 8):

Offshore Labrador Sea/Davis Strait:

- Cape Farewell St. 1–5
- Cape Desolation St. 1–5
- Paamiut St. 1–5
- Fylla Bank St. 1–5
- Maniitsoq St. 1–5
- Sisimiut St. 1–5

Fjords around Sisimiut:

- Amerdloq St. 1–5
- Ikertoq St. 1–5
- Kangerdluarssuk St. 1–6
- Qeqertalik St. 1

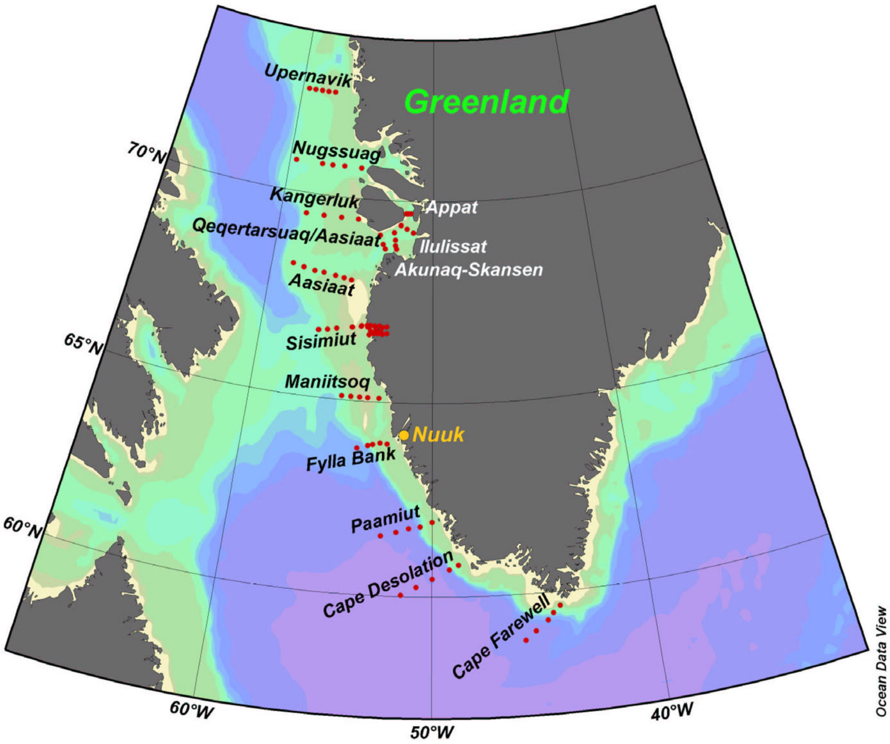

Figure 7. Position of the oceanographic sections off West Greenland where measurements were preformed in 2003. See Figure 8 for position of fjord measurements around Sisimiut measured in 2003. Map produced using Ocean Data View (Schlitzer, 2003).

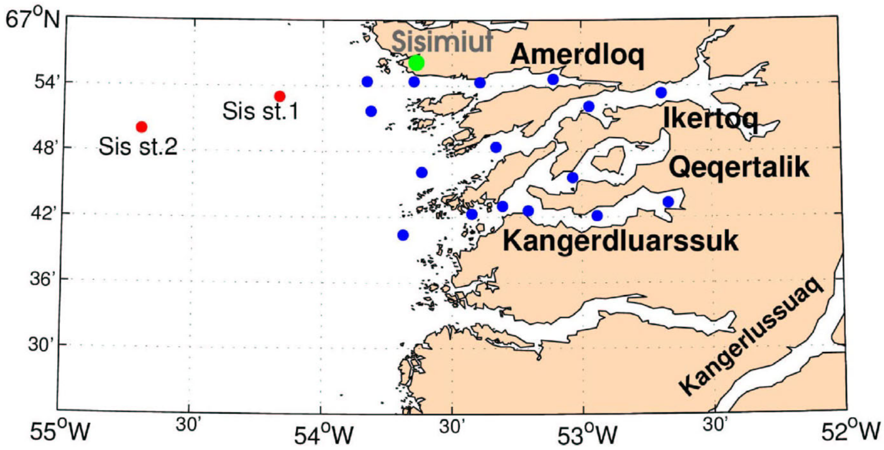

Figure 8. Position of the oceanographic fjord sections around Sisimiut where measurements were preformed in 2003. See Figure 7 for position of all sections measured in 2003.

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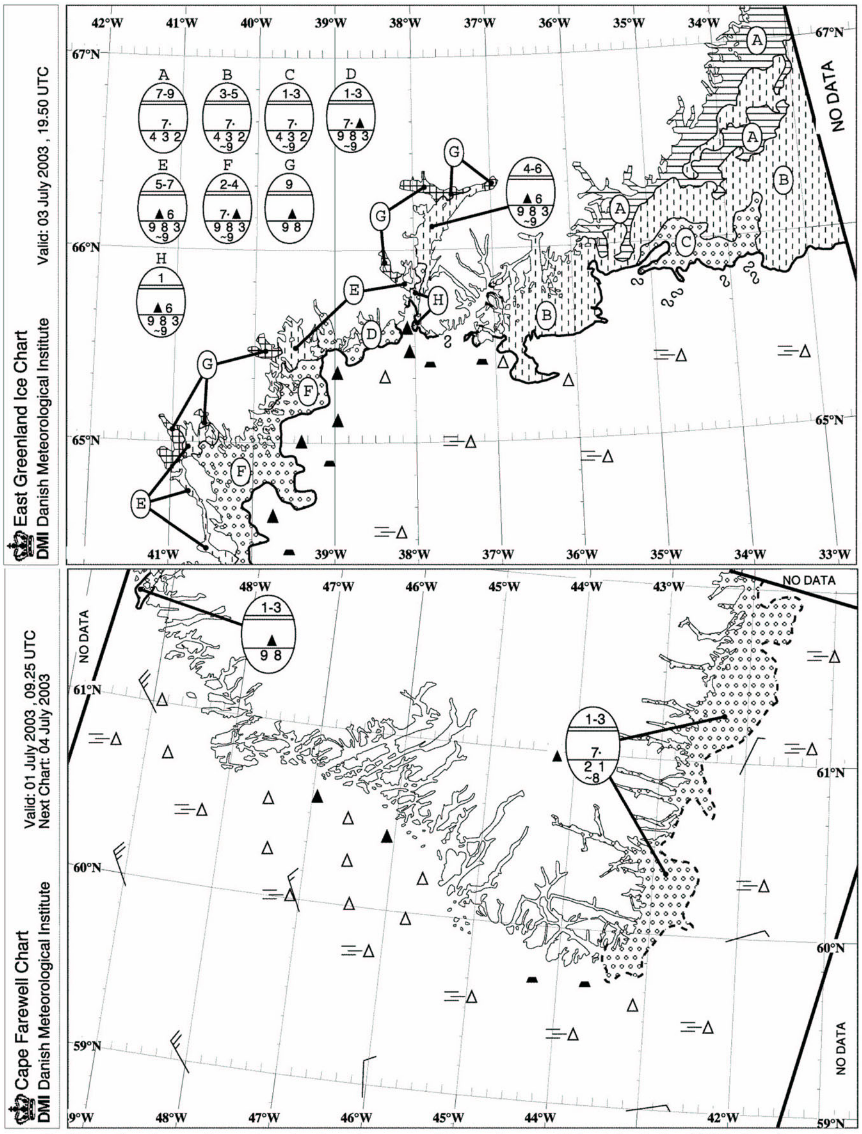

Figure 9. Distribution of sea ice in the Amerssalik region valid at 3. July 2003 (top) and in the Cape Farewell region valid at 1. July 2003 (bottom).

On each station the vertical distributions of temperature and salinity was measured from surface to bottom, except on stations with depths greater than 750 m, where approximately 750 m was the maximum depth of observation.

The cruise was blessed with favourable weather and ice conditions. Both ”Storis”[2] (Figure 9) and “Vestice”[3] was not present at all. The absent of “Storis” is very seldom for the area at that time of the year.

[2] “Storis” is multi year ice transported from the Arctic Ocean through Fram Strait by the East Greenland Current to Cape Farewell, where it continues northward by the West Greenland Current.

[3] “Vestice” is one year ice formed in the Baffin Bay, Davis Strait, and western part of the Labrador Sea during winter.

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In mid July/early August the Greenland Institute for Natural Resources carried out trawl surveys in the Disko Bay area and further North onboard R/V PAAMIUT. During these surveys CTD measurements were carried out on national oceanographic standard stations (Figure 7):

Offshore Davis Strait/Baffin Bay:

- Aasiaat (Egdesminde) St. 1–7
- Kangerluk (Disko fjord) St. 1–4
- Nugssuag St. 1–5
- Upernavik St. 1–5

Disko Bay:

- Qeqertarsuaq–Aasiaat (Godhavn–Egdesminde) St. 1–3
- Akunaq–Skansen St. 1–4
- Ilulissat (Skansen–Jakobshavn) St. 1–4
- Appat (Arveprinsens Ejlande) St. 1–3

3. Data handling

Measurements of the vertical distribution of temperature and salinity were carried out using a SEABIRD SBE 9-01 CTD. For the purpose of calibration of the conductivity sensor of the CTD, water samples were taken at great depth on stations with depths greater than 500 m. The water samples were after the cruise analysed on a Guildline Portosal 8410 salinometer.

The CTD data were analysed using SEASOFT 4.249 software provided by SEABIRD.

CTD data collected by the Greenland Institute of Natural Resources during cruises with R/V Paamiut using the same instrumentation have gone through the same calibration and quality check.

All quality-controlled data are stored in the Marine Database at the Danish Meteorological Institute from where copies have been sent to ICES and MEDS.

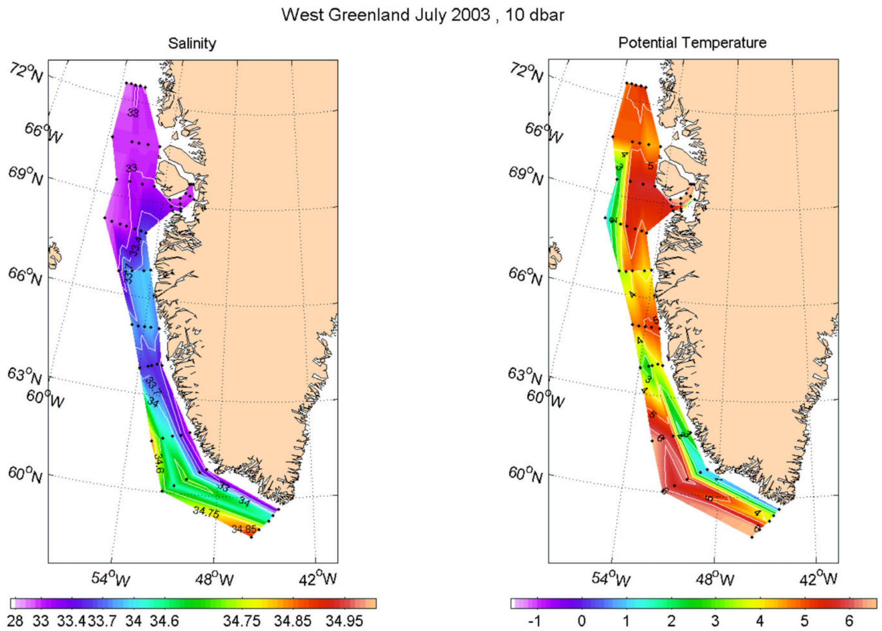

Figure 10. Salinity and temperature at 10m from late June/early July 2003 south of Sisimiut and from mid July/early August north of Sisimiut (section near 67°N).

4. Oceanographic conditions off West Greenland in 2003

The surface temperatures and salinities observed during the 2003 cruise are shown in Figure 10. The cold and low salinity conditions observed close to the coast off Southwest Greenland reflect the inflow of Polar Water carried to the area by the East Greenland Current. Water of Atlantic origin (T> 3°C; S> 34.5) is found at the surface at the two outermost stations on the Cape Farewell Section, at the mid and outermost station on the Cape Desolation section and on the outermost station on the Paamiut section.

The surface salinity seems in general to be close to normal, except for the innermost stations on the southern sections where the surface salinities are higher than normal. This indicate low inflow of Polar Water, which additionally is seen by the lack of "Storis" west of Greenland at this time of the year (Figure 9). In general the concentration of "Storis" measured in 2003 was extreme low.

The vertical distribution of temperature, salinity and density at sections along the West Greenland coastline is given in Figure 12–Figure 26. In addition to data from the six standard sections obtained during the AGPA cruise in early July, data further north from Sisimiut up to Upernavik obtained during the R/V PAAMIUT cruise in mid July/early August are shown.

Temperature and salinity observations at greater depth showed that pure Irminger Water (T ~ 4.5°C, S > 34.95) was present at the Cape Farewell section up to the Fylla Bank section, where it was seen as a small blob at the outer section. Modified Irminger Water (34.88 < S < 34.95) was traced up to the Sisimiut section.

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In the surface layer (0–100 m) week gradients between the cold, low-saline Polar Water and the warm, high-saline water of Atlantic origin was observed. This indicates a low intensity in the East Greenland Current component but a normal or high inflow of water of Atlantic origin, as pure Irminger Water are seen up to the Fylla Bank section.

Normally there is a very pronounced core of Polar Water, revealed by its low temperatures, just west of Fylla Bank at depth of 50–100 m, but in 2003 this core was hardly recognizable i.e. another sign of reduced inflow of Polar Water in 2003. The core was even more absent than in 2002 (for 2002 condition, see Buch and Ribergaard, 2003).

From the Sisimiut section up to the Upernavik section Polar Water originating from the Baffin Current are seen in the upper 100m as a very cold watermass with extreme cold temperatures around 75m. This watermass enters the Baffin Bay from the Arctic ocean through the Canadian Archipelago flowing southward at the Canadian side. At the Davis Strait part of this water crosses the strait moving northward at the Greenland side of the Baffin Bay. As this watermass is only located on the outer stations, and the salinity is slightly lower than at the stations closer to the coast (see also Figure 10), this water is not just entirely winter cooled surface water. The low saline surface water north of Disko Bay close to the coast is fresh water from the Disko Bay (Figure 10).

As usual parts of the Irminger Water recirculate in a cell from just north of Paamiut to the south of Cape Farewell (see e.g. Jakobsen et at., 2003). At Paamiut this recirculation is easily seen as a doming up of isolines for density with Pure Irminger Water both at station 3 (northward) and 5 (southward). The same overall pattern is seen at the Cape Farewell section. This cell was much more pronounced in 2003 than in 2002 as the inflow of Irminger Water was higher in 2003 compared to 2002.

The week inflow of Polar Water can be explained by the wind field. As mention in chapter 1. the wind anomaly over Denmark Strait was towards northwest and north of the strait towards north. This most likely caused a reduction of the strength of the East Greenland Current and thereby reducing the inflow of cold and fresh water towards south Greenland. At the same time the displacement of the low caused the windstress anomaly over large parts of the North Atlantic to be toward northwest and thereby strengthen the Irminger Current component, by enhancing the barotropic flow following the isobaths around Reykjanes Ridge into the Irminger Basin.

Finally, the direct heating of the surface waters east of Greenland by the atmosphere was most likely higher than normal in 2003, as the wind anomaly along East Greenland is generally from southwest into the Irminger Sea, i.e. from warmer environments dominated by the relative warm Atlantic Water. North of Denmark Strait the wind anomaly continues from south towards north. This could have altered the amount of sea ice seen at Cape Farewell.

5. Fjords around Sisimiut

The hydrography in fjords is to a large extent determinated by the land runoff of fresh water in the surface and at the inflow near the bottom at the mouth of the fjord (see Figure 11). Often fjords have a sill at the opening to the open ocean and it is the depth of this sill that determinate which watermass is allowed to enter near the bottom. Above sill depth water can freely flow either in or out of the fjord. At the surface the current are often directed out of the fjord caused by the runoff of fresh water, which will increase the sea level in the fjord. Thereby a pressure gradient is established and surface water will flow out of the fjord. Normally this surface water will entrain water from below. To compensate for this entrainment, inflow is taking place at the bottom as sketched in Figure 11.

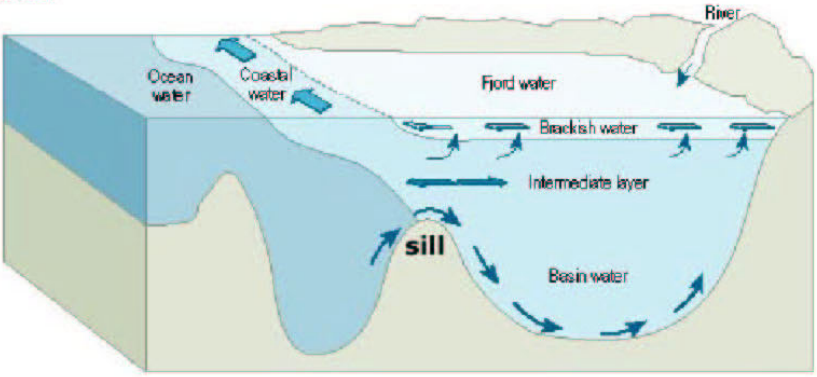

Figure 11. Sketch of the circulation in a fjord (modified from http://www.amap.no/maps-gra/show.cfm?figureId=58).

In the West Greenlandic fjord basically three different kinds of waters exists:

- Relative warm and saline waters of Atlantic origin (mixed Irminger Water).
- Cold and relative fresh water of polar origin (mixed Polar Water).
- Fresh surface water from land, either as melting of the Greenland Ice Sheet or from precipitation (surface water). The amount of this water is highly variable depending on the time of the year. The water is mixed with the surrounding surface waters, which is Polar Water. This mixing is continues going on along the coast, and the watermass stays close to the coast. In the following it is named Coastal Polar Water.

Four fjords around Sisimiut were investigated (Figure 8). They represent two very different types of fjords: two with deep sills (Amerdloq and Ikertoq) and two with shallow sills (Kangerdluarssuk and Qeqertalik). Section plot of the two fjords with deep sills are shown in Figure 27 and Figure 28. As both Qeqertalik fjord and Kangerdluarssuk fjord have a common sill, they should be regarded as one single fjord system Kangerdluarssuk (Figure 29). None of the fjords are directly connected to the Greenland ice sheet, and so the fresh water supply added are limited to runoff from land. The fresh water added is of minor importance as can be seen directly from a topographic map, but also by the fact, that almost no fresh water measured at the surface.

In the two deep sill fjords, Amerdloq and Ikertoq fjord, the conditions are different (Figure 27 and Figure 28). The sill depth of Amerdloq fjord is about 180m and about 150m in the Ikertoq fjord. These sill depths allow relative warm and saline waters of Atlantic origin to enter the fjords close to the bottom. The density is higher than the Coastal Polar Water above, even at the freezing point of the Coastal Polar Water. Thereby winter convection to the bottom is prevented. The bottom water up to about 150m from the surface remain saline and "warm" (2-3°C). In the upper 150m the salinities are almost homogenous whereas the temperature was coldest just above the interface between the diluted Irminger Water and the Coastal Polar Water. This cold water are likely a result of winter convection of Coastal Polar Water, as this cold water is not seen outside the fjord or in the Sisimiut section (Figure 17). It could also be some

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Coastal Polar Water entered from outside earlier of the year. Close to the surface a thin warm layer is found caused by the sun heating.

In the Kangerdluarssuk fjord with a shallow sill (sill depth about 50m, Figure 29) the whole bottom layer below sill depth are filled with Coastal Polar Water and the salinity are very homogeneous. During winter the Coastal Polar Water are cooled and undergoes convection. As the water inside the fjord have homogenous salinities the whole water column are gradually cooled by winter convection and the water become totally homogenous (neutral stability). Therefore cold temperatures are measured below sill depth. At the surface relative warm water is found caused by the solar radiation during spring and summer.

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6. Conclusions

The oceanographic conditions off West Greenland during the summer 2003 was characterised by:

- NAO index was for the second year very close to zero, but the center of the low and high was displaced towards southwest and central Europe (northeast) respectably.
- Northwest-ward anomaly in the wind component over the Iceland Basin, the eastern Irminger Basin and in the Denmark Strait.
- Anomaly warm air to East Greenland.
- Weakening East Greenland Current through Denmark Strait caused by the local wind stress.
- Nuuk air temperature was lower than in 2002 but still close to average.
- Medio June water Temperature on top of Fylla Bank about 1°C above average, while the salinity were close to average.
- Week inflow of Polar Water and normal inflow of Irminger Water reflected by the facts that:
    - the concentration of "Storis" was very small.
    - Cold core of Polar Water could hardly be distinguished at Fylla Bank.
    - the gradient between the two water masses observed was week.
    - Relative high salinities and temperatures of the surface Polar Water close to south west Greenland.
    - pure Irminger Water could be traced up to the Fylla Bank section and Modified Irminger Water could be traced up to the Maniitsoq section.
    - The temperature on top of Fylla Bank was high even though the mean air temperature was normal and the salinity was close normal.

13

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Jakobsen, P.K., Ribergaard, M.H., Quadfasel, D. and Schmith, T., 2003. The near surface circulation in the Northern North Atlantic as inferred from Lagrangian drifters: variability from the mesoscale to interannual. *Journal of Geophysical Research*, **108** (C8), 3251, doi:10.1029/2002JC001554.

Schlitzer, R., 2003. Ocean Data View, http://www.awi-bremerhaven.de/GEO/ODV.

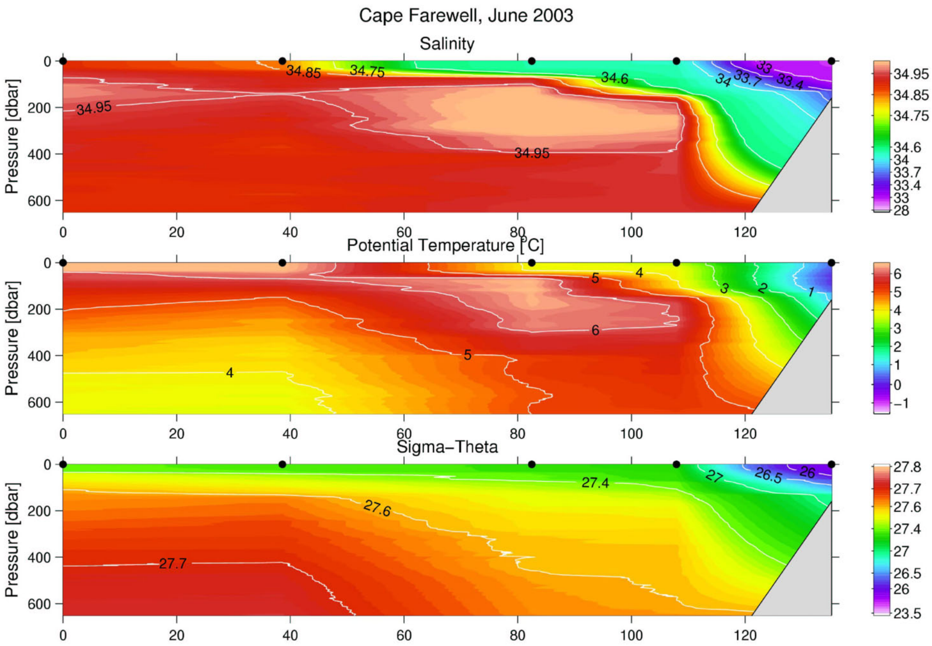

Figure 12. Vertical distribution of temperature, salinity and density at the Cape Farewell section, June 29, 2003.

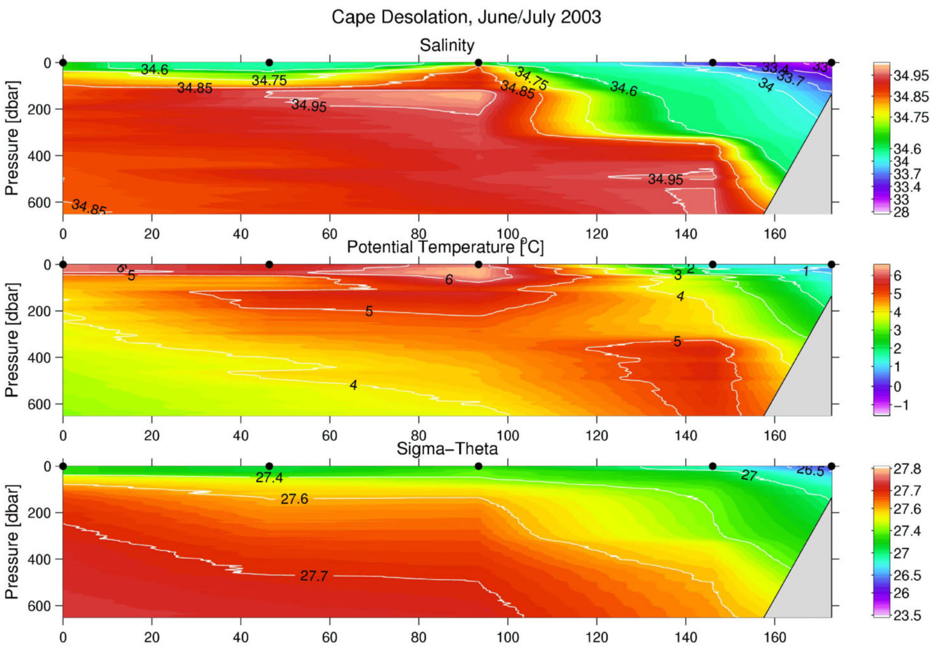

Figure 13. Vertical distribution of temperature, salinity and density at the Cape Desolation section, June 30–July 1, 2003.

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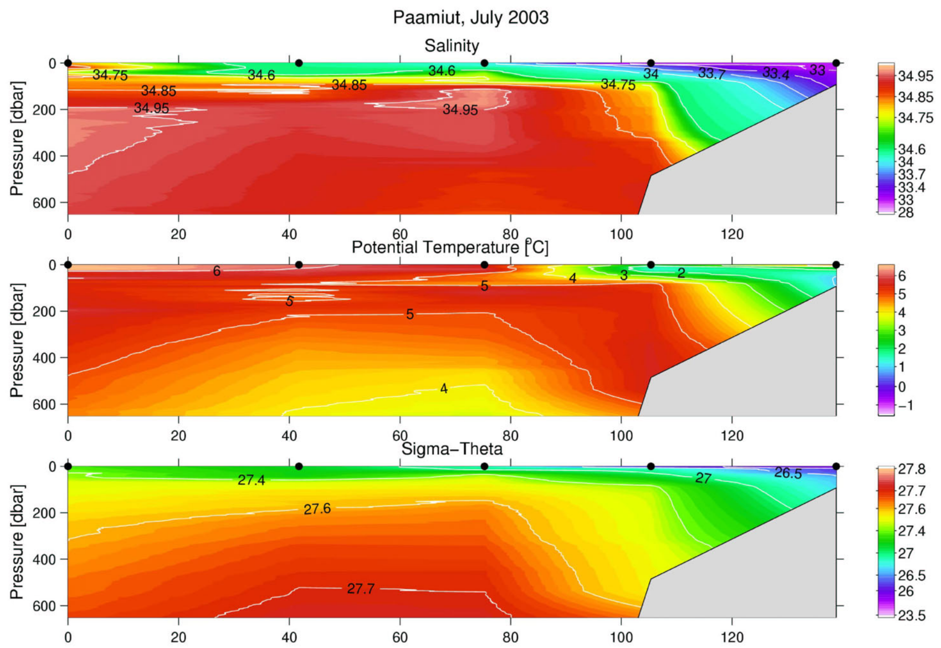

Figure 14. Vertical distribution of temperature, salinity and density at the Paamiut (Frederikshaab) section, July 1, 2003.

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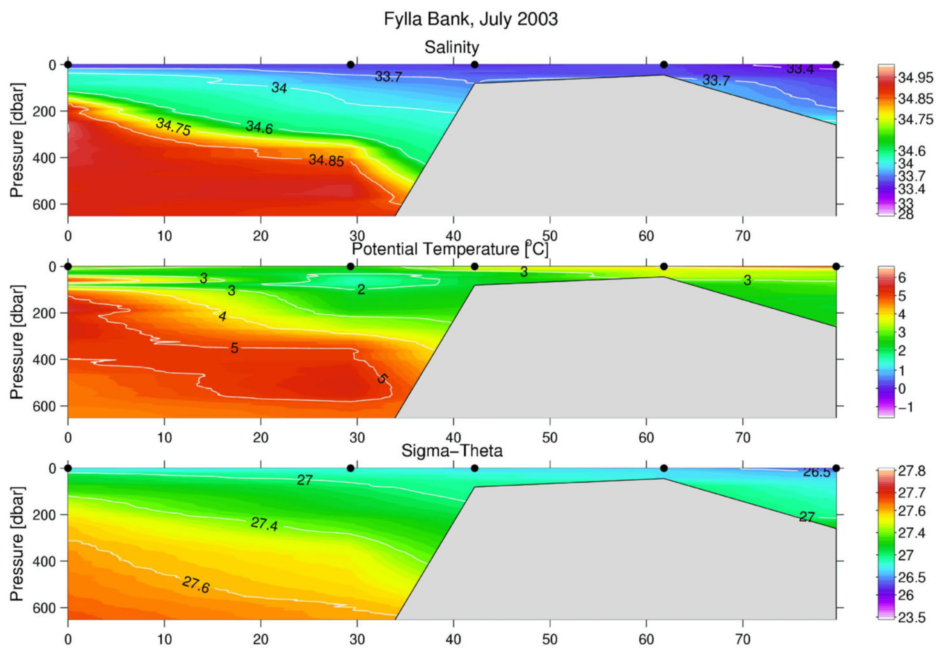

Figure 15. Vertical distribution of temperature, salinity and density at the Fylla Bank section, July 2, 2003.

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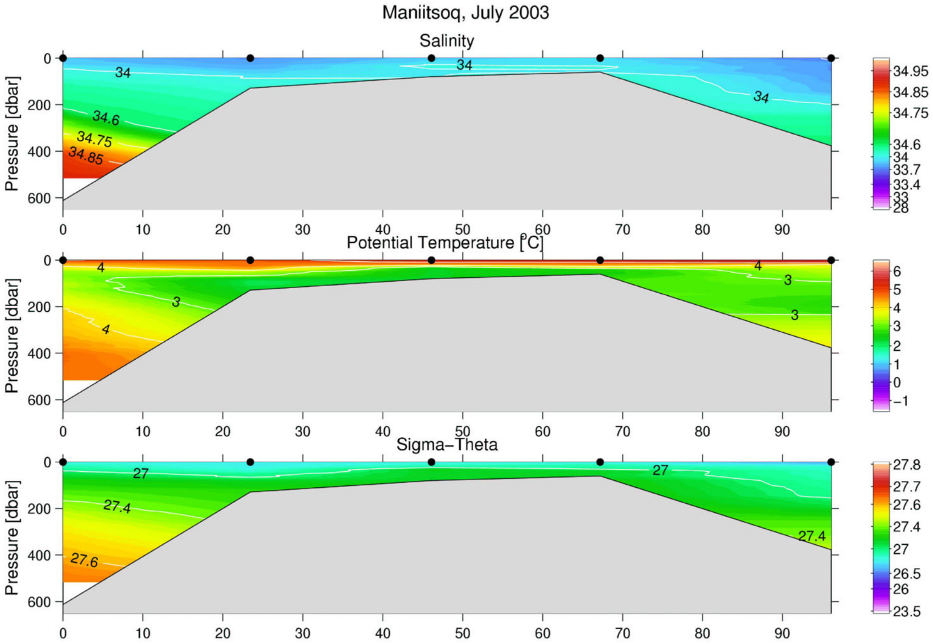

Figure 16. Vertical distribution of temperature, salinity and density at the Maniitsoq (Lille Hellefiske Banke, Sukkertoppen) section, July 4, 2003.

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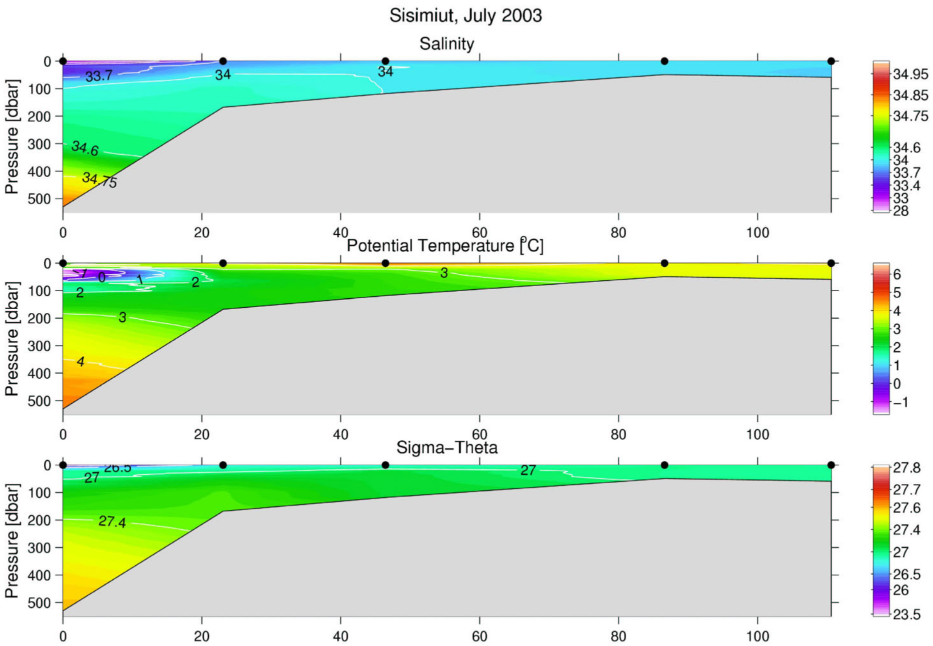

Figure 17. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, July 4–5, 2003.

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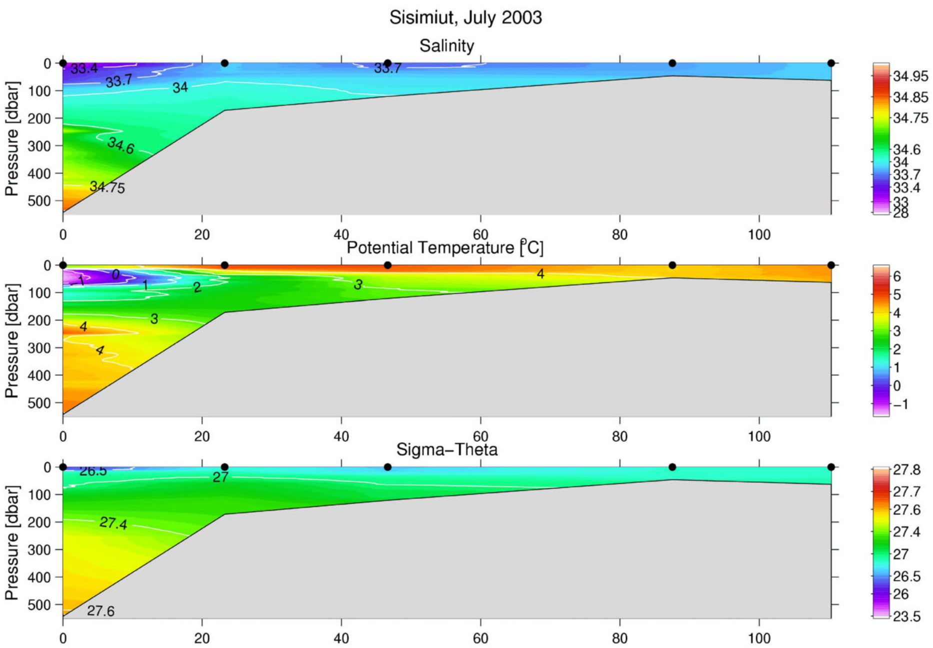

Figure 18. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, July 11–12, 2003.

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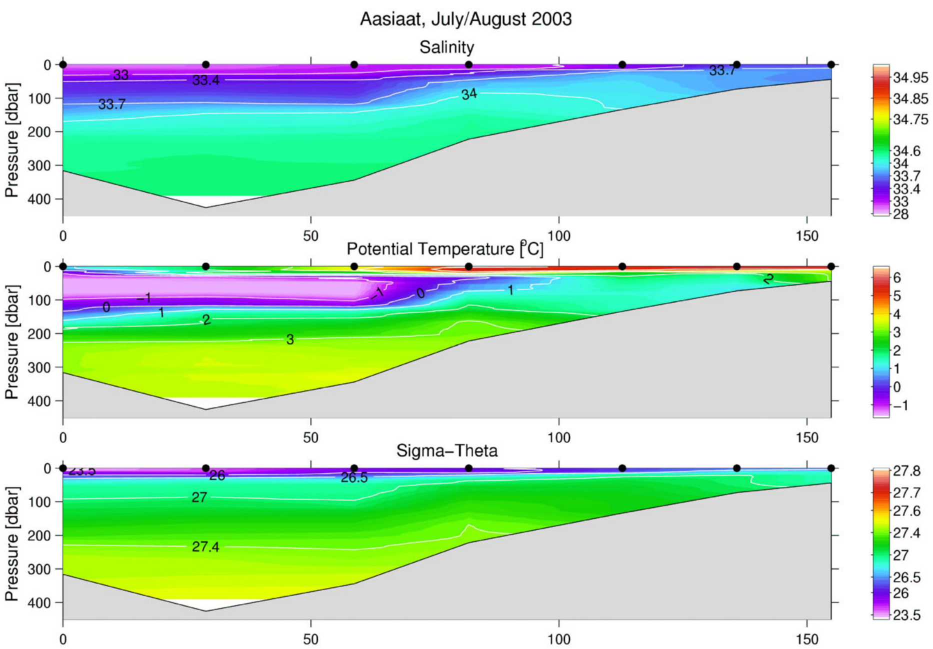

Figure 19. Vertical distribution of temperature, salinity and density at the Aasiaat section, July 14–16, 2003 and August 6–8, 2003 (3 deepest).

22

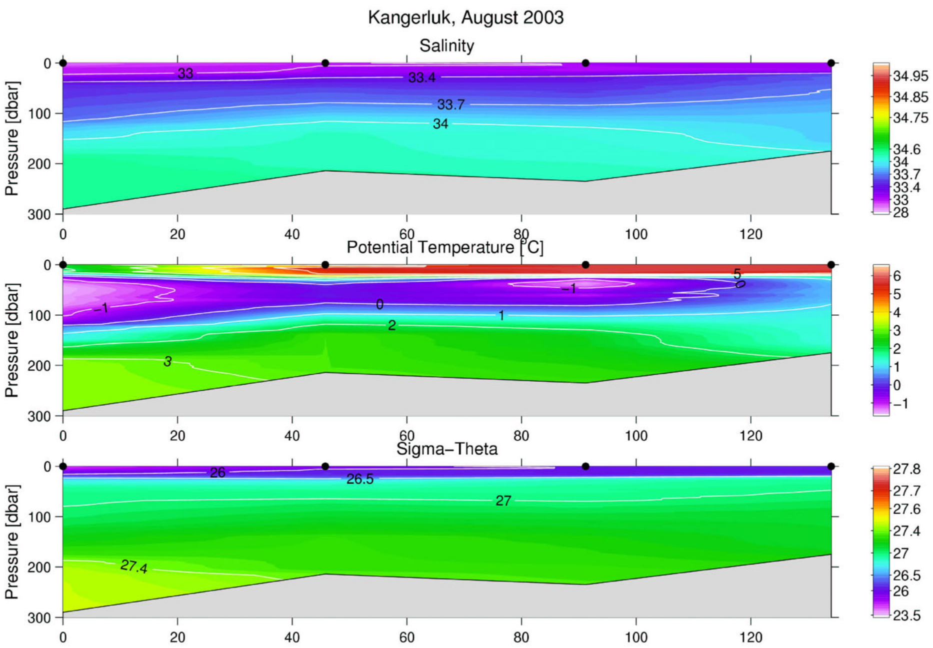

Figure 20. Vertical distribution of temperature, salinity and density at the Kangerluk (Disko Fjord) section, August 1–2, 2003.

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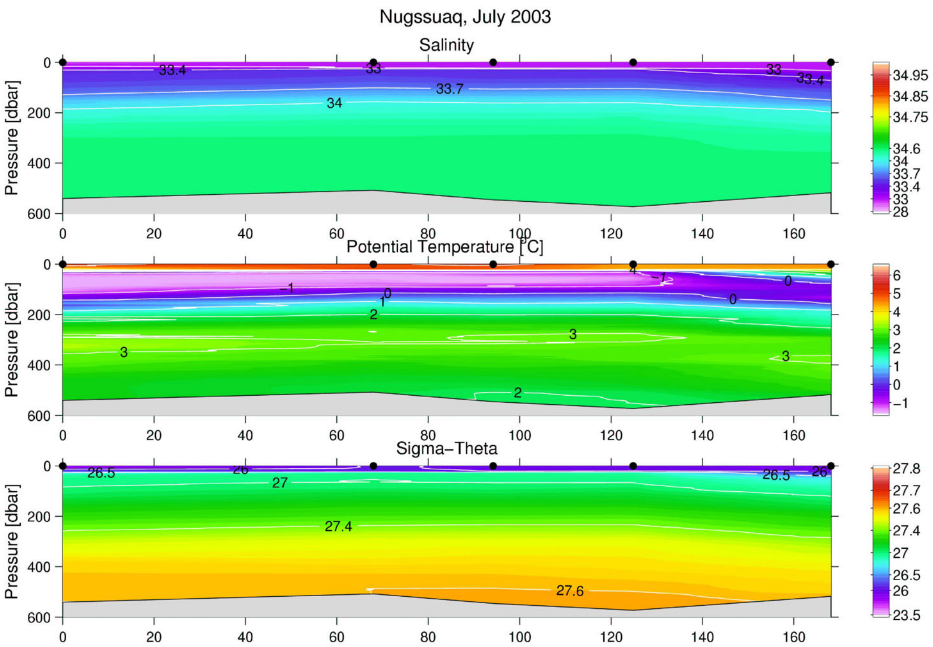

Figure 21. Vertical distribution of temperature, salinity and density at the Nugssuaq section, July 27–31, 2003.

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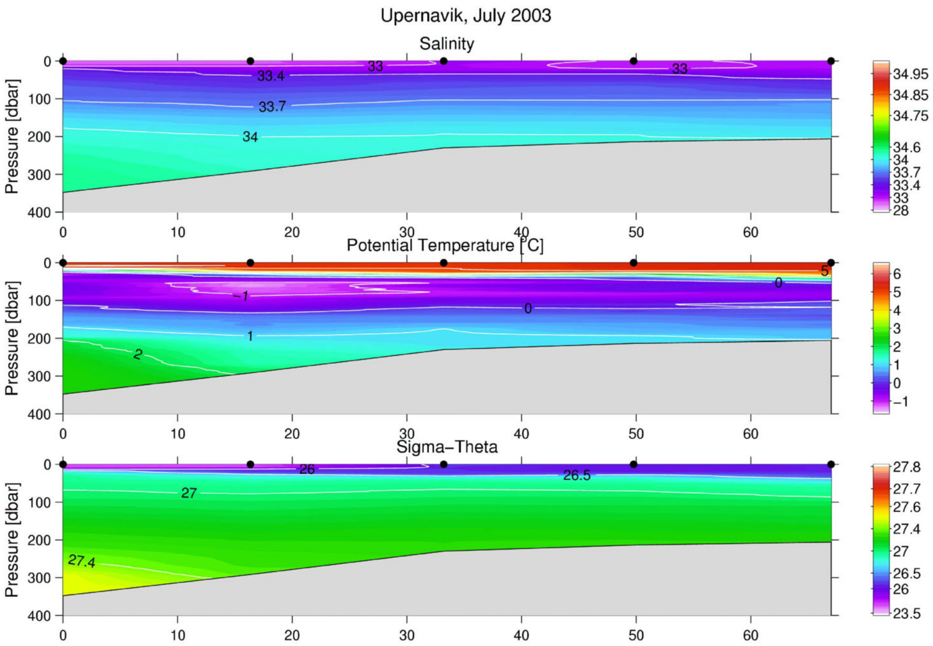

Figure 22. Vertical distribution of temperature, salinity and density at the Upernavik section, July 30–31, 2003.

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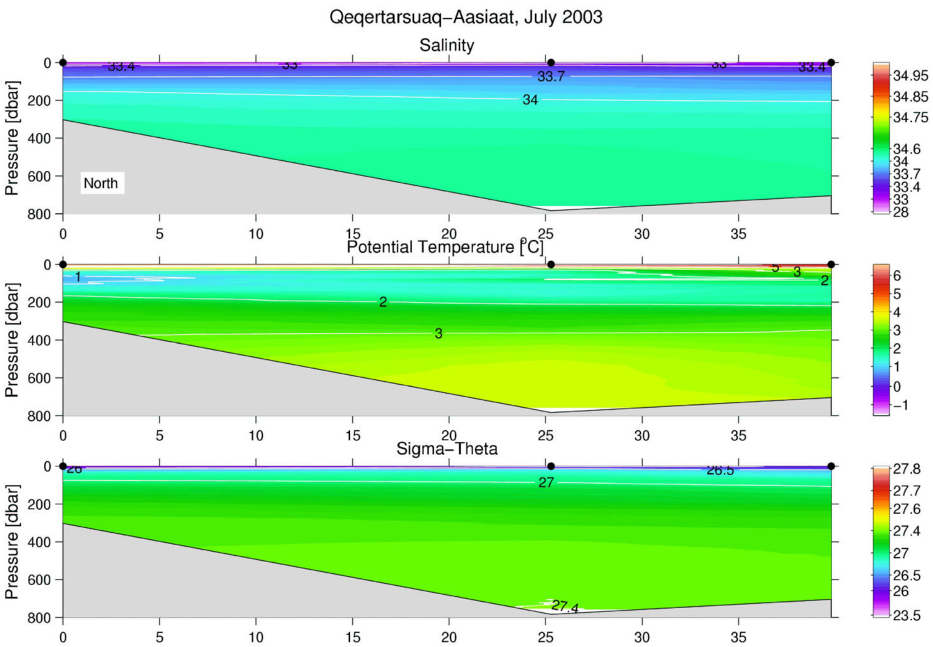

Figure 23. Vertical distribution of temperature, salinity and density at the Qeqertarsuaq–Aasiaat (Godhavn–Egedesminde) section, July 24, 2003.

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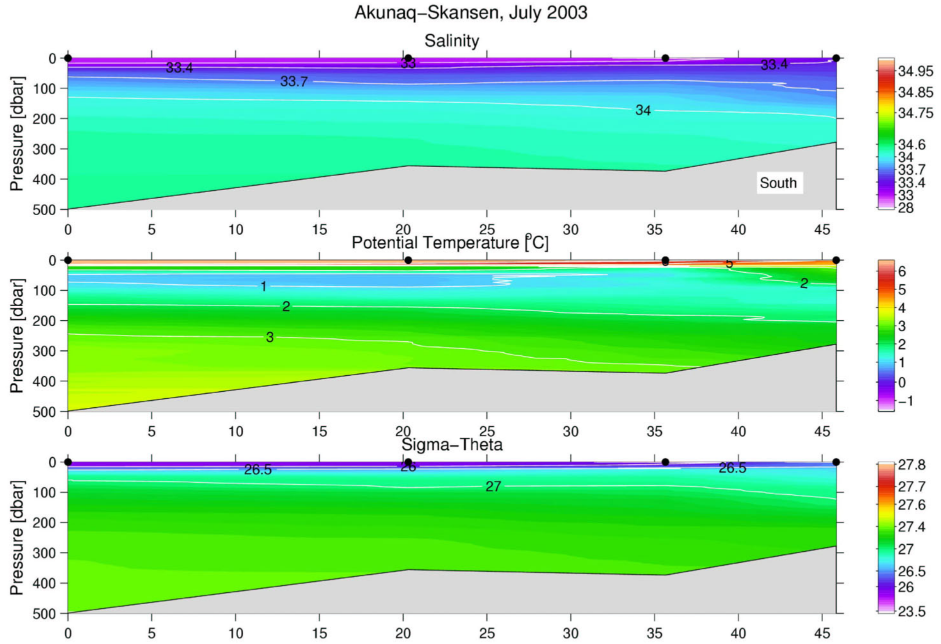

Figure 24. Vertical distribution of temperature, salinity and density at the Akunaq–Skansen section, July 22–23, 2003.

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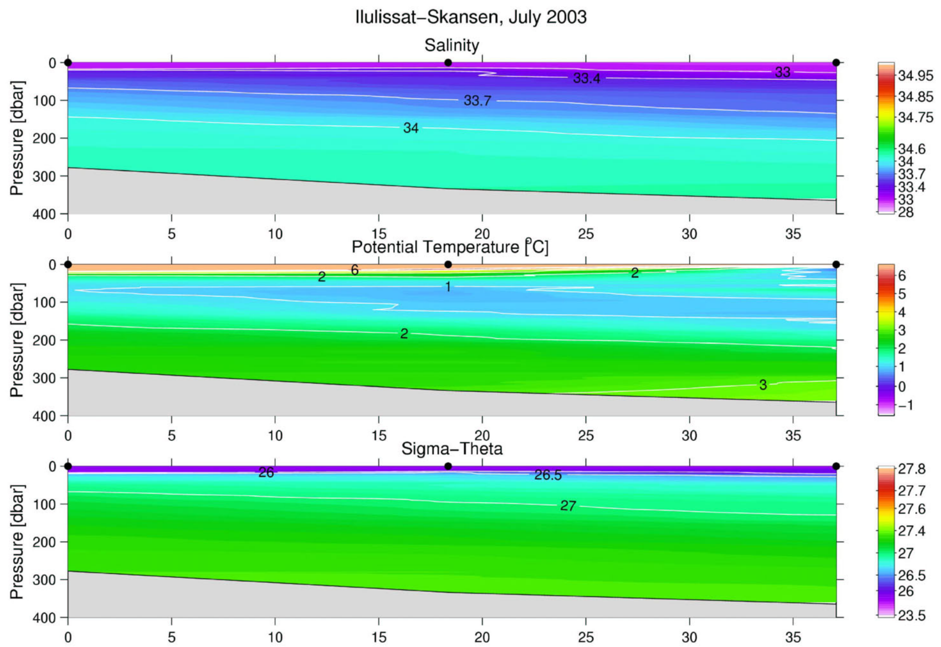

Figure 25. Vertical distribution of temperature, salinity and density at the Ilulissat–Skansen (Jakobshavn-Skansen) section, July 23–24, 2003.

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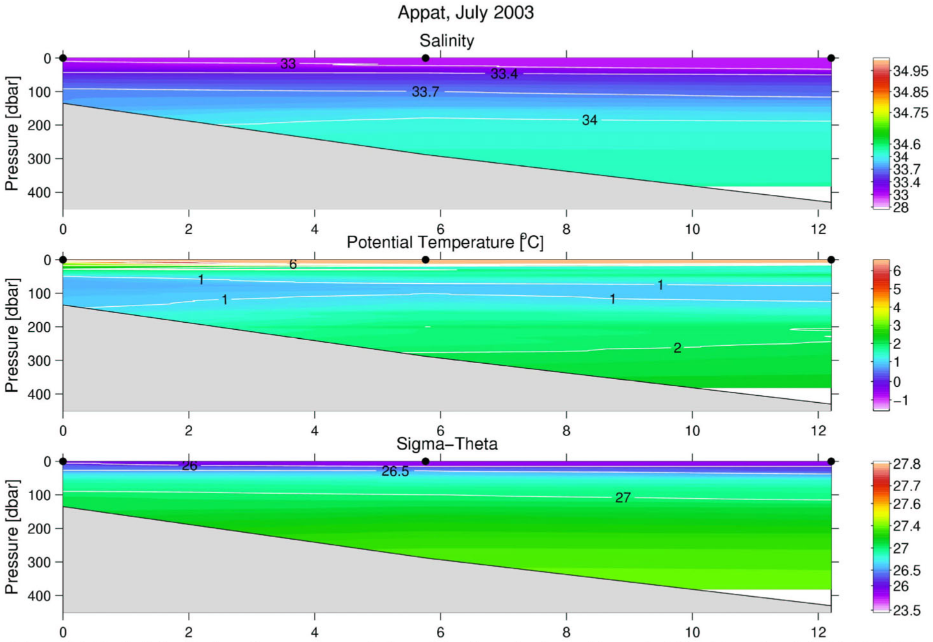

Figure 26. Vertical distribution of temperature, salinity and density at the Appat (Arveprins Ejlande) section, July 23–24, 2003.

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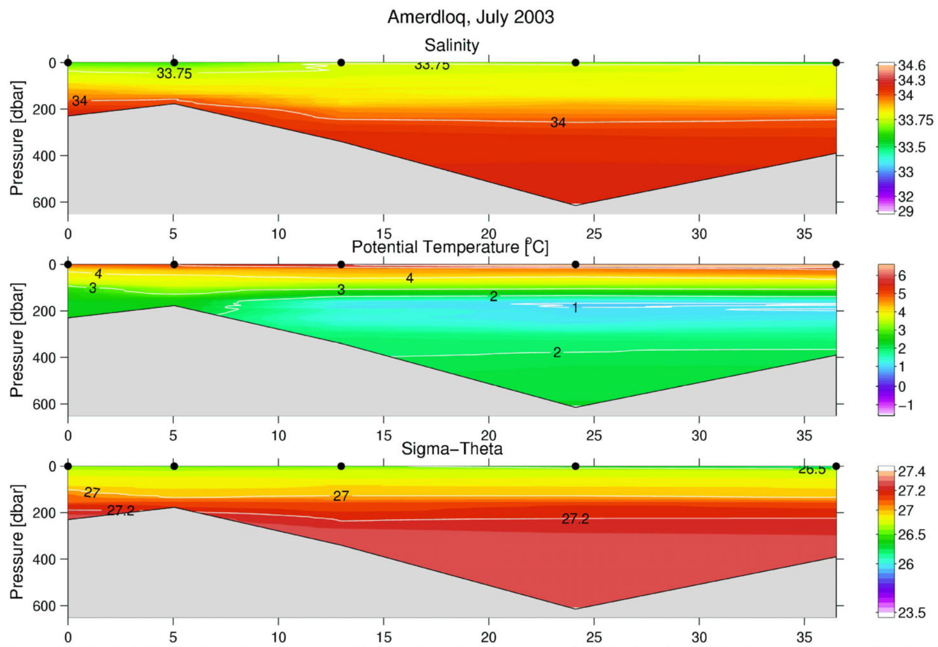

Figure 27. Vertical distribution of temperature, salinity and density at the Amerdloq fjord, July 6, 2003. St.1 (left) south of the fjord.

30

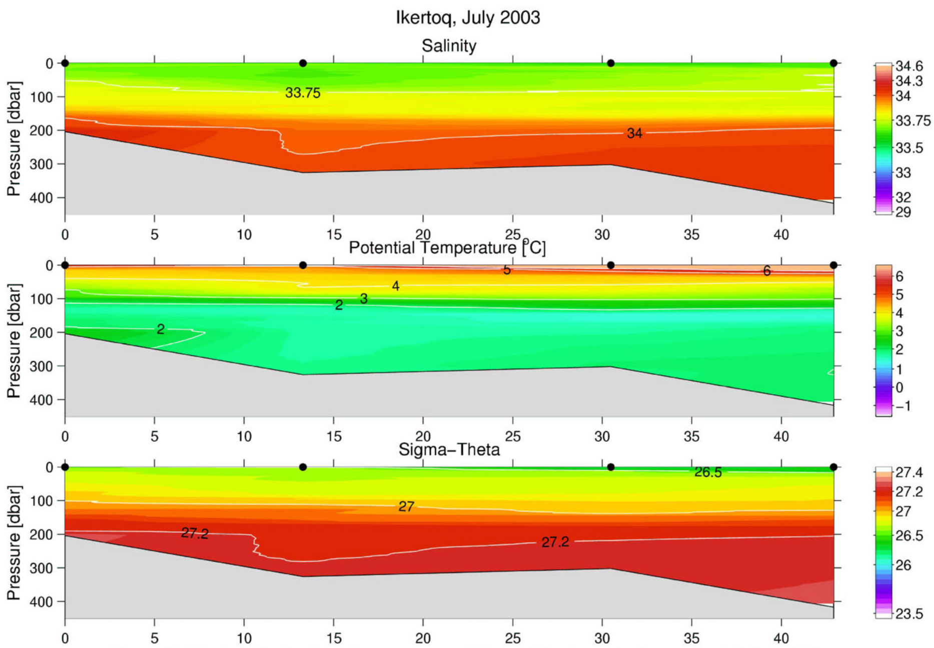

Figure 28. Vertical distribution of temperature, salinity and density at the Ikertoq fjord, July 5, 2003.

31

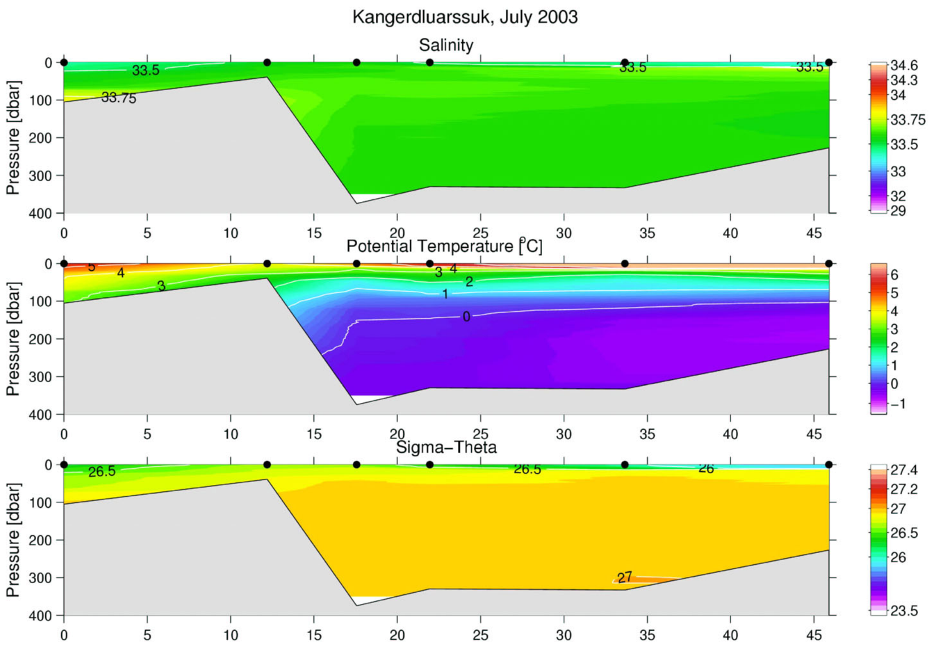

Figure 29. Vertical distribution of temperature, salinity and density at the Kangerdluarssuk fjord, July 5, 2003. Properties of Qeqertalik are very similar to the inner Kangerdluarssuk as they have common sill.

32

Annex G: Climatic conditions off west Greenland – 2003 (Area 1)

M. Stein

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Text

The pattern of sea level atmospheric pressure over the North Atlantic was anomalous during winter 2002/2003. In contrast to previous winters (1999-2001), the pressure anomaly fields during this winter differed considerably from a dipole pattern which is usually present in the North Atlantic region, with two pressure anomaly cells, one in the Icelandic Low area, the other in the Azores High area. As a consequence of this unusual anomaly pattern, the North Atlantic Oscillation (NAO) index for the winter 2002/2003 was weak and positive (0.07). Air temperature climatic conditions around Greenland continued to be warmer-than-normal and were record high. The climatic conditions at Nuuk are consistent with the NAO index (negative index=mild climate).

Warmer-than-normal conditions were observed around Greenland during most of the year 2003 with mean air temperatures at Nuuk indicating positive anomalies (+2.0K). The distribution of sea ice in the waters around Greenland was favourable. Subsurface oceanographic data from Fyllas Bank performed from board the German RV "Walther Herwig III" reveals considerable warming in the upper 200m of the water column during autumn 2003. Cold "polar events" during 1983, 1992 and 2002 characterise the long term ocean temperature time series. There is **no** significant correlation between variations of water temperature anomalies and variations of NAO index. The correlation found is negative and the correlation coefficients are r = –0.33 for the 0-50m layer, and r = –0.35 for the 0-200m layer. Irminger Water was found off Cape Desolation and at Fyllas Bank during autumn 2003. In the near-bottom water layer off Cape Desolation/West Greenland, at about 3000m depth, the Denmark Strait Overflow water mass was observed with salinities of 34.865, a value that was maintained since the year 2000.

Figures and Captions

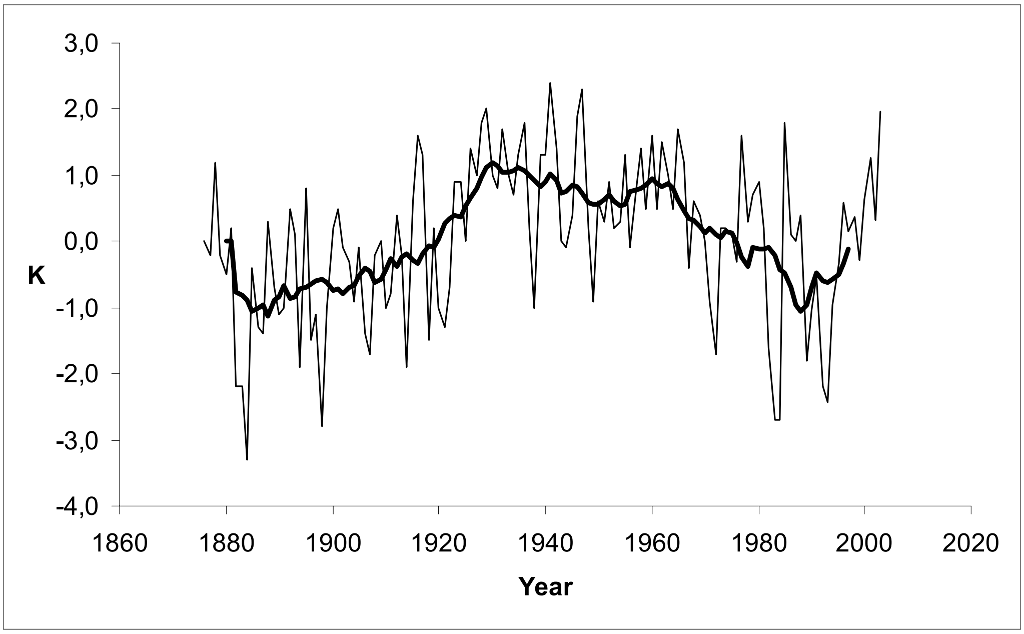

Figure. 1. Time series of annual mean air temperature anomalies at Nuuk (1876–2003, rel. 1961-90), and 13 year running mean.

