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REPORT OF THE WORKING GROUP ON OCEANIC HYDROGRAPHY (WGOH)

19–22 APRIL 2006

GALWAY, IRELAND

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

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Contents

Executive summary

ICES Report on Ocean Climate

- The ICES Annual Ocean Climate Status Summary (IAOCSS) will be renamed, with immediate effect, the **ICES Report on Ocean Climate (IROC)**.
- The date associated with the IROC will be the single year to which most of the data therein refer; this year's publication (2006) will be the **IROC 2005**.
- The main finding of the IROC 2005 is that the northern North Atlantic and Nordic Seas continued to be much warmer and more saline than the long-term mean.
- For IROC 2006 onwards, WGOH will include a new section on "Deep Waters", to supplement the existing material on the upper (<1000 m) ocean.
- WGOH will investigate new data sources and new products to further enhance the material presented in the IROC.
- WGOH will include in the IROC acknowledgements of the institutes and funding agencies responsible for producing the data reported in the IROC.

Publicising WGOH science

- The January 2007 issue of the CLIVAR *Exchanges* international newsletter will be dedicated to the work of the ICES WGOH. This will enhance the international profile of ICES and WGOH.
- There will be many presentations to the ICES ASC by WGOH members, including a keynote talk describing the IROC 2005.
- WGOH will submit an article to the *EOS* newsletter of the American Geophysical Union, describing the work of WGOH.

Communication within ICES

- WGOH will seek advice on targeting specific Expert Groups within ICES, in order to enhance the profile, format and content of the IROC.
- WGOH will seek to improve dialogue with REGNS.
- WGOH will encourage and support IBTSWG on making physical oceanographic measurements from research trawls.
- One or both of the Co-Chairs will attend the ICES ASC 2006, in order to pursue the preceding aims.

ICES Data Centre

- WGOH **strongly recommends** (i) that the ICES Data Centre gives priority to "data rescue" (digitising historical data) over finding new ways to present existing data (e.g. GIS), and (ii) that priority should be given to acquiring and delivering data, rather than in generating and distributing data products.

1 Opening of the WGOH meeting

WGOH was welcomed to the National University of Ireland (NUI), Galway by Prof. Paul Ryan, head of the Department of Earth and Ocean Sciences. **Annex 1** is the list of WGOH members attending, noting also those members who sent apologies for absence.

2 Agenda

The meeting agenda was as follows, based on the 2006 Terms of Reference, for which, see **Annex 2**.

1) Welcome; review aims of meeting; local arrangements, including the 2006 Mini Symposium; WGOH membership;

2) Update and review results from Standard stations and sections (2006 ToR a);

3) Consolidate inputs from member countries to, and continue development of the ICES Annual Ocean Climate Status Summary (IAOCSS), and align data source acknowledgements with IOC policy (2006 ToR b);

4) Review and improve relations with international climate monitoring programmes (2006 ToR c);

5) Formulate advice to the ICES Data Centre manager on the development of data products and services to improve access to physical oceanographic data for non-expert users (2006 ToR d);

6) Continue and extend the isopycnal analysis of *in situ* data (2006 ToR f);

7) review and report on the results of the North Sea ecosystem (overview) assessment undertaken by REGNS and prepare recommendations for further or modified analysis made where appropriate. The tables of gridded data used for the ‘overview’ assessment should be checked and where necessary new data (parameters) included and/or existing data (parameters) updated if relevant (2006 ToR g);

8) recommend equipment and protocols for collecting oceanographic data on ICES coordinated bottom trawl surveys and to determine the expected precision and accuracy of data thus collected. Report outcome to OCC and IBTSWG (2006 ToR h);

9) AOB;

10) Terms of reference, date and location of next meeting.

3 Agenda Item 1

3.1 Membership

The new Co-Chairs are presently undertaking a wide-ranging review of WGOH membership. Many discrepancies have been identified between the membership records held centrally by ICES and what we call the WGOH “mailing list”. We are most concerned that these discrepancies should be resolved, for the following reasons. Firstly, there are long-established and highly-valued members whose membership appears to have lapsed through no action either by them or by WGOH; secondly, members have retired and been replaced by new members who need to be properly accredited; and thirdly, there is a small subset of inactive members.

We are presently in the middle of this review, involving all WGOH members (including those who should be members but are not, for whatever reason), relevant national ICES Delegates, and Vivian Piil, the ICES Science Programme Departmental Secretary. We expect this review to be finalised before the next meeting in 2007. We note here that the list of ICES WGOH members, included here as **Annex 3**, is the list held centrally by ICES (with some deletions), and we do not consider it to be final.

We welcomed Holger Klein, of BSH, Hamburg, who replaces Gerd Becker. Gerd has retired. Also, we expect next year to see two new members from France. Virginie Thierry, of IFREMER, Brest, and Gilles Reverdin, of LODYC, Paris, will be very welcome active additions to WGOH.

3.2 2006 Mini Symposium

Following a recommendation made at the 2001 WGOH meeting in Reykjavik, a mini symposium was held in the Martin Ryan Institute, and a welcome and introduction given by the institute director, Prof. Mike Guiry. The morning sessions (the first six talks, by local speakers) were chaired by Glenn Nolan (WGOH and NUI Galway) and Martin White (NUI Galway), the afternoon sessions (the last seven talks, by WGOH speakers) by Sheldon Bacon and Penny Holliday (WGOH). The mini symposium talks are listed below.

i) Martin White: The Shelf Edge Current west of Ireland.
ii) Christian Mohn: Modelling the physics and ecosystem at Porcupine Bank.
iii) Jenny Ullgren: Water mass properties in Rockall Trough.
iv) Glenn Nolan: Shelf circulation west of Ireland.
v) Marcel Cure: Towards operational modelling at the Marine Institute.
vi) Guy Westbrook: Oceanographic Services - an emerging strategy for long term observations.
vii) Agnieszka Beszczynska-Möller and Waldemar Walczowski: Recent changes in the AW pathways and heat flux through Fram Strait.
viii) Bert Rudels: The 2005 Oden-Healy crossing of the Arctic Ocean (Alaska to Svalbard).
ix) Penny Holliday: Record-breaking waves in the Rockall Trough.
x) Hendrik van Aken: Deep Convection in the Irminger Sea.
xi) Stephen Dye: Seasonal Circulation and Climate Change Impacts in the North, Celtic and Irish seas.
xii) Harald Loeng: Climate Variability and the Ecosystems of the Norwegian and Barents Seas.
xiii) Tom Rossby: An isopycnal approach to understanding the Nordic Seas.

3.3 Meeting aims

The agenda was agreed; items to be discussed under “AOB” were noted; and ToR e (take action for strengthening the role of WGOH and physical oceanography within ICES) was dropped as a separate item because its aims were to be covered under Agenda Items 3, 4 and 6 (ToRs b, c and f). Actions are described in the relevant sections below, and collated in **Annex 4**. Next year’s (2007) proposed Terms of Reference appear in **Annex 5**.

4 Standard Sections and Stations (ToR a)

WGOH members presented their national / regional reports, as appropriate. The full text of each report is included in **Annexes 6–19**. The reports and annex numbers are listed below.

Annex 6: Climatic conditions around Greenland, 2005 (Area 1)
Annex 7: Northwest Atlantic, 2005 (Area 2)
Annex 8: Icelandic Waters, 2005 (Area 3)
Annex 9: Spanish Standard Sections, 2005 (Area 4)
Annex 10: Rockall Trough and Iceland Basin, 2005 (Area 5)

Annex 11: Western Irish Shelf and Rockall Trough (Area 5)
Annex 12: North-east Atlantic (WOCE AR7E), 2005
Annex 13: North Sea, 2005 (Areas 8 & 9)
Annex 14: Skagerrak, Kattegat and the Baltic (Area 9b)
Annex 15: Norwegian Waters, 2005 (Areas 8, 10, 11)
Annex 16: Atlantic Domain of the Nordic Seas, 2005 (Areas 8, 10, 11)
Annex 17: Barents, Norwegian and Irminger Seas, 2005
Annex 18: Greenland Sea and Fram Strait, 2005 (Area 12)
Annex 19: Environmental conditions in the Labrador Sea in 2005 (Area 2B)

5 ICES Climate Status Report (ToR b)

The ICES Annual Ocean Climate Status Summary has become the main output of WGOH, as a clear and readily-comprehended digest of the changes in the northern North Atlantic, Nordic Seas and adjacent and marginal seas (Labrador, North, Baltic, Barents), concentrating on temperature and salinity changes in the upper ocean (generally water shallower than 1000 m) in the preceding year. We see the Annexes to this present WGOH report as comprising supporting material to the Climate Summary, in that anyone wishing to find more detailed information about the measurements described in the Climate Summary can look in these Annexes.

In that context, the discussion about the Climate Summary was divided into four parts: (i) the preparation of the Summary; (ii) the further development of the Climate Summary; (iii) the issue of proper acknowledgement of data sources and funding in the Climate Summary, and (iv): better publicity for the Climate Summary. These issues, and our conclusions and subsequent actions, are described below. We describe items (i) and (ii) in reverse order, since some of our decisions impinge on the production of this year's Climate Summary.

5.1 Climate Summary Report Development

5.1.1 New Name for the Climate Summary Report

While the "ICES Annual Ocean Climate Status Summary" is a very accurate title for the report, it is a cumbersome and unmemorable title, with an unwieldy acronym (IAOCSS). Therefore it was opened to the meeting to think of a new name. Glenn Nolan's suggestion was adopted. In future, all summary reports will be called the **ICES Report on Ocean Climate**, or **IROC**, and this name will be used for the current report.

Additionally, the date associated with the climate report has not been helpful, in spanning two years: that immediately preceding the meeting, and the current year (e.g. last year's was the IAOCSS 2004–2005). Since most of the data presented within the report refer to the year preceding the current meeting, the full title of the present and subsequent reports will be the **ICES Report on Ocean Climate <*year*>**, where <*year*> is the year to which most of the data refer, so this year's title is (in short form) the **IROC 2005**. The publication date will (of course) be the current year, in this case 2006.

5.1.2 Report Format

Following discussions at last year's WGOH meeting at the University of Rhode Island in the US, it was decided that the IROC should target, in different ways, three levels of interested reader: (i) the inexperienced reader or the "general public"; (ii) the experienced non-specialist reader, and (iii) the specialist reader. The first of these would be addressed with a single-sentence summary of the state of ocean, expressed in simple terms. This would also correspond to the "highlight" requested by the Chair of the Oceanography Committee (OCC) through the ICES Consultative Committee (CONC), for presentation to ICES at the ASC: see Item 5.4 below.

The second level is intended for such groups as ecologists or biologists, either internal or external to ICES, and might conceivably include industrial readers, such as those involved in pollution monitoring or fisheries. The new report content to address this group is two related pages showing maps of the "WGOH area". The maps show in concise form (a) the temperature and (b) the salinity changes observed over the reporting year, as coloured dots. To provide the critical long-term (multi-decadal) context for each year's changes, the maps are surrounded by compact representations of the time-series of which the coloured dots are the latest point. To aid simple visual interpretation of these pages, the observations are grouped thematically, as follows. Many of the fundamental features of the ocean circulation in the "North Atlantic sector" are well known: for example, the north-going warm and saline Atlantic waters in the east (which it is practical to subdivide by latitude into two groups), and the south-going cold and fresh Polar waters in the west. Other useful groupings are: the waters around Iceland; the North and Baltic Seas, taken together; the eastern seaboard of North America south of Newfoundland. It may be that we choose to revise these groupings in the light of experience and further study, but the aims will remain the same: to have two simple, one-page visual representations of our principal results.

The third level is individual area summary reports, as have formed the body of all previous reports. These summaries provide the essential overview of each of the time-series. There is, as previously mentioned, an implicit fourth level of information, provided by the full area reports included as Annexes to this document, where further technical supporting information is to be found.

5.1.3 New section on "Deep Waters"

As previously mentioned, at present the IROC concentrates very much on the upper ocean. This is to ignore two facts: the great interest among physical oceanographers and climatologists in "deep waters", specifically such processes as overflows, deep and intermediate depth open-ocean convection, and deep winter mixing; and the very great resources within WGOH to provide information on these matters. Therefore, we will in next year's IROC include a section on these "Deep Waters", which we will aim to develop in subsequent years. Various individuals have been tasked with investigating the practicality of bringing new time-series to next year's meeting, and actually doing so if at all possible. This is the list of suggested topics, with the names of those responsible.

1) Denmark Strait Overflow T & S (Steven Dye, Hendrik van Aken);

2) Greenland Sea convection indicator, deep (3000 m?) T & S (Agnieska Beszczynska-Möller, who may request help from Gereon Budeus);

3) Labrador Sea convection indicator, deep (2000 m?) T & S (Ross Hendry, who may request help from Igor Yashayaev);

4) Rockall Trough / Iceland Basin deep winter mixing depth indicator (Penny Holliday);

5) OWS *Mike* deep T & S (Svein Østerhus, Kjell Arne Mork);

6) Irminger Sea deep winter mixing / convection indicator (Hendrik van Aken, who may request help from Johannes Karstensen);

7) Faroe Bank Channel Overflow (Bogi Hansen, Sarah Hughes);

8) Harald Loeng expressed an interest (as an ambition) in including flux measurements by using current meter arrays and correlations, mentioning Fram Strait, Svinøy, Bjørnøya, Faroe Bank Channel;

9) Alicia Lavin expressed an interest in Mediterranean water variability;

10) Tom Rossby, Vladimir Ozhigin and Sheldon Bacon will investigate the possibility of deriving a useful deep water product from the new Nordic Seas climatology (described later);

11) Iceland Sea deep water indicator (T & S from around 1500–1800 m; Hedinn Valdimarsson)

12) Surface fluxes (NCEP – Alicia Lavin; NOC climatology – Sheldon Bacon)

5.1.4 New data sources

In addition to our aim to include new "products" derived from "traditional" sources of data, we wish to investigate some of the new resources available to the scientific community. The *Argo* programme is one such resource. Penny Holliday presented to the meeting some example maps of sub-surface (200 m) salinity over the North Atlantic and southern Nordic Seas from the *Coriolis* project (www.coriolis.eu.org), showing how the float array has grown in the last five or more years. Penny will investigate the possibility of *Coriolis* producing maps of sub-surface temperature and salinity anomaly for us for next year.

Sheldon Bacon has described in previous meetings the potential utility of the Bernoulli inverse method as applied (by Steve Alderson at NOC, Southampton) to *Argo* floats. Alderson has been producing weekly gridded maps of sea surface height for data since 2002 (see www.noc.soton.ac.uk/JRD/PROC/people/sga/bernoulli/index.php). This has great potential for examining ocean circulation and variability in the North Atlantic. Technical difficulties prevented an update of last year's presentation, but it is hoped that these will be overcome in time for next year's meeting.

Finally, WGOH has included a measure of the North Atlantic Oscillation (NAO) in its reports for many years. Since there are many other modes of atmospheric variability apart from the NAO – even though the NAO is the dominant mode – Steven Dye will investigate the atmospheric variability "zoo" in time for next year's meeting, to see whether we could usefully include any other atmospheric variability indicators or indices in our deliberations.

5.2 Preparation of ICES Report on Ocean Climate 2005

A preliminary draft IROC was based on the summaries of the individual National Reports, and was prepared and presented by Sarah Hughes. WGOH considered the evidence and decided that a statement such as "the North Atlantic and Nordic Seas continued to be much warmer and more saline than the long-term mean" accurately described the state of the region in 2005. This statement is to be checked and, if necessary, refined after the meeting (in consultation with members via email), following consideration by the co-Chairs of the final draft of the IROC. The IROC will also be finalised after the meeting, and prior to transmission to ICES for publication in the *ICES Cooperative Research Report* series.

5.3 Data source and funding acknowledgements

WGOH is fully supportive of the intention to "align data source acknowledgements … with IOC policy". We propose to include as an Annex to the IROC a list, for each contributing member country, of the research institutes responsible for gathering the data presented, and of their national / international funding agencies. We will attempt to collate such a list in time for inclusion in this year's IROC, but if that proves not to be possible, we will certainly have the list ready in time for next year's IROC.

5.4 Publicising WGOH and IROC

We propose five routes, to be pursued in the coming year, whereby the work of WGOH in general and IROC in particular, may be better publicised, both within ICES and to the scientific community generally.

1) A dedicated WGOH issue of the CLIVAR *Exchanges* newsletter. This is described in detail in Section 6 following (ToR c).

2) Submission of an article to the *EOS* newsletter of the American Geophysical Union. This is to be led by Tom Rossby.

3) Submission of an abstract on the IROC 2005 to the 2006 ICES Annual Science Conference (ASC), to be prepared and submitted by Penny Holliday.

4) Submission of an abstract on the isopycnal approach to understanding the Nordic Seas to the 2006 ICES ASC, to be prepared and submitted by Tom Rossby.

5) Targeting of specific ICES Working Groups / Committees / Chairs, etc., for provision of feedback on the IROC. Sheldon Bacon and Penny Holliday will consult ICES and relevant WGOH members for advice on who best to target.

6 International climate monitoring programmes (ToR c)

WGOH is presently concentrating on *Argo* and CLIVAR. Plans and actions in respect of inclusion of *Argo* data and products in the IROC have already been described, in Section 5.1.4 above. For CLIVAR, we have made significant progress. The Director of the CLIVAR International Project Office, Dr Howard Cattle, has agreed that WGOH may have an entire issue of the *Exchanges* newsletter. In return, ICES has agreed to provide sponsorship of this special issue, to *ca.* UK £ 1500, to contribute to the costs of printing and distribution. The normal print run of *Exchanges* is about 1000, and it is sent to individuals and institutions all over the world, as well as being made available as a PDF for download from the CLIVAR website. We intend a couple of hundred extra copies to be printed, for distribution within ICES.

Constraints are as follows. Each issue of *Exchanges* is normally 32–36 pages long. Assuming 36 pages, then 3 pages are required for the front cover, the back cover (which lists the contents of the issue) and the inside front cover, for the editorial. With three pages per article, we may expect 11 articles, therefore. A description of the standard format is found at www.clivar.org/publications/exchanges/guidel.php (final page name has letters GUIDEL – short for “guidelines” – in lower case). Note that the page limit includes an “allowance” of one colour illustration per article; all colour illustrations are collected into the central 4 pages of the issue.

We have reserved the January 2007 issue of *Exchanges.* Guest editors will be the Co-Chairs, Penny Holliday and Sheldon Bacon. The **deadline** for submission of articles was fixed at **15 October 2006**. The meeting decided on the following outlines for articles and authors.

1) Norway and the Barents Sea: Harald Loeng;

2) Iceland: Hedinn Valdimarsson and Steingrimur Jonsson;

3) Fram Strait: Agnieszka Beszczynska-Möller and Eberhard Fahrbach;

4) Labrador and Irminger Sea, ventilation / convection / deep winter mixing: Ross Hendry, Hendrik van Aken, Igor Yashayaev;

5) New Nordic Seas Climatology / isopycnal analysis: Tom Rossby, Vladimir Ozhigin, Sheldon Bacon;

6) Floats / circulation (*Argo*, RAFOS, surface drifters, Nordic Seas): Kjell Arne Mork, Tom Rossby, Hedinn Valdimarsson, Penny Holliday, Sheldon Bacon;

7) Overflows: Hendrik van Aken, Steven Dye, Bert Rudels, Bogi Hansen;

8) North Sea: Holger Klein, Steven Dye, Einar Svendsen, Sarah Hughes;

9) Baltic variability and exchanges: Karin Börenas, Jan Piechura;

10) NAC (Spain – Rockall – Faroe Shetland Channel – Svinøy / Gimsøy / Sørkapp – West Spitzbergen Current) – Penny Holliday, Alicia Lavin, Glenn Nolan, Sarah Hughes, Kjell Arne Mork, Waldemar Walczowski;

11) Summary / extended introduction: Sheldon Bacon and Penny Holliday.

While the limitations of space preclude the possibility of all members contributing articles, we hope that this provides a representative selection of people, regions and subjects. Three non-members have been included on the author lists above, and will be approached by the designated lead authors with regard to their participation.

7 ICES Data Centre (ToR d)

Julie Gillin (ICES Data Centre Manager) attended the meeting, and gave a detailed and interesting presentation to WGOH about the structure, achievements, systems and strategy of the ICES Data Centre. The following specific issues were discussed.

1) GIS vs. historical data: The ICES Data centre is interested both in rescuing / digitising historical data, and in new forms of data presentation, such as by the use of Geographical Information Systems (GIS). WGOH **strongly recommends** that, in a resource-limited world, if there is any conflict between these two aims, the ICES Data Centre should give priority to the digitisation of historical data. We regard it as much more important that "new" (i.e. old) data should be made available, than that new ways should be found to present existing data.

2) Engine intake logs: In the context of historical data recovery, Tom Rossby remarked that the Ship Of Opportunity Program (SOOP: www.ifremer.fr/ird/soopip/) has logbooks of engine intake SST data, and asked whether the ICES Data Centre could access and digitise these records.

3) ICES Data Centre User Survey: the User Survey was described to WGOH. It was noted that (i) the majority of data downloads from the ICES Data Centre were of physical oceanographic data, and (ii) the majority of responses to the User Survey were from non-physicists. In order to provide some more representative feedback, the it was agreed that the User Survey would be circulated to WGOH members.

4) Data Centre products: there was some discussion of potential products that the Data Centre could provide. In summary WGOH agreed that priority should be given to acquiring and delivering data, rather than in generating and distributing data products.

5) Archiving WGOH data: Julie Gillin offered to archive WGOH data to ensure conformity with ICES data policy, and "traceability" of results presented in WGOH documents. The meeting suggested that this suggestion might most practically be met by the archiving of the time-series data presented in the IROC.

8 Isopycnal analysis (ToR f)

Progress and actions with this item have been described above (presentation of progress to date in Mini Symposium, section 3.2; development of new product for new section in IROC on "deep waters", section 5.1.3; preparation and submission of an abstract to the ASC 2006, section 5.4; article for *Exchanges*, section 6). Analysis has been led by Vladimir Ozhigin; presentations were by Tom Rossby. We expect to report on and conclude this item next year. Products will transfer to the IROC ToR. A paper will be prepared for the refereed scientific press.

9 REGNS (ToR g)

In response to the ToR requesting feedback from WGOH on REGNS, it was suggested that parameters describing physical dynamics were lacking. Specifically, the following were suggested: fluxes (transports of mass and properties), including Atlantic inflow to the North Sea; North Sea circulation and variability; stratification. Existing high-resolution regional ecosystem models might provide some of this information; high-quality long-term repeat time-series measurements could also be useful. In this latter context, measurements made by the MV *Nuka Arctica* were suggested, as it measures sea surface temperature and salinity, and upper-ocean currents using an ADCP. Its track, from Aalborg, Denmark to Nuuk, Greenland, takes it across the northern North Sea on a monthly basis.

WGOH thought that there was a broader issue here, to do with efficient communication within ICES and efficient use of meeting time. We received a large quantity of information about REGNS from Andrew Kenny. It would have been better for us if the request for feedback had been targeted, by which we mean we would have preferred REGNS to have distilled their questions into (say) 2 or 3 slides, suitable for consideration within the WGOH meeting. The expertise of WGOH is mainly focused on physical oceanography; only a few members have specialist knowledge of the North Sea; and we doubt the practicality of a request such as: “tables of gridded data used for the ‘overview’ assessment should be checked and where necessary new data (parameters) included and/or existing data (parameters) updated”.

We think that a better dialogue is required between REGNS and WGOH and propose that WGOH chairs and WGOH members involved in North Sea observations and analysis (Klein, Dye, Hughes) open an email discussion with REGNS to begin that process.

10 Bottom Trawl Surveys (ToR h)

On the issue of research trawl surveys: there is strong WGOH support for CTDs on trawls, in the contexts of climate monitoring and operational oceanography. WGOH are anxious to cooperate with IBTWG to make it happen.

WGOH requests further information from ICES, on (i) the actual or potential level of national / international interest / support; and (ii) the number of vessels, surveys, trawl profiles to be expected per year.

WGOH provides initial advice on parameters and accuracies, and will reconsider by email and at the next meeting (2007). CTDs measure pressure (P), temperature (T), and conductivity, from which is derived salinity (S). These three quantities (P, T, S) enable the calculation of seawater density (by use of the equation of state), and with two or more density profiles, relative current speed can be calculated. Therefore (if at all possible), all three parameters, including conductivity (and hence salinity) should be measured. Readily achievable accuracies are: P (5 dbar); T (0.005 ˚C); S (0.01).

CTDs require regular calibration, ideally before and after a research cruise, to determine the stability of the sensors. If operations permit, seawater samples should be collected to aid the calibration of conductivity (and salinity). The processing of CTD data requires expertise, and where the expertise is not available in the institute participating in IBTS, this should be sought through collaboration with national research laboratories and national data centres.

A most useful manner of collecting physical oceanographic data is to establish and to maintain standard sections that can be repeated regularly. The data then do not just stand alone, they accrue into a time-series which can be used to assess changes in physical conditions (temperature, salinity, circulation).

WGOH will request the Canadian protocols on the recording of physical data from research trawls.

11 AOB

11.1 WKREP

Harald Loeng reported on the deliberations of the Workshop on Review of the ICES Committee and Expert Group Performance (WKREP) to WGOH. A discussion paper issued by the Consultative Committee (CONC) concluded that most Expert Groups were working effectively, but considered that communication between groups was often missing. Conclusions from WKREP were:

1) There is a problem in communication between Science and Advisory bodies. Science groups must produce 1 page of highlights per year.
2) Chairs of Expert Groups should be prepared to go to the ASC to communicate with other scientists and policy bodies.
3) The implementation of the ecosystem approach requires a new level of communication.
4) A balance is required between future changes of structure and continuity of expertise.
5) ICES science goals must allow for alignment with member countries' priorities.
6) There is a need for strategic thinking within ICES; CONC should not 'micromanage'.

These findings have the following implications for WGOH:

i) WGOH needs to identify fellow Expert Groups, to target (a) the IROC, (b) our 'highlights' or 'main findings', with the help of Committee Chairs.
ii) Either or both of the Co-Chairs (Holliday, Bacon) should attend ASC.
iii) We should send the 'highlights' or 'main findings' to CONC via Vivian Piil.

It was noted that WGOH needs feedback from other groups to find out what of our output they use or need. The reply was that this is precisely why the meeting of Expert Group chairs at ASC is necessary.

Feedback on the IROC (formerly IAOCSS) was received from ACFM. They like it; they would like to see monthly data, where possible, in addition to annual means; they would also like information about episodic events.

11.2 SGGOOS

Sarah Hughes reported on a meeting of the ICES–IOC Steering Group on GOOS (the Global Ocean Observing System), SGGOOS. The main resulting comments/question was: do WGOH members submit data in real time, and if not, might they? A questionnaire was passed around WGOH during the meeting; the results suggest most members' institutes were willing in principle to submit data in real-time. However few members were aware of just how to send data to the GTS, and would benefit from some guidelines (definition of 'real-time', formats and resolution of data, transmission routes, etc.). The justification for the question was that ICES hydrographic data, even low resolution, would be useful for assimilation and modelling purposes.

11.3 Mini Symposium

There was a brief discussion on the relative merits of holding a mini symposium during every WGOH meeting. The argument against continuing to do so was that it consumes an entire day out of 3 ½ days of meeting, and, time being precious, we could not afford to continue thus. The argument in favour of continuing was that it is a good venue for information exchange, specifically (i) within WGOH, to update members with regard to each others' scientific activities, and (ii) between WGOH and the host institution, as an advertisement of the usefulness of ICES in general and WGOH in particular. Both of these arguments have merit. It was decided to compromise: next year's mini symposium will be half a day instead of a whole day. We will re-evaluate in the light of next year's experience.

12 Next Meeting

WGOH were invited by Karin Borenäs to visit the Swedish Meteorological and Hydrological Institute for next year's meeting.

Dates: Tuesday 27 – Friday 30 March 2007.

Terms of Reference were agreed for next year's meeting, and are attached as **Annex 5**.

Annex 1: List of participants

NAME	ADDRESS	EMAIL
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Apologies received from: Eugene Colbourne (Canada), Garry Dawson (UK), Niels Kristian Højerslev (Denmark), Vladimir Ozhigin (Russia), Jan Piechura (Poland).

Annex 2: WGOH 2005 Terms of Reference

2005/2/OCC08 The **Working Group on Oceanic Hydrography [WGOH]** (Co-Chairs: S. Bacon*, UK, and P. Holliday*, UK) will meet in Galway, Ireland, from 19–22 April 2006 to:

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

b) consolidate inputs from Member Countries to, and continue development of the ICES Annual Ocean Climate Status Summary (IAOCSS), and align data source acknowledgements in IAOCSS with IOC policy;

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

d) formulate advice to the ICES Data Centre manager on the development of data products and services to improve access to physical oceanographic data for non-expert users;

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

f) continue and extend the isopycnal analysis of *in situ* data;

g) review and report on the results of the North Sea ecosystem (overview) assessment undertaken by REGNS and prepare recommendations for further or modified analysis made where appropriate. The tables of gridded data used for the 'overview' assessment should be checked and where necessary new data (parameters) included and/or existing data (parameters) updated if relevant;

h) recommend equipment and protocols for collecting oceanographic data on ICES coordinated bottom trawl surveys and to determine the expected precision and accuracy of data thus collected. Report outcome to OCC and IBTSWG.

WGOH will report by 2 May 2006 for the attention of the Oceanography Committee, ACME and ACE.

Supporting Information

Priority:	The activities of this Group are fundamental to the fulfilment of the Oceanography Committee's Action Plan.
Scientific Justification and relation to Action Plan	Action Plan Nos. 1.2, 1.3, 1.6, 1.7, 1.10, 5.13.4, 5.14 and 6.3. a) This is a repeating task established by the Working Group to closely monitor the ocean conditions in the ICES area. The materials presented under this item will be utilised to prepare an overview of the state-of-the-environment in the North Atlantic for 2005. 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 the Working Group on Oceanic Hydrography. This agenda item will allow WGOH members to prepare the document during the meeting, thus avoiding delays in the dissemination of the information. c) Links have been made with the CLIVAR programme; it would be of benefit both to ICES and the international programmes to enhance internal information exchange. d) To assist the ICES data centre in defining physical oceanographic data products aimed in particular at non-expert users. e) To follow up on the ICES General Secretary's suggestions for increasing the visibility of WGOH within ICES. One action could be to hold a workshop (in 2006?) to demonstrate climate effects on ecosystems/fish stocks. f) To develop a method for consistent presentation and inter-comparison of datasets to help improve understanding of changes. g) This is in direct response to a request from REGNS. h) This is suggested to improve the links between climate and fish stock distribution and variability.

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:	b) Publication and reproduction costs for the IAOCSS c) Assistance with publication or distribution of a special CLIVAR *Exchanges* issue
Linkages to Advisory Committees:	ICES Annual Ocean Climate Status Summary available to the Advisory Committees on Fishery Management, Marine Environment, and Ecosystem
Linkages to Other Committees or Groups	Publications Committee; Consultative Committee; ICES/IOC Steering Group on GOOS
Linkages to Other Organisations:	IOC, JCOMM, CLIVAR
Secretariat Marginal Cost Share:	ICES:100 %

Annex 3: WGOH Membership

As stated in Section 3.1 of the 2006 WGOH Report, the WGOH membership is in a process of review. Therefore the list which follows is *neither final nor complete.* It is the list of members held centrally by ICES, modified by S. Bacon following some withdrawals/retirements. The membership list will be finalised before the next WGOH meeting in 2007.

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Annex 4: Actions and Recommendations

The following table summarises all actions and recommendations resulting from the 2006 WGOH meeting.

	RECOMMENDATION	ACTION
1	To rename the ICES Annual Ocean Climate Status Summary (IAOCSS) as the **ICES Report on Ocean Climate (IROC)**; see WGOH Report 2006, section 5.1.1.	
2.	To revise elements of the IROC format, as described in WGOH Report 2006, section 5.1.2.	Hughes, Holliday, Bacon
3.	To prepare a new section for next year’s (2007) IROC on “Deep Waters”.	WGOH members, listed in WGOH Report 2006, section 5.1.3
4.	To investigate new data sources for next year’s (2007) IROC.	WGOH members, listed in WGOH Report 2006, section 5.1.4
5.	To finalise this year’s (2006) IROC, and send to ICES by 1 June 2006.	Hughes, Holliday, Bacon
6.	To incorporate data source and funding acknowledgements in IROC; this year (2006) if possible, next year (2007) if not.	Hughes, Holliday, Bacon
7.	To publicise IROC and WGOH; actions specified in WGOH Report 2006, section 5.4.	WGOH members, listed in WGOH Report 2006, section 5.4
8.	To produce a WGOH special issue of the CLIVAR *Exchanges* international newsletter.	WGOH members, listed in WGOH Report 2006, section 6
9.	WGOH strongly recommends that, in the event of a conflict of resources between implementing GIS and rescuing / digitising historical data, that historical data should receive priority; see WGOH Report 2006, section 7 point 1.	FAO ICES Data Centre
10.	Ship Of Opportunity Program engine intake logs can provide a source of “new” (old) SST data: see WGOH Report 2006, section 7 point 2.	FAO ICES Data Centre
11.	ICES Data Centre User Survey to be circulated to all WGOH members; see WGOH Report 2006, section 7 point 3.	Bacon, Holliday to circulate to WGOH members.
12.	WGOH recommends that priority should be given by the ICES Data Centre to acquiring and delivering data, rather than in generating and distributing data products; see WGOH Report 2006, section 7 point 4.	FAO ICES Data Centre
13.	WGOH to send time-series data (as published in IROC) to ICES Data Cente for archiving; see WGOH Report 2006, section 7 point 5.	Holliday, Hughes, Bacon
14.	better dialogue is required between REGNS and WGOH and propose that the WGOH chairs, the WGOH members involved in North Sea observations and analysis (Klein, Stein, Dye, Hughes) open an email discussion with REGNS to begin that process.	FAO REGNS; WGOH co-chairs and members: Bacon, Holliday, Klein, Dye, Hughes.
15.	WGOH encourage and support IBTSWG on making physical oceanographic measurements from research trawls. WGOH recommends that if the appropriate expertise is not available in an institute participating in the IBTS, co-operation should be sought from within national research laboratories and national data centres; see WGOH Report 2006, section 10.	FAO ICES (general) and IBTSWG.
16.	WGOH requests information from ICES / IBTSWG on (i) actual / potential level of national / international interest / support for physical measurements on trawls; (ii) the actual / potential number of vessels / surveys / trawls to be expected per year; see WGOH Report 2006, section 10.	FAO ICES (general) and IBTSWG.
17.	WGOH to follow up WKREP findings; actions described in WGOH Report 2006, section 11.1.	WGOH Co-Chairs and members.

Annex 5: Proposed WGOH 2007 Terms of Reference

2006/2/OCCxx The **Working Group on Oceanic Hydrography [WGOH]** (Co-Chairs: S. Bacon*, UK, and P. Holliday*, UK) will meet at the Swedish Meteorological and Hydrological Institute in Västra Frölunda, Sweden, from 27–30 March 2007.

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

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

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

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

e) conclude and report on the isopycnal analysis of *in situ* data.

WGOH will report by 2 May 2006 for the attention of the Oceanography Committee, ACME and ACE.

Supporting Information

Priority:	The activities of this Group are fundamental to the fulfilment of the Oceanography Committee's Action Plan.
Scientific Justification and relation to Action Plan	Action Plan Nos. 1.2, 1.3, 1.6, 1.7, 1.10, 5.13.4, 5.14 and 6.3. a) This is a repeating task established by the Working Group to closely monitor the ocean conditions in the ICES area. The materials presented under this item will be utilised to prepare an overview of the state-of-the-environment in the North Atlantic for 2006. b) The Working Group recognises the need for disseminating climate information in a timely and appropriate manner. This agenda item will allow WGOH members to prepare the document during the meeting, thus avoiding delays in the dissemination of the information. We will review proposed new developments in IROC content. c) Links have been made with the CLIVAR programme; it would be of benefit both to ICES and the international programmes to enhance internal information exchange. d) To follow up on the ICES General Secretary's suggestions for increasing the visibility of WGOH within ICES. To improve communications between working groups under the ICES system. e) To develop a method for consistent presentation and inter-comparison of datasets to help improve understanding of changes. Products from this item will in future appear under ToR (b) in the IROC.
Resource Requirements:	No extraordinary additional resources
Participants:	WGOH members; chair of Oceanography Cttee.
Secretariat Facilities:	N/a
Financial:	b) Publication and reproduction costs for the IAOCSS c) Assistance with publication or distribution of a special CLIVAR *Exchanges* issue
Linkages to Advisory Committees:	ICES Annual Ocean Climate Status Summary available to the Advisory Committees on Fishery Management, Marine Environment, and Ecosystem
Linkages to Other Committees or Groups	Publications Committee; Consultative Committee; ICES/IOC Steering Group on GOOS
Linkages to Other Organisations:	IOC, JCOMM, CLIVAR
Secretariat Marginal Cost Share:	ICES:100 %

Annex 6: Climatic Conditions Around Greenland, 2005 (Area 1)

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Abstract

The pattern of sea level atmospheric pressure over the North Atlantic during winter 2004/2005 indicated 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 anomaly pattern, the North Atlantic Oscillation (NAO) index for the winter 2004/2005 was positive (2.03). Air temperature climatic conditions around Greenland continued to be warmer-than-normal. The climatic conditions at Nuuk are inconsistent with the NAO index (positive index = cold climate).

Warmer than normal conditions were observed around Greenland during most of the year 2004 with mean air temperatures at Nuuk indicating positive anomalies (+1.6K). Based on satellite derived ice charts for all months of 2005 it is shown that winter sea ice conditions were favourable during 2005 off West Greenland. Subsurface autumn water temperatures off West Greenland and sea ice cover off Labrador during January-March of the following year, indicate significant negative correlation (r^2 = 0.72). At Fyllas Bank, subsurface warming during 2005 was in the range of the warm 1960s temperatures, but was less than during autumn 2003 when temperatures were 2.44K above normal, and normal for the layer 0–200m is 2.87°C.

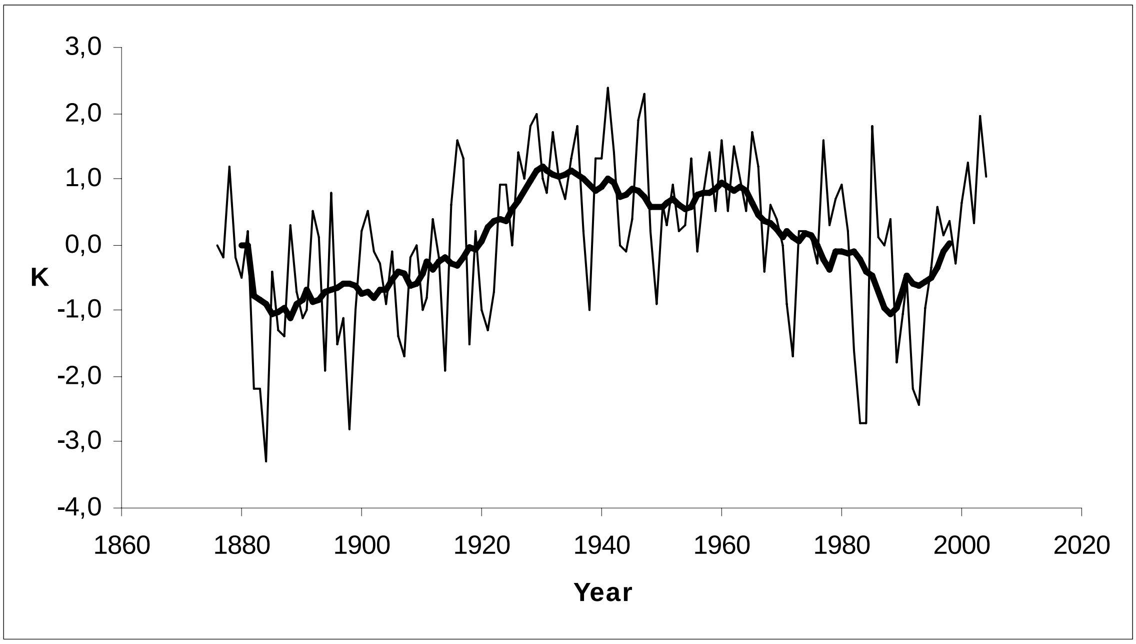

Figure A6.1: Time-series of annual mean air temperature anomalies at Nuuk (1876–2004, rel. 1961–1990); bold: 13 yr r.m.

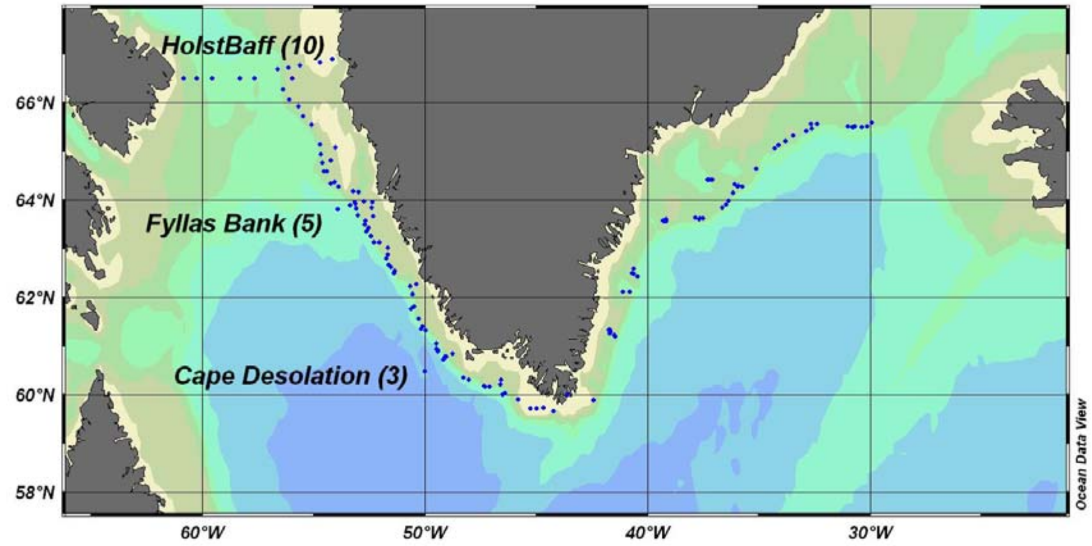

Figure A6.2: Positions of fishing stations off East and West Greenland (123), sampled NAFO Standard Sections: Holsteinsborg-Baffin Island (HolstBaff), Fyllas Bank, Cape Desolation; in brackets: No. of stations.

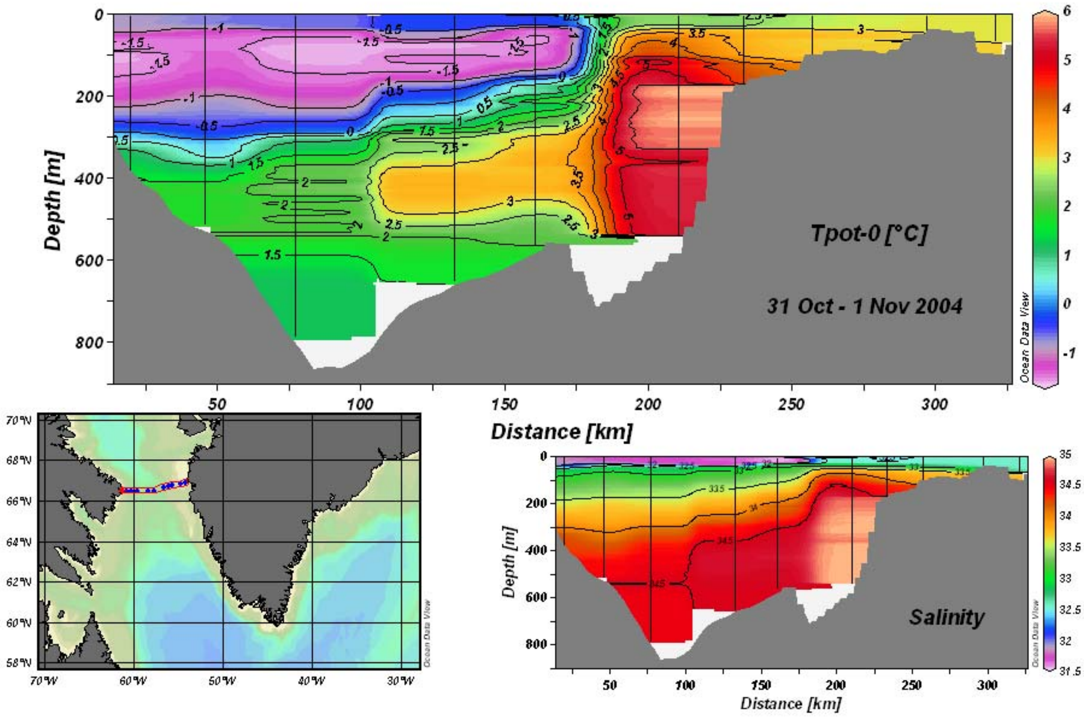

Figure A6.3: Vertical distribution of potential temperature and salinity along the Holsteinsborg-Baffin Island section; data: 31 October–1 November 2004.

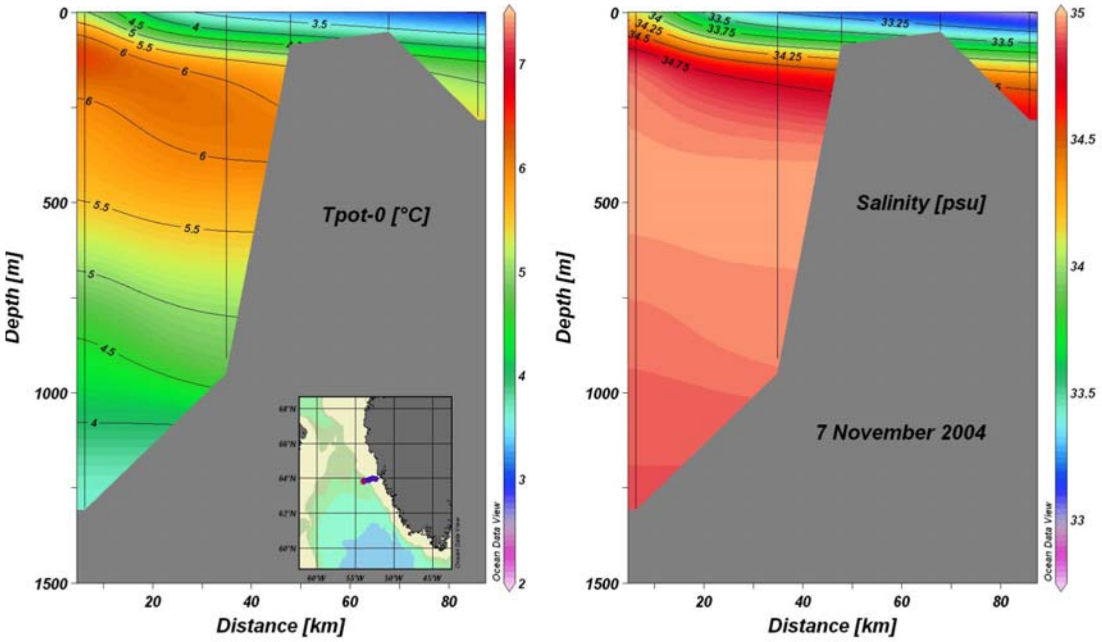

Figure A6.4: Potential temperature and salinity along Fylla Bank Section (7 November 2004).

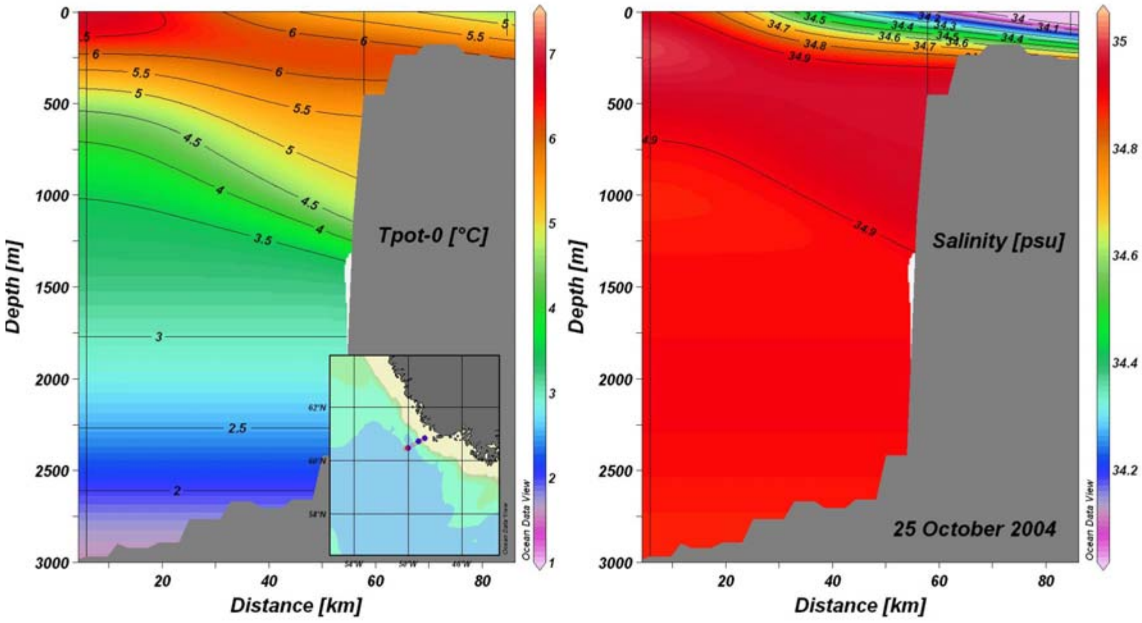

Figure A6.5: Potential temperature and salinity along Cape Desolation Section (25 October 2004).