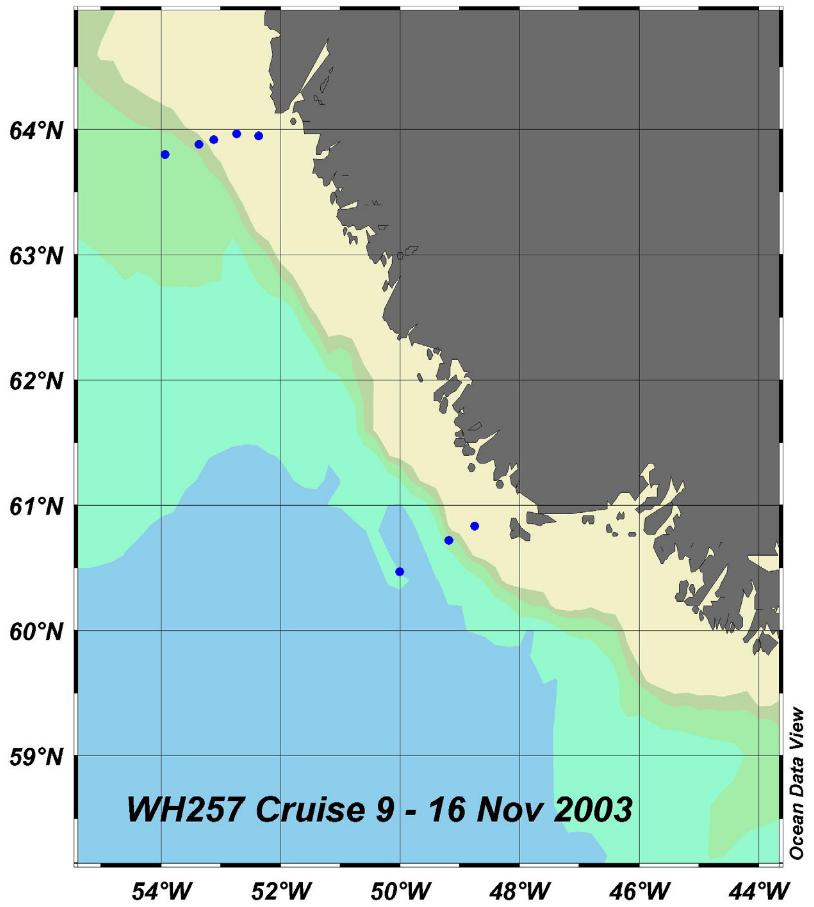

Figure 2 Positions of sampled NAFO Standard Stations and Sections (9–16 November 2003)

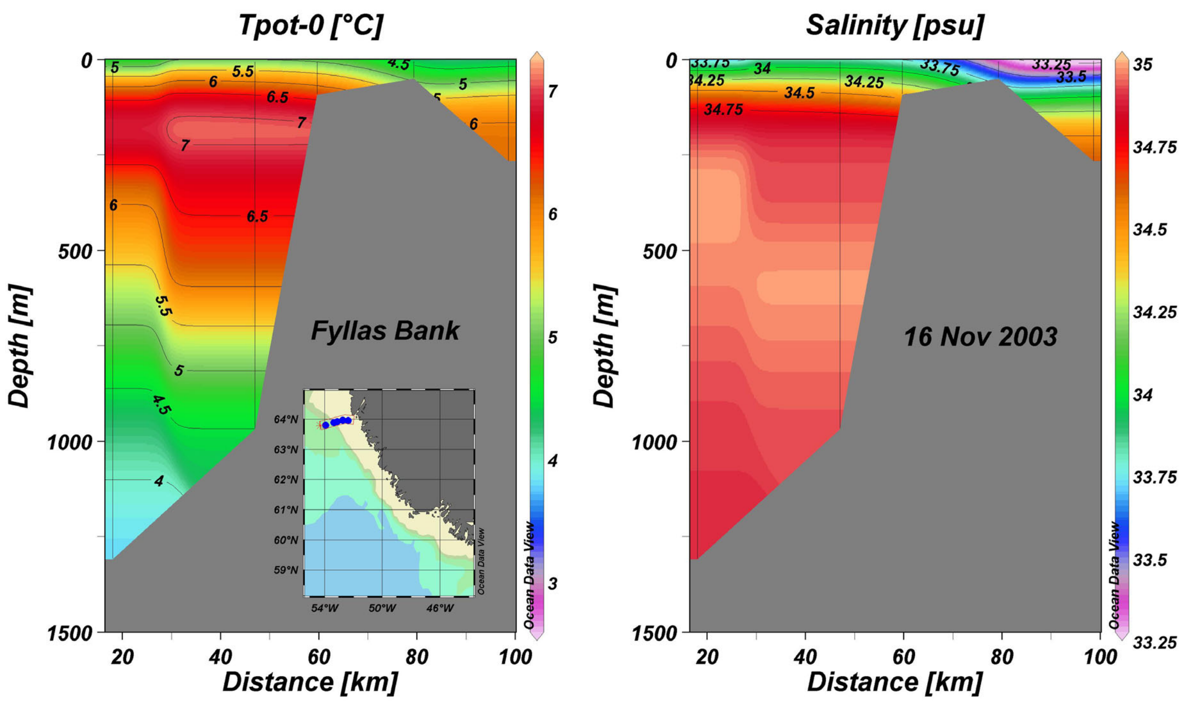

Figure 3 Potential temperature and salinity along Fyllas Bank Section (16 November 2003)

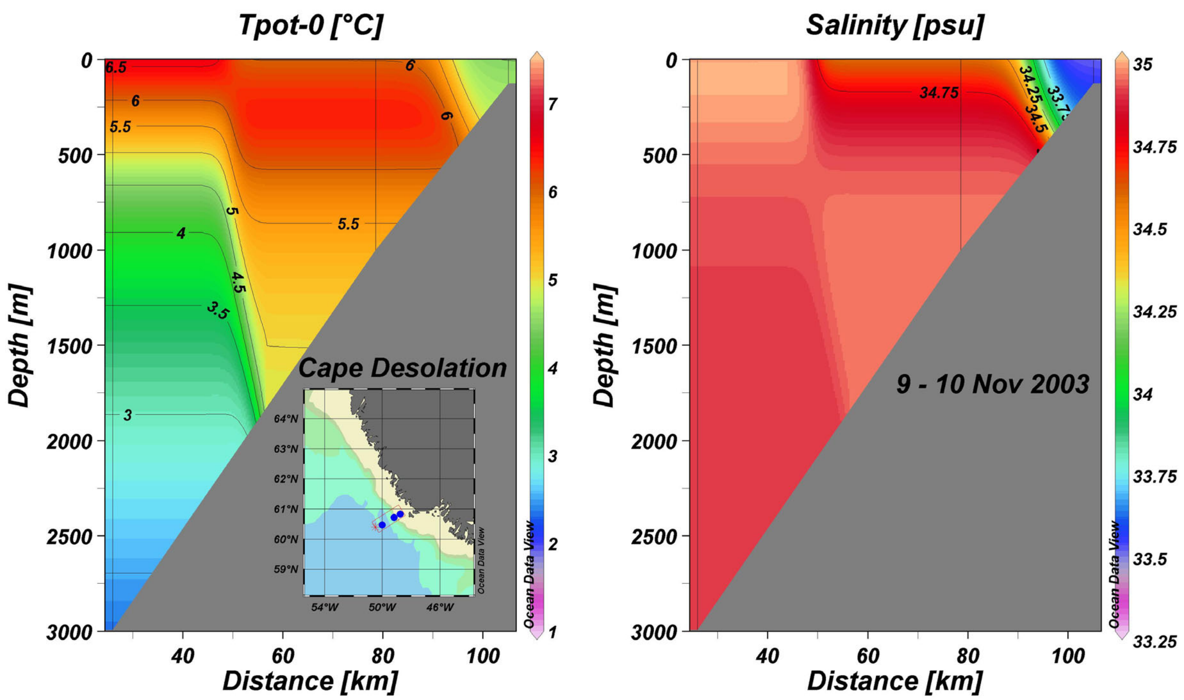

Figure 4 Potential temperature and salinity along Cape Desolation Section (9–10 November 2003)

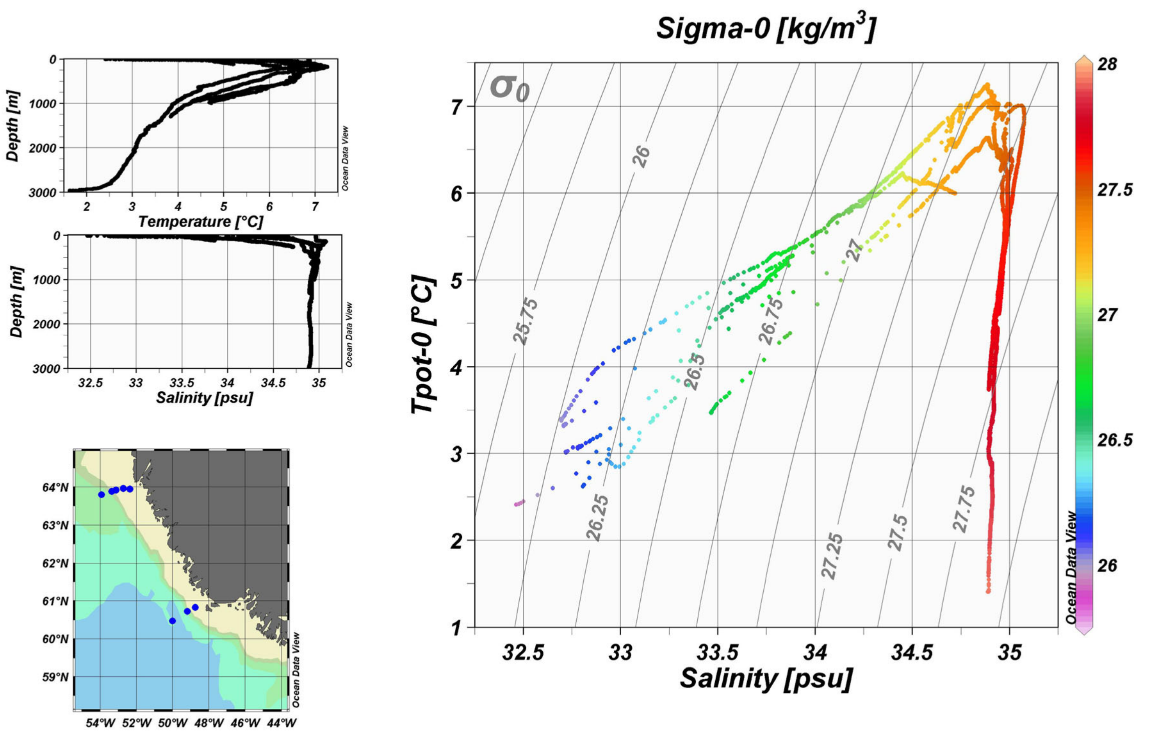

Figure 5. Theta/S diagram of station profiles indicated in Figure 2.

Figure 6. Mean temperature anomalies of water layer 0-200m at station 4 of the Fyllas Bank Section, "polar events"1983, 1992, 2002; data 1980-2003 (dashed: NAO Index).

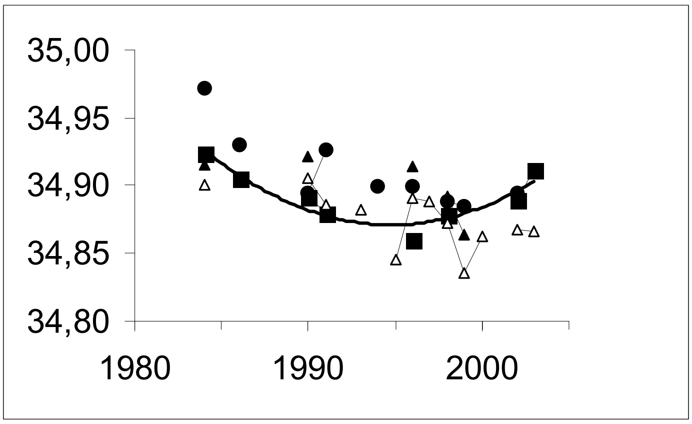

Figure 7. Salinity of calibration samples at Cape Desolation Section station 3 (60°28'N, 50° 00'W; data: 1984 - 2003); a quadratic polynomial was applied to the calibration data at 1500m depth (r^2=0.87, $p < 0.05$); 1500m: squares, 2000m: circles, 2500m: triangles, 3000m: open triangles.

Annex H: Labrador Sea (Area 2B)

ANNEX H: LABRADOR SEA (AREA 2B).

R.M. Hendry and R.A. Clarke

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Summary

Ocean Sciences Division, DFO Maritimes Region has monitored hydrographic properties on the AR7W line across the Labrador Sea in the early summer of each year since 1990. The most recent AR7W survey took place in July 2003.

The central Labrador Sea experienced milder than normal winters in the three years up 2002-2003, based on NCEP Reanalysis heat fluxes.

Hydrographic conditions in the Labrador Sea have been relatively stable over the past three years. The upper waters (0-1000 m) of the west-central Labrador Sea were slightly warmer, saltier, and less dense in July 2003 than in July 2002. Warm and saline Irminger Water was more abundant in the central Labrador Sea in July 2003 than in July 2002. Intermediate depths (1000-2000 m) remained warm and salty in mid-2003 compared with conditions in the early 1990's, but showed a slight decreasing trend in salinity. The net changes still gave the warmest and saltiest upper 2000 m observed in the past fourteen years of regular annual surveys.

In spite of the relatively mild recent winter conditions, there is evidence of enhanced convective renewal to depths of 1000 m and greater in the west-central Labrador Sea during the past two winters. This has resulted in a noticeable accumulation of water with potential temperature near 3.2°C, salinity near 34.83, and potential density anomaly near 27.73 kg m^{-3}.

Figure 1 shows a map of the Labrador Sea with AR7W station positions occupied in July 2003 on CCGS Hudson Cruise 2003-038.

The Labrador Sea

Hydrographic conditions in the Labrador Sea depend on a balance of atmospheric forcing, advection, and ice melt. Wintertime heat loss to the atmosphere in the central Labrador Sea is offset by warm waters carried northward by the offshore branch of the West Greenland Current. The excess salt accompanying the warm inflows is balanced by exchanges with cold, fresh polar waters carried by the Labrador Current, freshwater from river run-off, and ice melt. Atmospheric forcing plays a relatively small role in the mean freshwater balance of the Labrador Sea compared with advective effects.

Wintertime cooling and evaporation increase the density of surface waters in the central Labrador Sea. Wind mixing and vertical overturning form a mixed layer whose depth increases through the cooling season. The winter heat loss, the resulting density increase, and the depth to which the mixed layer penetrates vary with the severity of the winter. The density of the mixed layer and the depth of convection depend critically on the salinity of the waters exposed to the atmosphere. In extreme winters, mixed layers deeper than 2000 m have been observed. Labrador Sea Water (LSW) formed by these deeper overturning events spreads throughout the northern North Atlantic. During milder years, the vertical stratification of temperature, salinity, and density is re-established.

Deep convection associated with severe winters in the early 1990's created a pool of new LSW. In the process, the Labrador Sea lost heat to the overlying atmosphere. In the following years mild winters produced relatively shallow convection. Even though the Labrador Sea was still losing heat to the atmosphere over the annual cycle, advective effects led to a net warming of the upper layers. By Year 2000 the heat content of the upper 1000 m had increased to values close to those observed before the onset of deep convection in the early 1990's.

During the restratification phase from 1995 to 2000, intermediate-depth layers that were removed from direct contact with the atmosphere become notably warmer and saltier. Remnants of the earlier deep convection were replaced with warmer and saltier waters of the same density. The replacement waters had properties similar to Irminger Water found along the continental slope southwest of Greenland.

Atmospheric Forcing

On an annual average, the Labrador Sea loses heat to the overlying atmosphere. Monthly-averaged air-sea flux fields produced by the co-operative Reanalysis Project (Kistler et al., 2001) of the U.S. National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) were used to quantify these heat exchanges.

Figure 2(a) shows a time series of anomalies of December-January-February (DJF) average sea-air heat flux near the Bravo mooring site (Figure 1) for the 55-year period December 1948 to February 2003. The wintertime heat flux anomalies are autocorrelated on decadal time scales. Each of the past three winters has yielded lower-then-normal sea–air heat fluxes. The mean DJF heat loss for the 2002-2003 winter was 90 W m^{-2} less than the normal 300 W m^{-2}, a reduction of about 30%.

Figure 2(b) shows a similar time series of anomalies of March-April-May (MAM) average sea-air heat flux near the Bravo mooring site. The springtime anomalies show more high-frequency variability than the DJF anomalies. The past three years have been variable, but the 2003 spring season was apparently severe. The mean MAM heat loss for 2003 was nearly 50 W m^{-2} greater than the normal value of 30 W m^{-2}.

Results from 2003

CCGS Hudson Expedition 2003-038 accomplished the fourteenth annual occupation of AR7W under the scientific direction of R.A. Clarke. The 31 principal AR7W stations were occupied during the period July 23-29, 2003. Light ice conditions allowed complete spatial coverage.

Property distributions in 2003 are illustrated by contoured gridded sections of potential temperature, salinity, potential density anomaly, and dissolved oxygen in Figures 3(a) - 3(d). Along-section distance in kilometres increasing from southwest (Labrador) to northeast (Greenland) is used as the horizontal coordinate.

Notable in the upper levels of Figure 3(a) (potential temperature) are cold waters (<2°C) over the Labrador Shelf. Similarly cold waters in the upper few hundred metres over the outer edge of the West Greenland shelf are associated with the inshore branch of the northward-flowing West Greenland Current. Warmer waters (>4°C) in the upper 500 m of the water column over the West Greenland slope are associated with the offshore branch of the West Greenland Current.

Figure 3(a) shows a seasonal thermocline with a maximum surface temperature of just over 10°C. In the central Labrador Sea at depths between 600 m and 1200 m below the seasonal thermocline, reduced vertical temperature gradients mark recently-formed LSW with potential temperature less than 3.2°C. The LSW layer extends over much of the section, but its thickness is less on the Greenland half of the section than on the Labrador half. Waters in the upper 500 m on the Greenland side are notably warmer than on the Labrador side, showing a greater influenced of the warm Irminger Waters. The deeper Irminger Water influence centred near 1500 m below the LSW creates a layer with potential temperature greater than 3.3°C. An energetic eddy near 800 km is resolved by a single station.

In the salinity section in Figure 3(b), waters in the upper 500 m on the Greenland half of the section are notably saltier than waters in the same depth range on the Labrador half, again showing the Irminger Water influence. Patches of relatively fresh water near 2000 m depth are remnants of the extraordinarily deep convection of the early 1990's.

The potential density anomaly section in Figure 3(c) shows reduced vertical gradients in the recently-formed LSW near 1000 m depths.

The dissolved oxygen section in Figure 3(d) shows a relative maximum in the recently-formed LSW (values greater than 6.8 mL L^{-1}). Seasonal biological processes have reduced the near-surface oxygen values. The deep convection of the early 1990's shows up as a patchy relative maximum in dissolved oxygen near 2000 m depth with values greater than 6.5 mL L^{-1}.

The shallower of the pair of dashed lines near 1000 m depth in Figures 3(a)-3(d) traces a relative minimum in the vertical of potential temperature (< 3.2°C) in the recently-formed LSW. Waters shallower than this layer have been warmed by seasonal surface heating and lateral advection. It is not immediately clear if the relative minimum in potential temperature observed in July 2003 comes from convection during the previous winter, is a cumulative effect of convection during several recent winters, or is a remnant of convection during an earlier winter that was more severe than the most recent winter. This point is discussed below.

The deeper of the pair of dashed lines near 1500 m depth in Figures 3(a) - 3(d) traces a relative maximum in the vertical of potential temperature (generally >3.3°C) marking the core of the intermediate-depth warm, saline layer.

Changes from 2002

Properties observed in July 2003 can be compared to results from July 2002 and December 2002 Labrador Sea campaigns. CCGS Hudson Cruise 2002-032 occupied the AR7W section during July 2-8, 2002 under the scientific direction of Allyn Clarke. CCGS Hudson Cruise 2002-075 covered the entire section during December 1-9, 2002 under the scientific direction of Erica Head. The December 2002 survey was principally devoted to biological studies and the hydrographic program was reduced compared to the summer surveys. Selected stations near the Labrador and Greenland ends of the line were not occupied and measurements were restricted to the upper part of the water column at every other station in waters deeper than about 3000 m.

Figure 4(a) shows average profiles of potential temperature in the upper 2000 m for the four stations in the 320-520 km distance range for the three cruises. Selected standard deviations are also shown. Figure 4(b) shows the same profiles with an expanded temperature scale in the range 3-4°C. This particular distance range is selected to represent the area in the deep west-central Labrador Sea where deep convection has been observed to occur. It excludes the Greenland half of the section where the influence of the warm and saline Irminger Water is greatest.

The near-surface layers in the average profiles are much warmer in July 2003 than in July 2002. The 0-150 m average temperature in July 2003 was about 1.2°C higher than in July 2002. The changes are larger than the climatological seasonal warming over the three weeks between the early-July 2002 and late-July 2003 surveys. Historical Ocean Weather Station Bravo data show a climatological seasonal increase of 0-150 m average temperature by about 0.4°C during the corresponding three-week period. The December 2002 survey shows a 3.8°C mixed layer in the top 120 m, the beginning stages of the development of a deeper and colder winter mixed layer.

From the surface down to about 700 m depths, the July 2003 potential temperature profile shows warmer conditions than the July 2002 profile. Below 700 m the differences are small. Both profiles show similar relative minima in potential temperature of about 3.16°C near 1000 m depth. The December 2002 potential temperature profile shows warmer conditions between the bottom of the surface mixed layer and about 1000 m depth than either July 2002 or July 2003. The warming between July 2002 and December 2002 must be due to horizontal advection, since net seasonal air-sea heat exchange between July and December is small. The upper 1000 m in July 2003 had re-cooled to conditions more similar to those seen in July 2002. This shows that the similarity of the July 2002 and July 2003 profiles in the 500-1000 m depth range is not simply due to persistence. The simplest explanation is that the excess heat observed in December 2002 was removed by convective renewal to depths of at least 1000 m during the winter of 2002-2003. In this scenario, the upper 1000 m must have re-warmed following the winter of 2002-2003 to give July 2003 conditions similar to those seen in July 2002.

Figures 5(a) and 5(b) show average salinity profiles for the same distance range as for Figures 4(a) and 4(b). In general the upper 1000 m are slightly saltier in July 2003 than in July 2002. A superficial low-salinity layer is observed in the upper 40 m in July 2003. The December 2002 profile shows higher salinities in the 200 - 1000 m depth range than seen in July 2002 and July 2003. This corresponds with the warmer conditions in December 2002 noted above.

Figure 6 shows average profiles of apparent oxygen utilisation (AOU) in the upper 2000 m for the July 2002 and July 2003 surveys. Comprehensive oxygen measurements were not made during the December 2002 survey. AOU is defined as the difference between the saturation value of dissolved oxygen concentration at the measured temperature and salinity and the measured dissolved oxygen concentration. It is related to the time elapsed since the water was in contact with the atmosphere, since biological processes tend to reduce oxygen concentration with time. There is a relative maximum in AOU near 1500 m depth in the warm, saline layer influenced by Irminger Waters. AOU values between 500 m and the deep relative maximum from the July 2003 survey are notably lower than seen in July 2002. This supports the notion of a convective renewal of the upper 1000 m during the winter of 2002-2003.

Interannual variability

As an overview of interannual variability from AR7W surveys since 1990, time-series plots of pressure on selected potential density anomaly surfaces from average profiles in the 320-520 km distance range for each cruise as a function of the median station time are shown in Figure 7. This provides an update of Figure 4 in Lazier et al. (2002). The deep convection of the early 1990's is reflected in the 1993-1994 maximum in the separation of the 27.77 and 27.79 kg m^{-3} potential density anomaly surfaces. The volume of water in this potential density range decreased steadily from 1994 to 2000. Since 2000, changes in the separation of these isopycnals have been small. At the same time, there has been an increase in the separation of isopycnals in the 27.72-27.75 kg m^{-3} potential density anomaly range, especially during the past two years. The pressures corresponding to the minimum potential temperature in the 27.72-27.75 kg m^{-3} layer for each survey are noted in Figure 7. The depth of the relative minimum potential temperature shows an increasing trend in recent years. The property values at the relative minimum in potential temperature for 2001-2003 were similar: potential temperature near 3.2ºC, salinity near 34.83, and potential density anomaly near 27.73 kg m^{-3}. This suggests a strengthening cycle of intermediate-depth convective renewal in the west-central Labrador Sea during recent years.

Similar time series of the changes in heat and salt content in various layers from the spring/early summer AR7W surveys are shown in Figures 8(a) and 8(b). Each series is plotted as an anomaly relative to its1994 value. The changes in heat and salt from 1990 to 2000 were discussed by Lazier et al. (2002). A heat gain of 1 GJ m^{-2} for a 2 km column of water is equivalent to an increase in its mean temperature by about 0.14ºC. The same column gains 10 kg□m-2 of salt when its mean salinity increases by about 0.005. Also shown are cumulative sums of NCEP heat and salt changes relative to the normal period defined above.

The seasonal timing of the nominal spring surveys has varied from early May to late July. The 0-150 m depth range in particular shows strong seasonal variability.

The heat content in the 0-1000 m range increased in 2003 compared to the previous year, continuing a 4-year increasing trend. The heat content of the 1000-2000 m layer was nearly identical to the previous year's result. The net result is that the 0-2000 m early-summer 2003 heat content in the west-central Labrador Sea was the highest yet observed in theAR7W surveys. The increasing trend in cumulative NCEP heat anomaly reflects the milder-than-normal winters of the past several years.

The salt content of the 0-1000 m layer shows a more random behaviour than the heat content. Both 0-150 m and 150-1000 m depth ranges show slight increases in 2003 compared with 2002. The salt content of the 1000-2000 m layer in 2003 was slightly less than in 2002, continuing a decreasing trend from a maximum in 2001. The net result is that the mean salinity in the 0-2000 depth range in 2003 was the highest observed in the AR7W survey period.

In general, the observed changes in density are dominated by changes in temperature, with salinity changes playing a secondary role. Figure 8(c) shows anomalies relative to 1994 of layer geopotential differences corresponding to the heat and salt anomalies in Figures 8(a) and 8(b). The recent trend to warm, salty conditions has resulted in a decrease in density, and a corresponding increase in layer geopotential difference or layer buoyancy. The 1999 and 2003 cruise values of geopotential difference between 0 and 2000 decibars (dbar) are nearly equal. Higher salinities in 2003 partly compensate for the record-warm conditions.

Figure 8(c) includes time series of anomalies of surface geopotential at cruise times from 1993 onwards relative to the cruise value in 1994. These were derived from sea level changes near the Bravo mooring site from Mean Sea Level Anomaly (MSLA) fields produced from the combined TOPEX/POSEIDON and JASON 1 altimetric missions. The sea level anomalies have been multiplied by the acceleration due to gravity to convert them to changes in geopotential. The original data were low-pass filtered to remove variations on annual and shorter time scales. Versions with and without a fitted seasonal cycle are shown. In general, there is a close correspondence between the geopotential changes associated with density changes in the 0-2000 dbar layer and those due to sea level change.

Acknowledgments

The data from the NCEP Reanalysis were provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/.

The MSLA products altimeter products used were produced by the French AVISO/Altimetry operations centre at the CLS Space Oceanography Division.

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Lazier, J., R. Hendry, A. Clarke, I. Yashayaev. and P. Rhines. 2002. Convection and Restratification in the Labrador Sea, 1990-2000. Deep Sea Research,. 49: 1819-1835.

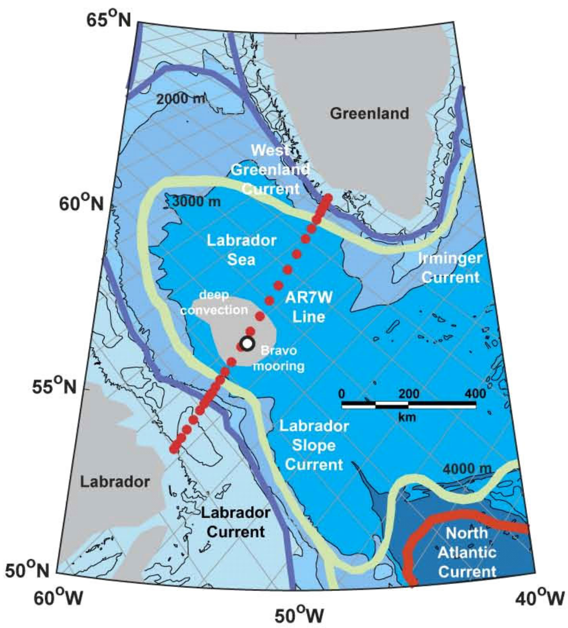

Figure 1 Map of the Labrador Sea showing AR7W station positions for CGCS Hudson Cruise 2003-038 superimposed on a schematic surface circulation. The Bravo mooring site in the central Labrador Sea is marked with an open circle. Ground tracks of the JASON 1 altimetric satellite are also shown.

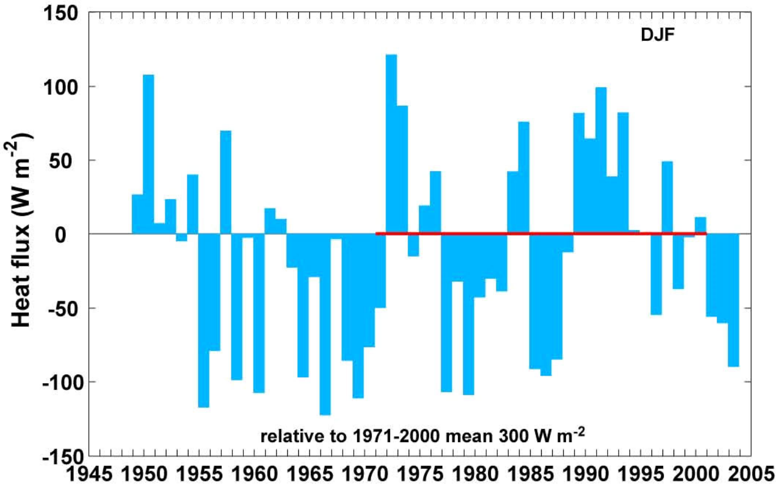

Figure 2(a) Winter (December-January-February average) heat flux anomalies near the Bravo mooring site relative to the 1971-2000 normal 300 W m^{-2}. Negative values mean the sea lost less heat than normal, indicating a mild winter.

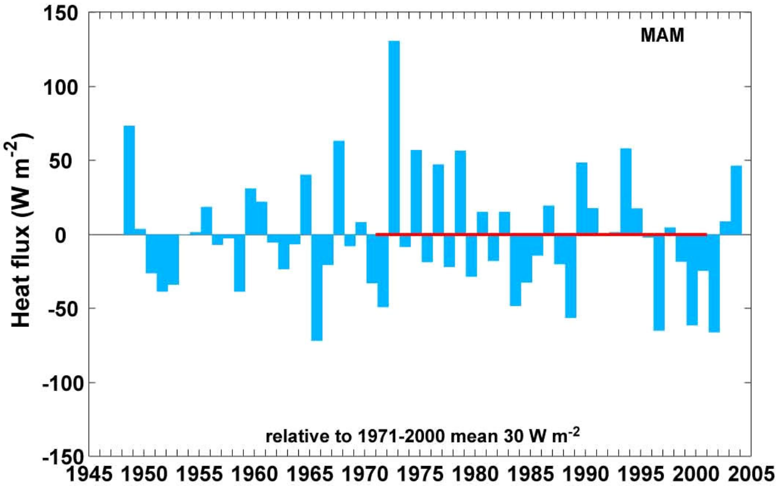

Figure 2(b) Spring (March-April-May average) heat flux anomalies near the Bravo mooring site as in Figure 2(a). The normal value is 30 W m^{-2}.

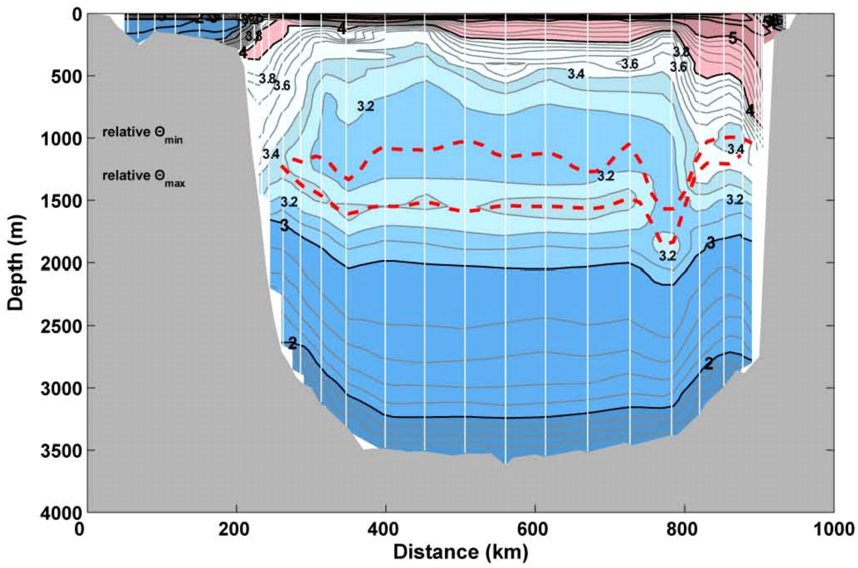

Figure 3(a) Potential temperature (°C) on AR7W during July 23-29, 2003, from Hudson 2003-038. The dashed lines trace layers of relative minimum potential temperature (< 3.2°C) and relative maximum potential temperature (generally >3.3°C). Vertical lines mark the station positions.

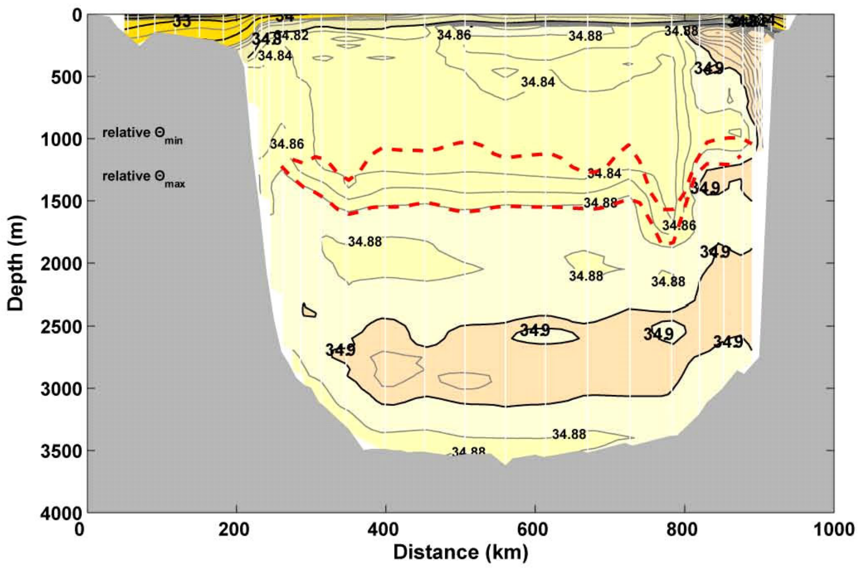

Figure 3(b) Salinity on AR7W during July 23-29, 2003 as in Figure 3(a).

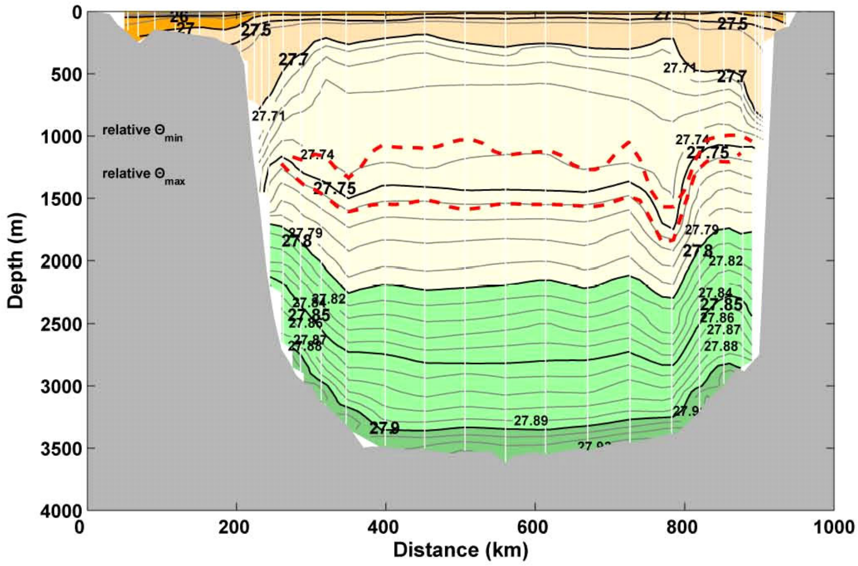

Figure 3(c) Potential density anomaly (kg m^{-3}) on AR7W during July 23-29, 2003 as in Figure 3(a).

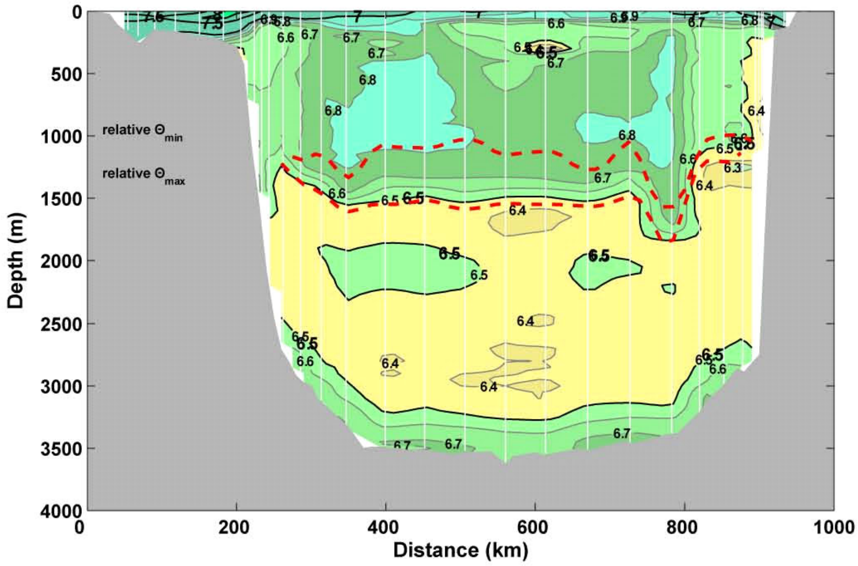

Figure 3(d) Dissolved oxygen (mL L^{-1}) on AR7W during July 23-29, 2003 as in Figure 3 (a).

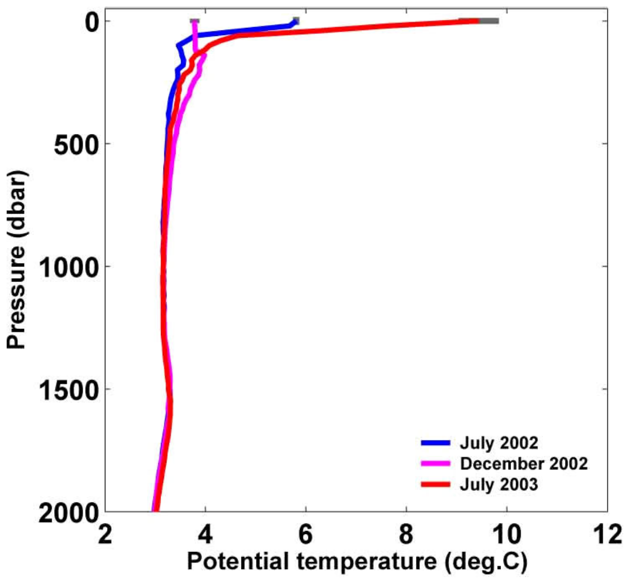

Figure 4(a) Average profiles of potential temperature in the 320-520 km distance range for July 2002, December 2002, and July 2003. The error bars are standard deviations for the four stations involved in each average.

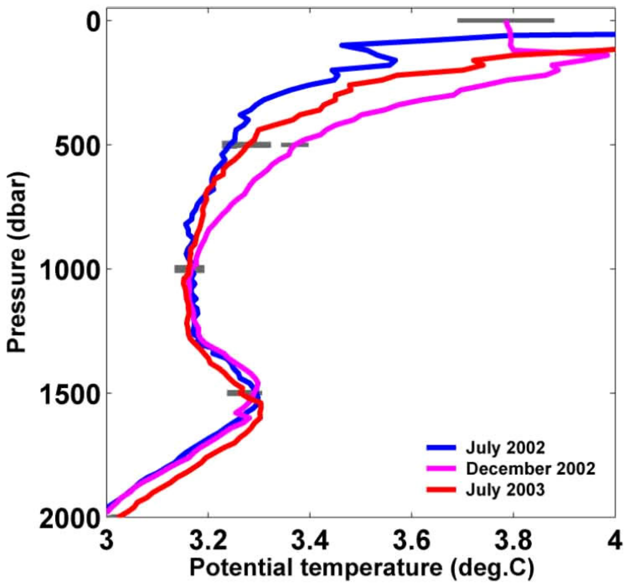

Figure 4(b) Average profiles of potential temperature for July 2002, December 2002, and July 2003 as in Figure 4(a) with an expanded temperature scale.

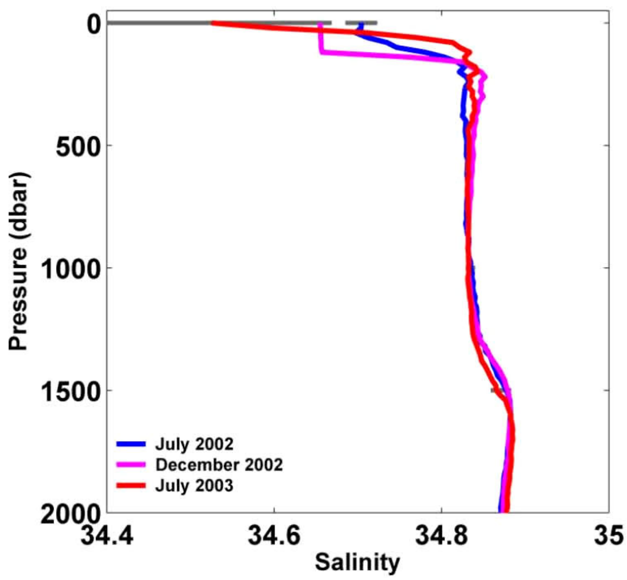

Figure 5(a) Average profiles of salinity in the 320-520 km distance range for July 2002, December 2002, and July 2003. The error bars are standard deviations for the four stations involved in each average.

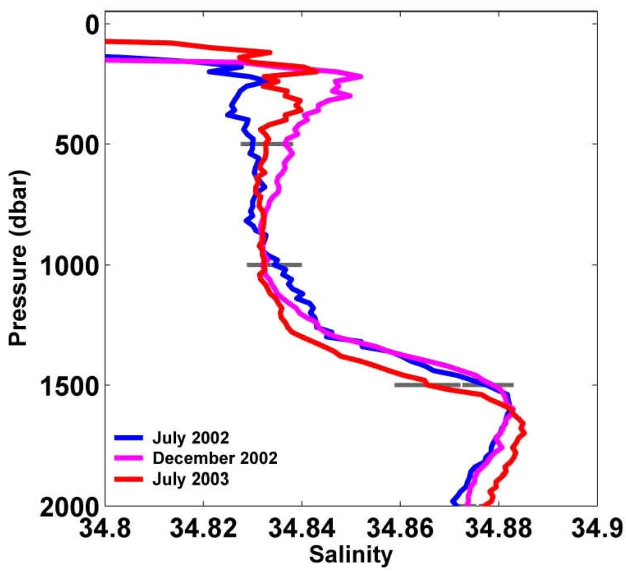

Figure 5(b) Average profiles of salinity for July 2002, December 2002, and July 2003 as in Figure 5(a) with an expanded salinity scale.

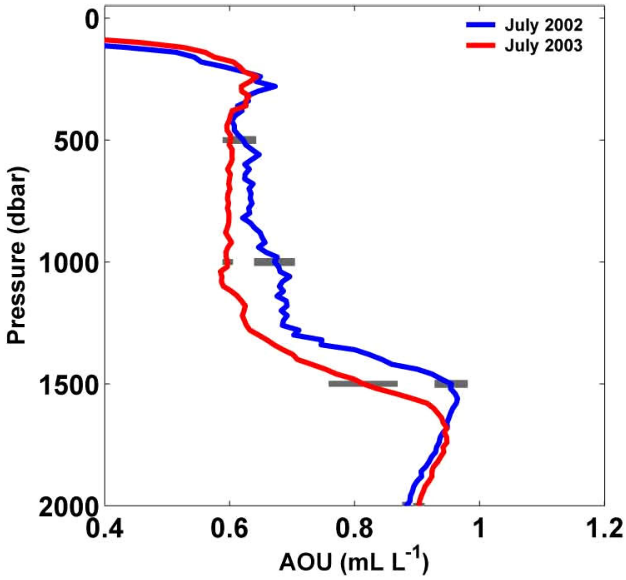

Figure 6 Average profiles of apparent oxygen utilization in the 320-520 km distance range for July 2002, December 2002, and July 2003. The error bars are standard deviations for the four stations involved in each average.

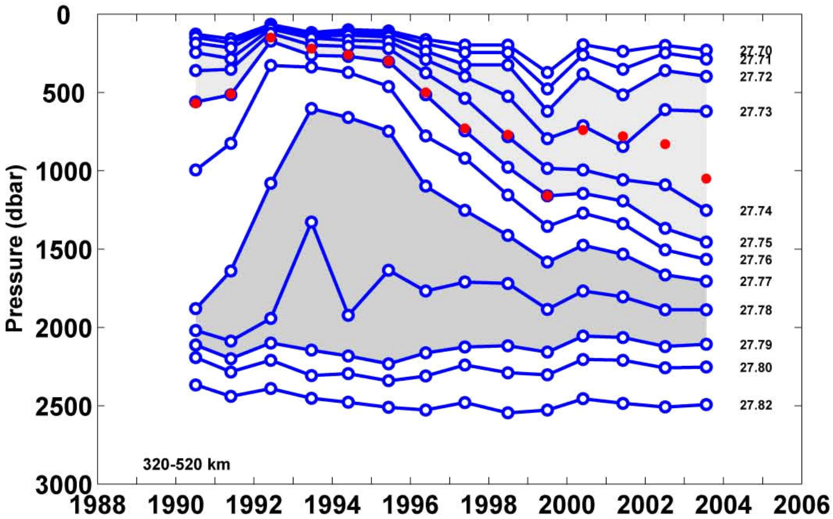

Figure 7 Pressure on selected potential density anomaly surfaces averaged over the 320-520 km distance range as a function of time. Cruise values are marked with open circles. The values of potential density anomaly in kg m^{-3} for each curve are noted at the right hand side of the figure. The 27.72-27.75 and 27.77-27.79 kg m^{-3} ranges of potential density are shaded for emphasis. Pressures corresponding to the minimum potential temperature in the shallower shaded layer are marked with filled circles.

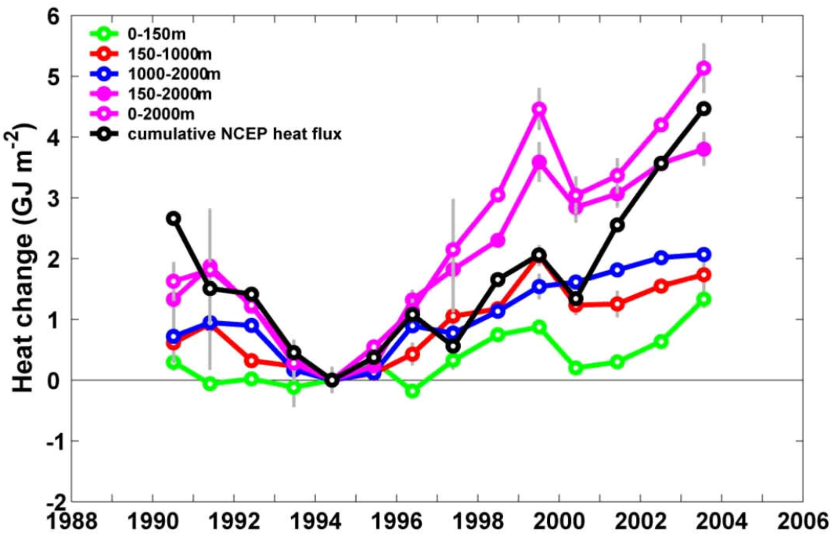

Figure 8(a) Heat content anomalies relative to 1994 from spring AR7W occupations averaged over stations in the 320-520 km distance range as a function of median station time. Integrals over selected depth ranges and associated standard deviation error bars are shown.

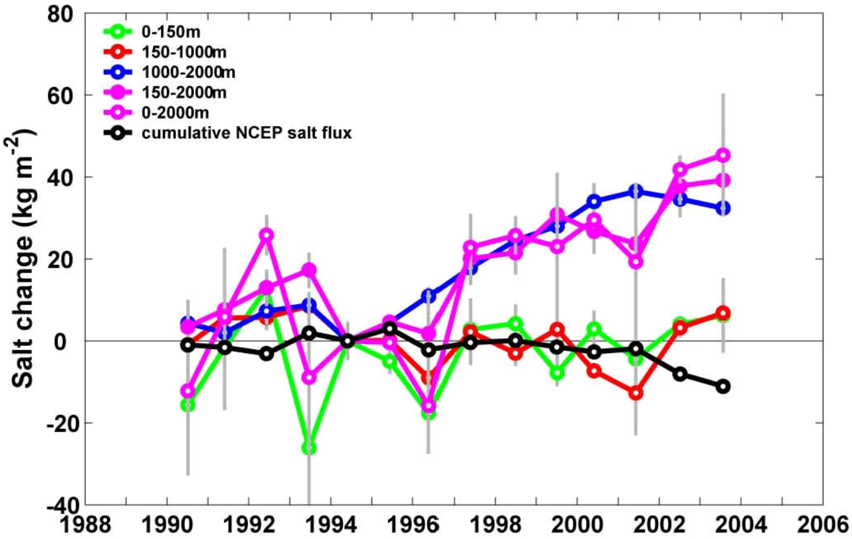

Figure 8(b) Salt content anomalies relative to 1994 from spring AR7W occupations as in Figure 8(a).

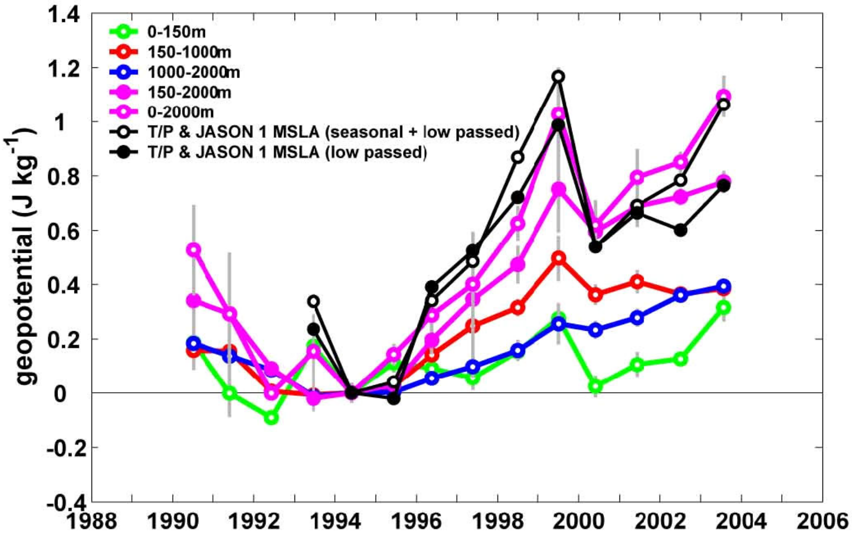

Figure 8(c) Geopotential anomalies relative to 1994 from spring AR7W occupations as in Figure 8(a). Also shown are two versions of surface geopotential anomalies at cruise times from the combined TOPEX/POSEIDON and JASON 1 altimetric missions. The MSLA curve marked with open circles at cruise times includes a fitted seasonal cycle.

Annex I: Environmental conditions in the Northwest Atlantic during 2003 (ICES area 2)

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Abstract

Meteorological and oceanographic observations from data collected at standard monitoring stations and sections in the Northwest Atlantic during 2003 are presented referenced to their long-term (1971-2000) means. Annual air temperatures throughout most of the Newfoundland and Labrador Region continued above normal during 2003 and in many areas increased over 2002 values. The North Atlantic Oscillation (NAO) index for 2003 was below normal for the second consecutive year. Sea ice coverage on the Newfoundland and Labrador Shelf during 2003 increased over 2002 to the highest observed since 1997 however it was still below normal for the 8th consecutive year. The annual water-column averaged temperature on the inner Newfoundland Shelf (Station 27) for 2003 remained above the long-term mean and increased over 2002 values at all depth ranges. Annual salinities measured at Station 27 remained above normal, similar to 2002 values that were the highest in over a decade. The cross-sectional area of <0^{o}C (CIL) water on the Newfoundland and Labrador Shelf during the summer of 2003 increased slightly over 2002 values but remained below the long-term mean along all sections, in some cases for the ninth consecutive year. Geostrophic estimates of the Labrador Current continued to show enhanced transport during the summer of 2003. The below-normal trend in water temperature, established in the late 1980s, reached a minimum in 1991, moderated by 1996, reached a maximum in 1999 and has continued above normal up to 2003. Ocean salinities on the Newfoundland Shelf also reached near-record lows in the early 1990s, remained below normal throughout most of the 1990s and up to 2001, however, during 2002 and 2003 there was a significant increase with surface values the highest observed in over a decade.

Introduction

Meteorological and oceanographic conditions during 2003 are presented referenced to a standardised base period from 1971-2000 in accordance with the convention of the World Meteorological Organisation. The data were collected by a number of researchers in Canada and compiled into time series for the standard sections and stations (Figures 1 and 2).

One of the most widely used and longest oceanographic time series in the Northwest Atlantic is from data collected at Station 27, located at latitude 47^o 32.8$'$ N and longitude -52^o 35.2$'$ W. This monitoring station was first occupied 1946, it is located in the inshore region of the eastern Canadian continental shelf about 8 km off St. John's Harbour Newfoundland (Figure 2), in a water depth of 176 m. The station is occupied on a regular basis mainly by oceanographic and fisheries research vessels at a frequency of about 3-4 times per month on average, with 59 occupations during 2003.

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 during mid-summer of every year 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 annually during mid-summer on an oceanographic survey conducted by the Canadian Department of Fisheries and Oceans (Figure 2). In this report the results for the Seal Island section on the Southern Labrador Shelf, the Bonavista section off the east coast of Newfoundland and the Flemish Cap section which crosses the Grand Bank at 47^o N are presented for the summer 2003 survey.

Meteorological and sea-ice conditions

Monthly and annual air temperature anomalies for 2003 relative to their 1971-2000 means at three sites in the northwest Atlantic from Iqaluit on Baffin Island to St. John's Newfoundland are shown in Figure 3. The predominance of warmer-than-normal annual air temperatures at all three sites during 2003 is clearly evident with annual anomalies ranging from a maximum of +2.0^{o}C at Iqaluit to +0.7^{o}C at St. John's Newfoundland. Monthly air temperatures were above normal in 7-9 months of 2003 at these sites. During the winter however, air temperatures had dropped to below normal values over much of eastern Canada, by 1.3°C over Labrador and near 1°C over southern Newfoundland. During March air temperatures had decreased even further to 3.5°C below normal over Labrador (Cartwright) and by 2.5°C below normal over Newfoundland (St. John's). By early summer conditions improved and temperatures warmed to near-record highs during the fall. As a result the annual values increased significantly over 2002, with some sites experiencing an increase of near 1°C. The inter-annual variability in air temperatures since 1960 at Iqaluit, Cartwright, and to a lesser extent St. John's, have been dominated by large amplitude fluctuations with minima in the early 1970s, early to mid-1980s and the early 1990s, suggesting a quasi-decadal period. Also note that all sites where data are available, cold conditions (relative to the 1971-2000 mean) existed throughout the late 1800s and early 1990s. Temperatures rose to above normal values between the 1910s and 1950s, the actual timing being site-dependent (Drinkwater *et al*. 2000).

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 north-westerly 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 on the Newfoundland and Labrador Shelf regions. During both 1999 and 2000 the NAO anomaly was well above normal (approximately +14 mb) however the colder-than-normal winter conditions usually associated with high NAO index did not extend into this region during these years due to shifting pressure fields. The NAO index for both 2002 and 2003 was below normal (by about 3 mb) indicating a reduced Arctic outflow to the Northwest Atlantic during the winter months (Figure 4). The spatial extent of the atmospheric low-pressure system during the winter months of 2003 however, was displaced to the west resulting in strong cyclonic circulation over the Labrador Sea. This caused air temperatures in much of the Northwest Atlantic to fall below normal during the winter and early spring of 2003. Overall, the changes in the NAO index fit the pattern of quasi-decadal variability that has persisted since the 1960s.

Information on the location and concentration of sea ice is available from the daily ice charts published by Ice Central of Environment Canada in Ottawa. The time series of the areal extent of sea ice on the Newfoundland and southern Labrador Shelf (between 45°-55°N) show that the peak extent during 2003 increased over 2002 but remained below average for the 8th consecutive year (Figure 4). The average ice area during both the period of southward advancement (January to March) and northward retreat (April to June) also increased slightly relative to 2002, but again remaining much less than the heavy ice years of the early 1990s (Figure 4). In general, sea ice coverage was lighter-than-average during 2003, however, the duration of ice season was slightly longer than normal in most areas of the Newfoundland and Labrador Shelf.

Time Trends in Temperature and Salinity at Station 27

Station 27, located in the Avalon Channel off Cape Spear (Figure 2), was sampled 59 times (50 CTD profiles, 9 XBT profiles) during 2003. The data from this time series are presented in several ways to highlight seasonal and inter-annual variations over various parts of the water column. Depth versus time contour maps of the annual cycle in temperature and salinity and their associated anomalies for 2003 are displayed in Figure 5. The cold near isothermal water column during the winter months has temperatures ranging from 0° to –1.5°C. These temperatures persisted throughout the year in the bottom layers. Surface layer temperatures ranged from about –1° to 0°C from January to mid-April, after which the surface warming commenced. By mid-May upper layer temperatures had warmed to 2°C and to over 13°C by August at the surface, after which the fall cooling commenced. These temperatures were about 0.25° to 0.5°C above normal during the winter months over most of the water column. Temperatures during the spring were generally below normal. During the remainder of the year, temperatures were above normal (by >1.5°C in surface layers during the summer) except for a mid-depth cold anomaly during the fall.

Surface salinities reached maximum values by late winter (>32.4 in mid-March) and decreased to minimum values by late summer (<31.3 in September). These values were generally above normal throughout the year in the upper water column, reaching a maximum of about 0.4 above normal during the fall months. In the depth range from 50-100-m, salinities generally ranged from 32.4 to 32.8 and near bottom, they varied throughout the year between 32.8 and 33. Except from May to July bottom salinities were near normal during most of 2003 (Figure 5).

The annual time series of temperature and salinity anomalies generally show three significant colder and fresher-than-normal periods at near decadal time scales since the early 1970s (Figures 6 and 7). At the surface negative temperature anomalies reached a minimum in the early 1990s, began to moderate to near-normal conditions by the summer of 1994 and have continued at normal to above normal up to 2003. Near bottom at 175-m depth, temperatures were generally below normal from 1983 to 1994, the longest continuous period on record. During 1994 and 1995 bottom temperatures started to warm and by 1996 were above the long-term average. Annual bottom temperatures from 1998 to 2003 have remained above the long-term mean. Monthly surface and bottom temperatures were above normal in all months of 2003 except during the spring (Figure 6 right panels).

Near-surface salinity anomalies (Figure 7) show the large fresher-than-normal anomaly that began in early 1991 had moderated to near normal conditions by early 1993 but returned to fresher conditions by the summer of 1995. Annual salinities approached near normal values during 1996 but decreased to mostly below normal values from 1997 to 2001. During 2002 and 2003 surface salinities increased to above normal and to the highest in over a decade. In general, during the past several decades cold ocean temperatures and fresher-than-normal salinities were associated with strong positive NAO index anomalies, colder-than-normal winter air temperatures, heavy sea-ice conditions and larger than normal summer cold-intermediate-layer (CIL) areas on the continental shelf (Colbourne *et al*. 1994, Drinkwater 1996). During the past several years (up to 2001) however, salinities have remained below normal during a time period of warm air temperatures and lower than normal ice conditions. During 2003 surface salinities were above normal for 11 of 12 months, near-bottom however, they were slightly below normal in most months especially during spring and summer (Figure 7 right panels).

The depth averaged (0-175 m) annual temperature and salinity anomaly time series at Station 27 are displayed in Figure 8. The temperature time series shows large amplitude fluctuations at near decadal time scales with cold periods during the early 1970s, mid-1980s and early 1990s. During the period from 1950 to the late 1960s the heat content of the water column was generally above the long-term mean. It reached a record low during 1991, a near record high during 1996, near normal in 1997 and 1998 and above normal from 1999 to 2003 (Figure 8).

The depth averaged (0-50 m) salinity time series (Figure 8 bottom panel) show similar variability as the heat content time series, with fresher-than-normal periods generally corresponding to the colder-than-normal conditions up to at least the early 1990s. The magnitude of negative salinity anomaly on the inner Newfoundland Shelf during 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 anomaly was mainly restricted to the inner Newfoundland Shelf. From 1991 to 2001 annual salinities were below normal on the inner Newfoundland Shelf. During 2002 and 2003 salinities increased over 2001 values and were the highest in about 12 years in the upper water column.

Standard Sections

The Labrador Current which generally flows south eastward along the shelf break through the Flemish Pass is comprised of a relatively strong western boundary current following the shelf break and a considerably weaker component over the banks and inshore regions (Figure 1). This current is responsible for advecting cold, relatively fresh, polar water together with sea-ice and icebergs from the Arctic to lower latitudes along the Labrador Coast to the Grand Banks of Newfoundland. The water mass characteristics observed along sections crossing the Newfoundland and Labrador Shelf (Figure 2) are typical of sub-polar waters with a sub-surface temperature range of -1° to 2ºC and salinities of 32 to 33.5. Along the shelf edge and into the Flemish Pass region, the 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 warm to 10° to 12°C during late summer, while bottom temperature remain <0°C over the Grand Bank but increase to 1° to 3°C near the shelf edge below 200-m. In the deeper waters of the Flemish Pass and across the Flemish Cap bottom temperatures generally range from 3° to 4°C. 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. This water mass is generally referred to as the cold intermediate layer (CIL) which is formed during the winter months. It usually remains present throughout most of the year as the seasonal heating increases the stratification in the upper layers to a point where heat transfer to the lower layers is inhibited, although it undergoes gradual decay during the summer reaching a minimum during the fall. In general the water masses found along the standard sections undergo seasonal modification in their properties due to the seasonal cycles of air-sea heat flux, wind forced mixing, ice formation and melt, leading to intense vertical and horizontal gradients particularly along the frontal boundaries separating the shelf and slope water masses.

Flemish Cap (47° N)

Near surface temperatures along the Flemish Cap section (Figure 2) during the summer of 2003 ranged from 7° to 10°C while <0°C water was present below 60-m depth to the bottom over most of the Grand Bank. The coldest water is normally found in the Avalon Channel and at the edge of the Grand Bank corresponding to the inshore and offshore branches of the Labrador Current (Figure 9). Temperatures were generally above normal over most areas along this section during the summer except for isolated areas near the surface and in the deeper waters of the Flemish Pass. To the east of the Flemish Cap temperatures were higher than normal by over 8°C. Salinities along the section on the Grand Bank (Figure 10) are characterised by generally fresh conditions on the bank (<33), a strong horizontal gradient at the shelf break separating the saltier (>34.5) slope water offshore in the Flemish Pass. Salinity anomalies during 2003 were generally higher than average in the upper layers and near normal below 50-m depth. To the east of the Flemish Cap salinities were above normal by over 1 practical salinity unit (Figure 10).

Bonavista

The dominant water mass feature along this section during the summer months is the cold intermediate layer of <0°C water (CIL) which develops during early spring after intense winter cooling. Temperatures along the Bonavista section during the summer of 2003 in the upper water column ranged from 7°to 8°C. These values were above normal in the extreme inshore areas, below normal at mid-shelf and generally above normal in the offshore areas. The offshore area of the Labrador Current appeared warmer-than-normal as did the near bottom areas across most of the eastern Newfoundland Shelf. Intermediate depth waters corresponding to the CIL were colder than normal (Figure 9). Salinities along the Bonavista section generally range from <32.5 near the surface in the inshore region to >34 in the offshore region (Figure 10). Bottom salinities ranged from 32.5 in the inshore regions, to 34.75 at about 325-m depth near the shelf edge. Similar to the Flemish Cap section salinities were generally above normal throughout the section, with the magnitude of the anomalies decreasing with depth. In general, salinities along the Bonavista section during 2002 and 2003 increased over values observed in 2001.

Seal Island

The Seal Island section, which crosses Hamilton Bank on the southern Labrador Shelf (Figure 2), was also sampled in July of 2003 (Figure 9 and 10 bottom panels). Upper layer temperatures across the shelf in this region ranged from –0.5°C at approximately 50-m depth to between 7°to 8°C at the surface. Temperatures below 50-m depth were generally <0°C over most of the shelf, corresponding to the CIL water mass, except near bottom where they range from 0° to 1°C due to the influence of warmer slope water. Near the shelf break in Labrador slope water, bottom temperatures increase to 2°-3°C. Temperature anomalies in the surface and near-bottom layers were up to 1° to 2°C above normal over most of the shelf. At intermediate depths corresponding to the CIL water mass, anomalies generally varied about the mean. Surface salinities along this section ranged from <31.5 inshore of Hamilton Bank to >34 in the offshore region. Bottom salinities ranged from 32.5 near the coast of Labrador to 34.5 at the edge of the shelf in water depths >300-m. Near-surface salinities were saltier-than-normal particularly in the inshore area and about normal over the remainder of the water column. Offshore of the shelf break however, salinities were below normal in the upper water column.

Cold Intermediate Layer (CIL) Time Series

As shown in the cross-shelf contour plots (Figure 9), the vertical temperature structure on the Newfoundland Continental Shelf during the summer is dominated by a layer of cold <0°C water trapped between the seasonally heated upper layer and warmer slope water near the bottom. This water mass is commonly referred to as the cold intermediate layer or CIL (Petrie *et al*. 1988). The spatial extent of this winter chilled water mass is evident in the section plots of the temperature contours, for example along the Seal Island section (Figure 9) the CIL extends offshore to over 200 km, with a maximum vertical extent of approximately 150 m. This corresponds to a cross-sectional area of around 25 km^2. The annual summer CIL cross-sectional area anomalies defined by the 0°C contour for the Flemish Cap, Bonavista and Seal Island sections are displayed in Figure 11. Along the Flemish Cap section the CIL area was below the 1971-2000 normal in 2003, similar to conditions observed during the past 5-years but a slight increase over 2002. Off Bonavista the CIL area was also below normal for the ninth consecutive year. Along the Seal Island section the area of <0°C water increased slightly over 2002 but was still below normal. In general, the CIL area observed along all sections, while showing a slight increase over 2002, it continued the trend of below normal values observed since 1995. This is in contrast to the near record high values measured during the early 1990s, which was a very cold period on the Newfoundland Shelf.

Geostrophic Circulation and Transport

Temperature and salinity data were used to compute geostrophic currents relative to 300 m along several sections sampled during the summer of 2003 (Figure 12). The geostrophic component of the southward flowing Labrador Current along these sections generally shows distinct inshore and offshore branches. The inshore branch is weaker than the shelf-slope branch and is usually restricted to the inshore troughs within approximately 50-100 km of the coast. Typical current speeds in these regions range from 0.05-0.10 m/s, although some estimates were up to 0.15 m/s along the Seal Island section during 2003. The offshore branch is located at the shelf break in water depths generally >400 m. The offshore distance and the width of the current vary according to the underlying topography. Along the Seal Island section, for example, the core of the offshore branch is about 100 km wide, centred at about 200 km offshore over the 400-m isobath; while further north, on the mid-Labrador Shelf, the width of the current is approximately 50 km centred at about 125 km offshore. In the offshore branch, typical speeds range from 0.05 m/s at 175-m depth to >0.25 m/s in the upper water column. At mid-shelf the geostrophic signal is generally weak with current speeds in these areas <0.05 m/s. In general, geostrophic currents along the Labrador Shelf (Seal Island section) appear stronger than those on the eastern Newfoundland Shelf (Bonavista section) with speeds over 0.3 m/s offshore from Hamilton Bank for example. During the summer of 2003 the North Atlantic Current east of the Flemish Cap was particularly strong (Figure 12).

The historical data along these sections were used to compute time series of geostrophic transports estimates (Figure 12 right panels). A common reference level of 135-m was chosen for these calculations since this was the deepest level common to all three sections that did not intersect the bottom, thus eliminating potential problems associated with a bottom reference level. Also, the main interest was to examine variations in volume transport during recent ocean climate changes on the continental shelf. Short-term climate changes generally result in variations in upper layer shelf stratification due mainly to salinity changes resulting from increased ice formation and melt. This determines in part, the magnitude of the shelf-slope density front and hence the strength of the geostrophic component of the Labrador Current. The time series of volume transport of the offshore branch of the Labrador Current for the three sections show large inter-annual variations with an average transport of between 0.4-0.5 Sv to the south, relative to 135 m. In general, the time series indicate higher than average transport during the late 1950s and into the 1960s, lower than average values during the cold period of the early 1970s and to a lesser extent during the cold period of the mid-1980s. During the late 1980s the transport increased to above average values, which for the most part continued into the early 2000s. Except for the Flemish Cap section, the transport of the Labrador Current during 2003 was very similar to 2002. Along the Flemish Cap section in 2003 the transport was the highest in the time series (Figure 12).

Summary

Annual air temperatures throughout most of the Newfoundland and Labrador Region continued above normal during 2003 and in many areas increased over 2002 values. Annual mean air temperatures at Cartwright for example, on the southern Labrador Shelf warmed over 2002 values from 0.2°C above normal to 1.2°C above normal in 2003. The North Atlantic Oscillation (NAO) index for 2003 was below normal for the second consecutive year. The spatial extent of the NAO atmospheric low-pressure system during the winter months however was displaced to the west bringing enhanced Arctic outflow to the region resulting in colder than normal air temperatures during late winter and spring. Sea ice coverage on the Newfoundland and Labrador Shelf during 2003 increased over 2002 to the highest observed since 1997, however, it was still below normal for the 8th consecutive year.

The annual water-column averaged temperature at Station 27 for 2003 remained above the long-term mean and increased over 2002 values at all depth ranges. The annual surface temperature at Station 27 was 0.7°C above normal, while the annual bottom temperature remained similar to 2002 at 0.2°C above normal. Bottom temperatures were above normal during January and February, below normal during spring and above normal during the remainder of the year. Water-column averaged annual salinities at Station 27 remained above normal, similar to 2002 values, the highest in over a decade. Surface salinities at Station 27 were above normal for 11 of 12 months, while bottom salinities were generally below normal, particularly during the period April to July.

The cross-sectional area of <0°C (CIL) water on the Newfoundland and Labrador Shelf during the summer of 2003 increased slightly over 2002 values but remained below the long-term mean. The CIL areas were below normal along all sections from the Flemish Cap section on the Grand Bank to the Seal Island section off southern Labrador. Off Bonavista for example, the CIL area was below normal for the ninth consecutive year. Geostrophic estimates of the Labrador Current continued to show enhanced transport during the summer of 2003.

In summary, the below-normal trends in temperature and salinity, established in the late 1980s reached a minimum in 1991. This cold trend continued into 1993 but started to moderate during 1994 and 1995. During 1996 temperature conditions were above normal over most regions, however, summer salinity values continued to be slightly below the long-term normal. During 1997 to 1999 ocean temperatures continued to warm over most areas, with 1999 one of the warmest years in the past couple of decades. During 2000 to 2002 ocean temperatures were cooler than 1999 values, but remained above normal over most areas continuing the trend established in 1996. The past year was one of extremes in many areas, with the below normal temperatures during the spring increasing to above normal values by fall. From 1991 to 2001 the trend in salinities on the Newfoundland Shelf was mostly below normal, however, during 2002 there was a significant increase with surface values the highest observed in over a decade. Annual salinity measurements at Station 27 during 2003 continued to show above normal values.

Acknowledgements

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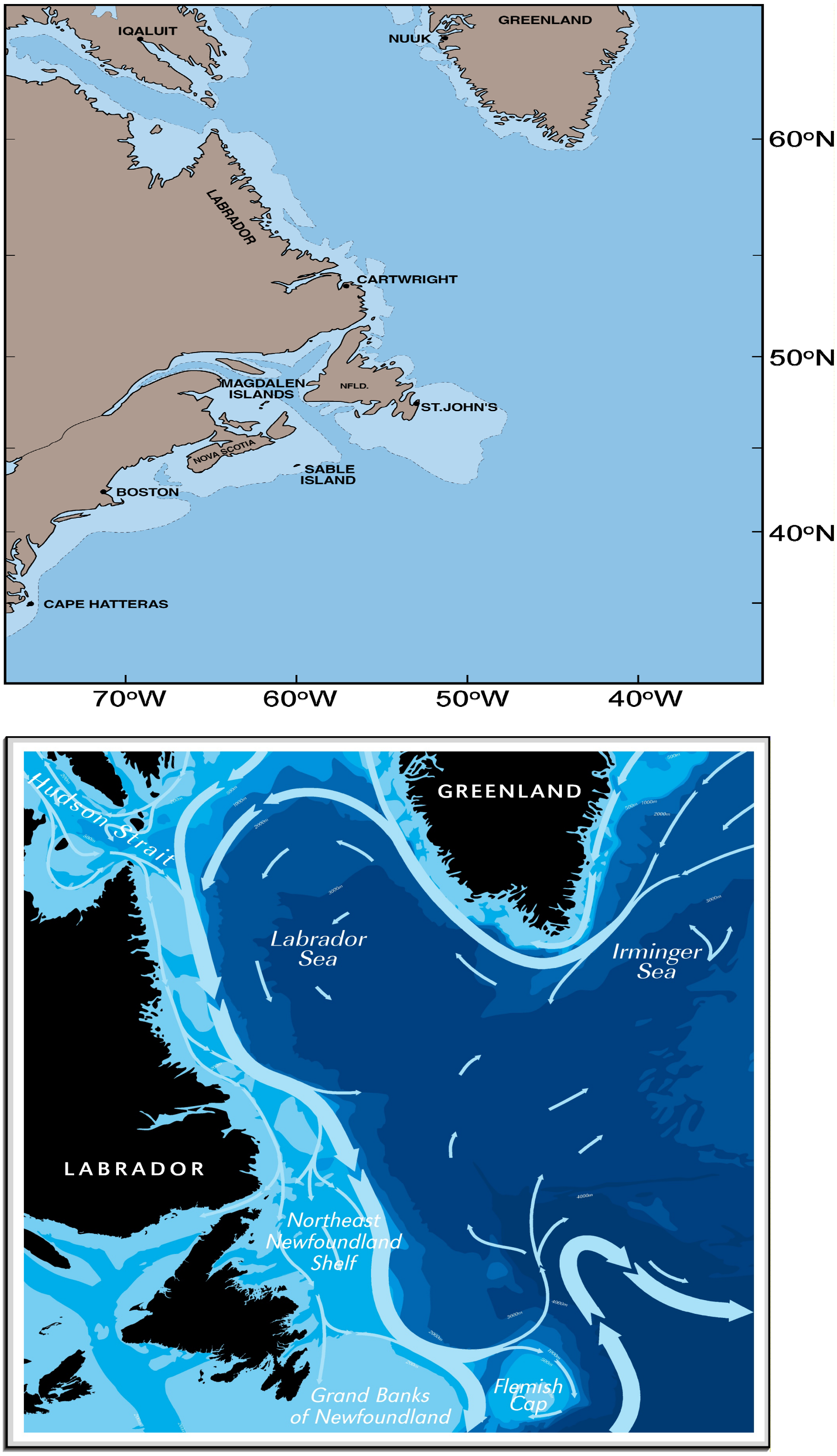


Figure 1. Northwest Atlantic showing coastal air temperature monitoring stations (top panel) and the general circulation features of the Northwest Atlantic.

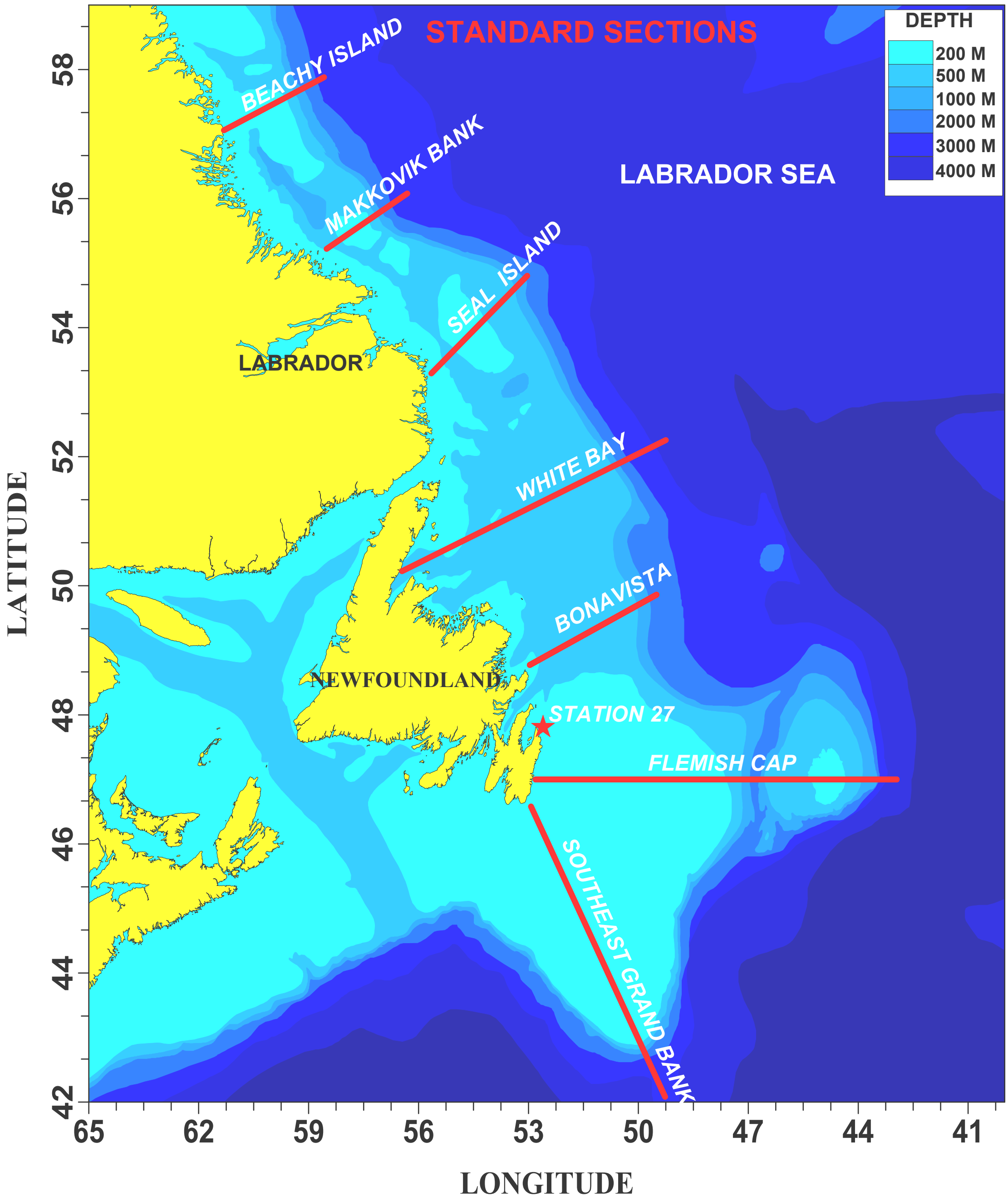


Figure 2. Map showing the location of Station 27 and the locations of standard monitoring sections on the Newfoundland and Labrador Shelf.

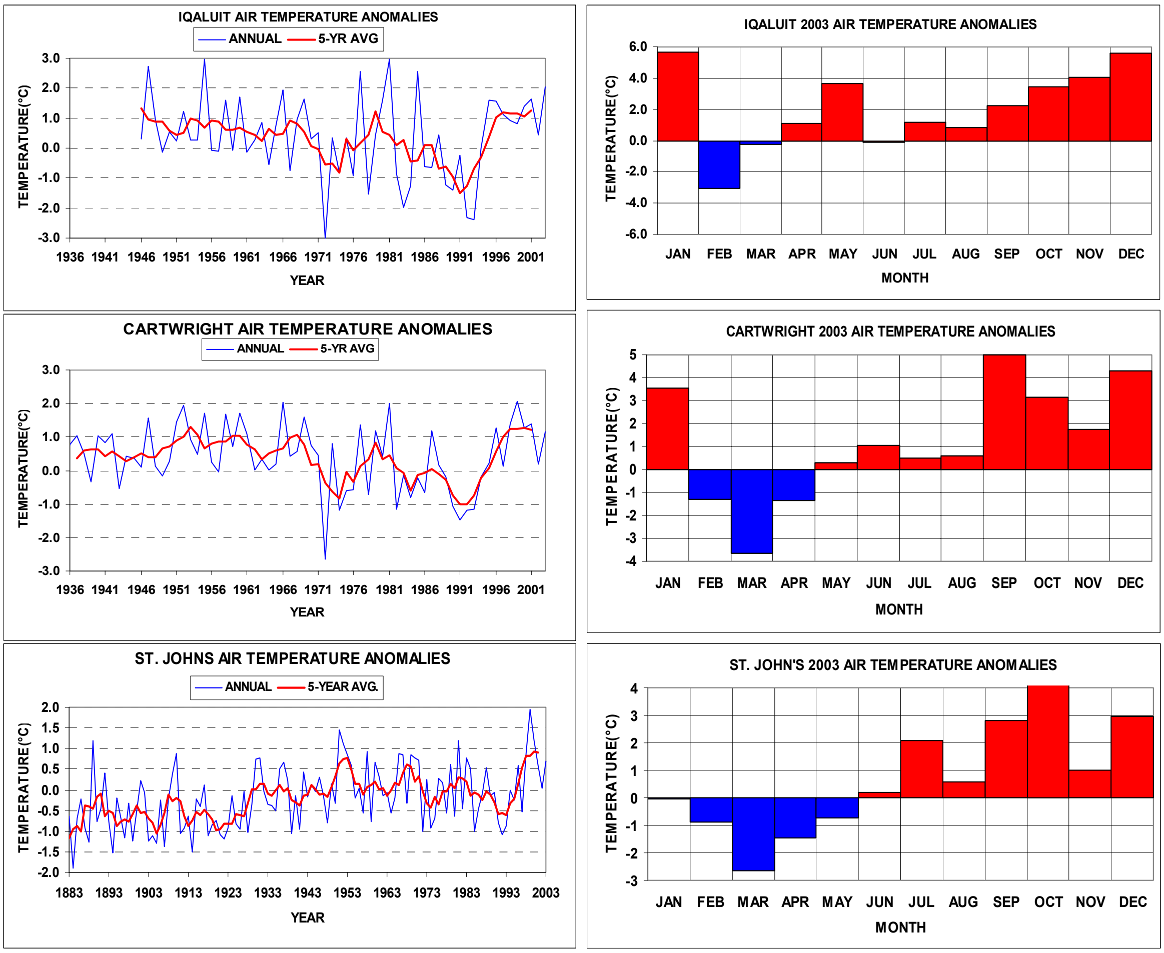


Figure 3. Annual and monthly air temperature anomalies in 2003 at selected coastal sites (see Figure 1 for locations). The anomalies are referenced to their 1971-2000 means.

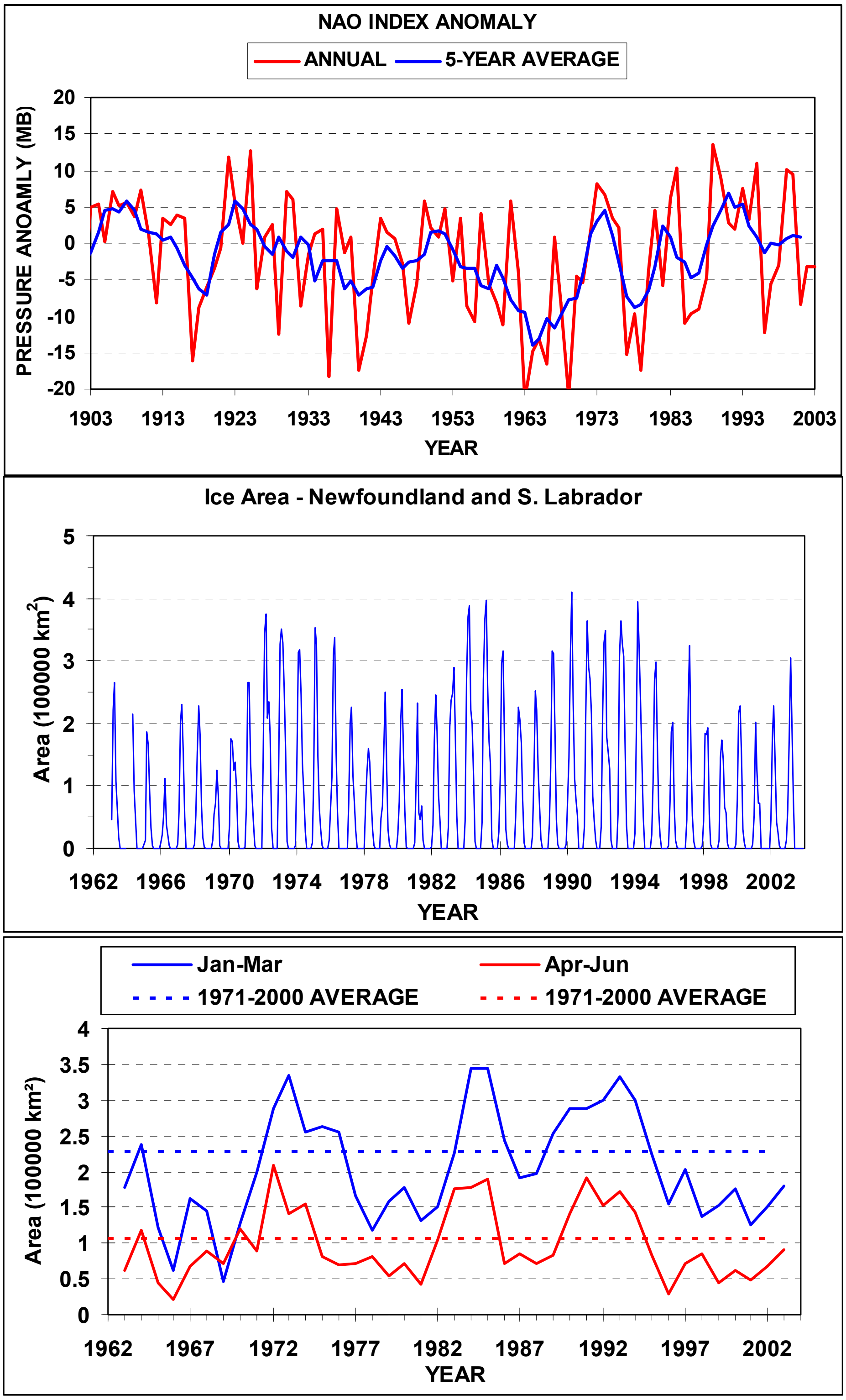


Figure 4. Anomalies of the North Atlantic Oscillation Index relative to the 1971-2000 mean (top panel), monthly mean ice areas off Newfoundland and Labrador between 45°N- 55°N (centre panel) and the average ice area during the normal periods of advancement (January-March) and retreat (April-June) (bottom panel).

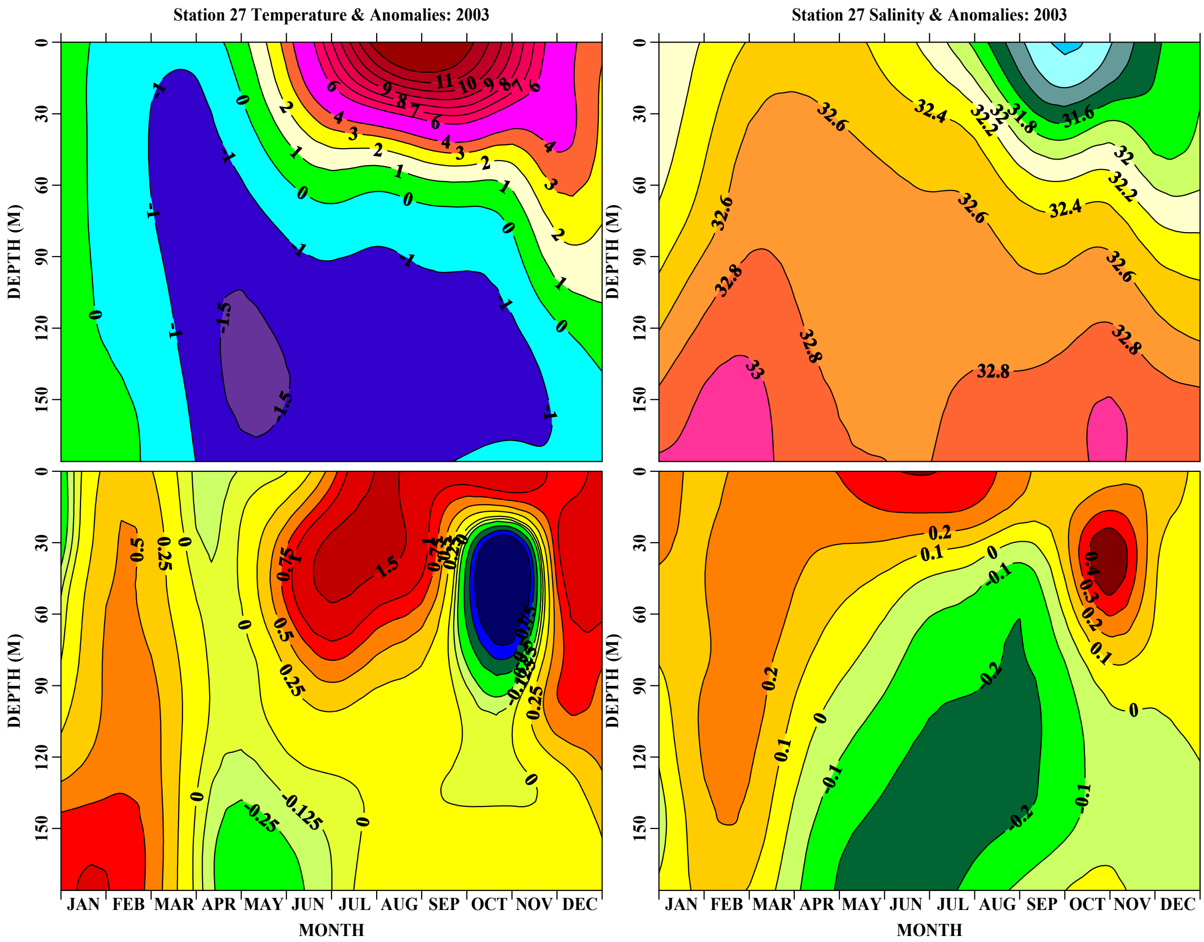


Figure 5. Contours of the annual cycle of temperature and temperature anomalies (in °C) (left panels) and salinity and salinity anomalies (right panels) as a function of depth at Station 27 for 2003.

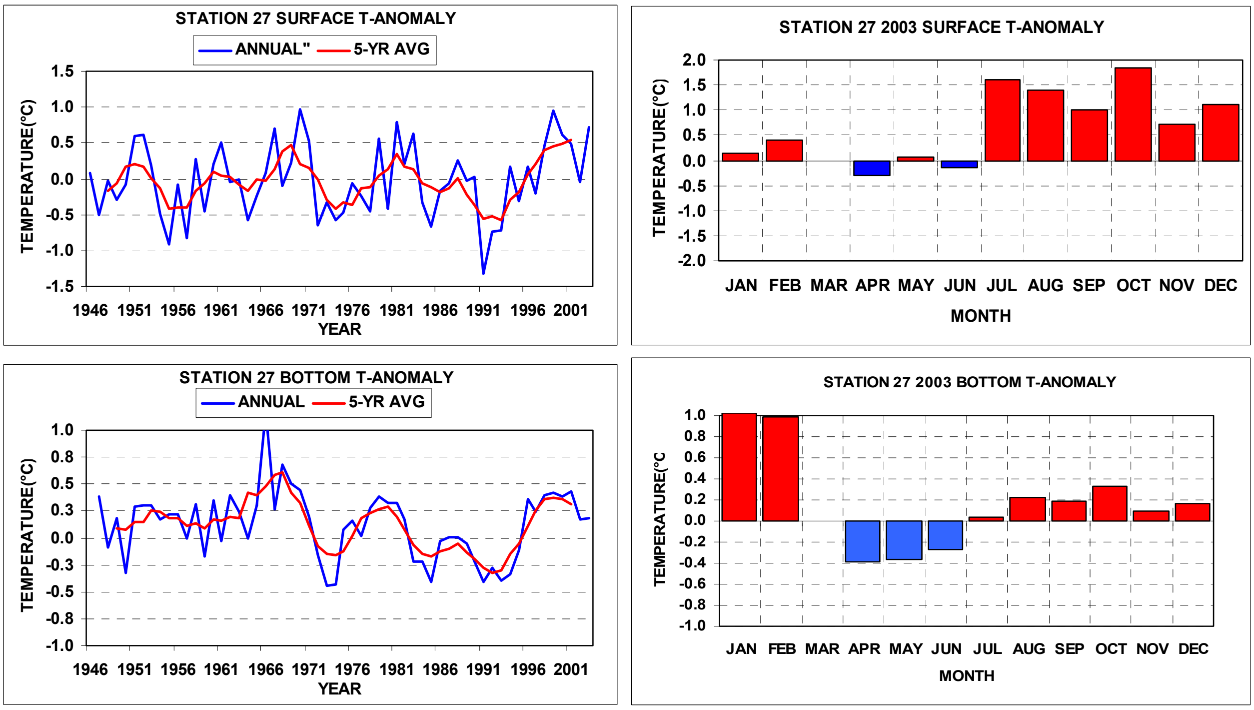


Figure 6. Monthly surface and bottom temperature anomalies at Station 27 during 2003 (right panels) and their annual anomalies with 5-year running means (left panels).

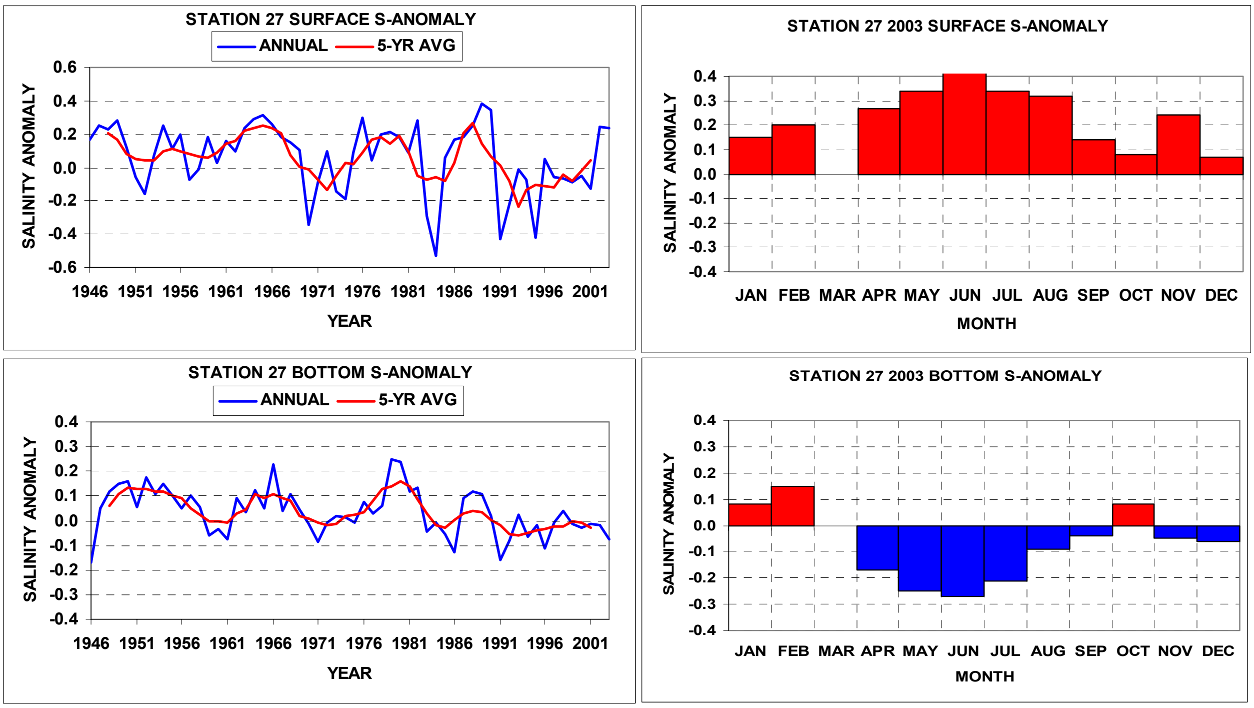
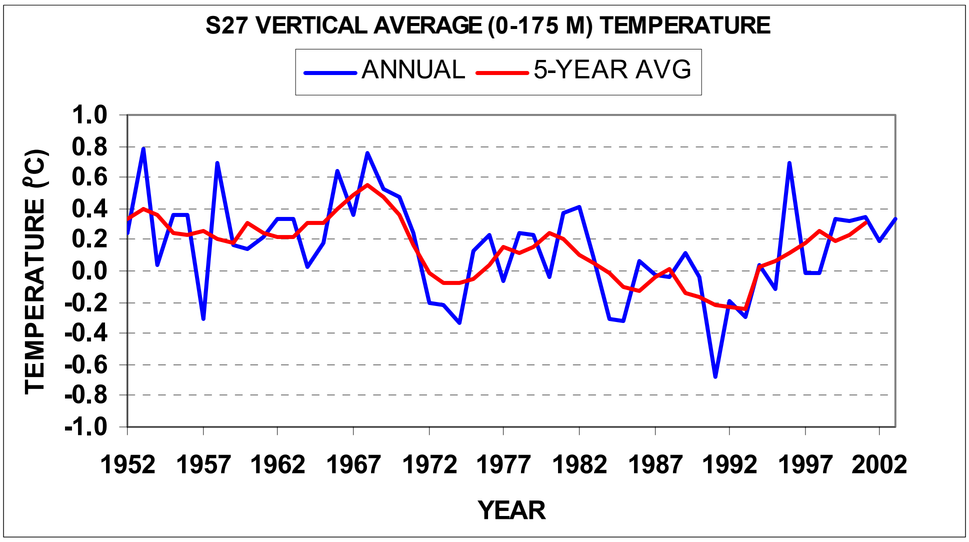


Figure 7. Monthly surface and bottom salinity anomalies at Station 27 during 2003 (right panels) and their annual anomalies with 5-year running means (left panels).



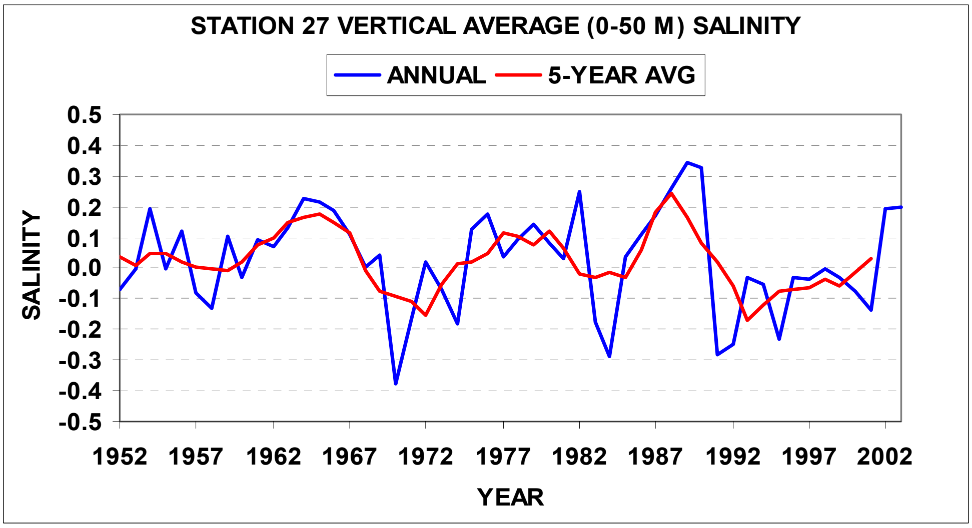


Figure 8. The annual vertically averaged Station 27 temperature and salinity anomalies.

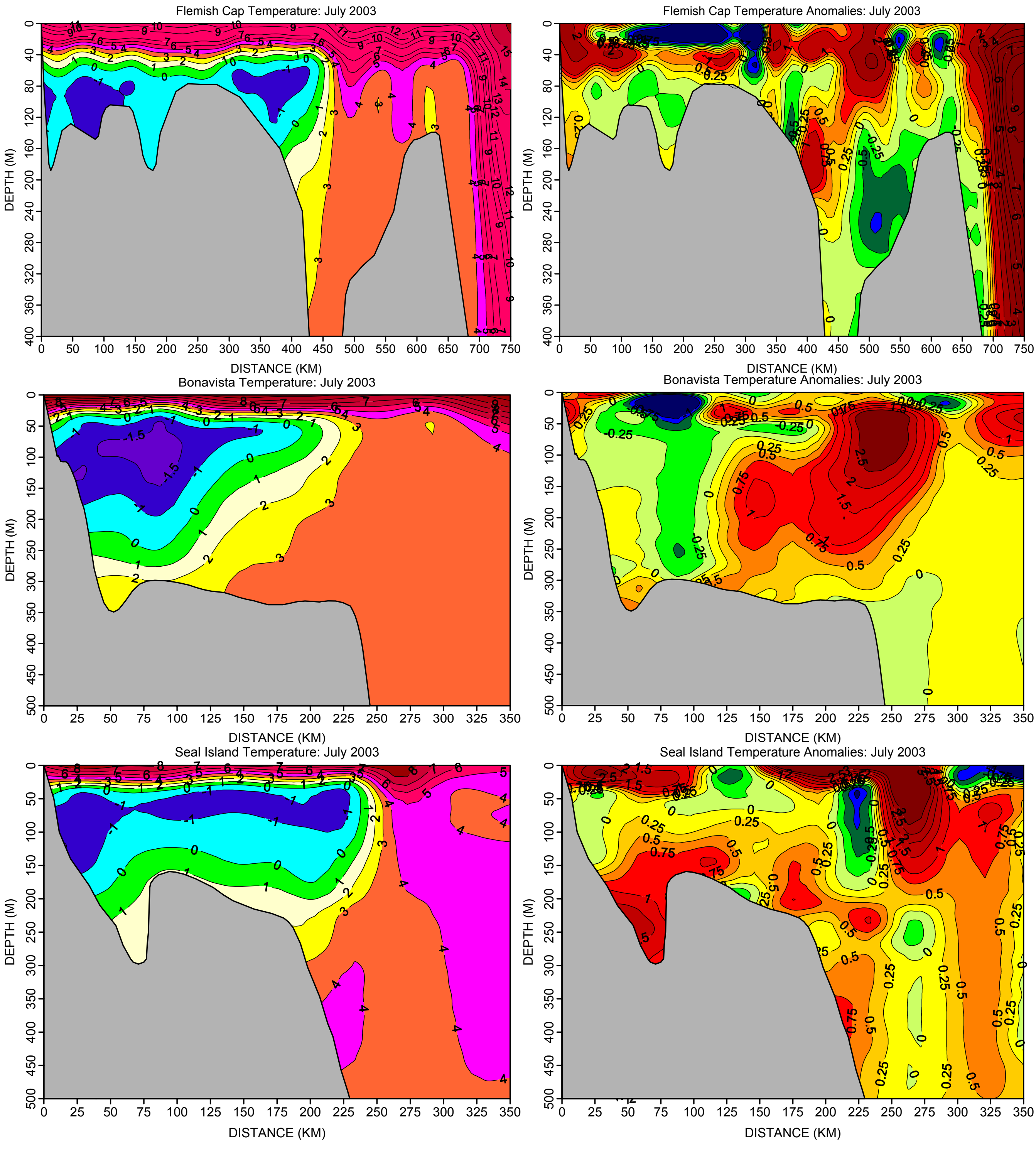


Figure 9. Contours of temperature and temperature anomalies (in °C) along the Flemish Cap, Bonavista and Seal Island sections (Figure 2) during the summer of 2003.

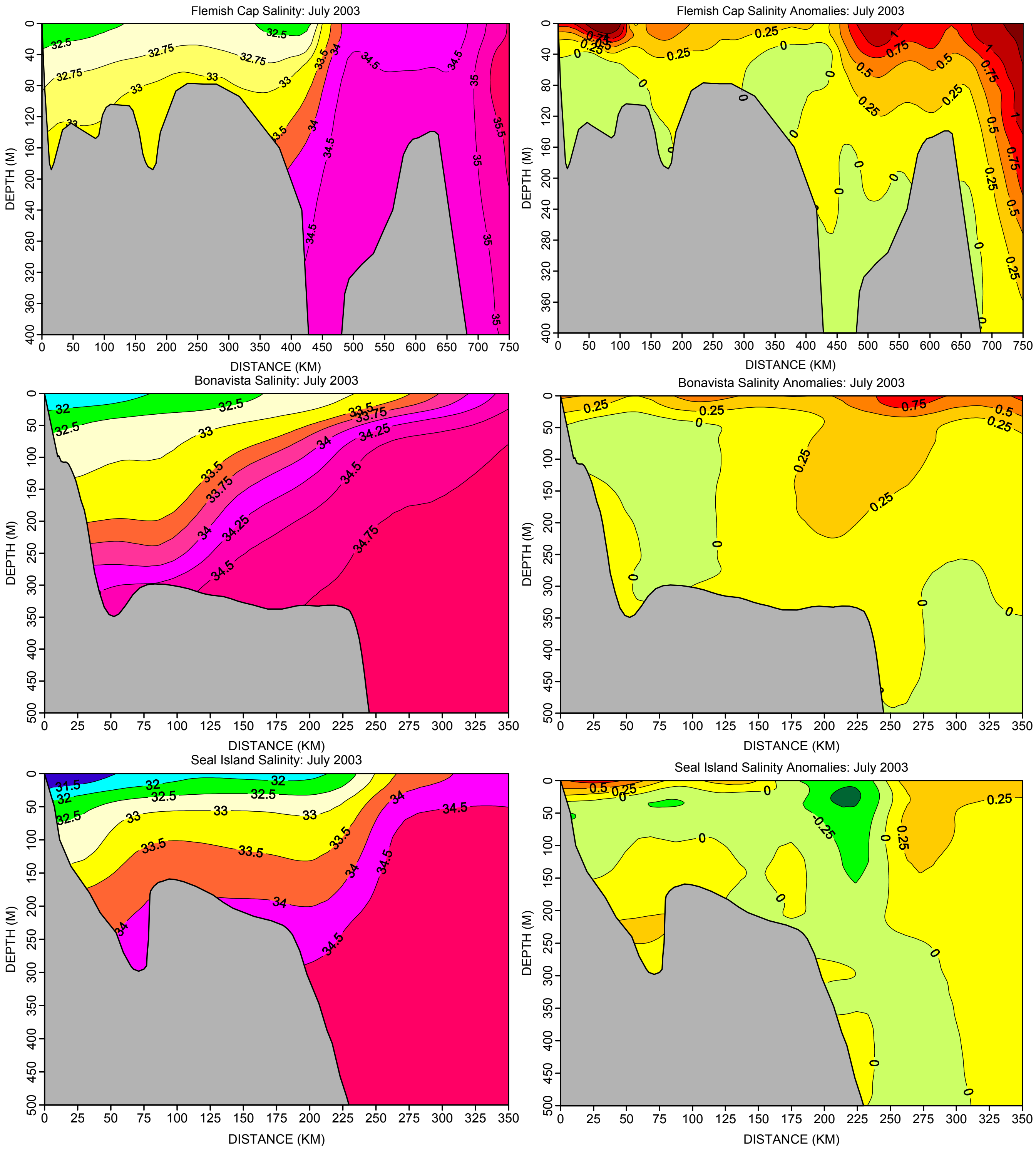


Figure 10. Contours of salinity and salinity anomalies along the Flemish Cap, Bonavista and Seal Island sections during the summer of 2003.

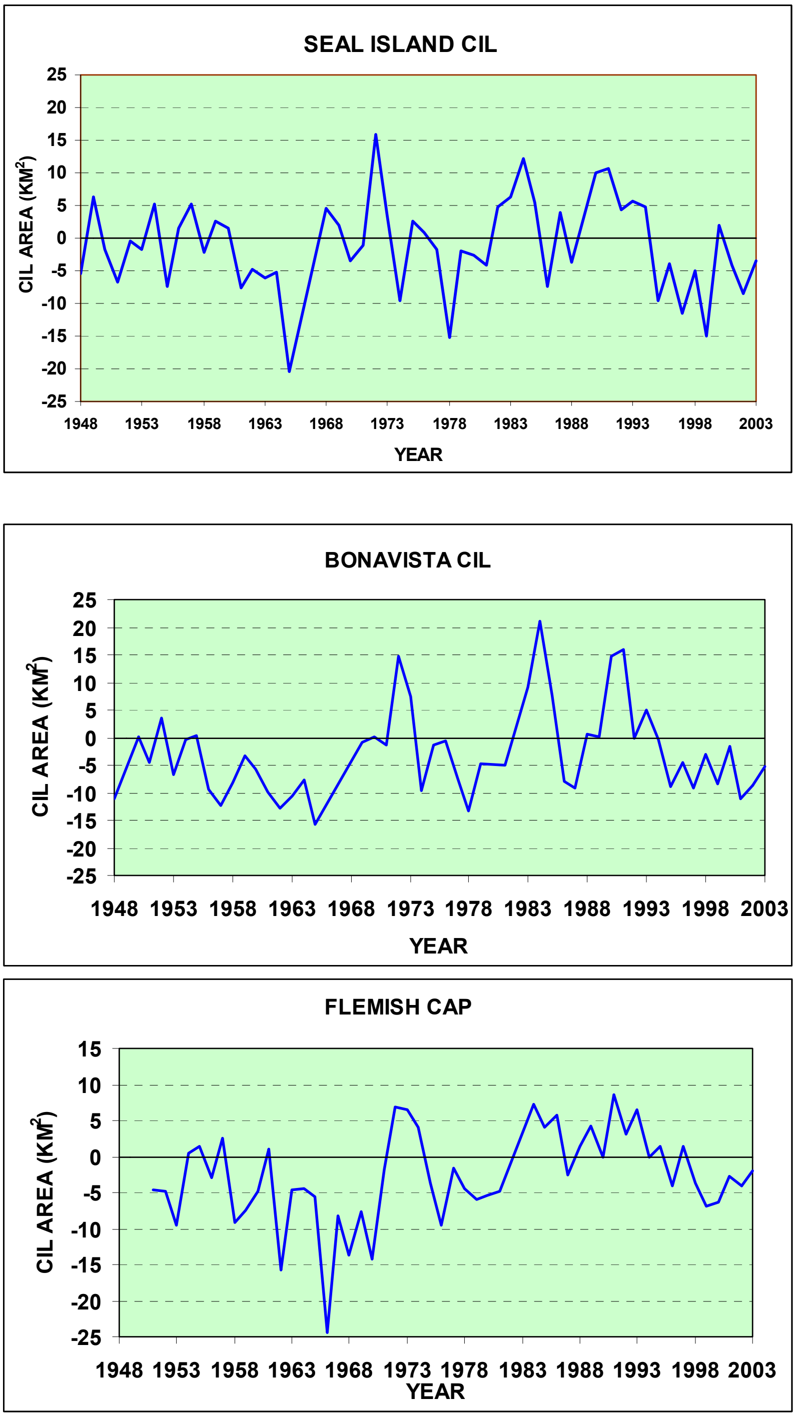


Figure 11. Annual summer CIL cross-sectional area anomalies along the Flemish Cap, Bonavista and Seal Island sections. The anomalies are references to the 1971-2000 means.

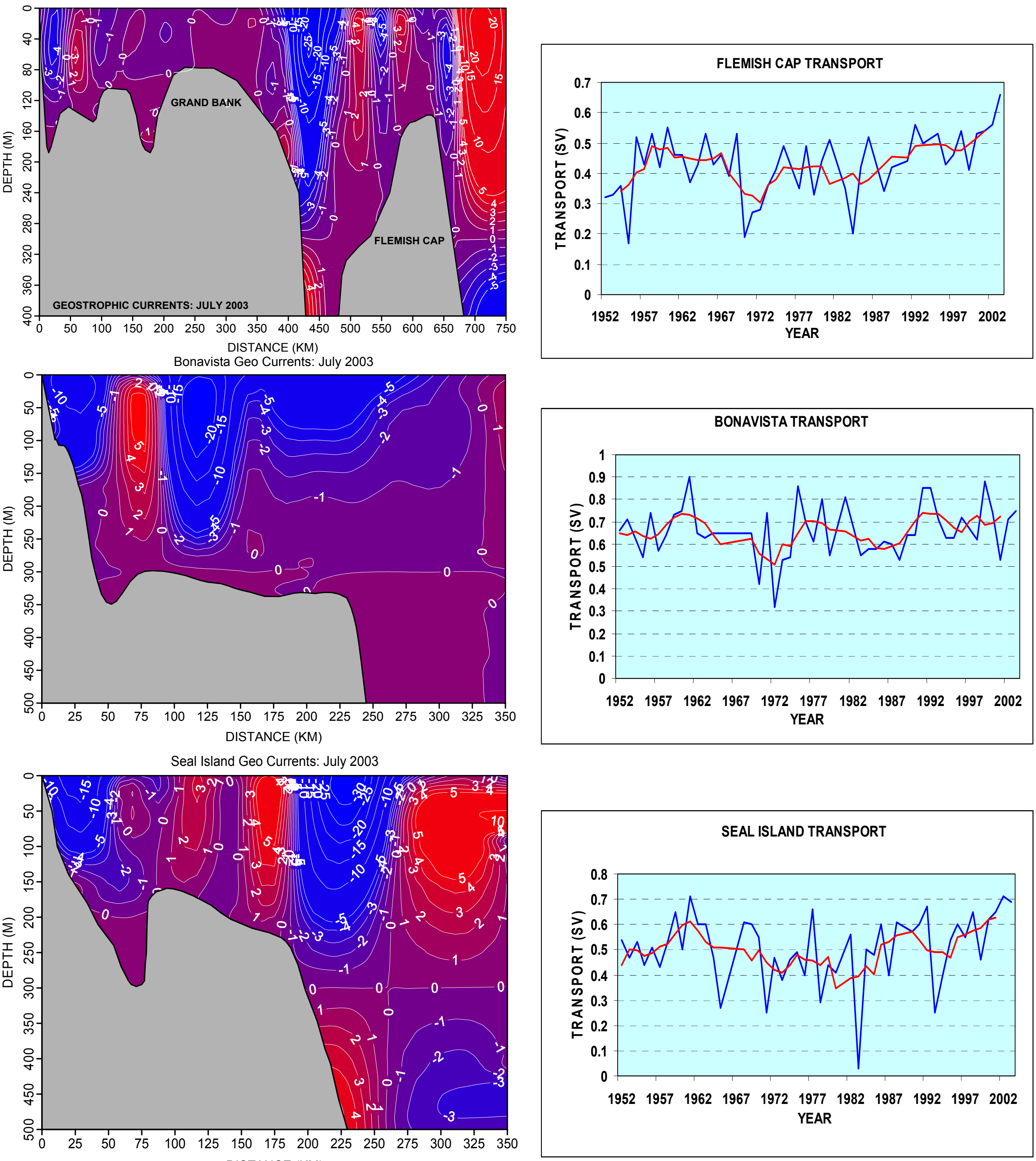


Figure 12. Contours of geostrophic currents (in cm/s) along sections on the Newfoundland and Labrador Shelf (Figure 2) during the summer of 2003 (left panels) and annual estimates of geostrophic transport (10^6 m^3/s) relative to 130-m depth of the offshore branch of the Labrador Current.

Annex J: Decadal variations in surface properties in the mid-Atlantic bight

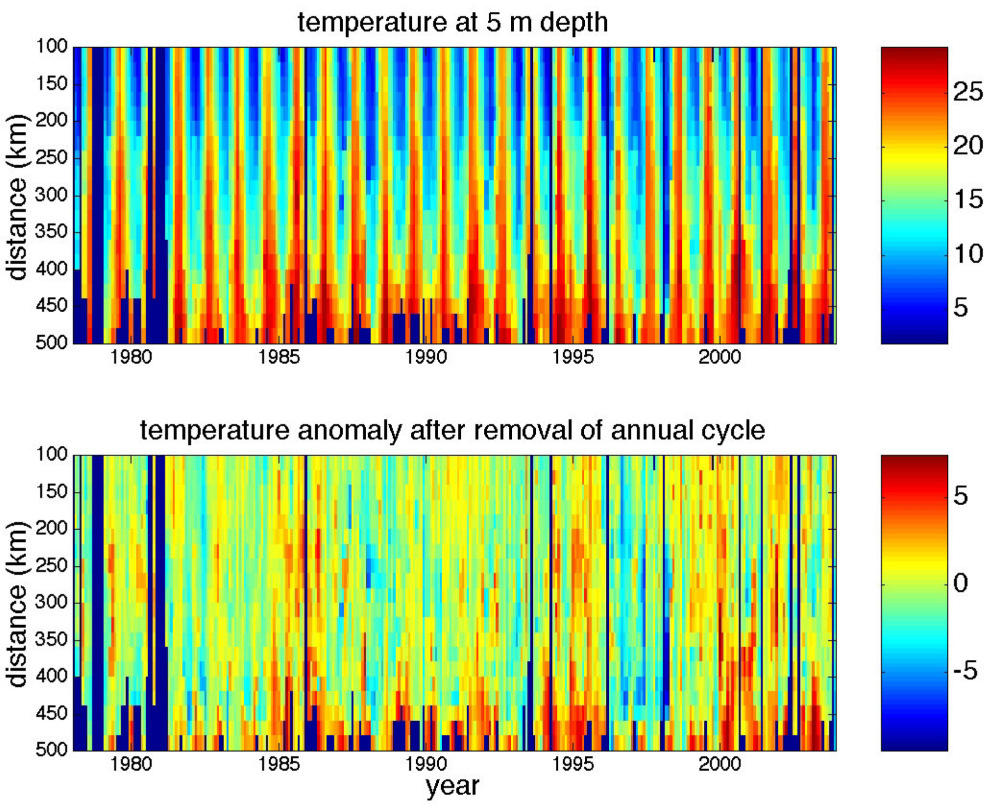
T. Rossby

University of Rhode Island, USA.

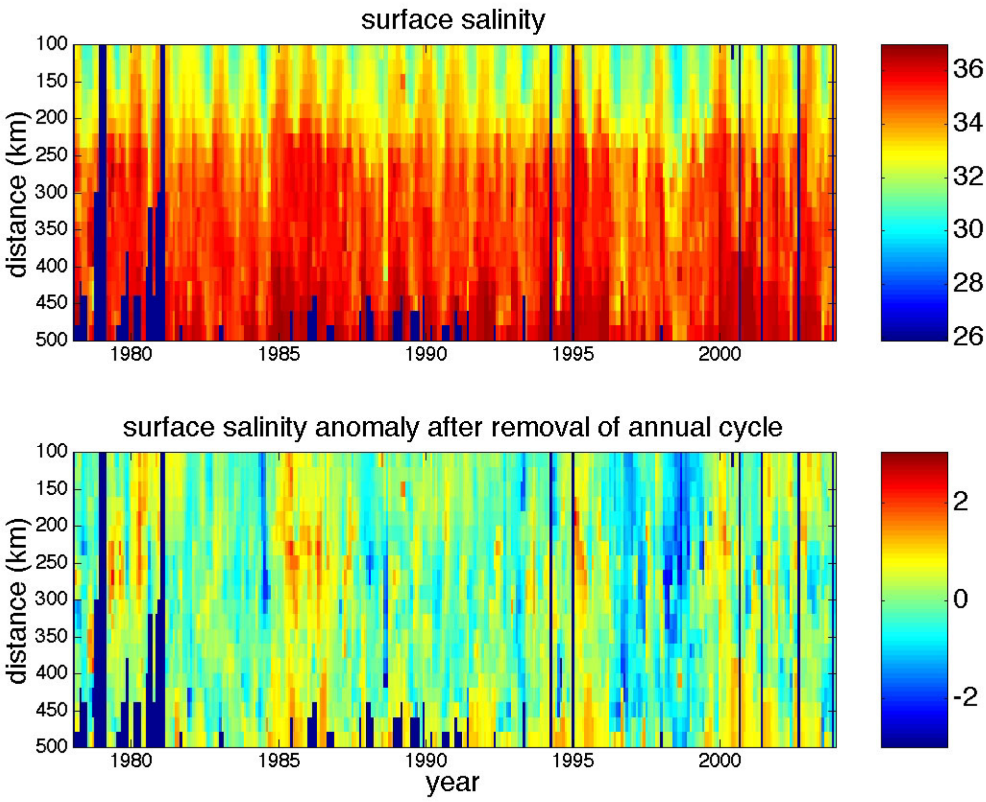
XBT and sea surface salinities

Starting in 1978 the National Marine Fisheries Service has been taking XBTs and surface salts on a monthly schedule from commercial vessels operating between Bermuda and Port Elizabeth, NJ. The sampling program, which continues today, has now completed 25 years of operation. In this report we give a brief overview of the data and point out of some the major features of interest. The first figure shows a Hovmöller diagram of temperature at 5 m depth binned every 20 km and with a monthly resolution. The distance is in km from NJ. The very dark blue stripes indicate no data.

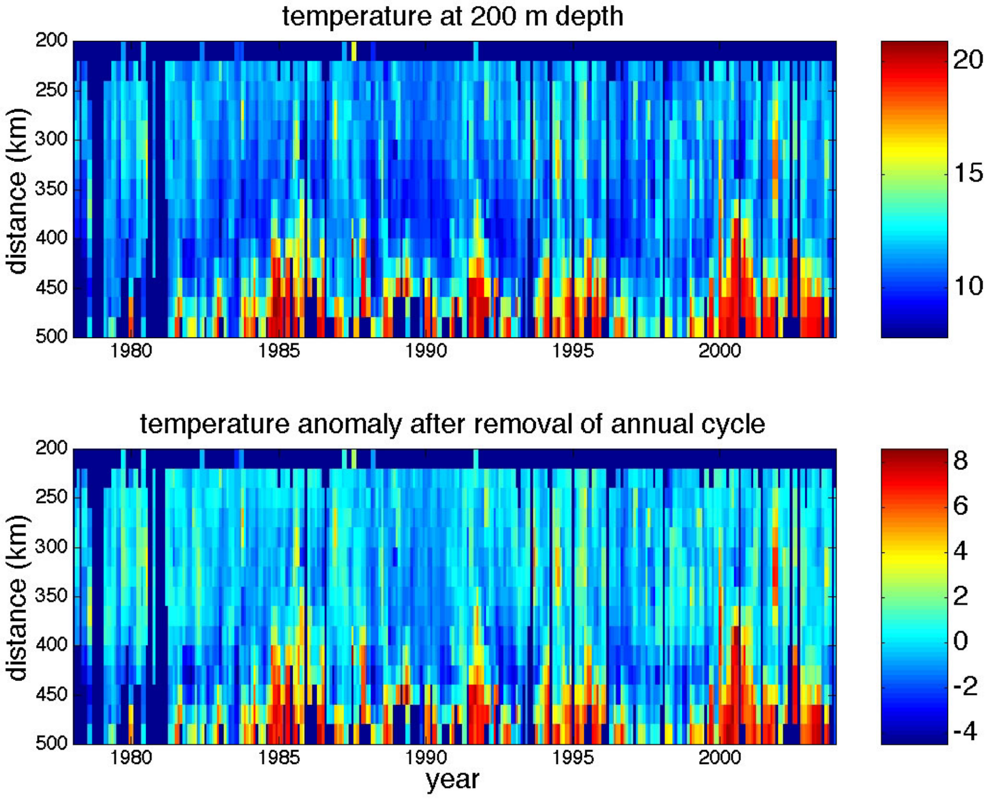
The annual cycle shows up very clearly. The variable presence of warm waters along the bottom reflects the low frequency meandering of the Gulf Stream in and out the 500 km limit. One can also see the continental shelf edge at about 200 km, north of which the waters are generally cooler. To highlight low frequency variations in temperature we subtract out the mean annual cycle for each distance bin and show the residuals in the lower panel. Roughly pentadal variations in temperature occur with maxima near 1979, 1985 1991, 1995, and more generally after 1999. We also see a striking cold period in the 1996-1997 time frame. During this time the Gulf Stream was significantly displaced to the south. (See also Rossby and Benway, 2000; hereafter abbreviated as RB).



Surface salts were taken along with each XBT. These are plotted next. The annual cycle does not show up as conspicuously (given the salinity range), but one can, nonetheless observe lower salinities in summertime. One can also see (barely) the variable presence of high salinity Gulf Stream waters at the bottom. More evident is the strong salinity contrast across the shelf edge. The interannual anomalies show up clearly after removal of the mean and annual cycles, bottom panel. Again, roughly pentadal variations in salinity are evident with maxima corresponding to the temperature maxima in the previous figure. Note the O(2) PSU range in salinity anomalies in the vicinity of the shelf break. Due to the large swings in salinity it is not possible to discern longer term trends with any certainty. Broadly speaking the anomalies in temperature and salinity tend to compensate such that the density variations are quite a bit smaller (RB).



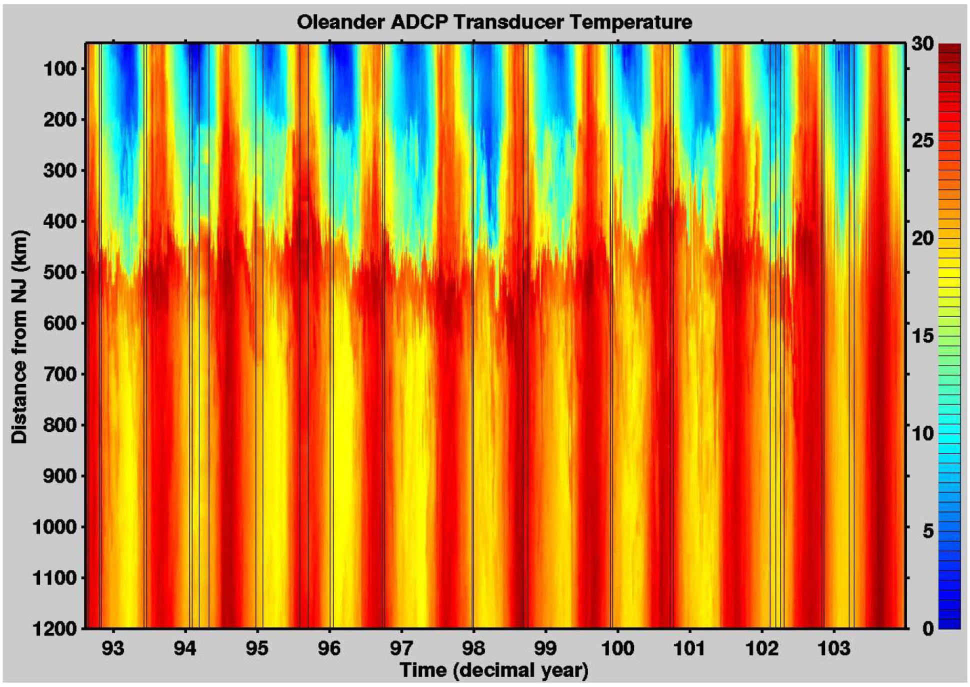
To illustrate the richness of the data set, the following figure shows temperature at 200 m from the XBTs. This plot starts at 200 km due to the continental shelf. The meandering in and out of the 500 km limit shows up very clearly here. One can also observe a band of somewhat colder waters ~100 km north of the Gulf Stream. This reflects a slight shoaling of the pycnocline associated with the cyclonic circulation in the Slope Sea, the waters between the Gulf Stream and the continental slope. Almost certainly, the occasional hot spots in the Slope Sea indicate the passage of warm core rings. The bottom panel shows the residuals after removing any seasonal cycle and the mean for each distance bin. Unlike the surface fields, we see little interannual variation at this depth; the field appears to be far more uniform.



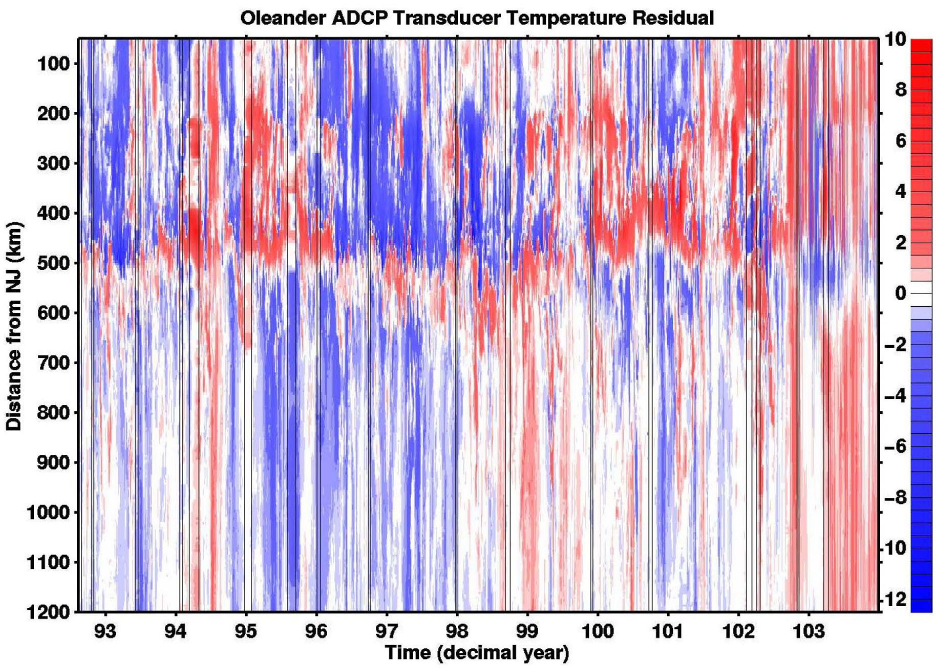
The low frequency variations in SST and SSS correlate with mean path of the Gulf Stream: when displaced to the north both SST and SSS are higher and vice versa when the stream is farther offshore (RB).

High resolution sections

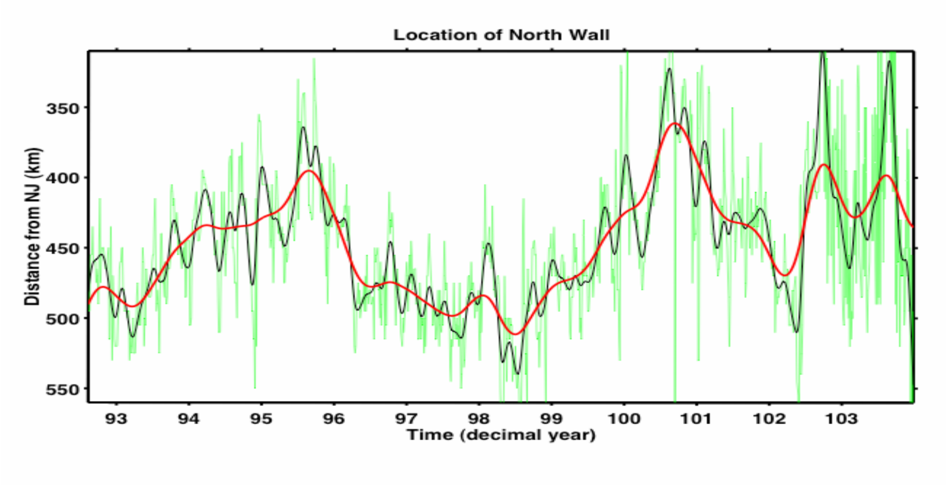
Since the fall of 1992 the container vessel operating between New Jersey and Bermuda, the Oleander, has been equipped an acoustic Doppler current profiler. This instrument also records temperature, shown below. This is essentially a high resolution version of the first figure except that it goes all the way to Bermuda. Again, one can see the shelf break and the meandering Gulf Stream. Note that the Gulf Stream is warmer than the waters to either side; it shows up as a maximum. The gradual shifting north and south of the Gulf Stream emerges clearly.



As before, the next figure shows the anomaly of temperature after removal of the seasonal cycle and mean. The cold 1996-1998 period shows up clearly, similarly the recent warm period starting about 1999. The magnitude of SST variability is significantly higher north of the Gulf Stream than south. The interannual anomalies in SST can be quite substantial. South of the stream the SST variability is less extreme, and appears more gradual over time. Nor does it appear to correlate with SST variations north of the stream.

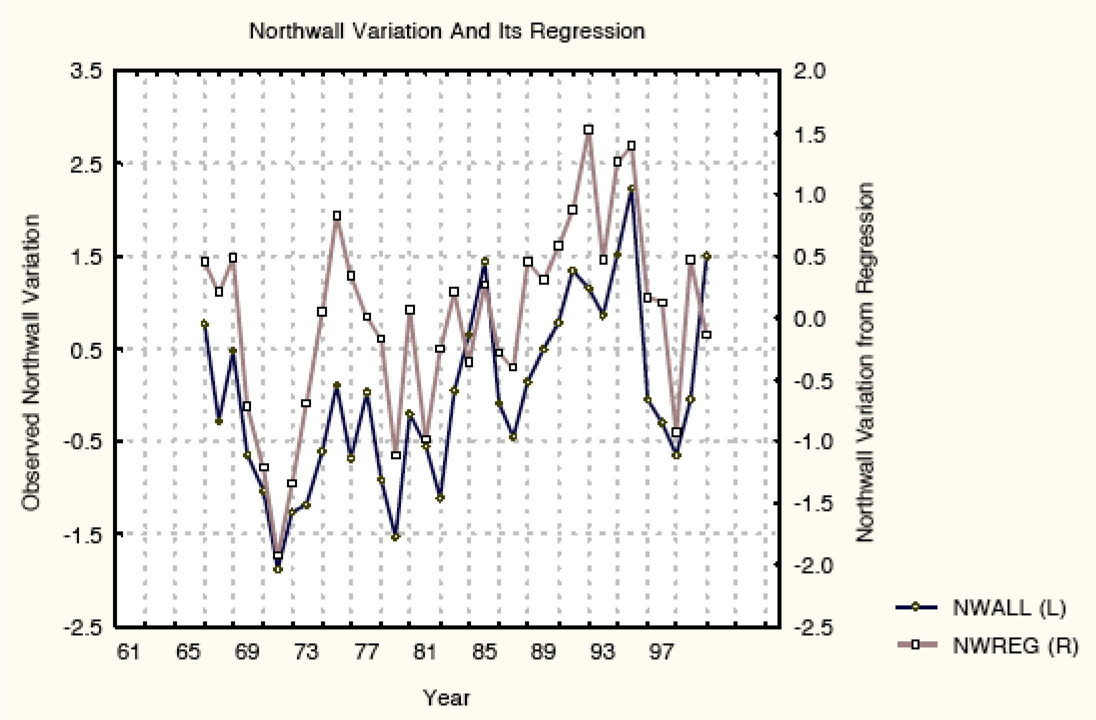


To illustrate more clearly the lateral shifting of the Gulf Stream one can define an ad hoc north wall position as the place where the temperature drops 2°C below the maximum temperature in the stream (this type of definition is far more robust than looking for the sharpest drop or gradient). The following figure shows the lateral shifting of the north wall, as determined from individual sections (light green), with a three-month low-pass filter (black) and one year LP filter (red). For the last several years the northwall has generally been north of its 12 year average. The very large swings during the last two years have not been looked at yet.



On the cause of these variations

What drives the position (or path) of the Gulf Stream and variations in SST and SSS? It is beyond the scope of this report to go into this in detail, but one hypothesis argues that the Gulf Stream separation is set by changes in transport induced by changes in wind stress curl (the Parsons-Veronis theory), an idea that has been tested with some success by Gangopadhyay *et al*. (1992). Another idea is that variable fluxes of water from the Labrador shelf 'push' the Gulf Stream farther offshore as well as dilute the salty waters leaking from the stream (RB). A recent very interesting study by Hameed and Piontkovski shows a striking correlation between the northwall position and an index based on the intensity of the Icelandic low and its longitude (with a couple of years' lag). While the ideas developed here have a close tie to the standard NAO index, the authors found that the role of the Azores High played a negligible role. What was much more important was the intensity and position of the Icelandic low. The correlation in the 30 year record is quite striking, next figure.



Comparison of the Gulf Stream north wall variation (solid line) and the results of the regression: GSNW = 342.8 – $0.343(IL_p)_{-2} + 0.083(IL_{lon})_{-3}$. The regression explains 64% of the northwall variance. Hameed and Piontkovski, 2004. (Shown with kind permission from the authors.)

References

Gangopadhyay, A., P. Cornillon and D. R. Watts, 1992. A test of the Parsons-Veronis hypothesis on the separation of the Gulf Stream. J. Physical Oceanography, 22: 1286-1301.

Hameed, S. and s. Piontkovski, 2004. The dominant Influence of the Icelandic Low on the Gulf Stream north wall. To appear in Geophysical Research Letters.

Rossby, T and R. Benway, 2000. Slow variations in mean path of the Gulf Stream east of Cape Hatteras. Geophysical Research Letters. 27(1),117-120.

Annex K: Area 3: Icelandic waters

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Iceland is situated 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. To the south is the warm Irminger Current, which is a branch of the North Atlantic Current (6-8°C), and to the north are 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.

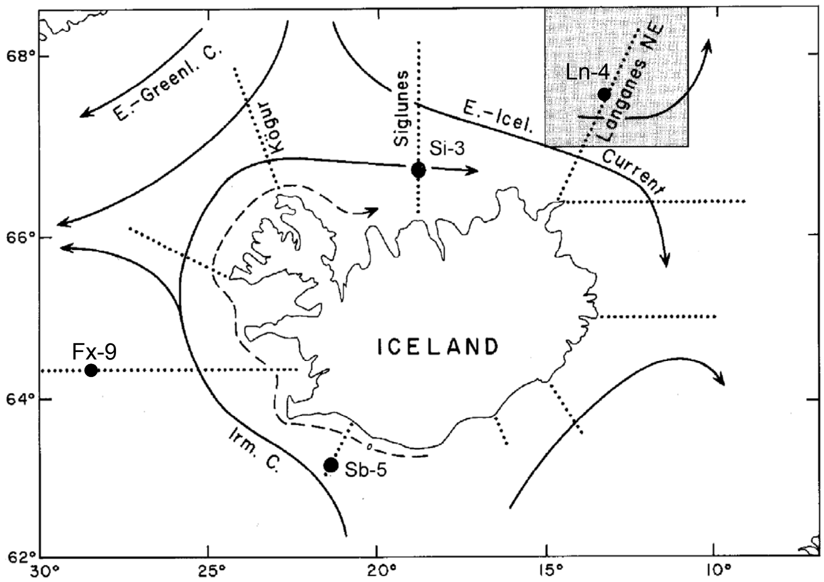


Figure 1. Main currents and location of standard hydro-biological sections in Icelandic waters. Selected areas and stations dealt with in this report are indicated.