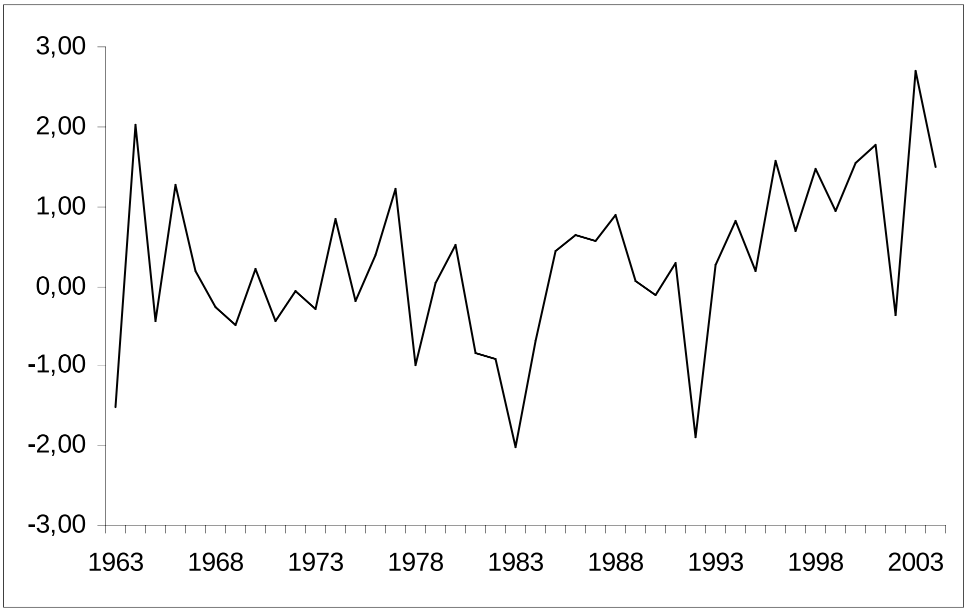

Figure A6.6: Mean water temperature anomalies of layer 0–200 m at station 4 of the Fyllas Bank Section during SEP-DEC; data: 1963–2004

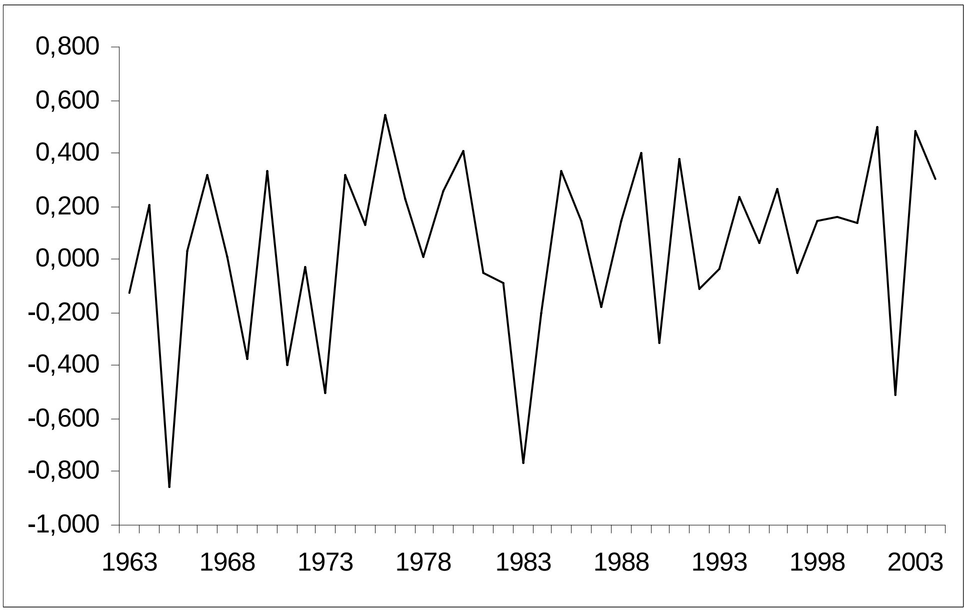

Figure A6.7: Mean water salinity anomalies of layer 0–200 m at station 4 of the Fyllas Bank Section during SEP-DEC; data: 1963–2004.

Annex 7: Northwest Atlantic, 2005 (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 2005 are presented referenced to their long-term (1971–2000) means. The North Atlantic Oscillation winter index for 2005 was 4 mb above normal. However, arctic outflow to the Northwest Atlantic was weaker-than-normal as the most significant SLP anomalies were shifted to the east. Annual air temperatures were above normal throughout the Northwest Atlantic from West Greenland to Baffin Island to Labrador and Newfoundland. Sea-ice extent and duration on the Newfoundland and Labrador Shelf remained below average for the 11th consecutive year. At Station 27 off St. John's, the depth-averaged annual water temperature decreased slightly from the record high of 2004 to just over 0.5°C above normal, the 7th highest on record. Annual surface temperatures at Station 27 were identical to 2004, 1°C above normal, the highest in the 60-year record. Bottom temperatures were also above normal by 0.8°C, the 3rd highest in the 60-year record. Annual surface temperatures on Hamilton Bank were 1°C above normal, the 4th highest on record, on the Flemish Cap they were 2°C above normal, the 3rd highest and on St. Pierre Bank they were 1.7°C above normal, the highest in 56 years. Upper-layer salinities at Station 27 were above normal for the 4th consecutive year. The area of the cold-immediate-layer (CIL) water mass on the eastern Newfoundland Shelf during 2005 was below normal for the 11th consecutive year and the 5th lowest since 1948. In general water temperatures on the Newfoundland and Labrador Shelf decreased slightly from 2004 values, but remained well above their long-term means, continuing the warm trend experienced since the mid to late 1990s. Newfoundland and Labrador Shelf water salinities, which were lower than normal throughout most of the 1990s, increased to the highest observed in over a decade during 2002 and have remained above normal at shallow depths during 2005.

Introduction

Meteorological and oceanographic conditions during 2005 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 (Figure A7.1).

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 47º 32.8' N and longitude 52º 35.2' W. This monitoring site 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 A7.1), 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 49 occupations during 2005.

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 seasonally on oceanographic surveys conducted by the Canadian Department of Fisheries and Oceans (Figure A7.1).

Climate conditions in the northwest Atlantic are largely determined by the strength of the winter atmospheric circulation (Colbourne *et al.*, 1994; Drinkwater 1996). In general, when the normal cyclonic circulation is weak during the winter months, usually corresponding to a negative NAO index, warm-saline ocean conditions predominate and conversely when the NAO is positive. Water properties on the Newfoundland and Labrador Shelf are influenced by several factors including the Labrador Current (Figure A7.2), cross-shelf exchange with warmer continental slope water and bottom topography. Superimposed on these oceanic processes are large seasonal and inter-annual variations in solar heat input, ice cover and storm-forced mixing. The resulting water mass on the shelf is characterised by large annual cycles with strong horizontal and vertical temperature and salinity gradients that exhibit significant inter-annual variations.

Meteorological and sea-ice conditions

Monthly and annual air temperature anomalies for 2005 relative to their 1971–2000 means at three sites in the northwest Atlantic, Iqaluit on Baffin Island, Cartwright Labrador and St. John’s Newfoundland are shown in Figure A7.3. The predominance of warmer-than-normal annual air temperatures at all three sites during 2005 is shown with annual anomalies ranging from a maximum of +2ºC at Cartwright to +1ºC at St. John’s Newfoundland. Monthly air temperatures were above normal in 9–11 months of 2005 at these sites. The main exceptions were January at Iqualuit and Cartwright and June at St. John’s when air temperatures were significantly below average. At Cartwright on the Labrador coast air temperatures were above normal in all months of 2005 except January, reaching a maximum of 4ºC above average in February. 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 northwesterly winds over the Northwest Atlantic. A high NAO index corresponds to an intensification of the Icelandic Low and Azores High, which in most years creates strong northwest winds, cold air and sea temperatures and heavy ice conditions on the 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 2002 to 2004 was below normal but increased to 4 mb above normal in 2005. However, the spatial patterns in the SLP anomalies indicated a reduced Arctic outflow to the Northwest Atlantic during the winter months of 2005 (Figure A7.4). This resulted in air temperatures over much of the Northwest Atlantic to remain above normal during 2005.

Data on the location and concentration of sea ice are 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 NL Shelf (between 45º–55ºN) show that spring conditions during 2005 were slightly lighter than 2004 and the overall sea-ice extent remained below average for the 11th consecutive year. The winter of 2004 had the lowest amount of sea-ice on the NL Shelf since

1965. In general, during the past several years, the sea ice season was shorter than normal in most areas of the NL Shelf.

Time Trends in Temperature and Salinity at Station 27

Station 27, located in the Avalon Channel off Cape Spear (Figure A7.1), was sampled 49 times (42 CTD profiles, 7 XBT profiles) during 2005. 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 2005 are displayed in Figure A7.5.

The cold isothermal water column during late January to early April has temperatures ranging from near 0º to –1ºC. These temperatures persisted throughout the year below 100 m. Upper layer temperatures warmed to >0ºC by mid-April and to >15oC by August, after which the fall cooling commenced with values decreasing to 2ºC by December. The seasonally heated upper-layer initially penetrated to about 60 m depth in June, then shoaled to 30-40 m during mid-summer due to local coastal upwelling and then gradually deepened to a maximum of about 100 m by late November.

Depth versus time contours of the annual salinity cycle for 2005 are also displayed in Figure A7.5. Surface salinities reached maximum values in early winter (>32) and decreased to minimum values by late summer (<31.2 in August). In the depth range from 50-100-m, salinities ranged from 32 to 32.7 and near bottom they varied throughout the year between 32.8 and 33.4. The period of low salinity values at shallow depths in late summer to late fall, a prominent feature of the salinity cycle on the Newfoundland Shelf, is due largely to melting sea-ice off Labrador earlier in the year followed by advection southward onto the Grand Banks.

Annual surface water temperatures off St. John’s were 1°C above normal, identical to 2004, the highest in the 60 year record; bottom temperatures were also above normal by 0.8°C, the 3rd highest in the 60-year record (Figure A7.6). The Station 27 depth-averaged annual temperature (which is proportional to the total heat content) shows large annual and decadal fluctuations throughout the time-series (Figure A7.6). From 1950 to the late 1960s, the total heat content was generally above the long-term mean. Recently, the heat content varied from a record low in 1991, to very high during 1996 and to a record high during 2004. The 2005 value decreased over the record high of 2004 to just over 0.5°C above normal, the 7th highest on record.

The depth averaged (0–50 m) salinity time-series (Figure A7.6) 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 summer salinities on the Newfoundland Shelf increased to the highest values in about 12 years. The 2003 to 2005 values remained above the long-term mean.

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 A7.2). 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 A7.2) are typical of sub-polar waters with a sub-surface temperature range of −1º 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 3o to 4oC and salinities in the range of 34 to 34.75. Surface temperatures warm to 10o to 12ºC during late summer, while bottom temperature remain <0ºC over the Grand Bank but increase to 1º to 3ºC 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 3º to 4ºC.

The most revealing feature of the temperature structure on the Newfoundland and Labrador Shelf, particularly during the summer, is the layer of cold <0°C water mass, commonly referred to as the Cold Intermediate Layer (CIL) (Petrie *et al.*, 1988). 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 which is formed during the winter months 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 undergoes seasonal modification in its properties due to the seasonal cycles of air-sea heat flux, wind forced mixing and ice formation and melt leading to intense vertical and horizontal gradients particularly along the frontal boundaries separating the shelf and slope water masses.

The seasonal extent of this winter chilled CIL water mass is evident in the contour plots of the temperature along the Bonavista section in 2005 (Figure A7.7). The water mass extended to near the surface during spring, was the 5th smallest since 1948 in the summer and was nearly gone by late autumn. Near-bottom temperatures across most of the shelf are influenced mainly by Labrador Slope Water with temperatures generally >3ºC. Seasonal cross sections of salinity for 2005 show remarkable similarities from spring to fall with slightly fresher upper-layer shelf values occurring during the summer (Figure A7.7).

The time-series of CIL area and the mean section temperature for eastern Newfoundland (Bonavista section) and southern Labrador (Seal Island) are displayed in Figure A7.8. In addition, oceanographic data collected along all sections sampled on the Newfoundland and Labrador Shelf during 2005 were used to construct time-series of temperature and salinity anomalies and other derived climate indices. The anomalies were normalized by dividing the values by the standard deviation of the data over the indicated base periods, usually 1971–2000 if the data permit. As a general guide anomalies within ±0.5 standard deviations in most cases are probably not significantly different from the long-term mean. The time-series from all sections are presented as normalized anomalies in 0.5 standard deviation (SD) units and summarized in Table A7.1. The anomalies are color coded with blues representing cold-fresh environmental conditions and reds warm-salty conditions. In some instances (water mass areas or volumes for example) negative anomalies indicate warm conditions and hence are colored red.

In 2005 the CIL areas along all sections during spring, summer and fall were below normal, implying warmer-than-normal water temperatures on the continental shelf. Along the Bonavista section for example, the summer CIL area was below normal for the 11th consecutive year ranking the 5th warmest year in the 57 year time-series (Figure A7.8 and Table A7.1). This represents only a slight cooling from 2004 when it was the 2nd lowest on record. This is in contrast to the near record high values measured during the cold period of the early-1990s on the Newfoundland and Labrador Shelf. The overall section temperature time-series for both Newfoundland and Labrador show a continuation of the increasing trend since the early 1990s with the 2005 value the 3rd highest off eastern Newfoundland and the 7th highest off southern Labrador, surpassed only by 2004 and 1965 (Figure A7.8).

On the southern Labrador Shelf south to eastern Newfoundland temperature and salinity has been increasing since the near-normal year of 2000 reaching near-record high values in 2004 and continuing warm and salty during 2005. From 1990 to 1994 conditions were significantly below normal in these areas. Farther south on the Grand Bank and St. Pierre Bank conditions have been more variable with near-record cold conditions during the spring of 2003. During 2004 and 2005 however ocean conditions in this area have also become generally warmer and saltier than normal, although the magnitude of the anomalies are lower than those observed farther north (Table A7.1).

On the Grand Bank along the 47ºN section, the summer CIL area was below normal for the 8th consecutive year and along the southeast Bank section it was below normal for the 6th consecutive year with the spring of 2005 the 2nd lowest and 2003 the highest since 1972. On St. Pierre Bank the CIL area decreased sharply over the record high value during the cold spring of 2003. In this area, 1999 appears to be the warmest year in the time-series. Salinities continued above normal along northern sections (Bonavista, White Bay and Seal Island) but were near normal on the Grand Bank and St. Pierre Bank.

Temperature and salinity data along the Seal Island, Bonavista and Flemish Cap sections were used to compute geostrophic transports estimates of the near-surface component of the offshore branch (Figure A7.2) of the Labrador Current (Colbourne *et al.*, 2005). 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 long-term trends in the volume transport of the offshore branch of the Labrador Current through the three sections show large variations with average upper-layer transport between 0.4–0.8 Sv to the south. In general, the time-series indicate higher than average transport occurred during the late 1950s and into the 1960s, lower than average values during the cold-fresh 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 (Figure A7.8). The baroclinic transport was above normal during 2005 off southern Labrador and off the Grand Bank through the Flemish Pass, continuing a six-year trend. Along the Bonavista Section however, where a significant component of the flow is in the offshore direction, there are no apparent trend in the estimates of transport in recent years (Table A7.1).

Summary

The North Atlantic Oscillation winter index during 2005 was about 4 mb above normal. However, arctic outflow to the Northwest Atlantic was weaker-than-normal as the most significant SLP anomalies were shifted to the east. Annual air temperatures were above normal throughout the Northwest Atlantic from West Greenland to Baffin Island to Labrador and Newfoundland. Sea-ice extent and duration on the Newfoundland and Labrador Shelf remained below average for the 11th consecutive year. As a consequence, water temperatures on the Newfoundland and Labrador Shelf remained well above normal in 2005, continuing the warm trend experienced since the mid-to-late 1990s. The 2005 values however decreased slightly over the record highs of 2004. Salinities on the NL Shelf, which were lower than normal throughout most of the 1990s, increased to the highest observed in over a decade during 2002 and have remained above normal during the past three years.

Main Highlights for 2005:

Annual air temperatures were above normal in Newfoundland and Labrador during 2005 by 1.8°C at Cartwright and by nearly 1°C at St. John's.

Annually, sea ice extent remained below normal for the 11th consecutive year on the Newfoundland and Labrador Shelf in 2005. The ice extent increased slightly during the winter but decreased during the spring compared to that of 2004.

Only 11 icebergs drifted south of 48ºN onto the Northern Grand Bank during 2005, the lowest number since 1966, well below the 106 year average of 477.

The Station 27 depth-averaged annual water temperature off St. John's decreased over the record high of 2004 to just over 0.5°C above normal, the 7th highest on record.

Annual surface temperatures off St. John's at Station 27 remained at the 60 year record high value of 2004 at 1°C above normal.

Bottom temperatures at Station 27 have been above normal for the past 10 years. In 2005 they were 0.8°C) above normal, the 3rd highest in the 60-year record.

Annual surface temperatures on Hamilton Bank were 1°C above normal, the 4th highest on record. On the Flemish Cap they were 2°C above normal, the 3rd highest and on St. Pierre Bank they were 1.7°C above normal and the highest in 56 years.

Near surface salinities off St. John's at Station 27 were above normal for the 4th consecutive year. The average salinity along the Bonavista section has remained above normal since 2002.

The area of <0°C (CIL) water mass on the eastern Newfoundland Shelf during the summer of 2005 was below normal for the 11th consecutive year and the 5th lowest since 1948.

The density driven component of the shelf-slope Labrador Current volume transport shows an increasing trend off southern Labrador and through the Flemish Pass from 2000–2005.

Acknowledgements

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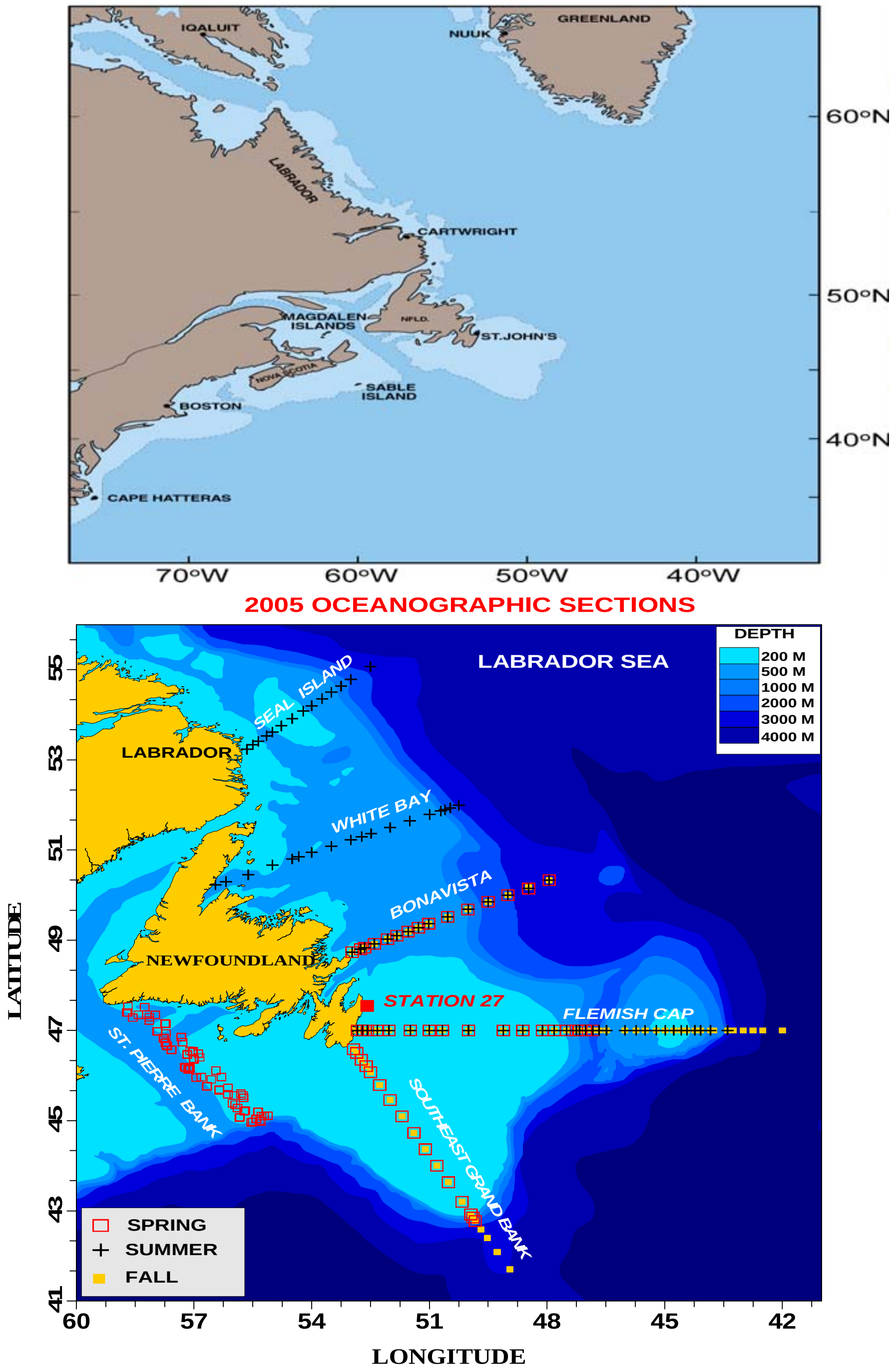


Figure A7.1: Northwest Atlantic coastal air temperature monitoring stations (top panel) and the location of Station 27 and oceanographic sections occupied on the Newfoundland and Labrador Shelf in 2005.

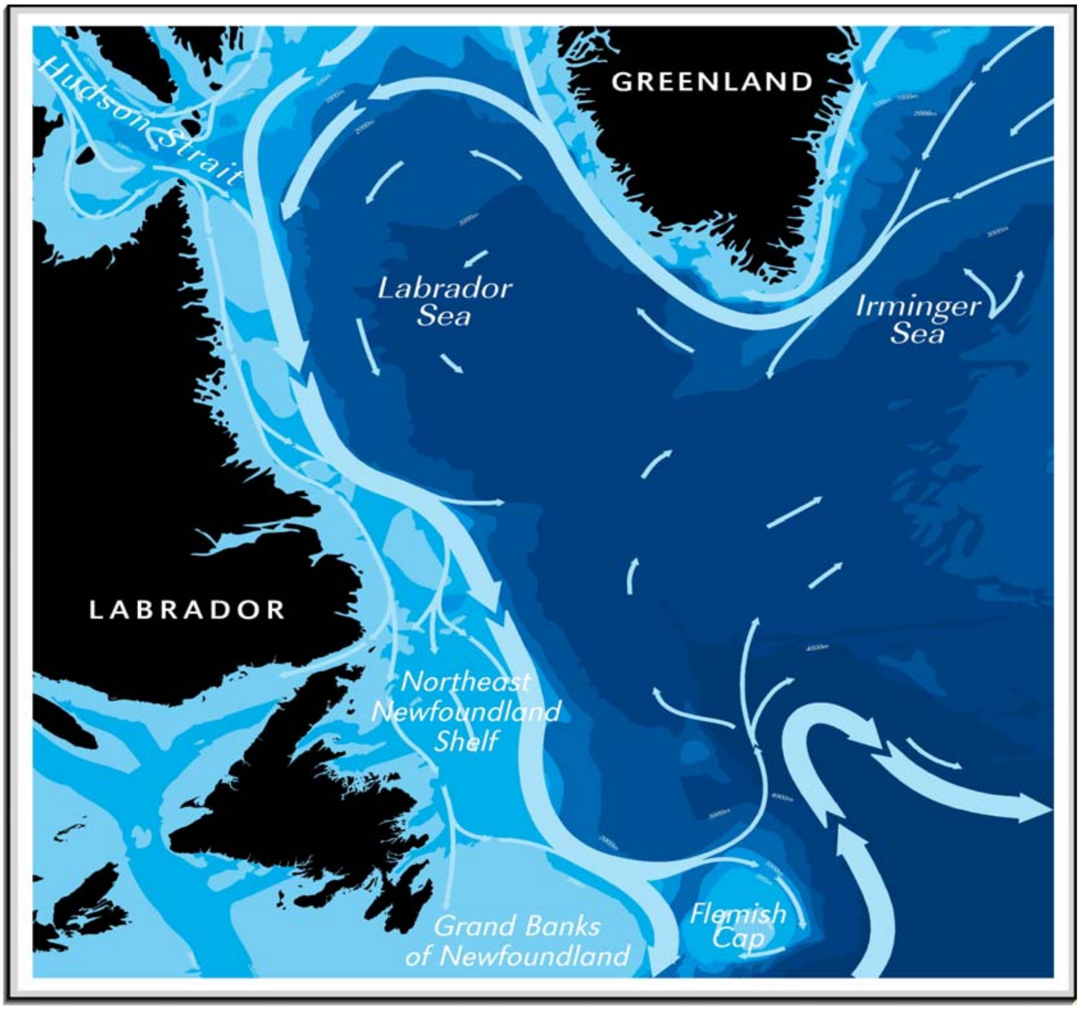


Figure A7.2: Map showing the general circulation features of the Northwest Atlantic. The Labrador Current is shown as two separate branches, the strongest flowing south eastward along the Labrador and Newfoundland Shelf and a weaker inshore component.

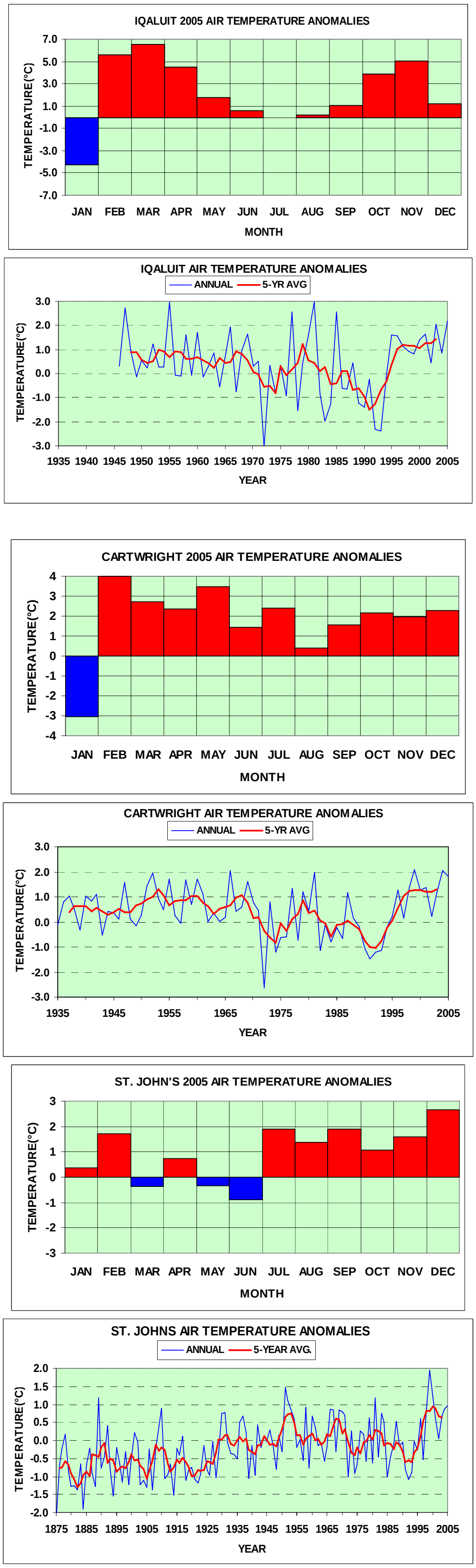


Figure A7.3: Annual and monthly air temperature anomalies in 2005 at selected coastal sites (see Figure A7.1 for locations). The anomalies are referenced to their 1971–2000 means.

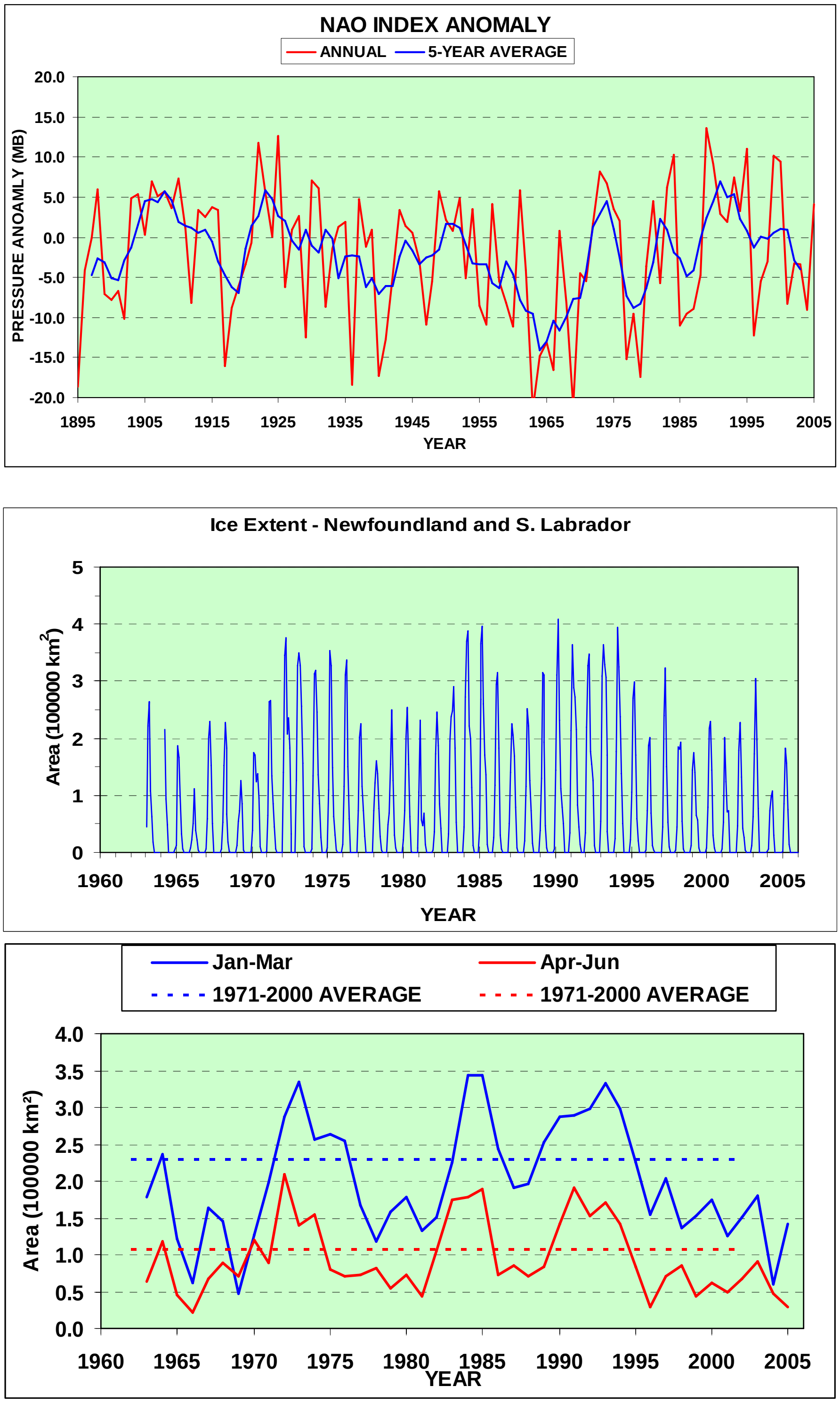
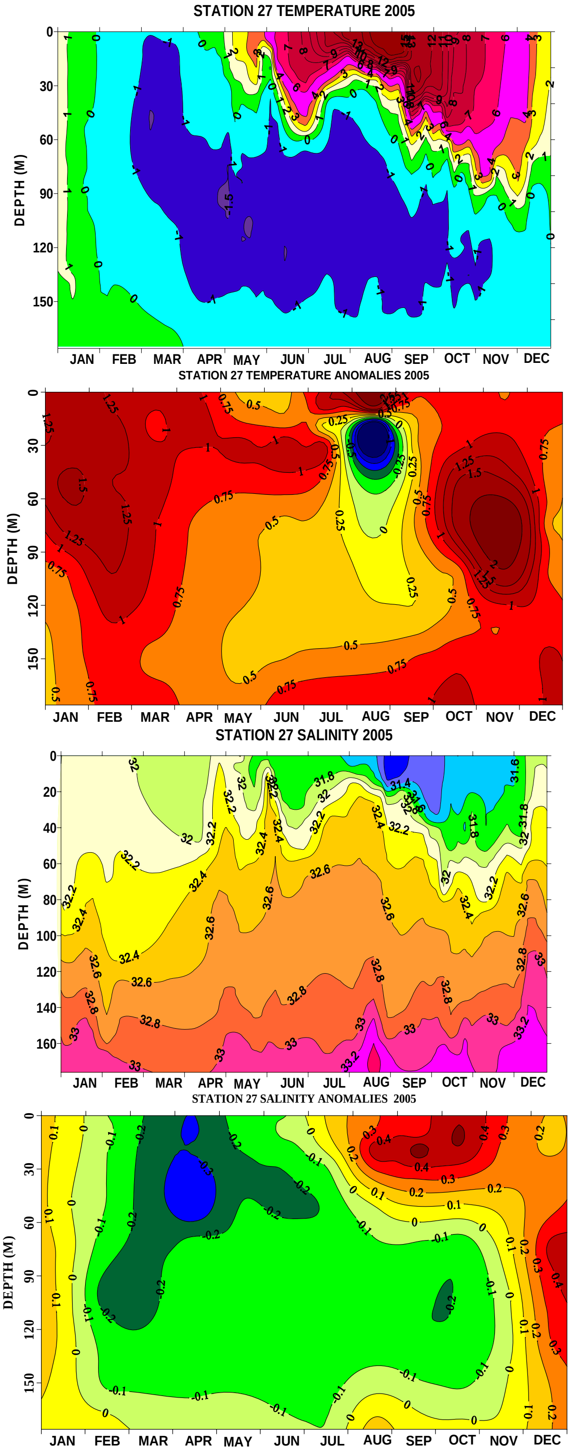


Figure A7.4: Anomalies of the North Atlantic Oscillation Index relative to the 1971-2000 mean (top panel), monthly mean ice extent off Newfoundland and Labrador between 45°N–55°N (centre panel) and the average ice extent during the normal periods of advancement (January-March) and retreat (April–June) (bottom panel).



STATION 27 TEMPERATURE 2005

STATION 27 TEMPERATURE ANOMALIES 2005

STATION 27 SALINITY 2005

STATION 27 SALINITY ANOMALIES 2005

Figure A7.5: Contours of the annual cycle of temperature and temperature anomalies (in °C) (top panels) and salinity and salinity anomalies (bottom panels) as a function of depth at Station 27 for 2005.

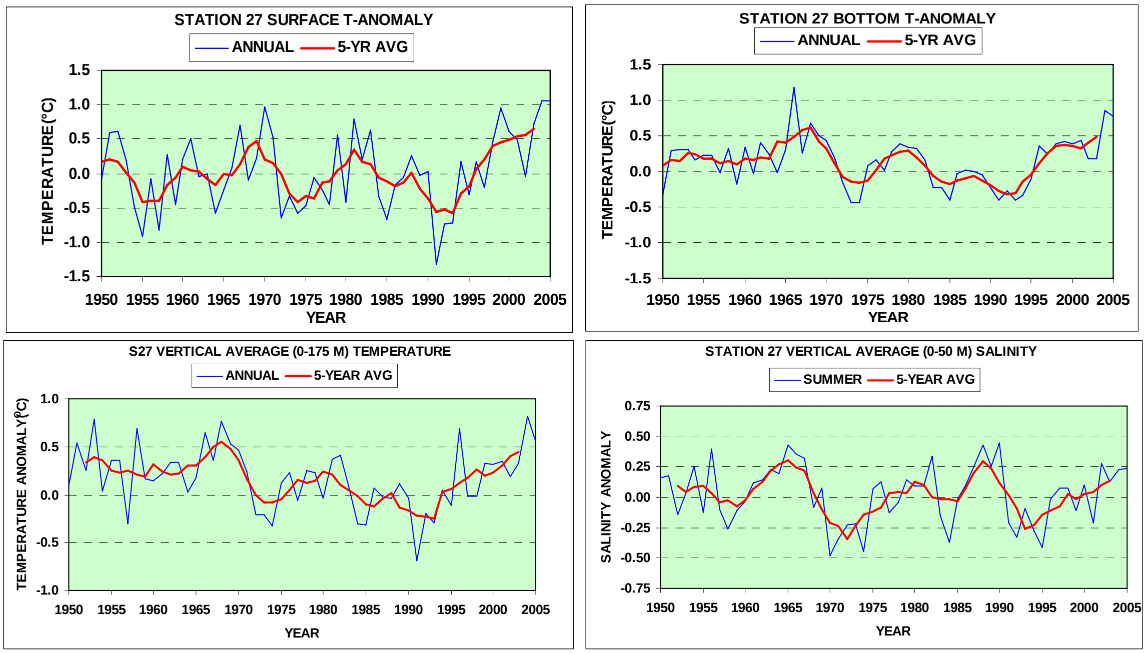
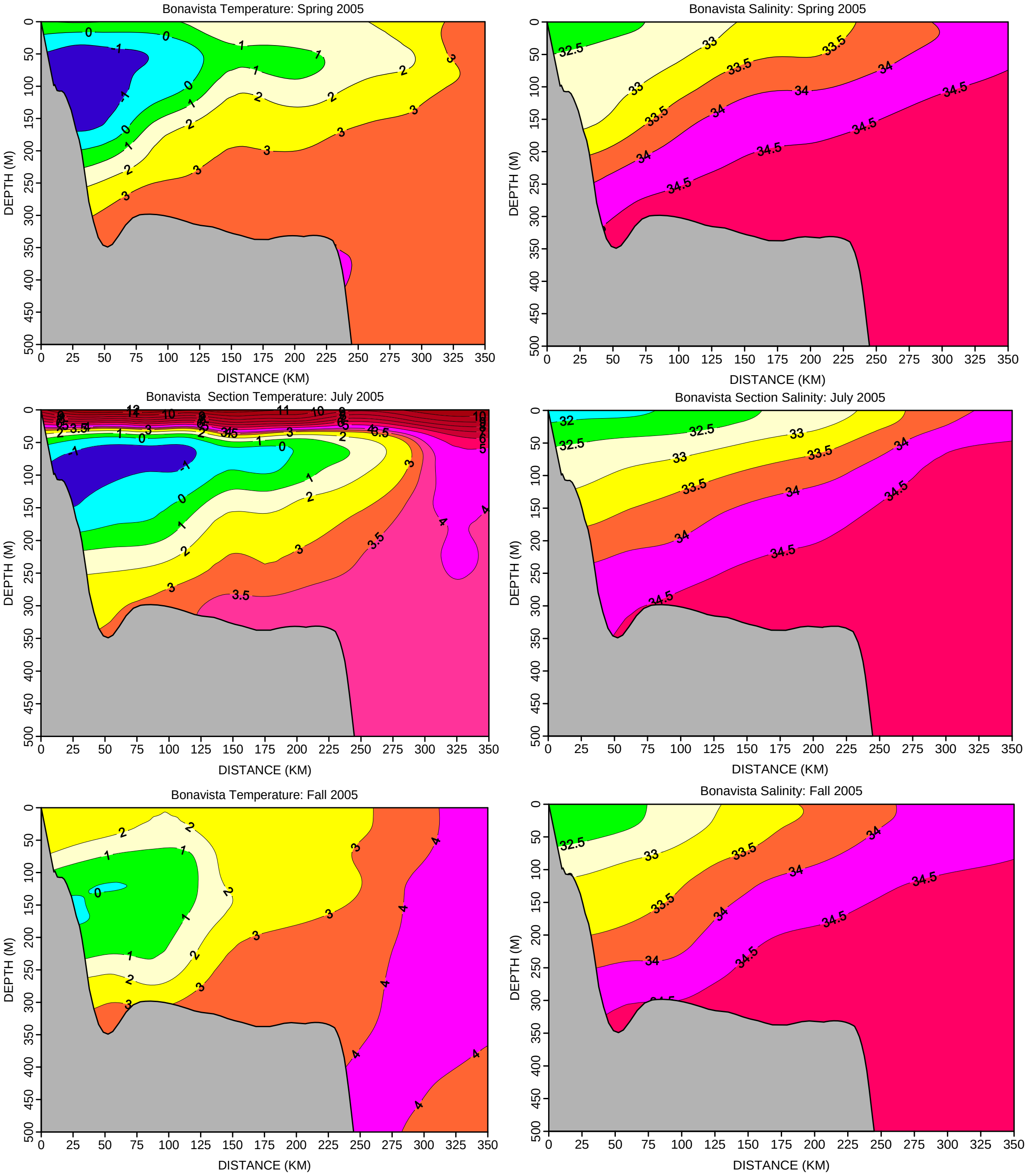


Figure A7.6: Surface, bottom and depth averaged (0–176 m) annual temperature anomalies and upper layer (0–50 m) depth averaged salinity anomalies at Station 27.



Bonavista Temperature: Spring 2005

Bonavista Salinity: Spring 2005

Bonavista Section Temperature: July 2005

Bonavista Section Salinity: July 2005

Bonavista Temperature: Fall 2005

Bonavista Salinity: Fall 2005

Figure A7.7: Contours of temperature (ºC) and salinity across the Newfoundland Shelf along the Bonavista Section (Figure A7.1) during the spring, summer and fall of 2005.

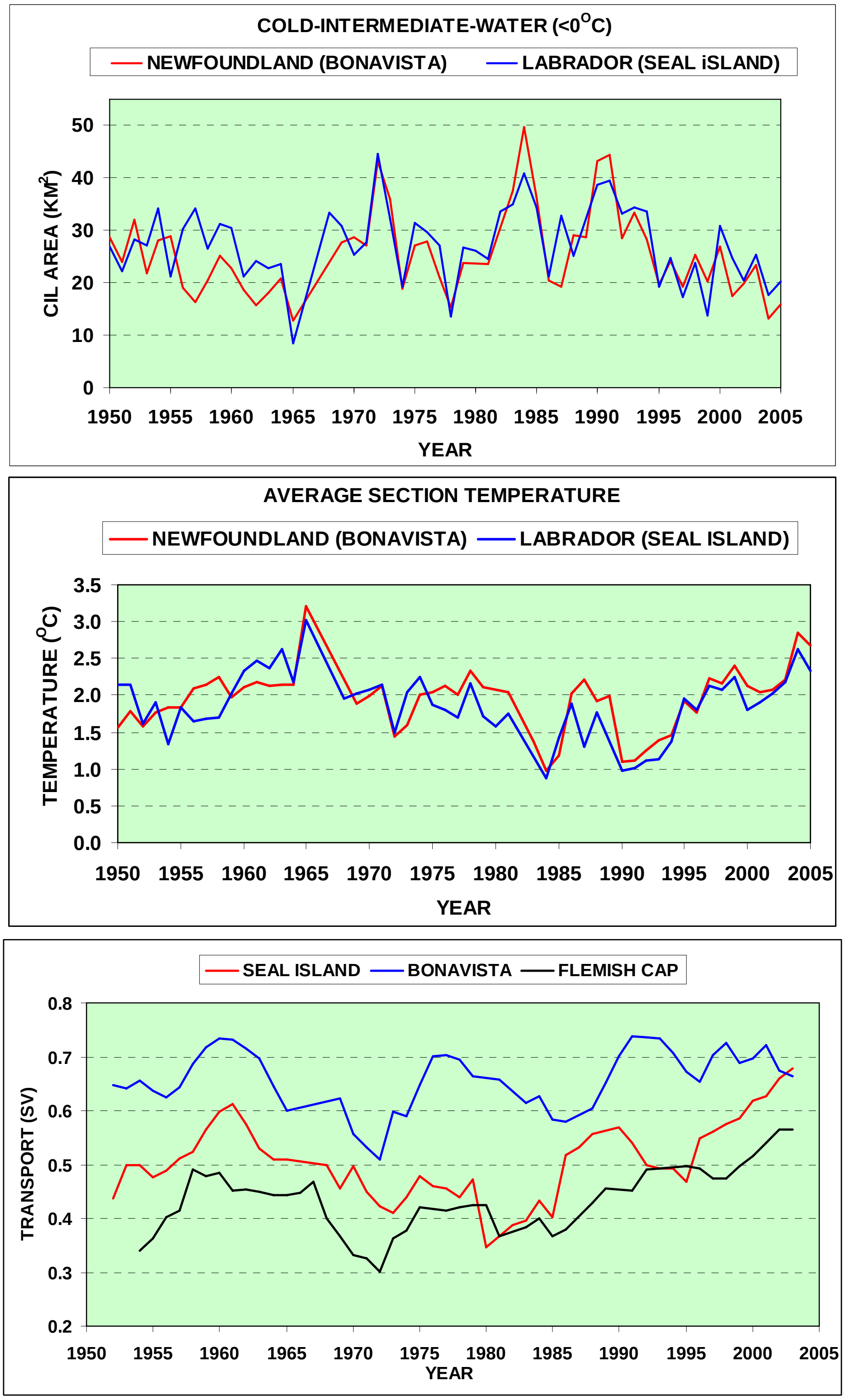


Figure A7.8: Time-series of the summer cold-intermediate layer (CIL) areas, the average temperature along the Bonavista and Seal Island sections and the five-year average geostrophic transport of the offshore component of the Labrador Current along each section. See Figure A7.1 for locations.