Hydrographic conditions in Icelandic waters are generally reflected in the atmospheric or climatic conditions in and over the country and the surrounding seas, mainly through the Icelandic Low and the Greenland High (Figure2). 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.

The hydrographic conditions in 2003 revealed winter, spring, summer and autumn values on the shelf (Figures 2a, 4, 5 and 7) above the long term mean (1970-2003) for both temperature and salinity.

The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years (Fig 3.b, 5 and 7), and even higher than the highest values observed earlier.

Atlantic water extended relatively far to the north in the northern area and the cold water north, north-east and east of Iceland and in the East Icelandic Current was far offshore in 2003. The salinity in the East Icelandic Current in spring 2003 was about average but temperature was above the 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 decrease in 2002 (Figure 2b) and were then followed by the mild conditions for all seasons in 2003.

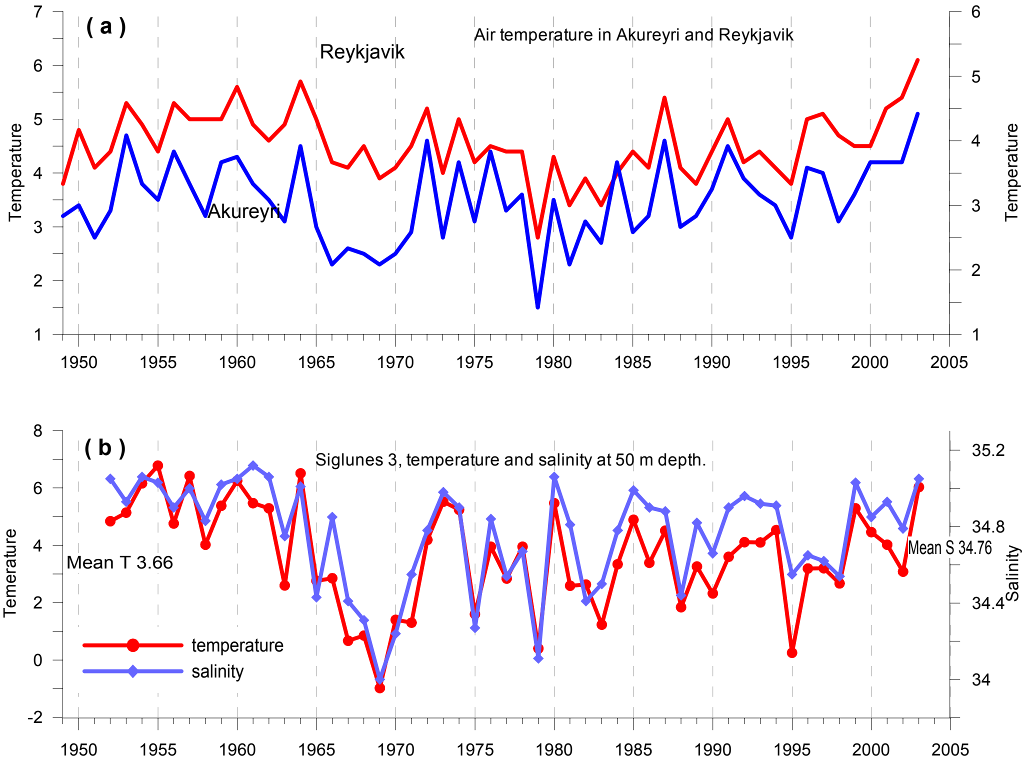


Figure 2:

a. Mean annual air-temperatures in Reykjavík and Akureyri 1950-2003;
b. Temperature and salinity at 50 m depth in spring at Station Si-3 in North Icelandic waters 1952-2003.

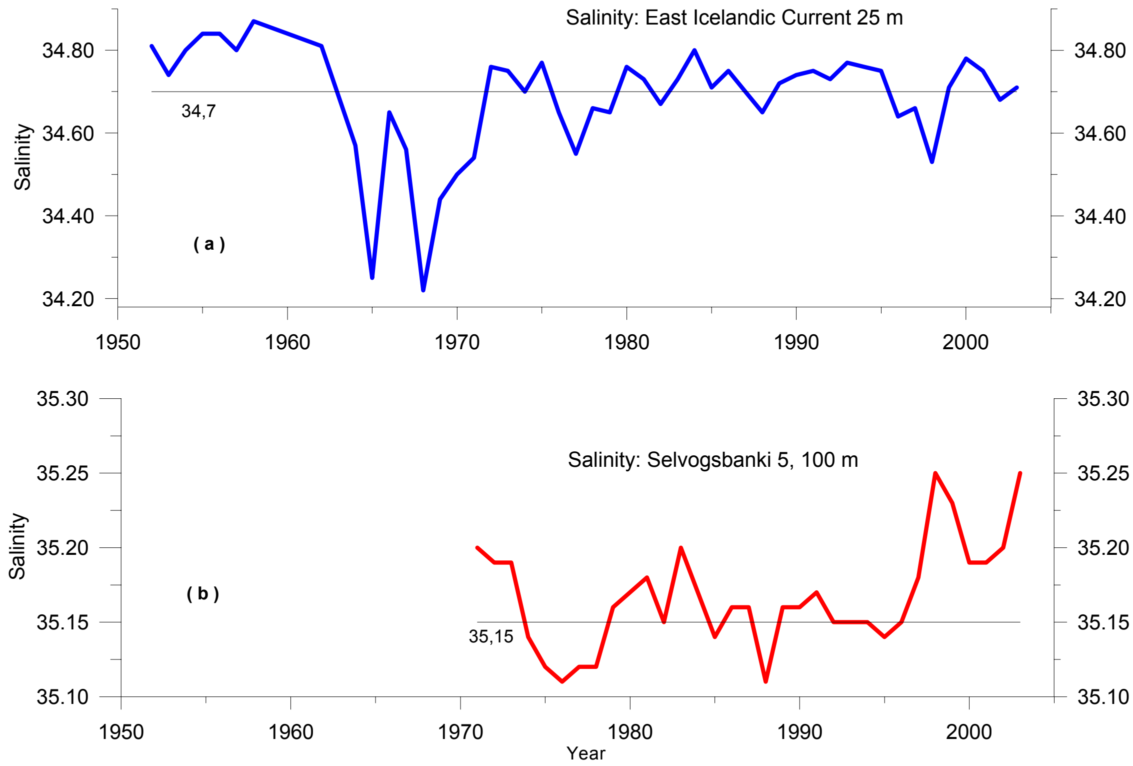


Figure 3. Salinity in spring at:

a. 100 m depth in the Irminger Current south of Iceland (Sb-5) 1971-2003.
b. 25 m depth in the East Icelandic Current north-east of Iceland 1952-2003, mean from shaded area in figure 1.

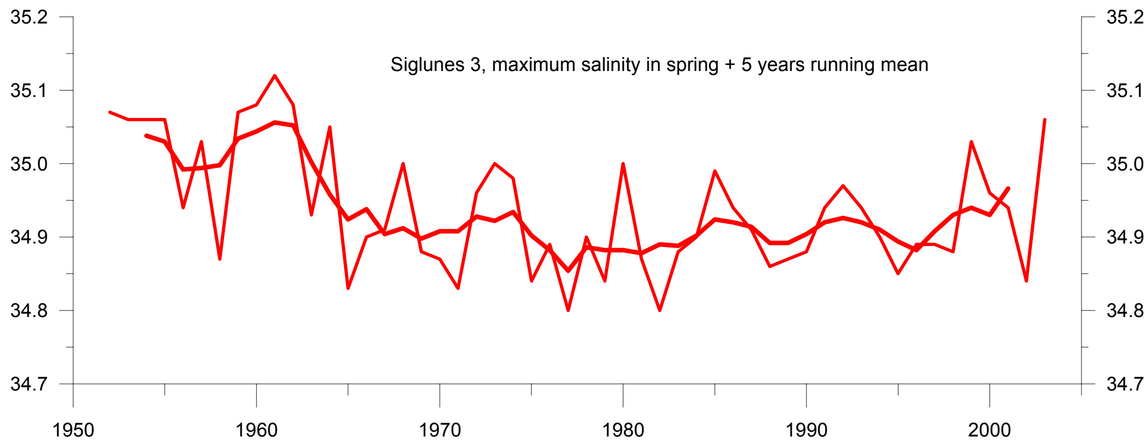


Figure 4. Maximum salinity in the upper 300 m in spring at station Si-3 in North Icelandic waters 1952-2003 and 5 years running mean.

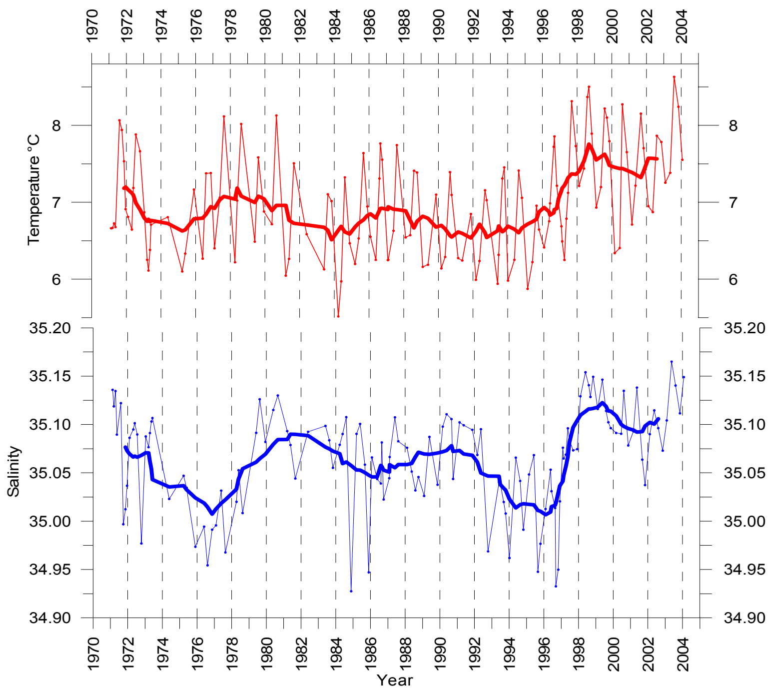


Figure 5. Mean temperature 0-200 m at the shelf brake west of Iceland, 1971-2004. Combined data from stations RE8 (1971-1984) and FX9 (1984-2004), 20 nm apart. Thick line is approx. 3 yrs running mean.

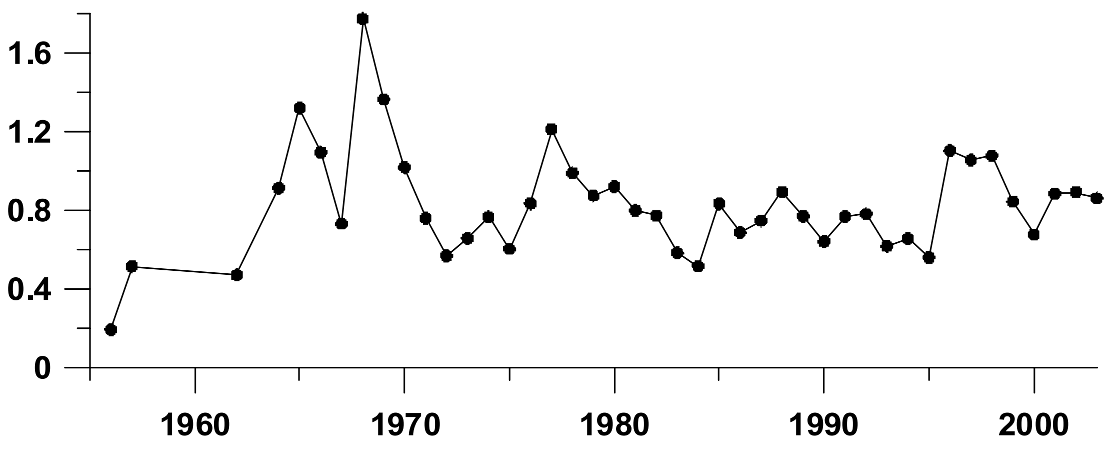


Figure 6. The fresh water thickness at Langanes NE 4 above 150 m, relative to salinity of 34.93 in May/June 1956-2003.

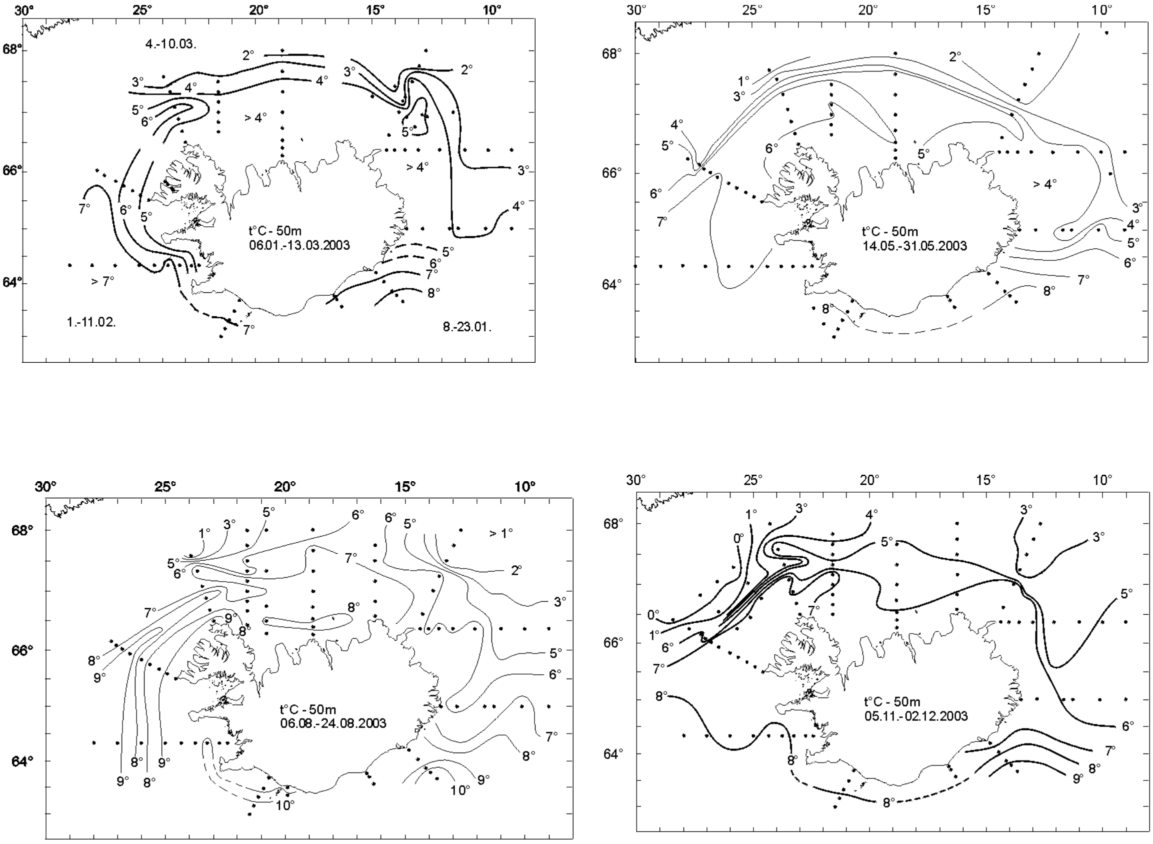


Figure 7. Temperature at 50 m depth in Icelandic waters in Jan/Feb/Mars, May, August and November/December 2003.

Annex L: Hydrographic Status Report 2003, Spanish standard sections (Area 4).

A Lavín, C. González-Pola and J. M. Cabanas
Spanish Institute of Oceanography (IEO, Spain)
V. Valencia, A. Fontán and A. Borja
Department of Oceanography and Marine Environment (AZTI Foundation, Spain).

The results for the Bay of Biscay (Area ICES 4) during year 2003 are presented as two independent documents from two different organisations. The part A is compiled from the IEO (Spanish Oceanographic Centre) and comprises the results from 5 Standard Sections along the Spanish North Coast from Vigo (~ 42ºN, 9ºW) to Santander (~ 43.5ºN, 4ºW). Part B is compiled from the Basque country Department of Oceanography and Marine Environment (AZTI) and covers the South-Eastern part of the Bay of Biscay based on a standard section located at ~ 43.5ºN, 2ºW. Both reports were written independently by the two organisations and the deadline for the report presentation to the ICES Working Group prevented the compilation of a unique document with a combined analysis for the whole area

A: IEO

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, the largest in Santander (43.5ºN, 3.8ºW), two in Asturias (43.6ºN, 6.2ºW) and (43.6ºN, 5.6ºW) from the year 2001, and in La Coruña (43.40ºN, 8.3ºW) and Vigo (42.1ºN, 9.0ºW). (Figure 1).

The Bay of Biscay is almost adjacent to the Atlantic, situated between the eastern part of the subpolar and subtropical gyres. The region is affected by both gyres depending on latitude, but the general circulation in the area mainly follows the subtropical anticyclonic gyre in a relatively weak manner (1-2 cm/s). At the southern part of the Bay of Biscay, east flowing shelf and slope currents are common in autumn and winter due to westerly winds, whereas in spring and summer eastern winds are predominant and coastal upwellin events are frequent.

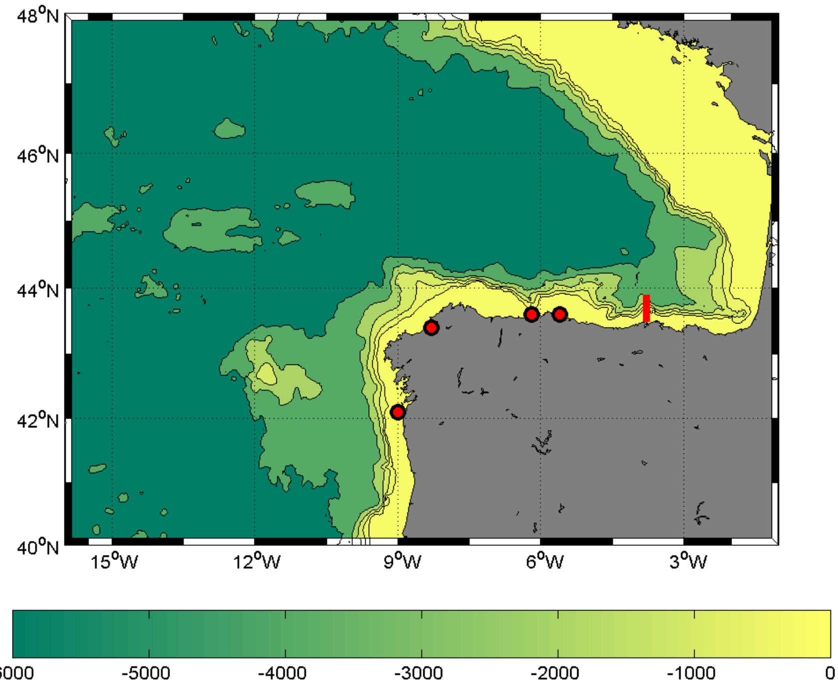


Figure 1. Spanish Standard Sections from the 'Instituto Español de Oceanografía'.

Meteorological Conditions

Meteorological conditions in the north of the Iberian Peninsula in 2003 (source: Centro Meteorológico Zonal de Cantabria y Asturias, Instituto Nacional de Meteorología) indicate that it was a warm year. Mean air temperature was 15.3ºC, 0.9ºC higher than the 1961-2003 average. This value is similar to those of 1994, 1995 and 1997 and lower than the 1989 value, the highest of the time series and higher than 2 standard deviations. The 2003 value exceeded the mean value by 1.5 standard deviations. After five years of air temperatures around 14.8, air temperature in 2003 increased again to values similar to the ones reached around the mid-nineties, but lower than those reached at the end of the eighties. Figure 2 shows the plot of the annual mean values and mean value of 14.4ºC.

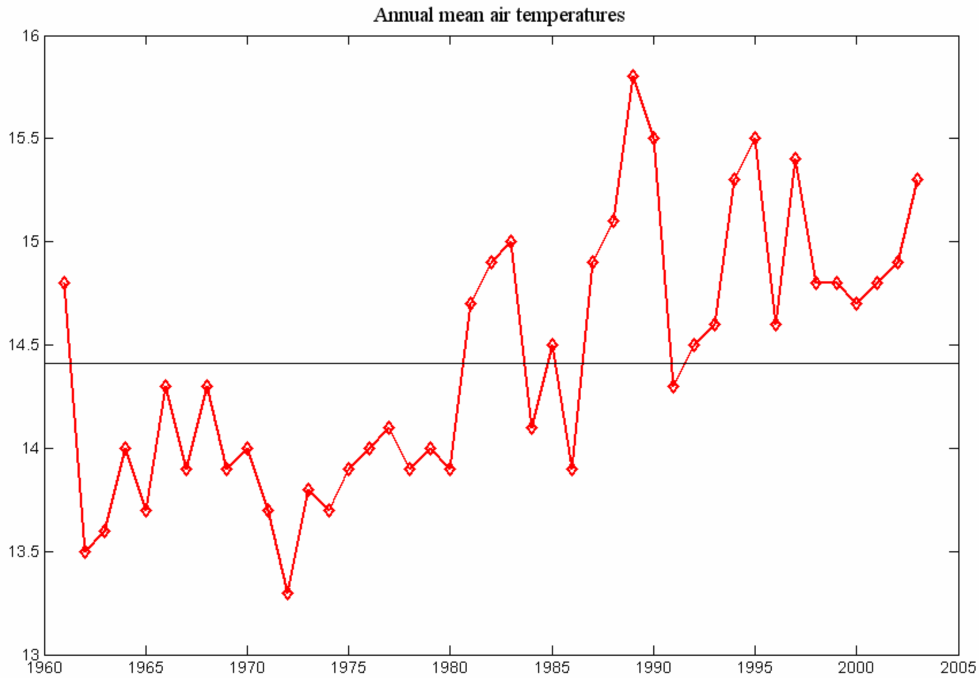


Figure 2. Annual mean temperatures in Santander (43.5ºN, 3.8ºW) and mean value of 14.4ºC.

Courtesy of the 'Instituto Nacional de Meteorología'

Nevertheless, negative anomalies in the annual cycle appear in winter (January and February) and autumn (October). From March to September, positive anomalous behaviour is outstanding and gave rise to the annual high value. The mean anomaly for this spring-summer period was of 1.5ºC/month. Behaviour in 2002 was the opposite with a warmer winter and a colder summer. The value of 22.8ºC in August is the highest monthly mean temperature of the INM time series 1961-2003. In relation to precipitation, the beginning of the 2000's is the driest period in the historical time series, only in the late 1980's (1987-1989) was precipitation low, coinciding with the warmest period in the series. Precipitation was below the mean value in all months of 2003 except January, October and December, and the April value was under one statistical deviation. Mean precipitation during the period March-September was half of the mean historical time series value. The difference between high summer temperatures and low winter temperatures (August-January), 13.2ºC, was the highest in 2003 following a historical minimum of just 6.7ºC (August-February) in 2002. Figure 3 shows the monthly mean air temperatures superimposed on the annual cycle in Santander ("Instituto Nacional de Meteorología"). This annual cycle was calculated as mean value from 1961 to 2003 and 1 and 2 standard deviations have been added. Monthly values of 2002 (black circles) and 2003 (red stars) are plotted.

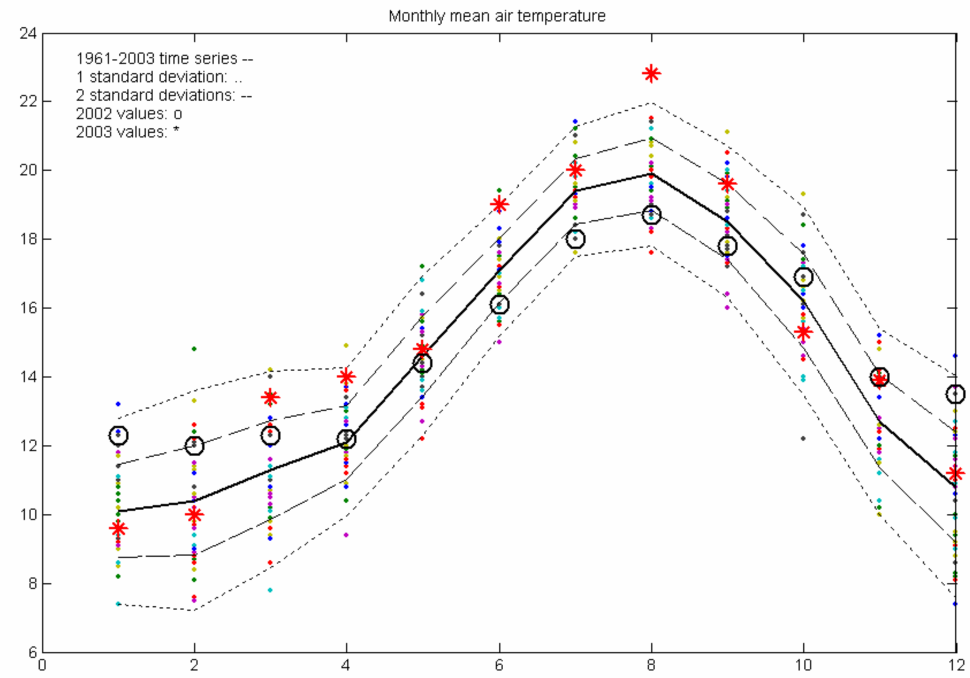


Figure 3. Air temperatures in Santander (43.5ºN, 3.8ºW).
Courtesy of the 'Instituto Nacional de Meteorología'

Hydrography

In order to get a first approximation to the data, contours of temperature and salinity (over the shelf, 100 m depth) in the Santander section are shown in Figure 4. The seasonal temperature cycle stands out clearly in the upper layers. Stratification develops between April-May and October-November, and during the rest of the period the water column is mixed. Summer stratification in 2003 presented a shallow picture similar to the previous ones of 2001 and 2002 (the thermocline reached as much as 30 m depth) but warming was stronger and more persistent in 2003 than those years, forced by the previously described meteorological conditions. The warming period was also the longest, in contrast to the previous one in 2002, which was the shortest in the time series. Some indication of bottom cooling seems to point to upwelling episodes. Salinity contours show low salinity values in the upper layers, in summer due to the advection from the east of warm surface water from river discharges in the southeast corner of the Bay of Biscay, and in spring due to local river overflow. In 2003 advection and river overflow were low compared with the strong years of 1995 and 2001. High salinity values over most of the shelf, which resulted from the strong incursion of saltier and warmer water in 1997, fell from January 2000 to values of the same order as those of 1995. The autumn 2002 saltier incursion (poleward current) increased salinity over the shelf, but after the episode salinity fell.

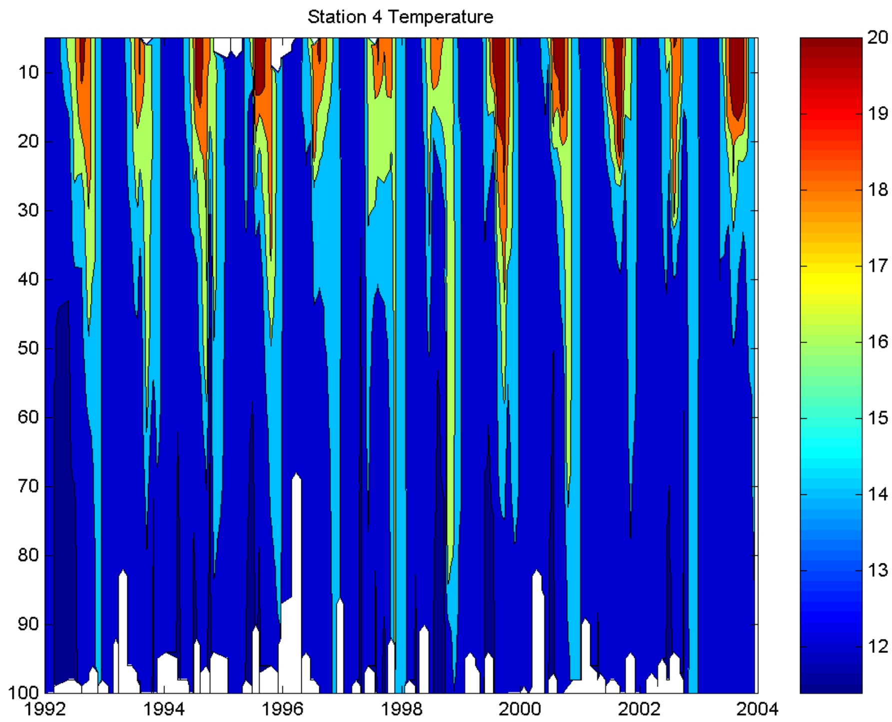


Figure 4a. Temperature evolution at Santander station 4 (shelf).

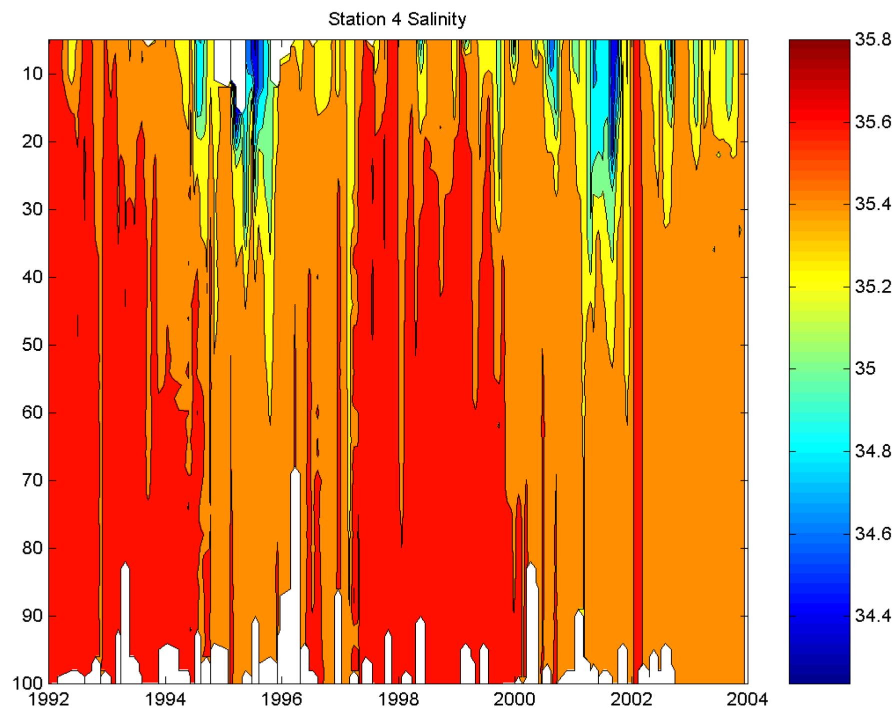
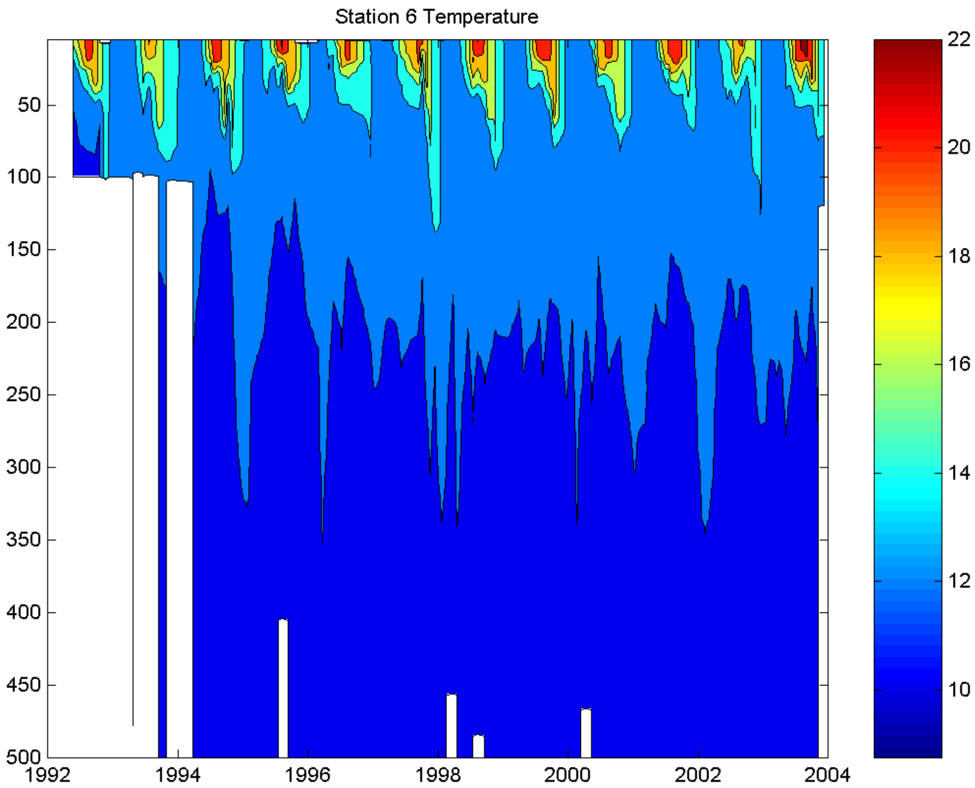


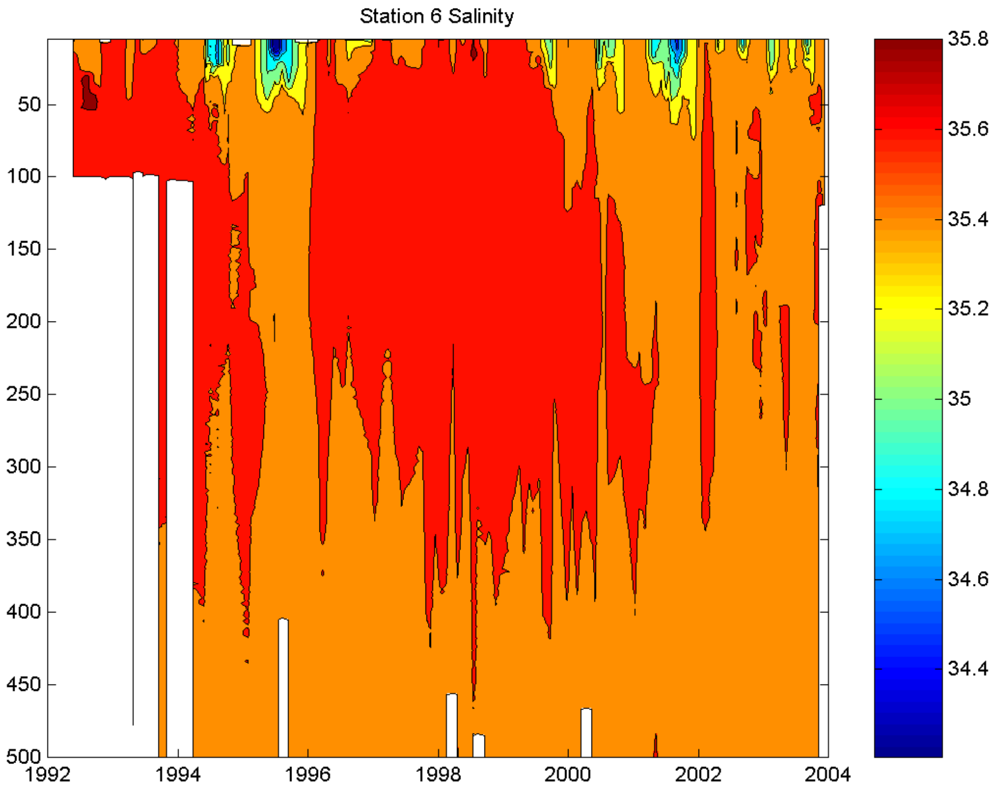
Figure 4b. Salinity evolution at Santander station 4 (shelf).

Contours of temperature and salinity over the shelf-break (600 m depth) in the Santander section are presented in Figure 5. During the first period (1992-1994) only upper layers were sampled. Temperature contours of 2003 presented the highest values of the time series, As happened over the shelf, the period of low salinity in the upper waters (1994-1995 and 2000-2001) was reduced to some extent. Below the mixed layer, salinity fell from 1992 to 1995 and increased again to 1997/1998 before falling once more until 2001. The 2002 winter poleward current showed increasing salinity in the upper 300 m, which then decreased in spring and seemed to increase again at the end of the year, presenting irregular values in autumn 2002 and 2003. Regarding temperature, this warm water mass is detected up to depths of 300m. Stratification develops between April-May and October-November, mainly reaching 100m depth, and during the rest of the period the water column is mixed, with autumn mixing outstanding even up to 300m depth.

Salinity contours show high values after the end of the mixing period at the beginning of winter, the saltier period sometimes extending to that depth due to the poleward current. Winter 1996 was a good example, in 1998 it looked strong and in 2002 it was also detected, but not during 2003.



Figures 5a. Temperature evolution at Santander station 6 (shelf-break).



Figures 5b. Salinity evolution at Santander station 6 (shelf-break).

A similar way of visualising the behaviour of the hydrography compared with the historical data is to superimpose several time series at different depths. Figure 6 shows such a representation for station 6. We can see how years with low salinity values in surface waters (NE regimes) enhance a shallow sharp thermocline.

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 autumn cooling is less abrupt. The warmer and long 2003 summer produced high surface temperatures but only in the upper layers. From 50m temperature conditions are similar to those of previous years. Low wind intensity produces this shallow effect. As mentioned previously, superficial salinity presents a seasonal decrease brought about by the advection of fresher water from the east of the Bay of Biscay, usually in spring-summer when the wind regime is from the first quadrant. The poleward winter signal in February is present at all depths, but mainly at 200m.

Fitting the temperature signal by two harmonic terms plus a linear trend, we can reproduce the signal approximately. Taking this into account, we can compare the year 2003 with the climatological mean for surface waters by finding a slightly cool winter followed by a persistent warm summer for the upper water layer (Figure 7). Anomalous high values are present from June to October, with values higher than 1ºC for four months (Figure 8). From the coldest surface waters of 2002 we have changed to the warmest year of the sampled period. Winter 2003 presents the coldest February of the sampled period but from late March conditions are warmer than the mean (Figure 9).

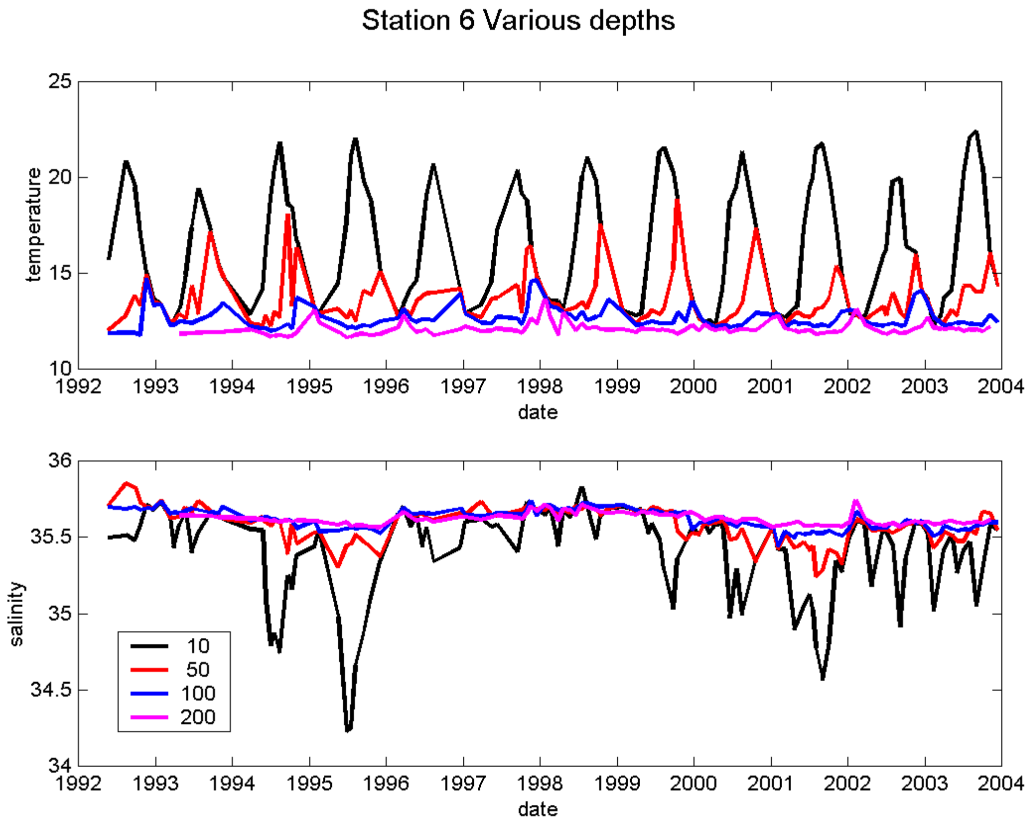


Figure 6.Temperature and Salinity at various depths, Santander station 6 (shelf-break).

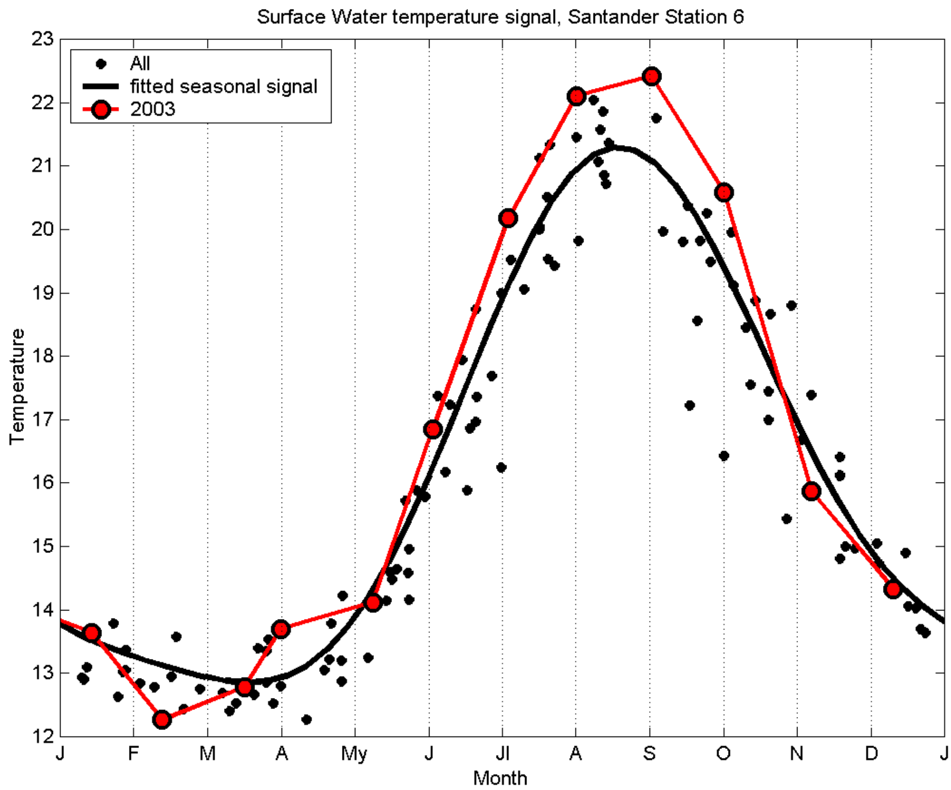


Figure 7.Seawater Surface Temperature at Santander station 6 (shelf-break).

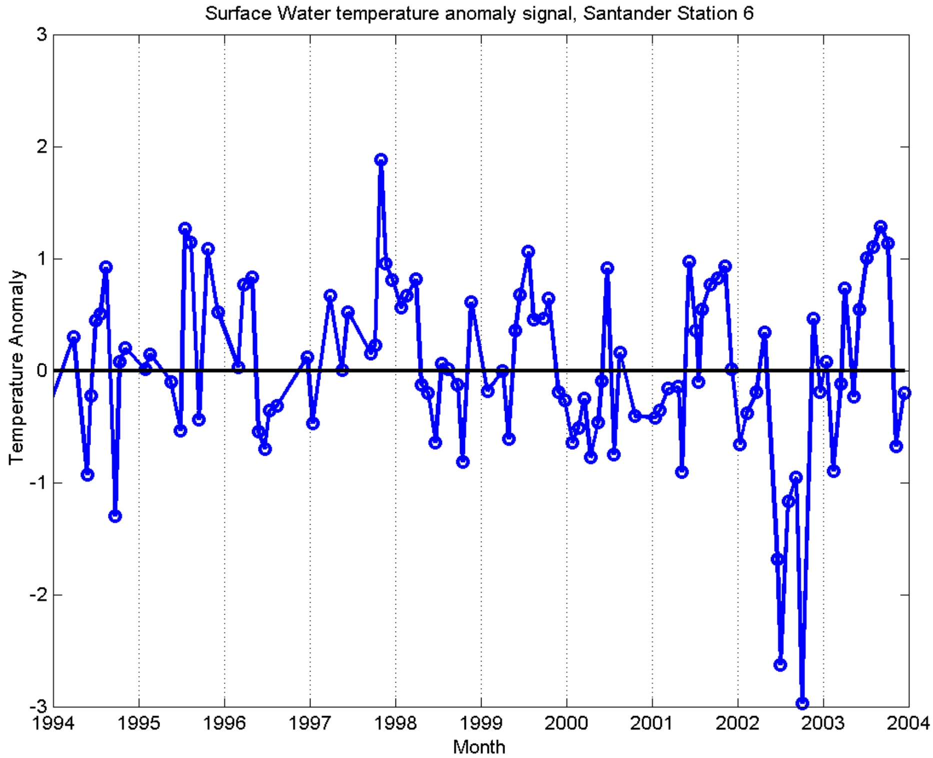


Figure 8. Seawater Surface Temperature Anomaly at Santander station 6 (shelf-break).

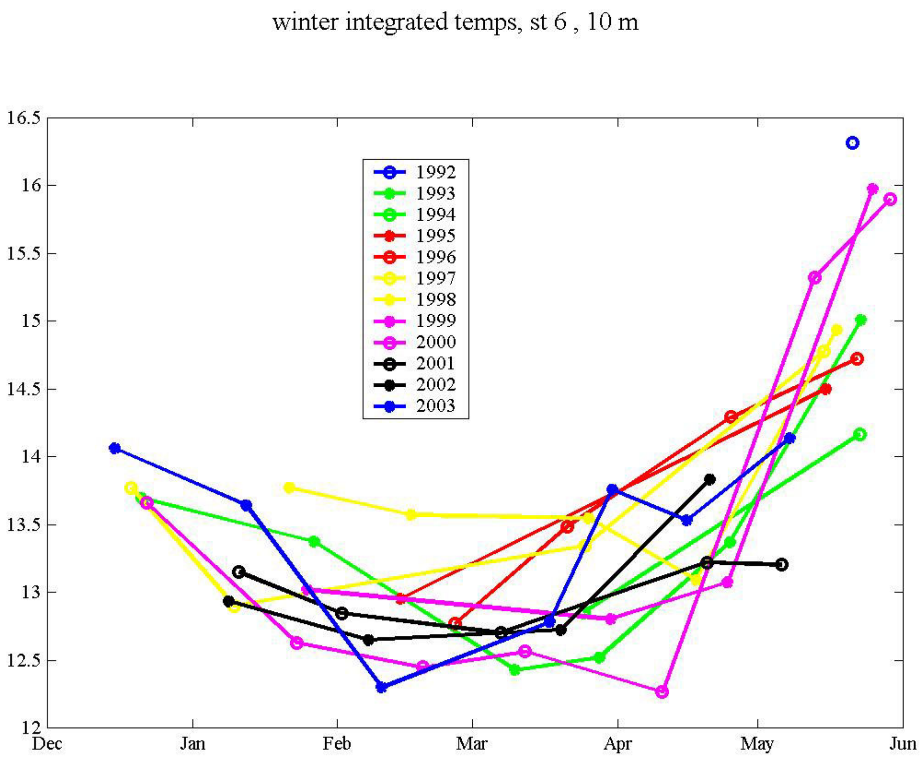


Figure 9. Winter-Spring surface temperatures at Santander station 6.

Between 1998 and 2001, evidence was found of a decline in salinity up to a depth of 300m. In 2002 this trend was inverted, especially during the poleward episode at the beginning of the year. After that, close to average salinity was found during 2002 and 2003. Low precipitation in the Bay of Biscay at the beginning of the 2000 decade also influenced this recovery of salinity values. Anomalies in the salinity of this layer (5-300 m) are shown in Figure 10 for station 6. The same behaviour is found for shelf stations. Down to this depth salinity evolution does not have clear cycles but positive trends towards higher salinities seem to appear at deep levels (North East Atlantic Central Water and Mediterranean Overflow Water).

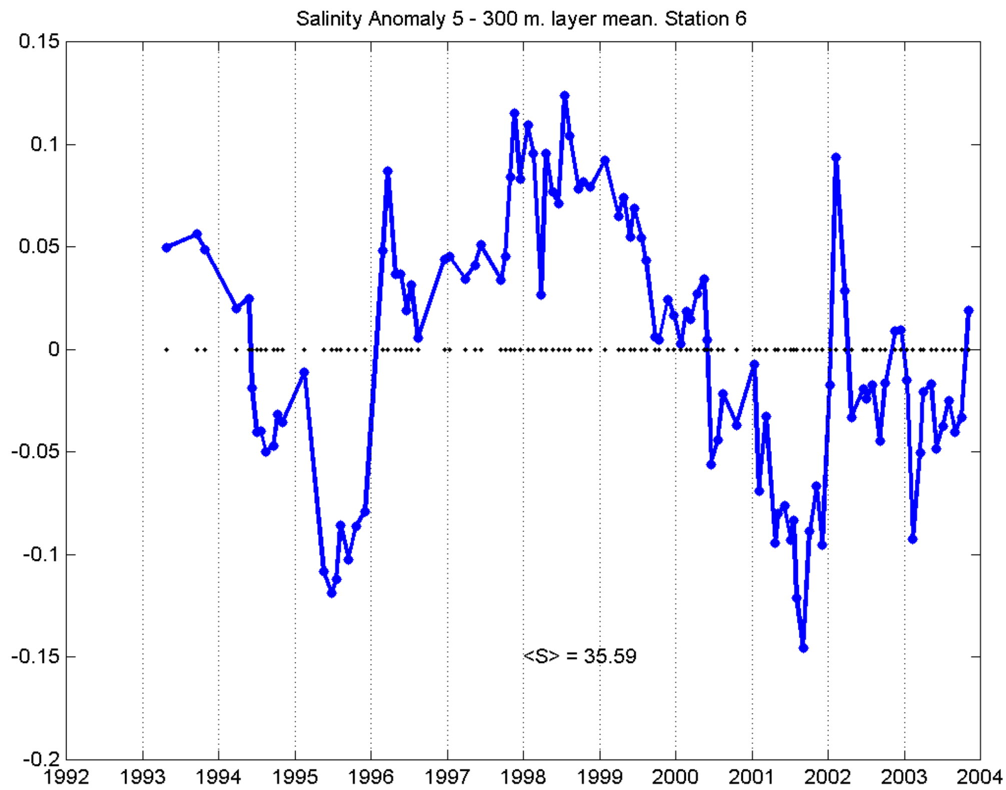


Figure 10. Salinity anomaly evolution (5-300m) at Santander station 6.

Heat Content

Heat content in 2003 seems to be around average. High summer temperature values were not relevant when we integrated the upper 500m of the water column. Winter poleward episodes produce high heat content, similar to the 1996 and 1998 values at 200-500m. Autumn mixing produces similar heat to the previous years but not as high as the 1998 values. In Figure 11 we can see evolution in both the mixing layer and NEACW. Total heat content for the whole 500m first layer during the last three years followed a repetitive annual cycle.

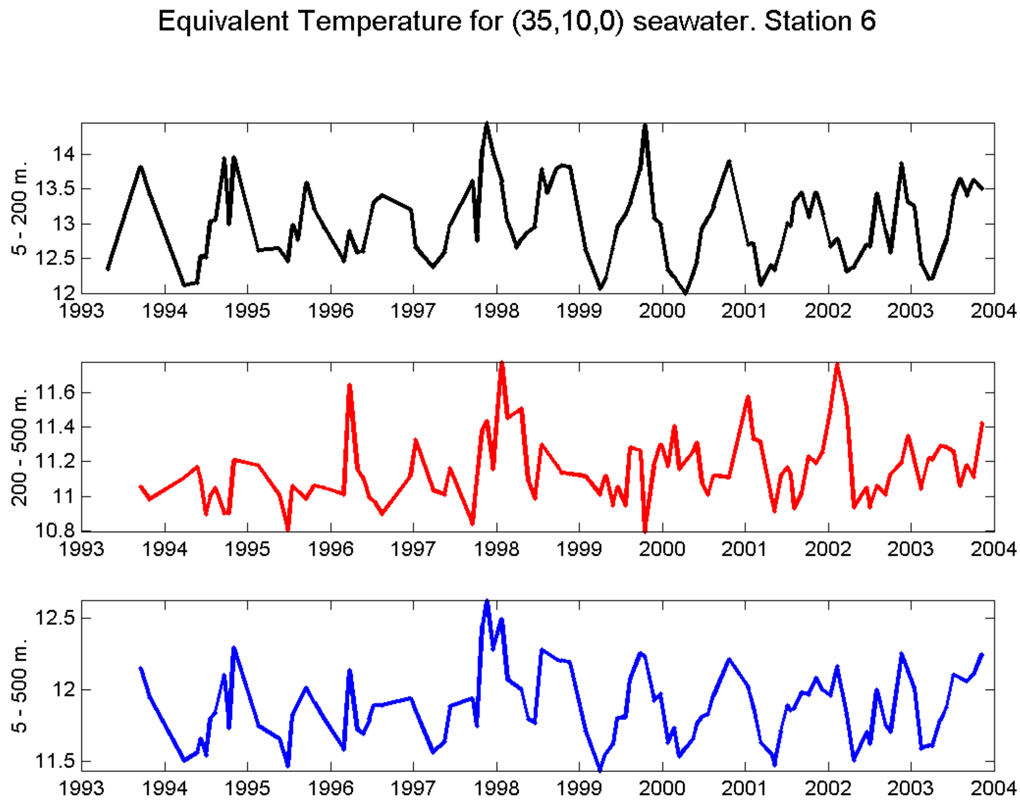


Figure 11. Heat stored in the water column at Santander station 6.

Vigo Standard Section

Contours of temperature and salinity over the shelf (94 m depth) in the Vigo section from 1994 to 2003 are presented in Figure 12. The seasonal cycle in temperature is outstanding in the upper layers; autumn 97/Jan98 was the warmest period of the time-series. Stratification develops between April-May until October-November, frequently broken by upwelling events. At some depths, salinity contours showed high values all year in 1996, 1997 and 2000; in the remaining years this was only true in winter due to the poleward current. Considering upwelling/poleward current timing and intensity, 2003 was below the last 10-year mean. In relation to winter poleward current (PWC), 2003 starts with a strong signal: high temperature and salinity according to the precipitation level; in summer poor upwelling and consequently water temperature above the mean was observed; at the end of the year a low level of PWC signal was observed. To summarise, 2003 was characterised by the lowest mean values of summer upwelling and low PWC signal at the end of the year. Salinity undergoes minor variations outside the runoff influence in upper levels near the coast.

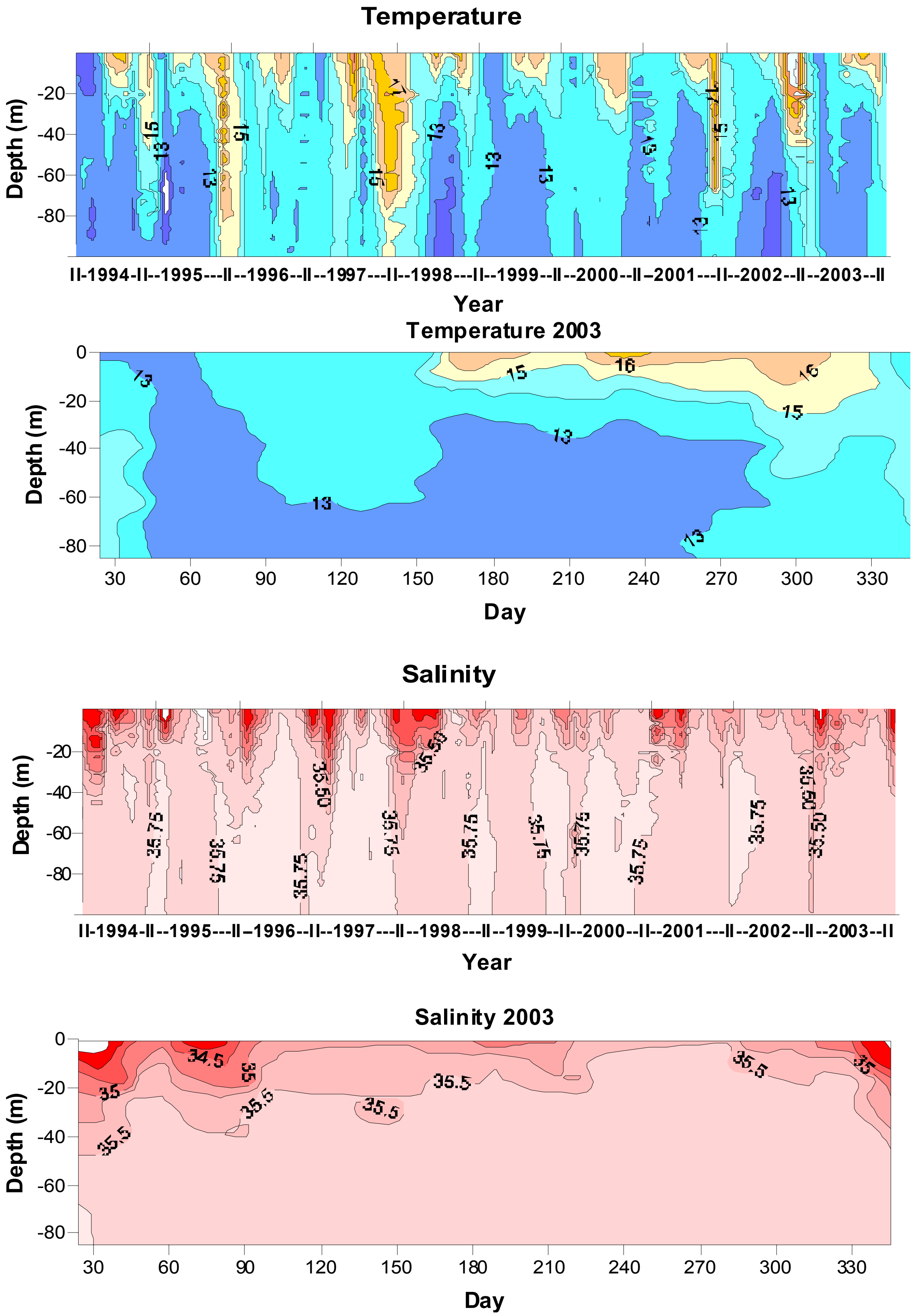


Figure 12a, b, c and d. Seawater evolution at Vigo (42.1ºN, 9.0ºW) station.

Part II: ***AZTI***

In addition to the area of the shelf and shelf-break, in the Eastern Atlantic and North Iberian Peninsula, covered by the Instituto Español de Oceanografía, AZTI collected oceanographic data at 43.30ºN, 2ºW (San Sebastián-Pasaia Section) over the continental shelf of the SE Bay of Biscay (Figure 1).

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

In the SE corner of the Bay of Biscay, relatively strong continental influence modifies both 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 can not 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, opposed to the atmospheric and sea surface cooling, should be explained by accumulation and downwelling of warm waters into the shelf area).

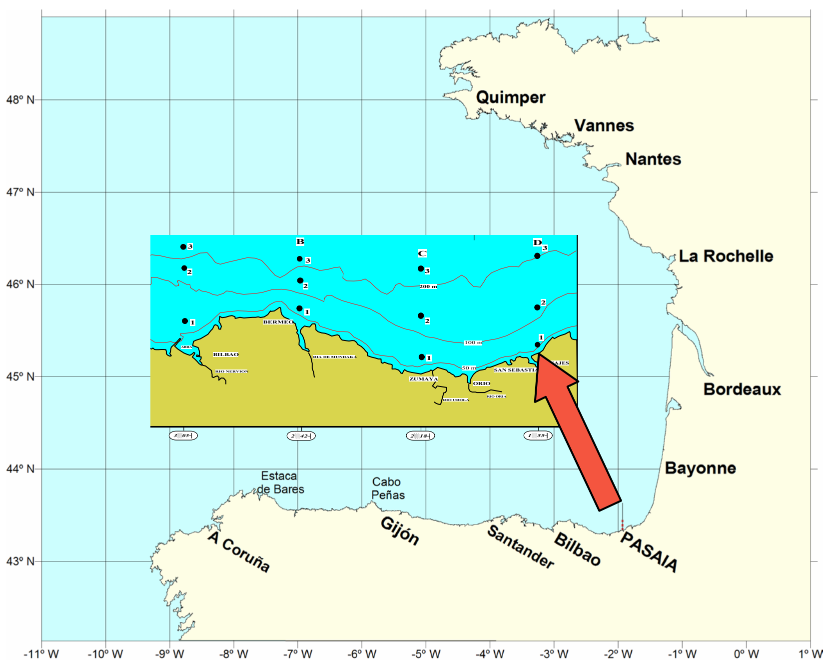


Figure 1. Spanish Standard Sections from the 'AZTI'

Meteorological Conditions

Meteorological conditions in the SE Bay of Biscay in 2003 (source: Observatorio Meteorológico de Igeldo, San Sebastián, Instituto Nacional de Meteorología) are characterised by very high summer temperatures (exceeding mean ± standard deviation for the period 1986-2003. Figure 2). The annual mean air temperature over the SE Bay of Biscay during 2003 (14.48°C) was 0.85°C higher than the 1986–2003 average temperature. In this period, only the years 1989 and 1997 was, as a whole, warmer than the year 2003. From March to September the mean monthly anomaly of the air temperature reached up to 1.86°C.

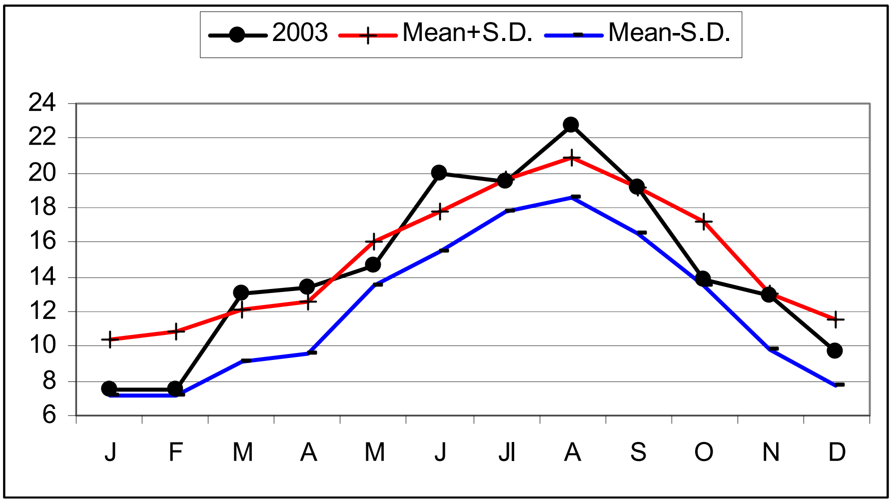


Figure 2. Monthly mean temperatures (°C) in San Sebastián (43°18.5′N 02°18.35′W) in 2003 in comparison with the mean ± standard deviation for the period 1986-2003. Data Courtesy of the 'Instituto Nacional de Meteorología'.

The peculiarities of the air temperature in 2003 can be observed in the context of the monthly mean temperatures of the reference period (1986-2003) and the evolution of the accumulated anomalies (Figure 3).

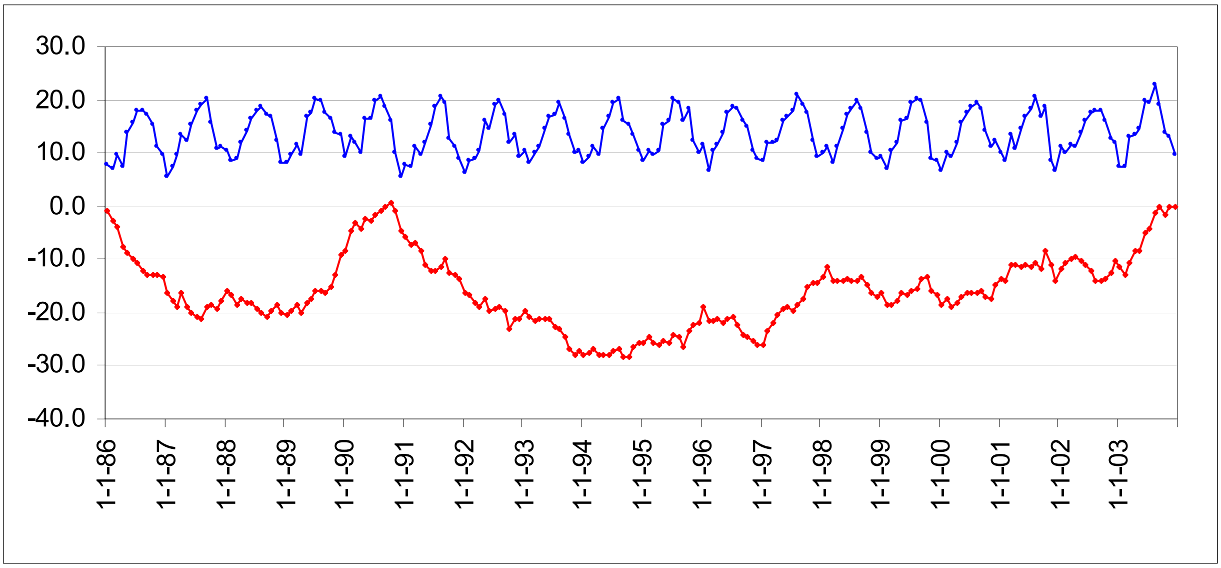


Figure 3. Monthly mean temperatures in San Sebastián (43°18.5′N 02°18.35′W) in 1986-2003 and accumulated anomalies. Data Courtesy of the *'Instituto Nacional de Meteorología'*.

In relation with the water balance, in 2003 predominates also the dry weather, especially during the summer season (Figure 4). In the context of the previous years, the second half of 2002 and the early 2003 shows a slightly recuperation in the precipitation, and in the precipitation minus evaporation balance, after the very dry autumn 2001 and winter 2002 seasons (Figures 5 and 6).

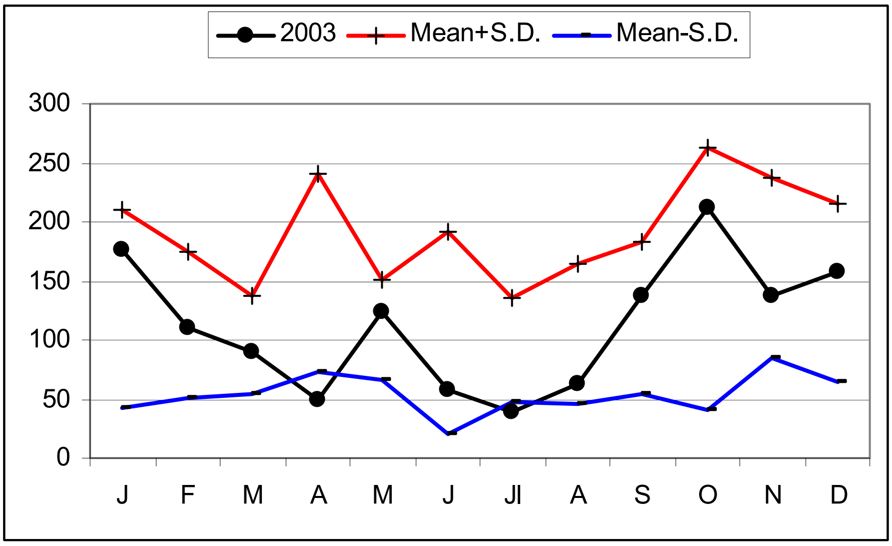


Figure 4. Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°18.35′W) in 2003 in comparison with the mean ± standard deviation for the period 1986-2003. *Data Courtesy of the 'Instituto Nacional de Meteorología'.*

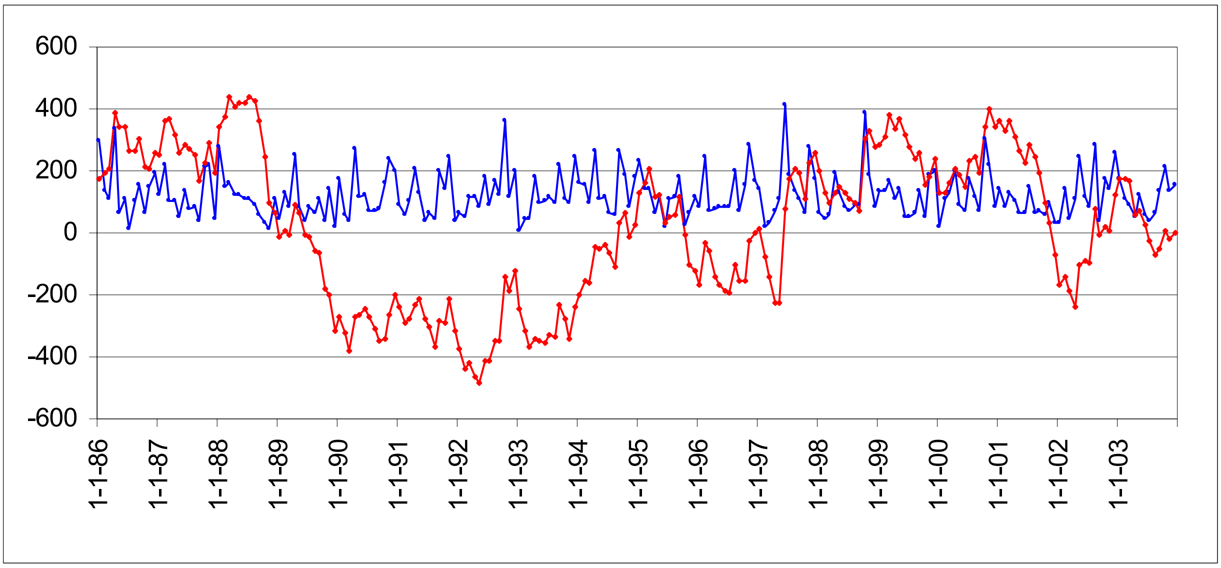


Figure 5. Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°18.35′W) in 1986-2003 and accumulated anomalies. Data Courtesy of the *'Instituto Nacional de Meteorología'.*

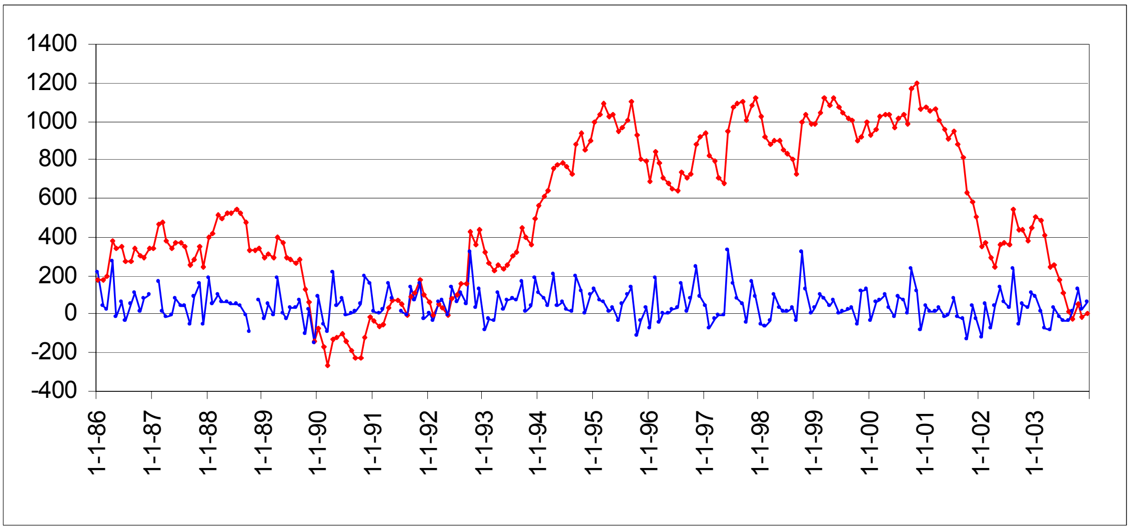


Figure 6. Monthly precipitation minus evaporation (mm) in San Sebastián (43°18.5′N 02°18.35′W) in 1986-2003 and accumulated anomalies. Data Courtesy of the *'Instituto Nacional de Meteorología'*.

The Gironde River runoff values represent well the water inputs 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. Figure 7 shows the very low flow period from April to November 2003 (-2260 m^3 s^{-1} accumulated anomaly) coincident with the warm (+ 10.5°C temperature accumulated anomaly) and dry same period (-183 mm in terms of precipitation accumulated anomaly and –425 mm in terms of precipitation minus evaporation accumulated anomaly).

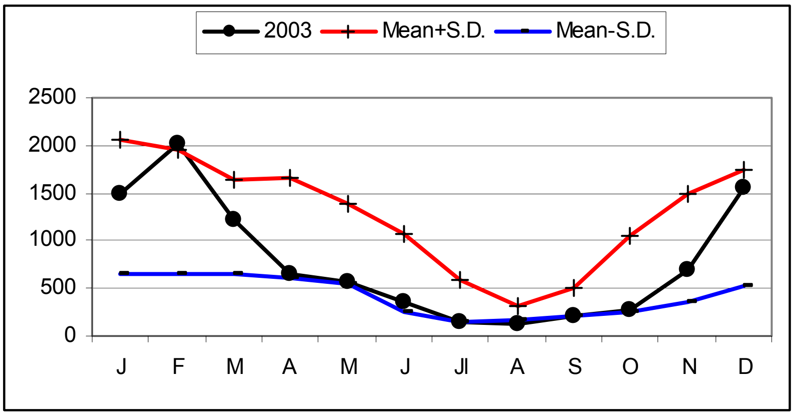


Figure 7. Monthly mean flow (m^3 s^{-1}) of the Gironde river in 2003 in comparison with the mean ± standard deviation for the period 1986-2003. *Data Courtesy of the 'Bordeaux Harbour Authority'.*

The peculiarities of the Gironde river flow in 2003 can be observed in the context of the monthly mean values of the reference period (1986-2003) and the evolution of the accumulated anomalies (Figure 8).

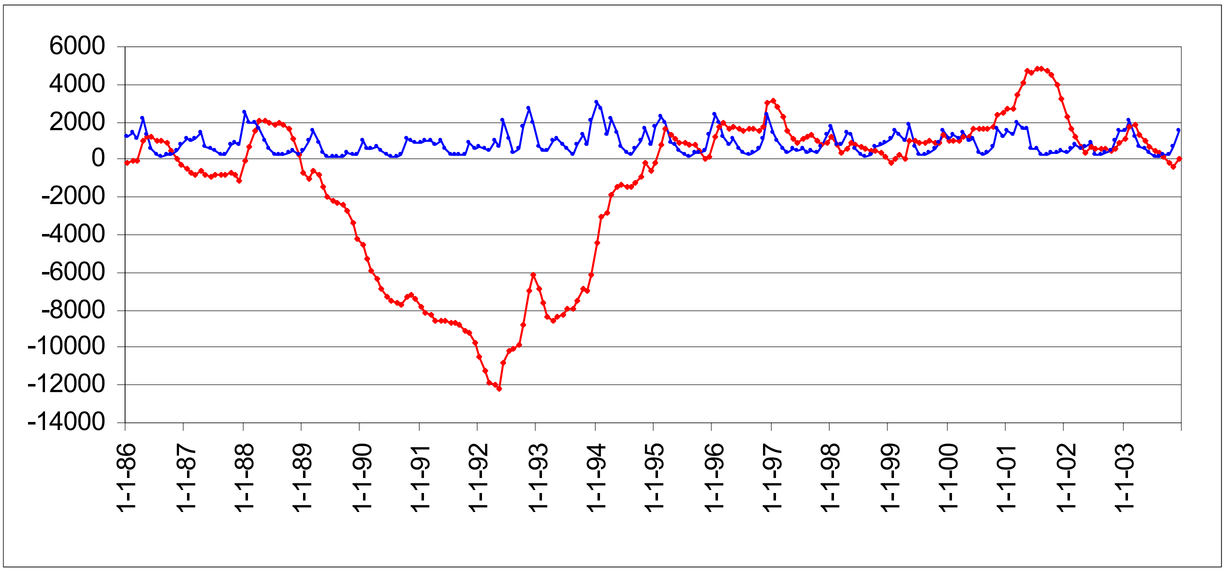


Figure 8. Monthly mean flow of the Gironde river ($m^3\ s^{-1}$) in 1986-2003 period and accumulated anomalies. *Data Courtesy of the 'Bordeaux Harbour Authority'.*

Hydrography

In order to get a first approximation to the hydrographic data collected during 2003, TS diagram of the waters over the continental shelf is shown in Figure 9.

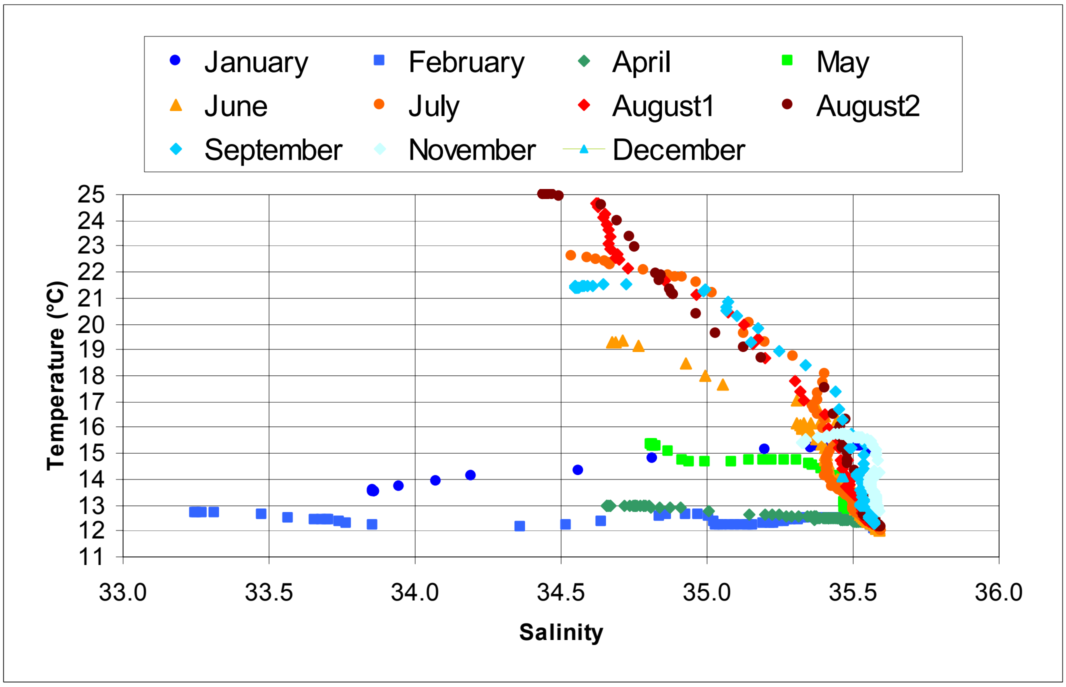


Figure 9. TS diagram of the waters over the continental shelf in the SE Bay of Biscay (43°30'N 02°00).

The response of the temperature and salinity of the upper layers to the climatological factors described is clearly observable in Figure 9. Thermal stratification develops between May and November. Moreover, a more or less extended haline stratification is present along 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.

Figure 10 shows the evolution of the mean monthly sea surface temperature (SST) in San Sebastián (time series from the Aquarium of the Sociedad Oceanográfica de Gipuzkoa). Very high values in summer 2003 can be observed. The peculiarities of the SST in 2003 can be observed in the context of the monthly mean temperatures of the reference period (1986-2003) and the evolution of the accumulated anomalies (Figure 11).

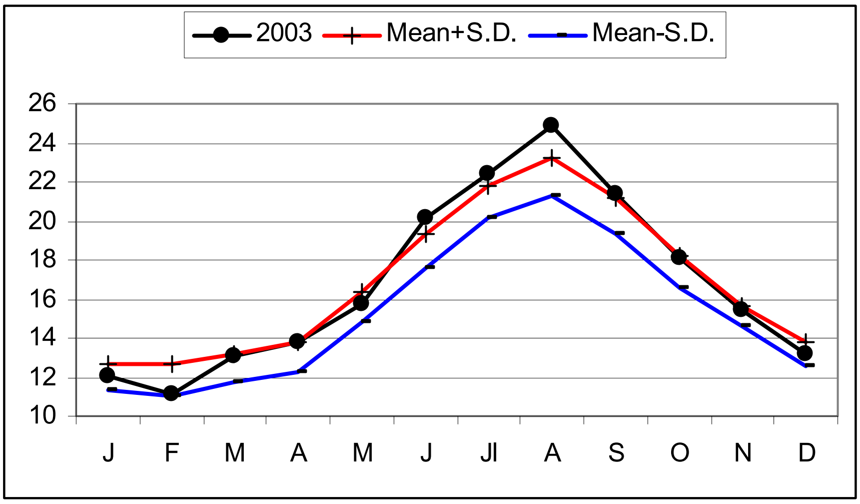


Figure 10. Monthly mean sea surface temperature (°C) in San Sebastián (43°20′N 02°00′W) in 2003 in comparison with the mean ± standard deviation for the period 1986-2003. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.

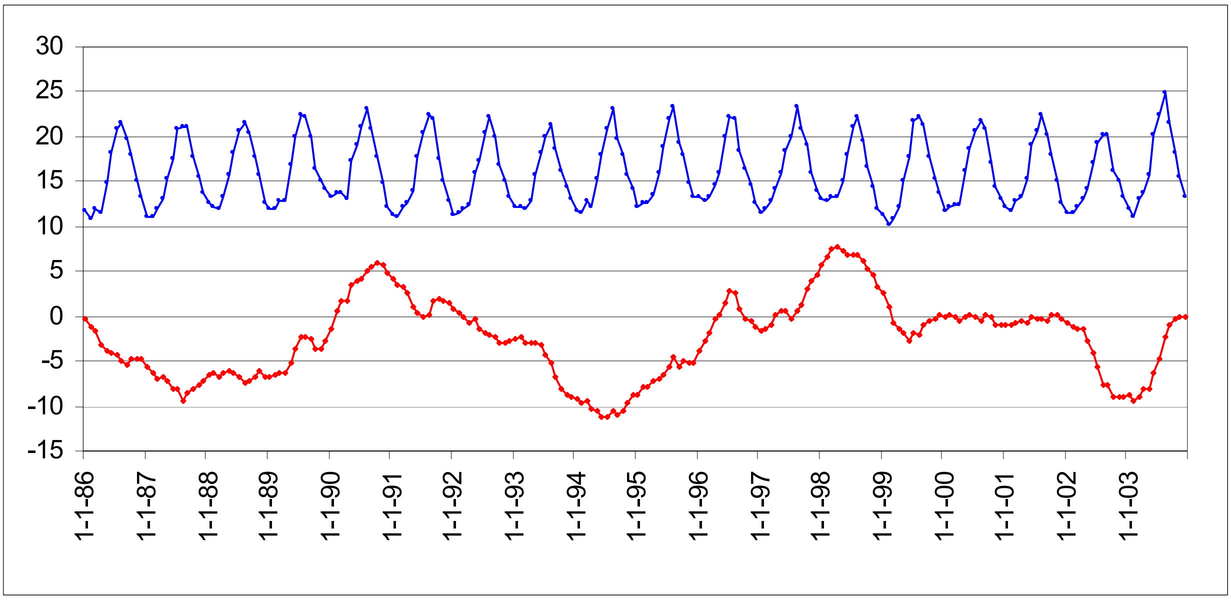


Figure 11. Monthly mean SST (°C) in San Sebastián (43°20′N 02°00′W) in 1986-2003 period and accumulated anomalies. *Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.*

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 the Figures 12 and 13 respectively.

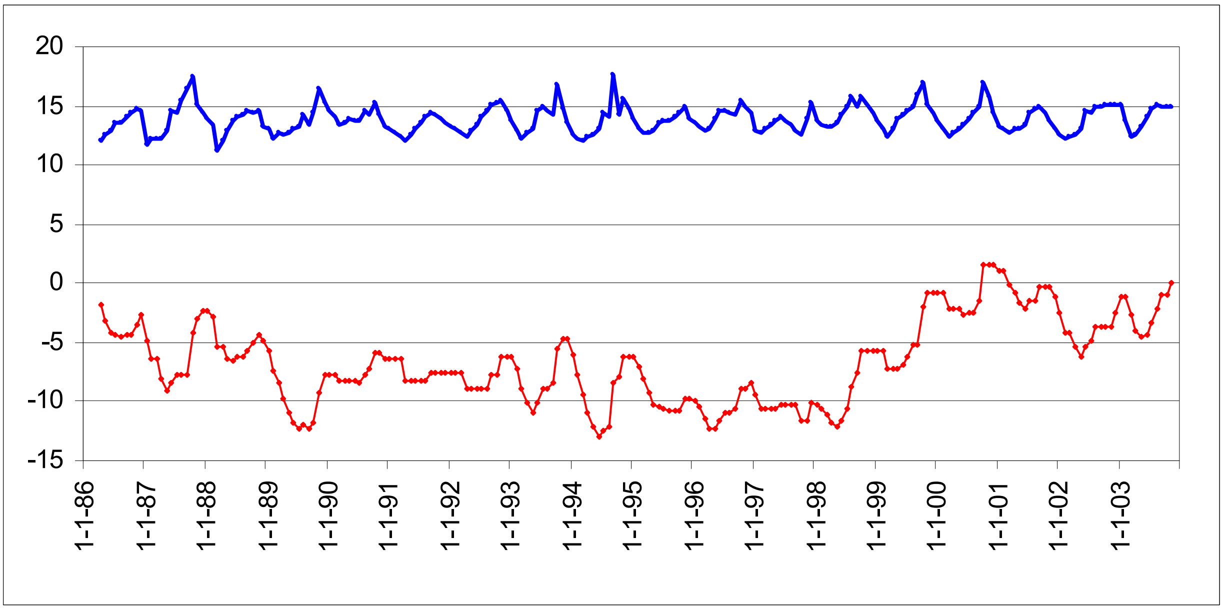


Figure 12. Monthly mean water column temperature (°C) in San Sebastián (43°30′N 02°00′W) in 1986-2003 period and accumulated anomalies.

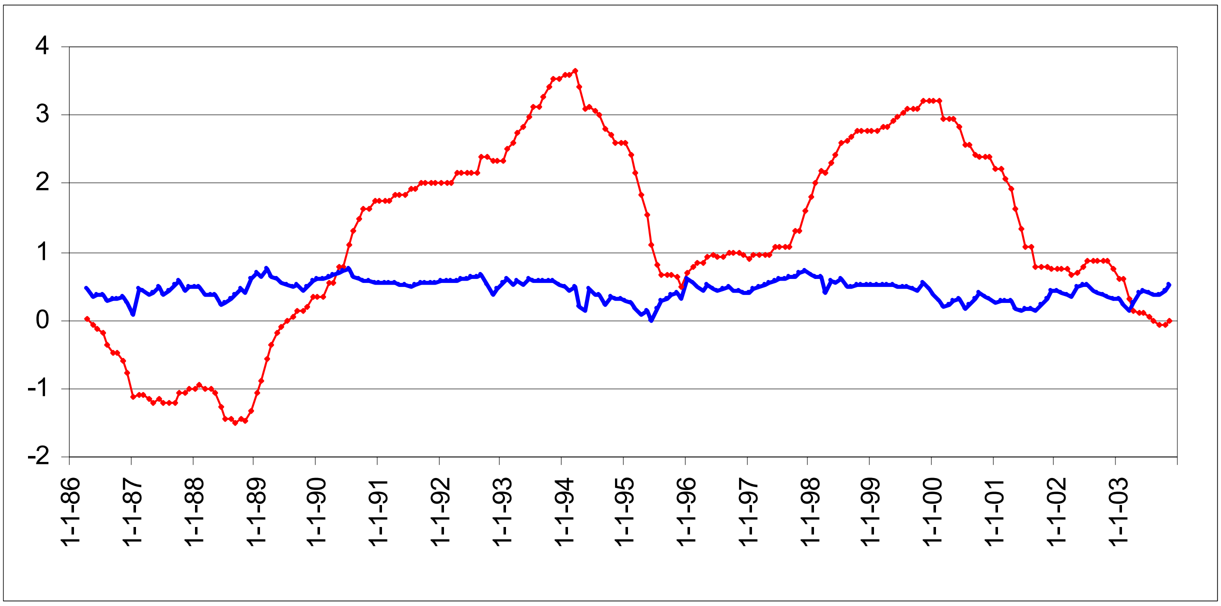


Figure 13. Monthly mean corrected salinity (S-35) in 100m water column temperature in San Sebastián (43°30′N 02°00′W) in 1986-2003 period and accumulated anomalies.

Others aspects on the hydrographic features during 2003 in the SE Bay of Biscay can be observed in Table 1. In January, thermal inversion was related with atmospheric cooling and, also, with freshwater input. On the other hand, markedly high subsurface temperature seems to be related with mild thermal conditions during autumn 2002 and with the relatively strong turbulence, convergence and subsequent downwelling and vertical mixing during late 2002. These processes integrated also the latest precipitations and river inputs and, thus, salinity was lower than the expected from the intensification of the poleward current and the eastward transport of ENACW. The most representative situation of the winter mixing was reached in February, even if thermal inversion related with the low salinity surface layer remains. Transition from April to May shows the early warming of the water column and also the salinity increase, especially in the subsurface layers.

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 27 m. From June to October this layer was placed around 35 m. The relatively scarce fluctuations of the depth of the 14°C isotherm through the summer season, as well as the sequence of the TS values at 50 m water depth and at the bottom layers, indicates a compensated occurrence of upwelling and downwelling processes. Moreover, the maintenance of low temperature values in the subsurface layers against the vertical progression of the summer warming should be related with the prevalence, in some extent, of upwelling and off-shore transport. From October to December, break down of stratification, downwelling and vertical mixing close, as usual, the annual cycle.

Table 1. Hydrographic data in the shelf waters in San Sebastián (43°30′N 02°00′W) in 2003. Mean temperature and salinity calculated for 100 m water column.

2003	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept.**	**October**	**November**	**December**
Surface Mean Temperature (°C)	12.03	11.16	13.07	13.84	15.70	20.18	22.43	24.86	21.43	18.11	15.44	13.22
Surface Salinity	33.862	33.248		34.661	34.809	34.688	34.537	34.623	34.441	34.548	35.329	35.458
Mean temperature (°C)	15.14	12.38		12.58	13.29	14.01	14.76	15.00	15.44	14.96	14.81	13.84
Mean salinity	35.315	35.144		35.267	35.396	35.433	35.393	35.379	35.346	35.372	35.510	35.499
Temperature at 50 m water depth	15.36	12.50		12.50	12.73	13.27	13.12	12.63	12.86	12.96	15.53	14.07
Salinity at 50 m water depth	35.497	35.488		35.418	35.538	35.517	35.505	35.545	35.549	35.553	35.557	35.467
Bottom (100 m) temperature	15.31	12.23		12.30	12.34	12.02	12.02	12.21	12.15	12.31	13.14	13.10
Bottom (100 m) salinity	35.543	35.563		35.542	35.556	35.593	35.596	35.577	35.595	35.571	35.579	35.577
Depth of the 14°C isotherm (m)	inversion	T<14		T<14	27	37	36	35	38	37	70	66
Depth of the 35.00 isohaline (m)	12	20		25	16	7	12	16	21	16	surface	surface
Depth of the 35.50 isohaline (m)	51	51		77	45	45	49	40	36	31	38	65
Depth of the 35.55 isohaline (m)		83			62	75	74	59	57	50	49	75

Annex M: 2003 Occupation of the Ellet Line (Rockall Trough) (ICES area 5)

N.P. Holliday and W.R. Turrell

Southampton Oceanography Centre, UK.

Recent Cruises

Although the Southampton Oceanography Centre intends to occupy the Extended Ellett Line (Scotland to Iceland) annually, in 2003 a lack of shiptime and personnel meant that the line was not visited that year. However in April 2003, Bill Turrell and colleagues (FRS Marine Lab) on the *FRV Scotia* occupied the Ellett line (Scotland to Rockall), and in July 2003 the section was repeated by Colin Griffiths and colleagues (SAMS) on the *RV Poseidon*. Data from the latter cruise were not available at the time of writing, but the Figure 1 presents CTD data from the April 2003 occupation.

Figure 2 shows the time series updated to April 2003. The salinities of the upper ocean were notably high in 2003, reaching the maximum of the time series since 1975. Temperatures were also high; both properties continuing the upward trend that began in the mid-1990s. In contrast, the deeper Labrador Sea Water was slightly cooler and fresher than previous years, continuing the overall trend since 1975.

Data Availability

A new Ellett line website was launched in August 2003 (http://www.soc.soton.ac.uk/GDD/hydro/nph/ellett/) including background to the section, data products and links to data centres that hold the data.

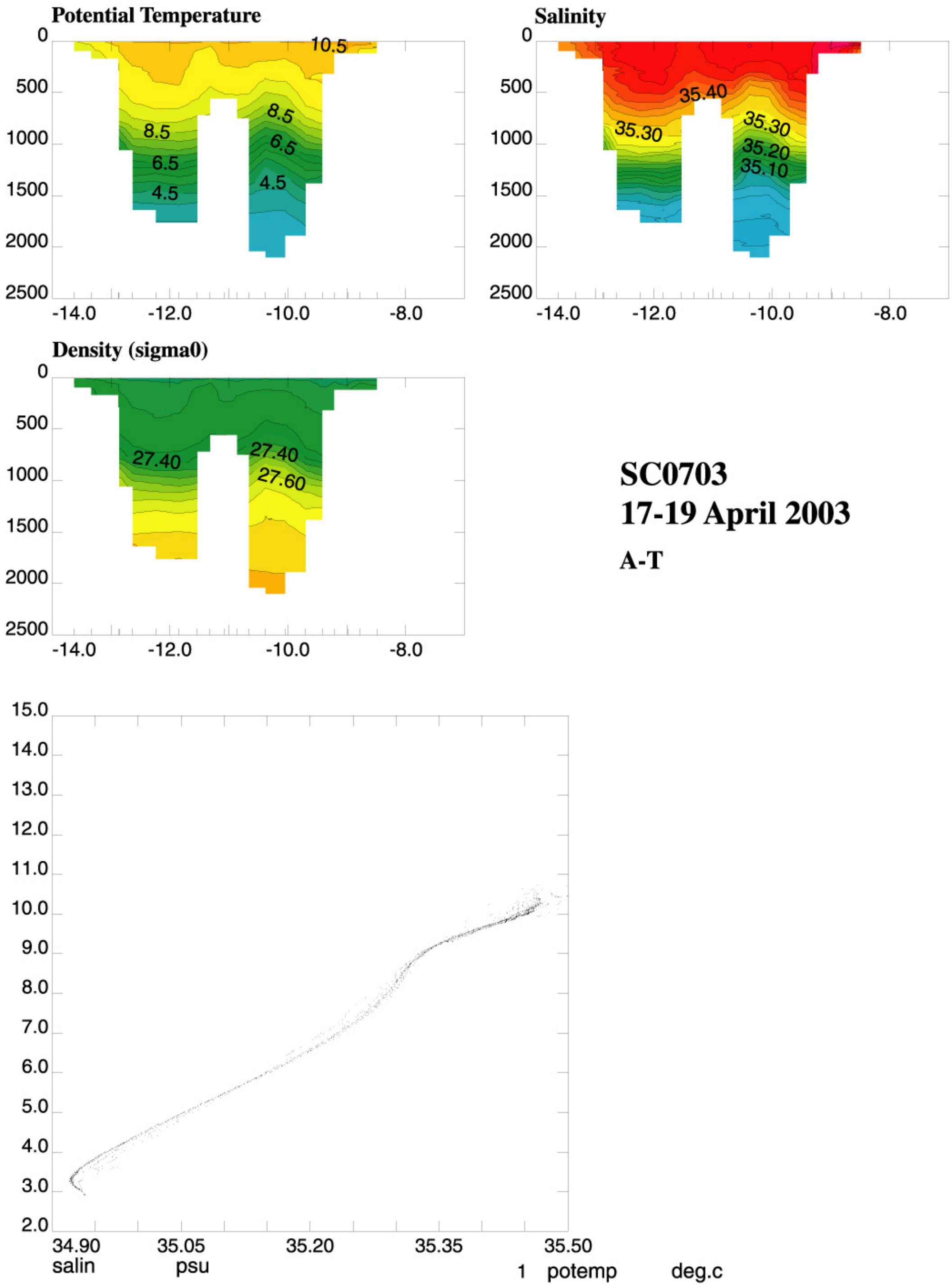


Figure 1. The April 2003 occupation of the Ellett line.

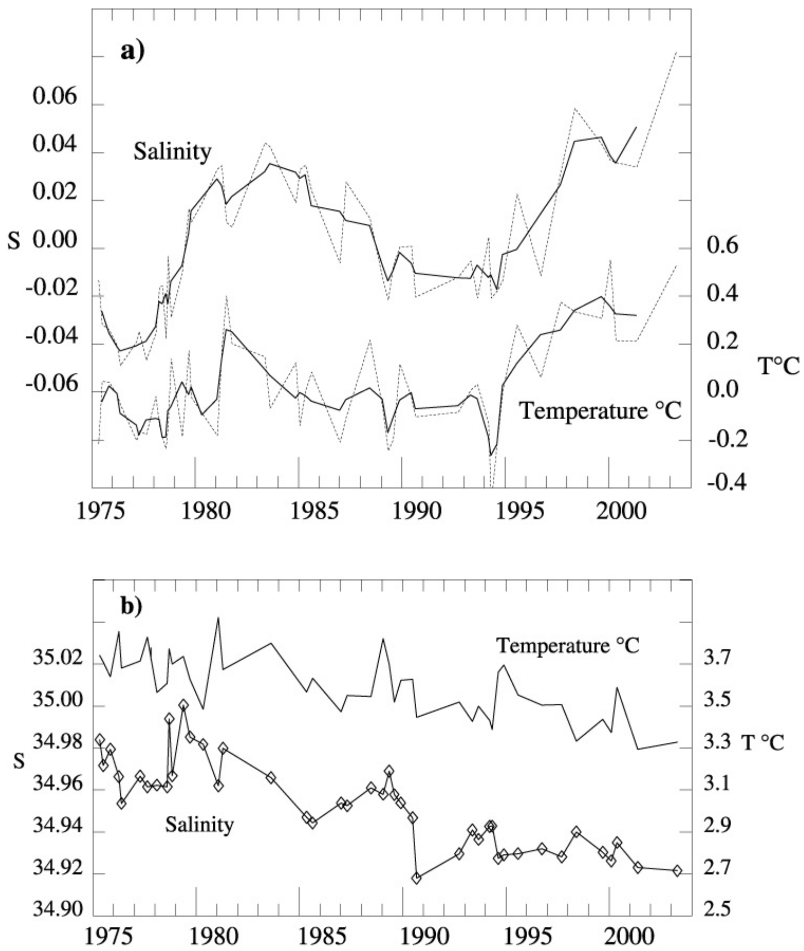


Figure 2. a) The time series of upper ocean properties (0-800m, anomalies are calculated by averaging all stations across the section then removing the 1975-1995 seasonal mean), b) the time series of intermediate Labrador Sea Water properties (values at the LSW core defined as the deep potential vorticity minimum).

Annex N: Report on WOCE/CLIVAR SECTION A1E, Northern North Atlantic (ICES area 5b)

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Royal Netherlands Institute for Sea Research, Texel, the Netherlands

From the start of WOCE in 1990 until present the a Trans-Atlantic section between the continental shelves of Ireland and Greenland (A1) has been surveyed nearly annually by German, Dutch and British research ships (Figure 1). The two different courses were used for this section, a northern nearly straight one, surveyed by the British and Dutch, and a southern dog-legged one, used by the Germans. While the former crosses the main topography nearly perpendicular, the latter evades the shallow Rockall-Hatton Plateau, but skims the deep boundary current along its slopes. West of the Reykjanes Ridge, in the Irminger Sea, these sections coincide, allowing a hydrographic time series of over a decade.

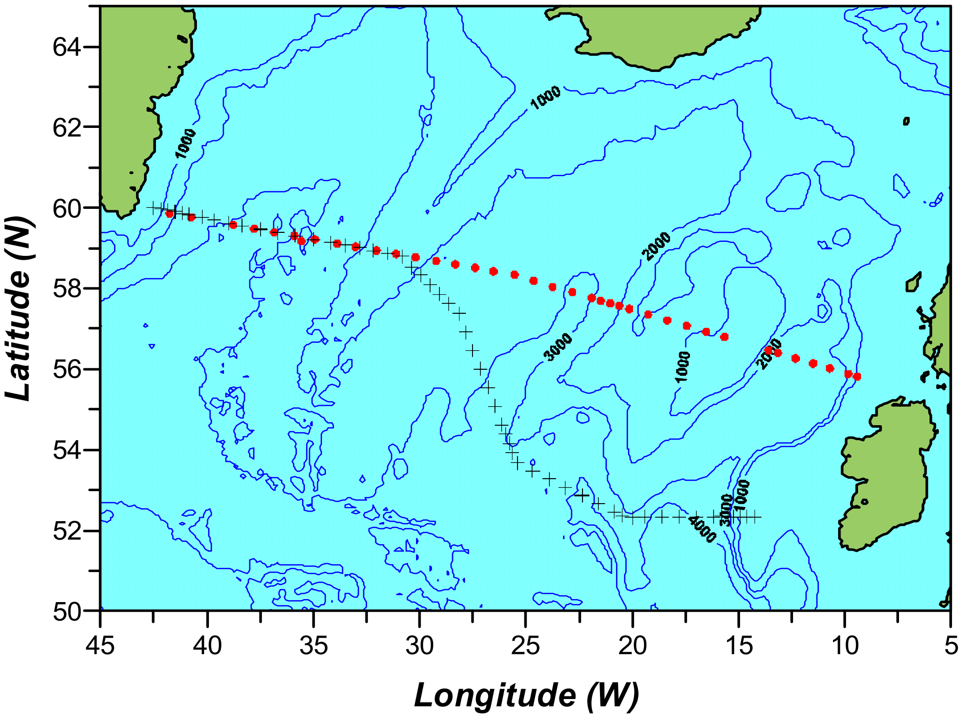

Figure 1. CTD stations along the WOCE/CLIVAR A1E hydrographic section. The dots show the positions of the stations during the 2003 survey by the Dutch RV Pelagia, the crosses the stations during the German Kommander Jack/Meteor survey in 2001.

The survey in August-September 2003 by RV Pelagia showed the regular distribution of potential temperature and salinity (Figure 2) observed before. Warm and saline Atlantic water, originating from the Gulf Stream was encountered in the upper 1000 m east of the Reykjanes Ridge. The Sub-Arctic Front which forms its western boundary was located over the western flank of this ridge. In the East-Greenland Current at sub-surface levels also Atlantic Water with a salinity above 35.0 was encountered, brought there by the cyclonic circulation around the Irminger sub-gyre.

In the centre of the Irminger Sea high temperatures and salinities were encountered in the upper 2000 m relative to the surrounding stations. This suggests that Atlantic Water from the surrounding cyclonic current had moved to the centre of the sub-gyre, replacing the colder and fresher Irminger Sea Water observed there in 2000 and 2001.

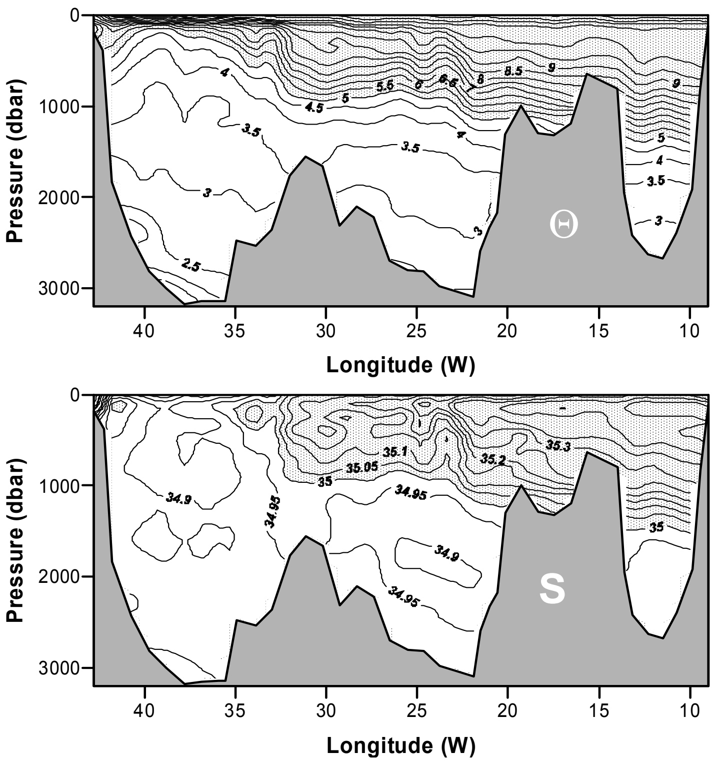

Figure 2. Zonal distributions of potential temperature, Θ (top panel), and salinity, S (bottom panel), measured in 2003 along section A1E.

The water mass properties at ~500 dbar can be considered as representative of the Mode Water in the northern North Atlantic. Potential temperature and salinity at this level were compared with the previous surveys of the straight version of A1E (dots in figure 1). Both in the Irminger Basin west of 32°W and over the Rockall-Hatton Plateau in the Rockall Channel east of 22°W the temperature and salinity had increased compared to the previous surveys in 1991 and 2000 (Figure 3). In the centre of the Irminger Basin near 36°W the Mode Water was about 0.5°C warmer than in 2000 and 1.0°C warmer than in 1991. The salinity in 2003 was about 0.05 higher than in 2000 and in 1991. I the Rockall Channel along the European continental margin the temperature of the Mode Water in 2003 was nearly 0.5°C warmer than in 2000, and 0.05 more saline.

In the Irminger Current and Iceland Basin between 32°W and 22°W the change of temperature and salinity between 2000 and 2003 at 500 m had a varying sign, suggesting a rearrangement the Sub-Arctic Front and related frontal eddies. However both in 2000 and in 2003 the mode water in the Iceland Basin was definitely about 1°C warmer than in 1991. The longitude of the zone with large temperature and salinity gradients suggests that in 2000 the Sub-Arctic Front was located further west than in 2000 and in 1991.

Comparison with the zonal distribution of the differences in temperature and salinity (Figure 4) shows that the change of water mass properties at ~500 dbar indeed reflect the hydrographic changes in the upper 1000 dbar. The decrease of potential temperature between 1000 and 2000 dbar in the Rockall Channel east of 15°W probably reflects the arrival after 2000 of the cold variety of Labrador Sea Water (LSW), formed in the early 1990s. However a recovery from the very deep position of the main thermocline also contributed to the observed change. In the Irminger Basin, west of 32°W both potential temperature and salinity increased between 2000 and 2003, reflecting the decay of that cold and fresh vintage of LSW in the western Atlantic.

Temperature and salinity of Iceland Scotland Overflow Water (ISOW) in the bottom layer between 30 and 25°W hardly showed any change from 2000 to 2003. In the near bottom layer over the East Greenland slope (41 to 38°W) the Denmark Strait Overflow water (DSOW) showed a slight fall in temperature since 2000 (O(0.5°C)) while the salinity hardly changed.

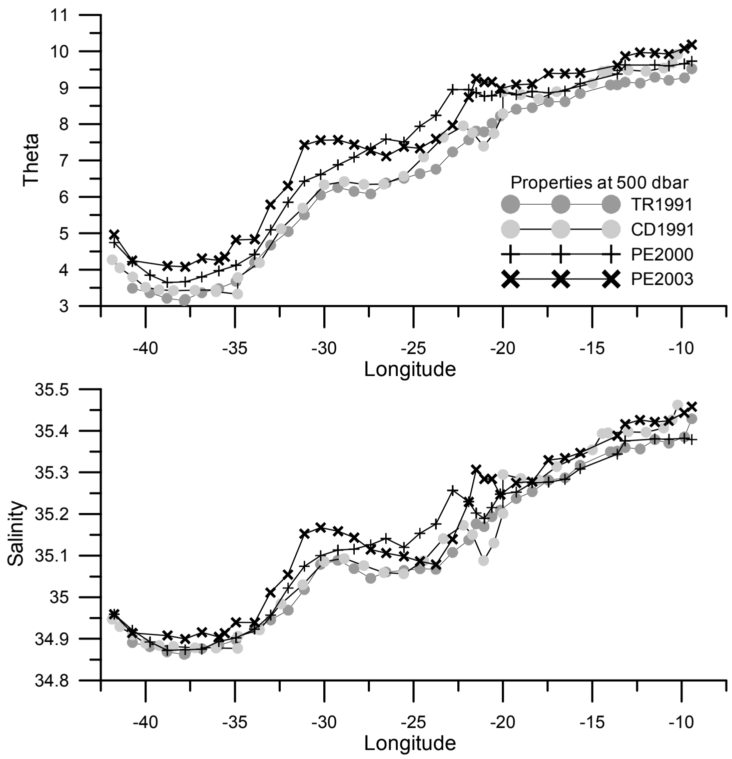

Figure 3. The potential temperature (upper panel) and salinity (lower panel) observed along the straight A1E line in 1991 by RV Tyro (TR1991) and RV Charles Darwin (CD1991), and by RV Pelagia in 2000 (PE2000) and in 2003 (PE2003).

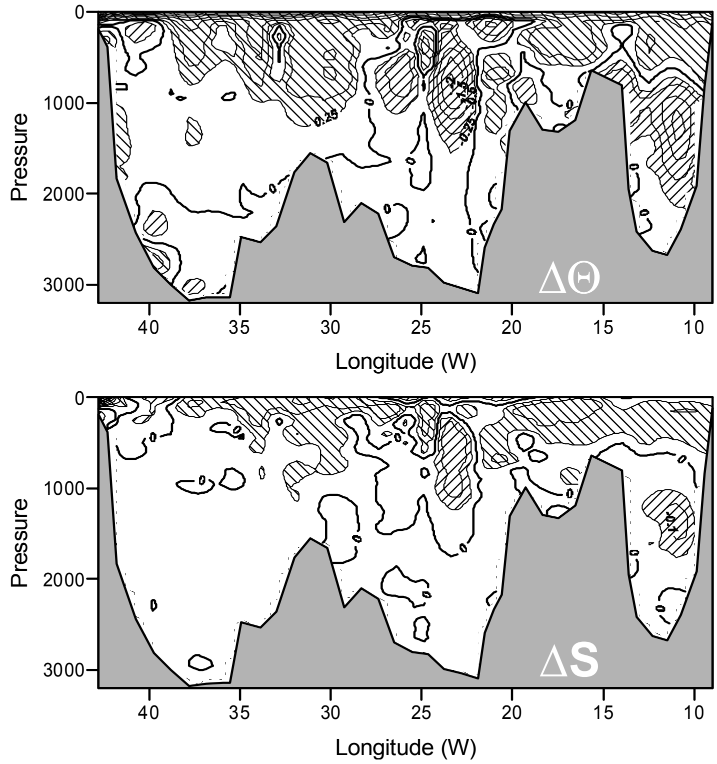

Figure 4. Difference in potential temperature (upper panel) and salinity (lower panel) between the surveys of 2003 and 2000. The hatched areas show the regions with relatively large positive and negative changes. Zero change is indicated with a thick line.

In the Irminger Basin the different version of the A1E line coincided, allowing a much better (near annual) temporal resolution of hydrographic change when using all available surveys by German, Dutch and British ships. For this region we will present the development of hydrographic properties for different hydrographic sub-regions

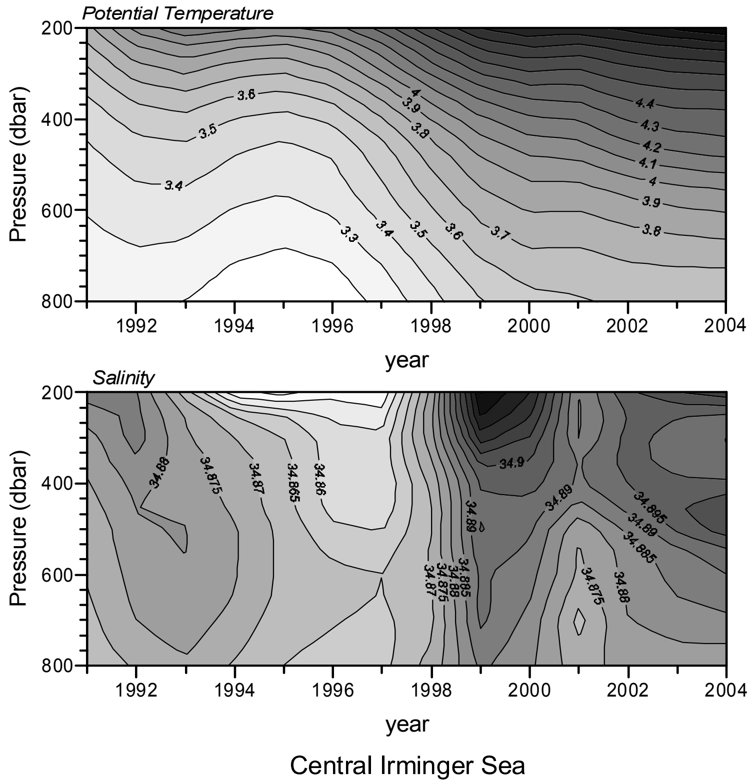

Figure 5. The development of the stratification of potential temperature (upper panel) and salinity (lower panel) in the near-surface layer of the central Irminger Sea. Since the upper 200 dbar mainly reflect the seasonal change, that layer is not shown.

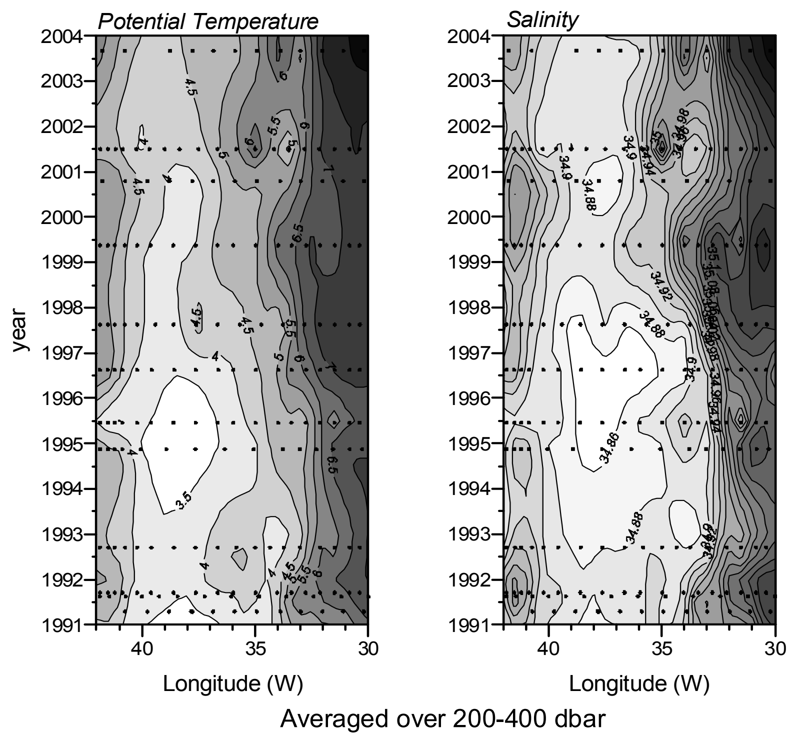

Figure 6. Hovmoller diagram of the potential temperature and salinity in the Irminger Sea. The dots show location and time of the hydrographic observations.

The temporal development of the thermal and saline stratification in the central Irminger Basin (Figure 5) shows that the main changes occurred in the two years after the 1996 winter with the strongly negative NAO index. The accompanying increase in sea surface height was also observed by means of satellite altimetry. A strong salinity change between 1997 and 1998 was observed at the end of the thermal transition period. The Hovmoller diagram showing the temporal development of the zonal distribution of the mean temperature and salinity between 200 and 400 m (Figure 6) shows a progressive westward shift of the iso-lines connected with the Sub-Arctic Front near the Reykjanes Ridge. The 4.5°C isotherm and the 34.9 isohaline move about 200 km westwards between 1991 and 2004. This suggests that the redistribution of heat and salt by a shift in the North Atlantic Current system is the major cause of the observed changes in the upper Irminger Basin.

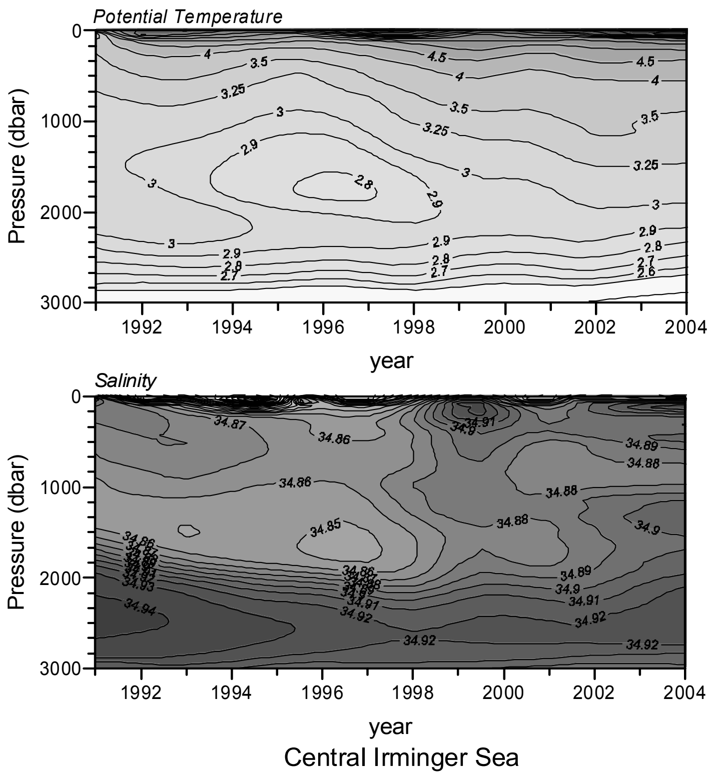

Figure 7. The temporal development of the stratification of potential temperature (upper panel) and salinity (lower panel) in the upper 3000 dbar of the Central Irminger Basin. The maximum bottom pressure in the region was slightly (< 200) over 3000 dbar.

At larger depths the time series of temperature and salinity (Figure 7) show the arrival of the of the core of the early 1990s vintage of LSW between 1000 and 2000 dbar, with the lowest temperatures and salinities in 1996, and its decay afterwards. Between 2000 and 3000 dbar Eastern North Atlantic Deep Water (ENADW) is found. This high salinity water originates from the ISOW and enters the western Atlantic Basins through the Charlie-Gibbs Fracture Zone. Its salinity maximum decreased from 1991 to 1996, coincident with the salinity decrease of the LSW core. When the cold LSW core decayed after 1996, the salinity of the ENADW core slightly increased again. These changes of the ENADW properties may be caused by entrainment and mixing with the changing LSW.

The temporal development of the vertical distribution of potential temperature and salinity along the East Greenland continental slope (Figure 8) reflect changing properties of the DSOW. The lowest temperatures in the DSOW core were observed in 1994/5 and 2000, mainly between 2000 and 3000 dbar. In 2000 a secondary cold core of DSOW was observed below 3000 dbar. After 1996 the isotherms above the DSOW core ascended several 100s m up the continental slope. The salinity in the DSOW core was relatively low when the low temperatures occurred, a relation which however is hardly significant (correlation R=0.49, N=13). The salinity of the ISOW core showed a highly significant correlation with the overlying salinity at a pressure of about 1900 dbar (R=0.85). At this shallower level the low salinity LSW core from the early 1990s vintage was found (see e.g. Figures 2 and 7). This effect suggests that entrainment of overlying water by the DSOW core during its descent from Denmark Strait along the Greenland continental slope is probably the main cause of the varying salinity of the DSOW core, and therefore probably also influences its temperature.

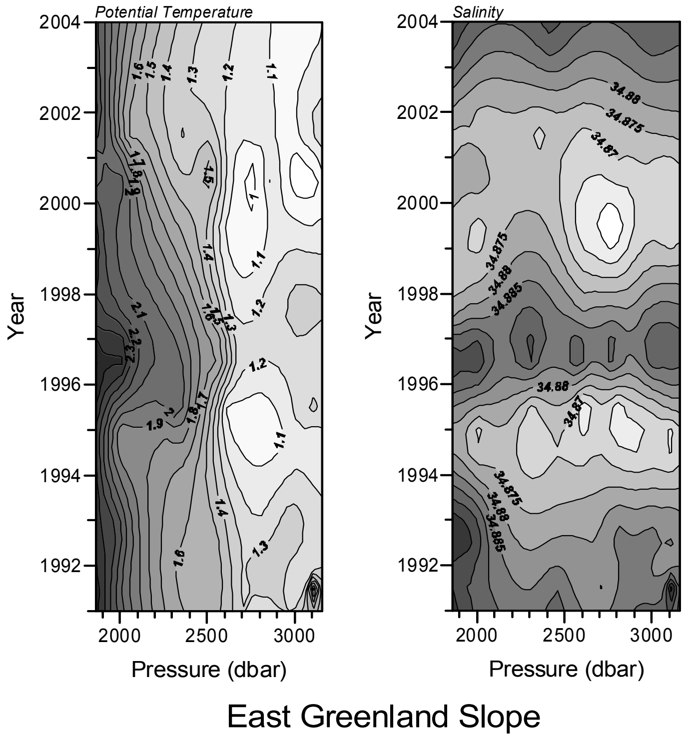

Figure 8. Hovmoller diagram of the vertical stratification of potential temperature (left panel) and salinity (right panel) along the East Greenland Continental slope.

Summarising one can state that in 2003 the upper 1000 m in the northern North Atlantic were relatively warm and saline, probable connected with a westward position of the Sub-Arctic Front and continuing re-stratification of the Irminger Basin. Between 1000 and 2000 m the hydrographic properties reflect the north-eastward advection of the cold LSW core from the early 1990s in the Rockall Channel and its decay due to mixing and re-stratification further west. The ISOW in the Iceland Basin hardly changed its properties. The observed changes of the properties of DSOW and ENADW in the Irminger Basin probably reflect a considerable interaction with water at the levels of the LSW core.

Acknowledgements

I thank al the PIs whose efforts during the survey of the A1E section made this analysis possible. When writing this report the hydrographic data from the A1E section, surveyed in 2002 by Hamburg University were not yet available. I hope to extend the co-operation on this A1E line and resume data exchange in future years.

In the central Irminger Basin two profiling CTD moorings were deployed in the summer of 2003. We hope to report on data from these instruments in 2005.

Annex O: Faroese waters (ICES Area 6)

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Summary

The Faroese research vessel Magnus Heinason occupied 481 CTD stations in 2003. Seven ADCP moorings at long-term mooring sites were recovered and redeployed, in addition to other short-term mooring work and coastal monitoring. The Atlantic waters in the upper layers were found to be exceptionally warm, both on the shelf and in the surrounding areas.

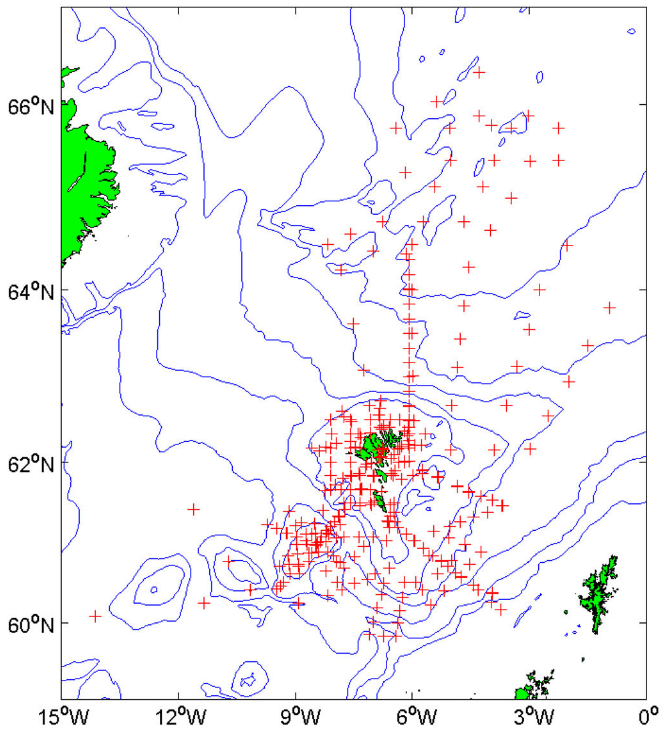

Figure 1. CTD stations occupied by R/V Magnus Heinason in 2003.

Observations

Positions of CTD stations, occupied in 2003 are shown in Figure 1. About half of the stations were on the standard sections that have been occupied about four times a year since 1988 (Figure 2). In 2003, sections E, N, and V were occupied 5 times and section S four times.

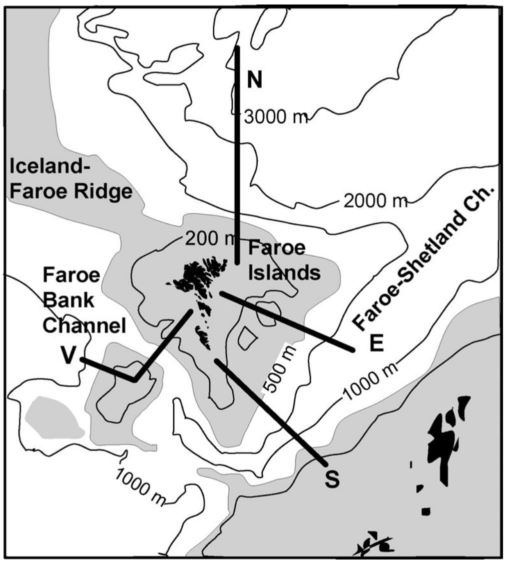

Figure 2. Standard sections in Faroese waters.

The Faroese Fisheries Laboratory (FFL) acts as a subcontractor in the FP5-funded MOEN project, which is a component of ASOF. Within this project, FFL maintains 7 ADCP moorings at standard mooring sites. In addition, two ADCPs were deployed on the Iceland-Faroe Ridge in MOEN in 2003 (Figure 3). Also, a dedicated experiment with moored temperature sensors in the Faroe Bank Channel was carried out in 2003. Coastal monitoring of shelf water temperature and salinity was continued in 2003.

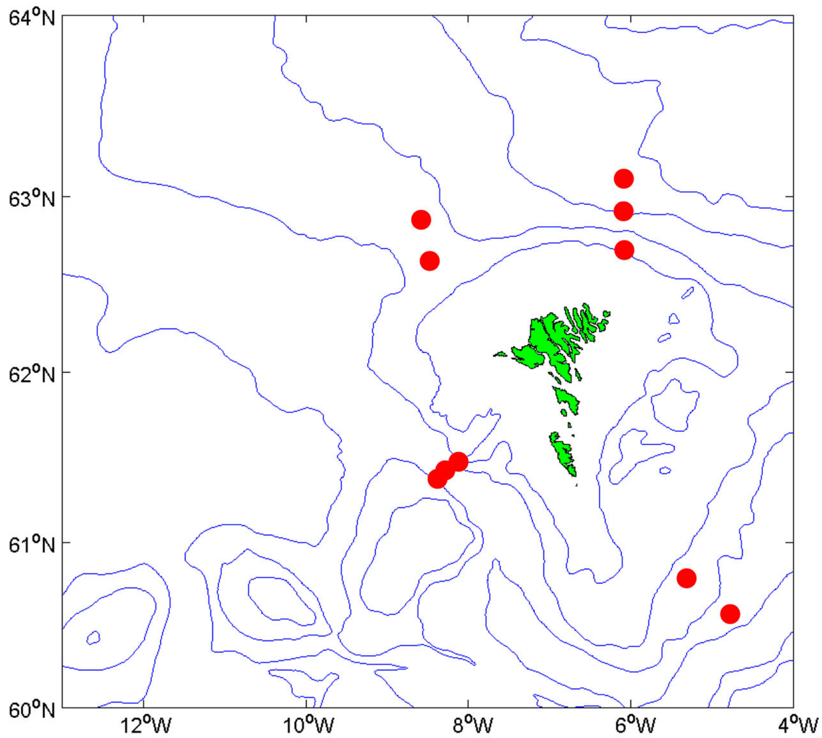

Figure 3. Moorings deployed in Faroese waters in 2003.

Changes in Atlantic water characteristics in Faroese waters

Figures 4 and 5 illustrate the development of water mass characteristics of the Atlantic water passing the Faroes, based on CTD observations on the standard sections. In the Faroe Bank Channel, southwest of the Greenland-Scotland Ridge, temperature and salinity generally vary in phase (Figure 4). Both parameters were low in the early 1990-ies and have increased since then. Beginning in the second half of 2002, temperature and salinity have increased exceptionally much and have made 2003 the warmest and saltiest year on record.

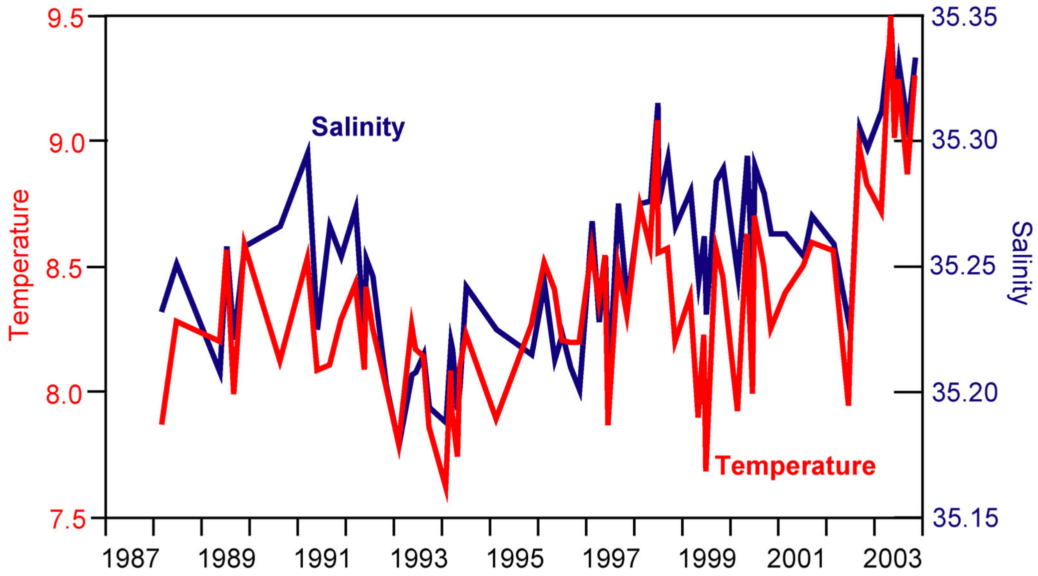

Figure 4. Temperature and salinity averaged between 100 and 300 m depth on the two deepest standard stations on section V, crossing the Faroe Bank Channel. The typical seasonal variation has been removed.

When the Atlantic water has passed the Iceland-Faroe Ridge, it flows through section N and Figure 5 shows the properties of the Atlantic core on this section. The temporal development on this section seems very similar to that in the Faroe Bank Channel, although the latest increase in temperature and salinity was perhaps delayed by a few months.

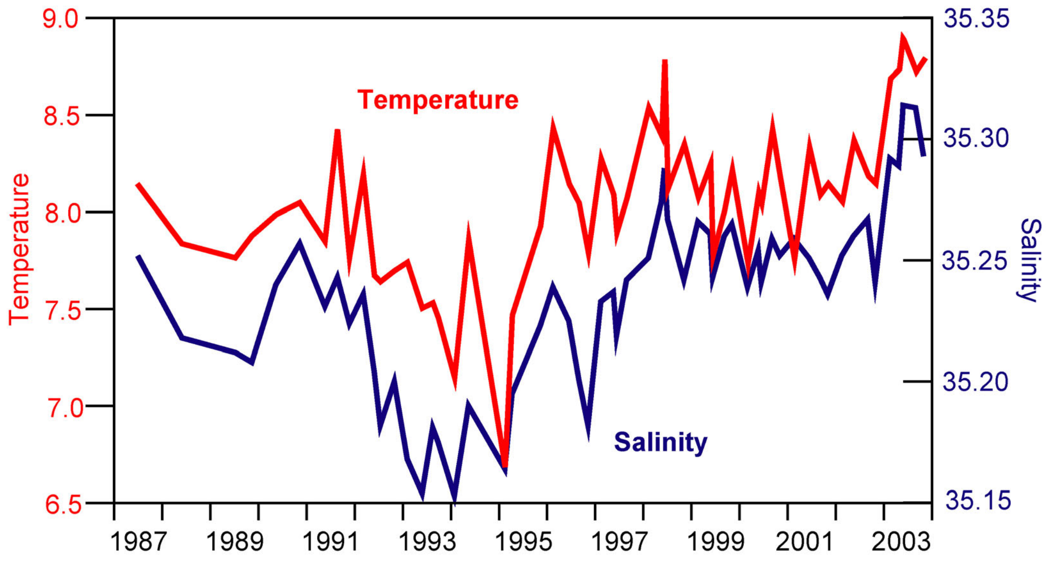

Figure 5. Temperature and salinity in the core of the Faroe Current on section N (defined as that 50-meter layer on the section, which has the highest salinity. The typical seasonal variation has been removed.