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

REGION/SECTION	INDEX	REFERENCE	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
SOUTHERN LABRADOR SEAL ISLAND SECTION (SUMMER)	COLD-INTERMEDIATE-LAYER AREA	1971-2000	1.26	1.36	0.55	0.71	0.61	-1.22	-0.51	-1.46	-0.63	-1.91	0.26	-0.52	-1.07	-0.43	-1.41	-1.09
	MEAN CIL TEMPERATURE	1971-2000	-1.42	-0.87	-1.11	-1.30	-0.79	1.25	0.27	0.31	0.11	1.13	-0.48	0.62	0.54	-0.09	0.58	1.01
	MINIMUM CIL TEMPERATURE	1971-2000	-0.45	-0.71	-0.46	-0.82	-0.18	2.39	0.11	-0.16	0.06	1.48	-0.06	1.42	-0.13	1.08	2.68	1.42
	MEAN SECTION TEMPERATURE	1971-2000	-1.32	-1.24	-1.04	-0.98	-0.51	0.66	0.37	1.02	0.90	1.26	0.35	0.55	0.82	1.12	2.03	1.42
	MEAN SECTION SALINITY	1971-2000	-0.62	-0.72	1.02	-0.14	-0.35	0.81	-0.14	0.86	0.44	0.91	-0.35	0.44	1.18	0.28	1.34	0.81
	INSHORE SHELF SALINITY	1971-2000	0.07	-0.77	0.98	1.05	-0.54	0.71	-0.54	0.67	0.48	1.05	-1.11	0.29	0.67	0.18	0.22	1.21
	LABRADOR CURRENT TRANSPORT	1971-2000	0.64	0.84	1.32	-1.54	-0.52	0.43	0.84	0.50	1.18	-0.11	0.98	1.18	1.59	1.46	1.05	1.59
NORTHEAST NEWFOUNDLAND WHITE BAY SECTION (SUMMER)	COLD-INTERMEDIATE-LAYER AREA	1977-2000	1.69	0.95	1.02	0.83	0.96	-0.69	-0.10	-0.50	-1.03	-1.10	0.10	-0.64	-0.98	-0.54	-1.90	-1.29
	MEAN CIL TEMPERATURE	1977-2000	-1.14	-0.54	-0.66	-1.08	-0.42	0.42	0.42	-0.24	0.42	1.55	-0.18	0.66	0.95	0.06	2.45	1.13
	MINIMUM CIL TEMPERATURE	1977-2000	-0.41	-0.68	-0.66	-0.94	-0.34	-0.16	0.80	-0.24	-0.20	1.20	0.29	0.15	0.22	0.37	4.65	0.75
	MEAN SECTION TEMPERATURE	1977-2000	-1.46	-0.84	-1.65	-1.29	-1.31	0.01	-0.11	1.00	1.22	1.50	0.55	0.53	0.60	1.00	1.92	2.00
	MEAN SECTION SALINITY	1977-2000	-1.07	-0.77	-0.66	-0.15	-0.77	0.57	-1.38	1.49	0.77	-0.25	-0.46	0.36	1.49	0.46	1.59	0.98
	MEAN SHELF SALINITY	1977-2000	0.17	-0.65	-1.21	0.98	-0.75	0.17	-0.90	1.59	0.07	-1.67	-0.60	0.07	1.19	-0.34	0.88	-0.09
EASTERN NEWFOUNDLAND BONAVISTA SECTION	CIL AREA (SPRING)	1977-2000	1.90	1.11	0.55	0.53	1.05	-0.74	-0.44	-0.44	0.14	-0.94	-0.14	-0.90	-0.34	-0.01	-1.02	-0.90
	CIL AREA (SUMMER)	1971-2000	1.66	1.78	-0.01	0.55	-0.03	-0.99	-0.49	-1.03	-0.35	-0.93	-0.17	-1.24	-0.98	-0.58	-1.72	-1.41
	CIL AREA (FALL)	1979-2000	1.46	0.45	0.84	1.33	0.92	-0.63	-0.45	-1.17	-0.76	-1.43	-0.19	-0.53	-0.93	-1.17	-1.43	-1.40
	MEAN CIL TEMPERATURE (SUMMER)	1971-2000	-0.95	-1.51	-0.40	-1.09	-0.47	0.71	1.41	-0.40	-1.02	-0.19	0.09	1.34	-0.26	-0.26	1.62	1.48
	MINIMUM CIL TEMPERATURE (SUMMER)	1971-2000	-0.41	-0.79	-0.25	-0.78	-0.48	0.19	0.88	-0.06	-0.09	0.62	0.34	1.22	0.54	0.28	2.78	1.73
	MEAN SECTION TEMPERATURE (SUMME	1971-2000	-1.68	-1.61	-1.30	-0.97	-0.83	0.30	-0.10	1.01	0.87	1.41	0.75	0.56	0.66	0.99	2.48	2.05
	MEAN SECTION SALINITY (SUMMER)	1971-2000	-1.18	-1.18	-0.32	0.04	0.53	1.63	-1.54	1.51	0.04	0.41	0.41	0.29	2.61	1.14	2.49	1.51
	INSHORE SHELF SALINITY (SUMMER)	1971-2000	0.74	-1.19	-1.10	0.30	0.56	-1.19	0.13	0.13	-0.31	-1.81	0.74	-0.40	2.32	0.04	1.00	1.09
	LABRADOR CURRENT TRANSPORT (SU	1971-2000	-0.16	1.49	1.49	0.39	-0.24	-0.24	0.47	0.08	-0.32	1.73	0.63	-1.02	0.39	0.70	-0.16	0.23
GRAND BANK FLEMISH PASS FLEMISH CAP 47 °N SECTION	CIL AREA (SPRING)	1971-2000	0.95	0.90	0.77	1.02	0.87	0.42	-0.50	-0.10	-0.94	-2.17	-0.36	0.05	1.22	1.44	-1.57	-1.14
	CIL AREA (SUMMER)	1971-2000	-0.03	1.68	0.62	1.26	-0.01	0.26	-0.80	0.26	-0.72	-1.37	-1.25	-0.54	-0.80	-0.41	-2.72	-1.06
	CIL AREA (FALL)	1973-2000	0.47	0.66	0.02	0.09	0.76	-0.36	-0.28	-0.33	0.04	-1.37	0.01	-0.17	-0.62	-0.54	-1.50	-0.57
	MEAN CIL TEMPERATURE (SUMMER)	1971-2000	-1.07	-1.83	-1.30	-1.70	-0.22	-0.85	0.86	0.27	0.59	1.39	0.99	0.90	0.14	-0.40	1.30	0.86
	MINIMUM CIL TEMPERATURE (SUMMER)	1971-2000	-0.11	-0.86	-0.25	-0.79	-0.55	-0.05	1.97	0.69	-0.08	1.06	0.93	2.34	-0.42	0.39	0.66	1.13
	MEAN SECTION TEMPERATURE (SUMME	1971-2000	-0.64	-1.31	-1.58	-2.47		-0.67	0.18	-0.12	0.82	1.59	0.45		-0.20	2.41	1.29	1.19
	MEAN SECTION SALINITY (SUMMER)	1971-2000		-0.15	0.05	0.15		0.54	0.34	1.12	0.73	0.83	-0.05		1.32	2.29	1.12	-0.44
	INSHORE SHELF SALINITY (SUMMER)	1971-2000		-0.54	-0.83	-0.42	-0.18	-0.42	-0.71	0.12	0.18	-0.06	-0.83	-0.83	0.47	0.06	-0.12	-0.30
	LABRADOR CURRENT TRANSPORT (SU	1971-2000		0.18	1.45	0.81		1.13	0.07	0.39	1.24	-0.14	1.13	1.24	1.45	2.51	1.13	1.13
SOUTHEAST GRAND BANK SECTION	CIL AREA (SPRING)	1972-2000	1.54	1.78	0.40	-0.21	-0.36	-0.83	-0.81	-0.19	-0.55	-0.87	-0.73	-0.21	0.79	2.98	-0.85	-0.94
	MEAN CIL TEMPERATURE (SPRING)	1972-2000	-0.08	-0.38	-0.38	-1.81	-0.94	-1.50	0.40	0.09	0.65	-0.60	0.70	1.39	0.74	0.09	2.38	0.78
	MEAN TEMPERATURE (SPRING)	1972-2000	-1.77	-1.40	-0.89	-0.48	-0.29	-0.47	0.03	-0.17	0.29	1.46	0.20	-1.21	-1.61	-2.34	-0.07	-0.26
	CIL AREA (FALL)	1990-2004	-0.51	1.47	-0.41	0.68	2.18	1.21	-0.54	-0.50	-0.38	-0.59	-0.38	-0.45	-0.57	-0.50	-0.70	-0.44
	MEAN CIL TEMPERATURE (FALL)	1990-2004	-1.28	0.79	-0.77	0.42	-0.17	1.98	0.64	-1.14	-0.99	0.57	0.20	0.05	-1.06	-1.28	2.05	1.38
	MEAN SECTION TEMPERATURE (FALL)	1990-2004	-0.95	-0.46	-1.27	-0.43	-0.67	0.92	-0.64	-0.10	1.44	1.52	0.99	0.35	-0.44	-0.48	0.22	-0.39
ST. PIERRE BANK SECTION (SPRING)	CIL AREA	1993-2004				1.16	0.95	0.40	-1.03	1.09	-0.84	-1.16	-1.16	0.55	-0.09	1.20	-1.09	-1.16
	MEAN TEMPERATURE (< 100 M)	1993-2004				-1.00	-0.82	-0.22	0.29	-0.96	0.80	1.81	1.45	-0.43	-0.16	-1.31	0.55	1.16
	MEAN SECTION TEMPERATURE	1993-2004				-0.81	-1.45	0.47	0.16	-0.74	0.54	1.88	1.42	-0.81	0.10	-0.96	0.19	1.36
	MEAN SALINITY < 100 M	1993-2004				0.99	-1.64	0.48	-0.68	-0.42	1.12	0.60	-1.64	1.12	-0.74	0.48	0.35	-0.55
	MEAN SECTION SALINITY	1993-2004				1.60	-2.00	0.97	-0.92	-0.47	0.43	1.15	-0.47	-0.11	-0.65	-0.02	0.52	0.07

Table A7.1: Temperature and salinity anomalies and ocean climate indices derived from data collected along standard sections from southern Labrador to southern Newfoundland. The anomalies are normalized with respect to their standard deviations over the indicated base period. See Figure A7.1 for locations of sections.

Annex 8: Icelandic waters, 2005 (Area 3)

Héðinn Valdimarsson, Steingrímur Jónsson, Marine Research Institute, Reykjavík

Iceland is at a meeting place of warm and cold currents (Figure A8.1), which meet in an area of submarine ridges (Greenland-Scotland Ridge, Reykjanes Ridge, Kolbeinsey Ridge), which form natural barriers against the main ocean currents. From the south flows the warm Irminger Current which is a branch of the North Atlantic Current (6–8°C), and from the north flow the cold East Greenland and East Icelandic Currents (−1 to 2°C).

Deep and bottom currents in the seas around Iceland are principally the overflow of cold water from the Nordic Seas and the Arctic Ocean over the submarine ridges into the North Atlantic.

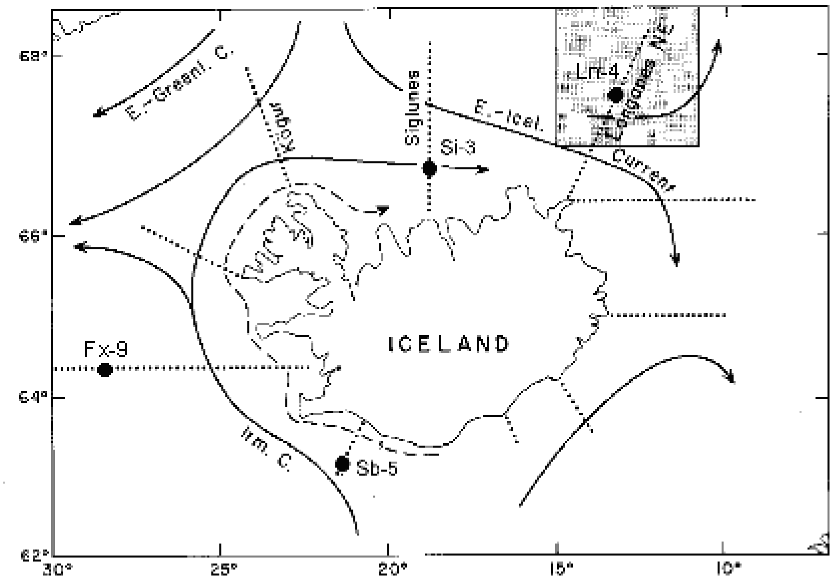


Figure A8.1: Main currents and location of standard hydro-biological sections in Icelandic waters. Selected areas and stations dealt with in this report are indicated.

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

In 2005 mean air temperature in the south (Reykjavik) and north (Akureyri) were above long time average (Figure A8.2a). Sea-ice was carried from the East Greenland Current into the waters north of Iceland late February and early Mars and extended east to north of Langanes in Northeast Iceland. This event was reflected in temperature and salinity og the surface layers in the north and east the rest of the year, but conditions seemed to have returned to pre-ice status February 2006.

However salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years (Figures A8.3.b, 5 and 7). The salinity in the East Icelandic Current in spring 2005 was about average but temperature was above long term mean (Figures A8.3a, A8.6 and A8.7).

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 (Figures A8.2b) and were then followed by the mild conditions for all seasons in 2003 and 2004. Slightly lower temperatures were seen in 2005. Recent years have been more comparable to the temperatures in the "warm period", 1920–1960, as can be seen from a newly compiled SST series from landstations in northern Iceland (Figure A8.8).

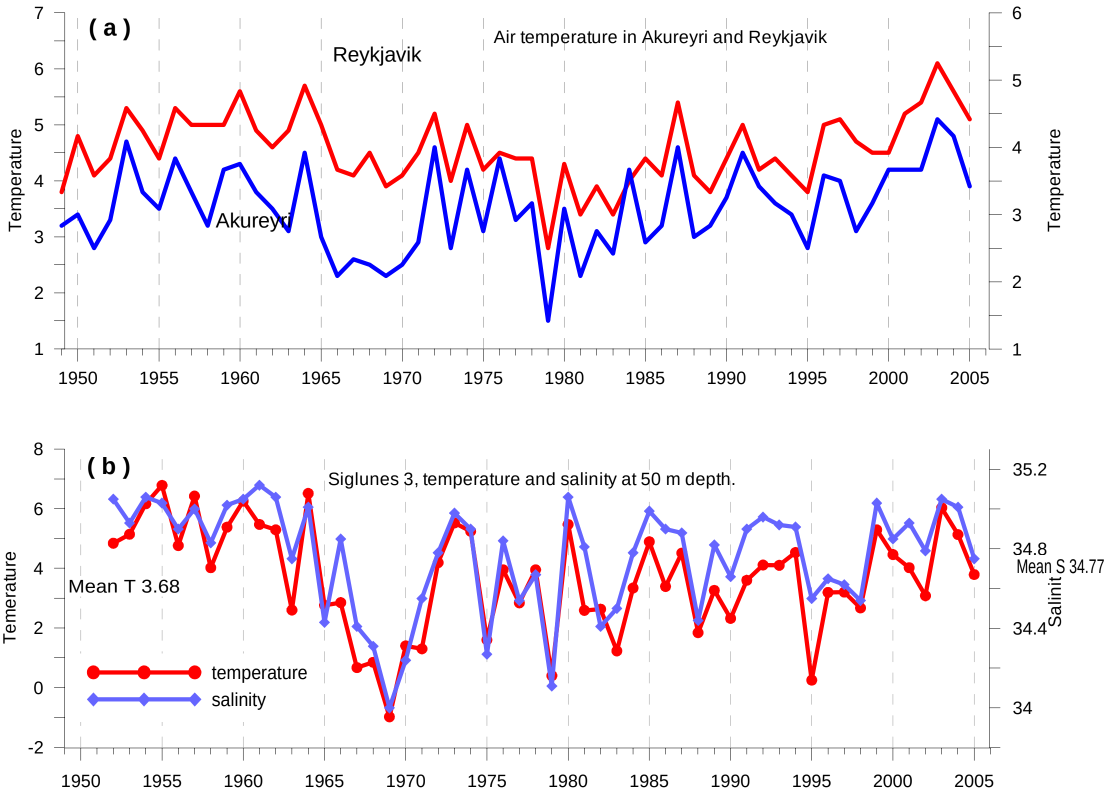


Figure A8.2: a) Mean annual air-temperatures in Reykjavík and Akureyri 1950–2005. b) Temperature and salinity at 50 m depth in spring at Station Si-3 in North Icelandic waters 1952–2005

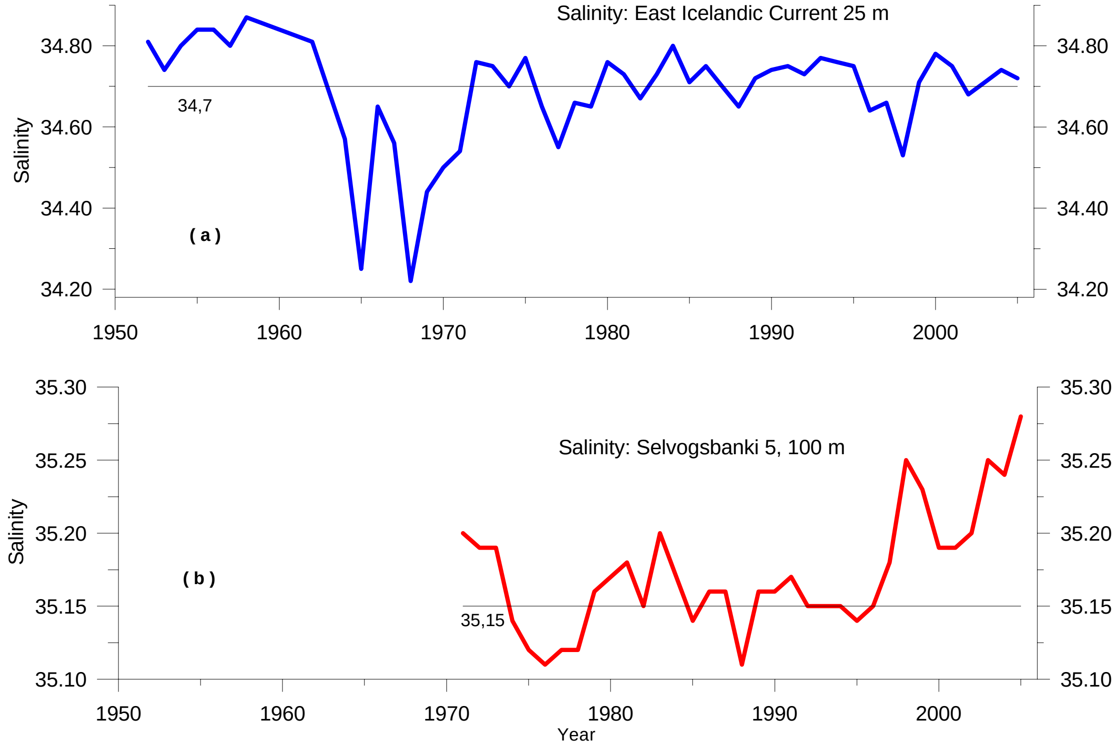


Figure A8.3: Salinity in spring at a) 100 m depth in the Irminger Current south of Iceland (Sb-5) 1971–2005. b) 25 m depth in the East Icelandic Current north-east of Iceland 1952–2005, mean from shaded area in Figure A8.1.

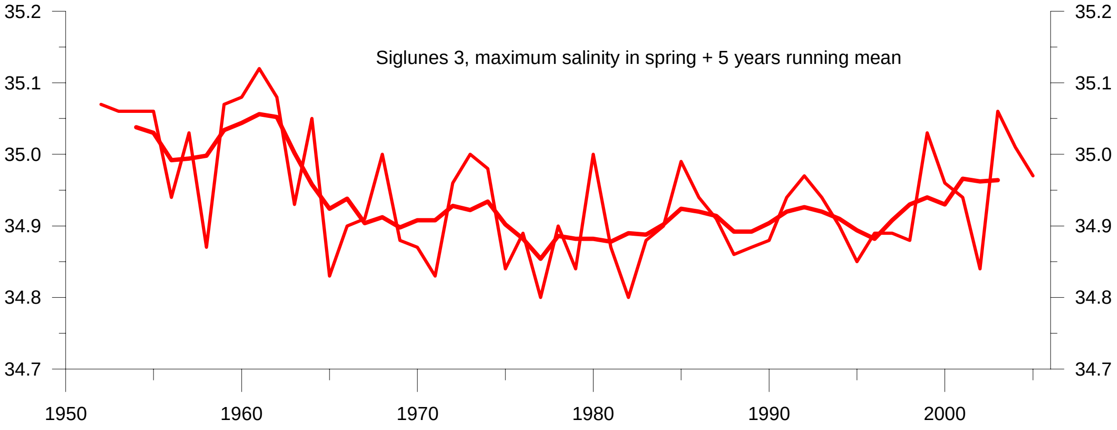


Figure A8.4: Maximum salinity in the upper 300 m in spring at station Si-3 in North Icelandic waters 1952–2005 and five years running mean.

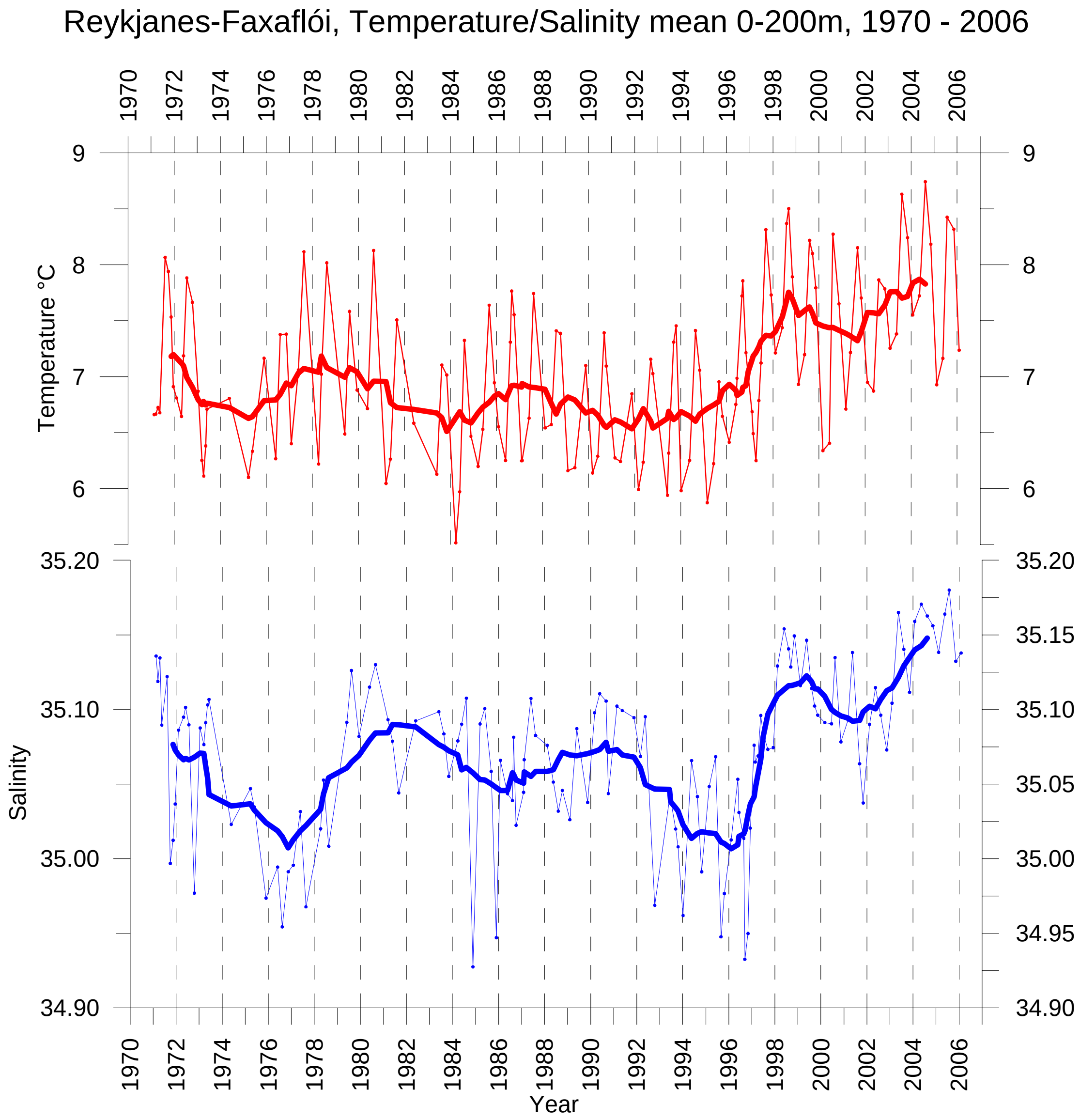


Figure A8.5: Mean temperature 0–200 m at the shelf break west of Iceland, 1971–2006. Combined data from stations RE8 (1971–1984) and FX9 (1984–2006), 20 nm apart. Thick line is approx. three years running mean.

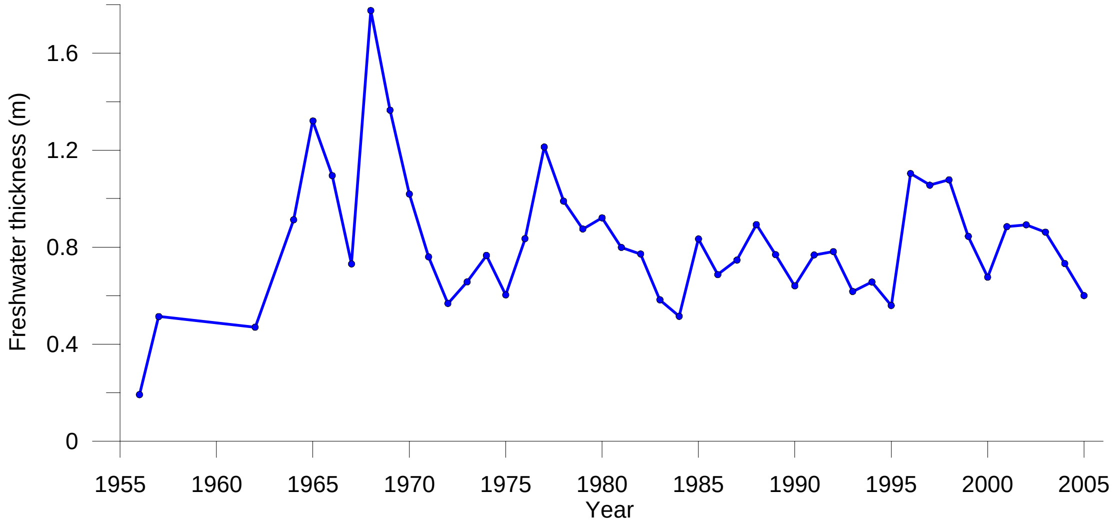


Figure A8.6: The fresh water thickness at Langanes NE 4 above 150 m, relative to salinity of 34.93 in May/June 1956–2003.

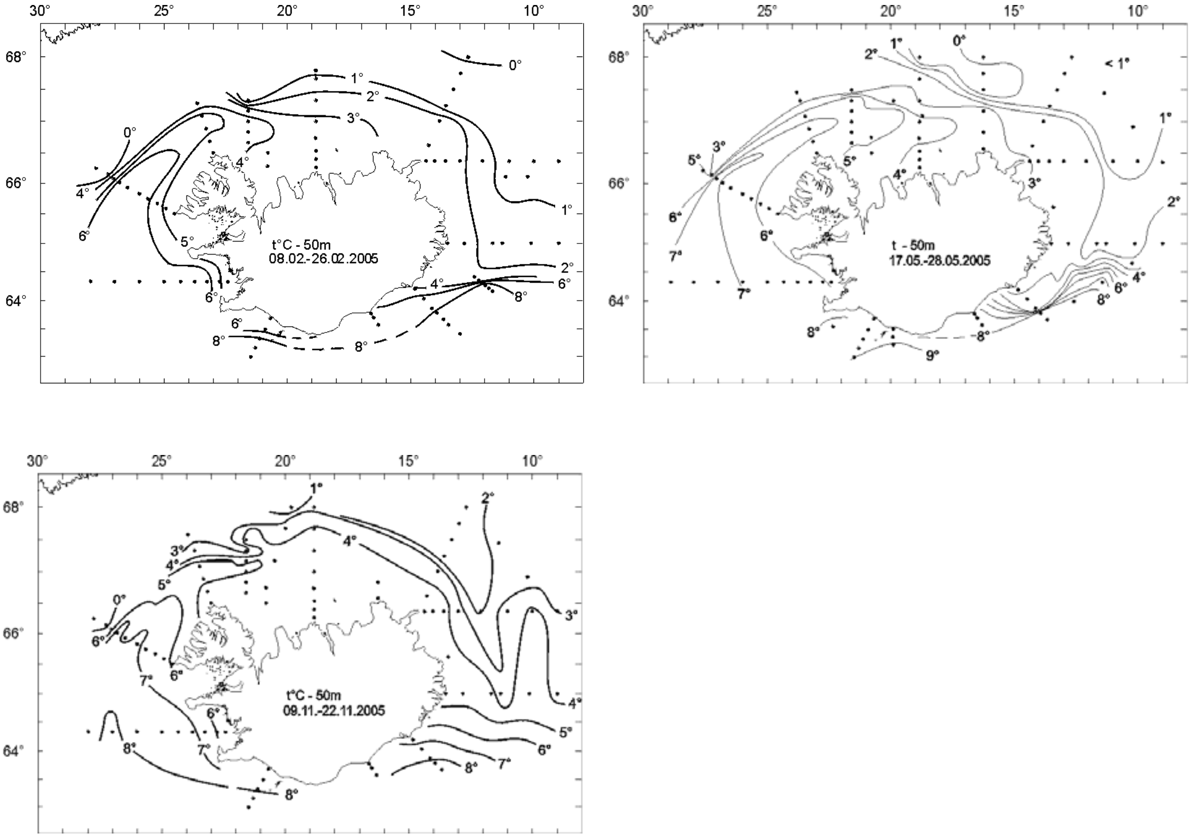


Figure A8.7: Temperature at 50 m depth in Icelandic waters in February, May and November 2005.

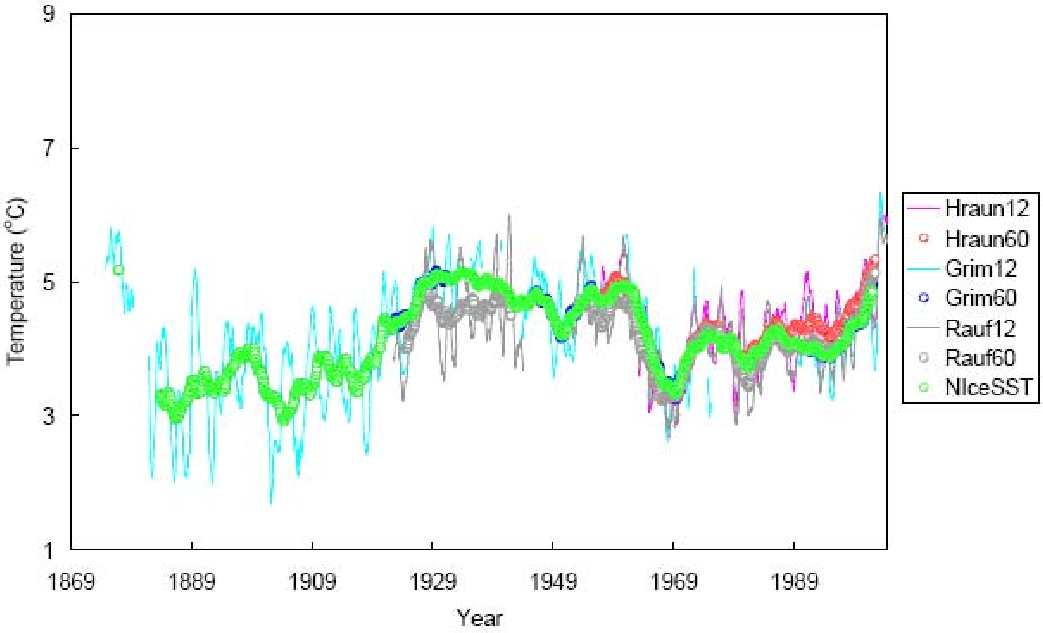


Figure A8.8: Newly compiled North-Icelandic SST series. NiceSST, 1870–2003.

Reference

Hanna, E., Jónsson, T., Olafsson, J., and Valdimarsson, H. Icelandic coastal sea-surface temperature records constructed: putting the pulse on air-sea-climate interactions in the northern North Atlantic. Part 1: Comparison with HadISST1 open ocean surface temperatures and preliminary analysis of long-term patterns and anomalies of SSTs around Iceland. Journal of Climate, in press.

Annex 9: Spanish Standard Sections, 2005 (Area 4)

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The Spanish Standard Sections cover the area of the shelf and shelf-break of the Eastern Atlantic and North Iberian Peninsula. Five sections are sampled monthly by the Instituto Español de Oceanografía, located in Santander (43.5ºN, 3.8ºW), which is the largest, two in Asturias (43.6ºN, 6.2ºW) and from year 2001 (43.6ºN, 5.6ºW), A Coruña (43.40ºN, 8.3ºW) and Vigo (42.1ºN, 9.0ºW). Additionally to the area covered by the Instituto Español de Oceanografía, AZTI collected oceanographic data at 43.30ºN, 2ºW (San Sebastián Section) over the continental shelf of the SE Bay of Biscay from year 1986 (Figure A9.1).

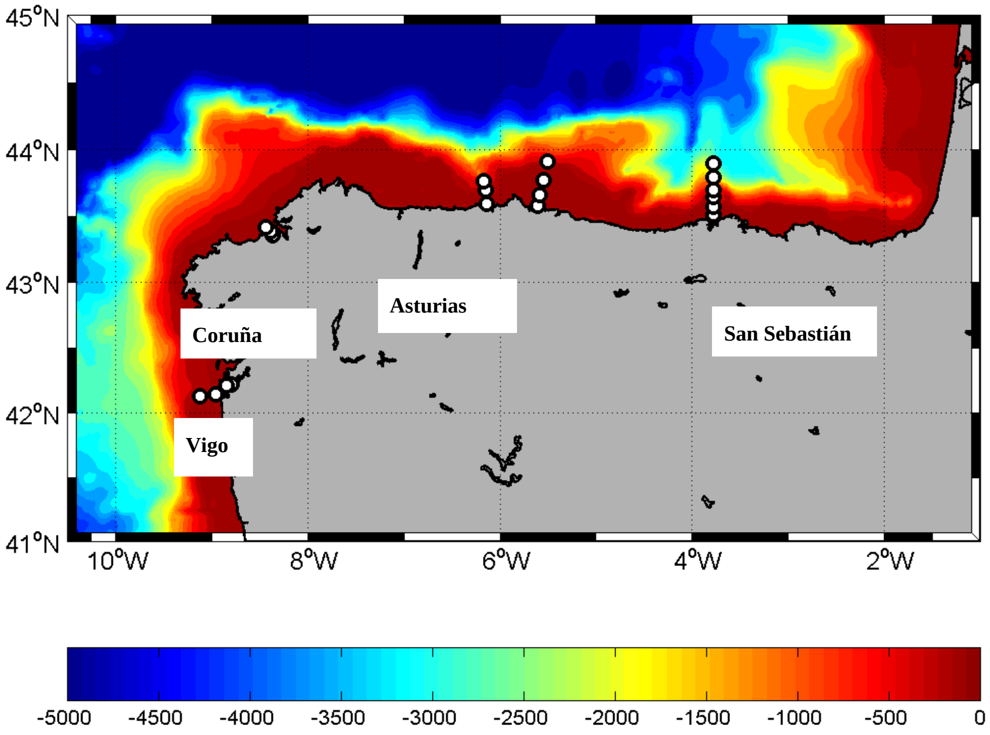


Figure A9.1: Spanish Standard Sections from the 'Instituto Español de Oceanografía' (Vigo, Coruña, Asturias, Santander and from AZTI (San Sebastián).

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

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

Meteorological Conditions

Atmospheric temperature

Meteorological conditions in the north of the Iberian Peninsula in 2005 (source: Centro Meteorológico Zonal de Cantabria y Asturias and Observatorio Meteorológico de Igeldo of the Instituto Nacional de Meteorología) indicate that, as a whole, it was an average year resulting from a cold winter and a warm summer. The annual mean air temperature over the southern Bay of Biscay during 2005 has remained at nearly the average, around 14.55°C, 0.1ºC over the 1961–2005 average. Figure A9.2 shows the plot of the annual means and total average. If we consider the last 25 years, 2005 was colder than the former year and the average atmospheric temperature in 2005 was noticeably lower than the average value of the last 25 years in Santander (0.4 ºC) as well as in San Sebastian (0.2°C). Figure A9.2 shows the plot of the annual means and total average.

Moreover, negative anomalies in the annual cycle appear in the winter (February), and in late autumn (November–December), being extraordinary important in February with anomaly (2.8ºC) under one standard deviation From March to October positive anomalous behaviour develops and in June and October with values over one standard deviation. The seasonal cycle amplitude was 12.7ºC from February (7.6ºC) to July (20.3ºC) and this large amplitude mainly due to the cold February. 2005 seasonal cycle amplitude behaviour was not as extreme as the maximum detected in 2003 with 13.2ºC of January (9.6)–August (22.8) and mainly due to the very warm August 2003. Figure A9.3a shows the monthly mean air temperatures with the standard deviation in Santander ("Instituto Nacional de Meteorología").

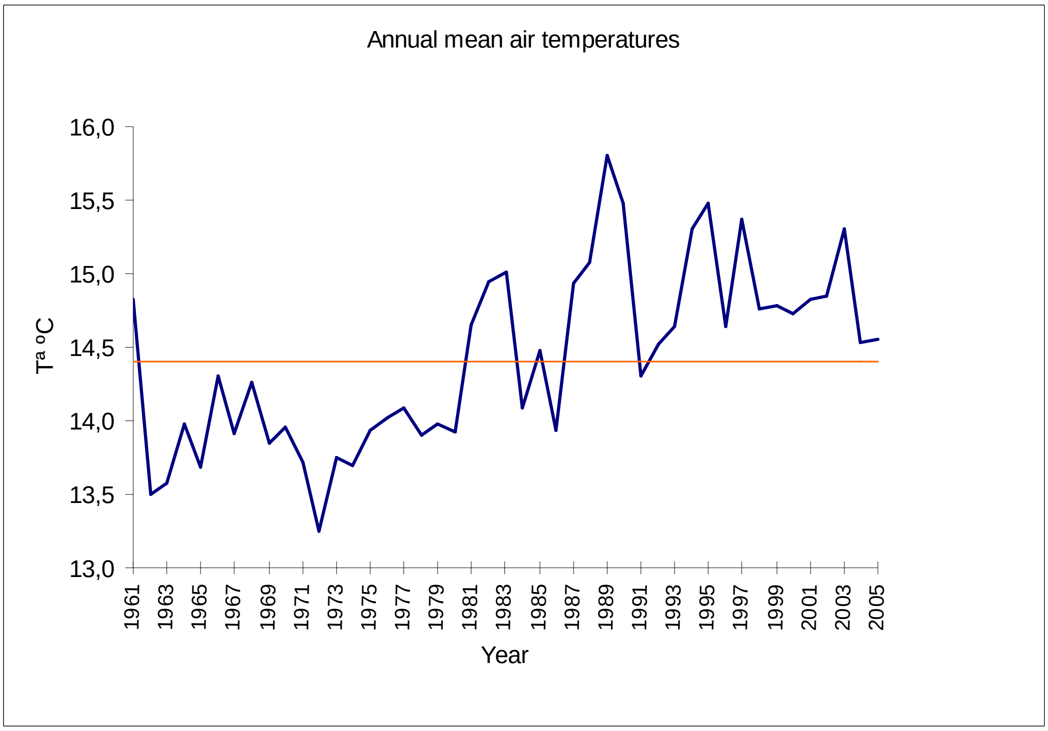


Figure A9.2: Annual mean temperatures in Santander (43.5ºN, 3.8ºW). Courtesy of the 'Instituto Nacional de Meteorología'.

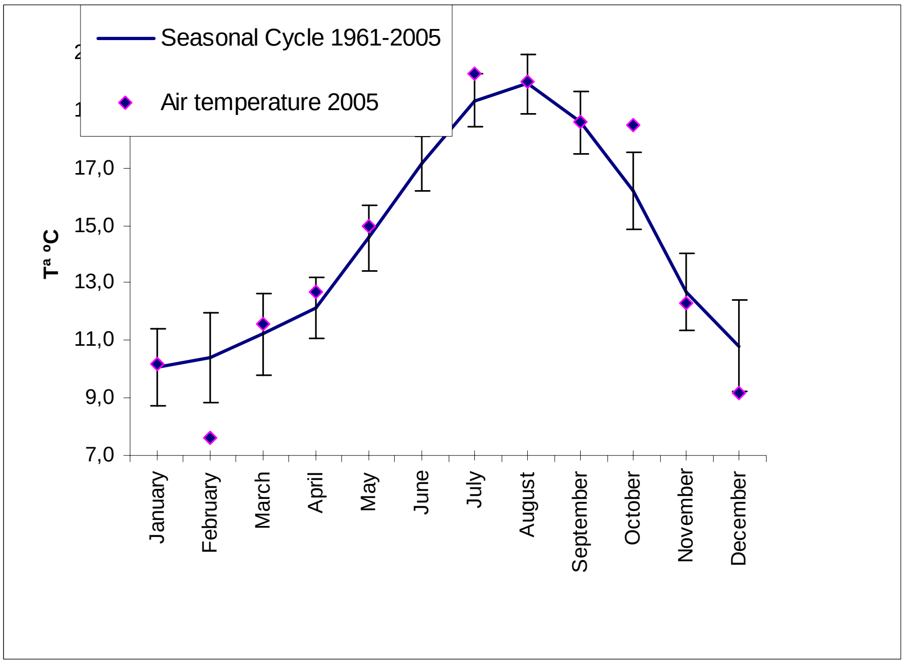


Figure A9.3a: Air temperatures in 2004 in Santander (43.5ºN, 3.8ºW) and mean value (1961–2005) and standard deviation. Courtesy of the 'Instituto Nacional de Meteorología'

Meteorological conditions in the SE Bay of Biscay in 2005 (Observatorio Meteorológico de Igeldo, San Sebastián, Instituto Nacional de Meteorología) are characterised by a cold winter (with the exception of March), a relatively warm spring and summer (around the mean+standard deviation for the period 1986–2004 (Figure A9.3b), and a cold autumn, excluding October.

The peculiarities of the air temperature in 2005 can be observed in the context of the monthly mean temperatures of the period (1986–2005) and the evolution of the accumulated anomalies (Figure A9.4).

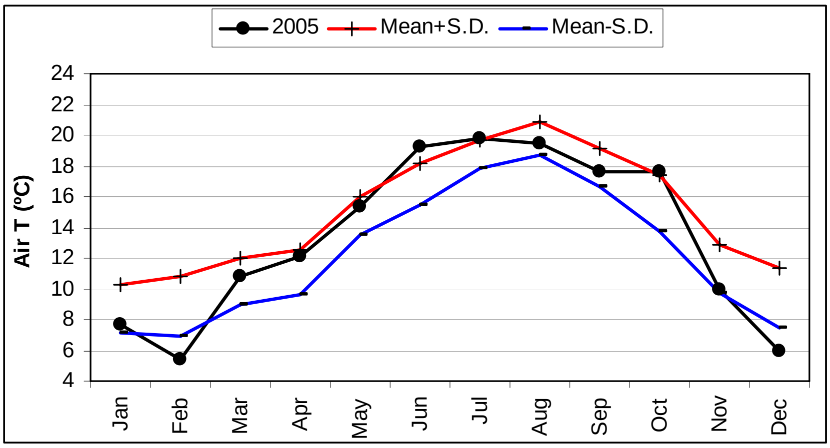


Figure A9.3b: Monthly mean atmospheric temperatures (°C) in San Sebastián (43°18.5′N, 02°2.37′W) in 2004 compared with the mean ± standard deviation for the period 1986–2005. Courtesy of the 'Instituto Nacional de Meteorología'.

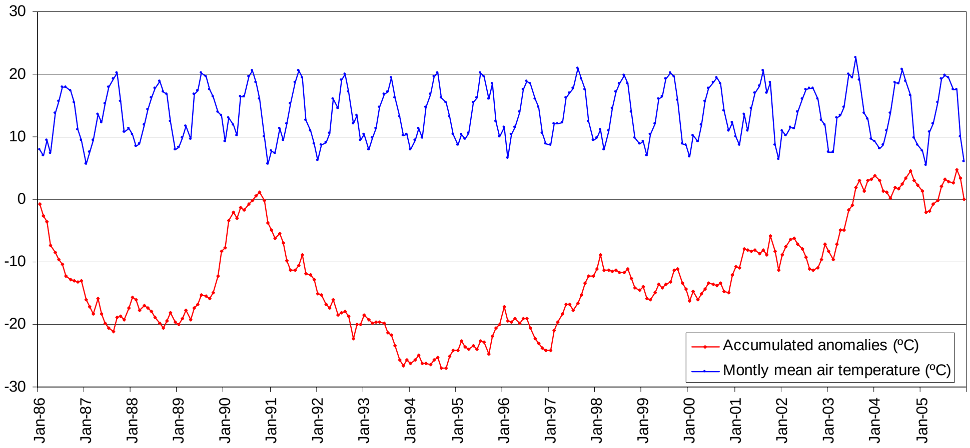


Figure A9.4: Monthly mean temperatures in San Sebastián (43°18.5′N, 02°2.37′W) in 1986-2005 and accumulated anomalies. Data Courtesy of the 'Instituto Nacional de Meteorología'.

Precipitation and evaporation

In Santander, 2005 was a drier year on the historical series (180 ml less than the annual mean). Only February and November were over the mean monthly value. Similarly, in San Sebastián the winter, spring and summer of 2005 are characterised by dry weather (excluding April and September); wet weather is prevalent in autumn 2005, with the exception of October (Figure A9.5). So, with regard to water balance, the year 2005 within the context of the previous years, 2005 year shows a decrease in the precipitation, in terms of accumulated anomalies (Figure A9.6). In spite of the fact that the annual mean precipitation in 2005 (113 mm) was around the 1986–2005 averaged precipitation (122 mm), mainly due to the precipitation in autumn, the precipitation minus evaporation balance shows that 2005 was characterised by dry weather, in terms of water balance (Figure A9.7).

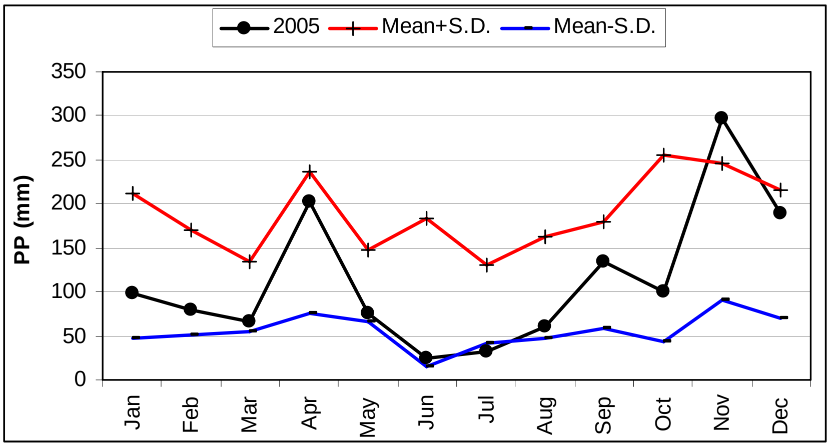


Figure A9.5: Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 2005 compared with the mean ± standard deviation for the period 1986–2005. Data Courtesy of the ‘Instituto Nacional de Meteorología’.

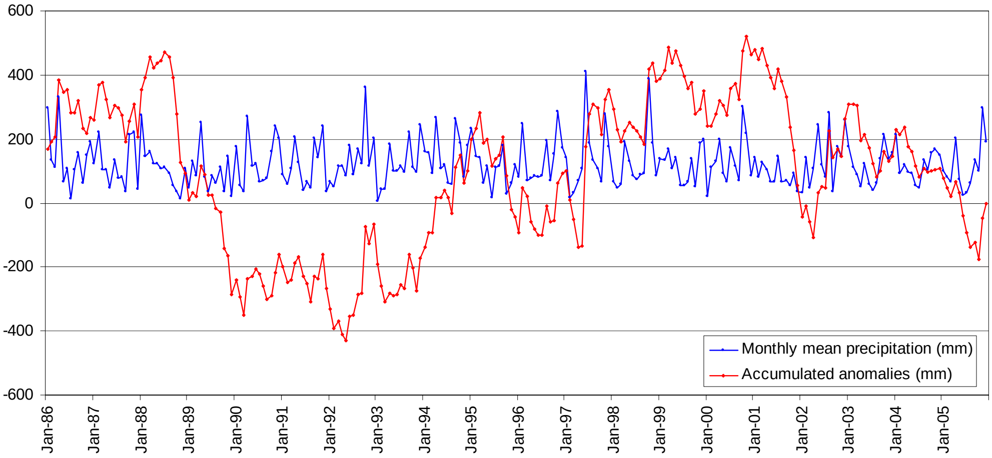


Figure A9.6: Monthly precipitation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 1986–2005 and accumulated anomalies. Data Courtesy of the ‘Instituto Nacional de Meteorología’.

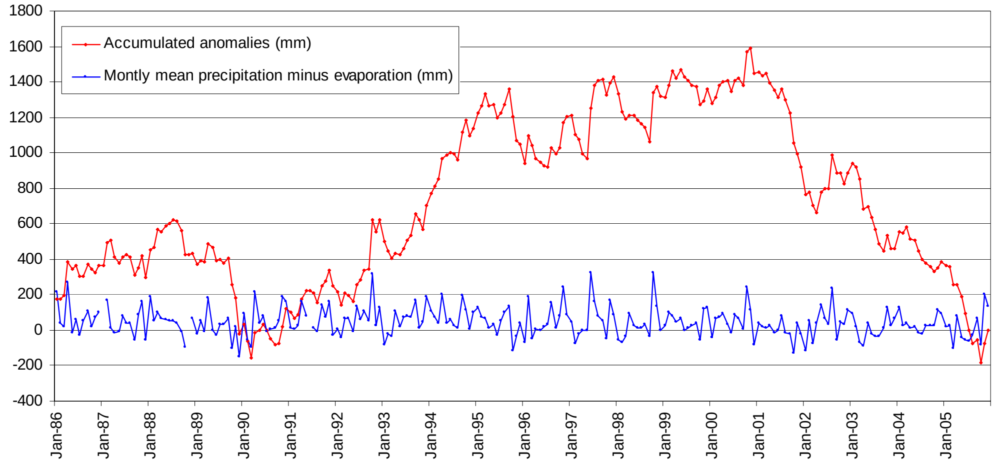


Figure A9.7: Monthly precipitation minus evaporation (mm) in San Sebastián (43°18.5′N 02°2.37′W) in 1986–2005 and accumulated anomalies. Data Courtesy of the 'Instituto Nacional de Meteorología'.

Continental runoff

The Gironde river runoff values represent well the water inputs of continental origin into the SE Bay of Biscay. In a quarterly basis, the Gironde river flow correlates significantly with the precipitation in San Sebastián as well as with the flow of the Adour river and the other small Cantabrian rivers incoming into the SE Bay of Biscay (Table A9.1).

Table A9.1: Correlation matrix for the Gironde river flow, precipitation in San Sebastián (PP) and precipitation minus evaporation balance in San Sebastián (PP-EV) on a quarterly basis.

	FLOW WINTER	FLOW SPRING	FLOW SUMMER	FLOW AUTUMN
PP WINTER	0.74***			
PP-EV WINTER	0.71***			
PP SPRING		NS		
PP-EV SPRING		NS		
PP SUMMER			0.64**	
PP-EV SUMMER			0.60*	
PP AUTUMN				0.69***
PP-EV AUTUMN				0.70***

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

Gironde river flow was low or very low along 2005. Even in April and May, when the spring thaw contributes to the maintenance of the river flow and some increase of the local precipitations was recorded, the river flow stays below the respective monthly average. In a similar way, the response to the increase in precipitation in late summer and during autumn was also low (Figures A9.5 and A9.8).

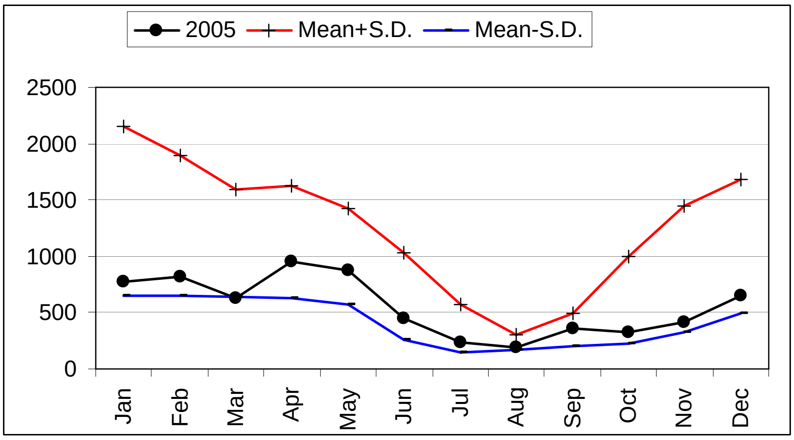


Figure A9.8: Monthly mean flow ($m^3 s^{-1}$) of the Gironde river in 2005 compared with the mean ± standard deviation for the period 1986–2005. Data Courtesy of the 'Bordeaux Harbour Authority'.

The peculiarities of the Gironde river flow in 2005 can be observed in the context of the monthly mean values of the reference period (1986–2005) and the evolution of the accumulated anomalies (Figure A9.9).

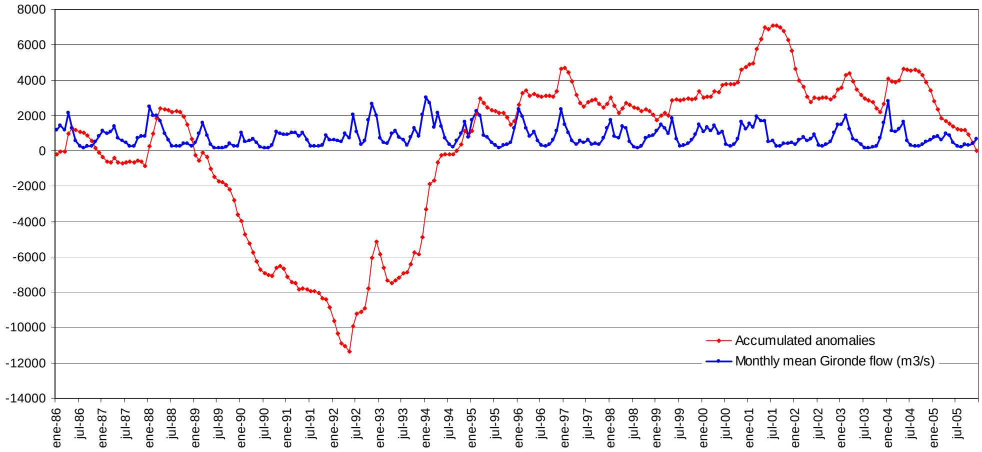


Figure A9.9: Monthly mean flow of the Gironde river ($m^3 s^{-1}$) in 1986–2005 period and accumulated anomalies. Data Courtesy of the 'Bordeaux Harbour Authority'.

Hydrography

Coastal and shelf waters

In order to obtain a first approximation of the hydrographic conditions in 2005, a TS diagram representing the waters over the continental shelf of the Bay of Biscay (43°30′N 02°00′W) is shown in Figure A9.10.

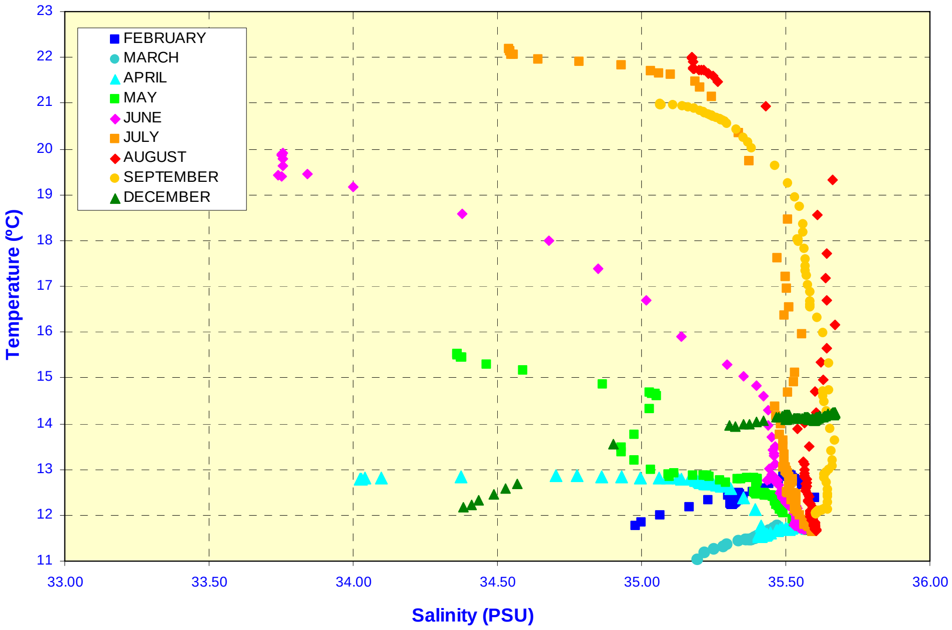


Figure A9.10. TS diagram of the waters over the continental shelf of the SE Bay of Biscay (43°30′N 02°00′W) in 2005.

The response of temperature and salinity of the upper layers to the meteorological factors described above is clearly observable in Figure A9.10. As a result of the low air temperatures in January and February, thermal content of the water column was at a minimum in March. Moreover, in despite of relatively low precipitation and river runoff, the TS diagram is characterised by a thermal inversion in February and March; this is due to the presence of very cold water of continental origin. April is characterised by high precipitation, contributing to the development of haline stratification as well as to the beginning of the spring warming. Comparisons in deepest levels of the water column suggest a very homogeneous and deep winter mixed layer.

Thermal stratification develops between May and September. Moreover, more or less extended haline stratification is present throughout almost all the year. The TS diagram shows also the variability in the temperature and salinity values and in the T-S relationships for the waters located below the seasonal thermocline.

Figure A9.11 shows the evolution of the monthly averaged sea surface temperature (SST) in 2005 (on the basis of a time-series obtained from the Aquarium of the Sociedad Oceanográfica de Gipuzkoa). In general, warm sea surface temperatures can be observed excluding February to April period and December. The annual averaged SST in San Sebastián in 2005 (16.41°C) was higher than the 1986–2005 averaged temperature (16.08°C). Nonetheless, the very low temperatures of winter and early spring can be considered as the most significant feature of the annual thermal cycle; this is due to the relation with the high extent of the winter mixed layer (around 250 m in the SE Bay of Biscay)

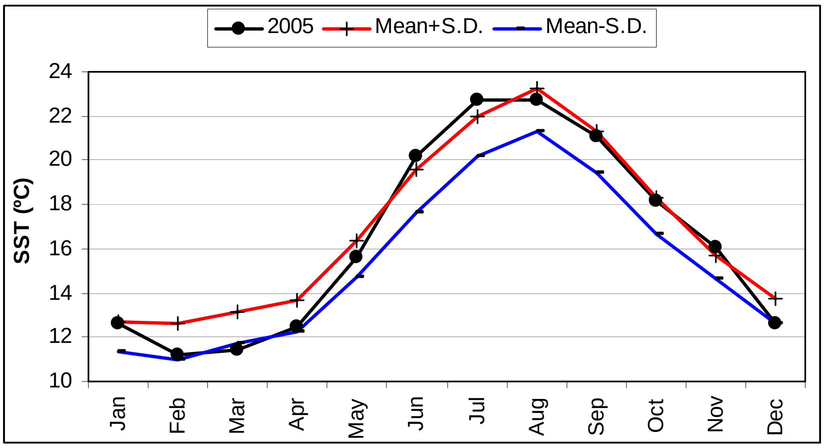


Figure A9.11: Monthly averaged sea surface temperature (°C) in San Sebastián (43°20′N 02°00′W) in 2005 in comparison with the mean ± standard deviation for the period 1986–2005 period. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.

The peculiarities of the SST in 2005 can be observed within the context of the monthly mean temperatures of the reference period (1986–2005) and the evolution of the accumulated anomalies (Figure A9.12).

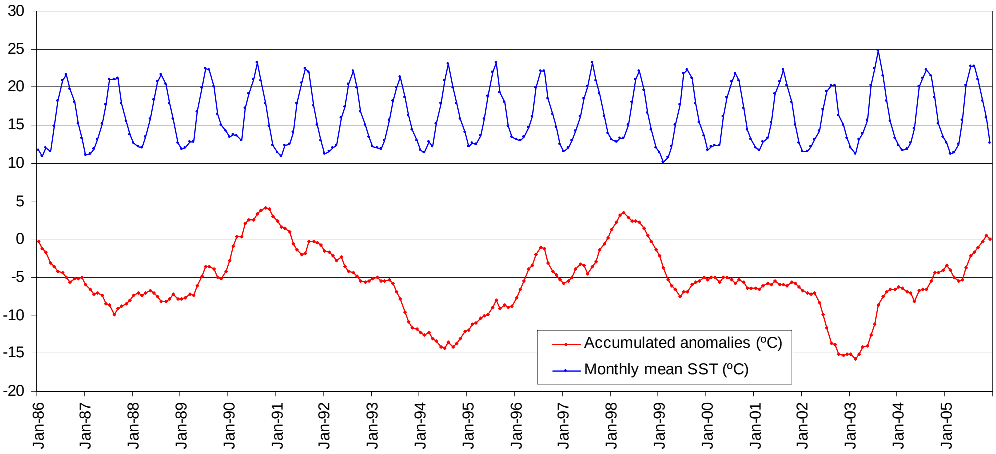


Figure A9.12: Monthly averaged SST (°C) in San Sebastián (43°20′N 02°00′W) during the 1986-2005 period, together with accumulated anomalies. Data Courtesy of the 'Sociedad Oceanográfica de Gipuzkoa'.

In a similar way, the evolution of the heat content (in terms of mean temperature) and the salt content (in terms of mean salinity minus 35) of the water column (100 m) over the continental shelf of the SE Bay of Biscay can be observed in Figures A9.13 and A9.14, respectively.

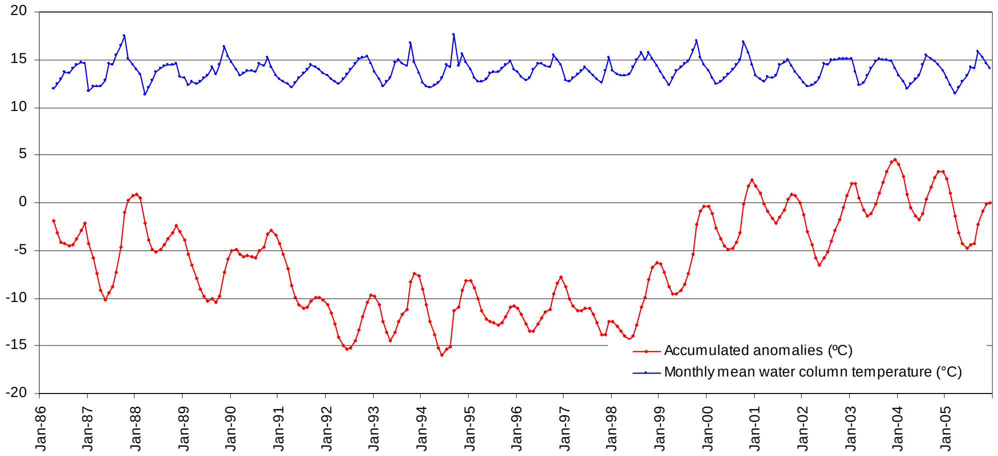


Figure A9.13: Monthly averaged water column temperature (°C) in San Sebastián (43°30′N 02°00′W) in the period 1986–2005, together with accumulated anomalies.

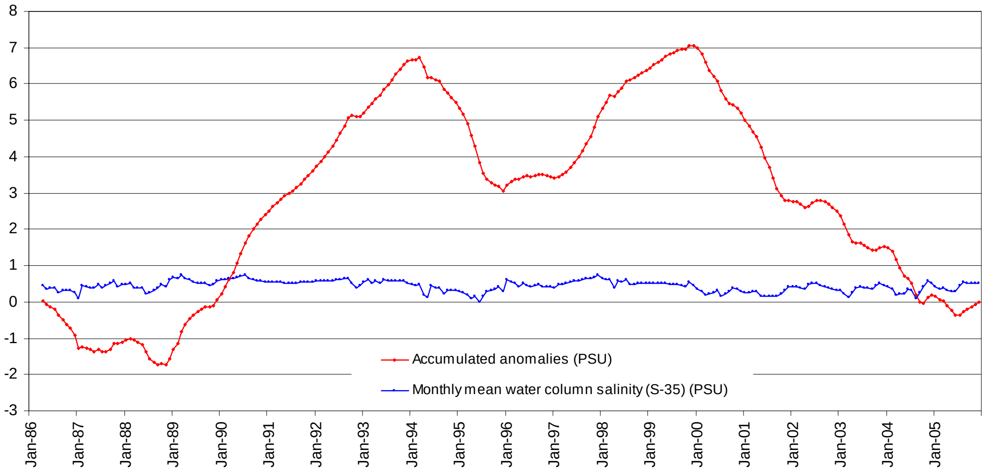


Figure A9.14: Monthly averaged corrected salinity (S-35) in 100 m water column in San Sebastián (43°30′N 02°00′W) in the period 1986–2005, together with accumulated anomalies.

Aspects related to the hydro-meteorological conditions during 2005, over the SE Bay of Biscay, are listed in Table A9.2. In spite of the low air temperatures in December 2004 and January 2005, the SST was higher than the mean SST for the period 1986–2005 (Figure A9.11) due to the vertical mixing, with relatively warm sub-surface waters. This pattern changed from February to April, as a result of winter cooling and the freshwater inputs. Thus, low SSS in April was coincident with the observed high precipitation events (see Figure A9.5). Despite the increase in air temperature in March and April, the warming of the sea surface and the water column began to be evident in May. The TS diagram shows that salinity was the main factor related to the variability of the water column, from February to May. Thermal and haline stratification are prevalent in June, due to the warming and freshwater inputs, respectively. Thermal stratification is predominant from July to September coinciding with relatively high air temperatures in summer. December is characterised by a thermal inversion, related to high freshwater inputs.

In the SE Bay of Biscay, the 14°C isotherm represents the mean annual temperature and also the lower layer of the thermocline, during the spring and summer stratification. In May, the 14°C isotherm depth was 15 m and, from June to September, this layer was placed at around 50 m. The intense fluctuations of the 14°C isotherm depth throughout the summer season, as well as the sequence of the TS values at 50 m water depth and within the bottom layers, indicates a dominance of downwelling processes. In December, the breakdown of stratification, downwelling and vertical mixing close, as usual, the annual cycle.

In any case, the thermal balance in the annual cycle of the year 2005 shows two different patterns. The SST signal indicates warming, following the trends of the previous years. Conversely, the average temperature of the water column shows some cooling as a consequence of the increase of the winter mixed layer depth with cold winter temperatures as well as a consequence of relatively narrow warm layer during the stratified season (Figures A9.12 and A9.13).

Table A9.2: Hydro-meteorological data in the shelf waters of San Sebastián (43°30′N 02°00′W) in 2005. Mean temperature and salinity calculated for 100 m water column.

2005	T (°C)	PP (mm)	Gironde flow (m3 s-1)	SST (ºC)	SSS (PSU)	Mean temp. (ºC)	Mean salinity (PSU)	Bottom temp. (ºC)	Bottom salinity (PSU)	14 ºC isotherm depth (m)
January	7.70	99	779	12.63		13.09	35.419			
February	5.40	80	821	11.23	35.274	12.37	35.337	12.37	35.603	T<14
March	10.80	66	629	11.41	35.188	11.50	35.390			T<14
April	12.10	202	951	12.50	34.024	12.07	35.324	11.73	35.577	T<14
May	15.40	76	872	15.63	34.361	12.75	35.303	11.68	35.586	15
June	19.20	24	446	20.17	33.755	13.28	35.303	11.69	35.568	19
July	19.80	33	240	22.74	34.542	14.24	35.441	11.63	35.594	29
August	19.50	61	189	22.73	35.174	14.04	35.538	11.67	35.606	27
September	17.60	134	359	21.09	35.066	15.81	35.505	12.03	35.604	50
October	17.60	100	329	18.16		15.22	35.504			
November	10.00	296	415	16.04		14.63	35.503			
December	6.00	190	648	12.65	34.382	14.03	35.501	14.19	35.666	12

In similar way, contours of temperature and salinity (over the shelf, 100 m depth) in the Santander section are shown in Figures A9.15a and 15b. The seasonal cycle in temperature is clearly marked in the upper layers. Stratification develops between April-May and October-November, and during the rest of the period the water column is mixed. Summer stratification in 2005 presented a shallower picture but with a long period and not too warm comparing with the previous years. Bottom cooling seems to indicate some upwelling episodes. Salinity contours show high salinity at the beginning of the winter due to the poleward current and in spring and autumn due to seasonal upwelling events. In summer low salinity appeared in the upper layers due to the advection from the east of warm surface water from river discharges in the corner of the Bay of Biscay. During 2005 the advection and river overflow was very low compared with the previous years, mainly 2001 and 1995. High salinity values appear over most of the shelf along the year and mainly in winter and autumn.

Upwelling events detected by low SST in satellite measurements (www.teledeteccionoceanografica-ieo.net/afloramientos) indicated that during 2005 some events occurred mainly in June (from 8 to 11, and the 18) with SST as low as 12.5ºC (Figure A9.16). During July and August light indications appear with SST of 14 and 15.5ºC in the Santander Section. This upwelling episodes occurred after some years without any as happened during 2003, that upwelling low SST signal never reach Santander and during 2004 when in August the signal reached 40 miles west of Santander.

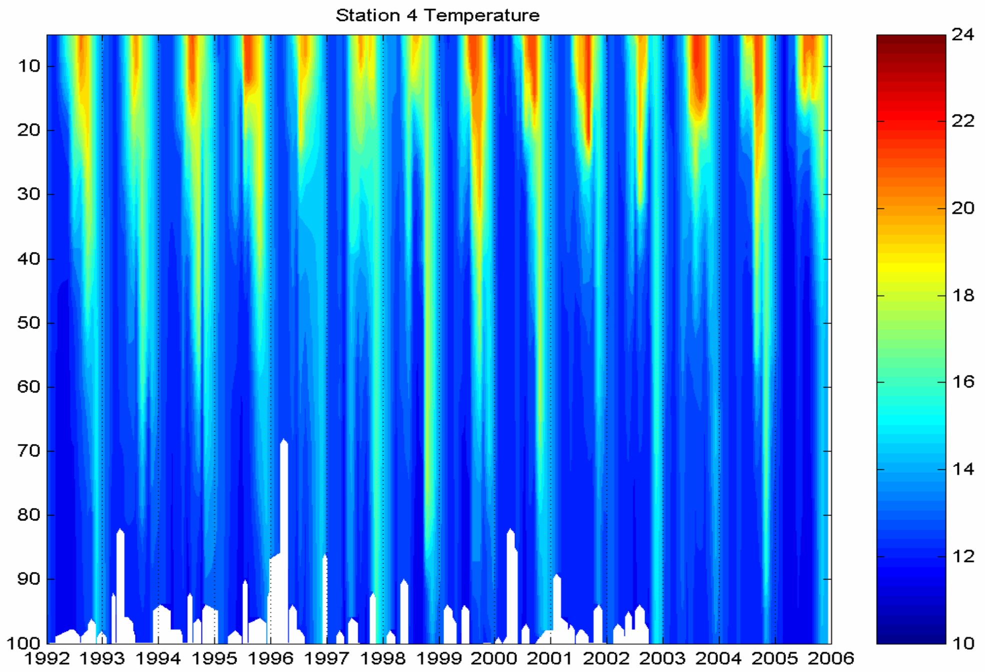


Figure A9.15a: Temperature evolution at Santander station 4 (shelf).

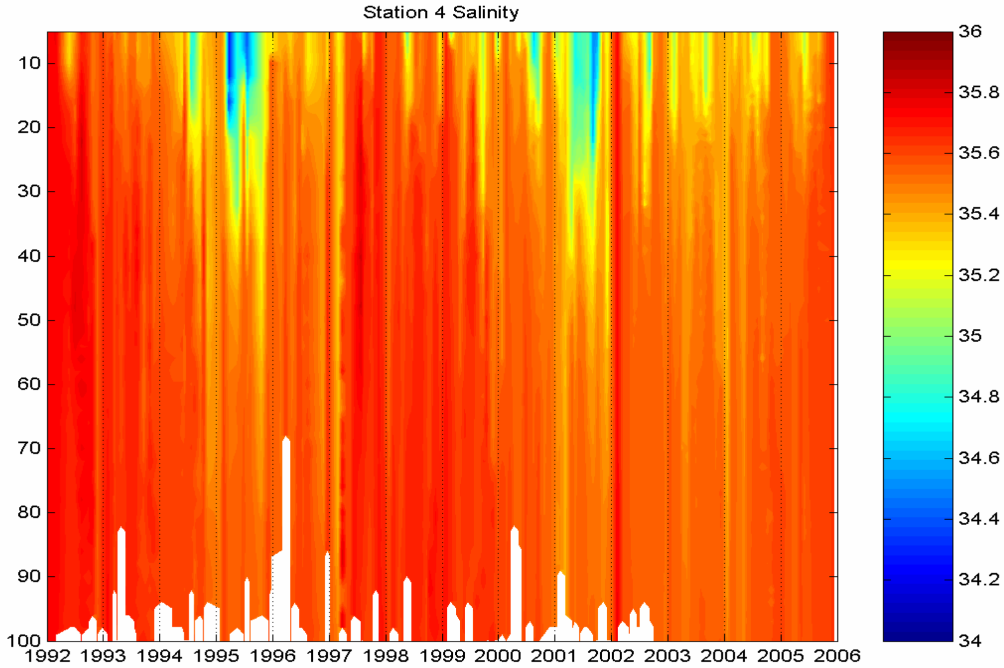


Figure A9.15b: Salinity evolution at Santander station 4 (shelf).

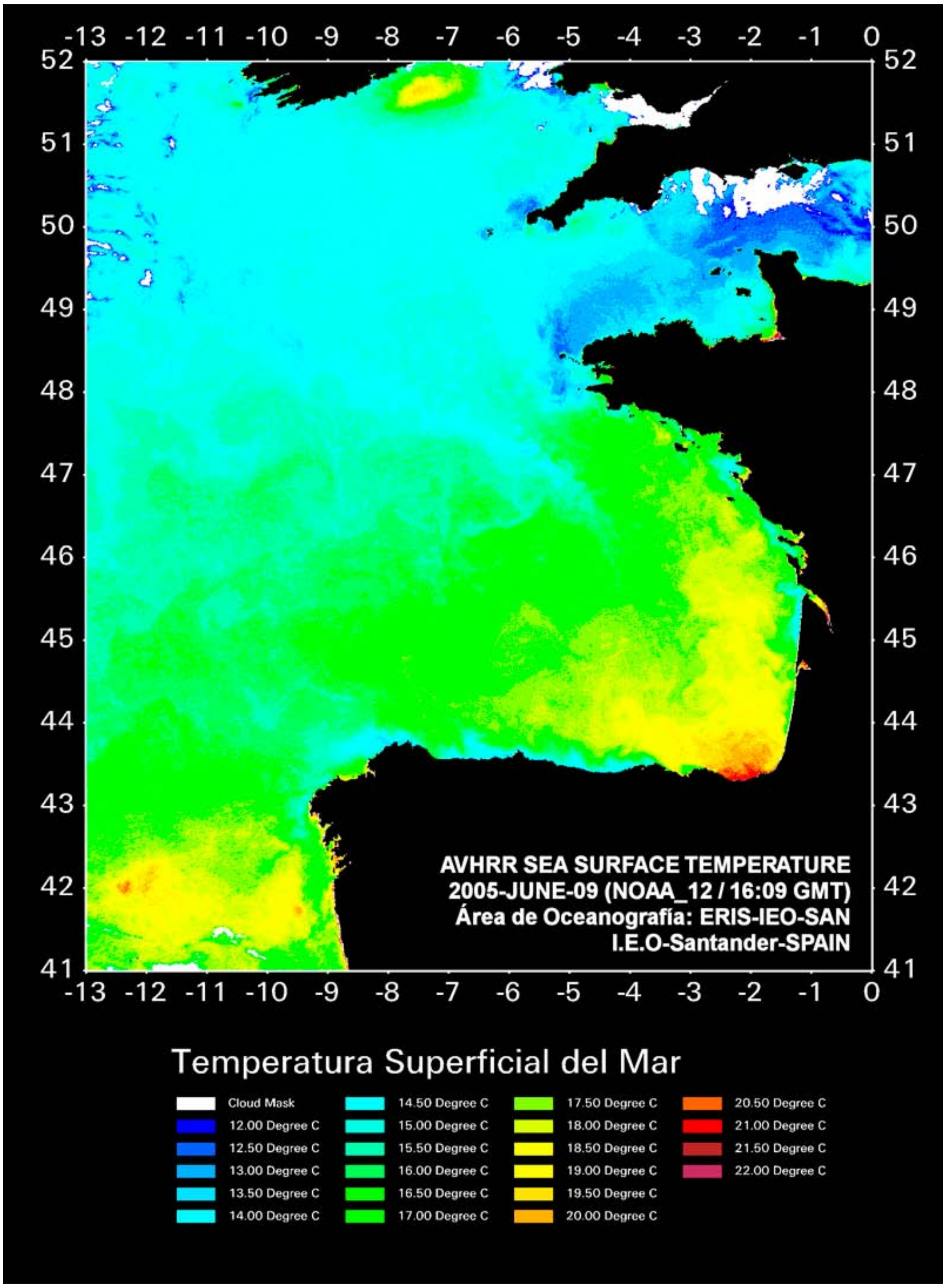


Figure A9.16: Sea Surface Temperature of the Eastern North Atlantic on June 9. Upwelling condition is showed by low temperature around the N/NW of the Iberian Peninsula, reaching 3º 47'W, position of the Santander Standard Section.

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

Contours of temperature and salinity and fluorescence over the shelf (94 m depth) in the Vigo section from 1994 to 2005 are presented in Figure A9.17. In summer cold waters were present at depth due to upwelling, while warm waters were at the surface in summer due to insolation. In autumn-winter there is a coastal poleward surface current that transports warm water. The year 2005 with respect of the water thermohaline seasonal characteristics may be classified as normal, in the middle of the time-series range; regarding the fluorescence, related to chlorophyll, 2005 seems to be more productive that the previous years. The end of 2005 was characterised by cold northerly winds unfavourable to poleward current progression and accordingly the coastal waters remain cold.

Salinity contours still continue show above normal values due to the drought year. In shallow shelf waters no clear tendencies are observed because coastal processes induce great variability, but along the time-series we observe that at 80 m, in winter and summer conditions from 1994 to 2005 a salinity decrease (0.05) and also the temperature in summer (0.25ºC), but increasing 0.25ºC in winter. At 20 m in winter the characteristics have no trend and in summer both decrease lightly. These tendencies are related mainly with the variability of the poleward current strength in winter and the upwelling in summer. At local scale, seems that the coastal processes in the west of Iberian peninsula have more influence that the general warming trend observed in some places of the eastern Atlantic.

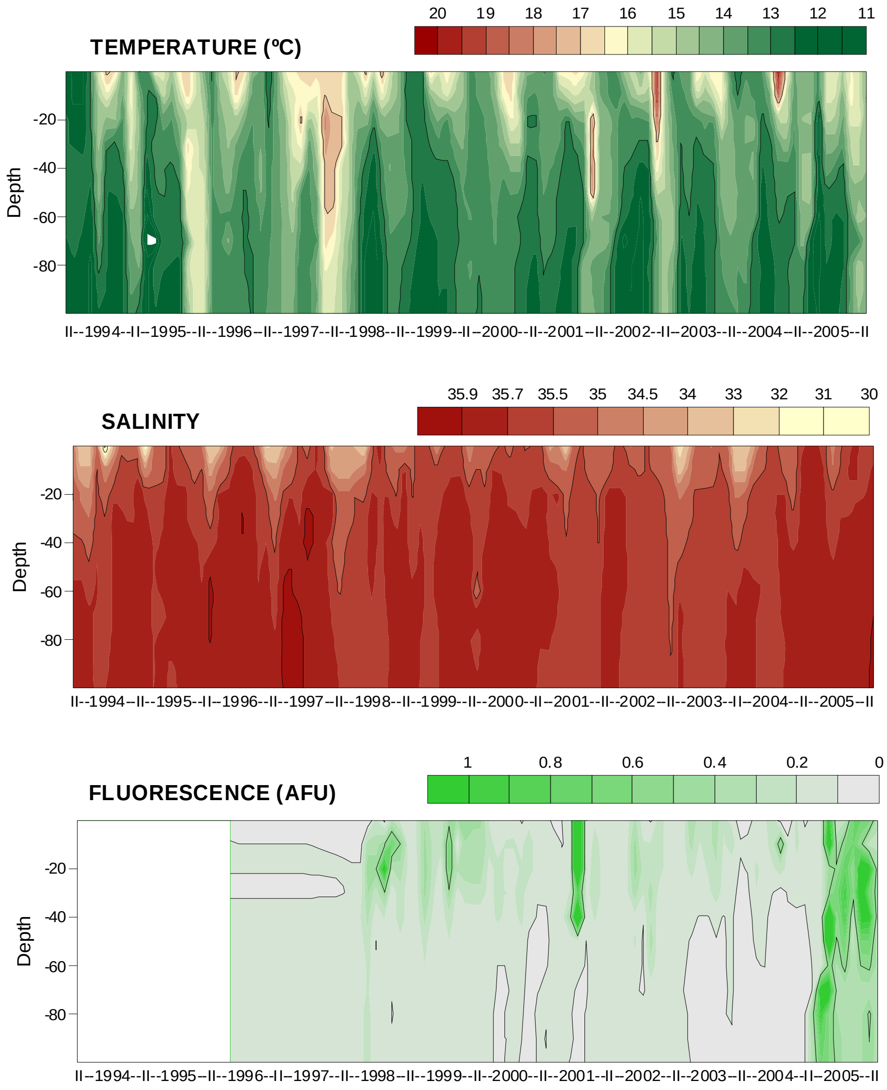


Figure A9.17 a, b and c): Seawater evolution at Vigo (42.1ºN, 9.0ºW) station of Temperature, salinity and fluorescence.

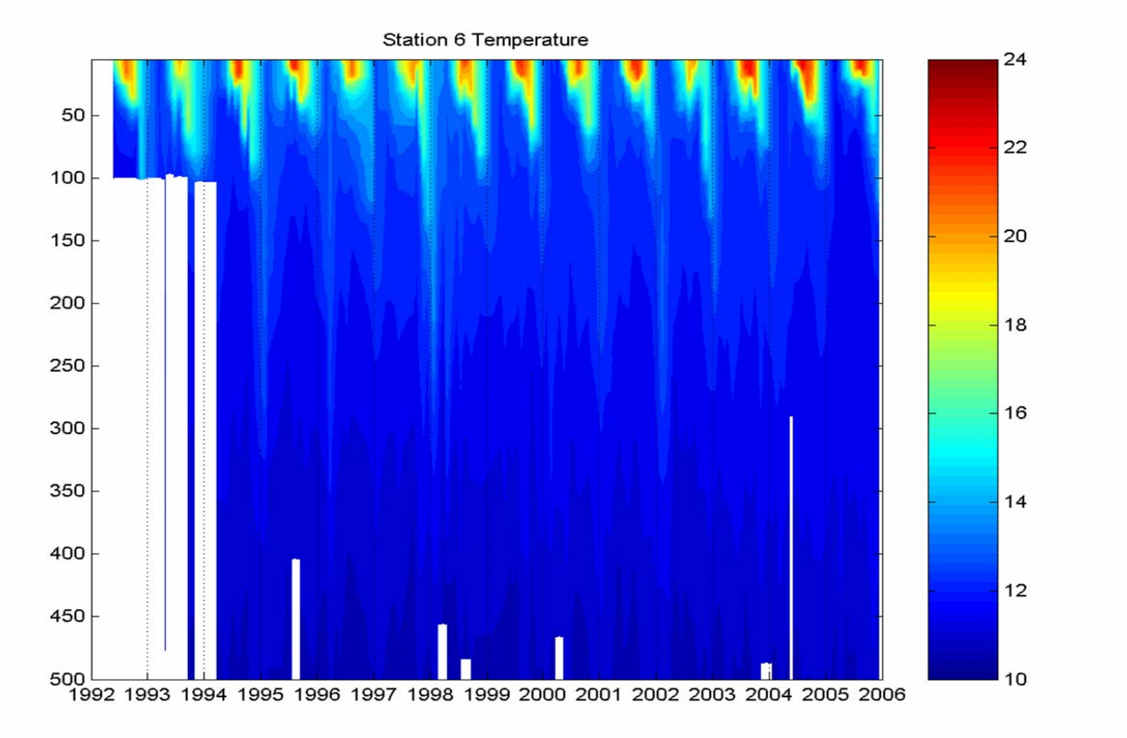


Figure A9.18a: Temperature evolution at Santander station 6 (shelf-break).

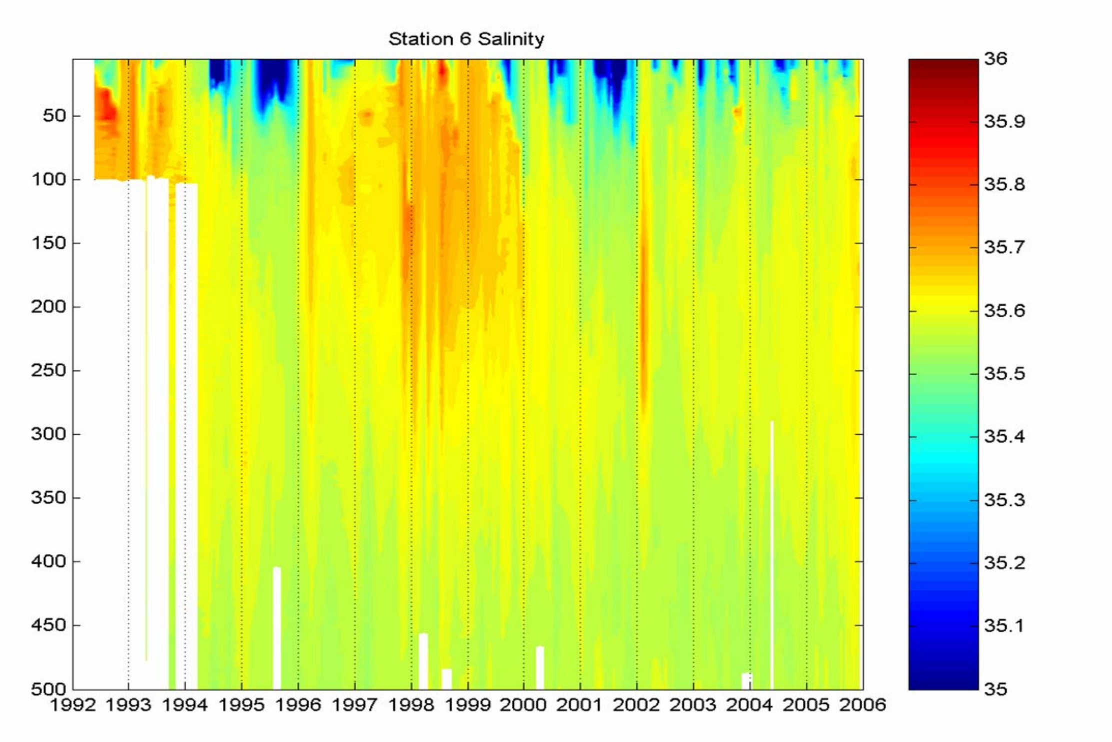


Figure A9.18b: Salinity evolution at Santander station 6 (shelf-break).

Offshore and Slope waters

Contours of temperature and salinity over the shelf-break (600 m depth) in the Santander section are presented in Figure A9.17. During the first period (1992–1995) only upper layers were sampled. As happened over the shelf, the period of low salinity in the upper waters (1994–1995 and 2000–2001) was reduced to a greater extent during 2002, 2003 and 2004 and nearly disappearing in 2005.

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, decreased in spring but seemed to increase again at the end of the year 2005 maybe indicating 2006 as an Iberian Poleward Current reaching the inner Cantabrian Sea. Also in temperature this warm water mass is detected until 300m depths. Stratification develops between April–May and October–November, mainly reaching 100 m depth, but during 2005 this stratification seems to be shallow as much as 60m and reaching twice in autumn.

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

Fitting the temperature signal by two harmonic terms plus a linear trend, we can reproduce the signal approximately (Figure A9.19). Taking this into account, we can compare the year 2005 with the climatological mean for surface waters. Following the cold air temperature in winter specially the very cool February, SST from February to March was under the mean value and in March the lower value of the time-series (11.4ºC). The rest of the year SST was higher than the average, especially in August when 22.5ºC were measured. The amplitude of the seasonal cycle of SST was of 11.1ºC, quite close to the air temperature seasonal cycle for the year (12.7ºC) and both of then larger than the long-term mean 8.7 and 9.8ºC respectively.

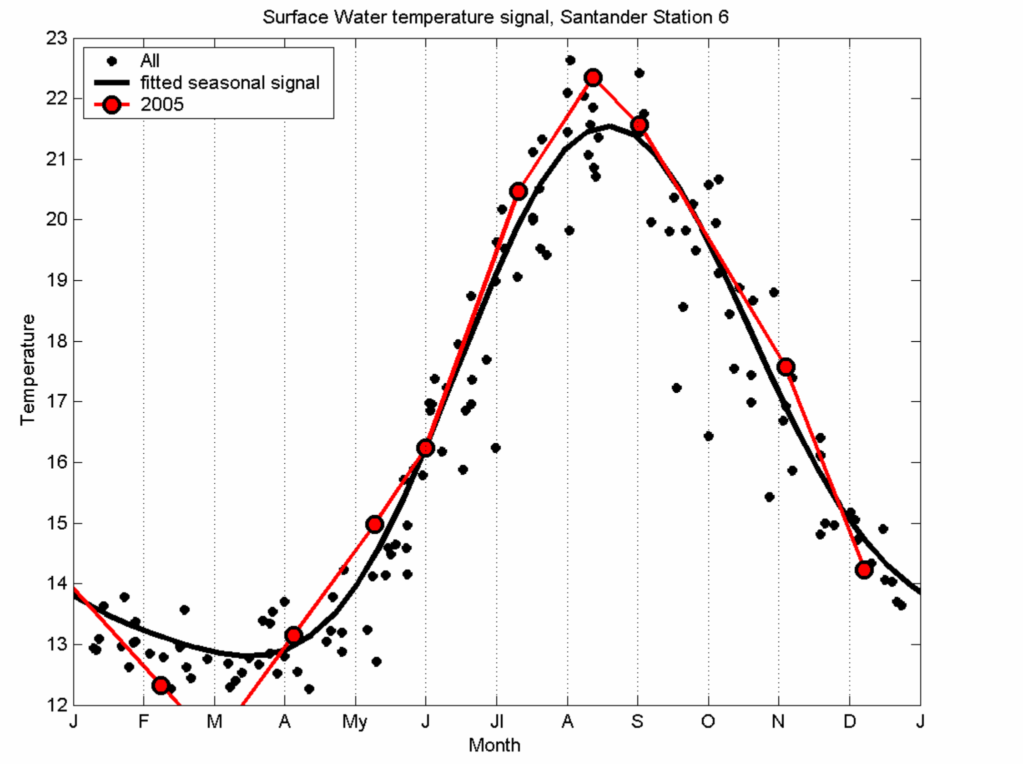


Figure A9.19: Seawater Surface Temperature at Santander station 6 (shelf-break).

The anomalous cold winter and warm summer produced a yearly temperature close to the average (Figure A9.20), but as previously mentioned, it is the first time we have found such as deep winter anomaly and it has important consequences in the mixed layer and upper Central Waters.

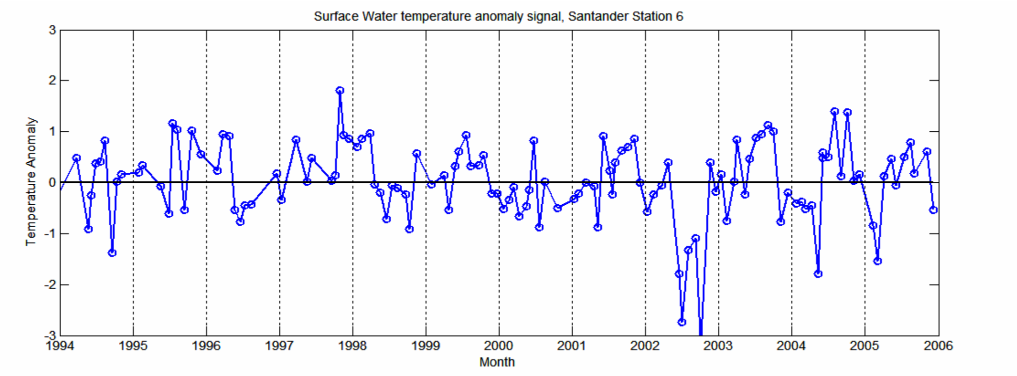


Figure A9.20: Seawater Surface Temperature anomalies at Santander station 6 (shelf-break).

When the analysis is produced all over the upper waters to 300m depth, 2005 due to the cool winter temperatures present a cold mean temperature with value of 12.34ºC lower than one standard deviation for the mean and the colder of the time-series (Figure A9.21). Only two years of the time-series are over the standard deviation, a positive situation in 1988 when the maximum warming was found in the Atlantic and Pacific after an El Niño phenomenon (Levitus, 2000) and 2005 due to this cold winter that have affected all the upper 300 m of water.

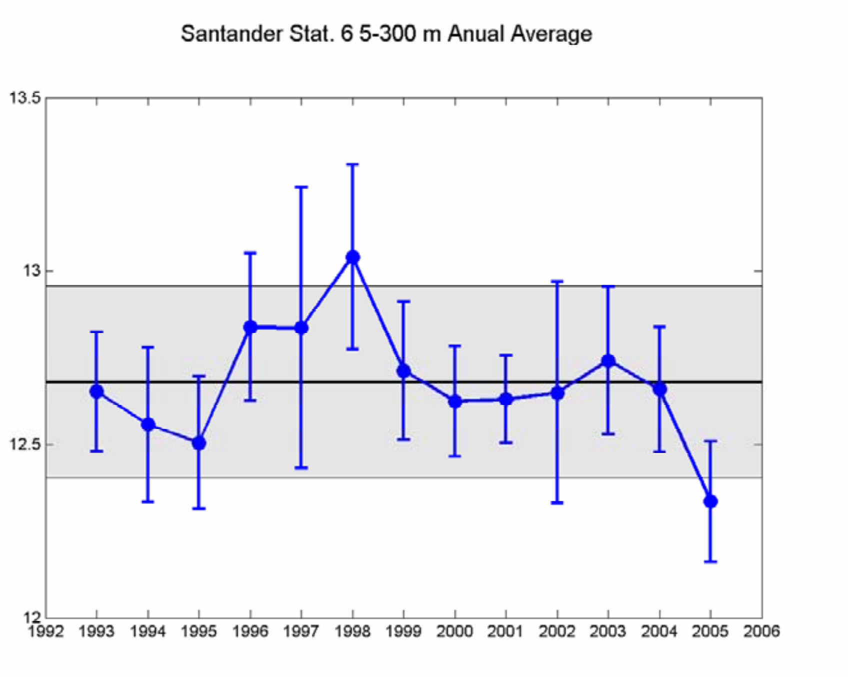


Figure A9.21: Annual average temperature (5–300 m. at Santander station 6 (shelf-break).

Between 1998 and 2001, evidence of a decline in salinity was found up to a depth of 300 m. In 2002 this trend was inverted, especially during the poleward episode at the beginning of the year. An salinity average of this layer (0–300 m) is shown in Figure A9.22 for station 6. During 2005 the trend has keep and the values are around the long term mean. The same behaviour is found for shelf stations. Down to this depth, salinity evolution does not have clear cycles (positive trends seem to appear at lower levels).

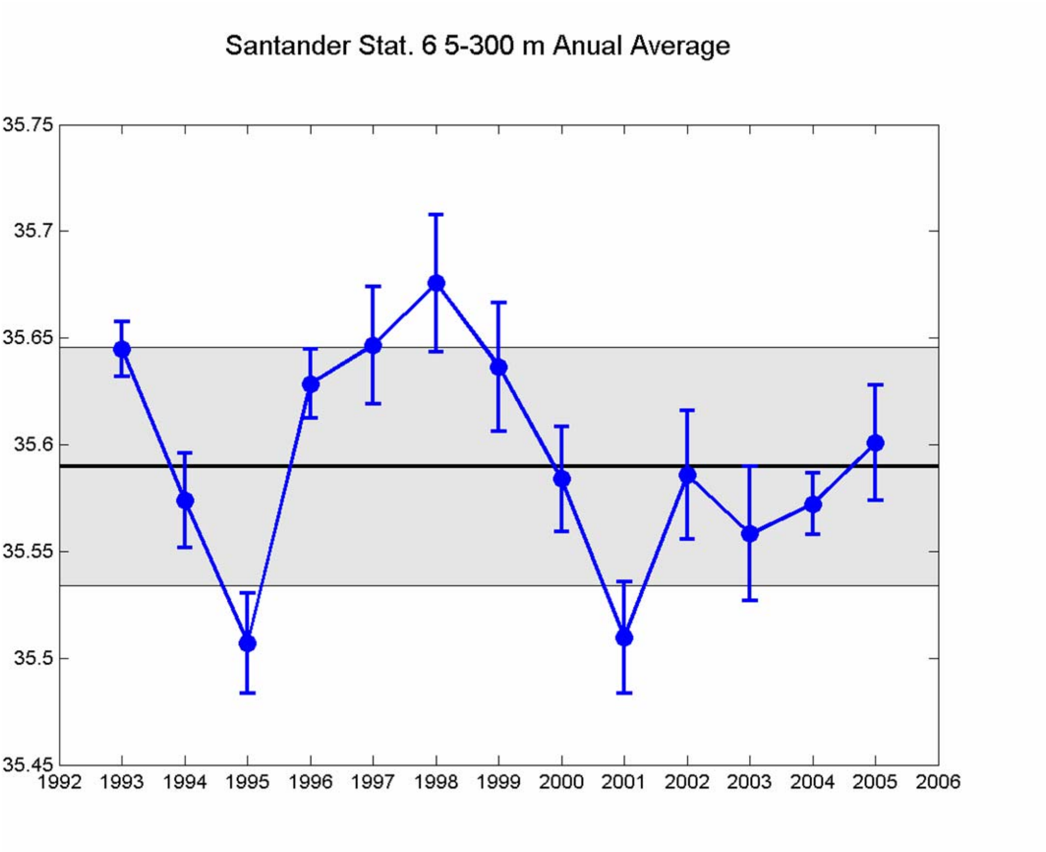


Figure A9.22: Annual average salinity (5–300 m) at Santander station 6 (shelf-break).

There is no signal of Iberian Poleward current at Santander shelf-break since early 2002. In Figure A9.23 distributions of potential temperature and salinity at 200–400 m is presented at the shelf-break (ST 6) and 6 miles northern (St 7) over the slope. The extreme highly value in temperature and salinity at January 2002 is clearly shown at the shelf-break, but not 6 miles northern. A reduction on temperature is detected in both stations from 2004 and a continuous increase in salinity with significant increase during 2005 is detected in both stations.