Regular monitoring of the Faroese standard sections only began in 1987. Before that there are a few sporadic measurements at similar locations, but for long-term trends in Faroese waters, the best information comes from coastal sea surface temperature (SST) observations. From 1914 to 1969, daily observations of SST were obtained from Mykines, although the regularity deteriorated through the period. Since the early 1990-ies, the FFL has carried out SST observations with automatic instrumentation moored at a site close to Mykines. The two series are believed to represent the same water mass and Figure 6 combines them.

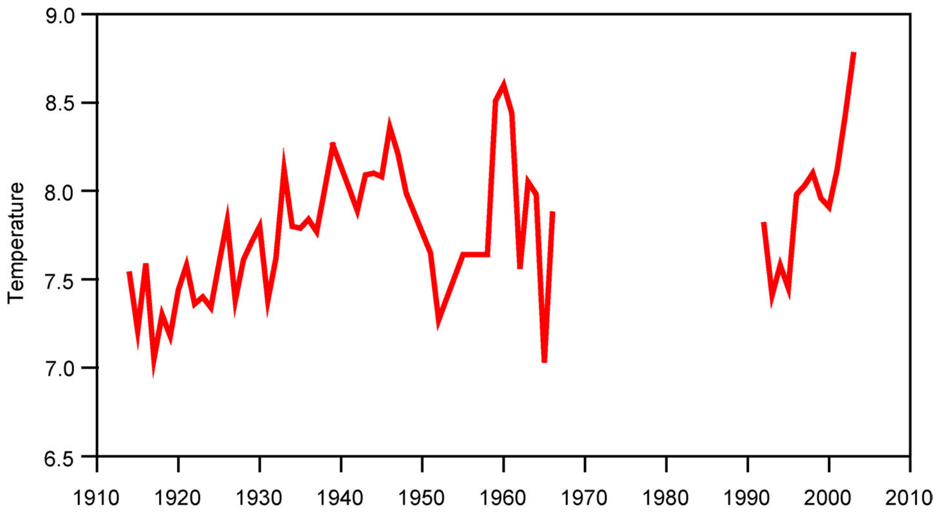

Figure 6. Annually averaged temperature on the Faroe shelf, based on observations from Mykines from 1914 to 1969 and on measurements from Oyrargjógv since 1991.

This figure also shows a dramatic increase in temperature towards the end of the period. During the 1990-ies and the early part of this century, the shelf water was not especially warm according to Figure 6 and, although 2002 was well above the average, it was still colder than 1960. In 2003, however, the temperature rose above any previous year on record.

Water samples for long-term storage

Based on the idea, that future technical development may allow determination of parameters that today cannot for analytical or economical reasons be routinely monitored, the FFL determined in 2001 to establish long-term storage of water samples from selected stations and depths. The samples are mainly from one station on section N and one from section V (Figure 2) and depths have been chosen to represent different water masses. The samples are stored in glass bottles similar to salinity samples and for each bottle stored, two other samples have been acquired from the same rosette bottle and have been analysed for salinity. Temperature and salinity for each bottle are recorded. Since this program was initiated, 8 bottles were stored in 2001, 56 bottles in 2002, and 44 bottles in 2003.

Annex Q: The North Sea mismash climate (ICES Area 8 and 9)

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Abstract

The regime character of North Sea SST is placed in the context of atmospheric circulation changes.

The temperature climate of the North Sea is characterized by long-lived quasi-stable cold and warm regimes that are separated through sudden shifts. Evidence is produced that SST regimes are manifestations of intra-annual monsoon-like shifts in the wind climate, while spontaneous reversals in SST regimes are accompanied by a semi-annual phase shift in seasonal wind characteristics. Specifically, the latest cold regime (1978-1987) was sustained by a wind regime that alternated between *continental* in winter and *maritime* in summer. By contrast, the recent warm regime is maintained by *maritime* winds in winter that give way to *continental* winds in summer. For lack of a better suited term for these bi-stable and hybrid climatic conditions in the North Sea region we call it mishmash climate.

Bi-stable SST Regimes

A stunningly long run of positive SST anomalies has continued since June 2001. This gave rise to a close inspection of the time series of monthly North Sea SST that was derived from BSH´s weekly SST analyses (*www.bsh.de/en/index.jsp*, menu: *marine data – observations – sea surface temperatures*). Serial monthly SST anomalies are displayed in Figure 1 as departures from the 1971-1993 base period means for 2 consecutive 16-year periods.

Perhaps the most important and just as striking feature is the regime character of SST anomalies, i.e. the persistence of positive and likewise negative departures from normal for extensive periods of time. The current warm regime shown in the upper frame of Figure1 was preceded by a cold regime of comparable length which again replaced a moderately warm regime in the mid 1970s.

Under the sensible constraint of 3 regimes during the period of observation, their respective lengths in time may be determined by maximizing $\Sigma|A(i)|$, where $A(i)$ denotes the mean anomaly of regime i. This procedure yields $max\ \Sigma|A(i)| = 0.24+0.36+0.51 = 1.11K$ and December 1976 through August 1987 for the duration of the cold regime.

Instantaneous termination and onset of adjacent regimes do not appear as unbearable idealizations in comparison to actual short term regime shifts. In any event, there is nothing that could be called a gradual or even linear evolution in SST (or SST anomalies). Instead, what is observed are irregular fluctuations about discernible quasi-stable states or levels – viz. $A(1)$, $A(2)$ and $A(3)$ – and spontaneous jumps and drops from one level of excitation to another.

As was verified from the SST record of Helgoland Roads, the alternation of cold and warm regimes extends through at least the past 130 years. The current warm regime turns out as the most intense and longest warm period since the 1870s (Loewe *et al*., 2003). The years 2002 and 2003, so far, are the warmest and 2^{nd} warmest, respectively, on the North Sea record dating to 1968.

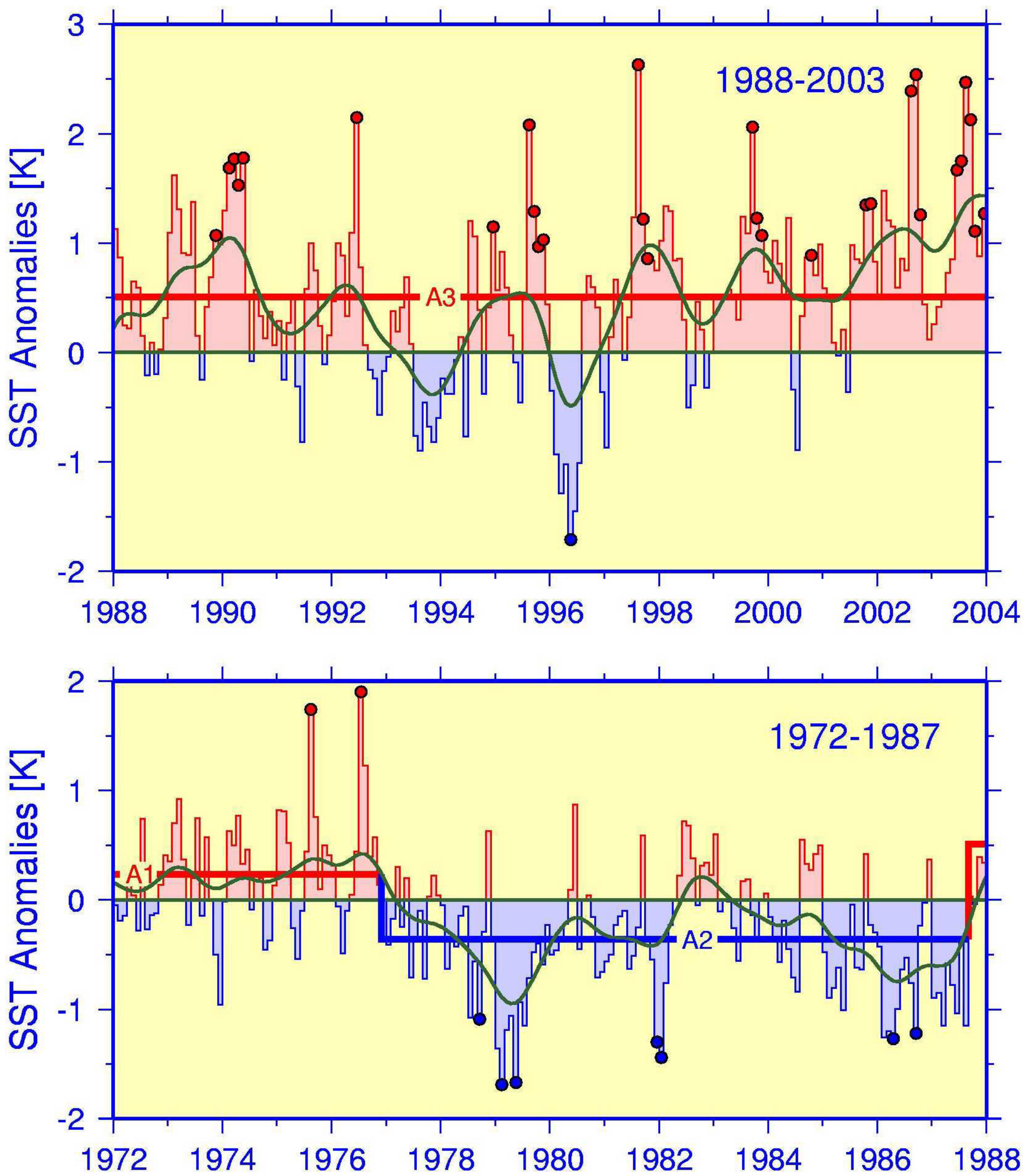

Figure1. Serial monthly North Sea SST anomalies (base period 1971-1993). Filled circles indicate anomalies beyond ±1.96σ, green curve is a low-pass smoother of width 24 month. Regime lengths and boundaries are given through a step function (cf. text).

Hybrid Wind Climate

The distinguished geographic situation of the North Sea on the continental shelf of northwest Europe – and thus on the border of the vast Atlantic ocean and the earth´s greatest landmass – makes it a region of competition for all major air masses that took on the surface characteristics of their maritime or continental source regions. As to temperature these characteristics result from the exceedingly large heat capacity of water as compared to rock and soil. Hence maritime climates are characterized by mild winters, cool summers and a flat seasonal temperature cycle, whereas continental climates experience cold winters, hot summers and an enhanced annual temperature range.

If Wladimir Köppen had cared to classify ocean climates, the North Sea had probably been assigned type *Cfb* standing for a moderately warm (maritime), permanently wet climate. This type would reflect the fact that the redistribution of heat in temperate latitudes is generally brought about by east-travelling waves and eddies such that winds from northwesterly to southwesterly directions predominate. Even so, one should not loose sight of the fact that atmospheric circulation in mid-latitudes is very changeable on all time scales such that large departures from mean wind conditions (and otherwise) are nothing particular.

It is a widely supported idea that the primary cause of climatic fluctuations are changes in the frequency of atmospheric circulation patterns. To gain further insight into the bi-stability phenomenon of North Sea SST dynamics a circulation typing scheme originally devised by Jenkinson and Collinson (1977) is currently being employed to analyze a North Sea subset of UK Met Office northern hemisphere daily mean sea level pressure fields. The data set was kindly placed at our disposal through BADC (*badc.rl.ac.uk/data/mslp*).

An intermediate step in the typing scheme is the calculation of a single geostrophic wind vector representative of the entire North Sea domain on a particular day. As wind is the motor of air mass advection it appeared natural for a first step to analyze seasonal wind distributions as to differences during the cold and warm SST regime. Results of this preliminary analysis are presented in Figure2.

For obvious geographical reasons winds from northeasterly to southerly directions (i.e. NE-S or 22.5°-202.5°) are qualified *continental*, while those from the complementary hemisphere are termed *maritime*. Since all modes of the set of 4 wind distributions are located in the maritime wind sector, the overall generalized wind climate indeed is maritime (*Cfb*). However, intensity and position of these modes in the velocity/direction plane exhibit substantial differences, not only among different seasons of the same SST regime, but also among the same seasons of different regimes. If, on the other hand, one had to choose 2 pairs from the set that best resemble one another, one would espouse the winter (summer) distribution of the warm regime and the summer (winter) distribution of the cold regime (to obtain pedigree maritime (continental) offspring). The *maritime* couple is characterized by intense modes about W and reduced densities about E. Conversely, attributes of the *continental* couple are E-shifted weaker modes and increased densities about E. Instead of selecting by the *birds of a feather flock together* rule, however, nature couples maritime and continental wind characteristics according to the complementary principle *opposites attract* which results in a hybrid wind climate.

While within-regime differences among the seasonal distributions are significant beyond doubt, the cross-regime differences for the winter and summer distributions (Figure 2, bottom) were felt to deserve statistical confirmation. To this end, a 2-dimensional Kolmogorov-Smirnov test (Press *et al.*, 1992) was performed on the unbinned seasonal sample distributions. The K-S test statistic D is the maximum difference in the fraction of data within 1 of 4 natural quadrants around the maximizing data point in the velocity/direction plane which is found by ranging over both all data points and associated quadrants. For the 2 winter distributions D attains a maximum of 19% in the quadrant northeast of approx. (8, 200°). Similarly, for the summer samples, D=17% again in the quadrant NE of about (5, 190°). Both, the wintry and the summery distributions turn out to be significantly different at p-levels next to certainty, viz. $< 5x10^{-8}$ % and $< 7x10^{-6}$ %, respectively. The D-values are in good agreement with cumulative differences within the ±0.5% contours of Figure 2 (bottom) which amount to ±18% for winter (JFM) and ±15% for summer (JAS). As an aside, the complementary difference patterns of Figure 2 (bottom) imply that annual wind statistics would not have produced any cross-regime differences to speak of due to mutual cancellation over the annual cycle.

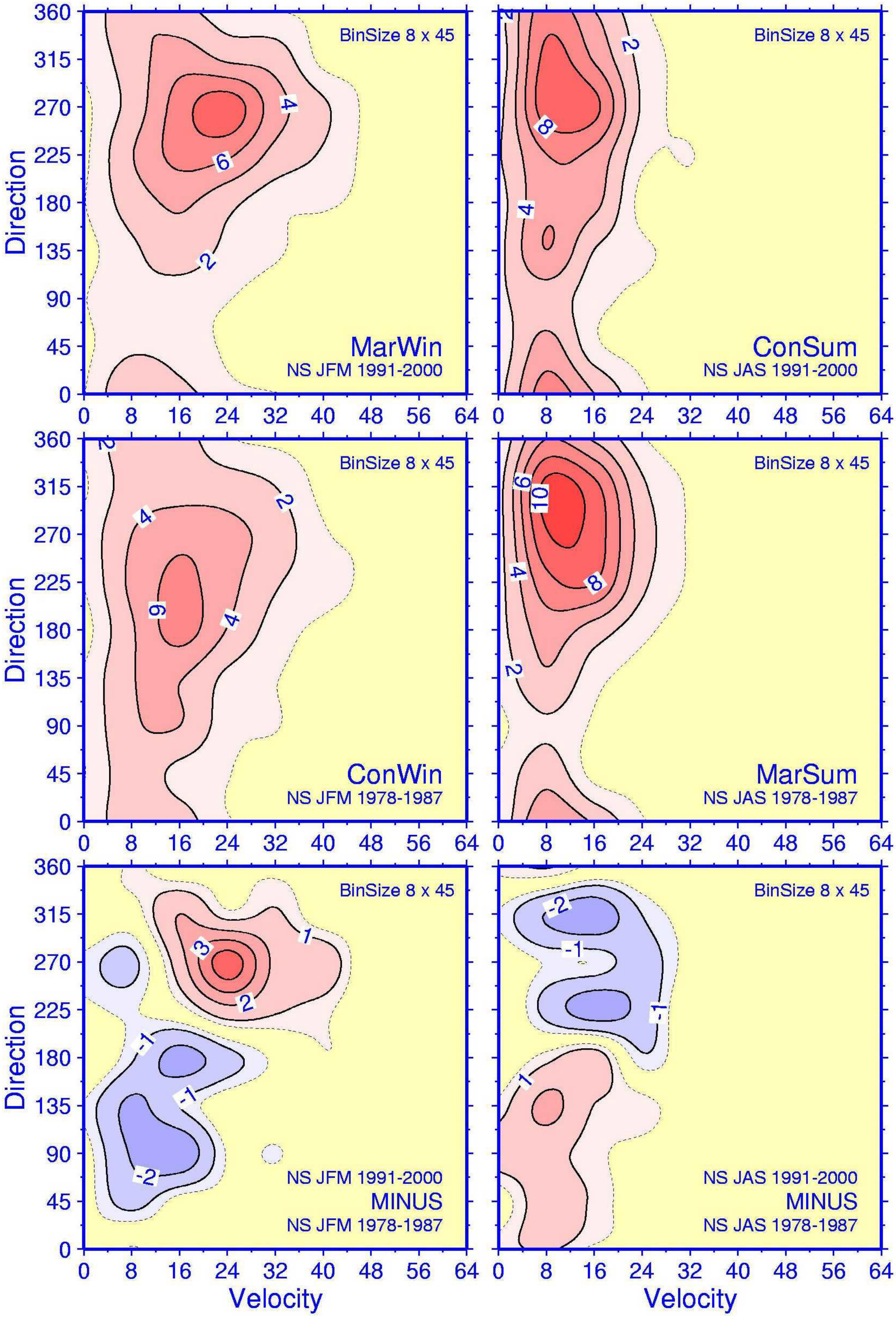

Figure 2. Seasonal percent frequency distributions of geostrophic wind speed and direction across the North Sea for warm (1991-2000, top) and cold SST regime (1978-1987, middle). Left panel is for winter (JFM = January - March), right panel for summer (JAS = July - September), bottom panel shows seasonal regime difference. The 0.5% contour (stippled) encloses about 98% of all samples (900 for JFM, 920 for JAS). Cumulative differences within ±0.5% envelopes (bottom) amount to ±18% for JFM and ±15% for JAS. Velocity is expressed in units of hPa per 10° latitude at 55°N, 1 unit being equivalent to 1.2 Kt or 0.62 m/s.

A quantitative summary of Figure 2 is supported by Tab.1. Notably different decadal SST regimes (-A(2)+A(3) ≈1K) are sustained by hybrid couples of wind distributions. The cold regime is consistent with an intra-annual shift from continental winds in winter (cold) to maritime winds in summer (cold). A regime shift in SST is accompanied by a consistent reversal of the seasonal wind climate.

The most recent cold to warm shift in the late 1980s went along in winter with a 61% increase in strong maritime winds on the expense of a 40% decrease in moderate continental winds (ConWin → MarWin). Conversely, strong maritime winds dropped by 26% in summer due to an overall increase of continental winds by 59% (MarSum → ConSum). While changes in direction and velocity were about balanced in winter, directional changes clearly surpassed velocity changes in summer.

Table 1. Contingency tables summarizing Figure 2. NE-S covers the sector 22.5°-202.5°. On account of different bin sizes for geostrophic wind velocity care should be used when comparing intra-regime tables

JFM 91-00	0-20	20-60	rowΣ
SW-N	36	**37**	73
NE-S	**19**	8	27
colΣ	55	45	MAR

JAS 91-00	0-12	12-60	rowΣ
SW-N	36	**29**	65
NE-S	**25**	**10**	35
colΣ	61	39	CON

JFM 78-87	0-20	20-60	rowΣ
SW-N	35	**23**	58
NE-S	**32**	10	42
colΣ	67	33	CON

JAS 78-87	0-12	12-60	rowΣ
SW-N	39	**39**	78
NE-S	**17**	**5**	22
colΣ	56	44	MAR

Diff JFM	0-20	20-60	rowΣ
SW-N	1	**14**	15
NE-S	**-13**	-2	-15
colΣ	-12	12	0

Diff JAS	0-12	12-60	rowΣ
SW-N	-3	**-10**	-13
NE-S	**8**	**5**	13
colΣ	5	-5	0

Concluding remarks

The bi-stability of SST regimes casts doubt on the usefulness of standard CliNo climatologies in climatic mishmash regions such as the North Sea where the implicit assumption of climatic stationarity is violated. As a consequence, the *significant-departure-from-normal* alert is *on* next to constantly (cf. Figure 1) because the alarm device is not aware of a significant change in normality. A solution might consist in judging the significance of anomalies from mixed probability density functions that account for the bi-stability phenomenon.

The findings as to hybrid and reversed wind distributions during different SST regimes were obtained for the cold period 1978-1987 and the recent warm episode. The robustness of these results should be examined e.g. by way of extending the analysis to the long SST time series of Helgoland Roads.

Finally, it would appear useful to explore how the changeable wind characteristics across the North Sea associate with large scale (anomalous) features of the general atmospheric circulation. While the wintry wind characteristics correlate with preferences of the North Atlantic Oscillation for its negative mode during the cold SST regime, and, conversely, for its positive mode during the current warm regime (Loewe *et al.*, 2003), the NAO cannot probably be held responsible for the alternation in the summery wind climates, even though the Azores high is expected to be a key player.

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Annex R: Surface temperature and salinity in the Southern Bight of the North Sea (ICES Area 9) and a coastal temperature network

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Background

Near surface hydrography has been collected by a ferry along 52°N between Felixstowe and Rotterdam since 1971. Temperature and salinity samples are collected weekly at 9 standard stations by the *Stena Partner* providing an insight to the seasonal, interannual and decadal variability of surface water in the Southern Bight of the North Sea. Here we show data collected at the six standard stations most isolated from high variability coastal processes (Figure1) in order to put the conditions seen in 2003 in the context of those of the previous 3 decades. In 2003 the English port for the ferry route moved from Felixstowe to Harwich and no data was collected in January; however the same standard positions continued to be sampled from February onwards. Coastal temperature stations have been occupied for up to 100 years, here we briefly introduce the data-set and present the time-series of temperature at Scarborough as an indication of the time-series available to be reported on fully next year and as a potential contribution to the REGNS process.

Surface Temperature and Salinity in 2003 along 52 °N

Conditions in 2001 saw an extreme freshening take place during spring across the entire section that persisted until the late spring of 2002. Where data was available for the second half of 2002 sea surface salinity (SSS) appeared to have returned to close to the long–term mean. SST was high through the summer of 2001 with some delay of the cooling phase of the seasonal cycle into November and the early part of 2002 was warm as cooling towards the usual seasonal cycle minimum in late winter did not take place. Figure 2 shows the seasonal cycles of SST and salinity at 3 of the stations on the standard section and compares the conditions of 2003 to those in 2001-2 and the climatology (1971-2000). SST at the stations was close or below the average in the first few months of the year, but summer SST was extremely warm mirroring the atmospheric conditions experienced over western Europe. By October the SST had returned to the long-term average for this section. SSS at Station 2 and 4 clearly shows an extreme freshening event in the late winter and early spring, by June salinity at both stations was close to the long-term average. Station 6, further east, shows no clear sign of low salinity water apart from during May where the monthly mean salinity was close to 1 standard deviation below the climatology (Figure 2). In contrast to the freshening event of 2001-2002 the fresh event seems localised and short lived, and seems most likely to have been caused by runoff from the Thames catchment. Figure 3 compares the Station 4 SSS measured by the ferry route with that measured by an autonomous mooring within 10km. Despite the difference in temporal resolution of the two measurements, the smart buoy closely confirms the strength and duration of the freshening event at that position.

Figure 2 illustrates that variability of SSS and SST differs from station to station, which makes a comparison of salinity anomaly across the section particularly difficult. In order to make both anomaly time-series across section comparable we have normalised the anomaly to the standard deviation of the data at each station. Figure 5 shows a time-series of the seasonal section means of the normalised temperature and salinity compared to the NAO_{DJFM} index. The SST time-series clearly shows the so-called regime shift towards warm conditions in the late 1980s. Examining the time-series suggests that whilst the summer was very warm compared to the last 30 years it seems typical (if at the warmer extreme) of the present warm period. In the same way it is possible to say that spring and winter SSTs were close to the long-term mean in 2003, yet compared to the last 15 years they were cooler than has been typical.

Further explanation is required as to the cause of the periodic salinity anomalies that are apparent from this section (Figure 5), the lows of 1994-96 being followed by high salinity in 1997-1999, and return to low salinity 2001-summer 2002. Variations in precipitation and output of the large catchments around the Southern Bight is a process by which salinity variability could take place, these would generally be only weakly correlated with the NAO in this region. Variations in flow through the Dover Strait would affect the salinity of the Southern Bight, either through changes in the volume transport (likely to be wind-driven and related to the NAO) or properties of the water transported out of the Channel. Rough comparison with time-series from other areas in the ICES WGOH region (e.g., Area 4-Bay of Biscay and Eastern Atlantic, Area 5b-North East Atlantic, and Area 8-Northern North Sea) is suggestive that these longer term variations in salinity may be a regional rather than locally driven process.

Coastal Temperatures

To meet the requirements of fisheries scientists, CEFAS has managed a network of observers recording regular (daily-weekly) near-surface sea temperature at selected coastal locations since the 1960s. In addition to the voluntary observers a selection of companies, councils and other organisations have collected sea-surface temperatures for up to 100 years. Figure 5 shows the locations of these temperature time-series, which will be fully reported on next year and could be a contribution to the REGNS process. The quality of the data does not approach that of hydrographic sections but the CEFAS data is calibrated to ± 0.1°C, and the other data-sources are thought to be no worse than accurate to ± 0.2°C.

As an example we show the time-series at Scarborough on the North Sea coast of seasonal SST normalised to the standard deviation (Figure 6). The warm period identified above in the ferry data can be clearly seen here, where the 11 warmest winters and 7 warmest summers have taken place since 1988 and of all the summer records 2003 was by far the warmest at the Scarborough site.

Figure Captions

Figure 1: Positions of the six standard stations described here on the 52°N Felixstowe-Rotterdam Route, Station 4 is boxed and circled to show the position of the CEFAS Gabbard Smartbuoy as well as a station on the ferry route.

Figure 2: The annual cycle of temperature and salinity at stations 2, 4 and 6 of the 52°N Felixstowe-Rotterdam Route. The climatology in black is constructed from the full database of monthly means at each station, with the error bar showing the standard error.

Figure 3: Comparison of a) salinity b) temperature at standard station 4 (green) with the semi-continuous salinity from successive deployments of the CEFAS Gabbard Smartbuoy (orange line) and R/V CTD data (pink, blue, purple symbols). Data for the period Jan 2001 to August 2002 when the Smartbuoy mooring was moved.

Figure 4: Normalised monthly a) Temperature b) Salinity anomaly along the 52°N Felixstowe-Rotterdam Route. Contours show the number of standard deviations that a particular month is from the monthly mean at that station.

Figure 5: Normalised seasonal a) Temperature b) Salinity anomaly along the 52°N Felix-Rotterdam Route. c) Hurrell NAO_{DJFM} index www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html

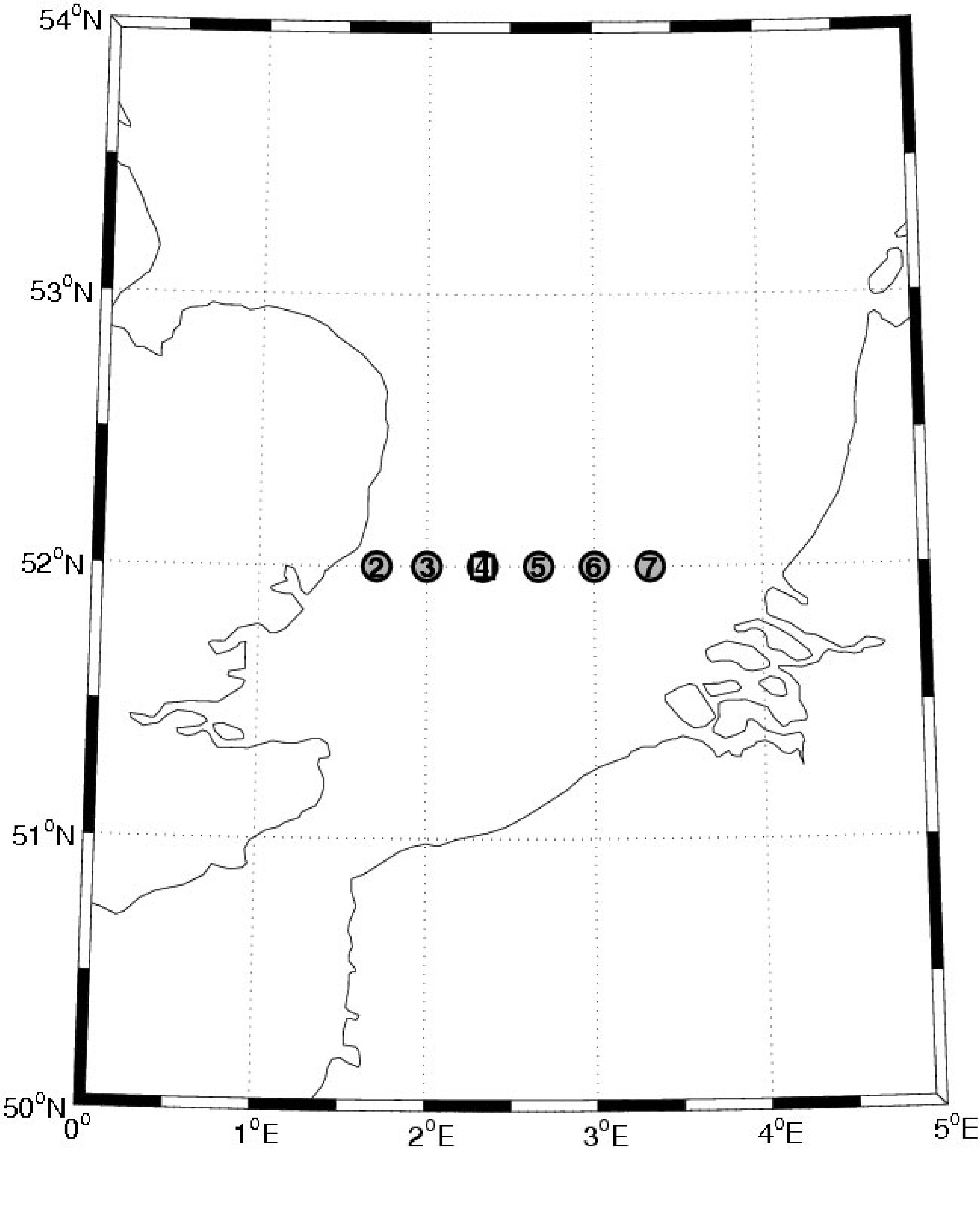
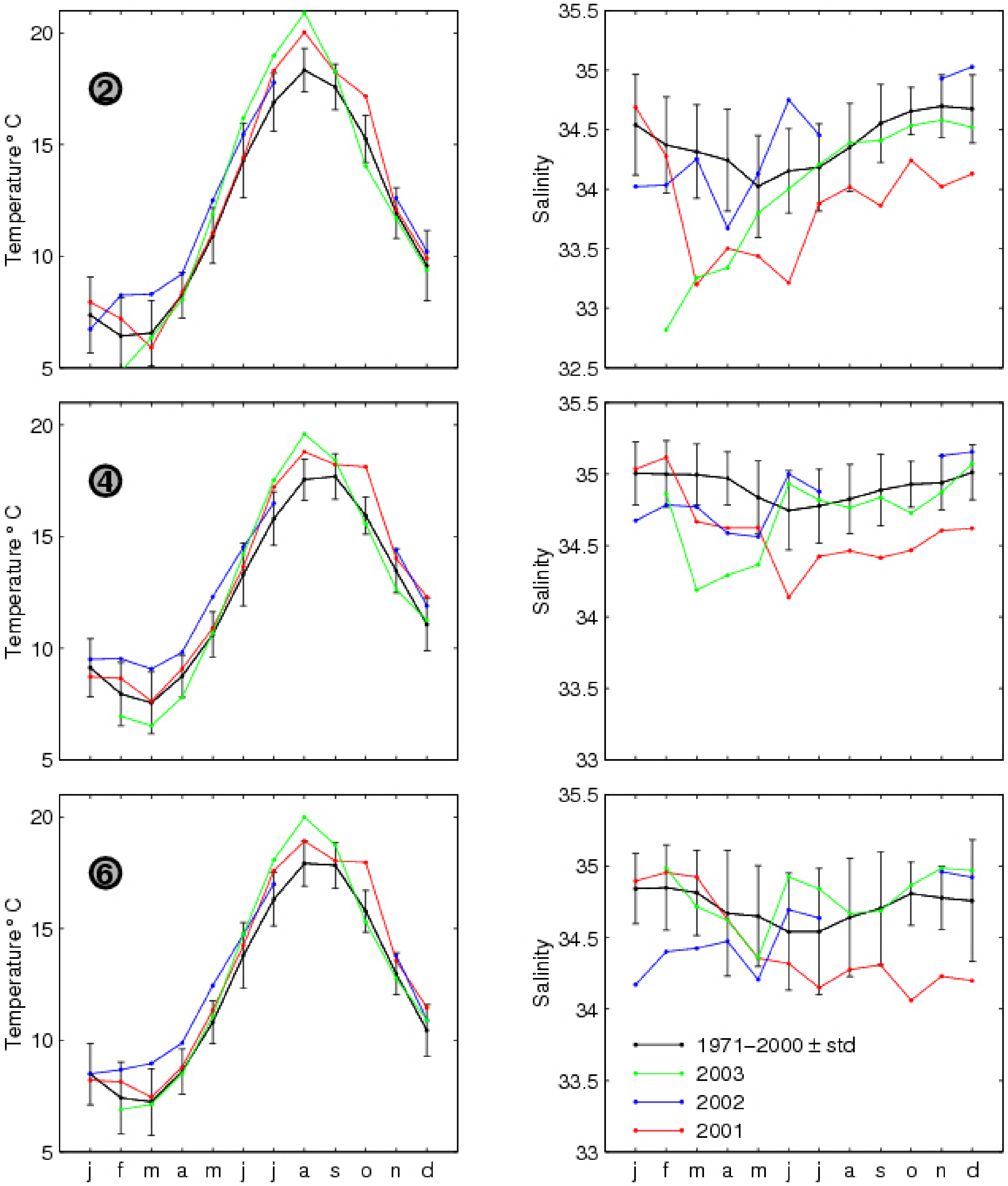
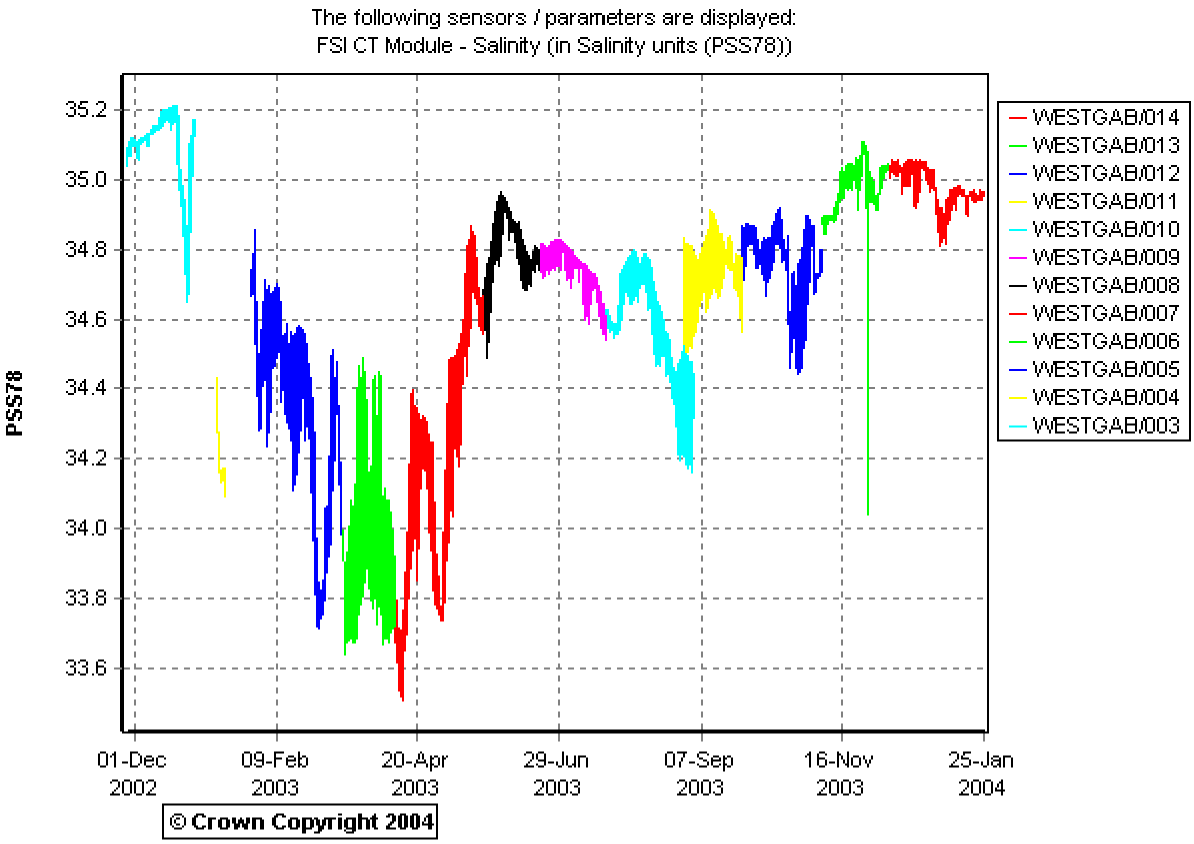


Figure 1.



2
4
6
Temperature ° C
Salinity
1971–2000 ± std
2003
2002
2001
j f m a m j j a s o n d

Figure 2.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FSI CT Module - Salinity (in Salinity units (PSS78))
PSS78
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35.0
34.8
34.6
34.4
34.2
34.0
33.8
33.6
01-Dec 2002
09-Feb 2003
20-Apr 2003
29-Jun 2003
07-Sep 2003
16-Nov 2003
25-Jan 2004
WESTGAB/014
WESTGAB/013
WESTGAB/012
WESTGAB/011
WESTGAB/010
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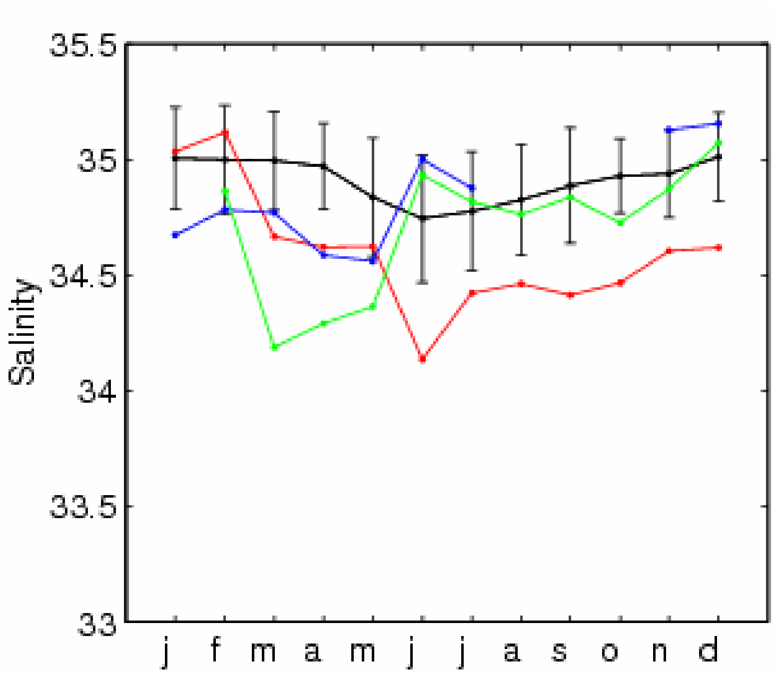
Salinity
35.5
35
34.5
34
33.5
33
j f m a m j j a s o n d

Figure 3.

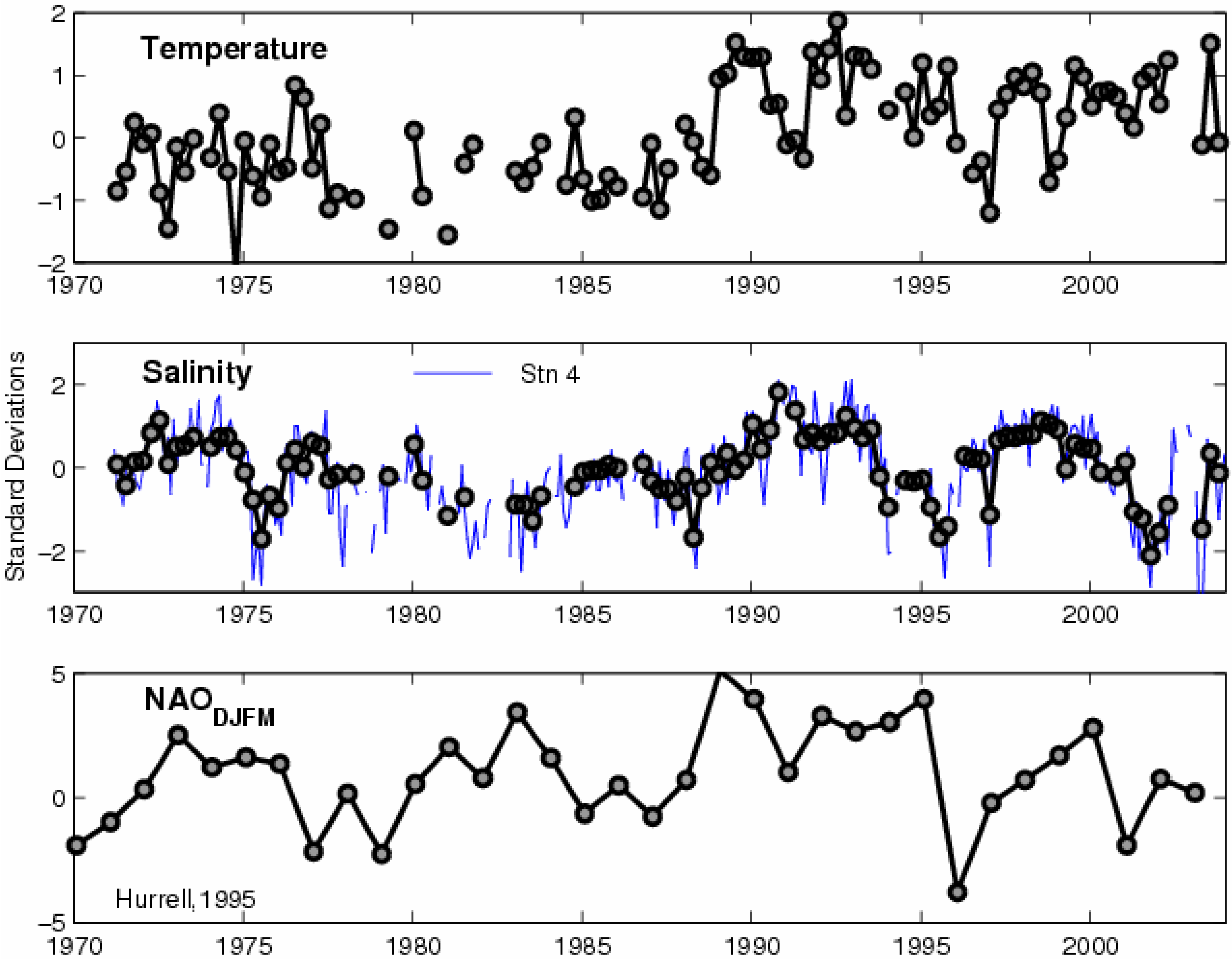
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Figure 4.

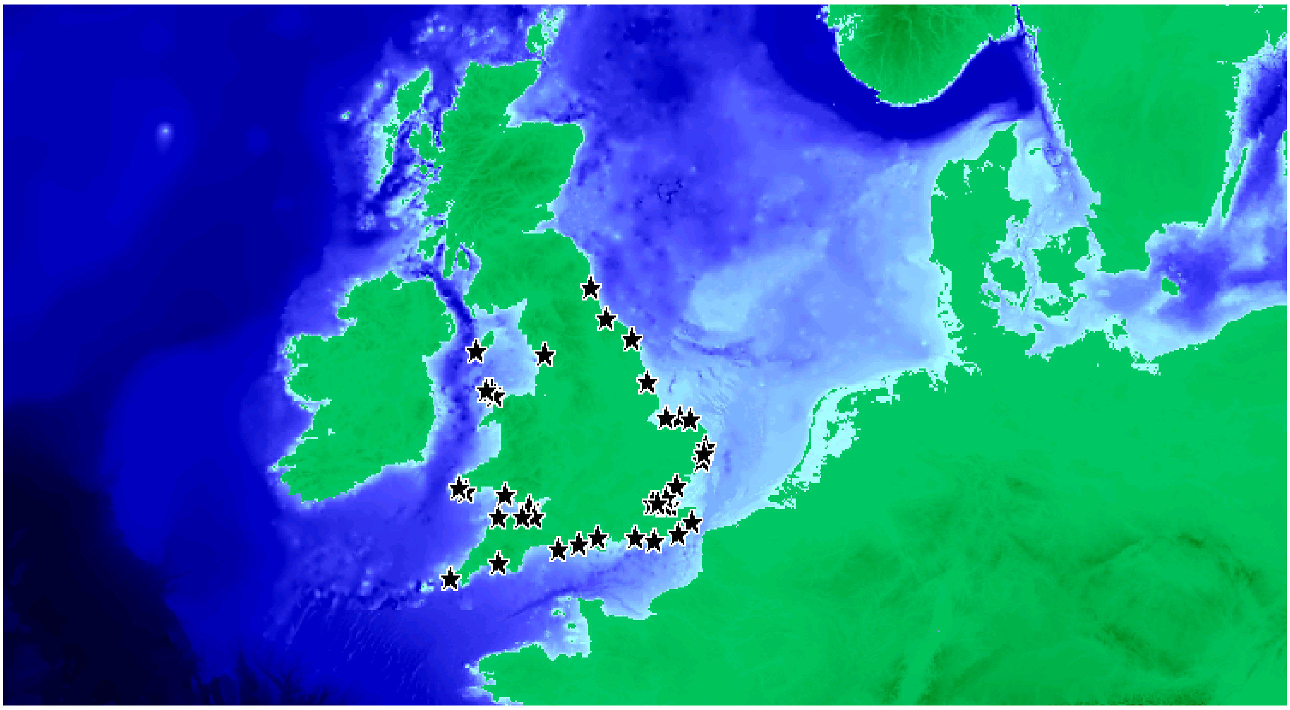


Figure 5.

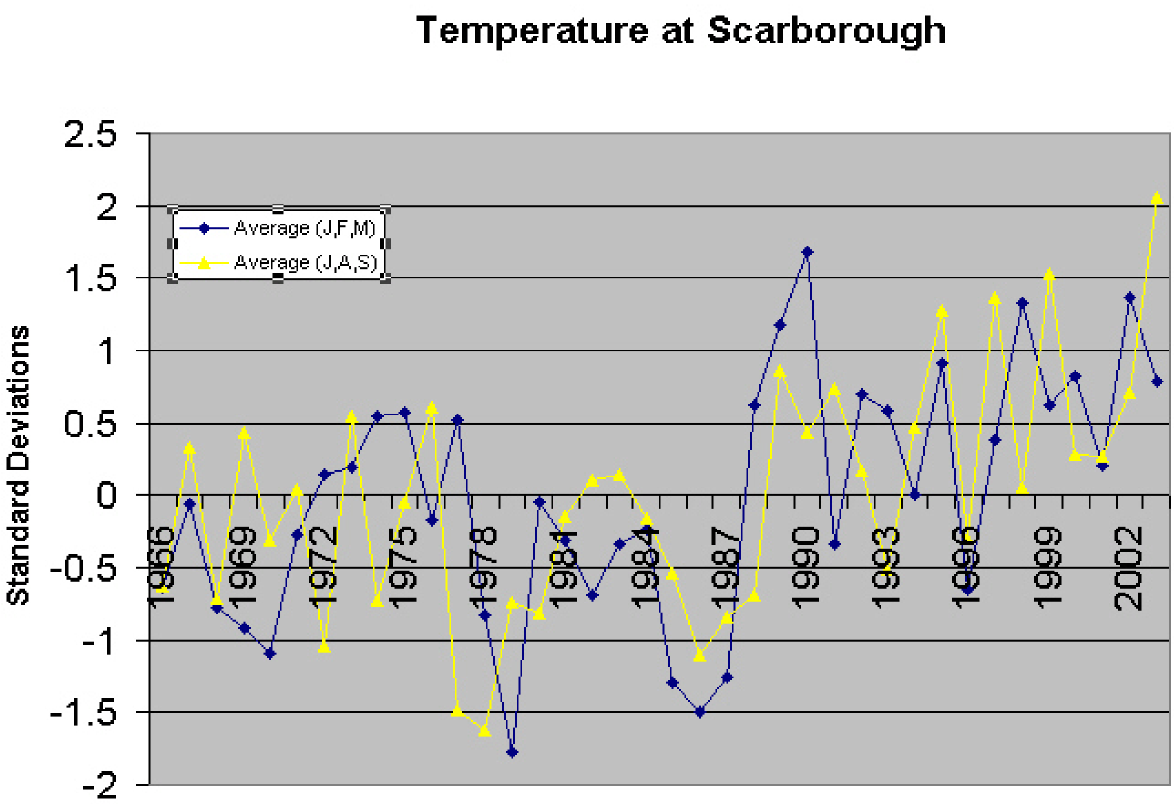


Figure 6.

Annex S: Area 9b: Skagerrak, Kattegat, and the Baltic

K. Borenas

Swedish Meteorological and Hydrological Institute, Sweden

The seas around Sweden are distinguished by the large salinity variations . In Skagerrak, water masses from different parts of the North Sea are found. The Kattegat is a transition area between the Baltic and Skagerrak. The water is strongly stratified with a permanent halocline. The deep water in the Baltic Proper, which enters through the Belts and the Sound, can in the inner basins be stagnant for long periods. In the relatively shallow area south of Sweden small inflows passes fairly quickly causing large variations and the conditions in the deeper parts are here very variable. The surface salinity is very low in the Baltic proper and the Gulf of Bothnia. The latter area is ice covered during winter.

The ice winter 2002/2003 was classified as severe with the maximum ice extent occurring on 3 March 2003. The Gulf of Bothnia, the Gulf of Finland and the northeastern parts of the Baltic Proper was then covered with ice (see Figure 1). The cold winter conditions were manifested in the sea surface temperature records, which showed values below average during winter and spring. As an example the record from station BY15 (east of Gotland, see map in Figure 5) is shown in Figure 2. The end of the summer was fairly warm and sea surface temperatures in August were found to be above average at most stations around Sweden. The trend of decreasing values of the surface salinity in the Baltic Proper continued in 2003 (Figure 3).

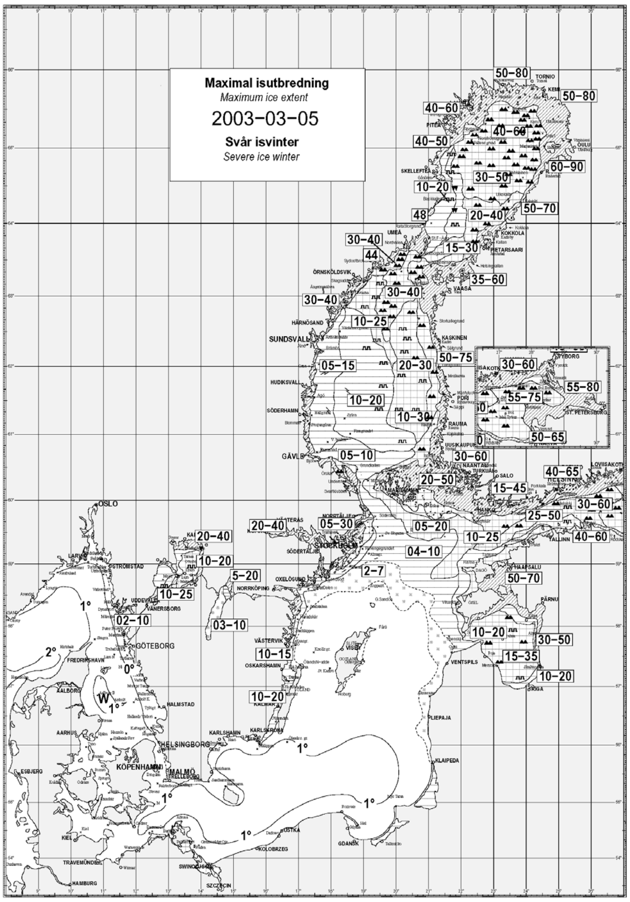


Figure 1. The maximum ice extent in the Baltic Sea during the winter 2002/2003. The map was constructed by SMHI.

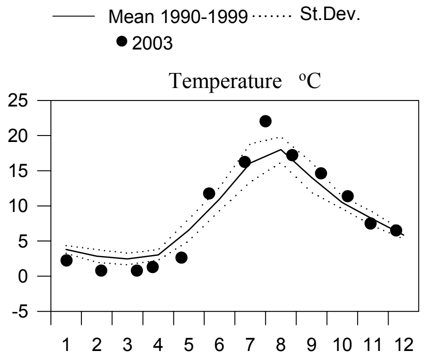


Figure 2. Annual cycle of surface temperature at station BY15 (east of Gotland). The data were collected by R/V Argos within the Swedish National Monitoring Programme.

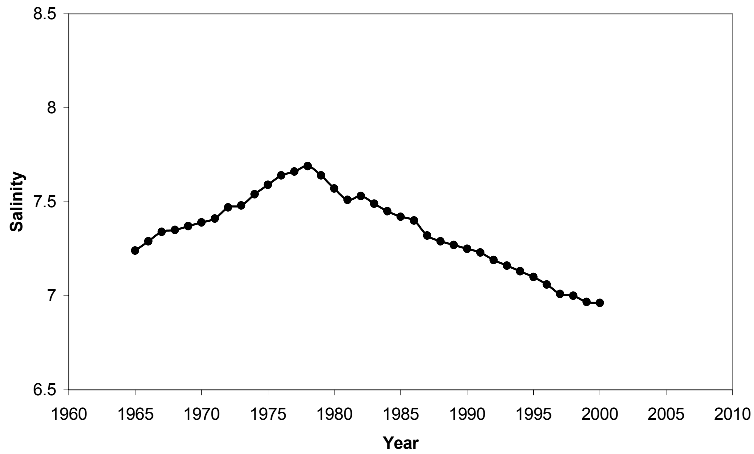


Figure 3. The surface salinity at station BY15 (east of Gotland) in the Baltic proper (5-year running mean).

An inflow of saline water into the Baltic took place in January and the effect can clearly be seen in the salinity along the transect. Anholt E-BY38 obtained in February (Figure 4). As a comparison the conditions found in July/August are also shown. The positions of the stations are shown in Figure 5. The red dots in the map represent stations pertaining to the Swedish National Monitoring Programme while stations in blue are additional stations sampled by SMHI on a regular basis.

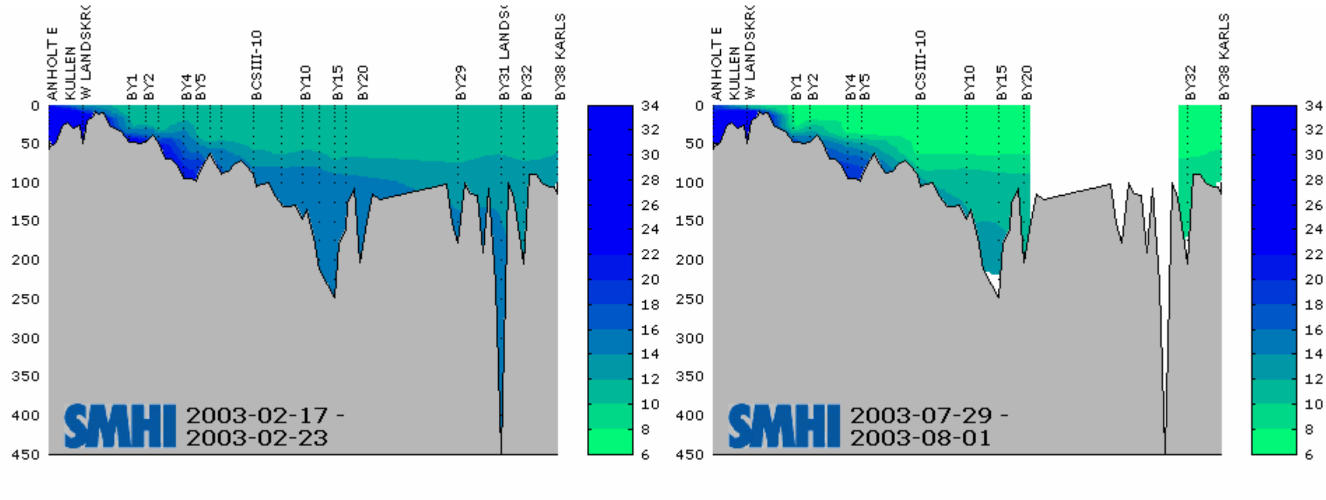


Figure 4. Salinity along the transect Anholt E-BY38 in February (left) and July/August (right). For station positions see map in Figure 5.

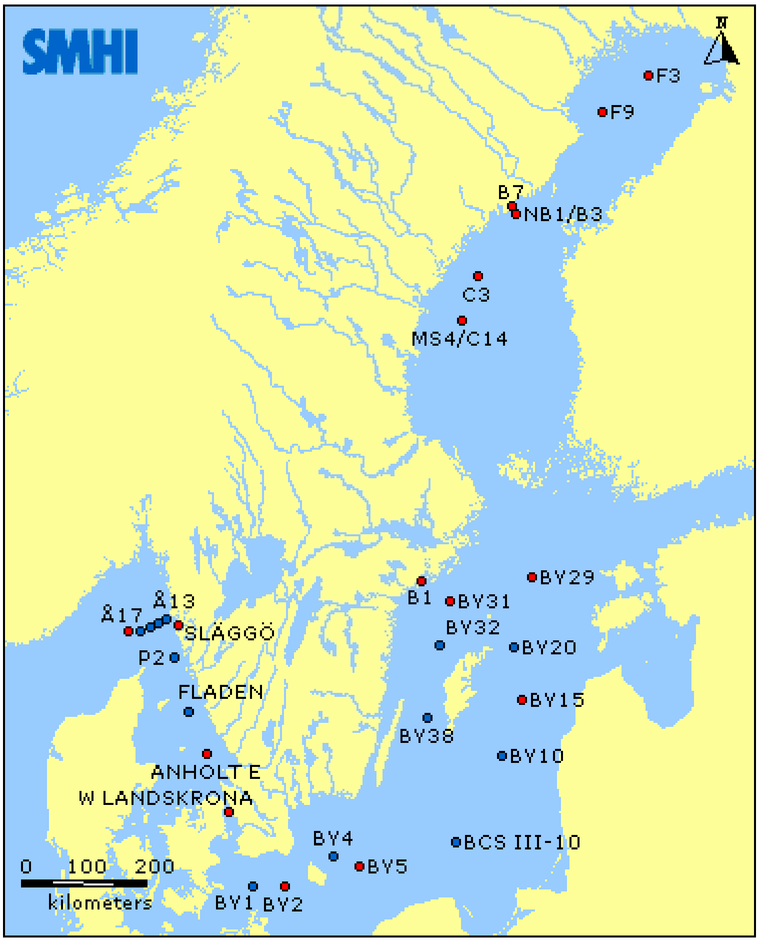


Figure 5. Position of stations visited on a regular basis. Stations marked with red pertain to the Swedish National Monitoring Programme while stations in blue are additional stations sampled by SMHI.

Annex T: Area 9B: Skagerrak, Kattegat, and the Baltic

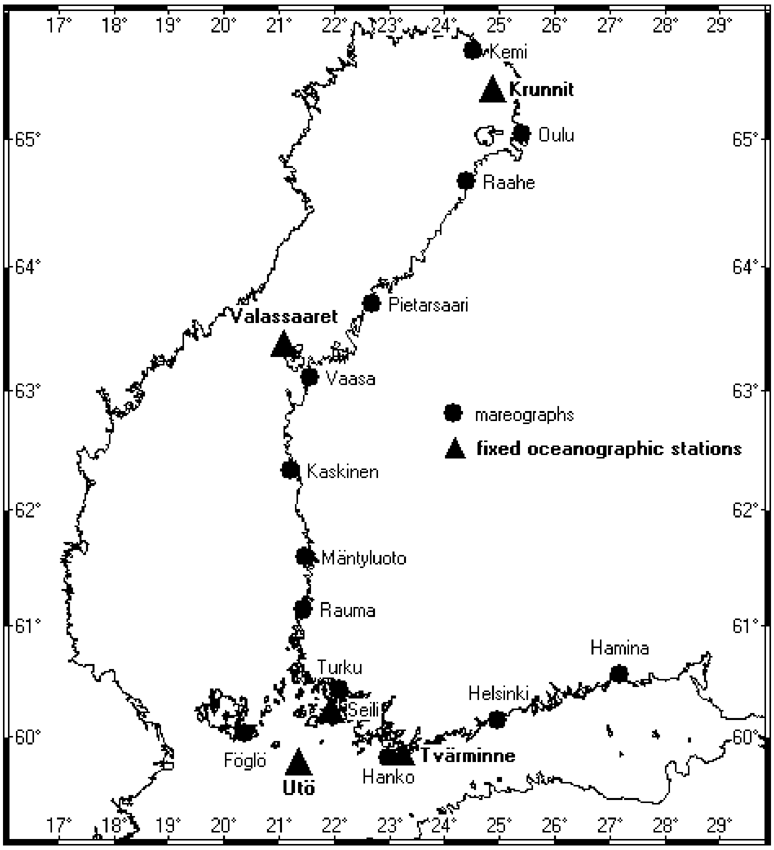
B. Rudels

Finnish Institute of Marine Research, Helsinki, Finland

The Finnish long-term temperature and salinity records are mainly from permanent coastal and island stations. In recent years also the tide gauges have been equipped for temperature recording (Figure 1). The temperature time series from the tide gauges are still fairly short, in the order of 5 years. The sea surface temperature measured at Seili, in the Archipelago Sea, was below the 30-year mean temperature in winter and spring. This is probably due to the early cooling in 2002 and the long, cold winter 2002-2003. In spring and early summer the temperature was close to average, while in the end of July and in early August the temperatures were at and above the 30 years averaged maximum temperature. By the end of August the temperature was again close to the 30 year mean and remained so to the end of the year (Figure 2).

The hydrographic stations taken during 2003 with RV Aranda covered the Bay of Bothnia, the Gulf of Finland and a substantial part of the Baltic Sea proper (Figure 3). Among the Finnish offshore stations especially station LL7 in the Gulf of Finland (Figure 4) has been repeatedly visited during the summer months. Apart from a cold early spring the summer surface temperatures were high but not among the highest recorded during the last 40 years (Fig 5). The sea surface salinity was close to the 40 year mean and higher than the last 3 years (Figure 6). LL7 has recently also become a repeat station, taken whenever one of the research vessels Aranda or Merikarhu passes the position. The record is still short and gaps exist. The observations since 1999 are shown in Figure 7. In January 2004 winter convection appears to have broken through the halocline and reached 70m, homogenising the water column to this depth. In the existing time series a similar situation is only found in January 2000 (Figure 7).

The ice winter 2002-2003 was normal as compared to the long-term record, but it was considerably more severe than in the preceding 5 years.



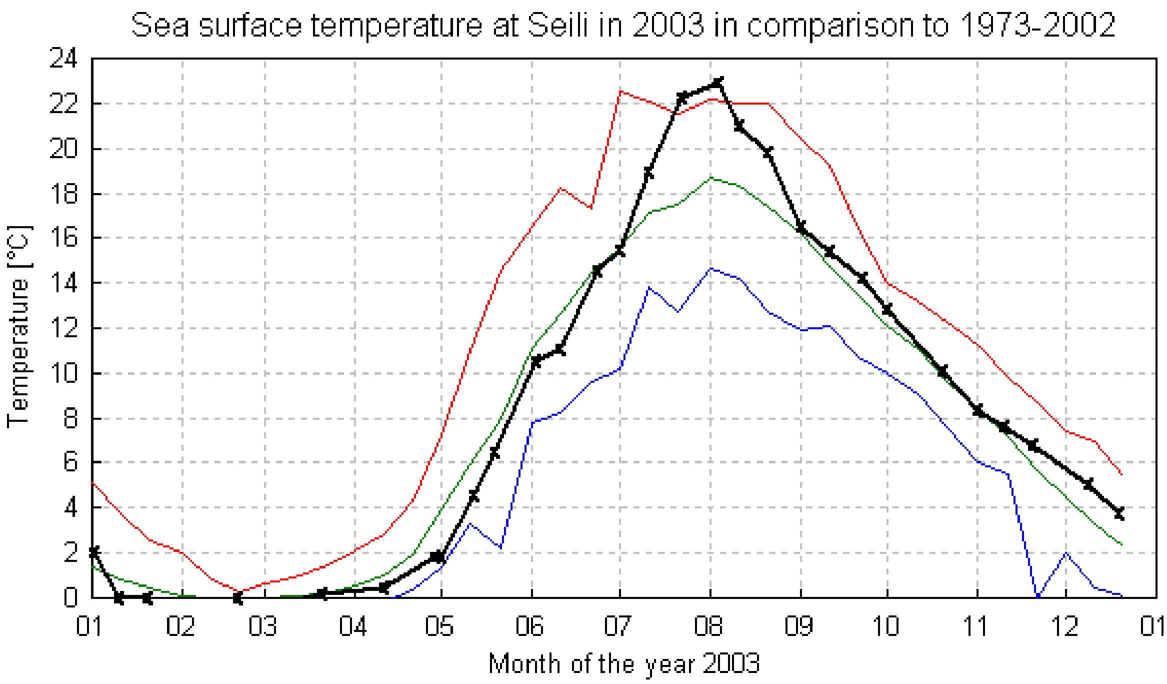


Figure 1. Finnish permanent oceanographic stations and tied gauges.

Figure 2. Sea surface temperature at station Seili in the Archipelago Sea in 2003 compared to the average, maximum and minimum temperatures 1973-2002.

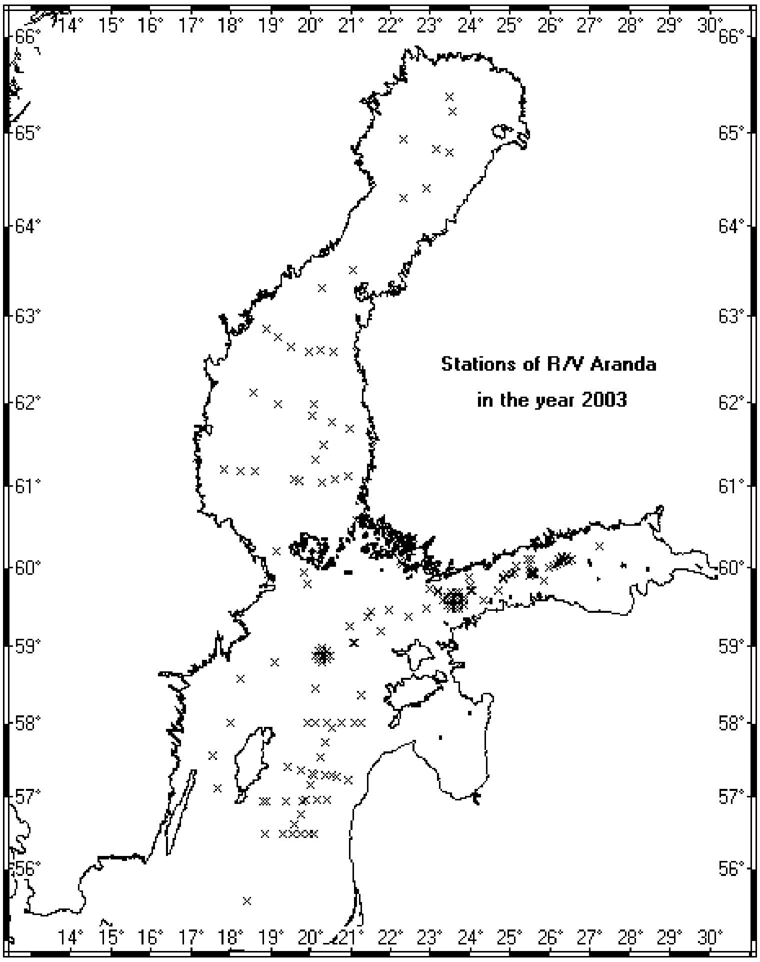


Figure 3. Hydrographic stations in the Baltic taken by RV Aranda.