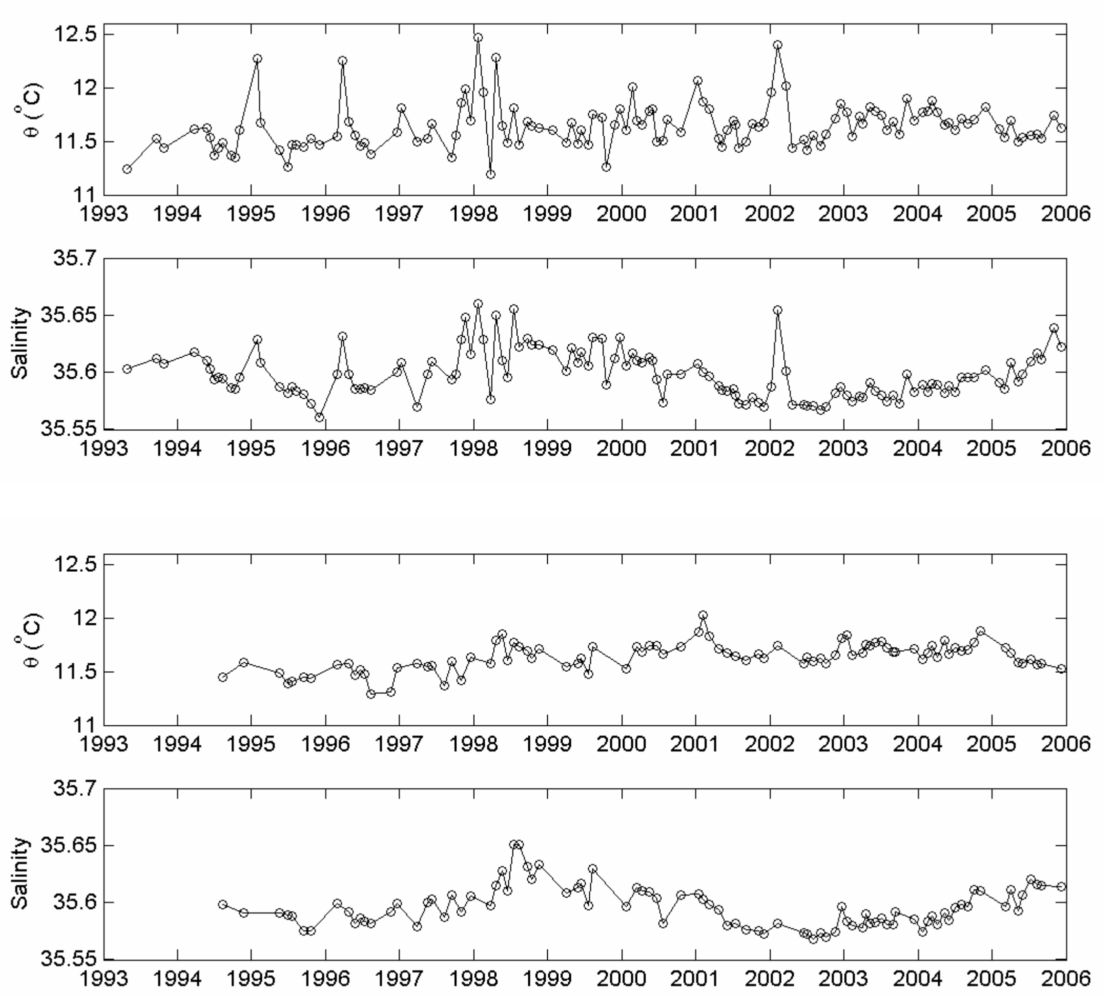


Figure A9.23: Upper slope (200–400 m) water properties at Santander station 6 (43º 42'N, 3º 47'W) (shelf-break) upper panels and station 7(43º 48'N, 3º 47'W) (slope) lower panels.

Water Masses

The big extension of the mixed layer is the main feature detected in the southern Bay of Biscay waters during 2005. The extremely cool SST around 11.5ºC with strong winds has produced a never previously detected 300 m depth mixed layer at this latitude. This depth mixed layer has had an important effect in the Upper layers of the North Atlantic Central Water of the area. In these layers the warming trend detected previously has stopped and inverted towards cooling from the end of 2004. Deeper that 300m warming trend keeps I the deeper ENACW and in the Mediterranean Overflow Water. See the effect of the colder 2005 in the yellow lines in the TS diagram of Figure A9.24 as well as the high values on the lower NEACW, salinity minimum and MOW.

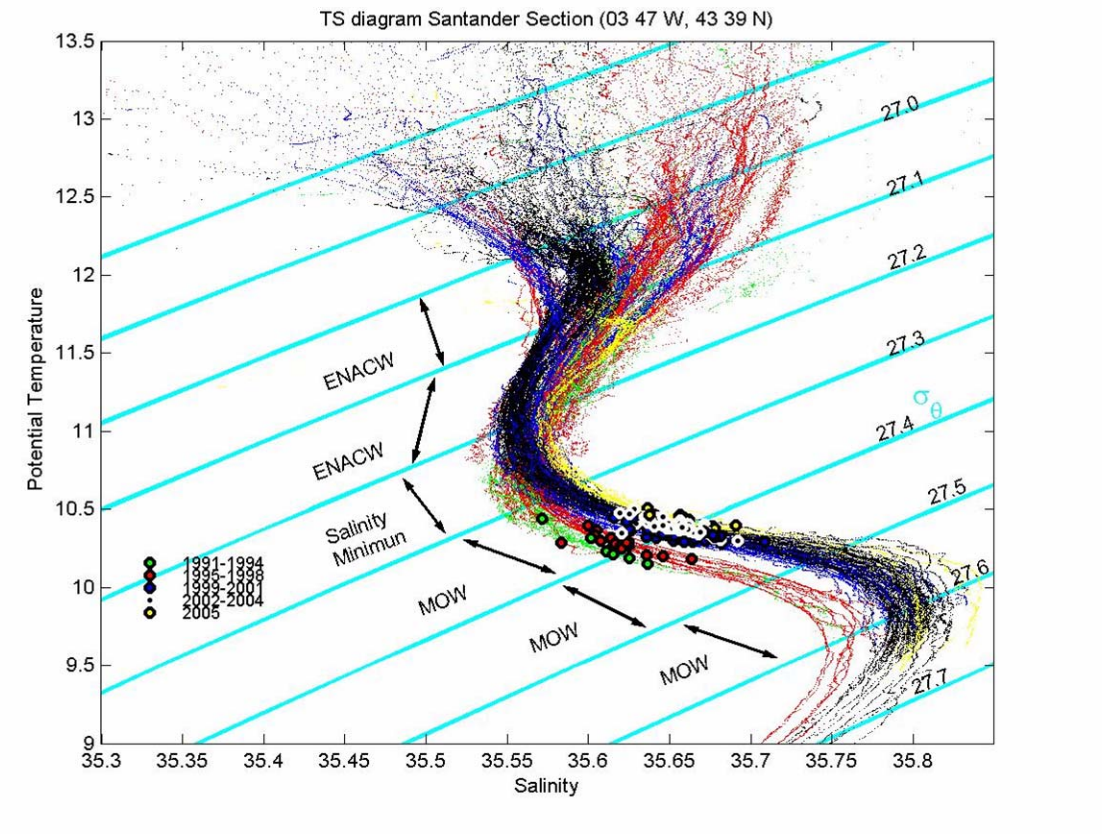


Figure A9.24: Water masses at Santander stations 6 and 7 presented in a TS diagram.

Annex 10: Rockall Trough and Iceland Basin, 2005 (Area 5)

N. P. Holliday (NOCS), C. Griffiths (SAMS), J. F. Read (NOCS), T. Sherwin (SAMS)

Introduction

The Extended Ellett Line (EEL) is a hydrographic section that extends west of Scotland to Rockall, into the Iceland Basin and north to Iceland. It is maintained approximately annually by a consortium of UK institutes, primarily the National Oceanography Centre, Southampton, the Scottish Association for Marine Science and with additional sections by the Fisheries Research Services in Scotland. The EEL has been occupied since 1996 and build on the time series between Scotland and Rockall, the Ellett Line.

This report describes work on the section in 2003–2005, updates the Ellett Line time series previously reported to the WGOH, and introduces some ideas for reporting the Iceland Basin part of the EEL within the WGOH report and the IAOCSS.

Further details are at http://www.noc.soton.ac.uk/GDD/hydro/nph/ellett/

Recent Sections

In 2003 the Ellett Line was occupied by Turrell (FRS) on the RV Scotia in April (see ICES WGOH Report) and by Griffiths (SAMS) on the RV Poseidon in July (Figure A10.1). Read (NOCS) occupied the Extended Ellett Line on the RV Poseidon in July 2004 (Figure A10.2), and Sherwin (SAMS) occupied the EEL on RRS Charles Darwin in October 2005 (Figure A10.3)

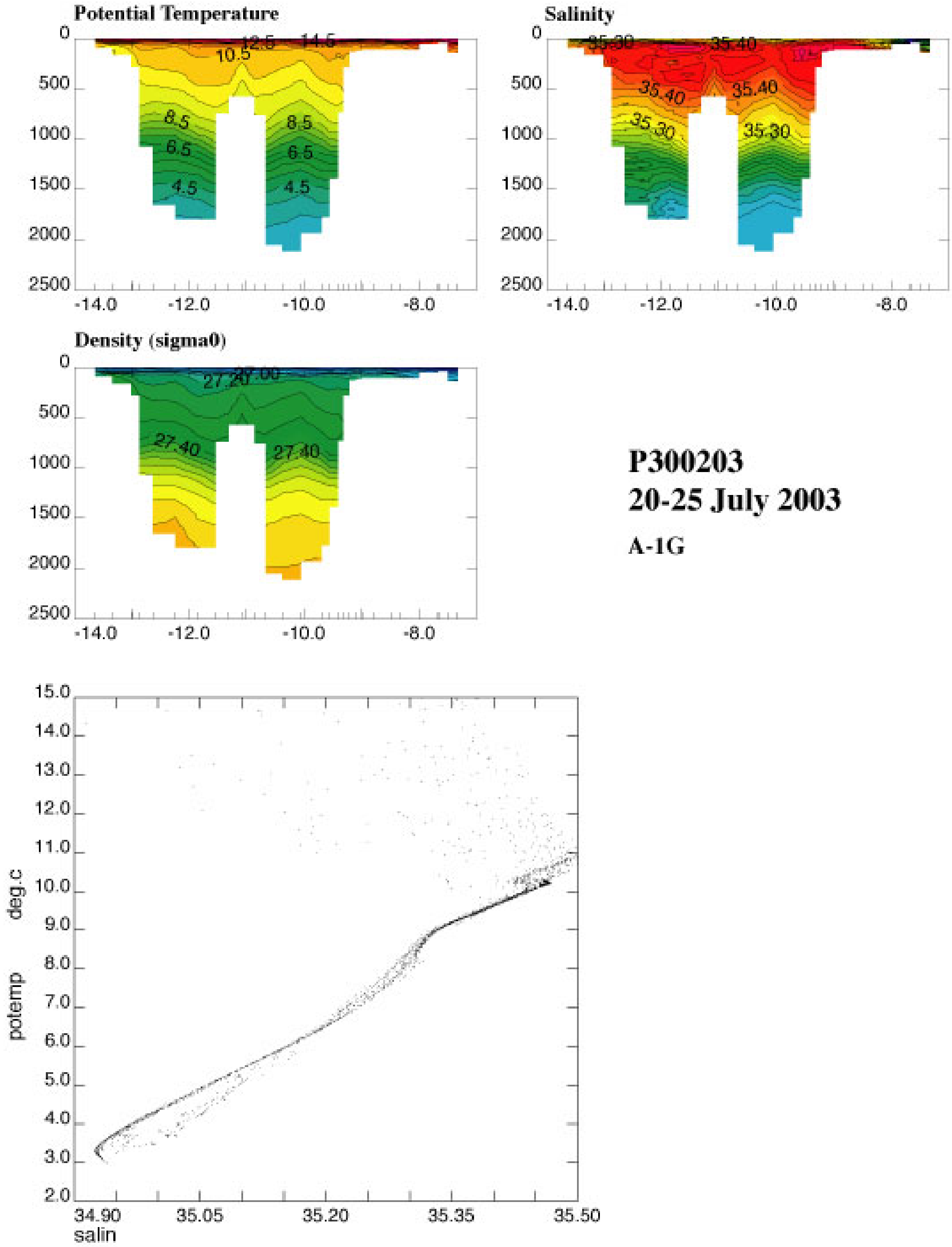


Figure A10.1: July 2003 occupation of the Ellett Line.

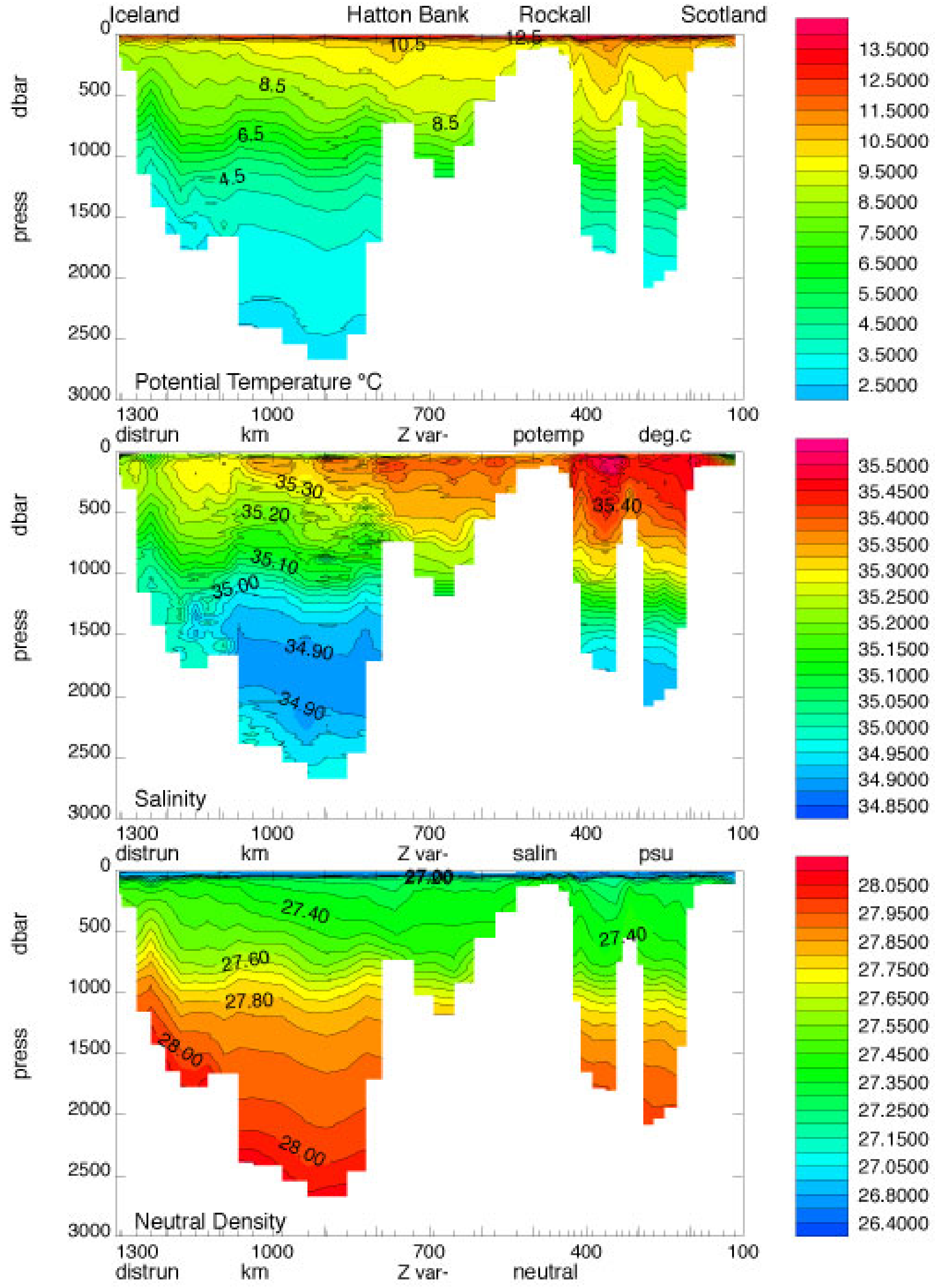


Figure A10.2: July 2004 occupation of the Extended Ellett Line.

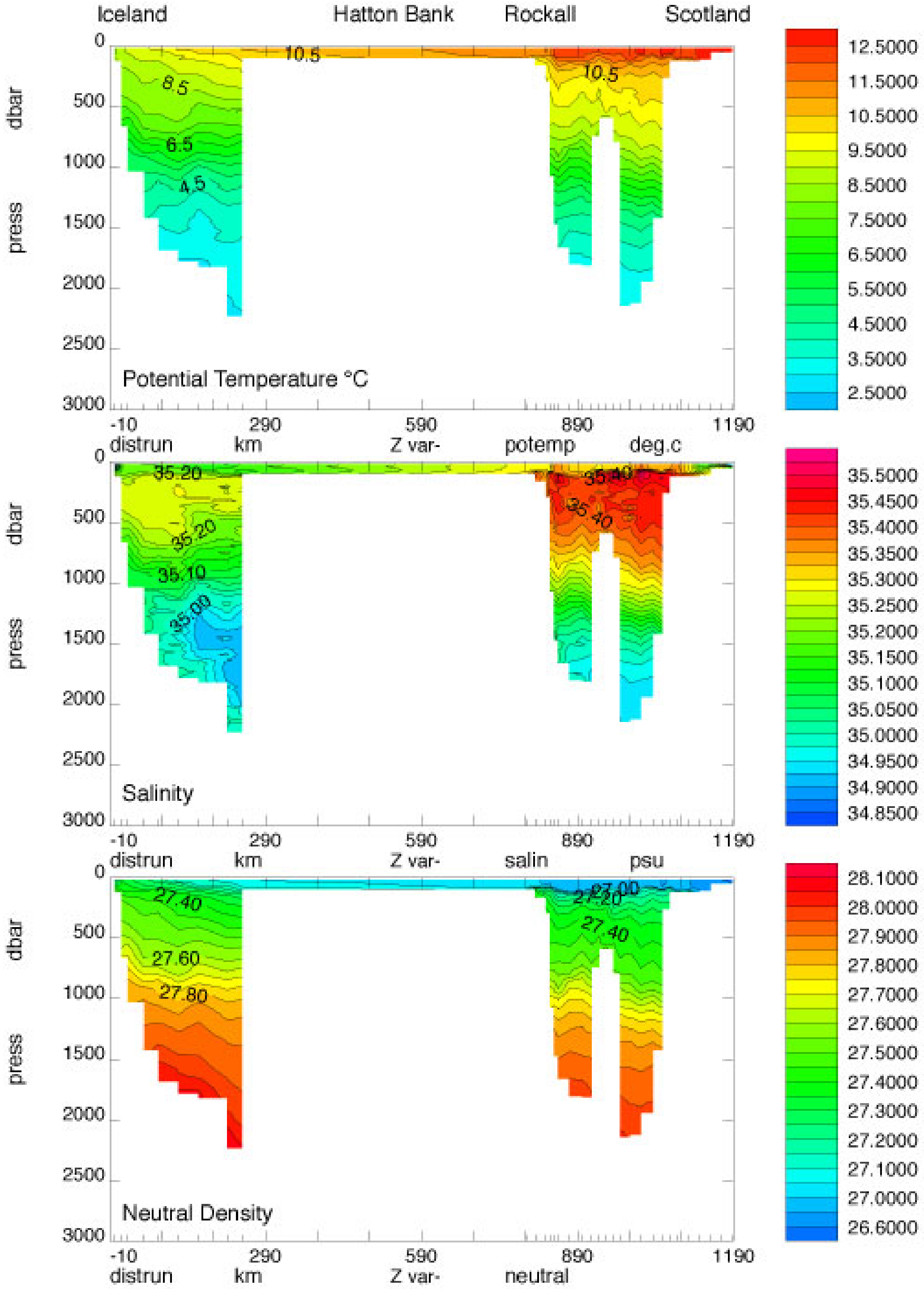
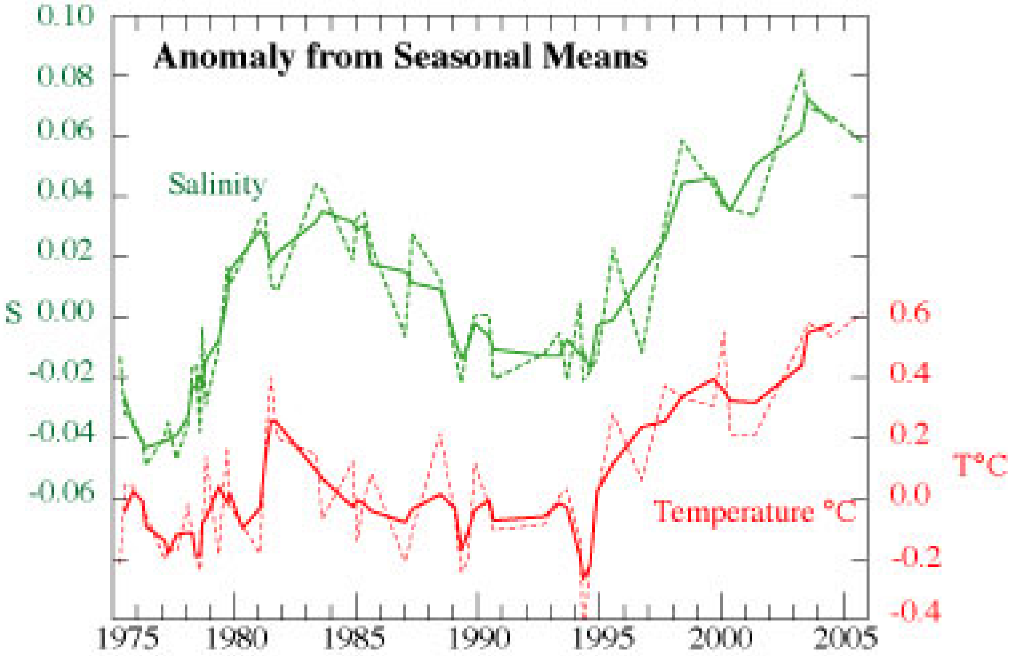


Figure A10.3: October 2005 occupation of the Extended Ellett Line (stations across Hatton Bank are missing through bad weather).

The Updated Ellett Line Time-series

In 2005 in the Rockall Trough the decade-long trend towards warmer and saltier water continued (Figure A10.4). Temperatures were the highest recorded, though salinity showed a very small decrease from 2004 and 2003. Still temperatures were 0.6°C above the long term mean (1975–2000) and salinities 0.06 above the long term mean. Meanwhile the core of the Labrador Sea water showed continued cooling; a trend that has dominated the entire time-series, though 2005 showed a substantial increase in salinity from the 2004 value. The depth of the core (defined as a minimum in stratification) had also increased from 2004.

a)



b)

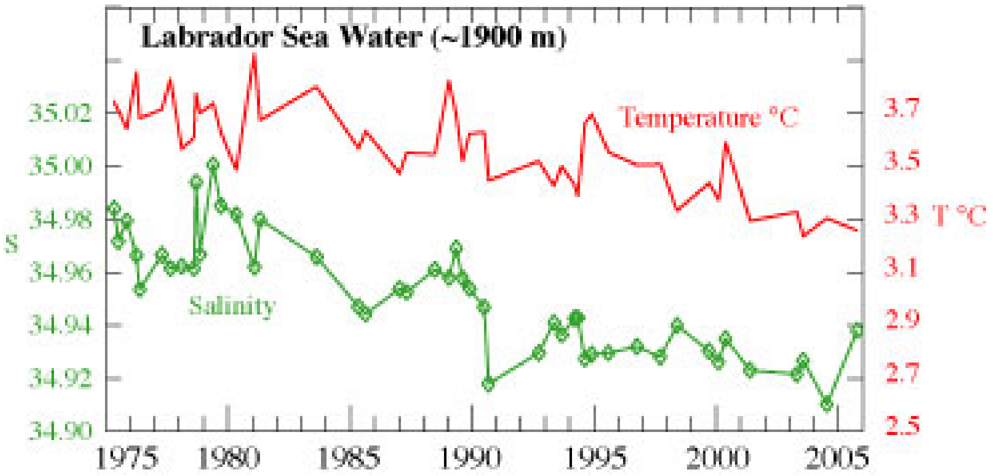


Figure A10.4: The Ellett Line Time-series from 1975 to 2005. Dashed lines show cruise data points, solid line are running means. a) Eastern North Atlantic Water properties: salinity (dotted green line) and temperature (red) represented by the anomaly from seasonal means over the upper 800 m of the water column. b) Labrador Sea Water properties salinity (green) and temperature (red).

The Extended Ellett Line Iceland Basin Time-series

Since 1996, nearly annually, the EEL consortium have occupied a continuation of the Ellett Line from Rockall across the Hatton Bank, into the Iceland Basin to 60N 20W and north along 20W to Iceland. Sections have been periodically presented in this report series, but no attempt has been made to incorporate the data into the IAOCSS or to present a summary time-series that represents the ocean properties. Here we make a first attempt at the latter.

The water sampled by the Iceland Basin part of the Extended Ellett Line can loosely be defined as SubPolar Mode Water. However, that broad label covers a number of local mode waters which may vary substantially in properties, specifically here we refer to temperature, salinity, and stratification in the form of potential vorticity (Pollard *et al.*, 2004; Read, 2001). Some fraction of the circulating surface waters in the Iceland Basin joins the water that flows northwards though the Rockall Trough and heads through the Faroe-Shetland Channel into the Nordic Seas. Thus the properties of this subpolar pathway go on to influence high latitude conditions (Hatun *et al.*, 2005).

The time-series shown in Figure A10.5 gives an overview of the variability across the whole section. We have chosen to provide a mean in three geographical regions over the depth range 150–500 m. This avoids some of the seasonal bias that is due to the formations of a summer and autumn warm, fresh surface layer, but since winter mixing extends at least to 500 m across this whole region, some seasonal bias will remain.

However, despite these reservations due to the analysis approach, the salinity gradient from Iceland to Rockall is clear, and the magnitude and pattern of the variability is shown to be similar in all regions.

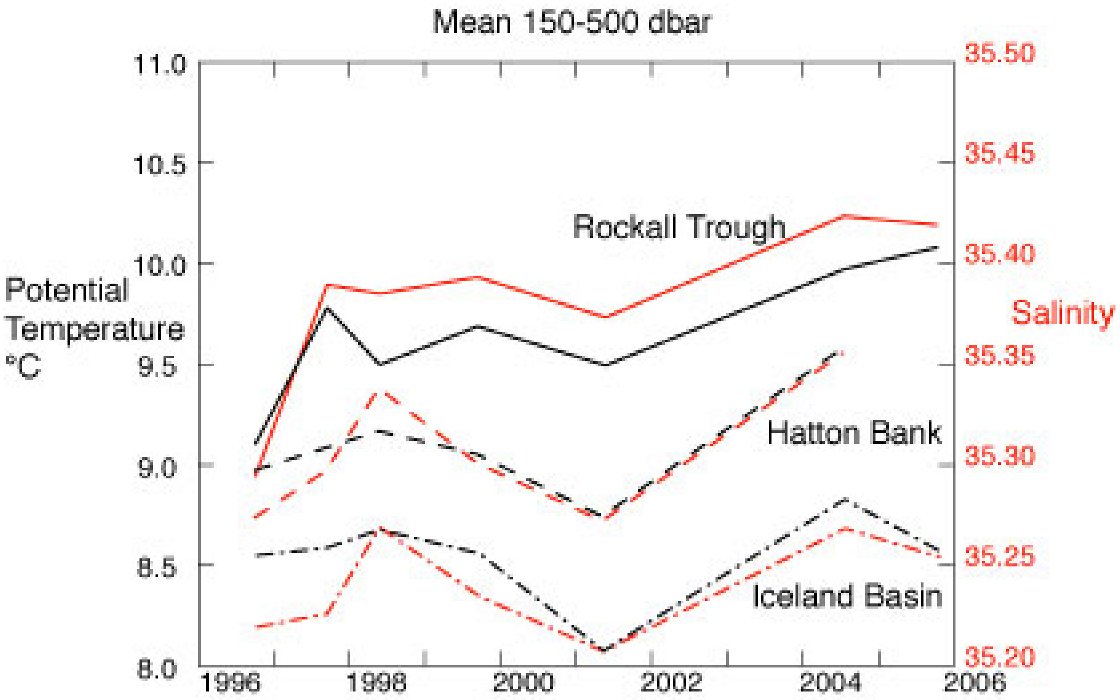


Figure A10.5: Time-series of temperature and salinity on the Extended Ellett Line.

References

Hatun, H., Sando, A.B., Drange, H., Hansen, B., and Valdimarsson, H., 2005, Influence of the Atlantic subpolar gyre on the thermohaline circulation. Science, 309: 1841–1844.

Pollard, R.T.; Read, J.F.; Holliday, N.P.; and Leach, H. 2004. Water masses and circulation pathways through the Iceland Basin during Vivaldi 1996. Journal of Geophysical Research C (Oceans); 109(C4) (2004); art. no.-C04004 (DOI:10.1029/2003JC002067).

Read, J.F. 2001. CONVEX-91: water masses and circulation of the Northeast Atlantic subpolar gyre, Progress in Oceanography, 48: 461–510.

Annex 11: Western Irish Shelf and: Rockall Trough (Area 5)

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In an attempt to fill the gap in long-term hydrographic measurements between the well established sections off Iberia and in the Northern Rockall Trough, Ireland has initiated several standard oceanographic sections in southern Rockall Trough and on the western Irish shelf (pictured below)

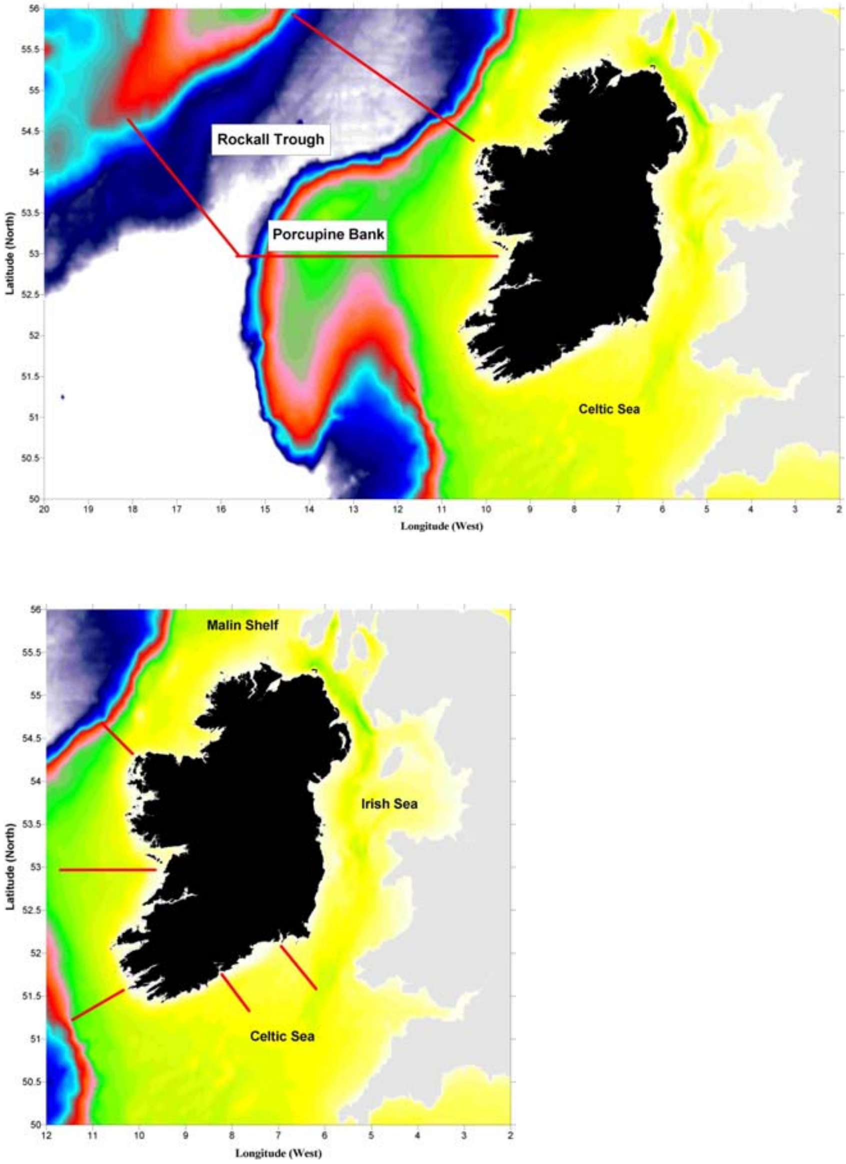


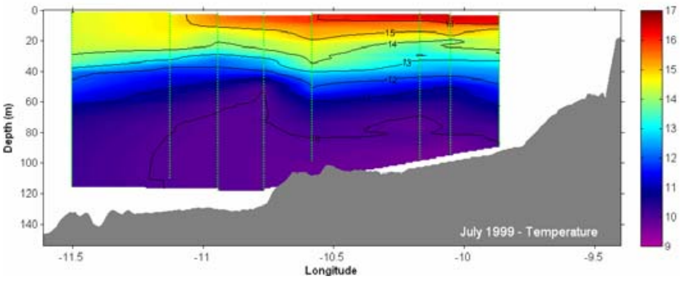
Figure A11.1: Irish standard sections a) Southern Rockall Trough and b) Irish Shelf.

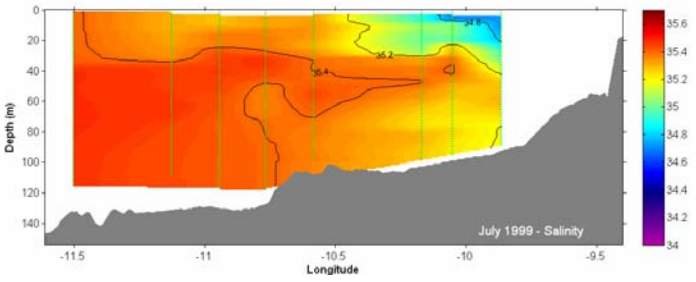
The continental shelf west of Ireland is relatively broad (180 km) and is exposed to the open Atlantic Ocean to the west. Fresh water discharges from Irish rivers (e.g. Shannon and Corrib) and those further afield (e.g. Loire, Severn) interact with Eastern North Atlantic Water on the Irish shelf to produce the observed circulation pattern. Summer CTD measurements have been made along a section at 53° North on the western Irish shelf since 1999.

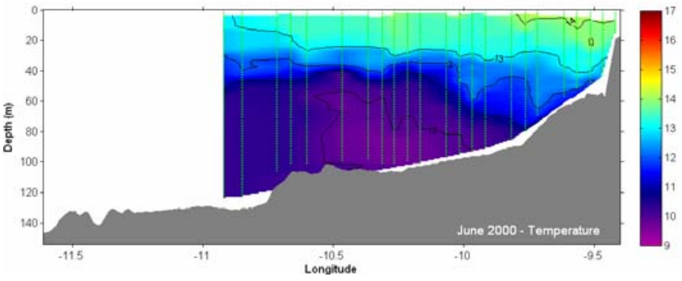
Warmer conditions were observed along this section in 2003 and 2004, broadly consistent with other regions of the NW European shelf while cooler conditions were observed in 2001 and 2002. Salinity also exhibits strong inter-annual variability along this section depending on the timing and magnitude of discharges both locally from Irish rivers and from rivers to the south of the section in the UK and France. Fresh conditions observed in 2001, 2002 and 2005 are linked to strong river discharges from the Loire and the river Shannon.

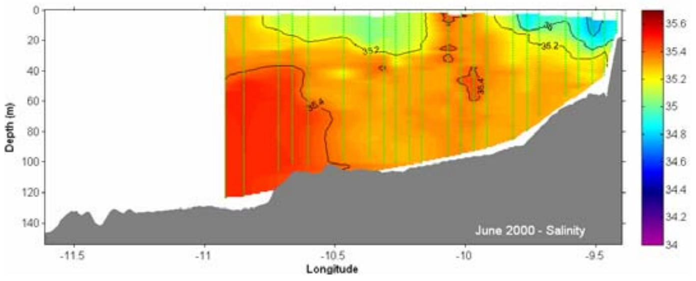
A long-term gridded climatology (Levitus) is used to discern the mean conditions along this section. Anomalies are calculated by comparing the observed conditions in each year with the long term mean conditions from the climatology. Because of the differing coverage of the 53° North section from year to year the integrated temperature and salinity anomalies (0–100 m) are calculated at 2 grid points at 10° and 10° 15’ West. The anomaly data is presented below.

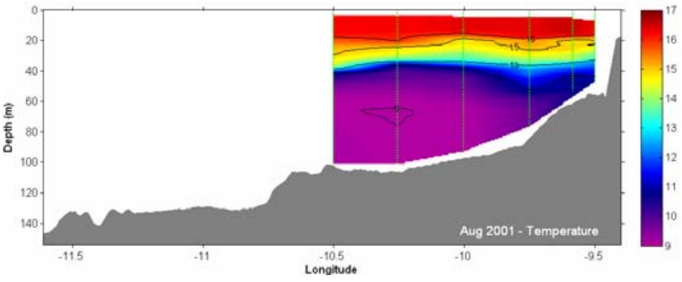
Temperature **Salinity**

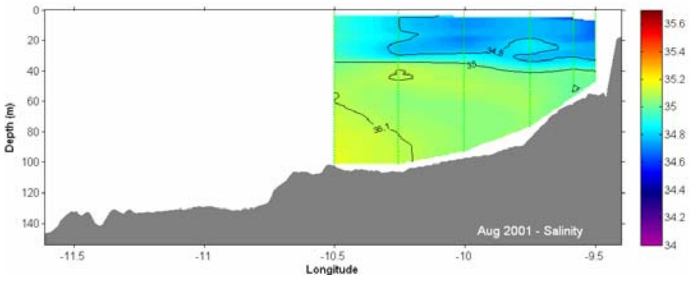


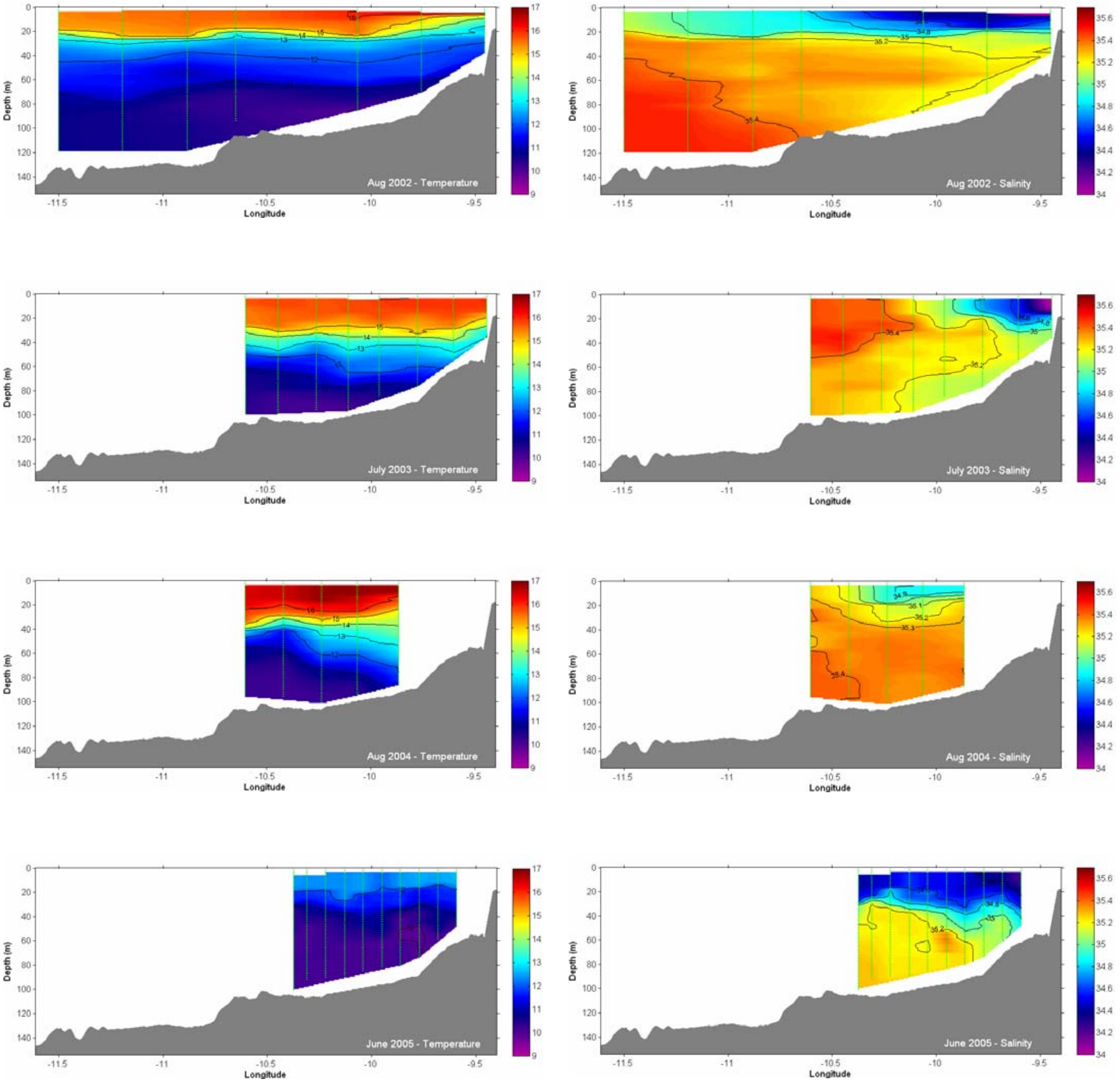












FigureA11.2: Summer temperature (˚C) and salinity structure along 53° North (1999–2005).

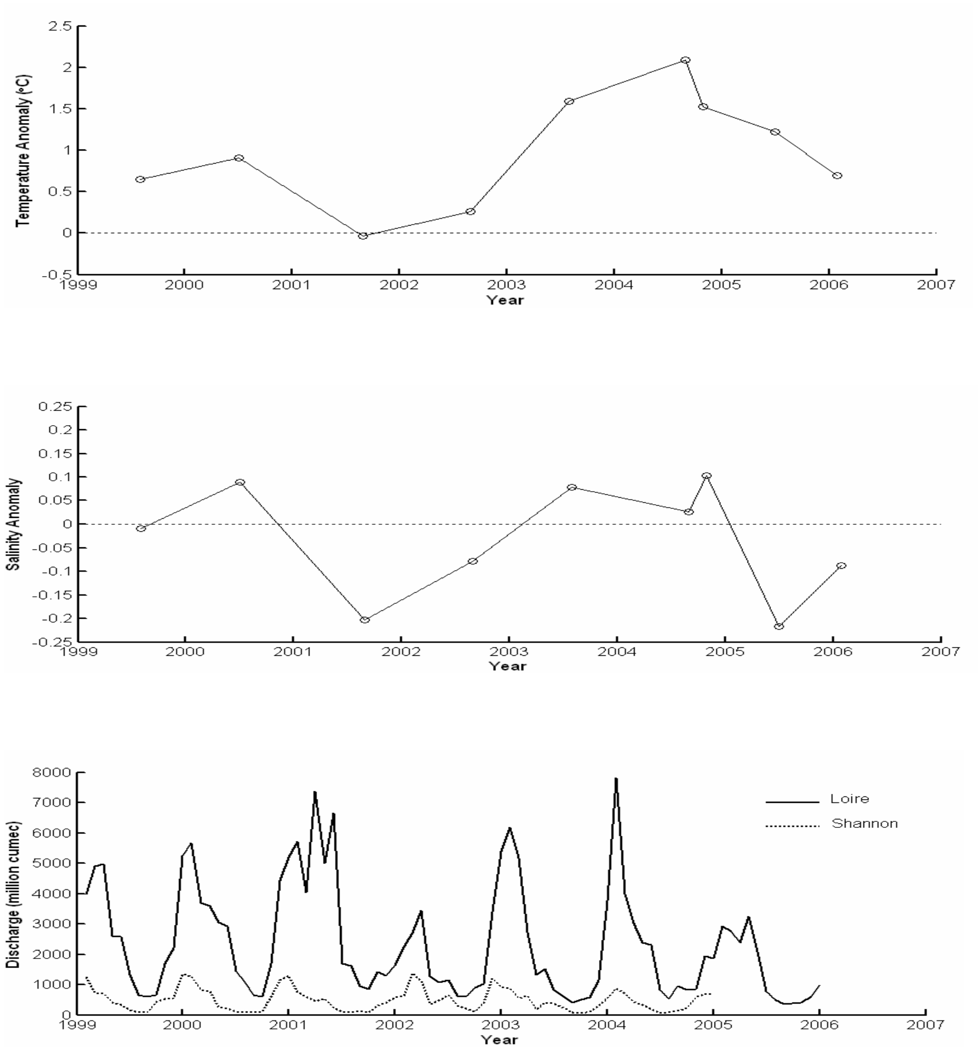


Figure A11.3: Anomalies along 53° North (1999-2005), a) temperature, b) salinity. Lower panel shows river discharges from rivers Loire (solid line) and Shannon (dashed line).

Annex 12: North-east Atlantic (WOCE AR7E), 2005

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From 7 September to 5 October 2005 a hydrographic survey of the former WOCE AR7E section was carried out by RV Pelagia, cruise PE240. CTD observations were performed with a station distance of about 30 nautical miles (Figure A12.1). Because of adverse weather conditions the planned stations over the Rockall Hatton Plateau had to be skipped. At each station water samples were taken for the determination of dissolved oxygen, nitrite, nitrate, silicate, total dissolved inorganic carbon (TIC) and total alkalinity, as well as salinity for calibration purposes.

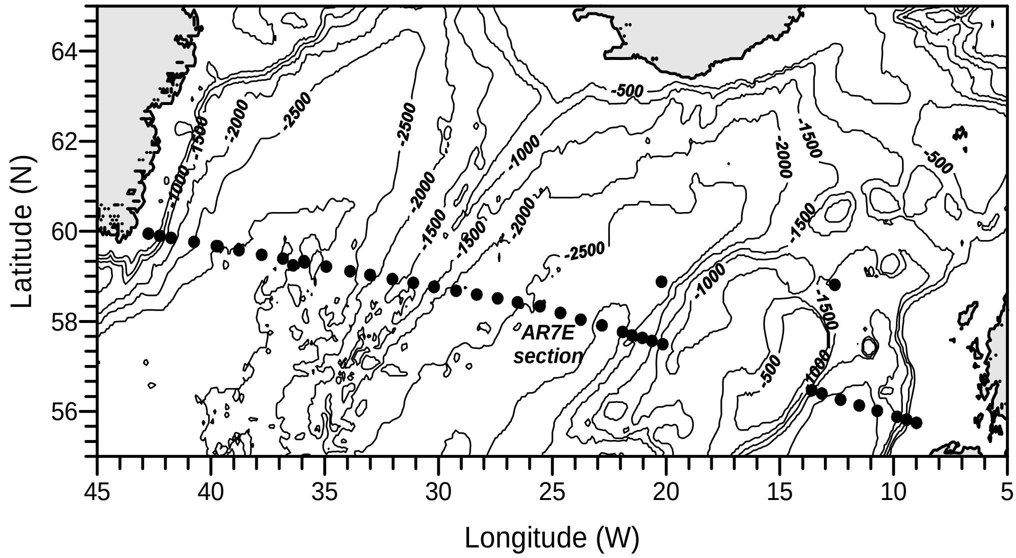


Figure A12.1: Hydrographic section, occupied during Pelagia cruise PE240, in September-October 2005. Except from two test stations, all CTD casts were performed along the former WOCE AR7E section.

Parameters, characteristic for most Subarctic Mode Water along the AR7E line are the salinity and temperature of the water at a pressure of 500 dbar (Figure A12.2).

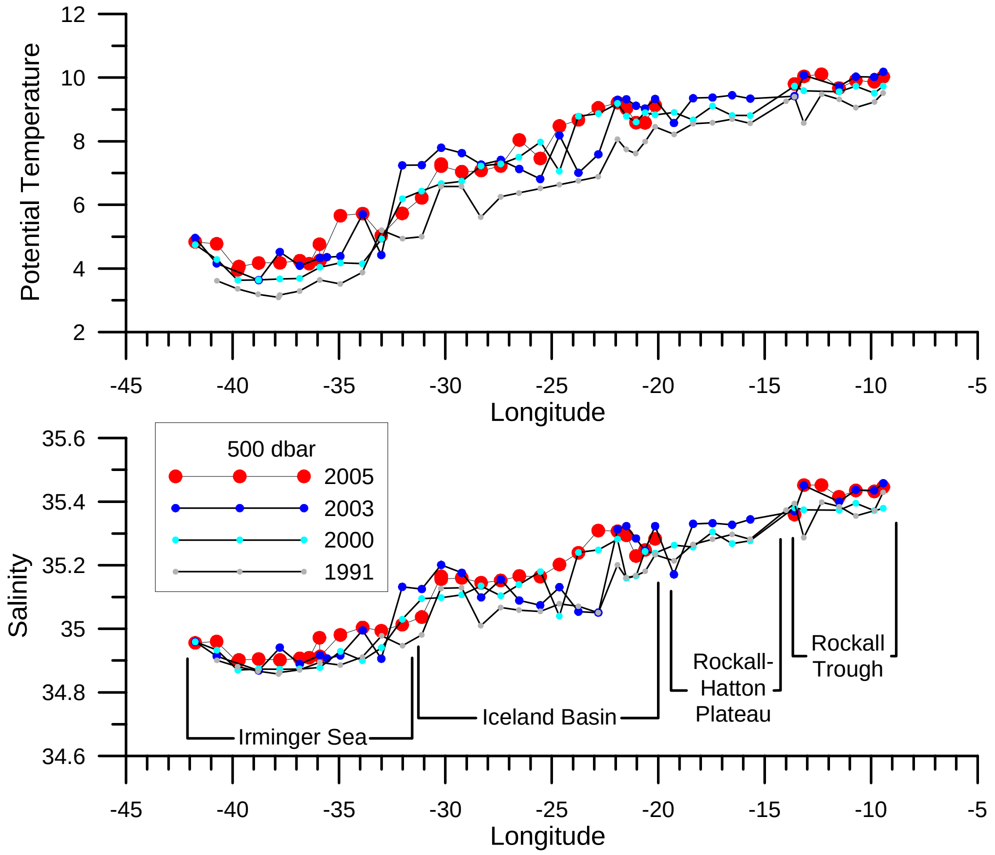


Figure A12.2: Potential temperature (upper panel) and salinity (lower panel) along the AR7E line at a pressure of 500 dbar for four surveys of the AR7E line in different years.