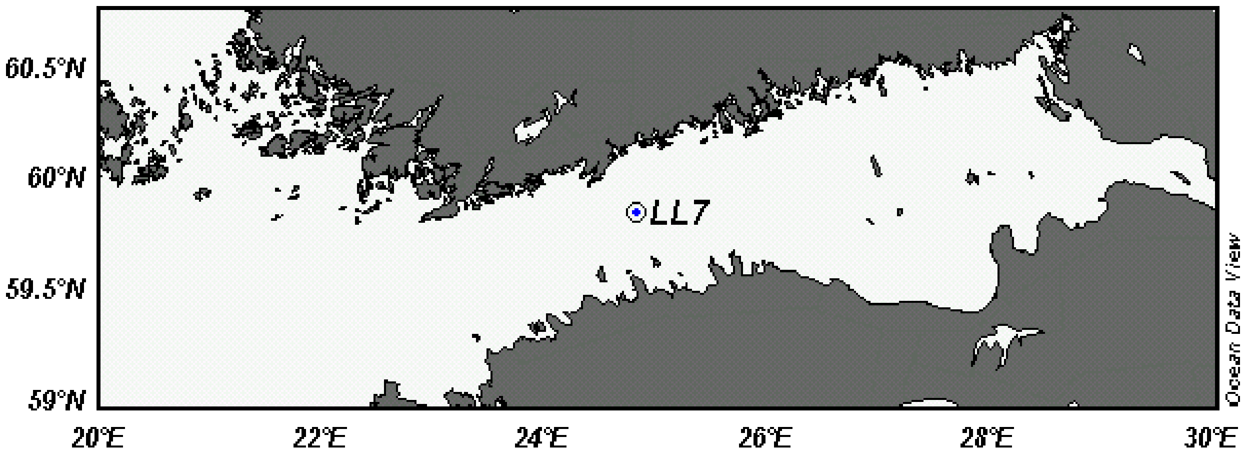


Figure 4. Position of station LL7 in the Gulf of Finland.

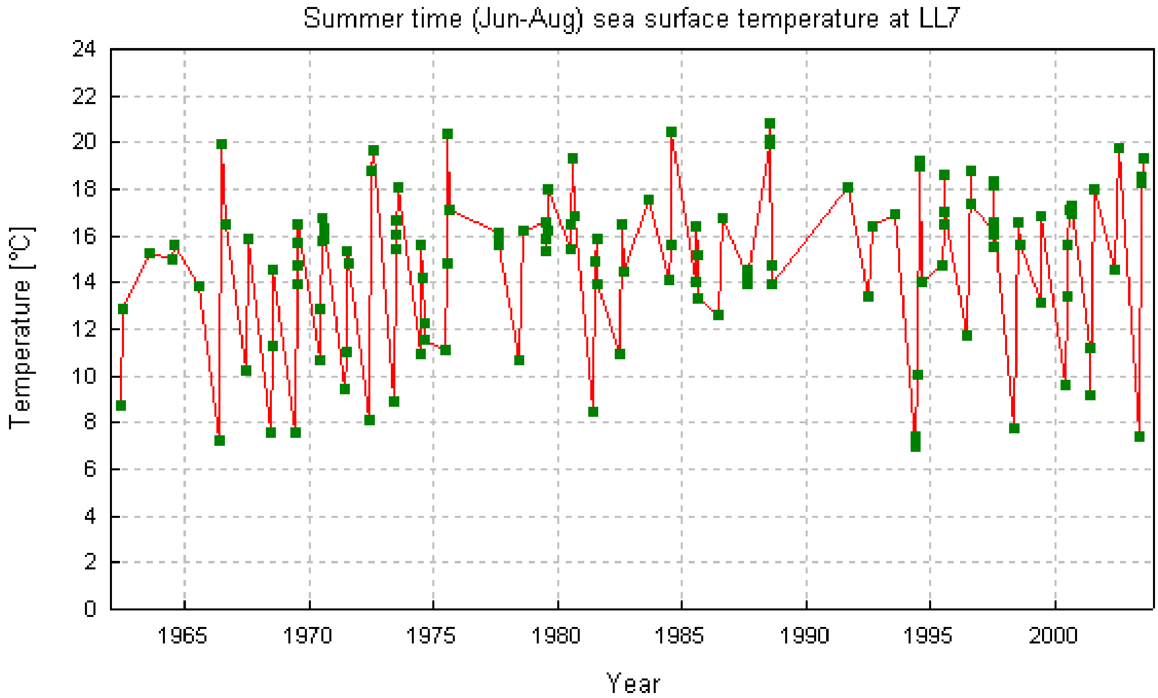


Figure 5. Sea-surface temperature in summer at LL7, 1963-2003.

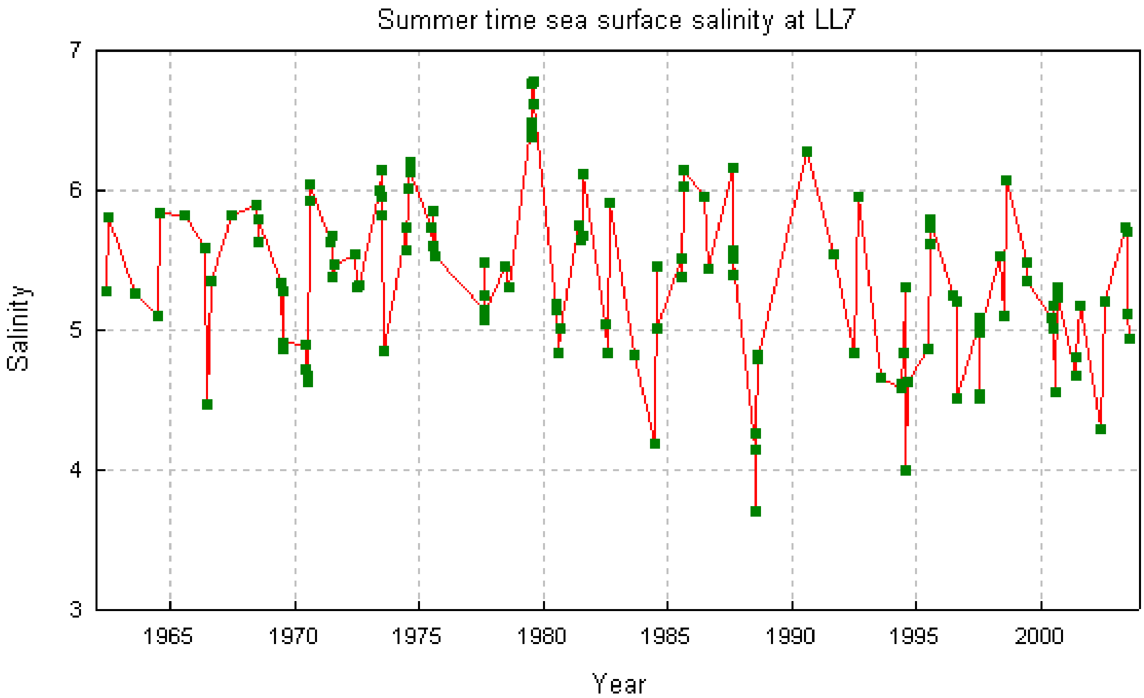


Figure 6. Sea-surface salinity in summer at LL7, 1963-2003.

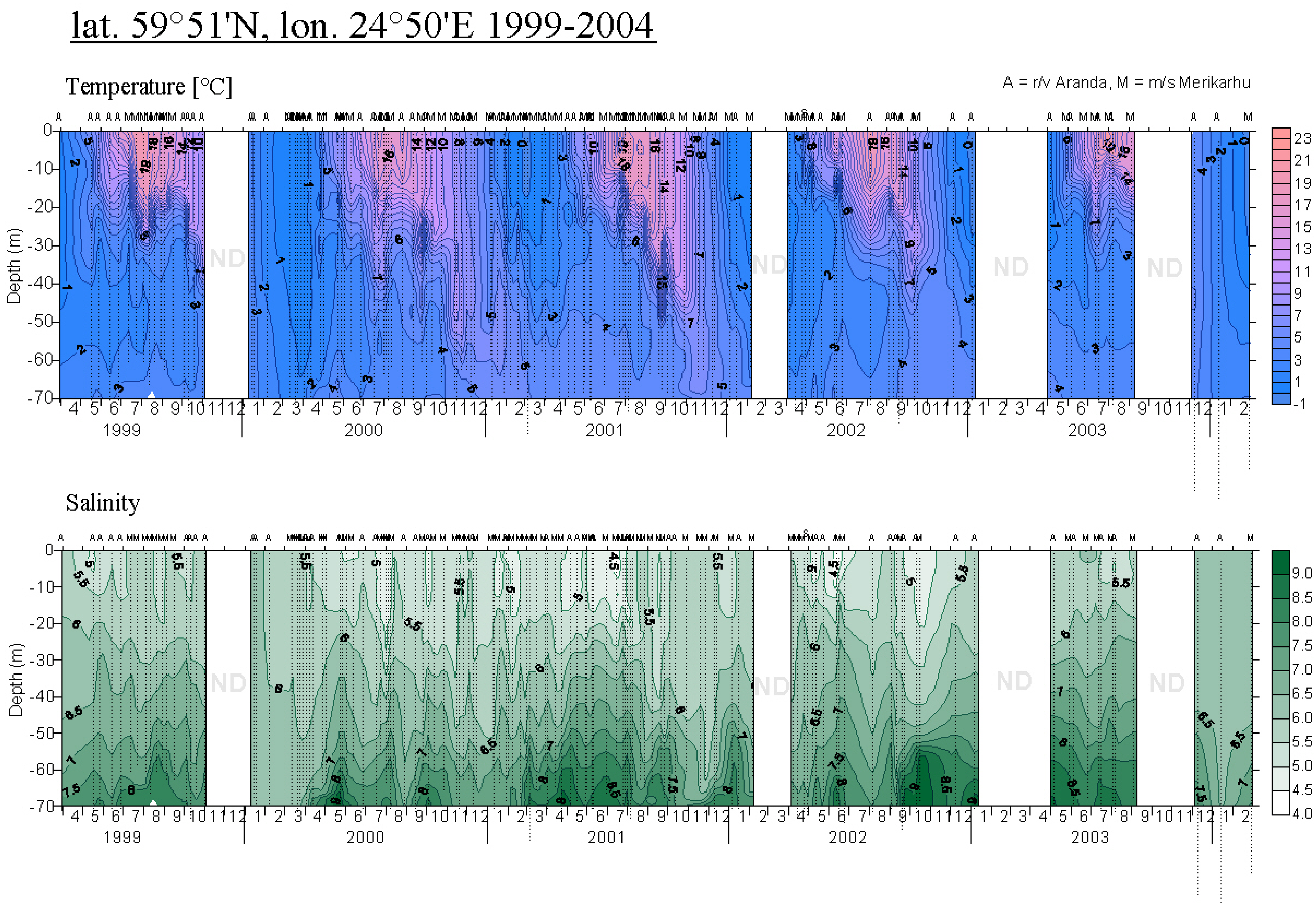


Figure 7. Time evolution of the temperature and salinity distribution at LL7, 1999-2004.

Annex U: Norwegian waters (Area 8, 10, and 11)

H. Loeng, K.A. Mork and E. Svendsen

Institute of Marine Research, Bergen, Norway

Summary

The Barents Sea temperature was approximately 0.5°C higher than average during summer of 2003. However, there was more sea-ice than average. In 2003 there was a more westerly distribution of Atlantic water in the Norwegian Sea compared to the long-term average, and consequently warmer than normal in the upper layer. In the North Sea, the temperature was above to the long-term mean in 2003.

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

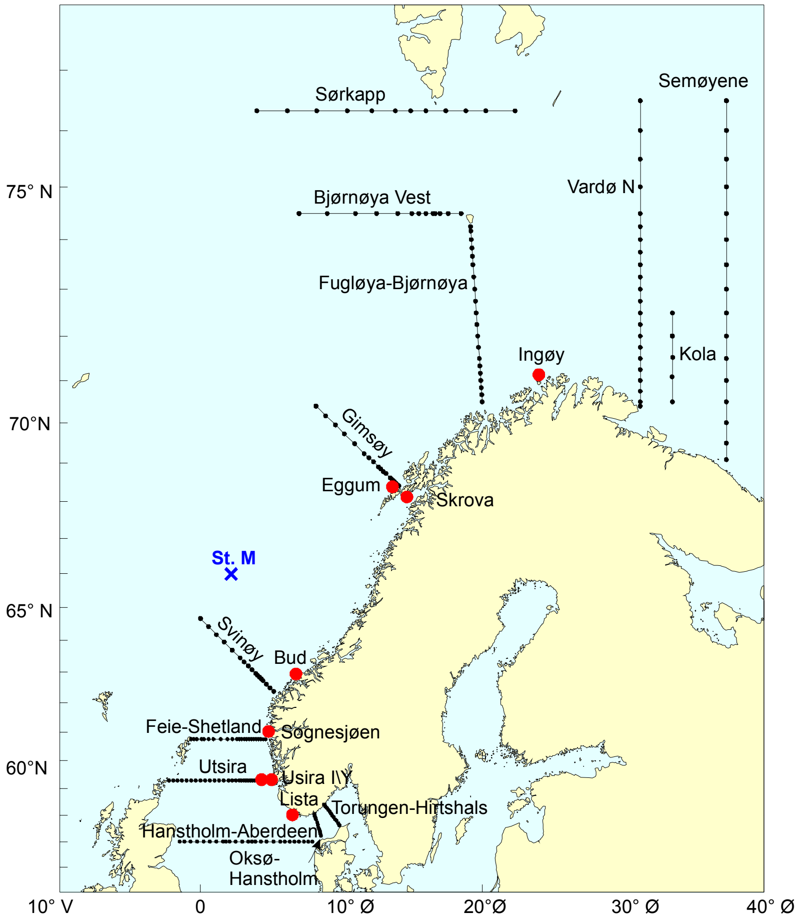


Figure 1. Standard sections and fixed oceanographic station worked by Institute of Marine Research, Bergen. The University of Bergen is responsible for station M, while the Kola section is operated by PINRO, Murmansk (ANON 2002)

The Norwegian Sea

High values of temperature were observed in the southern Norwegian Sea. There the Atlantic water was about 0,7 °C above the long-term-mean. In 2003 the Atlantic water in the southern and central Norwegian Sea had a larger westerly distribution than compared 2002 and also compared to a mean (averaged over the last ten years).

Figure 2 shows the development in temperature and salinity in three different sections from south to north in the Norwegian Sea (Figure 1). During the last 7 years the temperature and salinity in the Svinøy section have been above the long-term-mean while they were about average in the Gimsøy and Sørkapp sections. Unfortunately some data are missing in the Gimsøy and Sørkapp sections. In 2003 the salinity in the Svinøy section had the largest value in the time series, about 0.08 above normal. The temperature was the next largest in the time series, about 0.9°C above normal. Only in 2002 was the temperature higher.

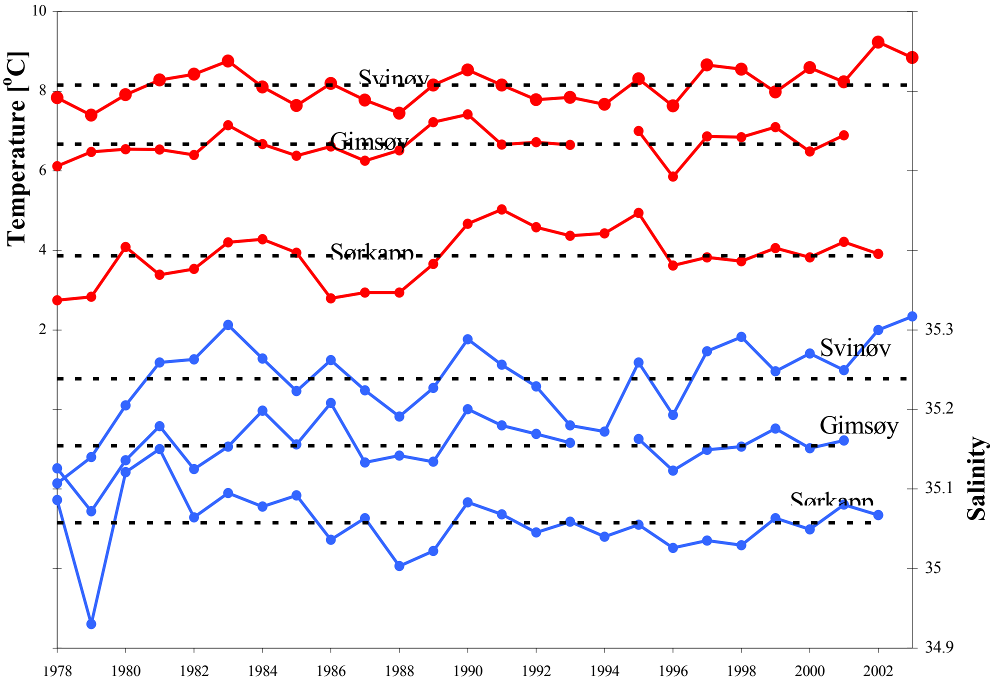
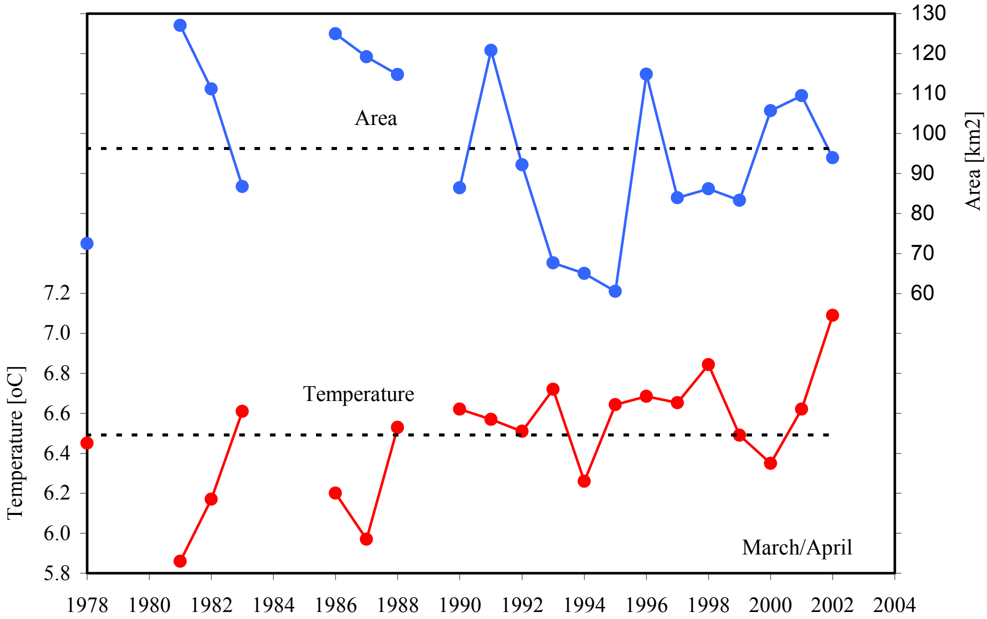


Figure 2. Temperature and salinity, observed in July/August in the core of Atlantic water in the sections Svinøy-NW, Gimsøy-NW and Sørkapp-W, averaged between 50 and 200 m depth. (ANON 2004).

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 both spring and summer are shown in Figure 3. There are considerable variations both in the area of Atlantic water distribution and its temperature. The distribution area of Atlantic water has decreased since the beginning of 1980s, while the temperature has shown a steady increase. Since 1978 the Atlantic water has been about 0.6°C warmer. During the years 1992-1995 the area was much lower than average for both seasons. In 1997-1999 there was a warm period followed by a substantial drop in temperature in 2000. Then in 2002 the temperature increased considerable and in 2003 it had the largest value in the time series. The temperature was in 2003 about 0.7°C higher than the long-term-mean for summer. The area of Atlantic water in 2003 increased also and had the largest value since 1987.



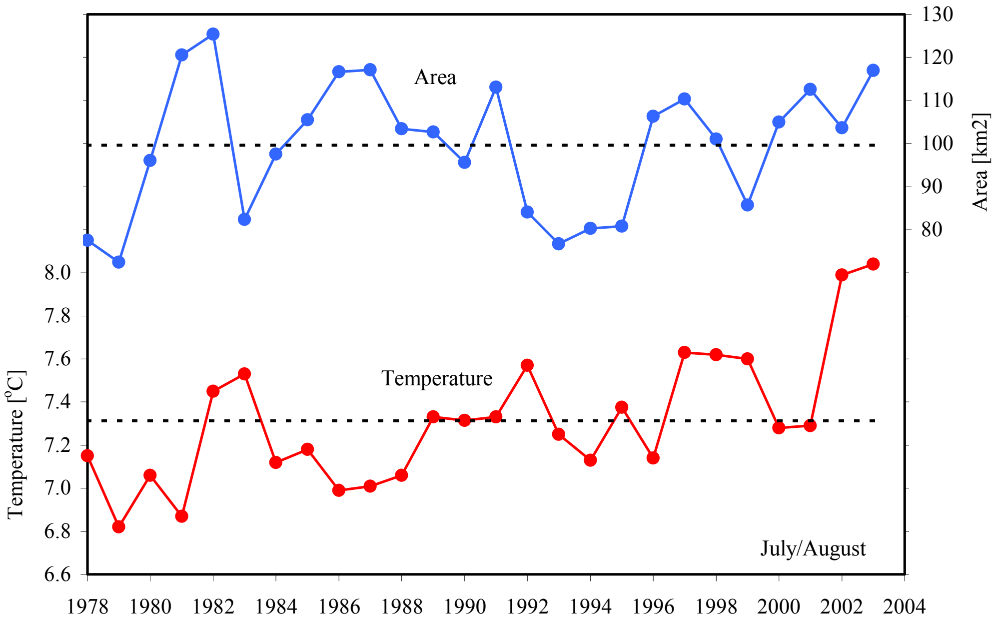


Figure 3. Time series of area (in km^2) and averaged temperature (red) of Atlantic water in the Svinøy section, observed in March/April (upper figure) and July/August (lower figure) 1978-2003 (ANON 2004).

During research cruises in May with the aim of estimating the pelagic stock hydrographic observations are also taken, covering most of the Norwegian Sea. Figure 4 shows the horizontal distribution of temperature at 100 m depth for 2003 and for a mean year (averaged over the last ten years). In 2003 there was a larger westerly distribution of Atlantic water than normal and also compared to 2002 (not shown). At 100m depth the temperature was about 0,5 °C above normal and in some areas 1,5 °C above normal.

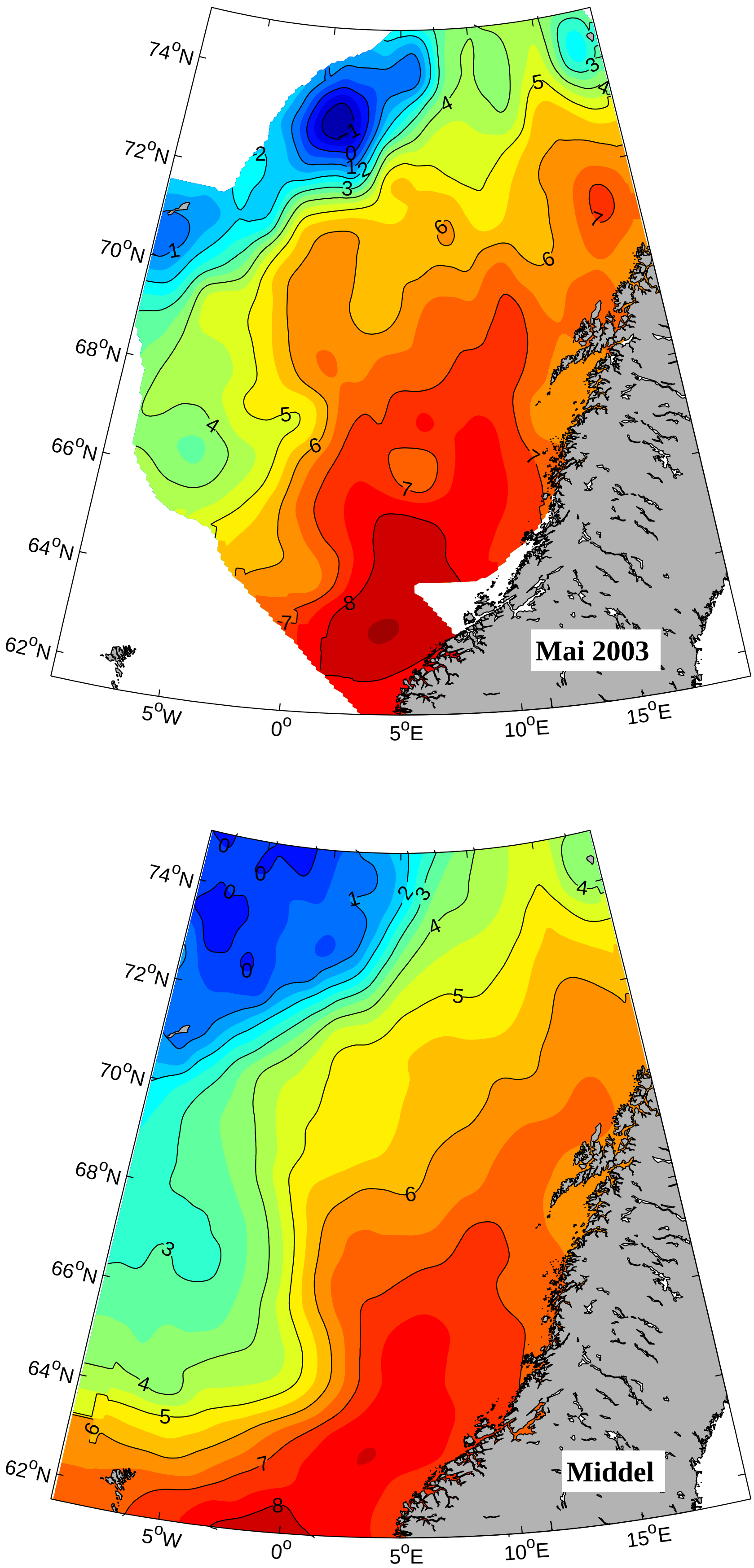


Figure 4. Distribution of temperature at 100m depth in the Norwegian Sea for May. Upper panel: 2003. Lower panel: mean temperature for May in 1993-2003.

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.

Figure 5 shows the temperature and salinity anomalies in the Fugløya-Bear Island section in the period from 1977 to January 2004. Temperatures in the Barents Sea were relatively high during most of the 1990s, and with a continuous warm period from 1989-1995. During 1996-1997, the temperature was just below the long-term average before it turned warm again at the end of the decade. Even the whole decade was warm, it was only the third warmest decade in the 20th century (Ingvaldsen *et al.* 2002).

In January 2003 the temperature was just above the long-term average in the whole Barents Sea, but then the temperature rose quickly until March when it was 0.7°C above the long-term mean. From April and the rest of the year, the temperature was 0.5°C above the long term average. In January and March 2004 the temperature was still 0.5°C above the average,

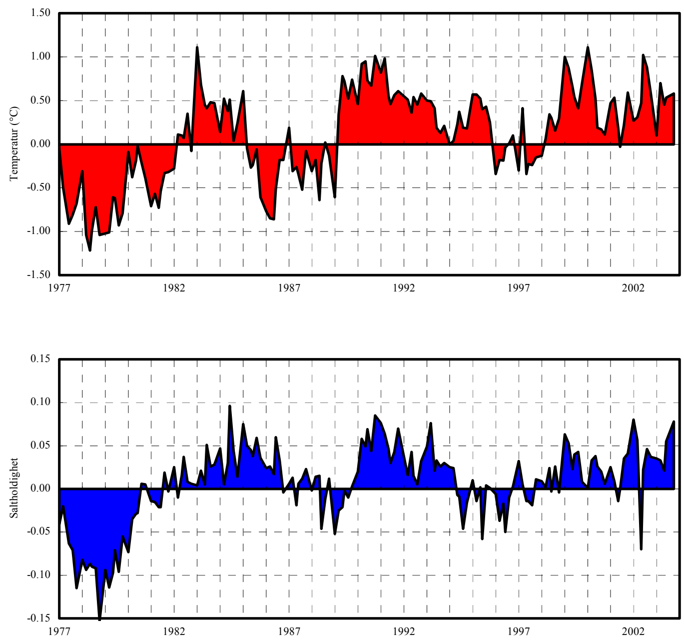


Figure 5. Temperature anomalies (upper panel) and salinity anomalies (lower panel) in the section Fugløya – Bear Island (ANON 2004).

Figure 6 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. 2004 had a negative ice index, which means more ice than average. This was very surprising since the sea temperature was high. There were two reasons for this. Firstly the really ice melt did not start before mid June, which is about one month later that usual. Secondly, the ice melt during summer was extremely low, most likely due to atmospheric forcing.

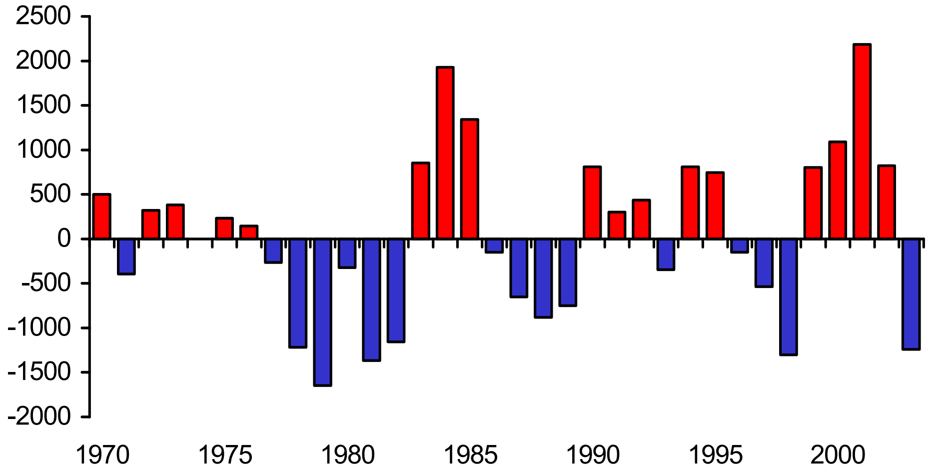


Figure 6. Ice index for the period 1970-2003. Positive values means less ice than average, while negative values show more severe ice conditions (ANON 2004).

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.,* 1999, 2000). Based on several years of hydrographic observations, and also by current measurement from a 2-month time series presented by Blindheim (1989), it was believed that the inflow usually take place in a wide core located in the area 72^{o}30’-73^{o}N with outflow further north. The long-term measurements that started in August 1997 showed a more complicated structure of the current pattern in the area. The inflow of Atlantic water 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^{o}30’N south to 72^{o}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 either by accumulation of water 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 and heat transports reveal fluxes with strong variability on time scales ranging from one to several months (Figure 7). The monthly mean volume flux is fluctuating between about 5.5 Sv into and 6 Sv out of the Barents Sea, and with a standard deviation of 2 Sv. 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. High outflows occurred in April both in 1998 and 1999 and in 2000 there were two periods with strong outflow, one in January and a second one in June. In the first half of 2003 the inflow was high, which may explain the rapid temperature increase between January and March. The intensity of the flow was reduced during spring and summer. Figure 8 shows the variability in the inflow as calculated from a wind driven numerical model. Except for January, it is a good fit with the observations. The model results indicate that the variations in local the atmospheric pressure field may be important for the inflow of Atlantic water to the Barents Sea (Ådlandsvik and Loeng, 1991, Ingvaldsen *et al*. in press).

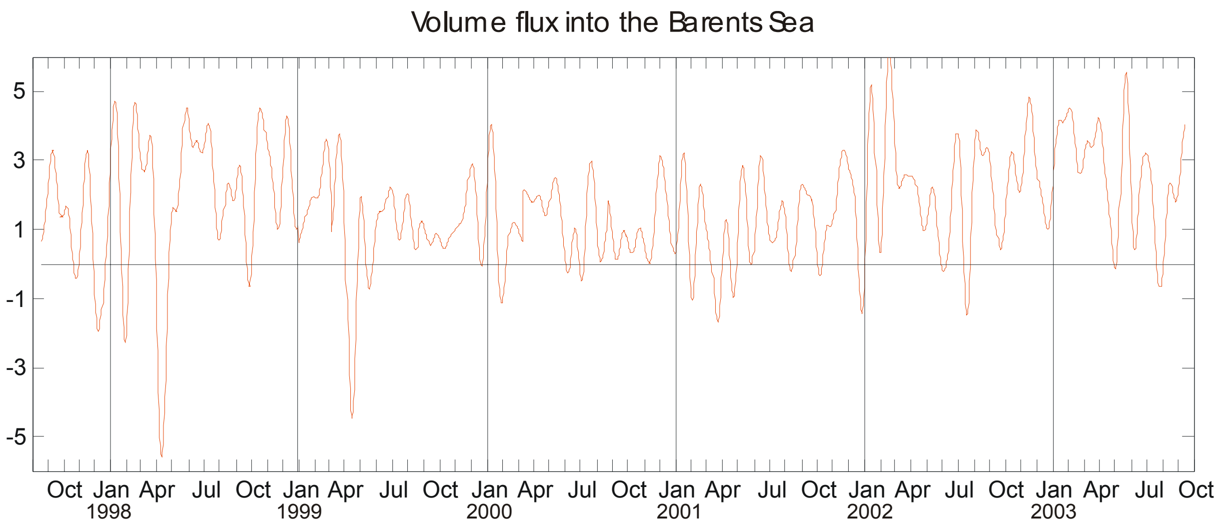


Figure 7. Total volume flux across the section Norway-Bear Island All data have been low pass filtered over 30 days (Anon. 2004).

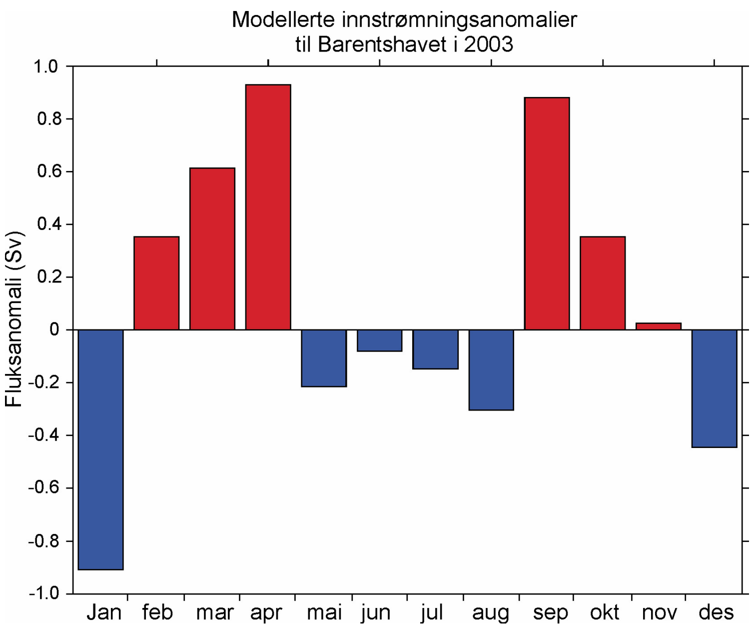


Figure 8. Modelled flux anomalies in 2003 through the section between Norway and Bear Island (Anon. 2004)

The North Sea

The temperature of the upper layer of most of the North Sea was somewhat warmer than normal during the first half of 2003. While being near normal in January (colder than normal at the Norwegian coast), the deviation increased gradually to 1-2 degree Celsius with the largest deviation in the western North Sea. During the 3rd quarter the surface temperature was about 2 degrees warmer than normal, while the 4th quarter was about 1 degree warmer. This means that the second half of 2003 was the warmest of the past 30 years. 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. At the plateau, there has been a continuous increase both in temperature and salinity from 1996 to 1999, while decreasing values were observed in 2000. The development is relative similar in the core of the Atlantic inflow. At both positions, the values from 2000 and 2001 were rather close to the long-term average, while in 2002 we see a certain increase in temperature. The temperature at the plateau increased further in 2003 making this a warm year well above normal. In the Trench extremely high values of salinity and temperature were observed in 2003. This is partly related to relatively strong inflow of Atlantic water in the 2nd quarter and particularly in June, and that the inflowing water was very salty and warm from the bottom to about 50 m depth.

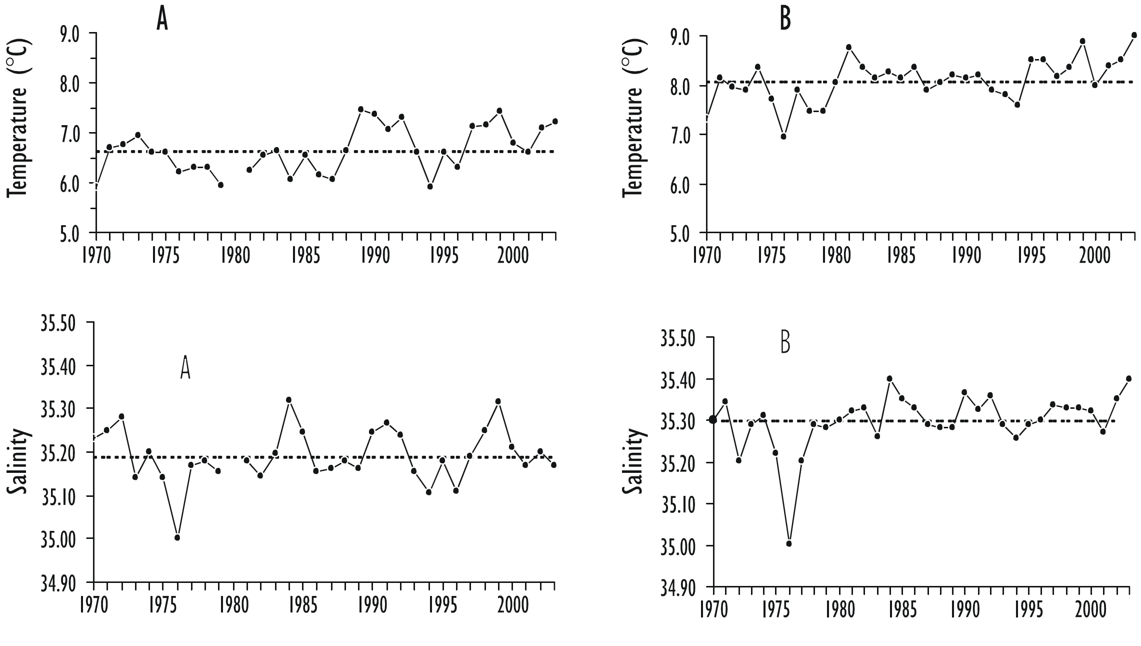


Figure 9. Temperature and salinity near bottom in the northwestern part of the North Sea (A) and in the core of Atlantic water at the western shelf edge of the Norwegian Trench (B) during the summers of 1970-2003 (ANON. 2004).

Estimates from a numerical ocean circulation model showed that the circulation in the North Sea was quite normal throughout 2003. However the net inflow through the English Channel was relatively weak (the weakest annual mean since 1976), although with a stronger than normal inflow during the 2nd quarter. The inflow of Atlantic water in the north was in total somewhat stronger than normal (Figure10). This inflow of Atlantic water introduced more nutrients in the North Sea system than usual and lead to a stronger (10-20 gCm^{-2}, model based) annual primary production in the northern North Sea compared to the mean production for the period 1985-2003. The production was significantly lower in the southern and eastern North Sea, in particular along the Danish west coast.

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 2003 the model prognosis was 33.000 ton while the following catches was 20.000 ton.

The Skagerrak coastal water is defined with salinity between 25.0–32.0. Water with lower salinity is defined as brackish water. Along the coast of southern Norway, the thickness of the Skagerrak coastal water was most of the year about 10-

30 m. The brackish water was found in the upper 5-10 m in spring, significantly thinner than in previous years. The transition between Skagerrak water (with salinity between 32-35) and the Atlantic water was found generally deeper than 75 m. The winter of 2003 was quite cold with temperatures less than 1 ^{0}C in the upper 5-10 m in January. A warm summer (June to September) resulted in very warm surface temperatures (2 degrees above normal in July), and 14 ^{0}C at 50 m depth in September. In 2003 we experienced some exchange of the deep water in Skagerrak during March to May seen as an increased oxygen concentration.

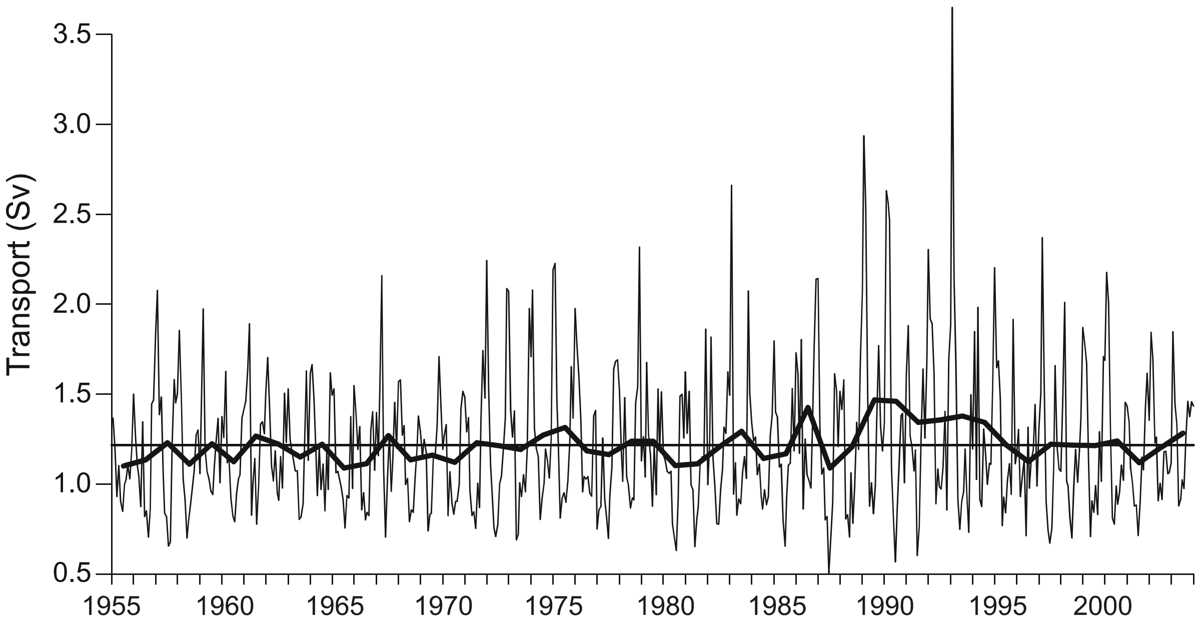


Figure 10. Time series (1955-2003) of modelled annual mean (bold) and monthly mean volume transport of Atlantic water into the northern and central North Sea southward between the Orkney Islands and Utsira Norway. 1 Sv = $10^6 m^3 s^{-1}$. (Anon., 2004).

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Annex V: Russian standard sections in the Barents and Norwegian Seas (ICES areas 10 and 11)

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The Barents Sea

Climatic conditions in the Barents Sea are closely linked to the large-scale sea level pressure patterns and atmospheric circulation.

In winter and spring 2003, low pressure dominated over the Barents Sea with southwesterly winds prevailing over its southern part while northerly and northeasterly winds were typical of the northern Barents Sea. In summer air pressure patterns were dominated by the Azores High and light northerly winds prevailed over the Barents Sea. In autumn atmospheric circulation over the sea was under the influence of the Icelandic Low, which led to the predominance of southwesterly and southerly winds.

Air temperatures averaged for the western Barents Sea (70-76°N, 15-35°E) were generally close-to-normal throughout the year with large negative anomalies (2.0-4.0 °C) in January and December. In the eastern Barents Sea (69-77°N, 35-55°E) slightly warmer-than-normal air temperatures prevailed throughout the year.

Sea surface temperature (SST) was close or colder-than-normal over most of the Barents Sea in January-July. The rest of the year was slightly (0.3-0.7 °C) above normal.

Close-to-normal air and sea temperatures resulted in close-to-normal ice coverage (% of the total Barents Sea area) throughout the year with increased amount of ice (5-10%) in January-February and December.

Figure 1 shows main Russian standard sections in the Barents Sea. The Kola section runs from the Kola Fjord mouth northwards, along 33°30'E, and crosses the coastal and main branches of the Murman Current. In 2003, the Kola section was occupied in 10 months out of 12. Measurements along other sections were done 2-3 times during the year.

Figure 2 shows monthly temperature anomalies in the upper 200 m layer of the coastal (St. 1-3; 69°30´-70°30´N, 33°30´E) and main (St. 3-7; 70°30´-72°30´N, 33°30´E) branches of the Murman Current.

In January and February, the temperature was close to normal both in coastal water and in the main branch of the Murman Current. In spring through autumn the temperature increased gradually, and in October-December positive temperature anomalies ranged from 0.5 °C to 0.8 °C. However, warming in coastal water was more rapid and more pronounced than that of the Murman Current. Positive temperature anomalies in May-December ranged between 0.4 °C and 0.8 °C in coastal water and from 0.0 °C to 0.6 °C in the Murman Current. The warming continued into 2004, and the temperature was higher than normal by 0.7-1.0 °C.

The annual mean temperature in the main branch of the Murman Current was 0.3 °C above normal (Figure 3). 2003 was the fifth warm year since 1999. The annual mean temperature in the upper 200 m layer in the Kola section in 2004 is expected to be close to the long-term average.

The section Bear Island - West (along 74°30´N) was occupied 3 times in 2003. The temperature in the Norwegian current (74°30´N, 06°34´-15°55´E) in the layer 0-200 m was warmer-than-normal by 0.5 °C in October and December. In November the temperature was higher than the long-term mean by 0.7 °C.

The section Bear Island - East (along 74°30´N) was occupied in September, October and November. A positive temperature anomaly in the northern branch of the North Cape Current (74°30´N, 26°50´-31°20´E) in the layer 0-200 m increased from 0.1 °C in September to 0.4 °C in November.

Measurements in the Kanin section (along 43°15´E) were performed in February, August and October. The temperature of Atlantic water (71°00´-71°40´N, 43°15´E) in the upper 200 m layer was 0.3-0.5 °C above normal.

In the near bottom layer close to normal temperatures prevailed over most of the Barents Sea throughout the year. Figure 4 shows bottom temperature anomalies in August-September. The anomalies were calculated using the data acquired during joint IMR/PINRO 0-group fish and pelagic fish surveys. Most of the bottom was dominated by close to normal temperatures (-0.5 – 0.5°C). The warmest anomalies ranging between 0.5°C and 2.0°C spread over the western, southern and southeastern Barents Sea along the North Cape, Murman and Novaya Zemlya Currents.

The Norwegian Sea

Large-scale sea level pressure patterns and atmospheric circulation led to the prevalence of the southwesterly winds over most of the Norwegian Sea throughout the year.

The air temperature over the Norwegian Sea was warmer-than-normal by 1-3°C throughout the year except January and October.

SST in the Norwegian Sea was above the long-term mean all year long. Positive SST anomalies were about 1.5-2.0°C in the central Norwegian Sea, while in the southern and western part of the sea (area of the East Icelandic Current) SST was above normal by 2.5-3.0°C.

Figure 5 shows standard sections occupied in July 2002 in the Norwegian Sea.

A considerably warmer-than-normal temperature in the Western Branch of the Norwegian Current and warmer-than-average temperature in the East Icelandic Current and in the mixed waters of the central part of the sea was the main feature of hydrographic conditions in the Norwegian Sea in summer 2003.

The vertically averaged temperature in the upper 200 m layer in the Western Branch of the Norwegian Current in the sections 6C (65°45´N, 01°45´W-02°00´E) and 7C (67°30´N, 01°00´W-02°40´E) was above normal by 0.9-1.5°C and by 0.3°C higher than in 2002 (Figure 6a).

The temperature of mixed waters in the central Norwegian Sea was above normal (by 0.7-0.9°C) in both section 6C (65°45´N, 04°00´W-02°30´W) and 7C (67°30´N, 04°00´W-01°45´W) (Figure 6b).

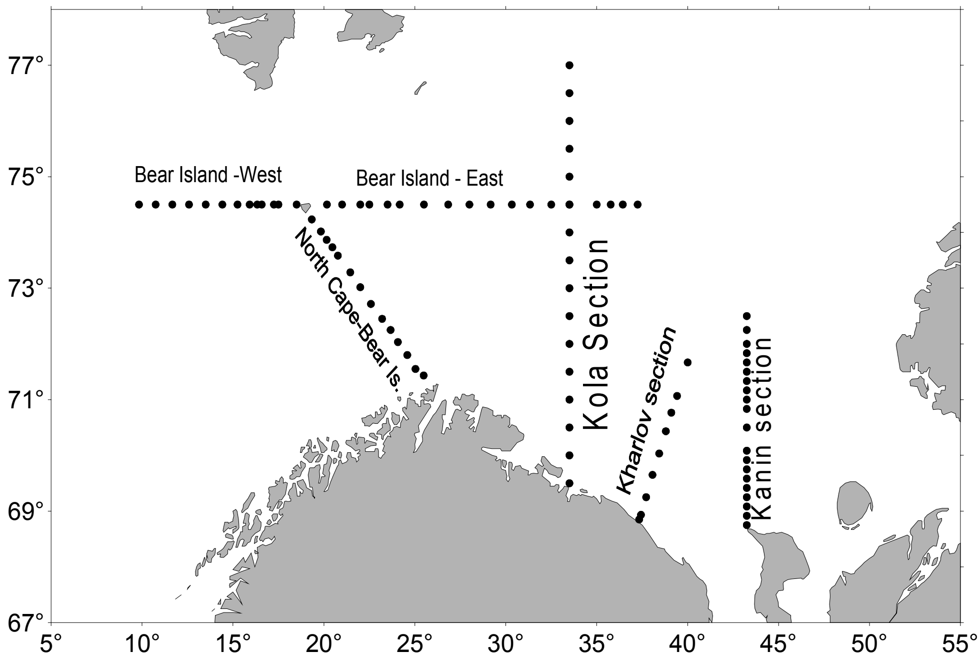

Figure 1. Main Russian standard sections in the Barents Sea.

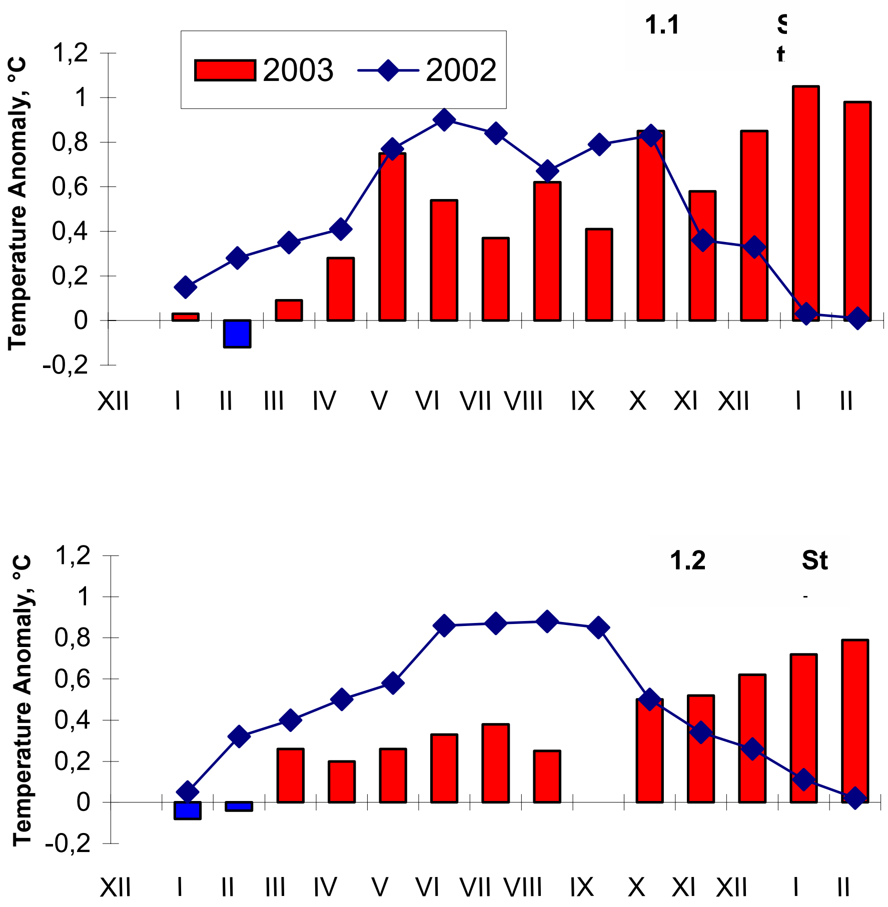

Figure 2. Monthly mean temperature anomalies in the 0-200 m layer of the Kola section in 2002 and 2003. St. 1-3 – Coastal branch of the Murman Current. St. 3-7 – Main branch of the Murman Current.

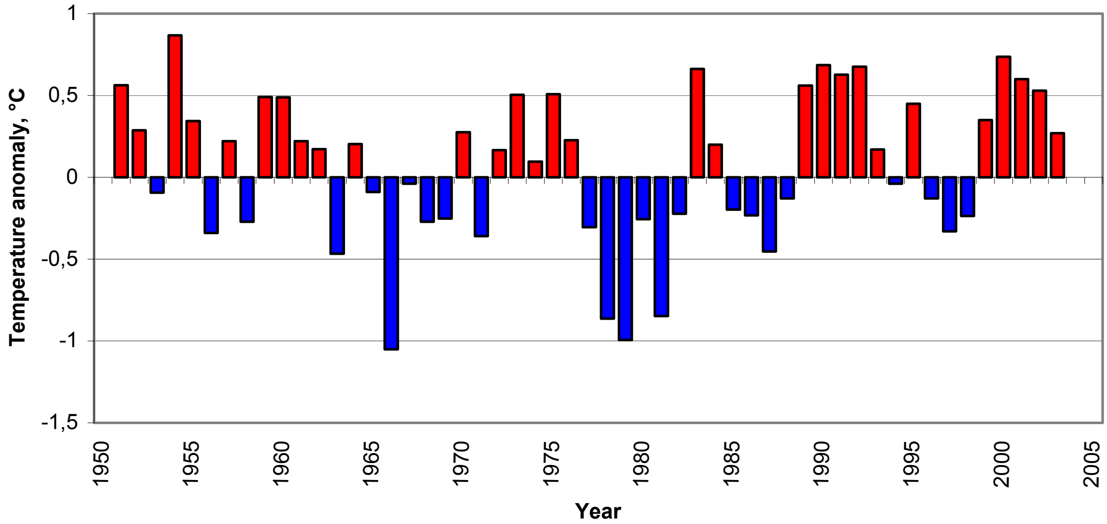

Figure 3. Mean yearly temperature anomalies in the 0-200 m layer in the Kola section in 1951-2003.

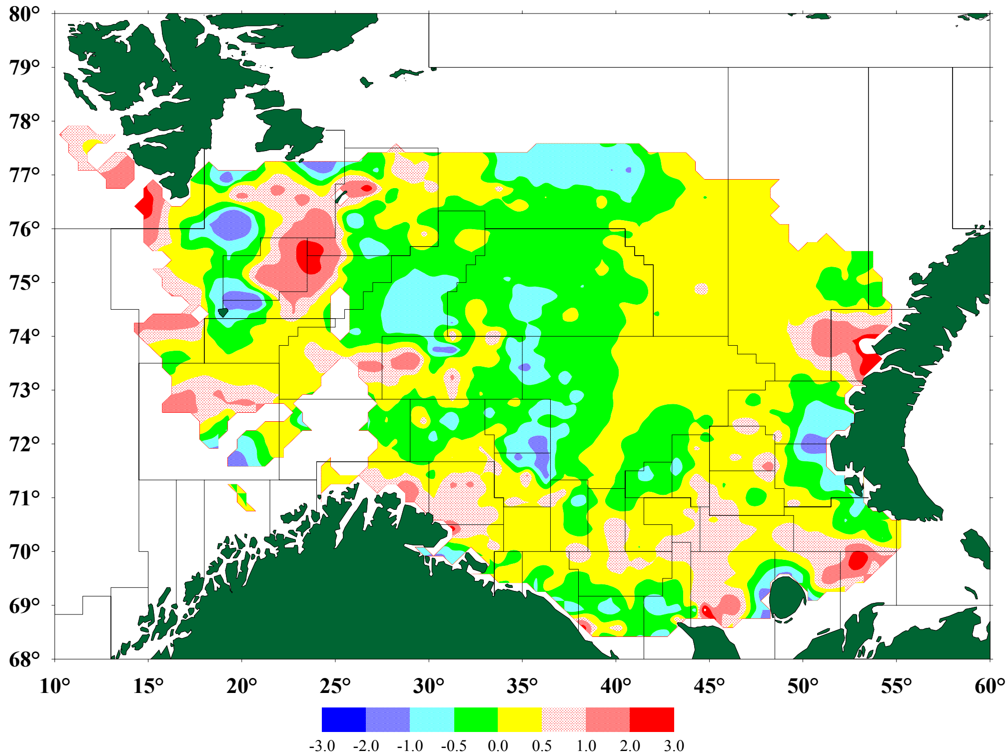

Figure 4. Bottom temperature anomalies in the Barents Sea in August-September 2003.

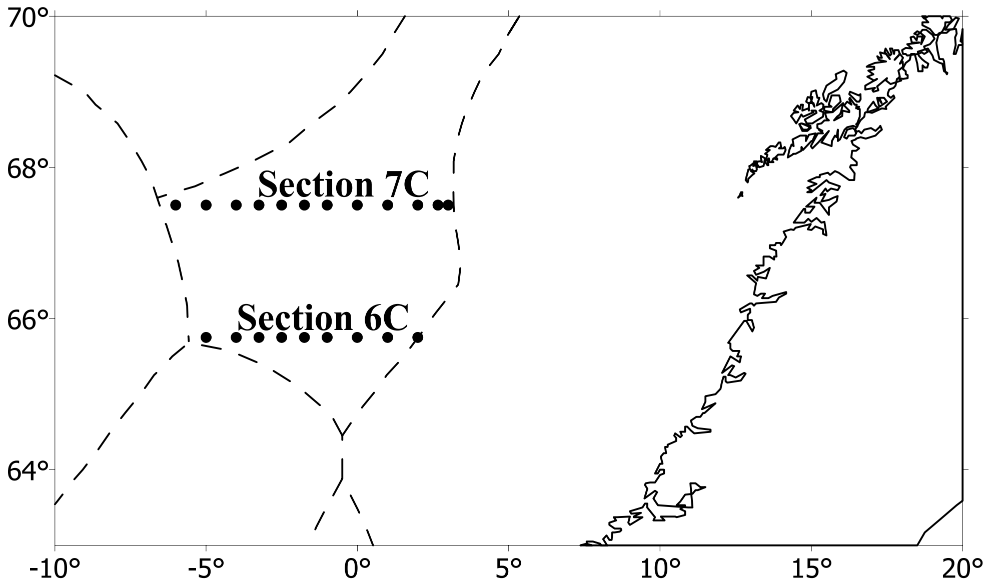

Figure 5. Standard sections in the Norwegian Sea occupied in July 2003.

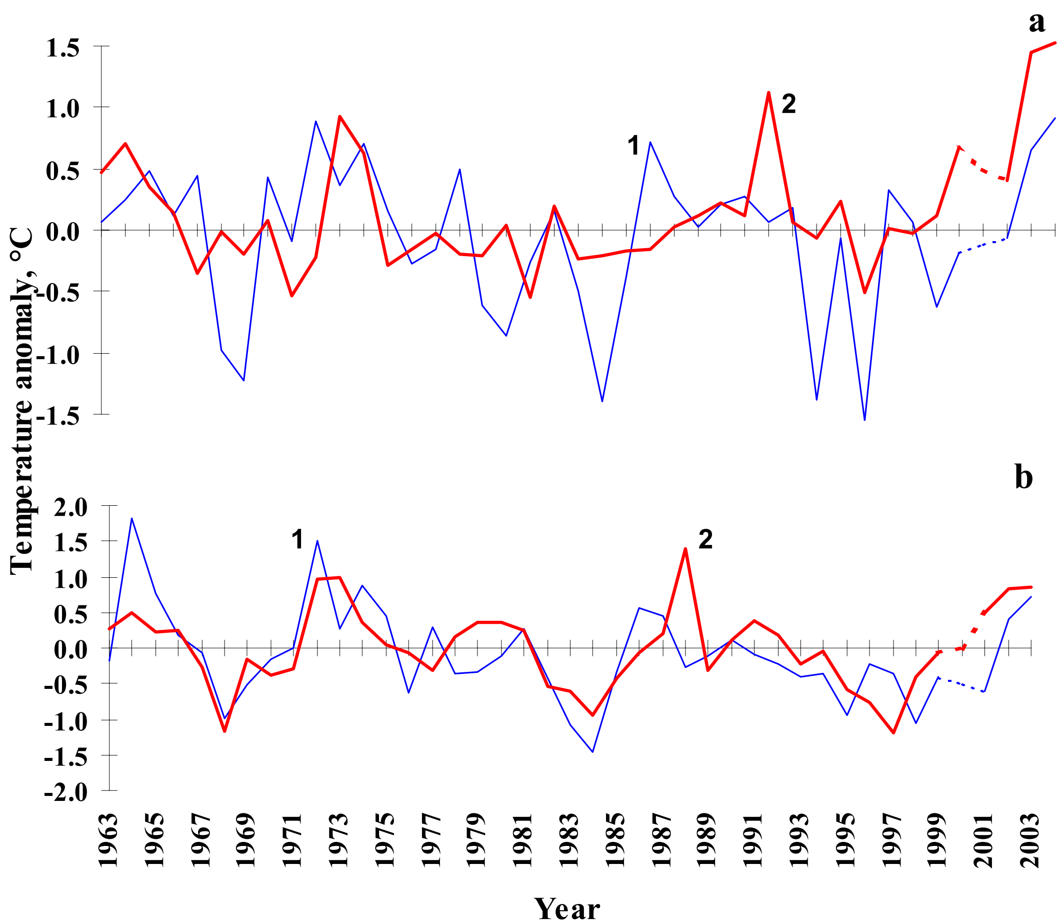

Figure 6. Temperature anomalies in the upper 200 m layer in the Western branch of the Norwegian Current (a) and mixed waters in the central Norwegian Sea (b) in sections 6c (1) and 7c (2) in summer 1963-2003.

Annex W: Polish National Report (Area 10, 11, 12)

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In summer 2003 IO PAS has been made hydrographic measurements at the Norwegian, Greenland and Barents Seas as a continuation of the previous years work. The main goal of the study was to investigate Atlantic Water (AW) pathways, properties and transport into the Arctic Ocean (AO). CTD stations grid is shown at Figure 1. In 2003 together with every deep-water CTD cast the Lowered ADCP (LADCP) were used. Ship-mounted ADCP measurements were conducted during whole cruise of R.V. Oceania.

The area of investigation covers a large part of the Atlantic domain and allows examination of horizontal and vertical distributions of water properties. Figure 2 shows horizontal distribution of water temperature at 100 m. Vectors represent baroclinic current calculated with reference to the no motion level of 1000 m. In comparison to 2002, strong recirculation into the East Greenland Current was observed west of Spitsbergen. Anomalous water temperature occurred in this region (Figure 3), which may indicate the cyclonic, westward circulation. West of Spitsbergen temperature of water at 100 m is lower in comparison to the 2002 (Figure 3a) and to mean temperature from July 2000-2003 (Figure 3b). Temperature in the western branch of AW flowing over the Mohns and Knipovich Ridge is higher then usually. Figure 3 shows also that determination of water properties at the specific depth along the single section may cause errors; water temperature at 100 m in the region of southern Spitsbergen is lower, but in northern Spitsbergen higher than usually. Nevertheless we present a graph showing temperature along the parallel 76°30’ N (section ‘N’) at 200 m, for last 8 years (Figure 4). The black bold line indicates temperature in 2003. AW temperature reaches values within the previously observed range.

Figure 5 shows entire section ‘N’ along the 76°30’ N parallel. The main stream of AW is located over the Spitsbergen slope; the second one is related to the Arctic Front. Between them the region of slow motion and mesoscale activity occurs. Maximal northward baroclinic velocities reach 24 cm/s over the slope, and 10 cm/s in the jet streams of the Arctic Front. Calculated baroclinic volume transport of AW (defined as water with T>0 °C, S> 34.92 PSU) is 1.47 Sv. Aw caries northward 18.8 TW of heat.

Inflow of AW into the Arctic Ocean was calculated from the hydrographic data for both branches (Barents Sea branch and Fram Strait branch) and measured directly by means of the LADCP for the West Spitsbergen Current. Results obtained from LADCP measurements show high barotropic flow component over the shelf and unexpected high (though lover than over the shelf) barotropic flow in the deep-water region. Pattern of measured currents is similar to the calculated from the hydrographic data (Figure 6), but volume transports are much higher. The total volume transport cross section ‘N’ reaches 13.9 Sv, AW transport is 6.6 Sv for water with S>34.92, and 3.5 Sv for water with S>35 Sv. It results huge heat fluxes cross section ‘N’: net heat transport is 70.9 TW to the north, AW heat transport is 80.79 TW and 57.81 TW for water with S>34.92 and S>35 respectively.

Lack of the barotropic component in calculations from the hydrographic data causes considerable underestimation of volume transports. Nevertheless presented at Figure 7 results are very useful in determinations of changes and trends of AW transports. Figure 7 shows also that in summer 2003 bigger volume of AW flow through the Fram Strait then through the Barents Sea Opening.

IO PAS will continue these investigations in 2004.

Summing up, we can conclude that 2003 observations show bigger component of Atlantic Water returning to the West and forming the Return Atlantic Water and smaller volume transport to the Arctic Ocean both through the Fram Strait and the Barents Sea Opening, than during summer 2002.