The potential temperature at a pressure of 500 dbar along the section shows (Figure A12.2, upper panel) that nearly everywhere its value in 2005 was as high as, or higher than during earlier surveys of the section. The increasing trend, started in 1991, has not reversed yet. Only near the Reykjanes Ridge, between the Irminger Sea and Iceland Basin, was the water in 2005 definitely cooler than in 2003. The salinity at 500 dbar (Figure A12.2, lower panel) in 2005 was similar to or higher than the salinity in the previous years. Also for this parameter the exception was over the Reykjanes Ridge, where higher salinities where observed in 2003. The combination of relatively high salinity and temperature along the section suggests that the main long-term changes are due to a meridional shift of the water mass in the upper ocean.

In order to show inter-annual change of water mass properties between 2003 and 2005, potetntial density-salinity diagrams for the main ocean basins can be used (Figure A12.3).

In the Irminger Sea the cold near-bottom layer of Denmark Strait Overflow Water (DSOW) still shows the salinity stratification from Denmark Strait near 60ºN. At the bottom the salinity is higher than 100 above the bottom. From 2003 to 2005 the salinity of the DSOW has decreased slightly, while also some cooling could be observed. The Labrador Sea Water vintage from before 1995 (LSW 95) near θ = 3ºC had increased in salinity between 2003 and 2005, while the warmer LSW variety that first was observed in 2000 (LSW 2000) had maintained its salinity and temperature over these years.

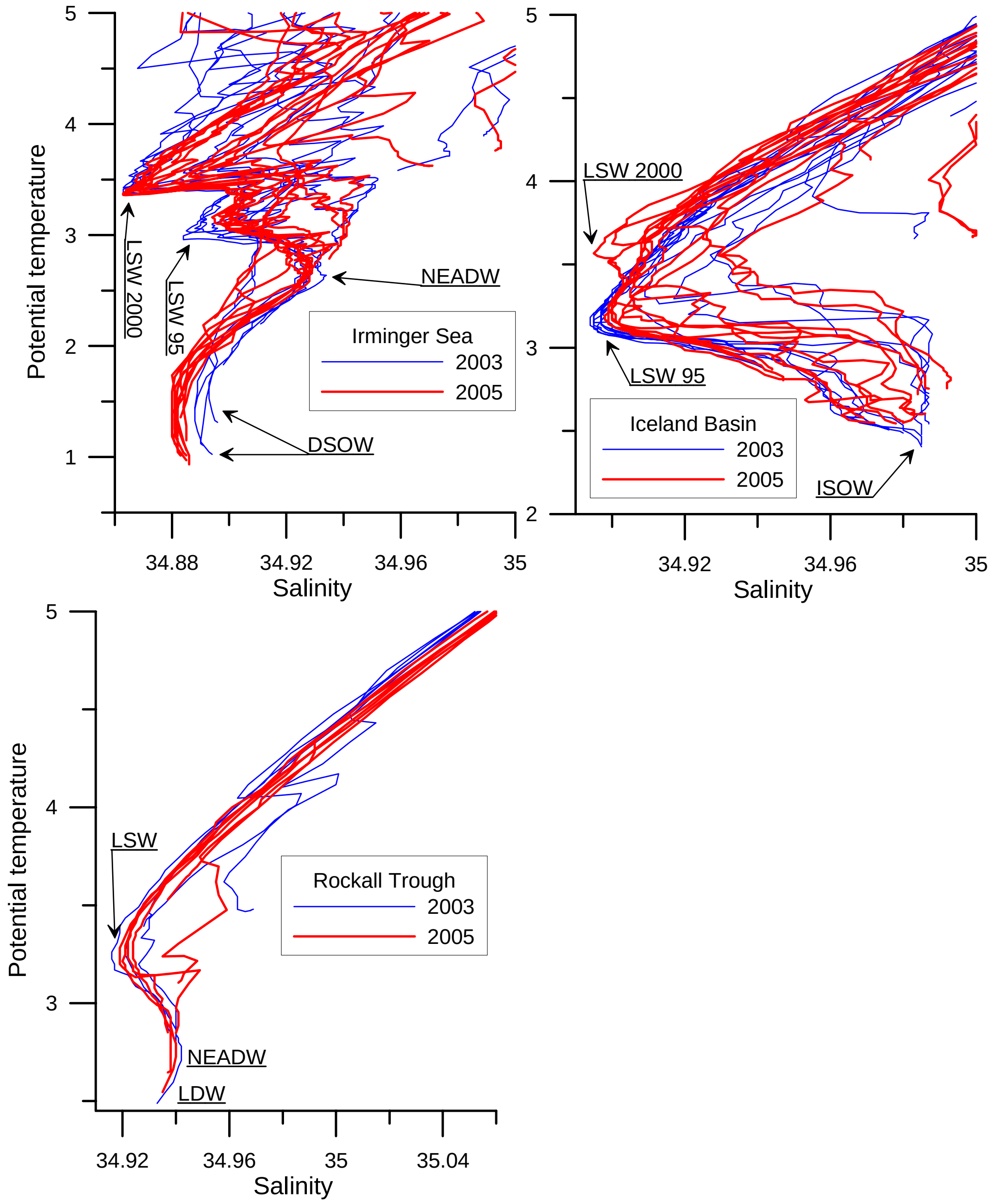


Figure A12.3. Potential temperature-salinity plots for the main ocean basins along the AR7E section. Blue lines, 2003; red lines, 2005.

In the Iceland Basin between 32 and 20ºW, the salinity of the LSW 95 core had increased slightly in salinity. The LSW 2000 core, first observed in the Iceland Basin along the southern Hatton Bank (~56ºN) in 2004 during the German survey of AR7E was in 2005 found along the Hatton Bank further North (~58ºN). The θ-S properties of the Iceland–Scotland Overflow Water (ISOW) below the intermediate LSW layers hardly had changed since 2003.

In 2005, in the Rockall Trough between 14 and 9ºW the deep-water θ-S properties hardly differed from the properties observed in 2003.

The hydro-chemical parameters like dissolved oxygen and nutrients will be studied for the interpretation of the observed changes of the TIC distribution.

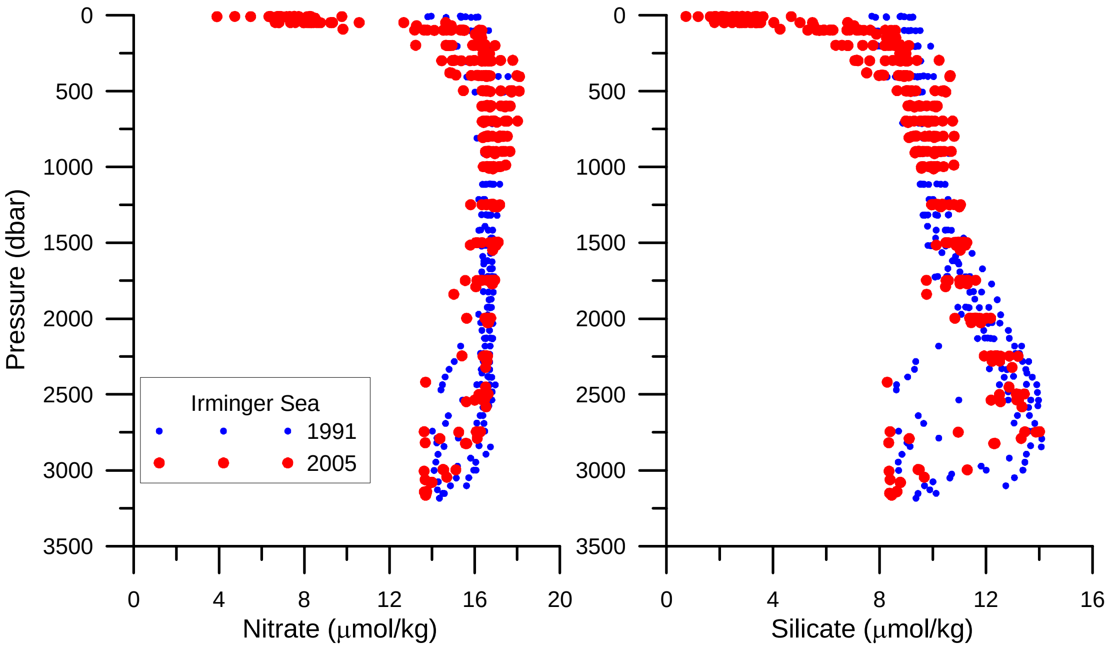


Figure A12.4: Vertical distribution of dissolved nitrate and silicate in the Irminger Sea for 2003 (blue dots) and 2005 (red dots).

The nutrients dissolved nitrate and silicate (Figure A12.4) show for 2005 a distribution, similar to the distribution observed in 1991. At levels below 2000 dbar the relatively low nutrient values are connected with the DSOW layers along the East Greenland slope, while the high nutrient samples were collected further east in the North-East Atlantic Deep Water (NEADW) core that contains ISOW mixed with LDW and some LSW.

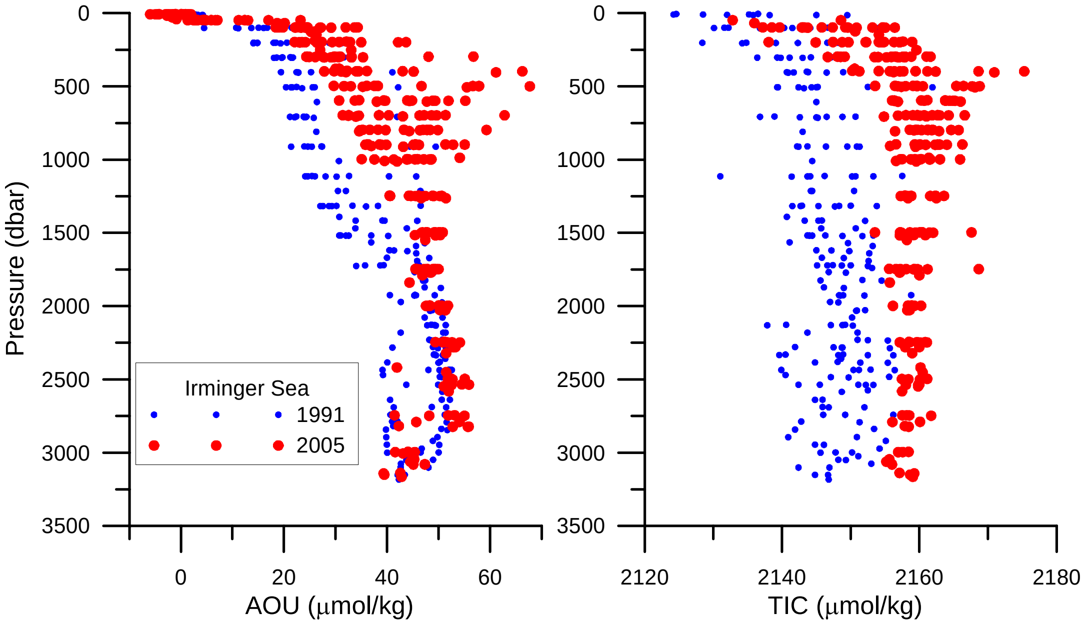


Figure A12.5: Vertical distribution of dissolved Apparent Oxygen Utilization (AOU) and dissolved total inorganic carbon (TIC) of samples from the Irminger Sea. (H. Zemmelink and S. van Heuven PI's)

The vertical AOU distribution in the Irminger Sea (Figure A12.5, left) below 2000 dbar was in 2005 similar to the distribution in 1991, with high values in the NEADW core, and low values along the East Greenland slope where DSOW is the dominant water mass. Above 1500 dbar the AOU values in 2005 were significantly higher than in 1991. That is probably due to the fact that in that pressure interval the relatively young LSW core was recently re-ventilated by local deep convection in the Irminger Sea.

The observed vertical TIC distribution in the Irminger Sea (Figure A12.5, right; H. Zemmelink and S. van Heuven PI's) in 2005 showed definitely less scatter than in 1991. This is probably indicative of the improved precision of these measurements. Apart from the near surface layer, where seasonal signals play a dominant role, a systematic increase of dissolved TIC with 11.5 µ mol/kg. This may be attributed to changes in the ventilation rate of the water column as well as to the anthropogenic CO^2 increase in the atmosphere.

In the Irminger Sea two moorings, fitted with a profiling CTD and ADCP's were recovered, serviced and redeployed during cruise PE240. Also a mooring with two sediment traps was serviced (G.-J. Brummer, PI). THe profiling moorings showed a clear seasonal cycle in the upper 600 m. During February 2005 deep convection formed a surface mixed layer with a thickness of over 600 m. At a depth near 1100 M a significant annual signal was discovered too.

The survey of the AR7E section by RV Pelagia, reported here, is part of an annual survey programme of this section, maintained by the Royal NIOZ, Texel and the IfMH, Hamburg.

Annex 13: North Sea, 2005 (Areas 8 and 9)

Holger Klein, Gerd Becker, Alexander Frohse, Peter Löwe, Achim Schulz, Giesela Tschersich

Bundesamt für Seeschifffahrt und Hydrographie, Hamburg

Content

- Global Radiation
- Elbe River Run-Off
- North Sea SST and Heat Content
- Stratification
- Synoptic
- Salt Content
- Chlorophyll *a*

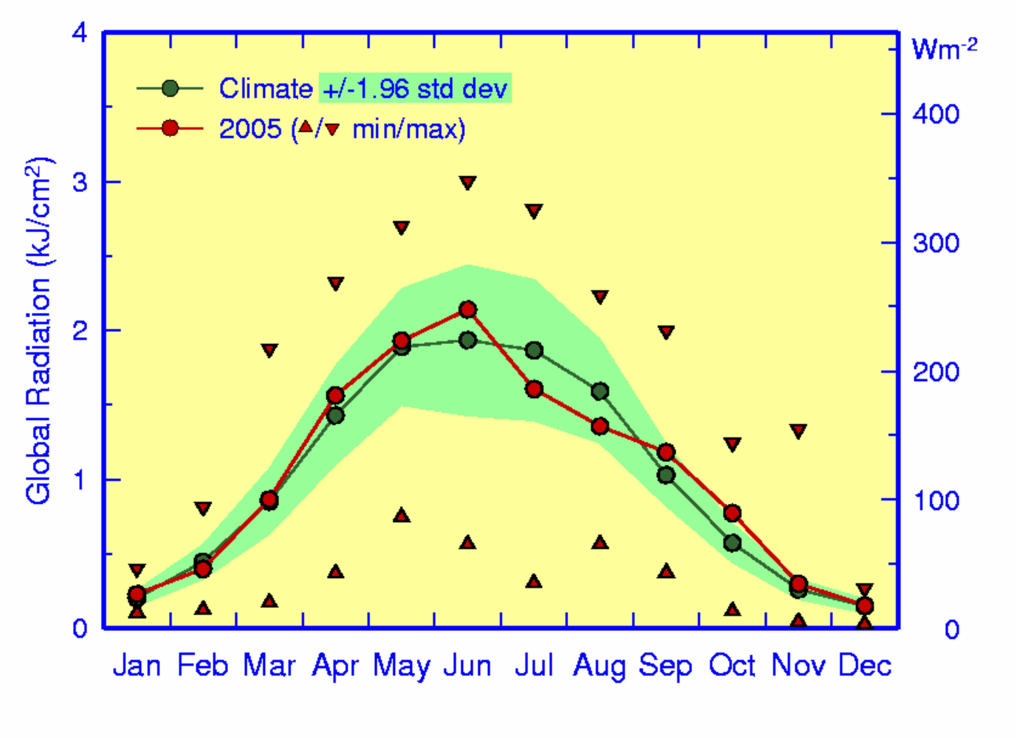


Figure A13.1: Monthly averaged global radiation at Norderney in 2005 [kJ/cm²].

Global Radiation

The global radiation at the East Frisian Island Norderney (Figure A13.1) was during the first five months of 2005 very close to the long-term means. June exceeded the long-term mean, but not significantly, and during July and August the radiation was lower than then long-term mean. The October radiation exceeded the mean significantly and October and November exhibits unusual high maximum values. This signal of high global radiation during fall had a high impact on the sea surface temperature (SST) during these months.

Elbe River Run-Off

During 2005 the monthly river run-off of the Elbe river was in the order of the long-term mean (Figure A13.2). The annual mean run-off of the Elbe river in 2005 (Figure A13.3) was very close to the long-term mean of about 22 km³/year.

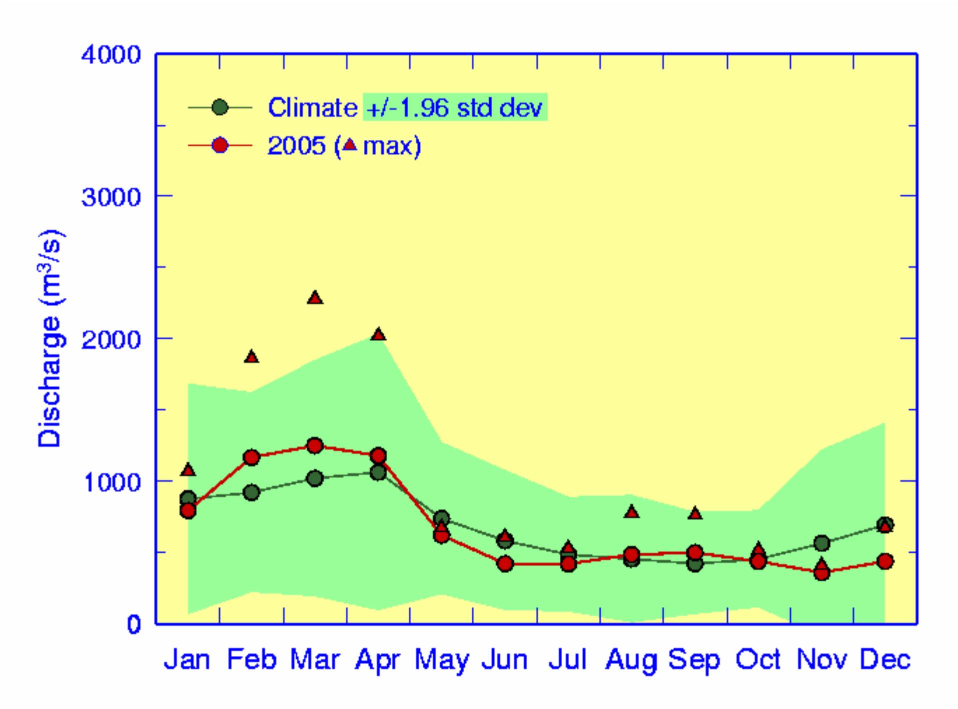
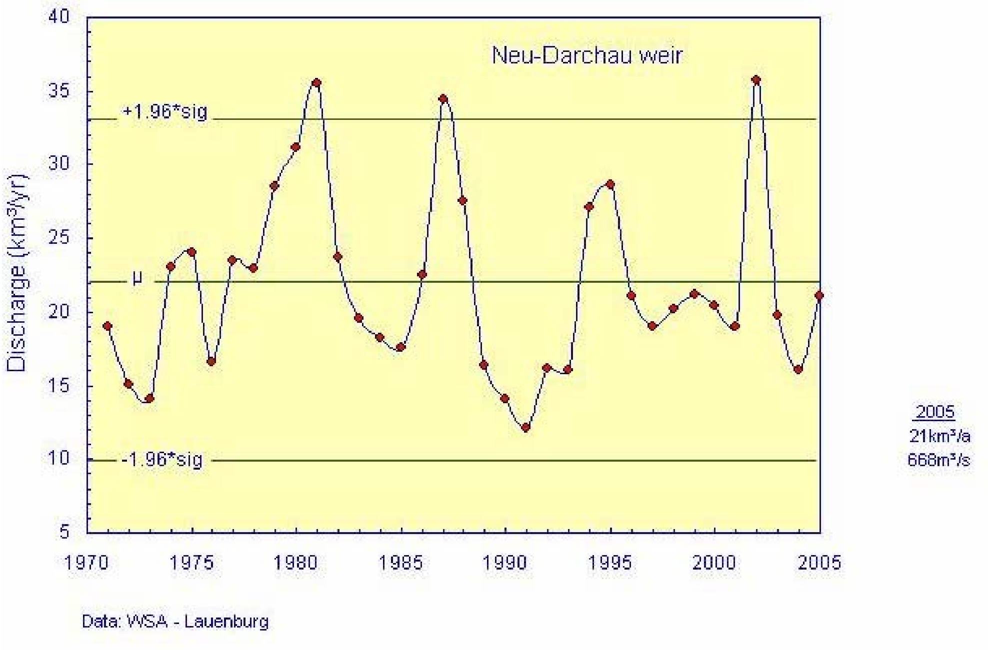


Figure A13.2: Discharge of river Elbe in 2005 [m³/s].



Data: WSA - Lauenburg

Figure A13.3: Long-term run-off of river Elbe in km³/year.

North Sea SST and Heat Content

During the first two month of the year 2005 the mean North Sea SST is still above the long term mean (Figure A13.4). During the following months the SST corresponds to the long-term mean, with the exception of the beginning of July. August and September are significantly colder compared to the preceding years. Due to the long and late summer the SST during October and November was remarkably high (see global radiation).

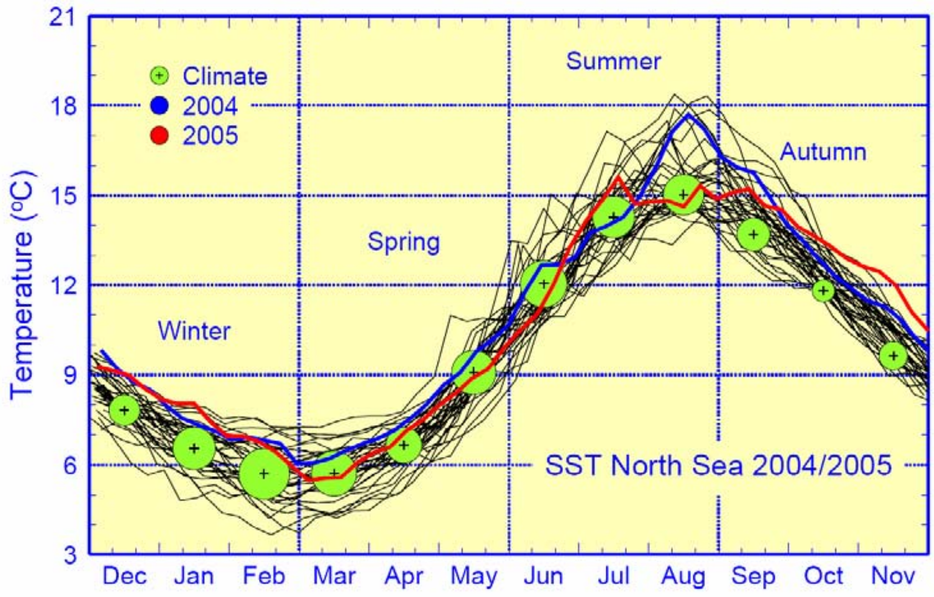


Figure A13.4: Weekly means of averaged North Sea SST from December 2004 until November 2005 (red line) and from December 2003 until November 2004 (blue line). The black lines are the annual cycles back to 1968. The green circles give the long-term mean, the radius gives the interannual standard deviation for the period 1971–1993.

This is also evident in the Helgoland Roads data: The warm period starting in 1988 is still visible. The summer periods became longer and warmer and the winters became less cold. The amplitude-decrease of the annual cycle of sea surface salinity, beginning in the mid-nineties, could still be observed in 2005.

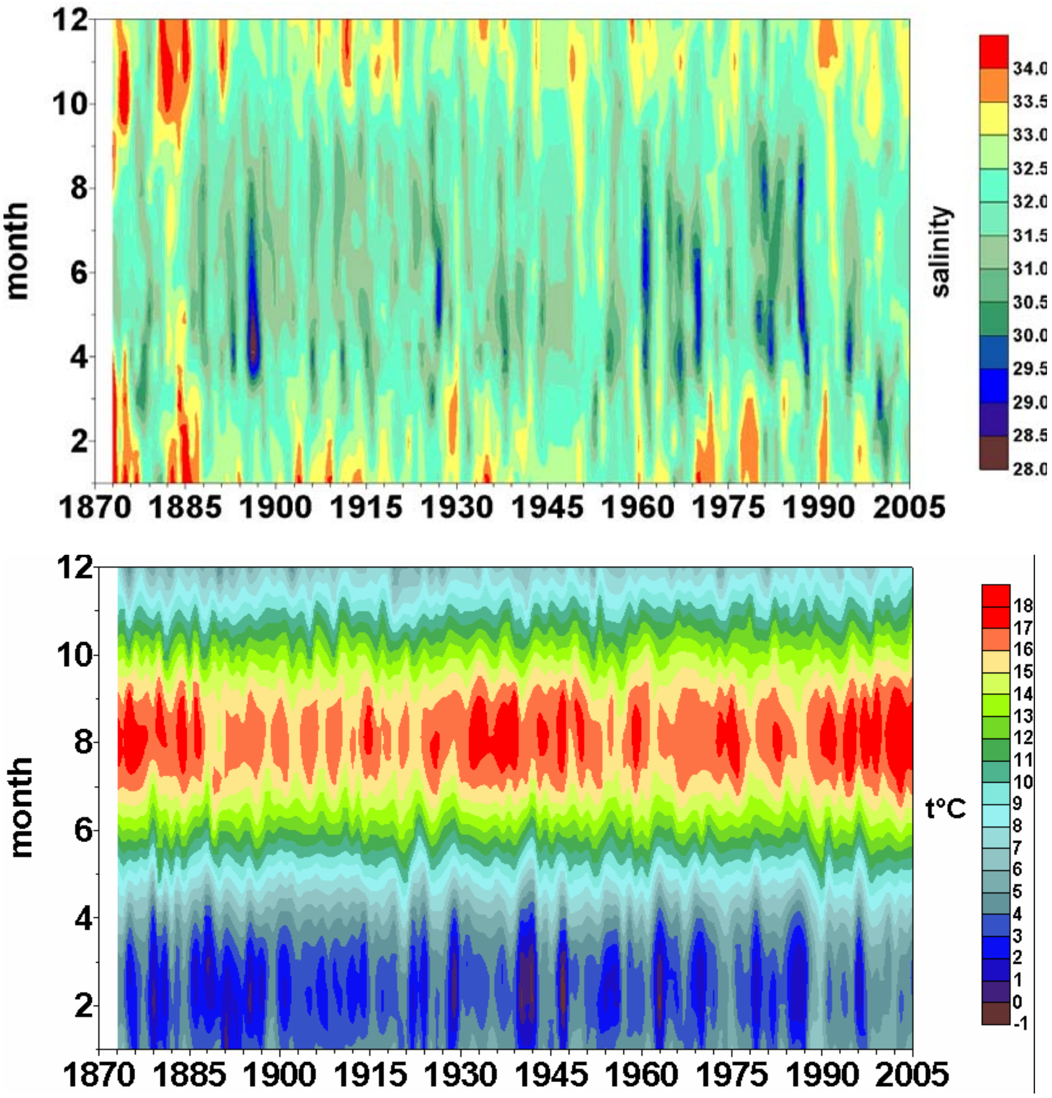
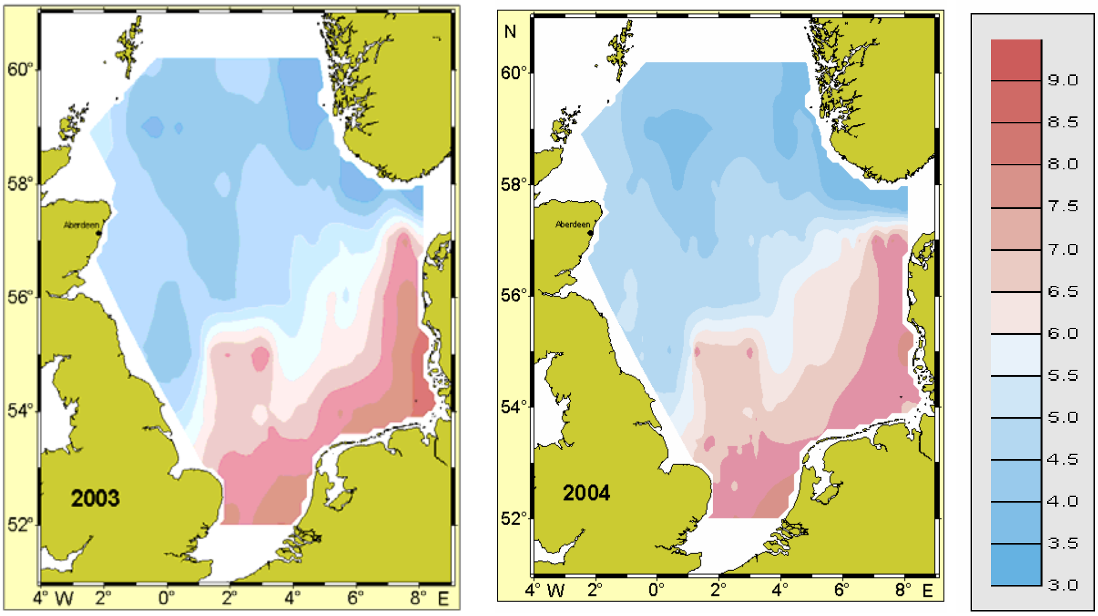
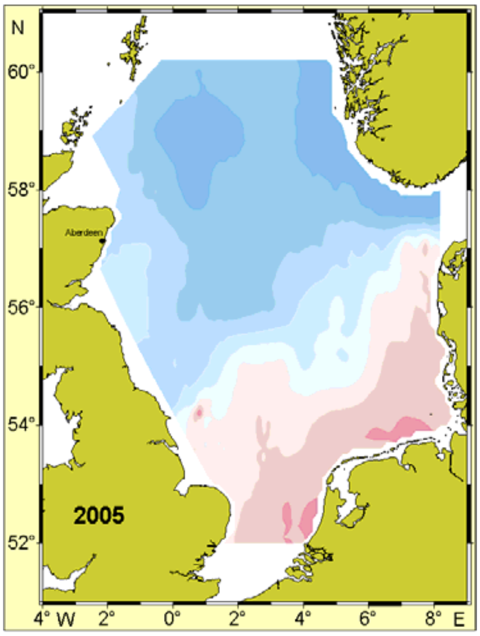


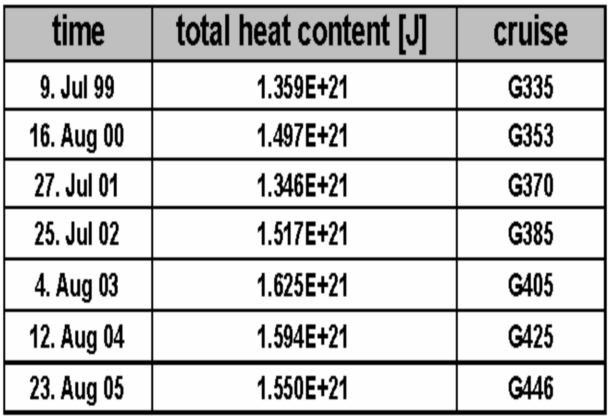
Figure A13.5: Helgoland Roads temperature and salinity time-series. Gaps in the time-series are closed by correlation and substitution with light vessel data.

Figure A13.6 shows the heat content per unit volume for the last three GAUSS summer cruises, related to the masked area. The table included gives the total heat content of the North Sea for the last six years. The total heat content of the North Sea is decreasing since 2003, indicating the end of the warm period starting in 1988.

The measurements during the yearly GAUSS summer cruises are taken by CTD profiles (stations) and by a towed CTD-system (Delphin) which is oscillating between near-surface and near-bottom depths during the transits.







time	total heat content [J]	cruise
9. Jul 99	1.359E+21	G335
16. Aug 00	1.497E+21	G353
27. Jul 01	1.346E+21	G370
25. Jul 02	1.517E+21	G385
4. Aug 03	1.625E+21	G405
12. Aug 04	1.594E+21	G425
23. Aug 05	1.550E+21	G446

Figure A13.6: Heat content per unit volume in J x 107/m^3, evaluated from GAUSS summer cruises. The table shows the total heat content of the North Sea [x 1021 J]

Stratification

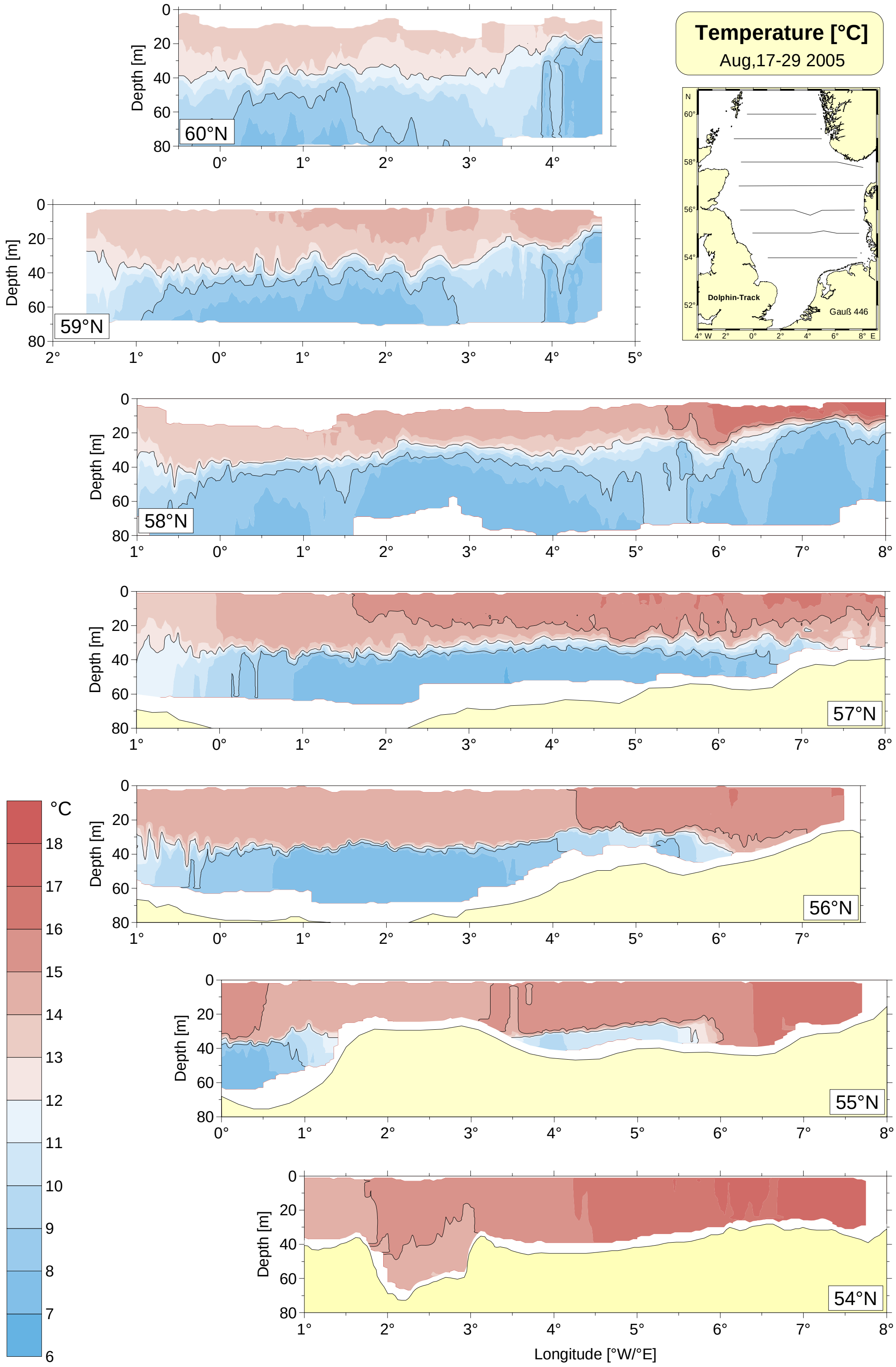


Figure A13.7: Temperature section from GAUSS cruise 446, August 2005.

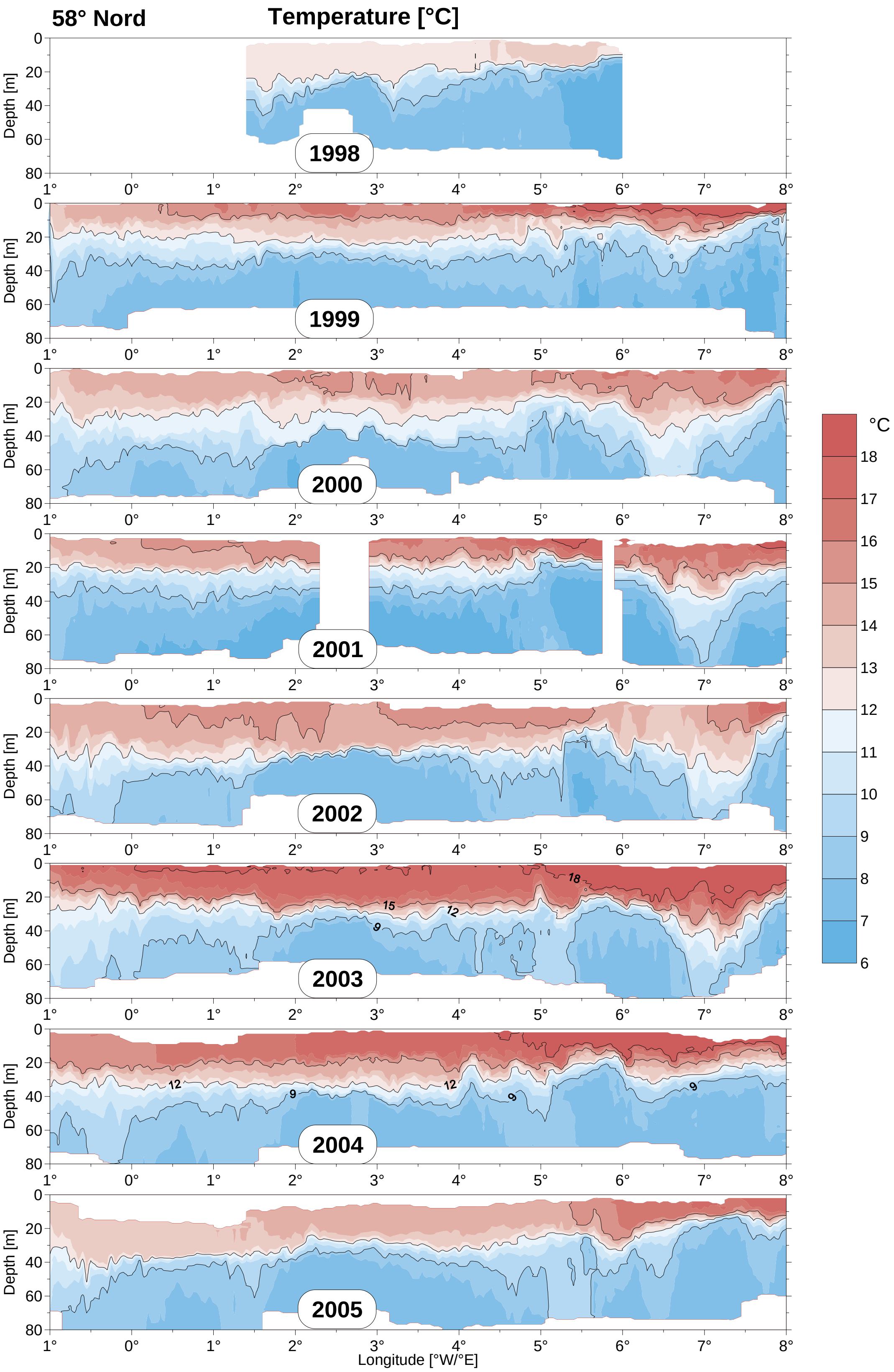


Figure A13.8: Temperature sections along 58°N from 1998 until 2005.

The temperature stratification shows a well developed thermocline with lower temperatures in the upper layer compared to 2004. Due to high tidal mixing there is no stratification in the German Bight and above the Dogger Bank, and a weaker stratification near the Fair Isle passage and off the Scottish coast (Figure A13.7).

The series of temperature sections along 58°N (Figure A13.8) confirms the decrease of near-surface temperatures compared to 2003 and 2004.

Synoptic

Figures A13.9 and A13.10 give a synopsis of SST, SSS, Secchi-depth, and near-bottom oxygen saturation during GAUSS cruise 446a from 10–29 August. The salinity distribution indicates a strong inflow of saline water from the North Atlantic. Remarkable is the signal of the Baltic outflow which is reaching far to the west compared to the preceding years. This is also evident in the salinity sections shown in Figure A13.12.

The maxima of Secchi depth coincide with regions of high saline – and obviously clearer - Atlantic water.

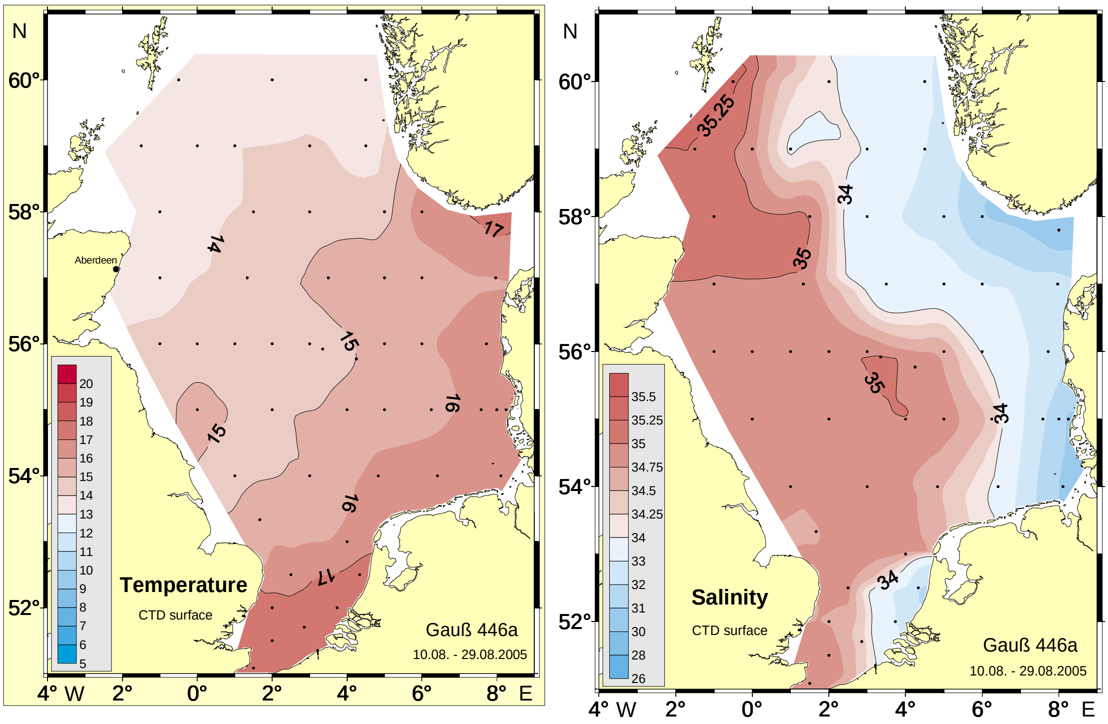


Figure A13.9: SST [°C] and SSS, GAUSS cruise 446a, 10–29 August 2005.

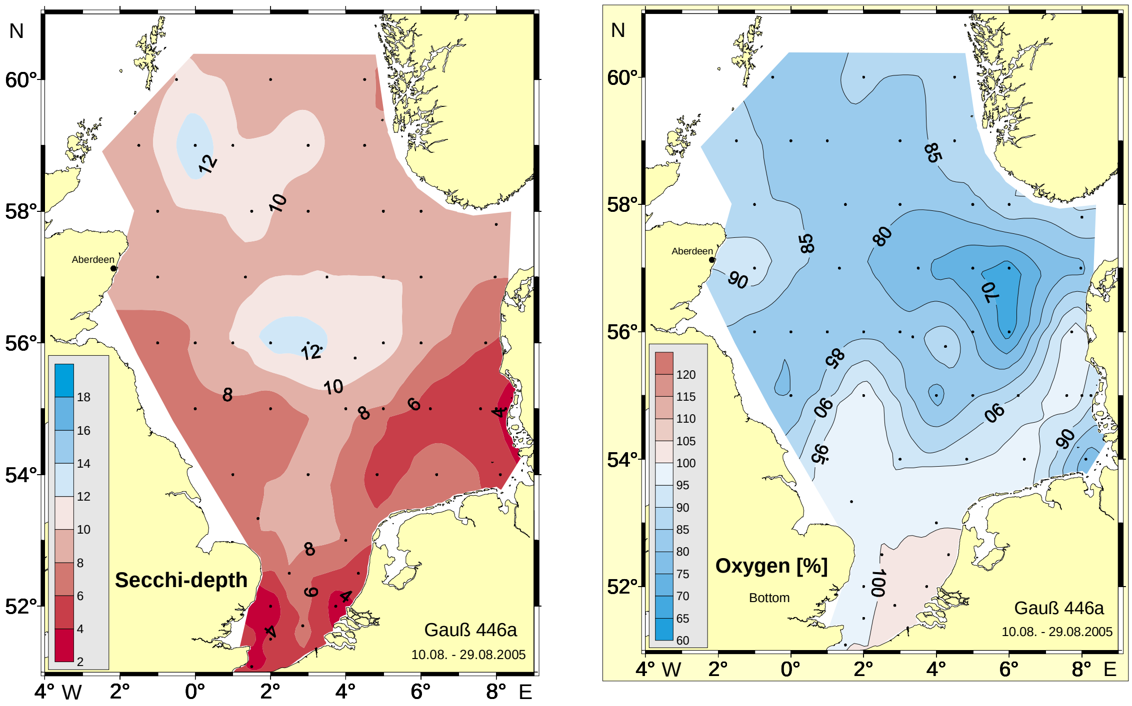
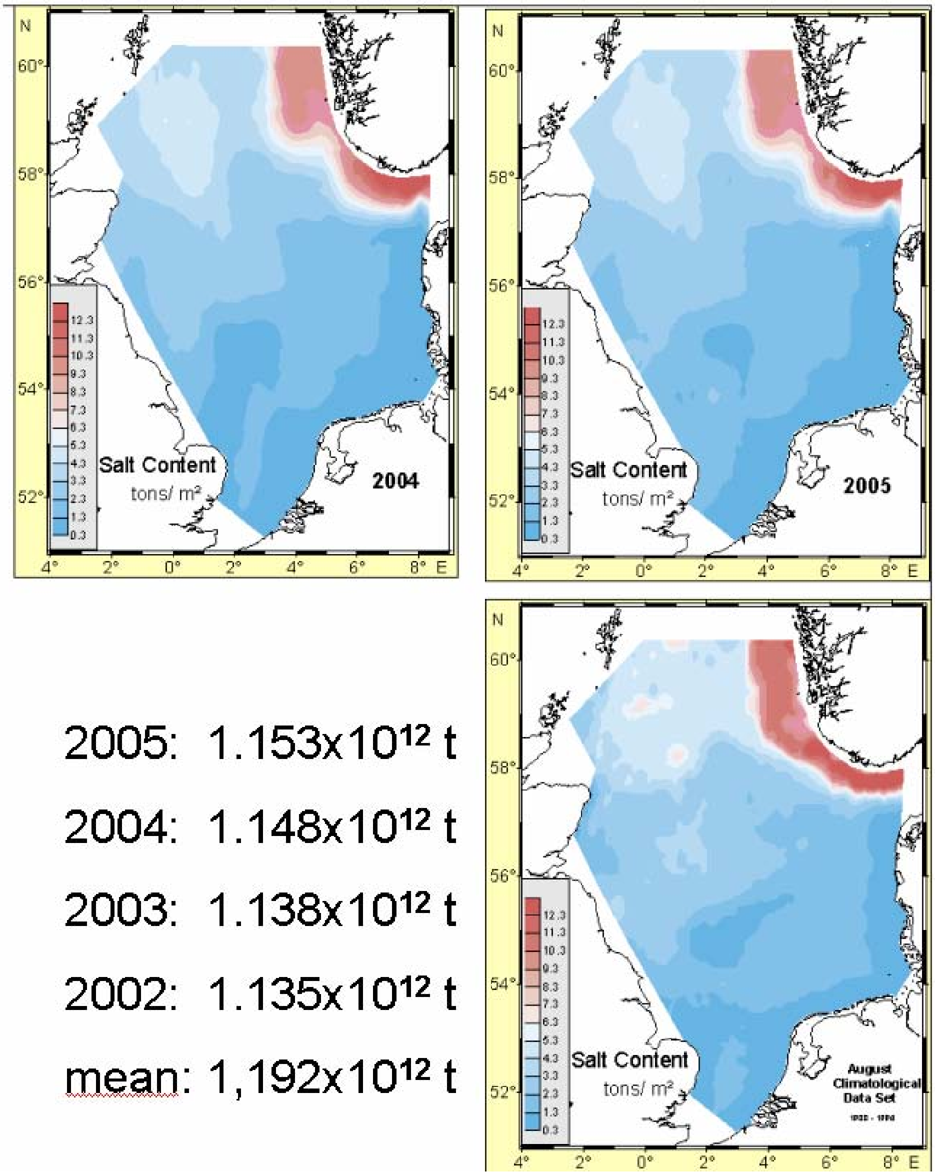


Figure A13.10: Secchi-depth [m] and near-bottom oxygen distribution [%], GAUSS cruise 446a, 10–29 August 2005.

Salt Content



2005: 1.153×10^{12} t

2004: 1.148×10^{12} t

2003: 1.138×10^{12} t

2002: 1.135×10^{12} t

mean: $1{,}192 \times 10^{12}$ t

Figure A13.11: Salt content of the North Sea evaluated from GAUSS summer cruises. The mean is the average of the years 1900 until 1996 calculated from historical data.

Using CTD data (Delphin) from the BSH summer cruises, the salt content of the North Sea was calculated (Figure A13.11). The table included shows that the salt content is gradually increasing since 2002. This is a hint of an increasing influence of the Atlantic during these years. The mean (1900–1996) was calculated from historical data [1]

Figure A13.12 shows salinity sections along 58°N from the summer cruises for the years 1998–2005. Evident are the increasing salinity concentrations at the Scottish coast during the last years and the increasing salinity at the eastern part of the section below the run-off of the Baltic Sea.

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

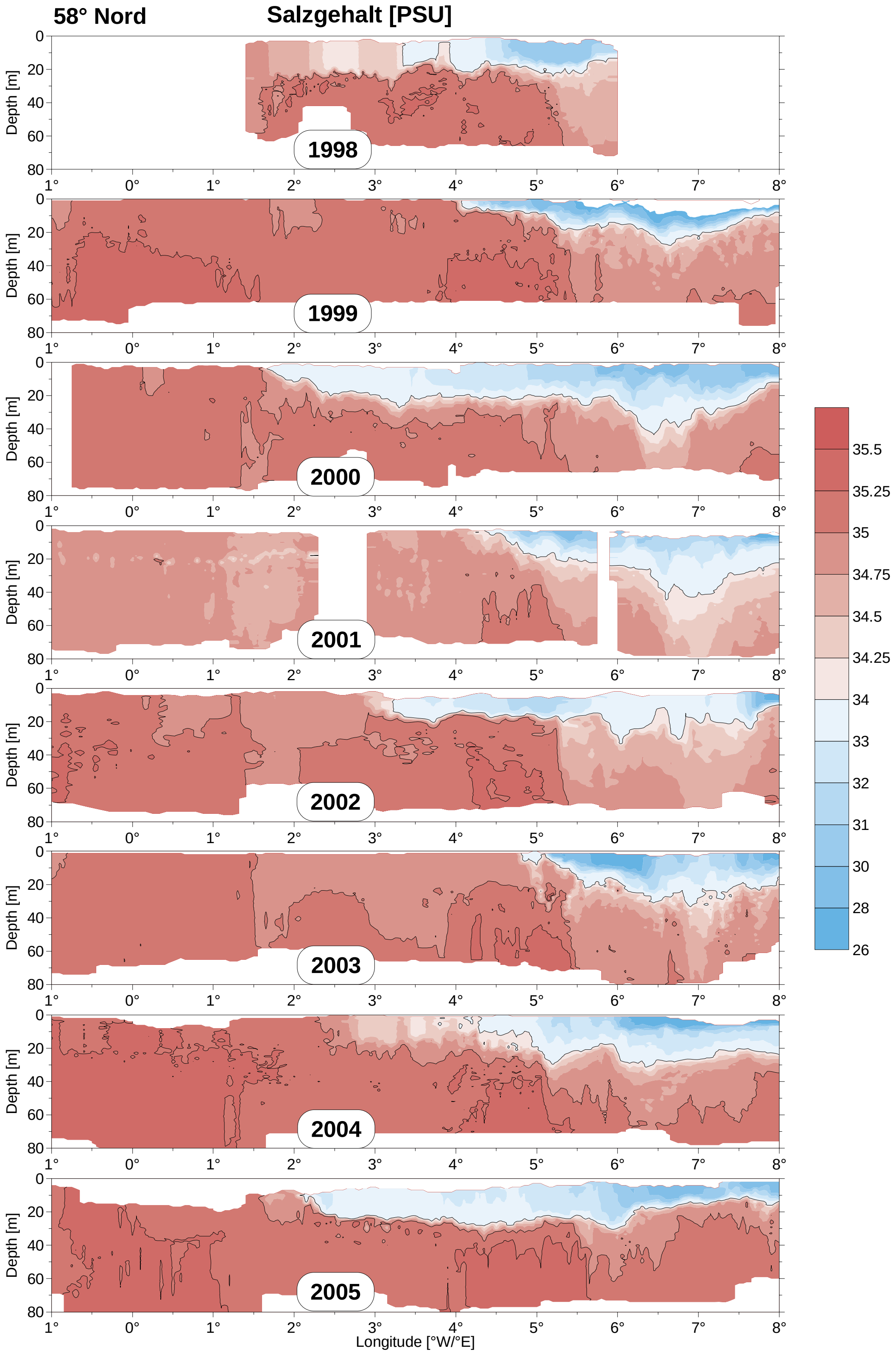


Figure A13.12: Salinity sections along 58°N from 1998 until 2005.

Chlorophyll *a*

The monthly averaged chlorophyll A distribution of the North Sea is show in Figures A13.13 –A13.15. The data are from the Moderate resolution Imaging Spectroradiometer (MODIS).

There is very poor information during the winter months due to cloud coverage. High concentration can be observed between April and October along the coasts of the southern part of the North Sea. In May there are patches of high concentration off the coasts in the German Bight and off the Netherlands and Belgium.

Compared to 2004 we observe higher concentrations along the coast East- and North Frisian coast, probably due to unusual high temperatures.

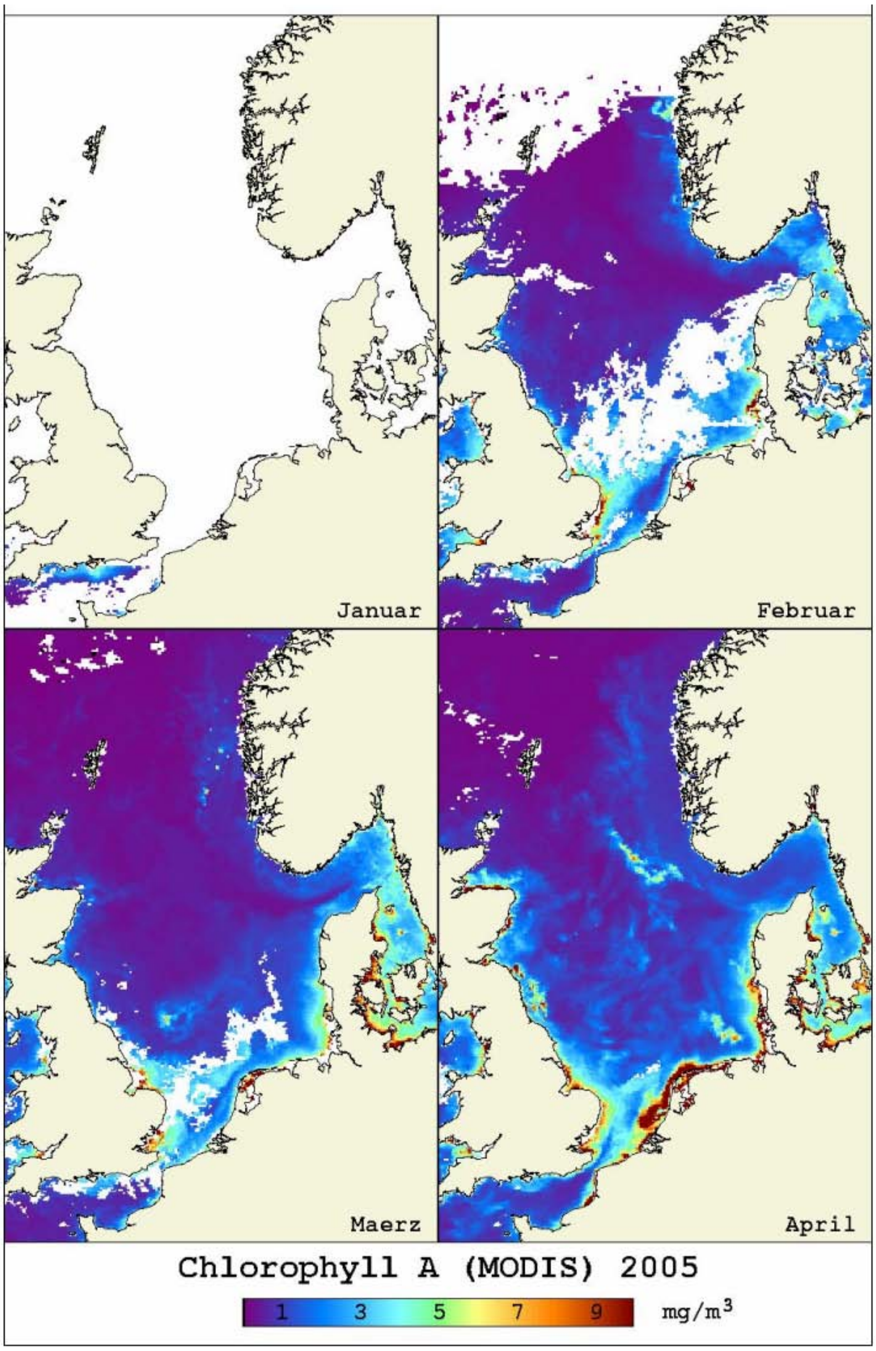


Figure A13.13: Monthly averaged Chlorphyll *a* distribution (MODIS) for January, February, March, and April, 2005.

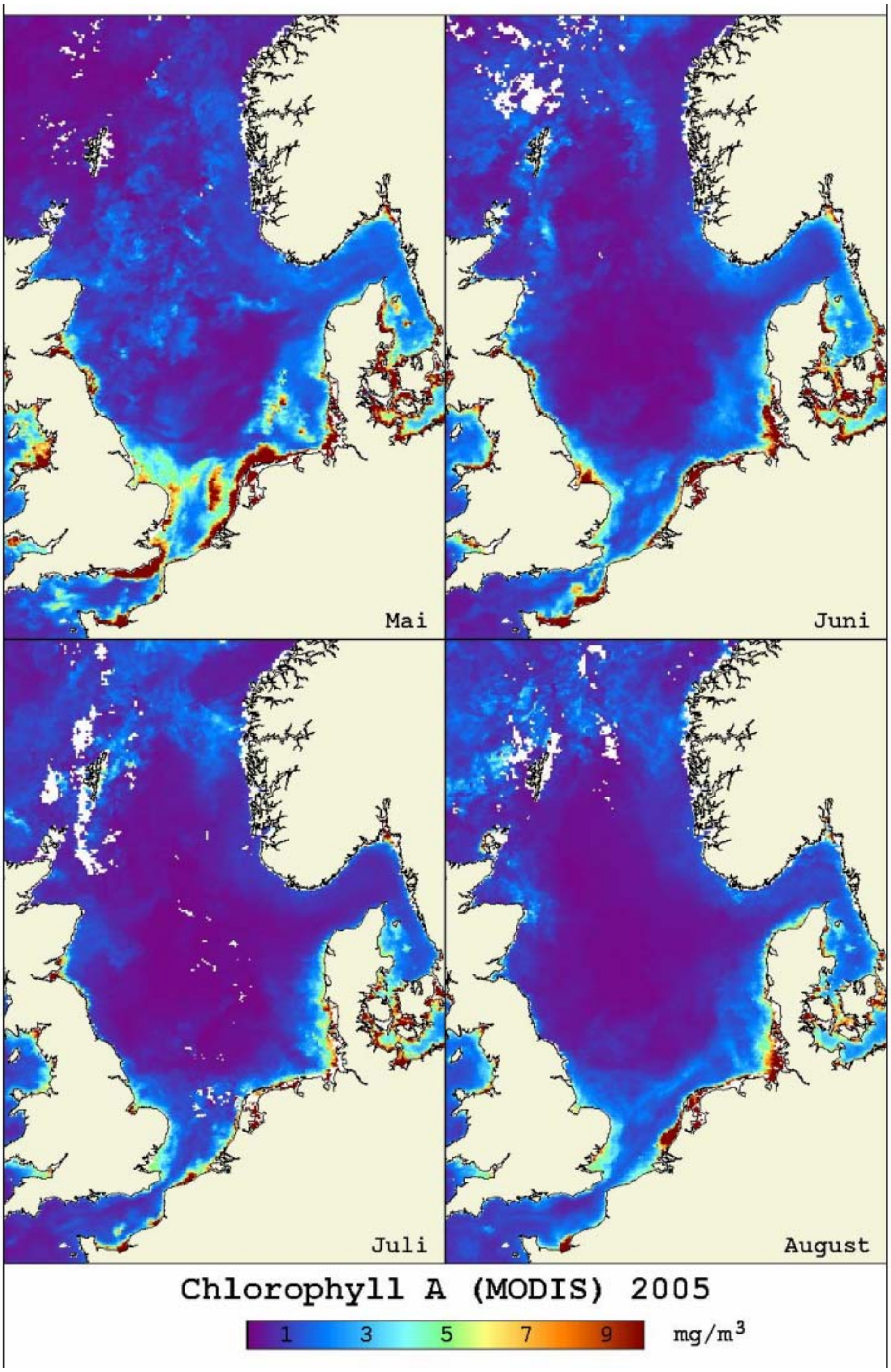


Figure A13.14: Monthly averaged Chlorphyll *a* distribution (MODIS) for May, June, July, and August, 2005.

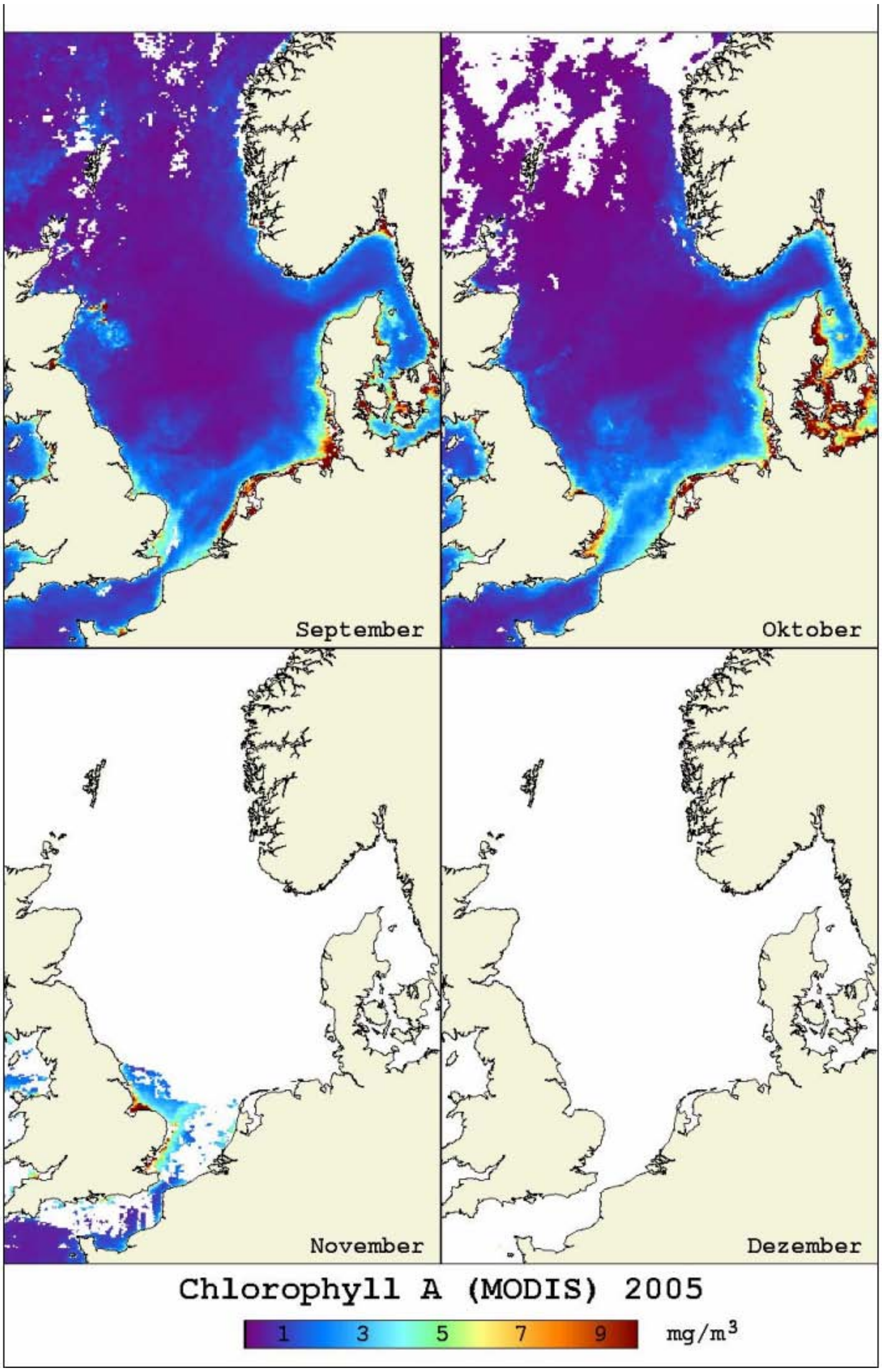


Figure A13.15: Monthly averaged Chlorphyll *a* distribution (MODIS) for September, October, November, and December, 2005.

Annex 14: Skagerrak, Kattegat and the Baltic (Area 9b)

Karin Borenäs, Pekka Alenius, Anniina Kiiltomäki, Bert Rudels and Jan Piechura

The storm Gudrun

The most dramatic event during 2005 was the storm Gudrun that hit the Nordic region on 9 and 9 January. The total amount of water in the Baltic Sea was already well above mean level in January and coupled with the storm this caused sea level to raise in record values on 9 January. Finnish mareographs in Hanko, Helsinki and Hamina measured the highest sea levels in their entire operation period, which is from 1887 in Hanko, 1904 in Helsinki and 1928 in Hamina. The new records above the theoretical mean sea level are 132 cm in Hanko, 151 cm in Helsinki and 197 cm in Hamina. In St. Petersburg, Russia, water levels reached 250 cm above reference level on the Swedish westcoast, the sea level raised 1 meter in 6 hours (Figure A14.1).

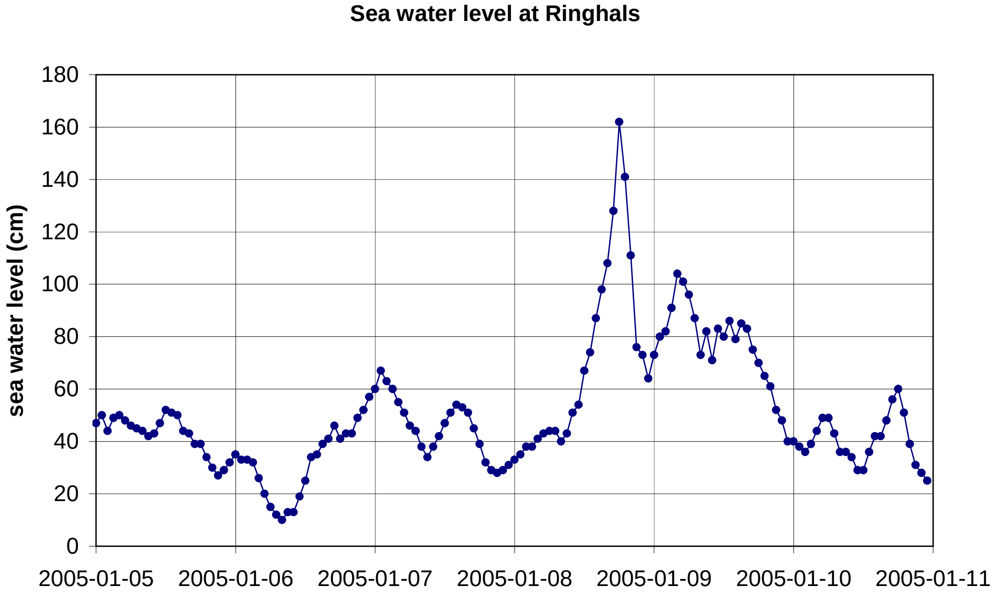


Figure A14.1: The seawater level at Ringhals on the Swedish west coast peaking on 8 January when the storm Gudrun passed.

Annual cycles of temperature and salinity

A large number of hydrographic stations are regularly visited in the Baltic Sea, the Kattegat and the Skagerrak, as exemplified in Figures A14.2 and A14.3 in which the Swedish and Finnish stations are displayed. The number of the Finnish oceanographic stations has decreased and is only five today. Some open sea stations are visited quite often but irregularly in time. Near surface, at about 2-m depth, temperatures are recorded at the 13 sea level stations, but these time-series are still only eight years long.

In addition to the regularly visited stations R/V Aranda had eleven cruises visiting altogether 377 stations covering the Baltic Sea proper as well as the Gulf of Finland, the Gulf of Riga and the Bothnian Bay (Figure A14.4).

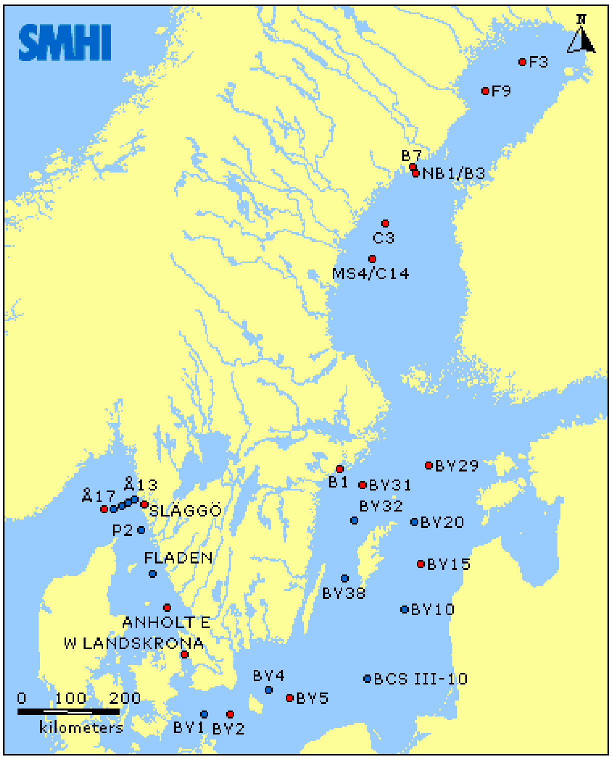


Figure A14.2: Position of stations visited on a regular basis. Stations marked with red pertain to the Swedish National Monitoring Programme while stations in blue are additional stations sampled by SMHI.

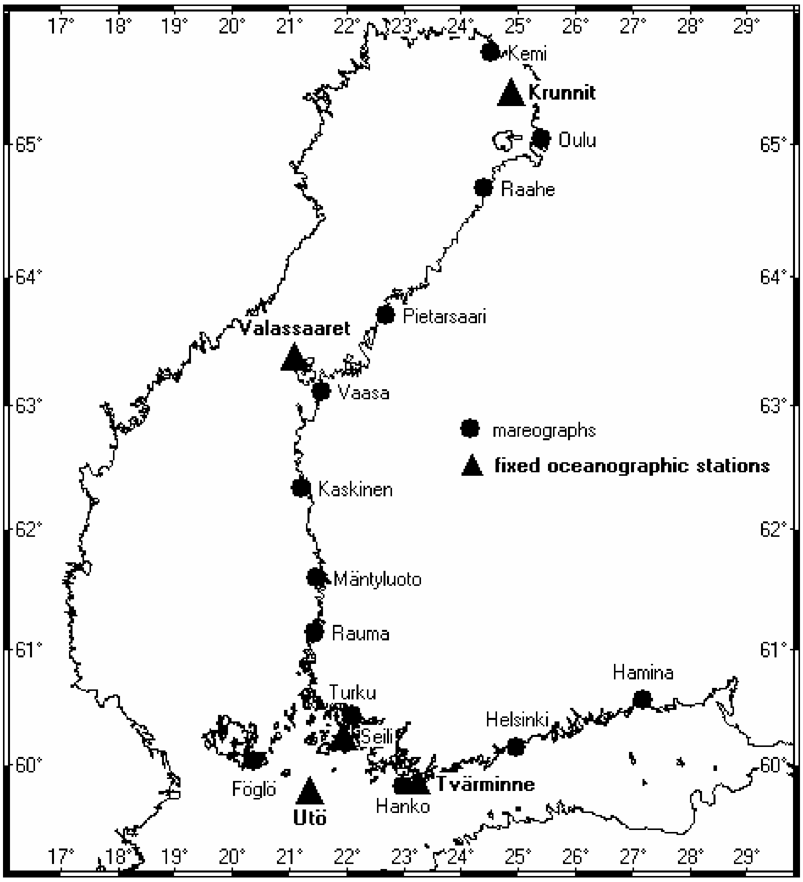


Figure A14.3: Finnish fixed oceanographic stations and sea level stations (mareographs).

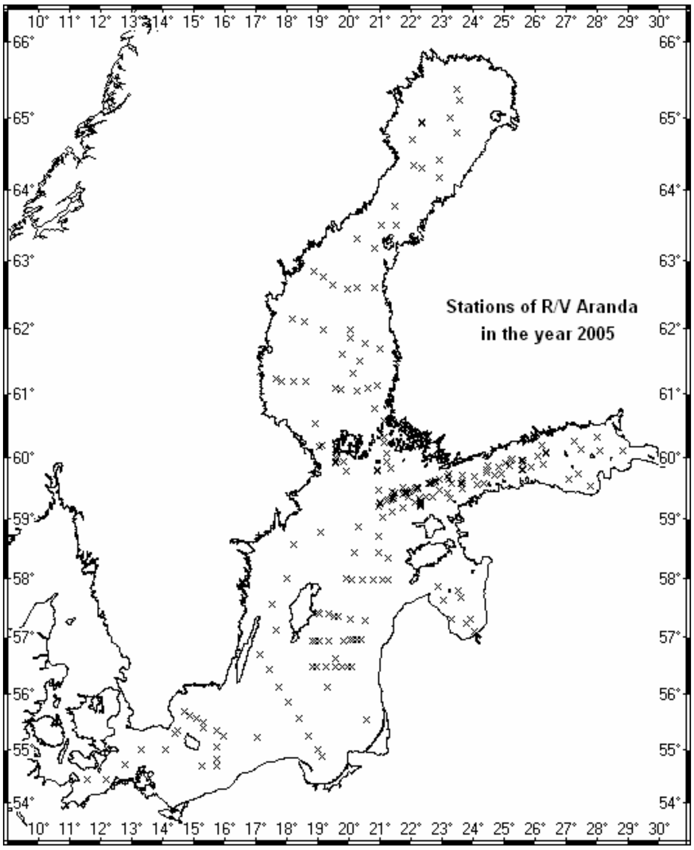


Figure A14.4: Hydrographic stations taken by R/V Aranda in the Baltic Sea in 2005. Aranda visited altogether 377 stations in 2005.

The hydrographic conditions in 2005 were, in general, close to the long-term mean values. As an example the surface temperature in 2005 from Seili in the Archipelago Sea is presented (Figure A14.5). The sea surface temperature was within the extreme values for the previous 30 years. The winter temperature was slightly higher than the average, the spring up to June was average, summer temperatures were higher than the average and the entire autumn was relatively warm.

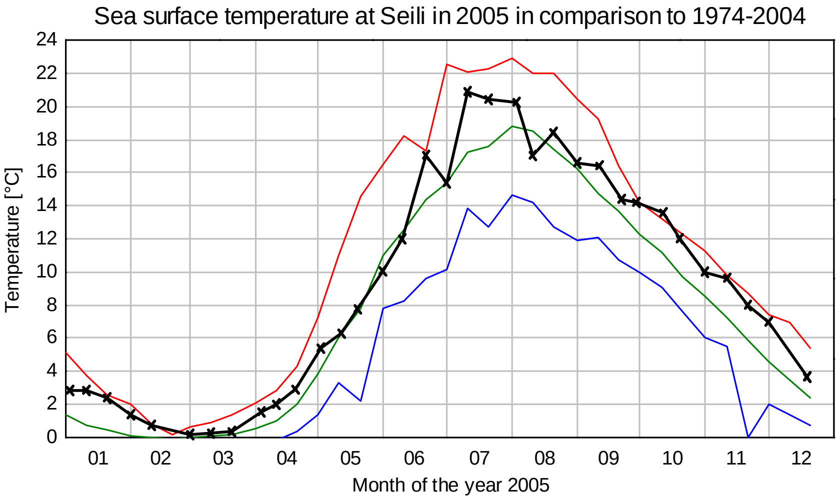
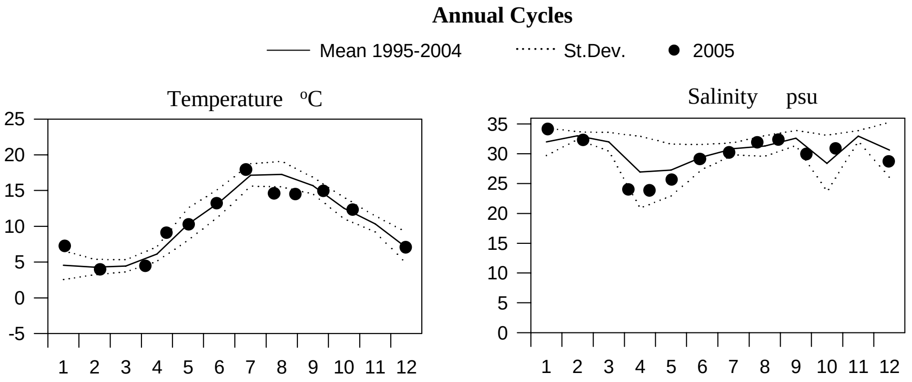


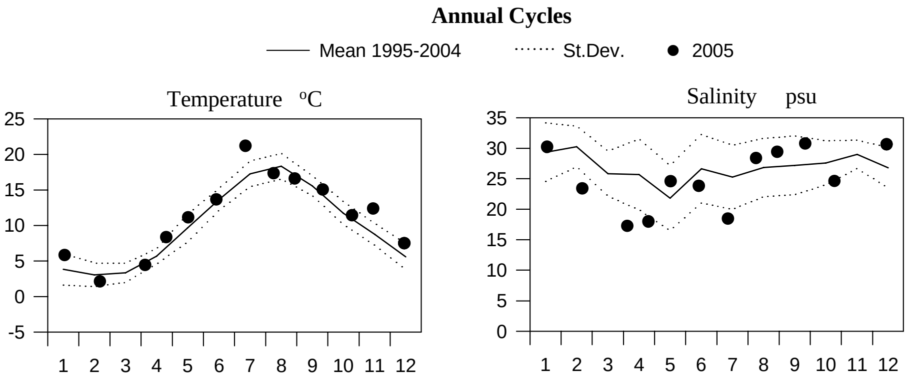
Figure A14.5: Sea surface temperature at Seili in 2005 (black line) compared to the average (green) and extreme values (red maximum, blue minimum) of the period 1974–2004. The position of station Seili is shown in Figure A14.3.

In Figure A14.6 the annual cycles of the surface temperature and salinity for a number of Swedish stations are shown. Due to warm weather at the end of June and beginning of July the highest sea surface temperatures were reached during the first half of July in the Baltic Sea as well as in Kattegat and coastal Skagerrak, which is half a month earlier than average. In the autumn the surface temperatures were somewhat higher than the mean values. The surface salinity was slightly above average in the southern part of the Baltic.

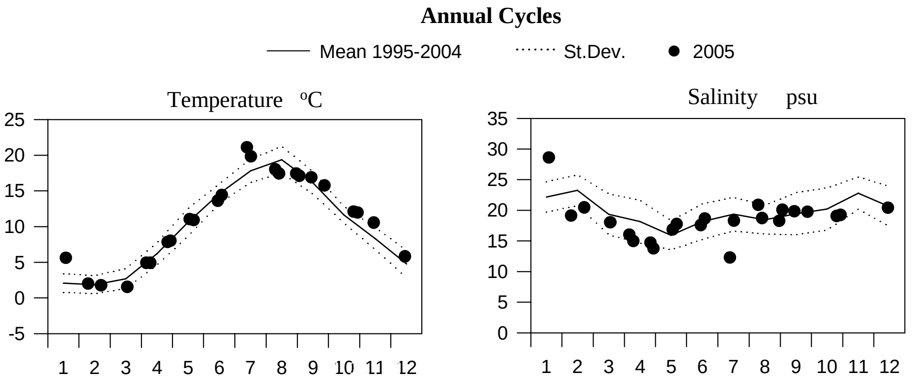
STATION A17 SURFACE WATER



STATION P2 SURFACE WATER



STATION ANHOLT E SURFACE WATER



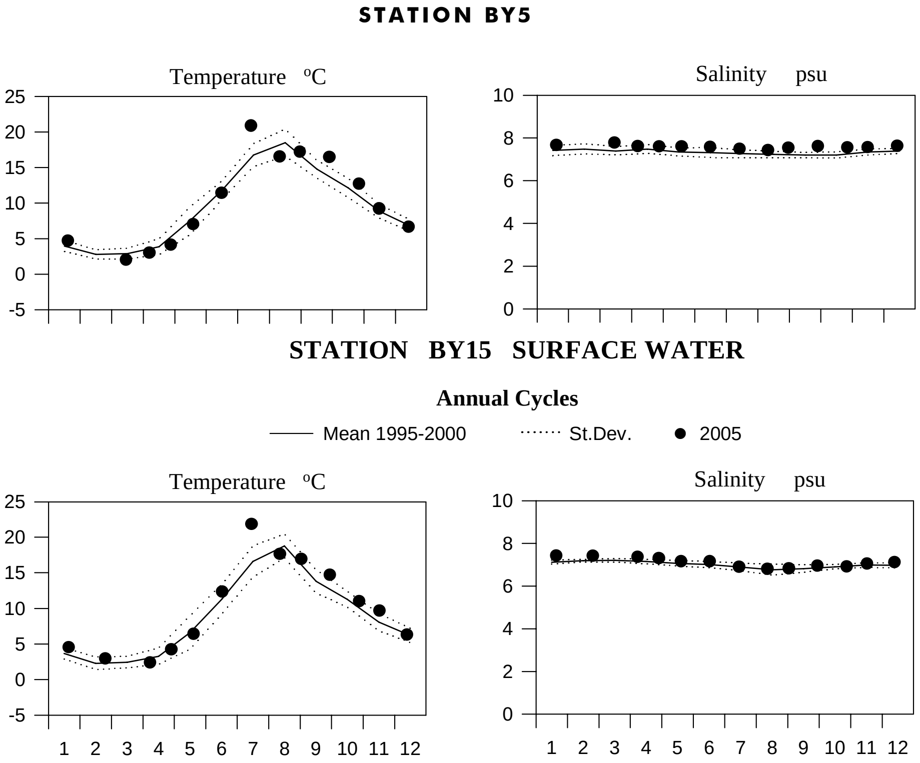


Figure A14.6: Annual cycles of temperature and salinity, see Figure A14.2 for station positions.

Long term observations

Long-term hydrographic time-series are shown for two stations, LL7 (Figure A14.7) in the Gulf of Finland and BY5 (Figure A14.2) in the Baltic Proper. At station LL7 the sea surface temperature in 2005 was similar to the two to three previous years (Figure A14.8, upper panel). A very weak trend towards warmer summers might be seen, but it is nothing dramatic. The summer sea surface salinity has decreased slightly on the long run (Figure A14.8, middle panel), but 2005 was still not exceptional. In the deeper parts of the Gulf of Finland the salinity is rather variable because of the dynamics and the large horizontal salinity gradients. However, the decrease in salinity from early 1970s to early 1990s is evident. Since 1993 there is slight trend towards higher salinity. In 2005 salinity variations in the deep water were large but not exceptional except that in May there was a short period when the salinity at 70 m depth was larger than ever since 1980s (Figure A14.8, lower panel).

The yearly mean surface salinity at station BY15 continued to increase in 2005 and the downward trend seen from the late 1970s seems to have turned (Figure A14.9).

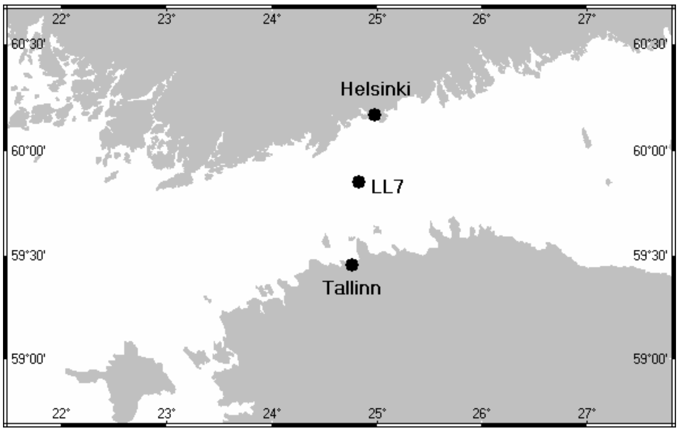


Figure A14.7: Position of station LL7.

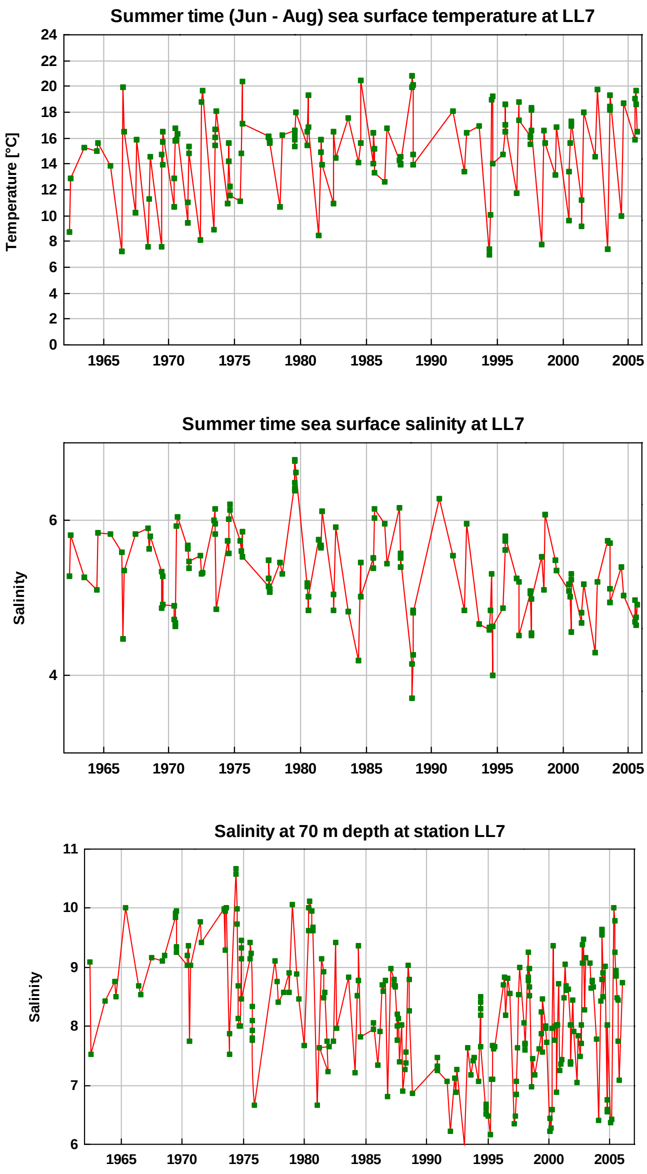


Figure A14.8: Time-series of temperature and salinity at LL7, 1962 – 2005.

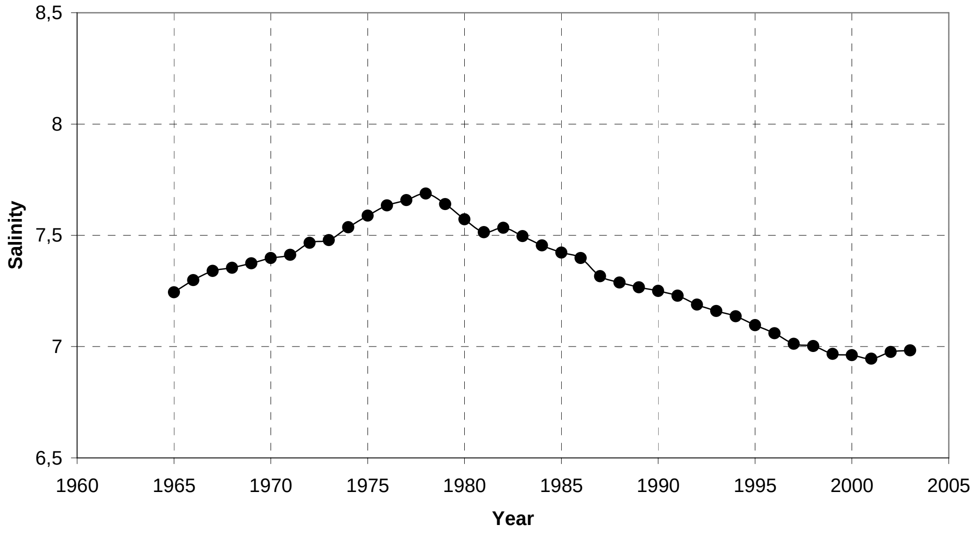


Figure A14.9: Surface salinity at BY15 (see Figure A14.1) in the Baltic proper (five-year running mean).

Water exchange

During 2005 only two minor deep-water inflows to the Baltic Sea took place, one in January and one in November (Figure A14.12a). At both occasions the volume was around 35 km^3 through Øresund. The November event brought very saline (over 24 psu) and warm (10–12°C) water to the Arcona Basin. However, the influence of the inflows was restricted to the southwestern parts of the Baltic and lasted only for short periods. The outflow from the Baltic through Øresund was close to mean values except for January and February when it was well above average (Figure A14.12b). The accumulated outflow through Øresund during 2005 was 694 km^3 which is larger than the mean value (650 km^3 for the period 1977–2004). The inflow was less than average giving a net outflow from the Baltic through Øresund of 432 km^3, which is higher than the mean value (352 km^3 for 1977–2004). The total transports into and out of the Baltic show the same pattern as the part that flows through Øresund.

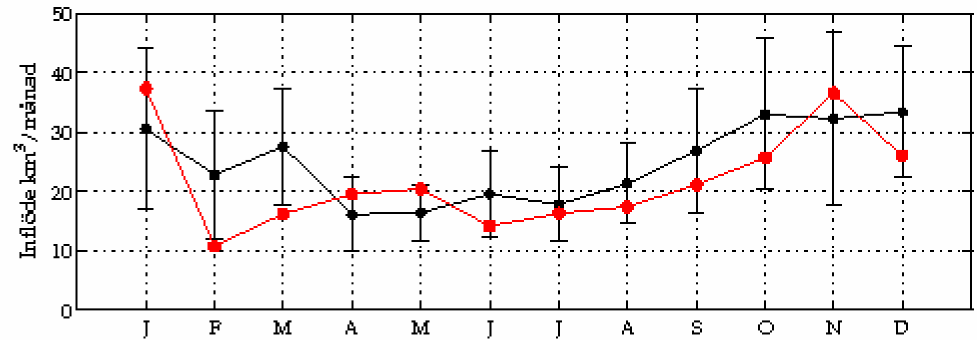


Figure A14.10a: Flow into the Baltic through Øresund summed for each month during 2005 (red) compared to 1977–2004 (black). The bars indicate +/- 1 standard deviation.

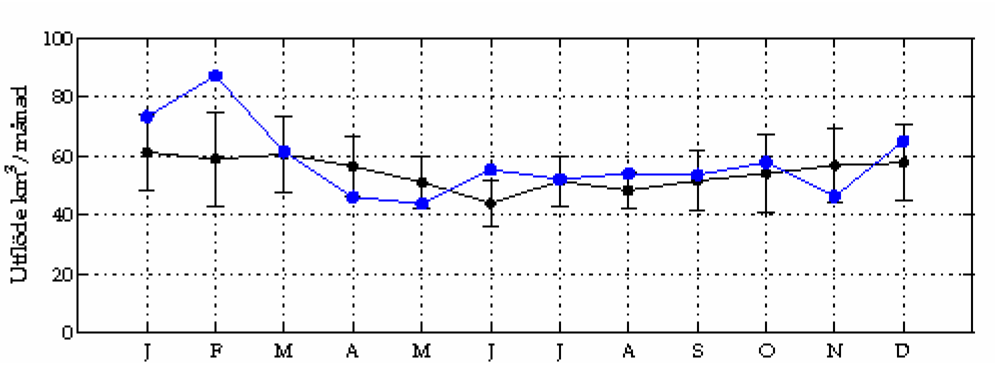


Figure 10b. Flow out from the Baltic through Øresund summed for each month during 2005 (blue) compared to 1977-2004 (black). The bars indicate +/- 1 standard deviation.

Ice conditions

The ice winter 2004/2005 was classified as average with the maximum ice extent occurring on 16 March 2005 (Figure A14.11).

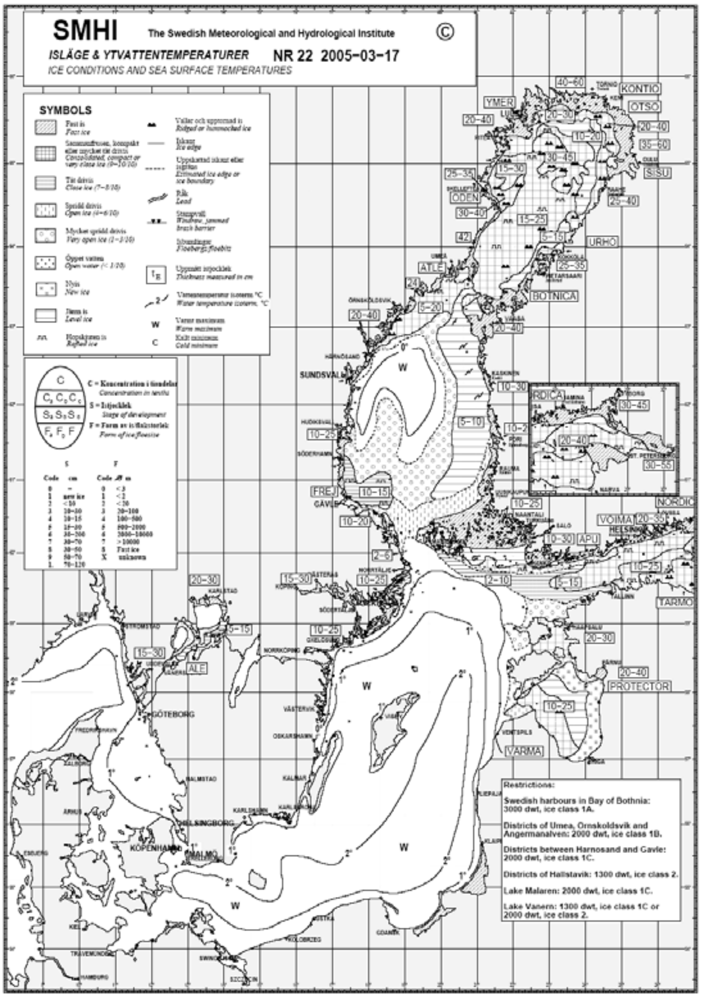


Figure A14.11: The maximum ice extent in the Baltic Sea during the winter 2004/2005. The map was constructed by the Ice Service at SMHI.

Alg@line

Alg@line is a research program lead by the Finnish Institute of Marine Research that monitors extensively fluctuations in the Baltic Sea ecosystem both in space and time. The main emphasis of Alg@line is an adequate monitoring of the phytoplankton, especially harmful algal blooms. Two different kinds of data sets are produced on the Alg@line ships by the flow-through system. Water samples are collected automatically on the 24 stationary locations for chemical and biological analysis. In addition measurements of fluorescence and physical parameters (temperature and salinity) are made every 20 seconds along the ship route.