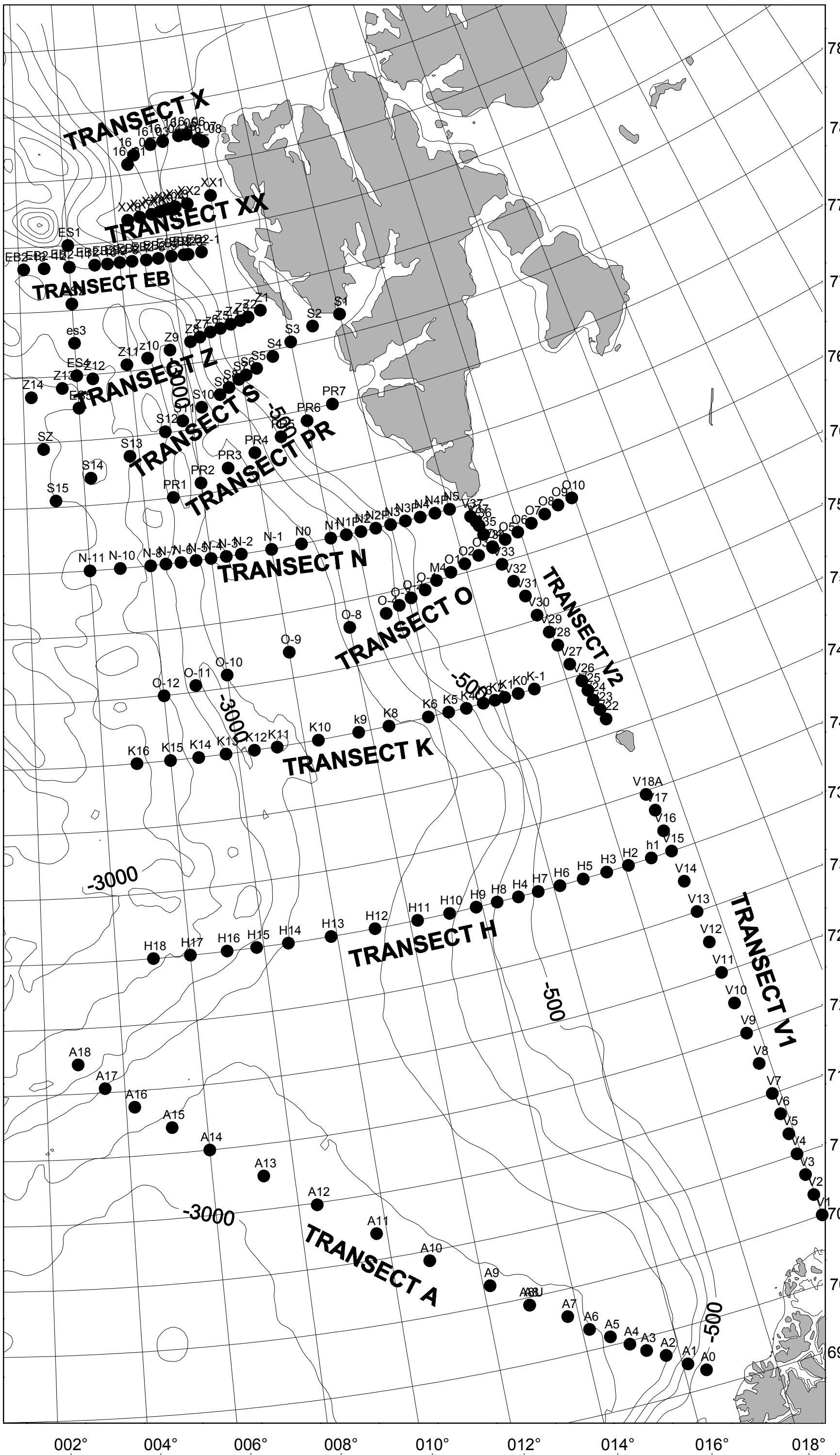

Figure 1. Map with the positions of the CTD stations investigated by IO PAS at the Nordic Seas during summer 2003.

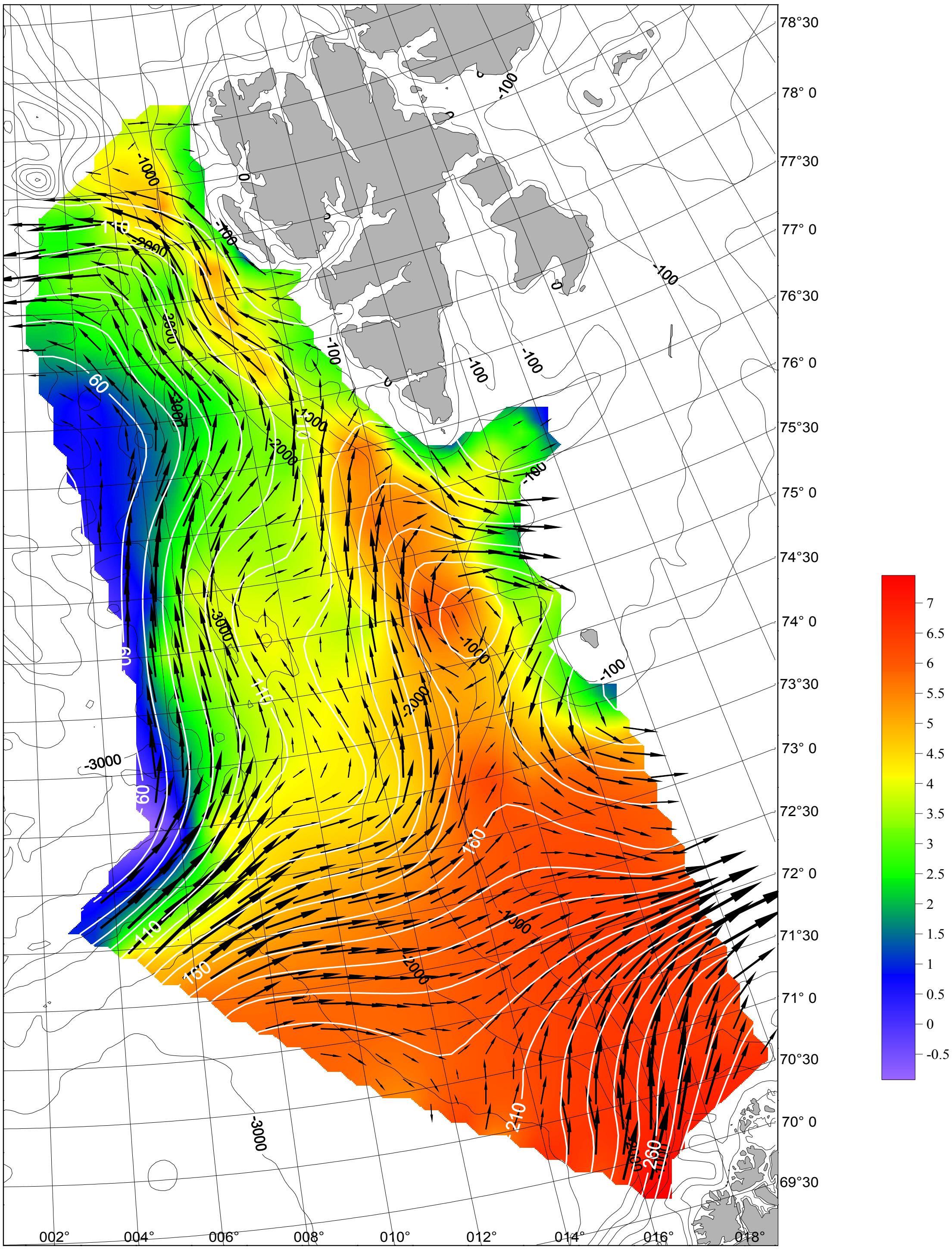

Figure 2. July 2003. Horizontal temperature (°C) distribution (colour scale) and baroclinic current vectors at depth of 100 m.

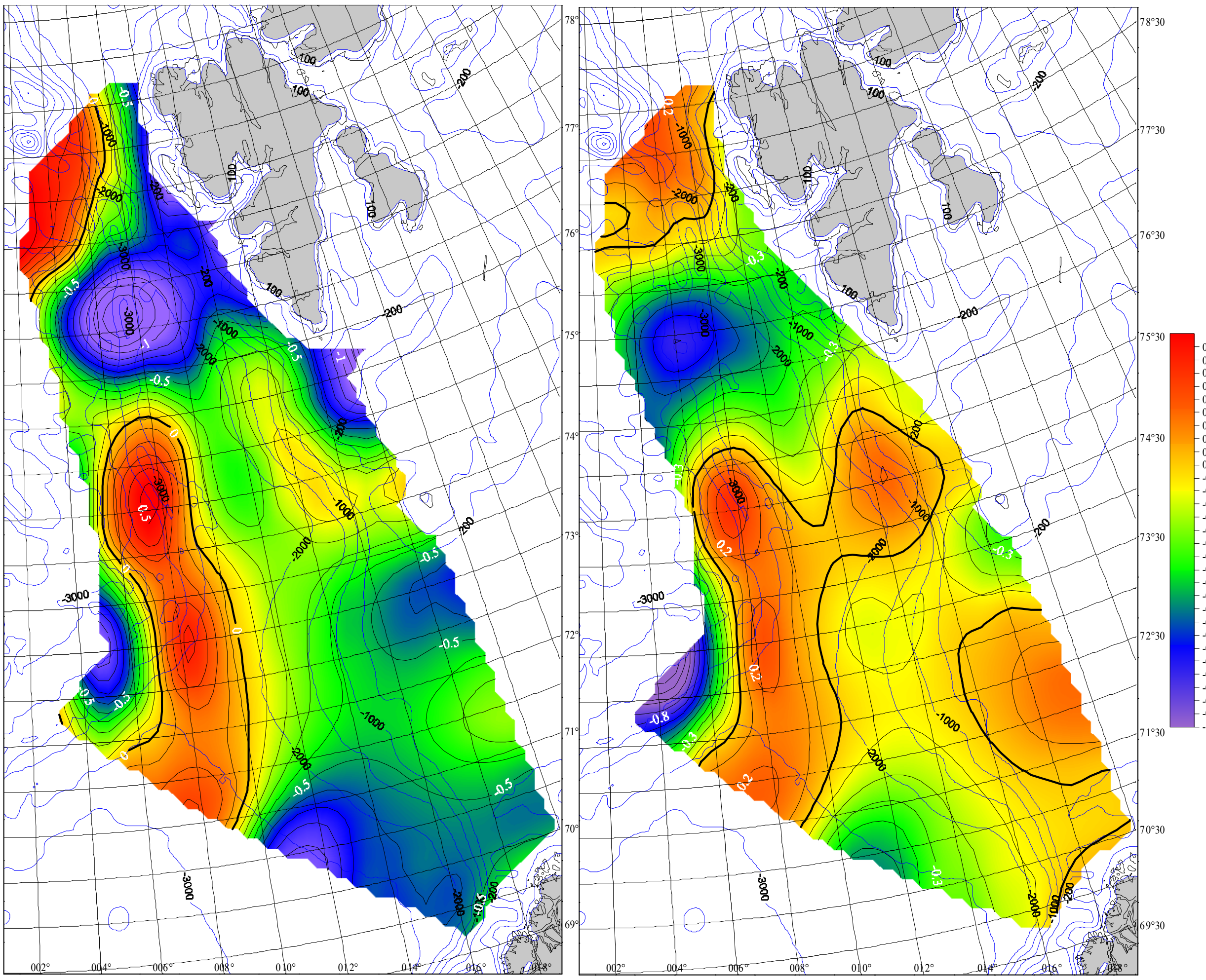

Figure 3. Differences of water temperature at 100 m:

a. 2003-2002
b. 2003 anomaly (in reference to 2000-2003 mean).

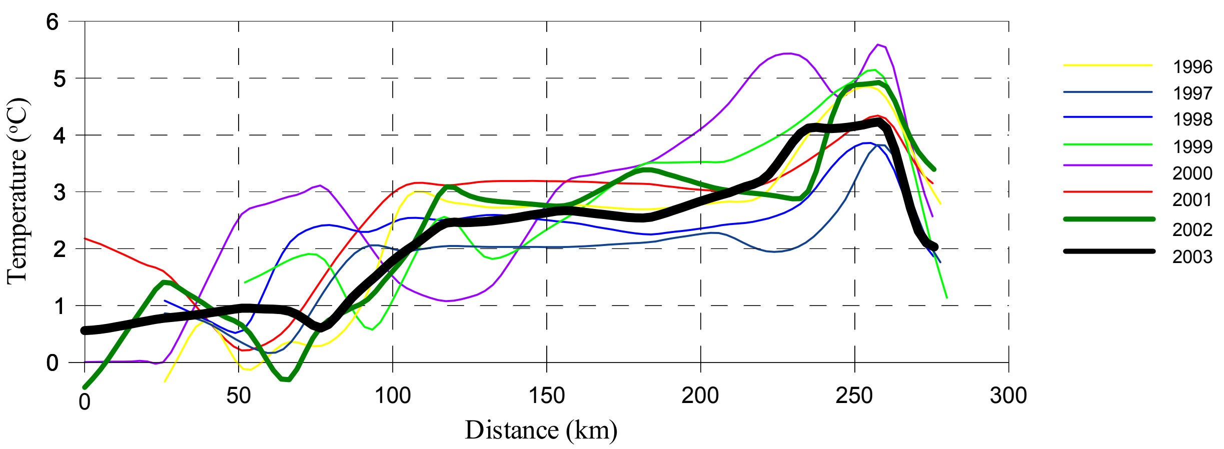

Figure 4. Temperature at 200 m along the section 'N' (76°30') in summers 1996-2003. Temperature in 2003 is marked by the bold black line.

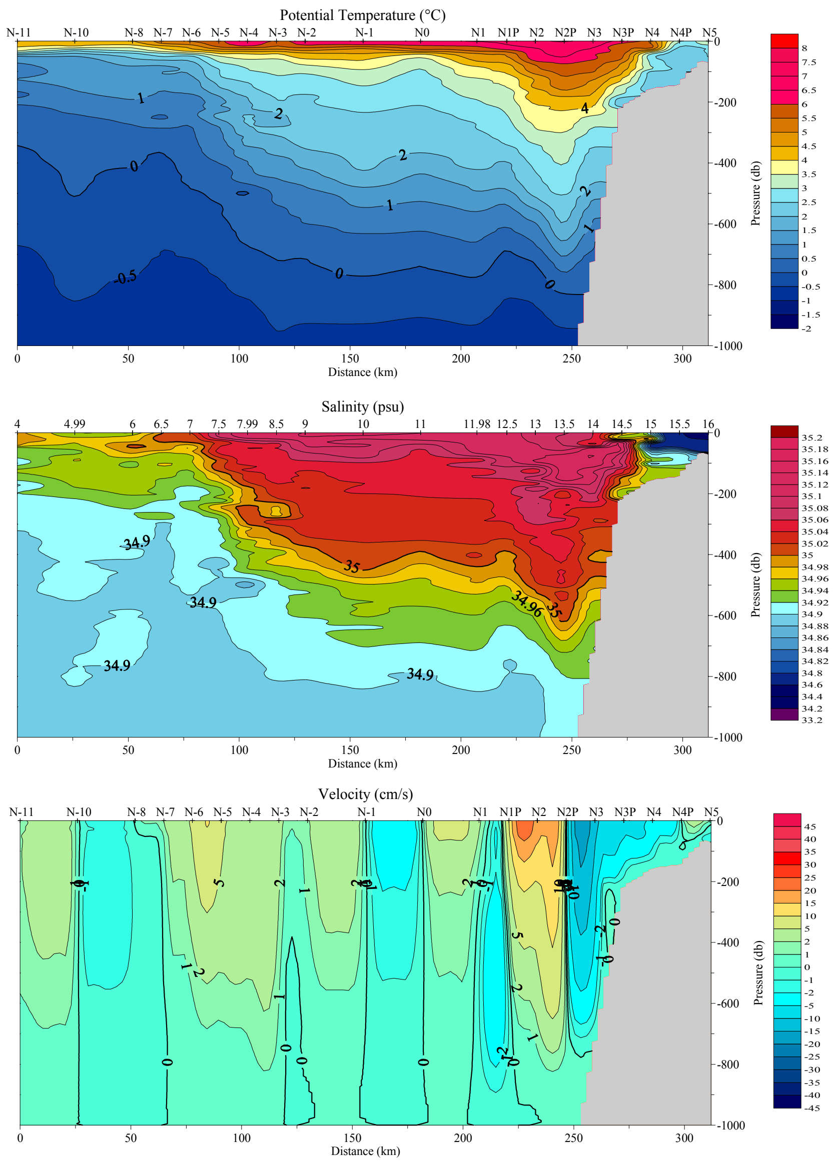

Figure 5. July 2003. Potential temperature (°C), salinity (PSU) and baroclinic currents (cm/s) in upper 1000 m of section 'N', along the 76°30'N parallel.

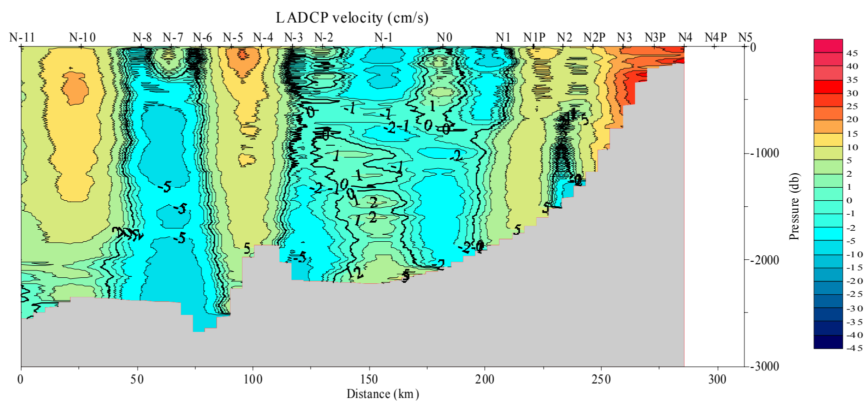

Figure 6. July 2003. LADCP measured currents (cm/s) at section 'N'.

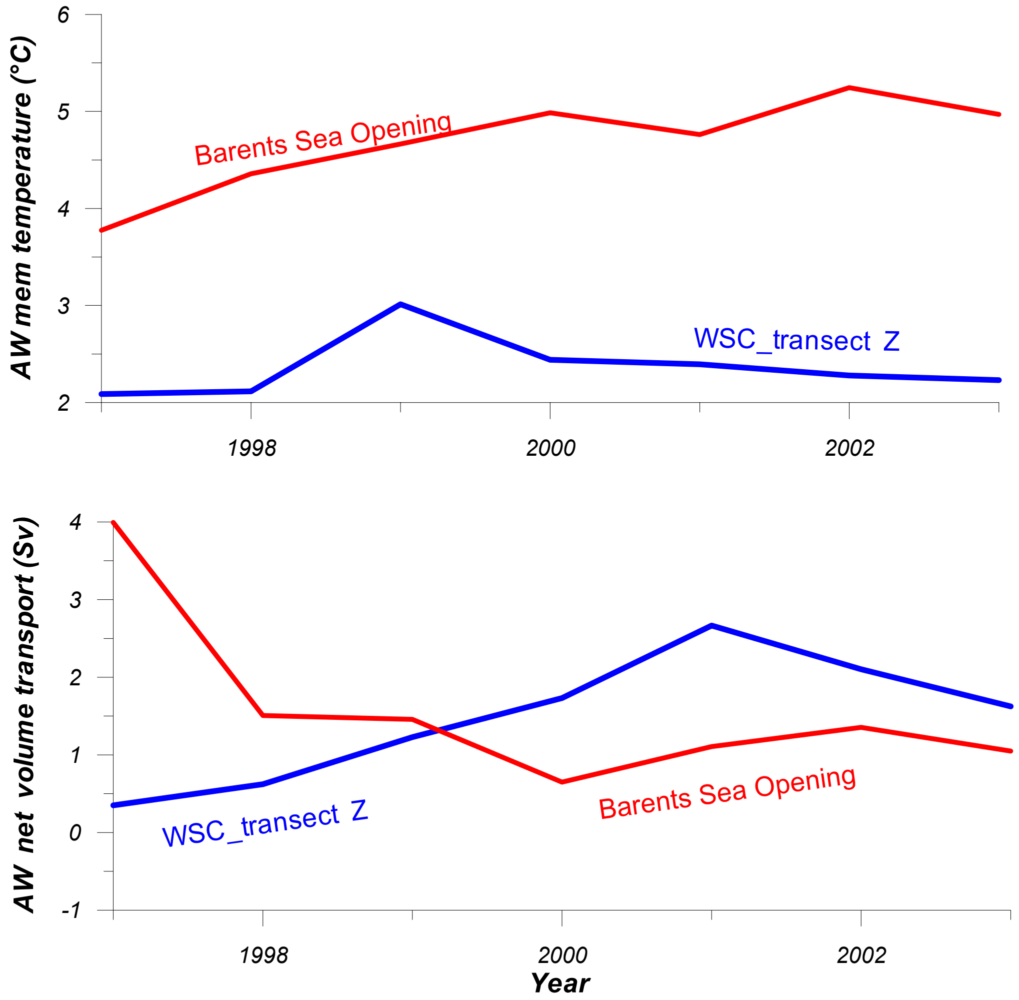

Figure 7. Atlantic Water (S>34.92 PSU) mean temperature and baroclinic volume transports through the Barents Sea Opening (red lines) and by the West Spitsbergen Current (blue lines).

Annex Y: Hydrographic conditions in the Greenland Sea and Fram Strait (ICES area 12)

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In summer 2003 the hydrographic measurements in the Greenland Sea (section along 75°N) and in Fram Strait (section along 78°50'N) were continued by the Alfred Wegener Institute. These two sections allow monitoring of the northward flow of Atlantic Water in the eastern part of the investigated area as well as the return flow located farther to the west.

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. Furthermore, the doming structure in the Greenland Gyre, as observed in the mid-80s, was superseded by the essentially two layer water mass arrangement with a marked density step, presently at about 1700 m.

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. The Atlantic water inflow 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. A second part flows northward along the north-western slope of the Yermak Plateau and the third branch recirculates immediately in Fram Strait at about 79°N. 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 April 2003 with a regular station spacing of 10 Nm. In addition, a long lived sub-mesoscale coherent vortex was investigated to reveal its role in the increasing of the winter convection depth. In September/October 2003 a hydrographic section across Fram Strait was carried out at 78°50'N with a high spatial resolution. The CTD and ADCP measurements were combined with recovery and redeployment of 12 moorings in the eastern and central part of the strait. Both sections and the locations of moorings are shown at Figure 1.

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 summer 2002. 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 fluxes between the Nordic Seas and Arctic Ocean. Until 2000 the observations were done in the framework of the European Union project 'VEINS' (Variability of Exchanges in Northern Seas). Since 2003 the work has been carried out as a part of international programme 'ASOF-N' (Arctic-Subarctic Ocean Fluxes-North). The moorings array covers the entire deep part of Fram Strait from the eastern to the western shelf edge. Altogether 17 moorings are deployed along 78°50'N and twelve of them are maintained by AWI. The Norwegian Polar Institute operates the remaining 5 moorings in the western part of the strait. In 2003 the first results from the array augmented with two new moorings in the recirculation area and an additional level of instruments at the AW lower boundary (ca 700 m) gave a new insight into a spatial structure and variability of the velocity and temperature fields in the Fram Strait.

The salinity and temperature distributions at the 75°N section were typical for the spring conditions (Figure 2). A stable surface layer had established due to melting pack ice floes, which were found already at 2W. The winter convection seemed to reach only a few hundred meters except of the small-scale convective eddy with a temperature minimum was shifted downward to 2700 m. This feature represented the deepest convection level in recent years but, being not well ventilated during the preceding winter; it has started to decay already. The bottom water temperature increase continued but there was no further descend of the temperature maximum and in the lower water column higher temperatures were found only within the down most 100 to 200 m. This effect was presumably due to the vertical diffusion. On the East Greenland shelf the near surface Arctic outflow normally contains waters of Pacific origin with the silicate maximum below but in 2003 these types of Polar waters were not found in spite of going close to the Greenland coast (20 Nm distance). The minimum salinities were just below 34.0 while the area covered with the old pack ice floes was extreme for the last 10 years. This fact might indicate a change in the Arctic surface current system, resulting in the increased release of ice through Fram Strait and different surface water paths. Also unusually high concentration of yellow substances with a maximum shifted close to the surface were observed.

The properties of the Atlantic Water (AW) and Return Atlantic Water (RAW) observed at the CTD section along 75°N have changed since last year (Figure 3). 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, which have a spacing of 10 Nm. The Return Atlantic Water is characterized by the temperature and salinity maximum below 50 m averaged over 3 stations west of 11.5°W with space interval less than 5 Nm. In contrast with the previous year, characterized by extremely high temperature and salinity of Atlantic water, their mean values in 2003 were significantly lower. The mean temperature of AW in the Greenland Sea was the lowest observed since 1989 while its mean salinity decreased to the long term average. It can be partly attributed to the seasonal variations because in 2003 the section was measured in spring, not in summer as during previous years. A decrease of mean temperature and salinity of the Return Atlantic water has continued for last three years and both values were below the long term average.

The temperature and salinity sections across the Fram Strait are shown in Figure 4 with the main core of the West Spitsbergen Current visible at the eastern slope. The lower boundary of the Atlantic water was slightly shallower than in previous year. The maximum salinity and temperature of AW were similar as observed in 2002 but the AW layer in a recirculation area spread much farther to the west, reaching nearly 4°W. The southward flow of Polar Water in the East Greenland Current was more confined to the west as compared with 2002 but at the same time a great amount of ice, encountered already at the shelf slope, prevented the section to be continued over the Greenland shelf like in previous years.

Time series of mean temperatures and salinities for two depth intervals (5 ÷ 30 m and 50 ÷ 500 m) reveal the variations of the water mass properties in the Fram Strait (Figure 5a, b). Three characteristic areas were 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. Mean salinities observed in the West Spitsbergen Current were close to the last year values while the mean temperature in the surface layer decreased slightly. Both mean temperature and salinity in the lower layer still remained higher than the long term average. A significant increase of mean temperature and salinity was found in the Return Atlantic Current in both layers. The salinity of Polar Water in the East Greenland Current was characterized by strong annual variations in last years. In 2003 the mean salinities in both layers of EGC increased significantly from the extremely low salinity observed in 2002 and nearly reached the high values from 2001. A drop of temperature in the upper layer reflects the severe ice conditions in the western part of Fram Strait. However, in the deeper layer of the EGC the mean temperature rose to the long term mean value.

When regarding the Atlantic Water as defined not by the spatial extent but by its hydrographic properties (T>2°C, S>34.92) the clear trend can be find for last 7 years (Figure 6). While the area of the cross-section occupied by AW varied strongly between years, the mean temperature and salinity of Atlantic Water have been increasing since 1997. In 2002 AW with the highest mean temperature and salinity had occupied relatively small area while in 2003 a slight decrease in the mean values of T and S was compensated by the greater spatial extent of the Atlantic Water layer.

Because the data from Fram Strait were collected in different seasons from spring to autumn, they are affected by the annual cycle which is most pronounced in the upper layers. Therefore, the observation time has to be taken into account when comparing particular years.

Time series of temperature and current velocities, registered at the array of moorings since 1997, were used to calculate volume and heat fluxes through Fram Strait. The annual averages of the northward, southward and net transports are shown at Figure 6. For the last measured period, 2002-2003, the yearly means of both volume and heat net fluxes increased slightly as compared with 2001-2002 while the northward transports remained close to the relatively high values the year before. The change in the net fluxes reflects the weak decrease of the southward volume transport. The annual average of the net volume transport in 2003 was estimated on about 2 Sv to the north, continuing the reverse of the net flow started in previous year. The monthly means of the volume and heat fluxes (Figure 7) reveal the prevailing northward net volume transport since the beginning of 2002. Since some minimum in winter 2002/03, the net flow to the north has been continuously increasing. The net heat flux to the Arctic Ocean was the highest in winter and decreased in spring and early summer. The significant drop of the northward and net heat and volume fluxes in the West Spitsbergen Current (Figure 8) suggests that the observed increase of the net flow through the Fram Strait has to be related to a change of flow structure in the recirculation area is strong enough to compensate the weaker AW inflow in its main core.

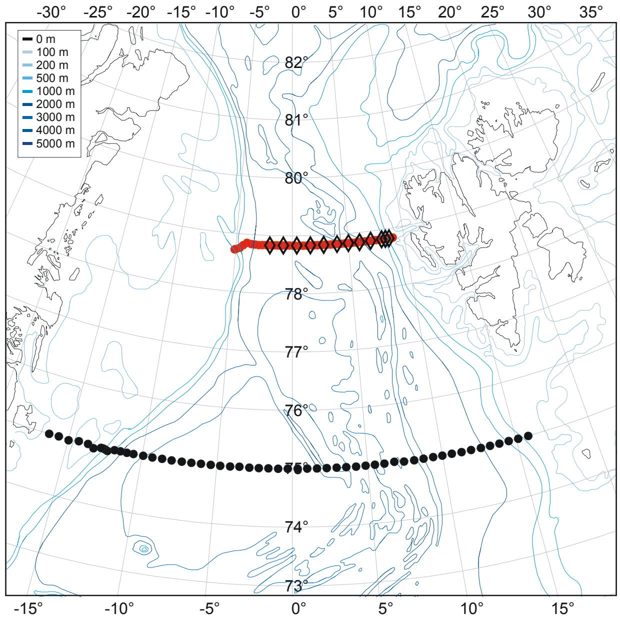


Figure 1. Location of sections (red dots – Fram Strait section at 78°50'N, black dots – Greenland Sea section at 75°N) and positions of redeployed moorings (black diamonds) in 2003.

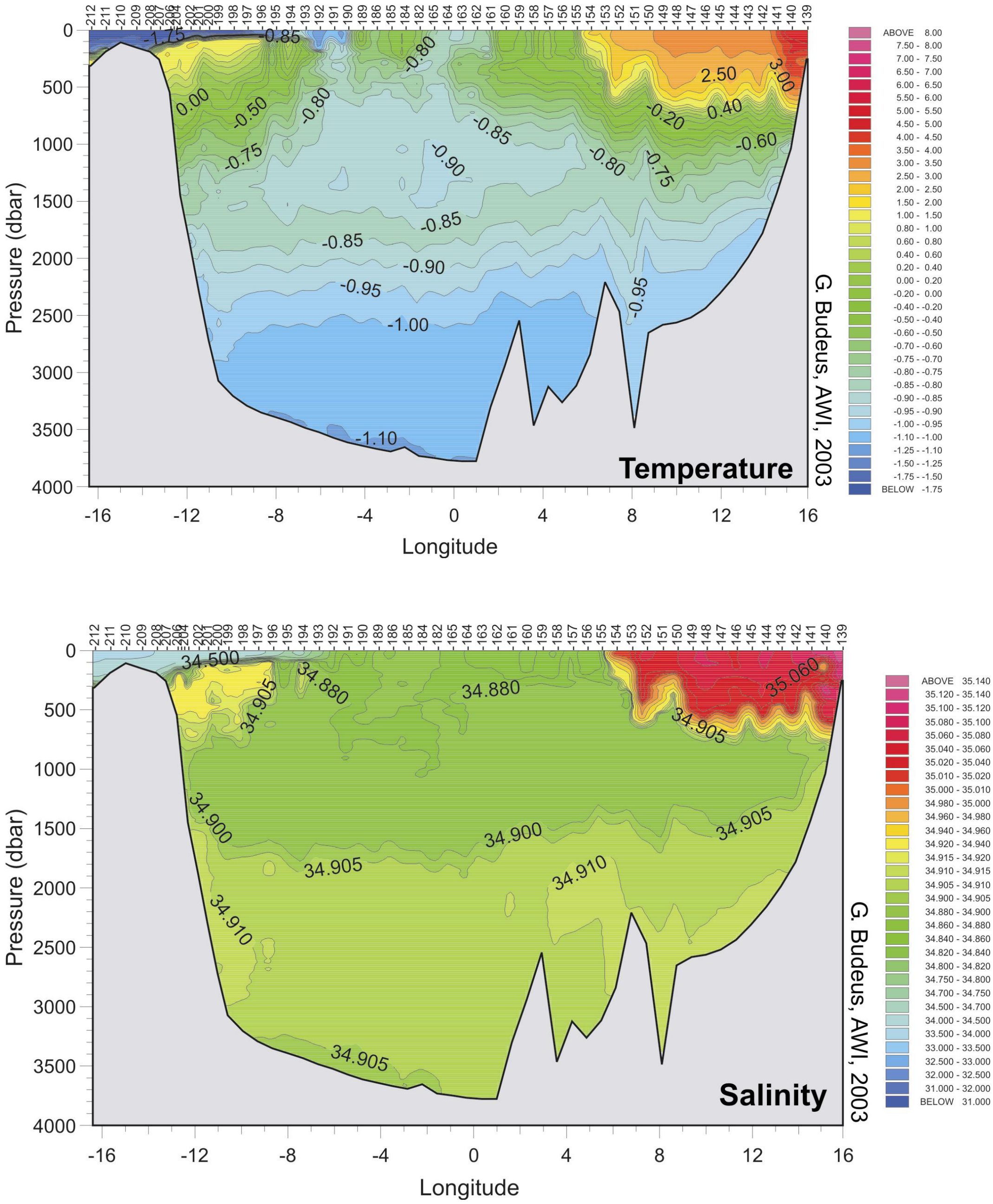


Figure 2. Distributions of potential temperature (upper Figure) and salinity (lower Figure) at the section across the Greenland Sea measured in spring 2003 (G. Budeus).

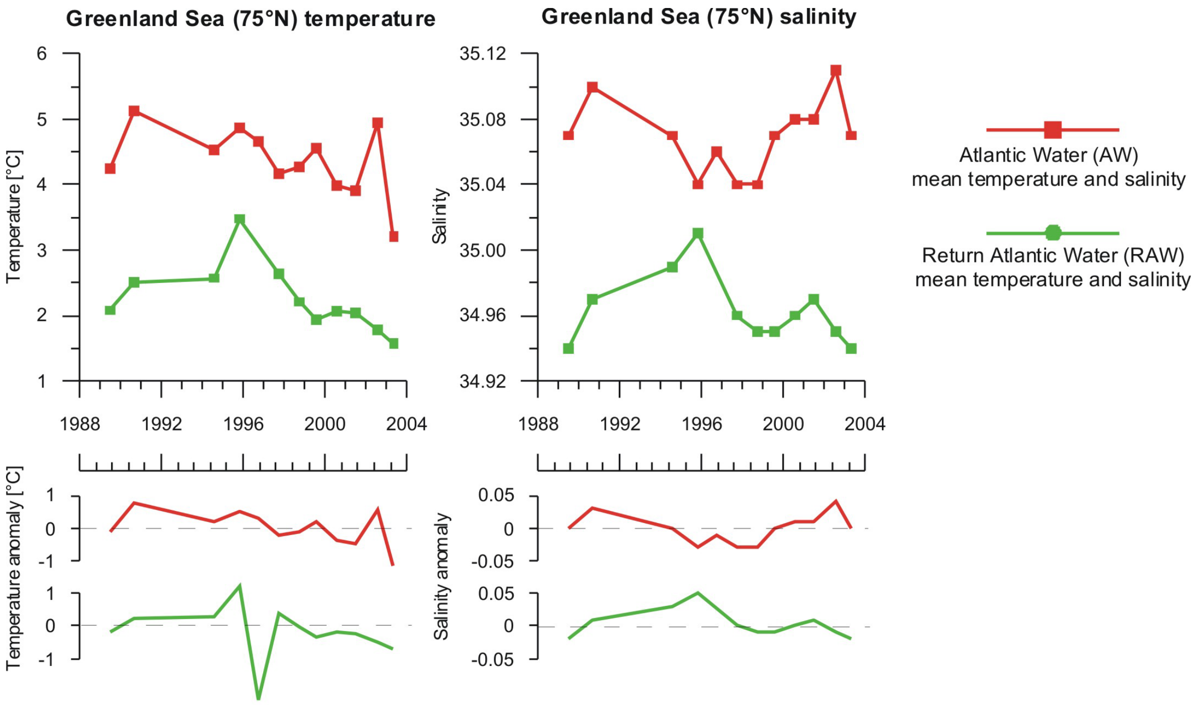


Figure 3. Properties of the Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea observed at the CTD transect along 75°N (G. Budeus). Anomalies from the long term averages shown at the bottom plots.

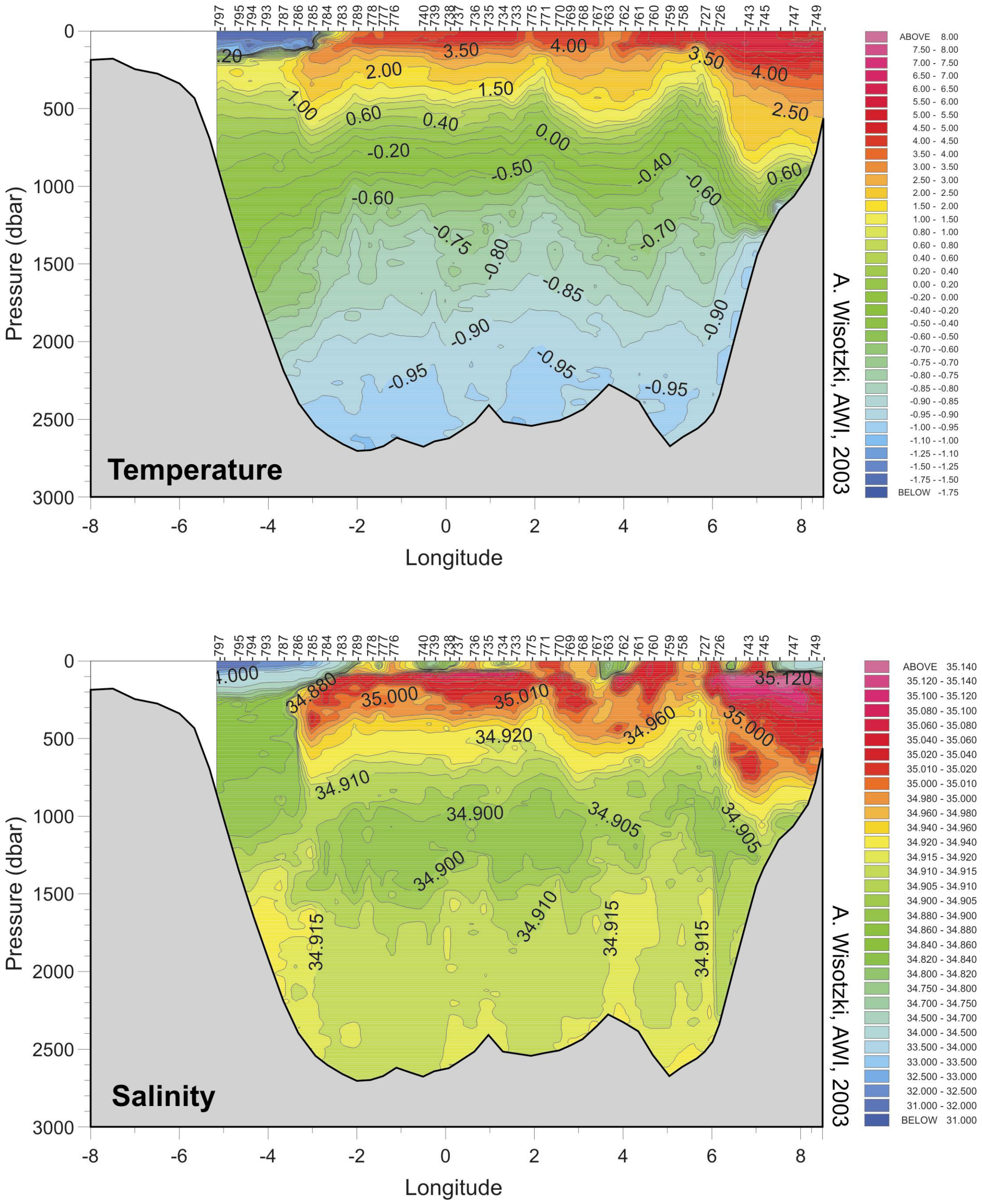
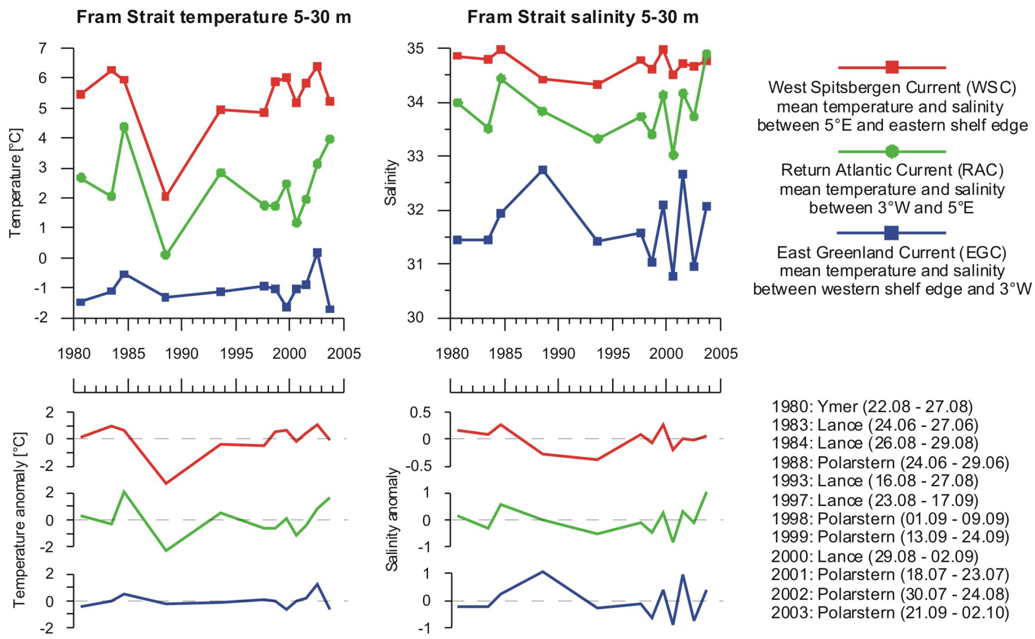
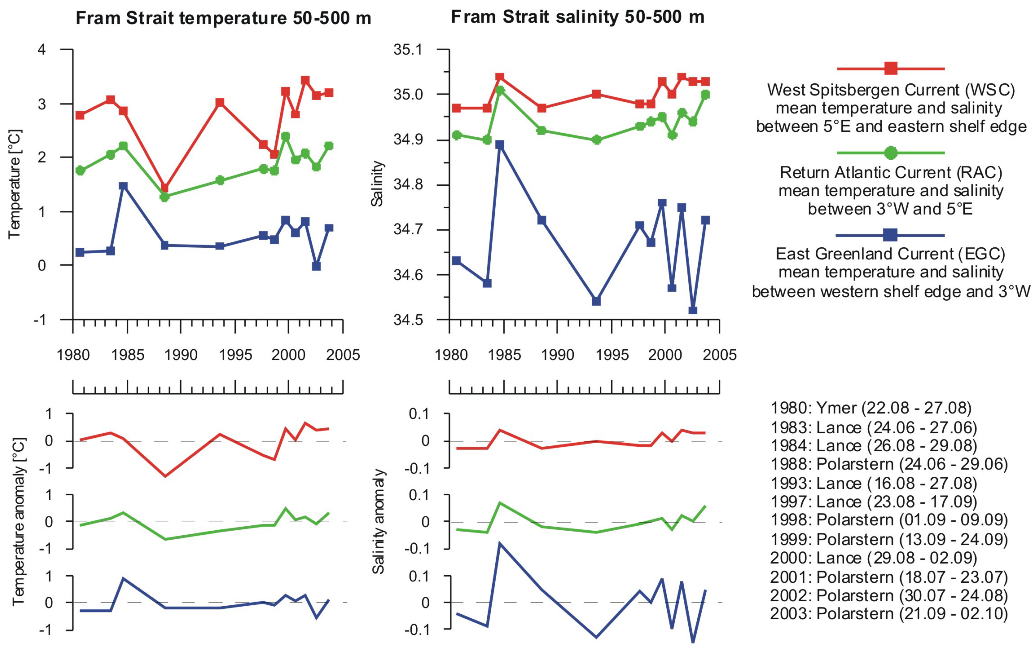


Figure 4. Distributions of potential temperature (upper Figure) and salinity (lowers Figure) at the section across Fram Strait measured in autumn 2003.



a)



b)

Figure 5. The variations of the mean temperatures and salinities in Fram Strait in the West Spitsbergen Current (WSC), Return Atlantic Current (RAW) and East Greenland Current (EGC) for the upper (figure a) and lower (figure b) layers. The values for the last years since were calculated by A. Wisotzki, U. Schauer and H. Rohr. Earlier values supplied by M. Marnela and B. Rudels from the FIRM. Additional data obtained from the ICES Data Centre in Copenhagen. Anomalies from the long term average shown at the bottom plots.

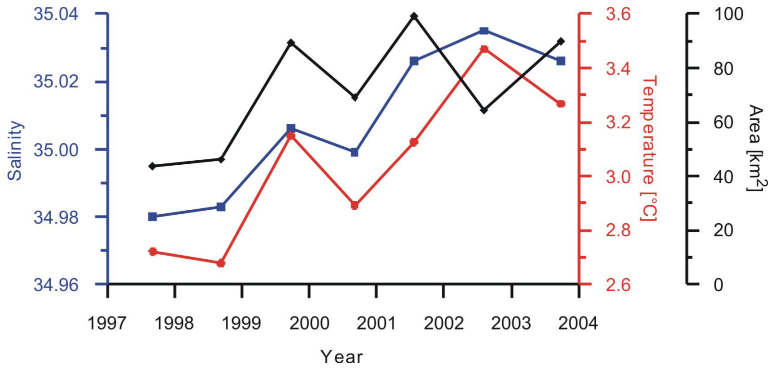


Figure 6. Mean properties of Atlantic Water (T>2°C, S>34.92) based on CTD sections in 1997-2003.

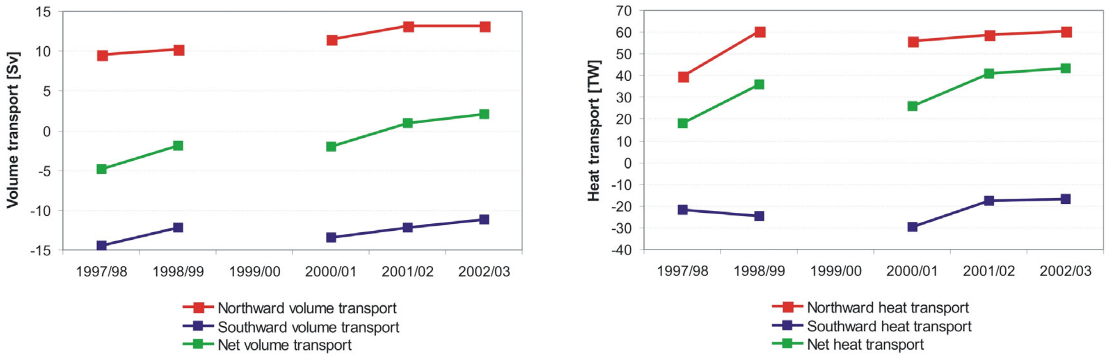


Figure 7. Annual averages of the northward, southward and net volume (left figure) and heat (right figure) fluxes through Fram Strait based on results from the array of moorings in 1997–2003.

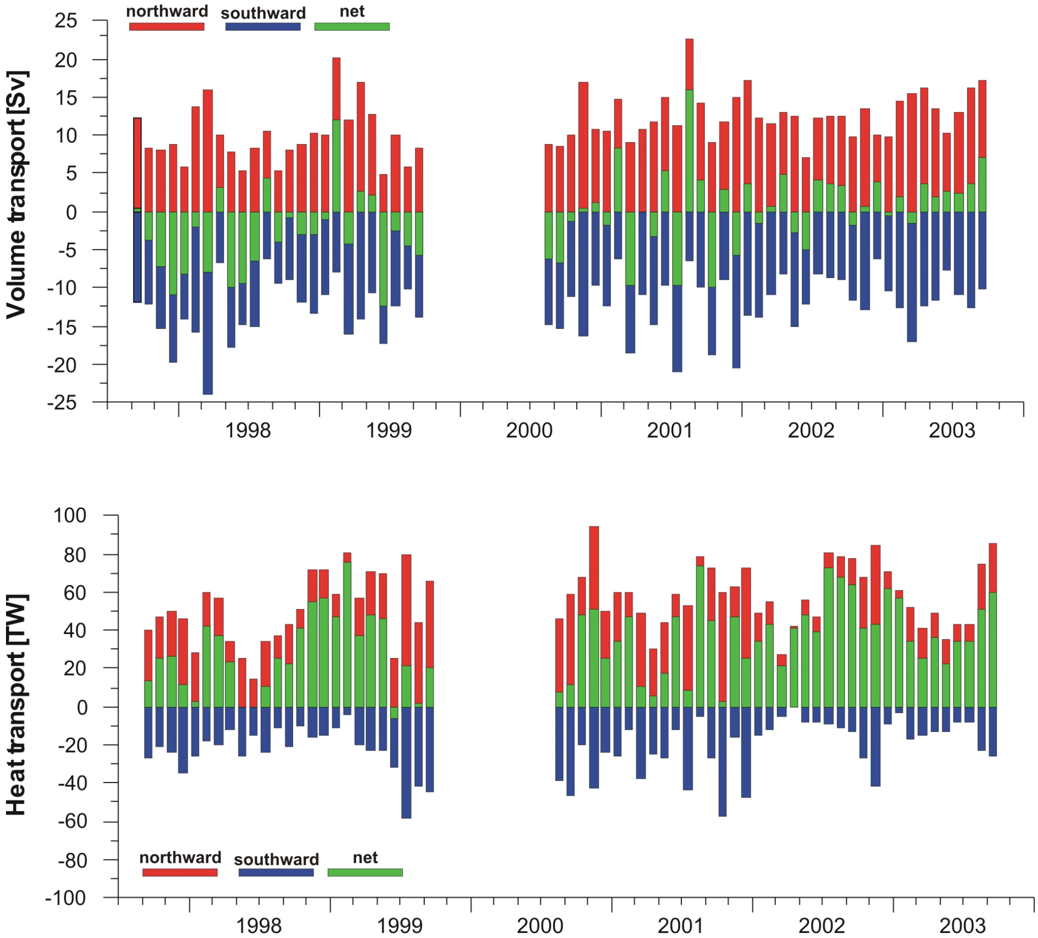


Figure 8. Monthly means of the northward, southward and net volume (left figure) and heat (right figure) fluxes through Fram Strait based on results from the array of moorings in 1997–2003.

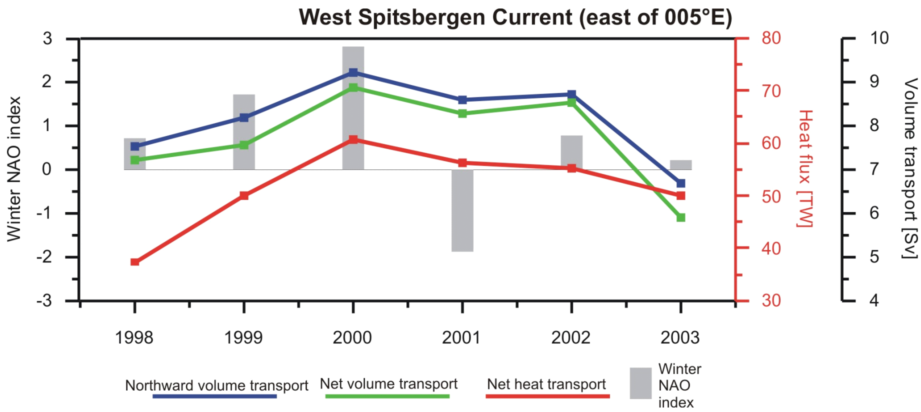


Figure 7. Annual averages of the northward and net volume and net heat fluxes in the West Spitsbergen Current (east of 005°E) from the array of moorings in 1997–2003.

Annex Z: An isopycnal framework for hydrographic pattern analysis

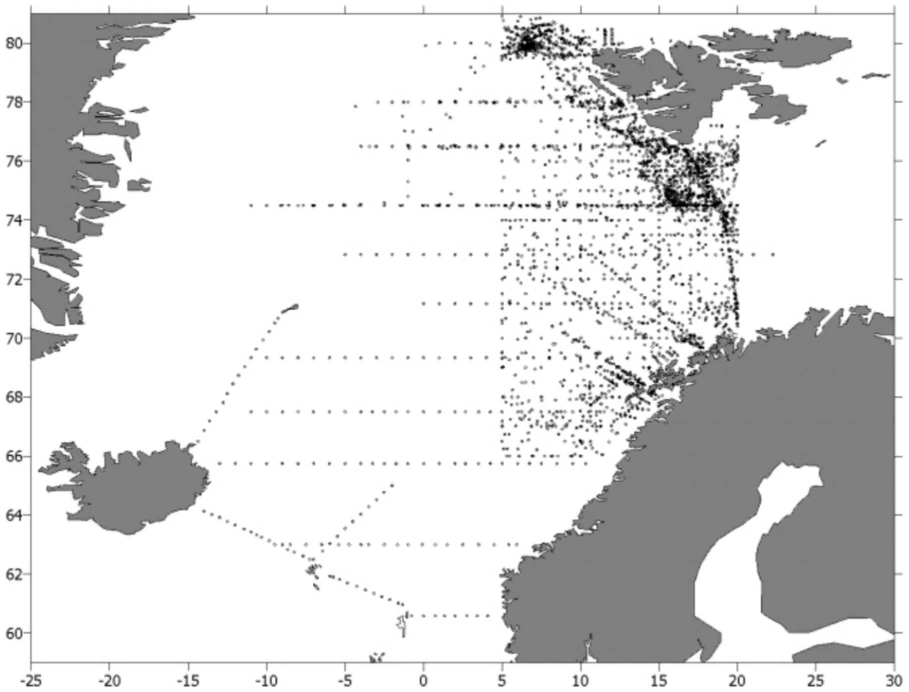
T. Rossby, V. Ozhigin

Over the last century hydrographers have collected a vast number of stations from especially the northeast Atlantic and Nordic Seas. The impressive study by Helland-Hansen and Nansen (1909) surely became the model for many a systematic study of the ocean in the years to follow and that continue today. This database allows for very detailed analysis of these waters and spatial changes in temperature and salinity distributions that take place over time. The following remarks outline a method for integrating all data into a framework with which to look for and identify patterns of variation.

The concept to be developed below pivots around the notion that the baroclinic structure of a region is comparatively robust such that the patterns of variations can be interpreted as departures from or anomalies around this state rather than as substantially different states. Unlike past intercomparisons of sections, emphasis is placed on horizontal patterns of variability. It focuses on two points, first that the (baroclinic) circulation is governed by the structure density field whereas variations in temperature or salinity are automatically compensated for when viewed on isopycnal surfaces (or as a function of isopycnal when viewed as vertical sections). Thus a single property suffices to describe property change when viewed in isopycnal space. One can collapse temperature and salinity into a single variable known variously as tau (Stommel, Veronis), later also referred to as 'veronicity', or as spiciness (Munk). The intended advantage of such a variable was that it was supposed to be orthogonal to density and thus serve as a tracer without dynamical content. A few authors have used one or other of these definitions, but precisely because the definition is so arbitrary little consensus has emerged. At high latitudes where density increasingly is controlled by salinity, temperature would be the more natural measure of water type whereas at subtropical latitudes temperature dominates density and salinity water type.

Let us suppose that we have constructed a mean field of density distribution, i.e. depth or pressure of selected densities. We can do this using all data or subdivided into seasons. These fields become the reference state for studies of variability. To illustrate this Vladimir Ozhigin has estimated the depth for selected density surfaces using data at locations shown in the first panel. The following three panels show the depths of the 27.7, 27.8 and 27.9 sigma-t surfaces. A shallower 27.6 surface is not included here mostly because it looks similar to the 27.7 surface but did not extend very far north into the Norwegian Sea due to outcropping. An appendix includes Vladimir's notes on the figure preparations.

Because of the region and data chosen the inflow along the Shetland Current appears to combine with the flow along the Faroe Current. This is a 'boundary condition effect' that can be addressed. More significantly, one can see very clearly how the deeper surfaces more sharply reflect the baroclinic flow pattern around the Vöring Plateau.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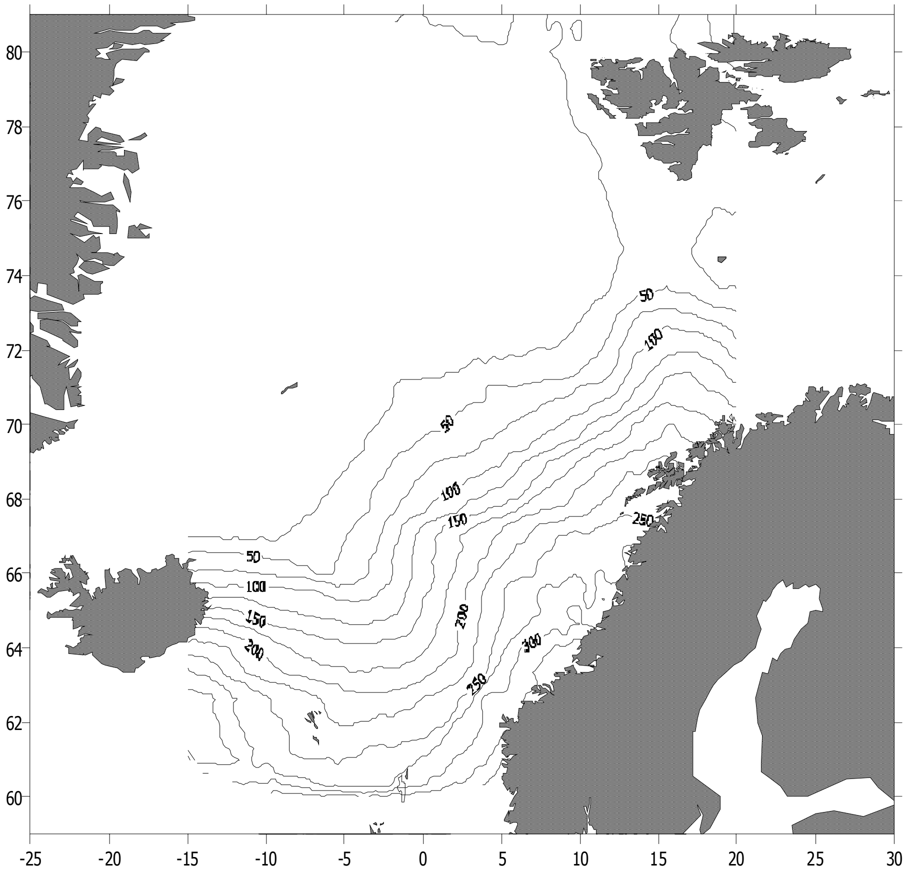
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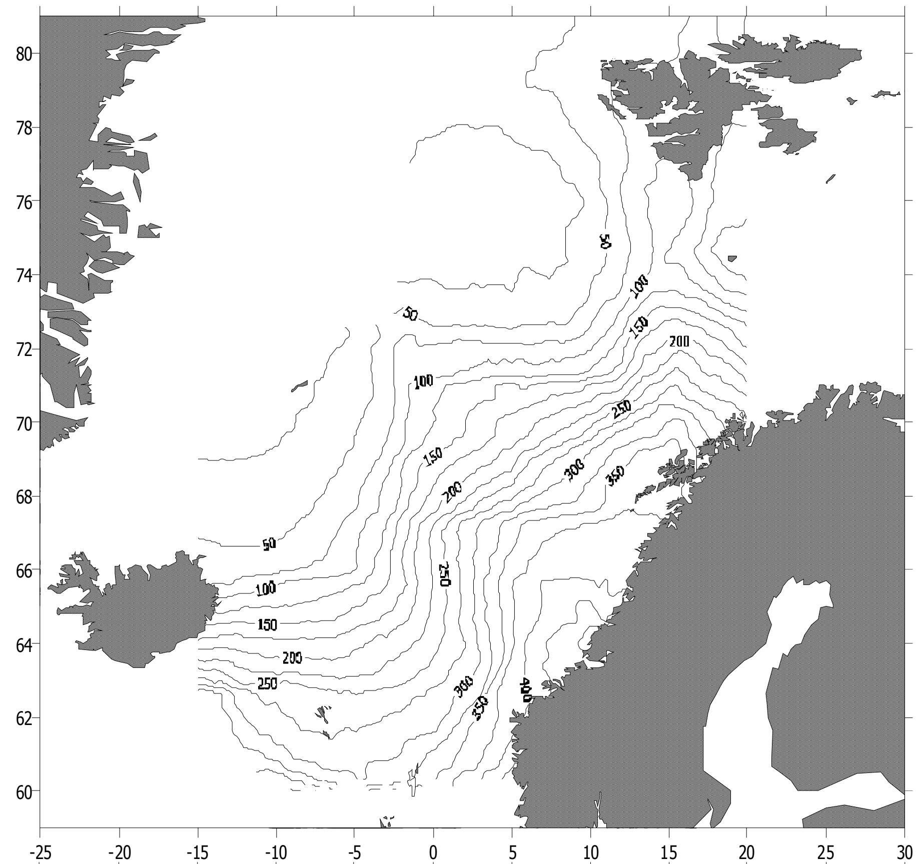

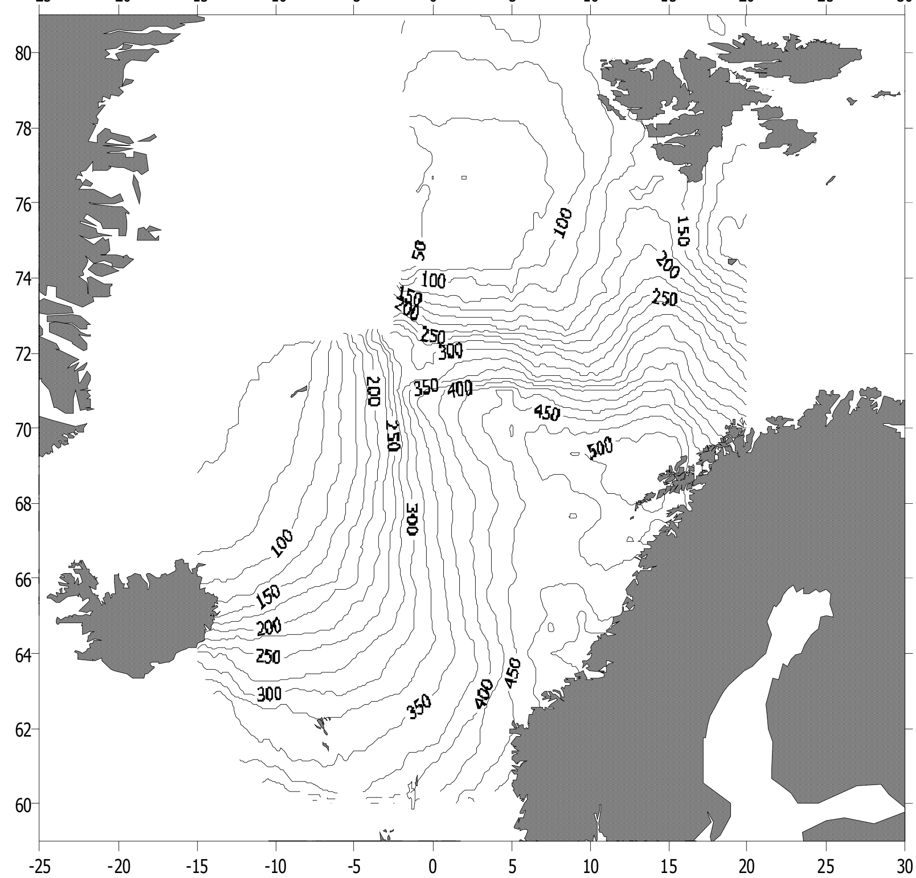

Now let us suppose that we could assemble all data available from the region, perhaps concentrating on the last 20-30 years of better and more coverage, spatially and temporally and proceed along a similar basis. All stations would first be resampled in the vertical to obtain the depth of a set of isopycnals and the properties on each of these, particularly temperature, salinity and oxygen, if available. These resampled stations in the vertical become the new input data for analysis. Clearly, construction of the reference fields will benefit from an as large and extensive data set as possible.

For the sake of the argument, let's assume that the coverage is best for June-July-August. We now compute the mean depths (after appropriate binning) in a fashion similar to what Vladimir has shown above. We also compute the property fields on each of these. The resulting maps become the mean or reference field for the period chosen. We can now project any subset of the data (or more recent data) onto these surfaces to find out if for a given period the isopycnals have shoaled or deepened and/or if the waters have become warmer/saltier or vice versa. This framework allows one to use observations that were obtained from different yet similar, i.e. overlapping but not identical sampling plans. Something like this may become quite useful also for melding Argo profile data and for comparing them with the historical database. The Nature paper by Bower *et al*. (2002) gives an example of isopycnal surface analysis from a large number of RAFOS floats.

In addition to trends analyses, the mapped fields can be used to compute baroclinic transports using the Fofonoff potential energy anomaly algorithm. Given a computed mean field one can now quantify the anomaly properties with much greater confidence. These include variability of eddy potential energy and hence baroclinic transport variability. As the velocity field at some reference depth becomes better known, one can add this to compute absolute transports. This will be important for the barotropic pattern may be characterised by strong yet topographically constrained recirculations and thus significantly modify the overlying baroclinic transport patterns.

In summary, the anticipated advantage of the proposed analysis would be that it provides a unified framework for intercomparing different datasets and allows for a systematic analysis of changes in the dynamical characteristics of a region and variations in water properties. It might be a way to provide a common framework of the various activities in different regions such as the annual climate assessment. These comments are written specifically for the development of an exploratory plan along the lines we discussed at the WGOH in Southampton. Many thanks to Vladimir for providing the figures; they were a huge help for the discussion.

References

BowER, A.S., B. Le Cann, T. Rossby, W. Zenk, J. Gould, K. Speer, P. Richardson, M.D. Prater and H.M. Zhang, 2002. Directly-measured mid-depth circulation in the northeastern North Atlantic Ocean. *Nature*, 419, 603-607.

Helland-Hansen, B. and F. Nansen, 1909. The Norwegian Sea: its physical oceanography based upon Norwegian researches 1900-1904. Report on Norwegian Fishery and Marine Investigations, 2(2), 390 p.

Appendix (Vladimir's processing comments):

Standard sections, about 170 hydrographic stations on average, have been occupied by PINRO's research vessels in June since 1959.

Step 1. Calculation of isopycnal depths at stations of standard sections.

To calculate the depth of an isopycnal at a station, average (1959-2000) temperature and salinity at standard depths were used. Set 1 resulted in isopycnal depths for about 170 stations.

Standard sections in the Greenland Sea were not occupied so regularly as those in the Norwegian Sea, so some additional data were used.

Step 2. Calculation of isopycnal depths at 'random' stations.

*June data (1950-2000) from about 6000 stations in the northeastern Norwegian and eastern Greenland Seas were taken from the CLIMATIC ATLAS OF THE BARENTS SEA: TEMPERATURE, SALINITY, OXYGEN issued by the Murmansk Marine Biological Institute (Russia) and the Ocean Climate Laboratory, National Oceanographic Data Center (USA).

Depths of isopycnals at about 6000 stations were calculated and interpolated into a grid (20' along meridian and 30' along parallel). Set 2 resulted in isopycnal depths in grid nodes.

Step 3. Amalgamation of Set 1 and Set 2.

Step 4. Mapping of isopycnal 27.60, 27.70, 27.80 and 27.90 depths (Figures above).