The Alg@line program has been ongoing since 1993 for biological use. The in-depth analysis of physical parameters has started in 2002 and the measurements have proved to provide valuable information. In the Appendix a report is given on a selected Alg@line merchant ship route in which the physical parameters observed and analyzed during 2005 are compared with the 10-year mean values at the same locations.

Appendix

Baltic Sea: Arkona Basin, Bornholm Basin, Gotland Basin, Northern Baltic Proper and Gulf of Finland.

Anniina Kiiltomäki, Tapani Stipa, Vivi Fleming, Seppo Kaitala

Finnish Institute of Marine Research

In this study we have analyzed the seasonal and interannual changes in physical parameters, salinity and temperature along a transect in the direction of the greatest surface salinity gradient in the Baltic Sea. The transects measured as a part of the Alg@line ship-of-opportunity program and covers different regions of the Baltic. We have used 24 significant locations per each transect to analyze the temporal and spatial variation of temperature and salinity during the year 2005, (see Figure 1). The base of comparison is the 10 years (1993–2003) average at the same locations through the year calculated as 10 days means.

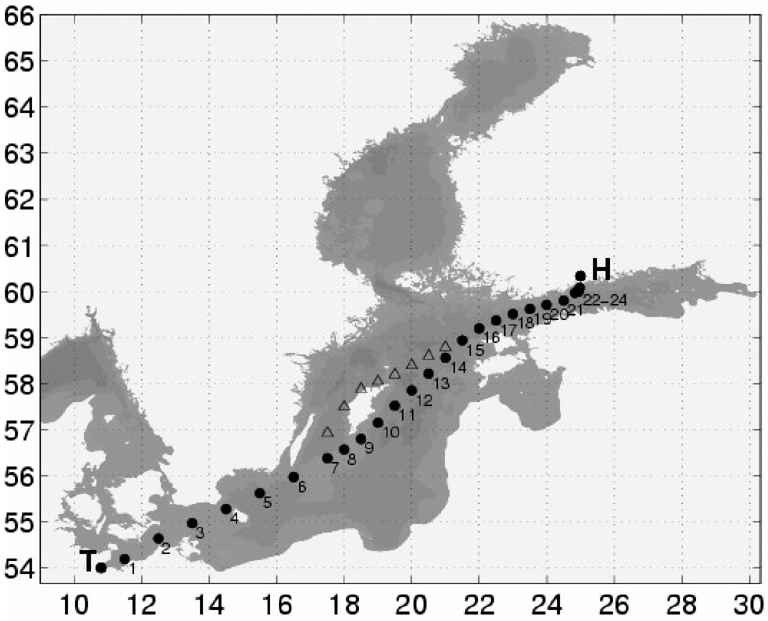


Figure 1. The measurement locations on the Alg@line route of M/S Finnpartner between Travemünde- Helsinki. The Alg@line transect locations are on following regions of the Baltic Sea: 1–2; Arkona Basin, 3-5 Bornholm Basin, 6–12; Gotland Basin, 13–18; Northern Baltic Proper and 19–24; Gulf of Finland. The triangles represents the case of west route of Gotland.

Temperature

In 2005 the surface temperature varied between −0.5°C and 24°C (see Figure 2). The temperature started to increase in the end of March reaching its highest values during the first half of July. The temperature maximum was reached half a month earlier than in the 10-year average (the reference), even though the increase of temperature started at the same time as in reference. Also in the autumn the surface temperature was warmer than in the reference.

Strong and clear upwellings occurred in the western Baltic at station 2 in the end of June-beginning of July and in the beginning of October, and at station 3 in mid August. In the northern Bornholm Basin at station 6 upwelling occurred in the end of September. In the Northern Baltic Proper and Gulf of Finland the colder surface waters were observed in the end of June, in the middle of August and in the end of September. Such phenomena are common in these areas.

Salinity

The high salinity winter inflow from the Belt Sea to the western Baltic occurred in the beginning of the year 2005 very much as in the reference. The salinity follows the reference in the western and in the central Baltic Proper. In the Northern Baltic Proper and in the Gulf of Finland the salinity starts to decrease earlier in 2005 than in the reference and also stays lower during the entire summer time period.

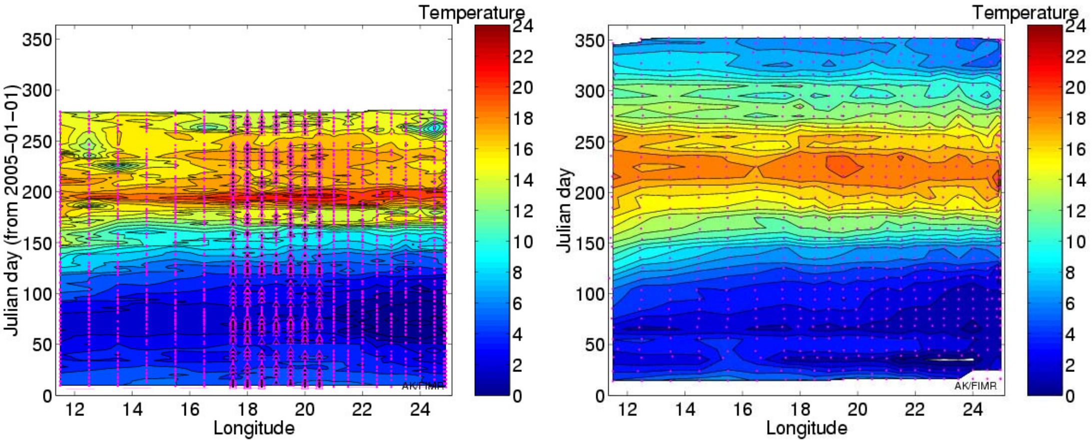


Figure 2. The annual variation in temperature (°C) as a function of position and time along the ship route (see Figure 1). On the left is the year 2005 with 2 days interval and on the right is the reference (10 year average 1993–2003) with 10 days interval. Cumulative day number is used as a temporal scale. The figures are based on red dots or triangles in case of west route of the Gotland.

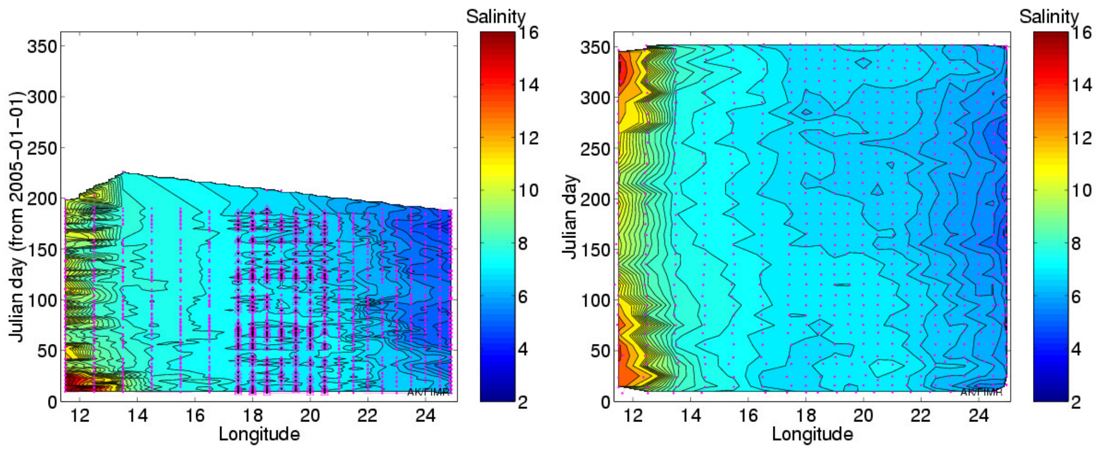


Figure 3. Idem, but salinity.

Acknowledgements

This work is partly founded by the Nordic Council of Ministers (No Comments and BANSAI projects).

Metadata

Technical information

1. Source: Finnish Institute of Marine Research, Alg@line project

2. Description of data:
Original unit of measure: salinity psu
Original unit of measure: temperature ºC
Original purpose of the data: Phytoplankton monitoring of FIMR, Alga@ine project

3. Geographical coverage: Gulf of Finland, the Baltic Proper.

4. Temporal coverage:
Reference: 1993–2003
Analysis: 2005

5. Methodology and frequency of data collection:

   Automated flow-through sampling system on merchant ships, sampling depth ca. 5 m, Weekly biweekly sampling.

6. Methodology of data manipulation: The average values are calculated from 10 year period (1993–2003). The figures are prepresenting 10 days averages on each location. The values of analysis year are represented as two days averages. Because of variability of ship time schedule and the number of transect per area under two days, those are averages of one to three transects.

Quality information

7. Strength and weakness (at data level):
Strength: Medium temporal and spatial sampling frequency. Weakness: storage time of samples from hours to a couple of days depending on the sampling site

8. a) Reliability, accuracy, precision, robustness (at data level) of Alg@line:
Measurement uncertainty: temperature relative=0.1°C, absolute=1°C
Measurement uncertainty: salinity 0.3

Annex 15: Norwegian Waters, 2005 (Areas 8, 10, 11)

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Summary

The temperature of the southern Barents Sea was approximately 0.5–1.4°C higher than average during 2005 and there was less sea-ice than average. In 2005 the Atlantic water in the Norwegian Sea was 0.4-1.0 °C warmer than normal with highest anomaly to the north. In the North Sea, the temperature was up to 2°C above the long-term mean in 2005.

Figure A15.1 shows all Norwegian standard sections and fixed oceanographic stations.

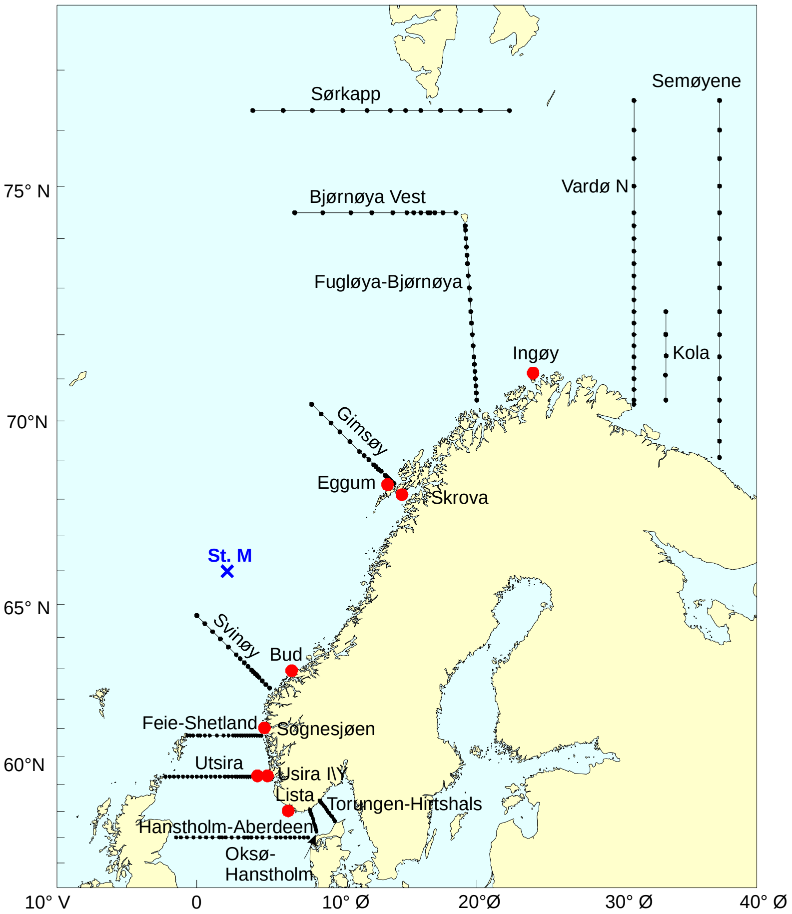


Figure A15.1: Standard sections and fixed oceanographic station worked by Institute of Marine Research, Bergen. The University of Bergen is responsible for station M, while the Kola section is operated by PINRO, Murmansk (Anon., 2002).

The Norwegian Sea

The four last years have both the temperature and salinity of the northward flowing atlantic water in the eastern Norwegian Sea been extraordinary high. Along the Norwegian continental slope the core of Atlantic Water was in 2005 0.4–1.0°C warmer than normal with highest anomaly in the north. The Norwegian Sea was also warmer than normal further offshore at 100 m depth in 2005. Largest differences were observed in central and northern parts of the Norwegian Sea.

The hydrographic condition in the Norwegian Sea is characterized by relatively warm and salt water in the east due to the inflow of the Atlantic water from the south. In the west, however, the hydrographic condition is also influenced by the fresher and colder Arctic water that arrive from the Iceland and Greenland Seas. Figure A15.2 shows the development in temperature and salinity in the core of Atlantic Water for three different sections from south to north in the eastern Norwegian Sea (Figure A15.1). There has, in general, been an increase of temperature and salinity in all three sections from the mid-1990s to present. In 2002-2004, the temperature in the Svinøy section had the largest values in the time-series. As Atlantic water flows northward the temperature increase can now also be observed further north, in the Sørkapp section. In 2005, the temperature was 0.4°C, 0.5°C and 1.0°C above the long-term-mean for the time-series in Svinøy, Gimsøy and Sørkapp sections, respectively. The salinity has the last years increased remarkable and has now the largest values in both the Svinøy and Gimsøy sections and the next largest value in the Sørkapp section for these time-series. In 2005, the salinity was respective 0.09, 0.08, and 0.07 above the long-term-mean. The large salinity values that are observed in the sections are a result of a saltier inflow of AW to the Norwegian Sea through the Faroe-Shetland Channel.

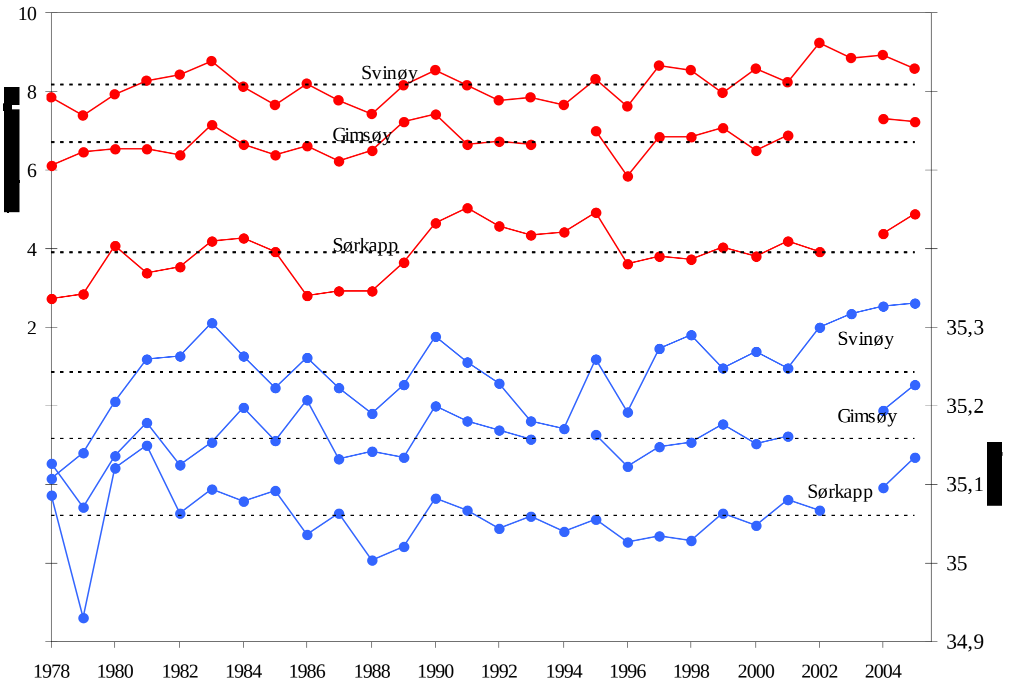


Figure A15.2: Temperature and salinity, observed in July/August in the core of Atlantic water in the sections Svinøy-NW, Gimsøy-NW and Sørkapp-W, averaged between 50 and 200 m depth. (Anon., 2006).

The area of Atlantic water (defined with S>35.0) in the Svinøy-section has been calculated. The mean temperature within the limited area has also been calculated, and the results for spring and summer are shown in Figure A15.3. Large values in the area are due to larger distribution of Atlantic water in the section. This is due to a more westerly or/and vertical distribution of Atlantic water. There are considerable variations both in the area of Atlantic water distribution and its temperature. The distribution area of Atlantic water decreased since the beginning of 1980s to mid 1990s and increased from there to present. The temperature has shown a steady increase. Since 1978 the Atlantic water has been about 0.7°C warmer. In 2002, the temperature increased considerable and had in 2003 the largest value in the time-series. The temperature has the last two years decreased and was in 2005 close to the long-term-mean. The area of Atlantic water was in 2005 also close to but somewhat larger than the long-term-mean.

Hydrographic data from an ecosystem cruise in May 2005 (figure not shown) show that the temperature at 100 m depth is above normal for most of the Norwegian Sea and not only in the east along the continental slope. In the central and northern parts the temperature was between 0.5°C and 1.5°C above normal while in the southern part it was between 0°C and 0.5°C above normal.

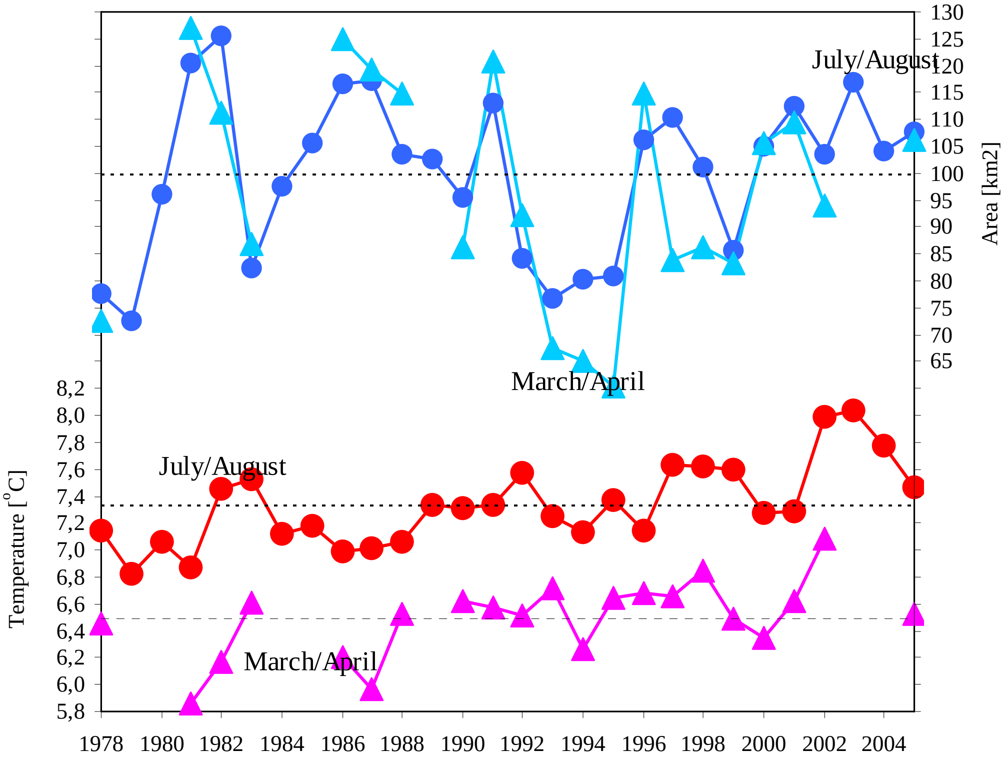


Figure A15.3: Time-series of area (in km2) and averaged temperature (red) of Atlantic water in the Svinøy section, observed in March/April and July/August, 1978-2005 (Anon., 2006).

The Barents Sea

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

The hydrographic observations were carried out according to the plan. Figure A15.4 shows the temperature and salinity anomalies in the Fugløya-Bear Island section in the period from 1977 to January 2006. 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.*, 2003).

At the end of 2004 and beginning of 2005, the temperature was more than 1°C higher than average, and the average temperature in the core of the Atlantic inflow passed 7°C for first time at the end of 2004. During spring and summer 2005 the temperature anomalies decreased to 0.5°C above average. In October 2005, the anomalies increased rapidly, and in January 2006, a positive temperature anomaly of 1.44°C was observed, which is all time high. High positive temperature anomalies were also observed in the entire Barents Sea at the end of 2005 and beginning of 2006. The salinity variations are similar to those in temperature, and there has been a high salinity during the last three years.

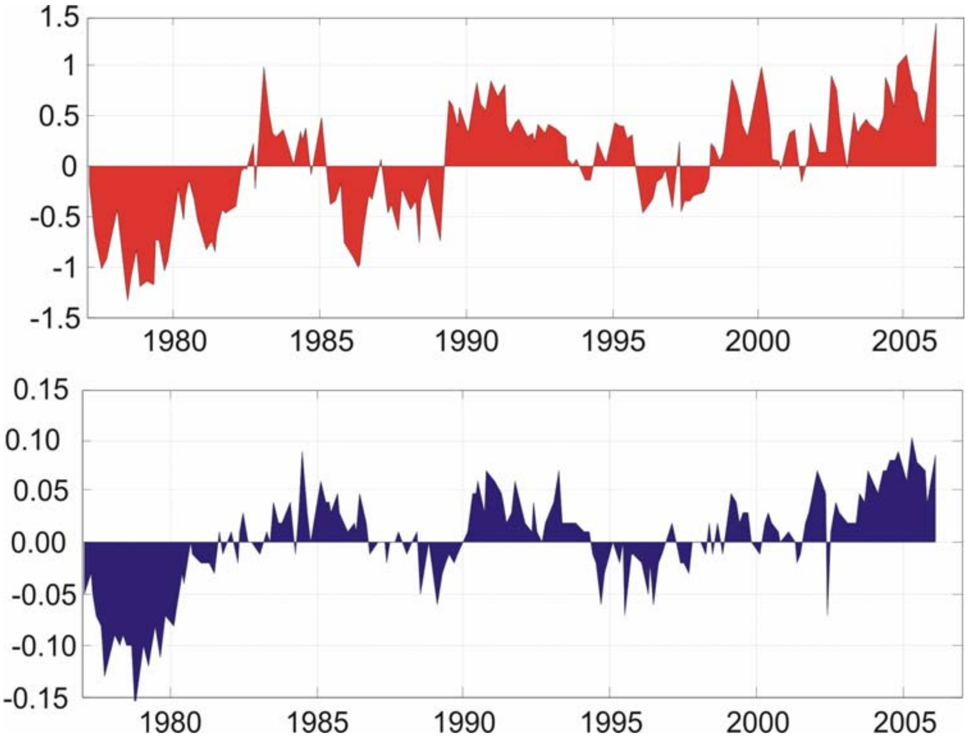


Figure A15.4: Temperature anomalies (upper panel) and salinity anomalies (lower panel) in the section Fugløya – Bear Island section.

Figure A15.5 shows the ice index for the Barents Sea. The variability in the ice coverage is closely linked to the temperature of the inflowing Atlantic water. The ice has a relatively short response time on temperature change (about one year), but usually the sea ice distribution in the eastern Barents Sea respond a bit later than in the western part. 2005 had a positive ice index, which means less ice than average. This was due to the high temperatures observed in the Barents Sea. Also 2006 started out with very little ice in the area.

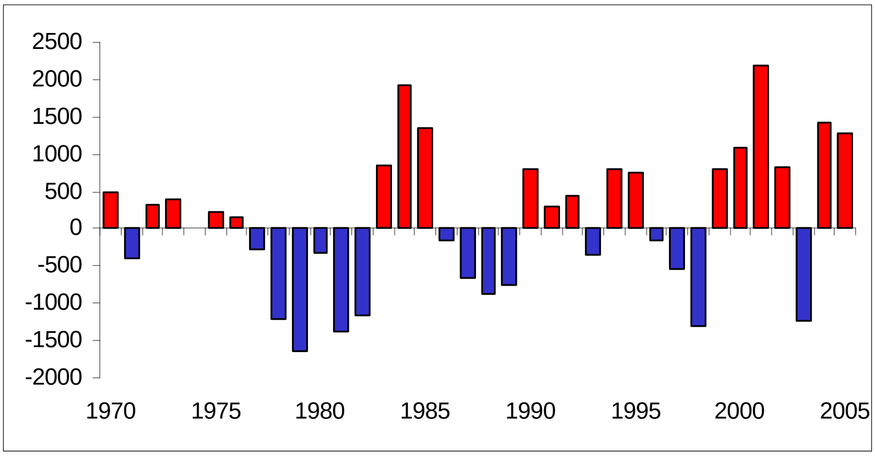


Figure A15.5: Ice index for the period 1970-2004. Positive values means less ice than average, while negative values show more severe ice conditions.

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

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

The time-series of volume transport reveals fluxes with strong variability on time scales ranging from one to several months (Figure A15.6). 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. After a maximum in 2003, the inflow decreased in 2004, and was low throughout most of the year. In 2005 there was a strong inflow in the in January and February, and after a short period with low inflow, there was a pretty strong inflow during summer 2005.

The time-series of volume transports shows a relatively high inflow during 1997 and 1998, before the transport decreased and reached a minimum in end of 2000. Then there was a strong increase in the transport until beginning of 2003. Earlier it has been believed that the temperature and the volume transport varied in a similar manner; that is that high temperature was linked to high volume transport and lower temperature was linked to reduced inflow of Atlantic water. However, Figure A15.6 shows that in periods there seems to be no correlation between the fluxes and the temperature of the inflowing water. In fact, in periods the temperature increase while the volume flux decreases, and high positive temperature anomalies observed in 2004 are not due to an increased inflow, as we did believe earlier. The changes in temperature seem to take place 1.5–2 years after the change in Atlantic inflow.This shows that in the Fugløya-Bear Island section the temperature is independent of the volume flux into the Barents Sea. The reason is simply that while the temperature of the inflowing water depends on the temperatures upstream in the Norwegian Sea, the volume flux depends mainly on the local wind field. This shows the importance of measuring both volume transport and temperature, since they not always are varying in the same manner. This is a new discovery that we can relate to ASOF.

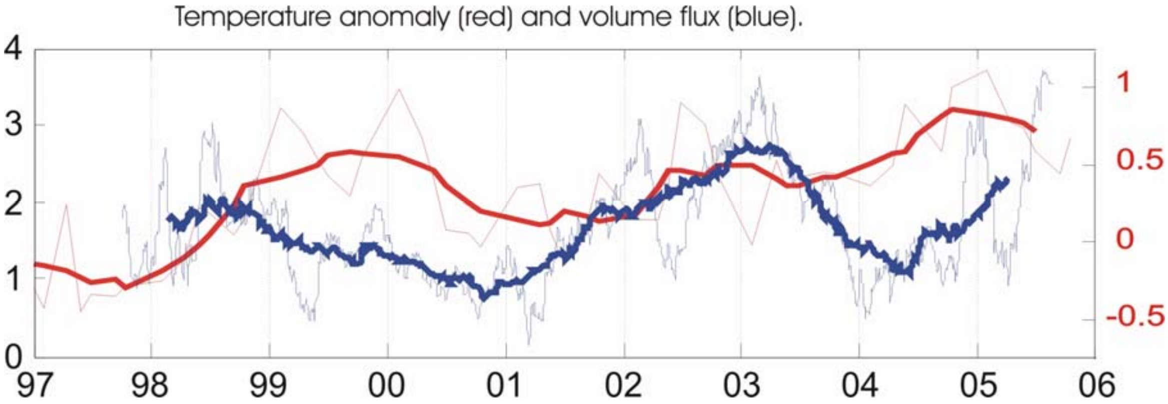


Figure A15.6: The blue lines show Atlantic Water volume flux across the section Norway-Bear Island. Time-series are 3 and 12 months running means. The red lines show temperature anomalies the Fugløya – Bear Island section. Time-series are actual values and 12 months running means.

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

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

A comparison of modelled and observed sea surface temperature (SST) with data from the Pathfinder AVHRR satellite, show that in March, the model produces a realistic transport of warm water northward west of Spitzbergen and the region encompassed by the 2 degree isotherm matches the satellite SST distibution. The model results for September also show good agreement with the satellite SST field (Figure A15.7).

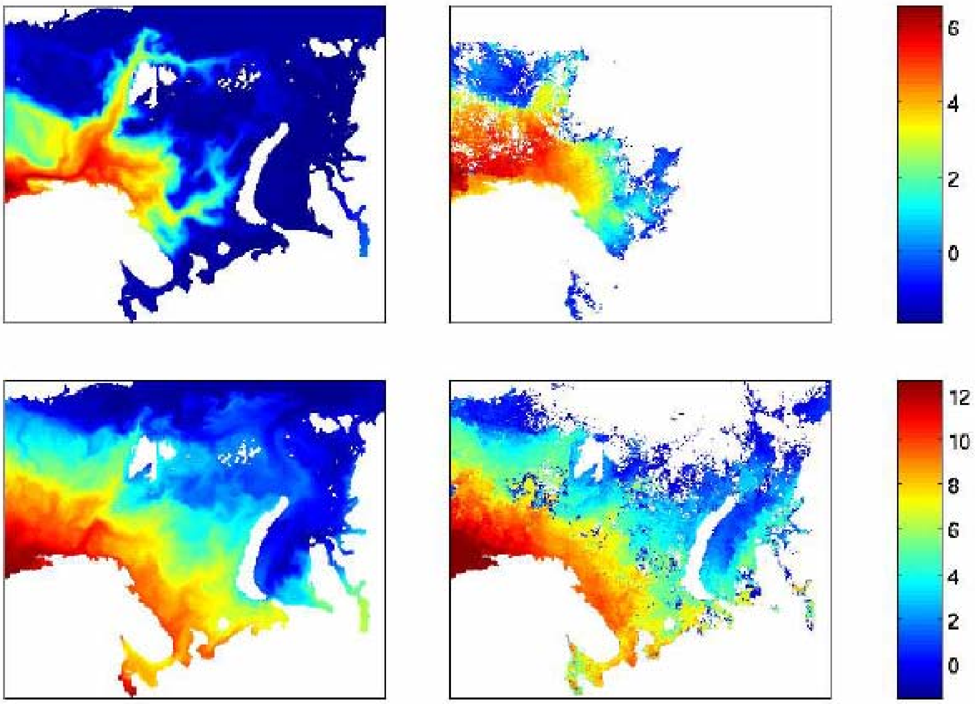


Figure A15.7: Modelled vs. Pathfinder AVHRR monthly-mean SST. The top row is from March, 1993, the lower row is from September, 1993. The left-handed column contains the ROMS model fields, the right-hand column contains the Pathfinder AVHRR fields.

The sea ice concentration in the Barents Sea can exhibit considerable variation both seasonally and inter-annually, and a comparison with an integral estimate of monthly-mean total area ice cover with observations from the SSM/I satellite show excellent agreement for the winter and an excessive ice melting in the model during summer (Figure A15.8). This melting is most likely due to poor surface forcing during summer.

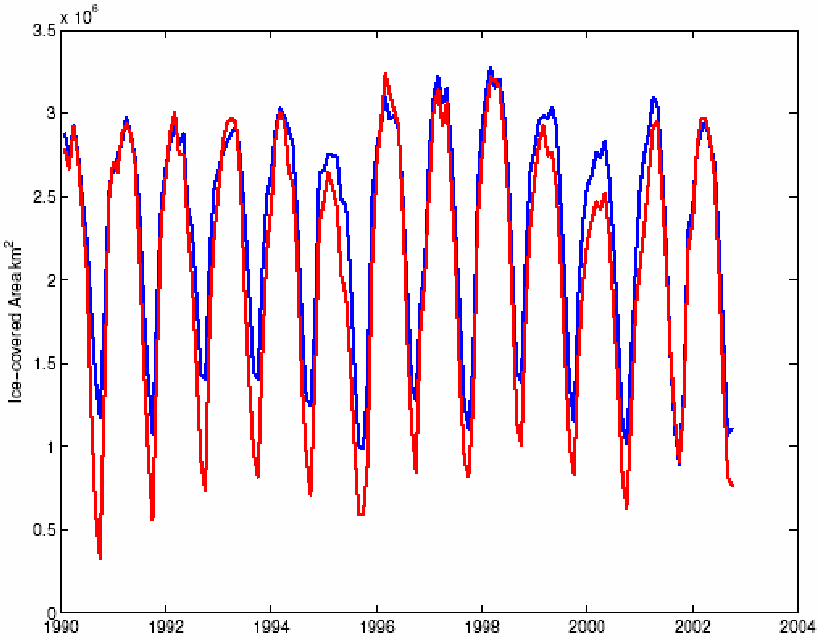


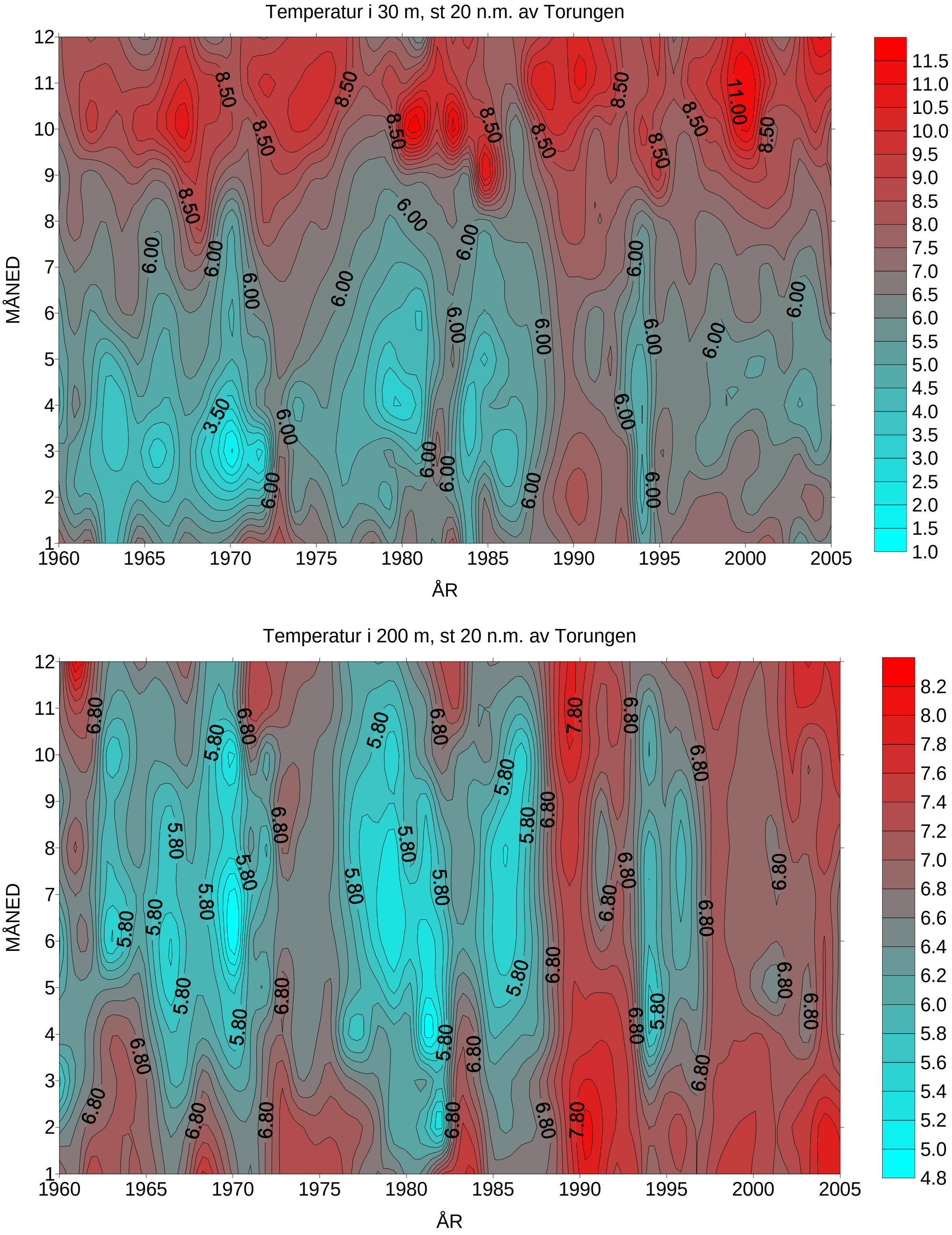
Figure A15.8: Monthly mean modeled (red) and SSM/I (blue) time-series of the ice-covered area in the Barents Sea model domain.

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

The North Sea

At the end of 2005 and the start of 2006 the temperatures in the upper layer of the North Sea were extremely high, about two degrees warmer than normal. The cold water previously present for large parts of the year has now been absent for several years. We assume that this together with the high temperatures must have significant effects on the ecosystem dynamics both in the North Sea and the Skagerrak.

In the beginning of 2005 the upper water masses were about 1–1.5°C warmer than normal basically all over the North Sea. Mild southerly winds in December 2004 and January 2005 was followed by relatively cold winter weather which led to a rapid normalizing of the temperature which stayed near the normal up to the autumn. Extremely warm weather in the late summer and autumn lead to the warmest water observed during the last 35 years. The development of the temperature over time in the Skagerrak is assumed to be quite representative for the development in large parts of the North Sea. In addition to increased temperature, it is seen from Figure A15.9 that also the length of the warm season has increased significantly during the last years. This is quite unique in relation to the last 45 years, and similar conditions were observed just around 1990. The earlier observed coldest water, especially the deeper water, has been absent for several years.


Temperatur i 30 m, st 20 n.m. av Torungen

Temperatur i 200 m, st 20 n.m. av Torungen

Figure A15.9: Temperature development though the year and from the period 1960-2005 at 30 meter (upper) and 200 meter depth in Skagerrak 20 nautical miles outside Torungen lighthouse near Arendal, Norway.

Figure A15.10 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 A15.10). Also the salinity is slightly lower at the plateau. In both places there was extremely high temperature and salinities in 2004. This is a result of very high salinity in the inflowing Atlantic water and the effect of a mild winter. The relatively cold winter and spring of 2005 lead to less extreme temperatures in the deep layers than in 2004, while the salinity particularly on the North Sea plateau are extremely high due to very high salinity of the inflowing Atlantic water.

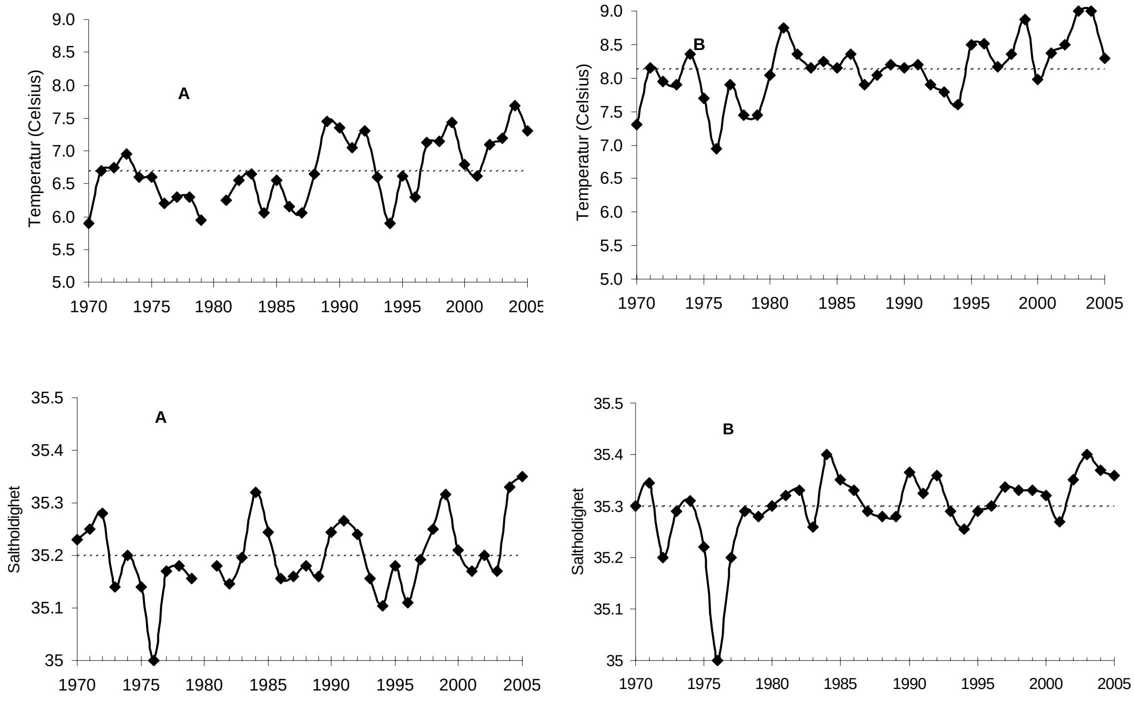


Figure A15.10: Temperature and salinity near bottom in the northwestern part of the North Sea (A) and in the core of Atlantic water (B) at the western shelf edge of the Norwegian Trench during the summers of 1970–2005 (Anon., 2006).

Estimates from a numerical ocean circulation model (NORWECOM) showed that the circulation in the North Sea was quite variable during 2005. After a strong inflow of Atlantic water to the northern North Sea in December 2004 and January 2005, the inflow during the rest of the winter and the spring was quite normal. In the third quarter a new relatively (to the season) strong inflow occurred, while it was quite normal in the fourth quarter with quite low inflow in December (Figure A15.11). The inflow through the English Channel was quite weak, particularly during the first quarter with a net outflow in February. During spring we had a strong inflow of Baltic water to the Skagerrak, co-occurring with high inflow of Atlantic water, being found higher in the water column (at the opening to Kattegat) than observed the last 18 years.

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 (first quarter) approximately half a year earlier. In 2005 the model prognosis was 45 000 ton while the following catches was 25 000 ton.

As predicted in 2004 there was in the Skagerrak renewal of the deep oxygen-rich water early in 2005, with oxygen rich and high density water. We therefore do not expect a new renewal in 2006.

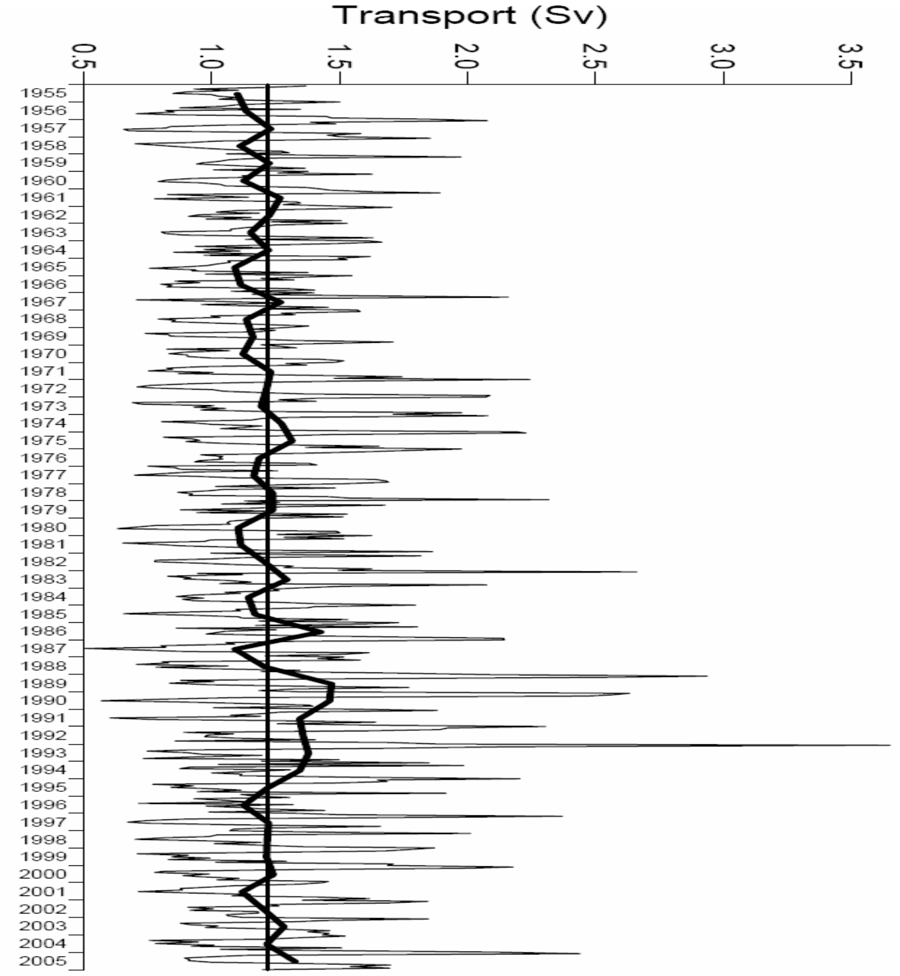


Figure A15.11: Time-series (1955–2005) of modelled annual mean (bold) and monthly mean volume transport of Atlantic water into the northern and central North Sea southward between the Orkney Islands and Utsira Norway. 1 Sv = $106 m^3 s^{-1}$. (Anon., 2005).

Annex 16: Atlantic Domain of the Nordic Seas, 2005 (Area 8,10,11)

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Institute of Oceanology Polish Academy of Sciences, Sopot, Poland

1. Observations 2005

AREX2005 cruise of Institute of Oceanology Polish Academy of Sciences (IOPAS) vessel R.V Oceania was performed in period of 8 June 2005–19 July 2005. 200 CTD casts along 13 sections were done (Figure A16.1). The SBE 9/11 device was used. Measurements of currents were performed by means of lowered Acoustic Doppler Current Profiler (LADCP). The self-recording 300 kHz RDI device was used to profile entire water column during the standard CTD casts. During the whole cruise continuous currents measurements by the ship-mounted ADCP, RDI 150 kHz were conducted.

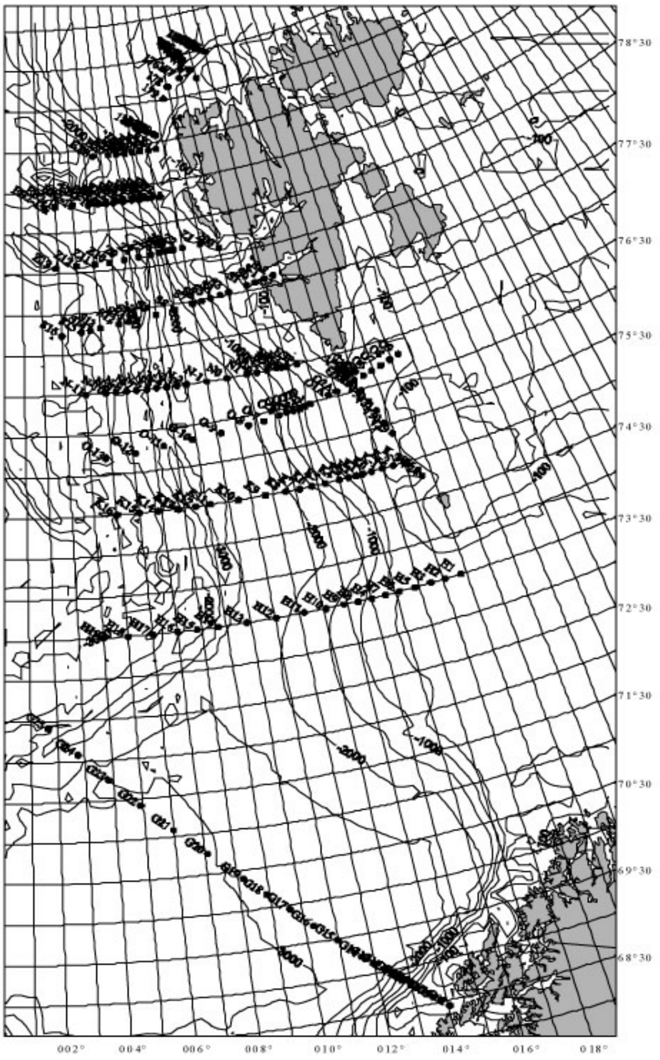

Figure A16.1: Stations grid performed during R.V 'Oceania' cruise, summer 2005.

2. Hydrographic conditions

In June/July 2005 temperature and salinity in the upper layer of investigated region (Figure A16.2) was higher than observed in summer 2004 and higher than mean properties for summers 2000–2005 (Figure A16.3). Also measurements at standard sections show much higher then usually temperature and salinity of inflowing Atlantic Water.

Measurements at the section ‘N’ along the 76° 30’ N parallel, from latitude 004°E to 015°E has been performed from the board of R.V. ‘Oceania’ every summer since 1996. For entire section in 2005, mean temperature and salinity at 200 dbar was respectively 3.71°C and 35.090 in comparison to 3.30°C and 35.047 in 2004. Between latitudes 009–012°E mean temperature and salinity at 200 dbar was in 2005 respectively 3.78°C and 35.103 in comparison to 3.37°C and 35.061 in 2004 (Figure A16.5). The Atlantic Water core temperature was lower than in summer 2004, but west of Spitsbergen shelf, especially over the Knipovich Ridge water temperature and salinity reached the highest ever observed by R.V. ”Oceania” values (Figure A14.4).

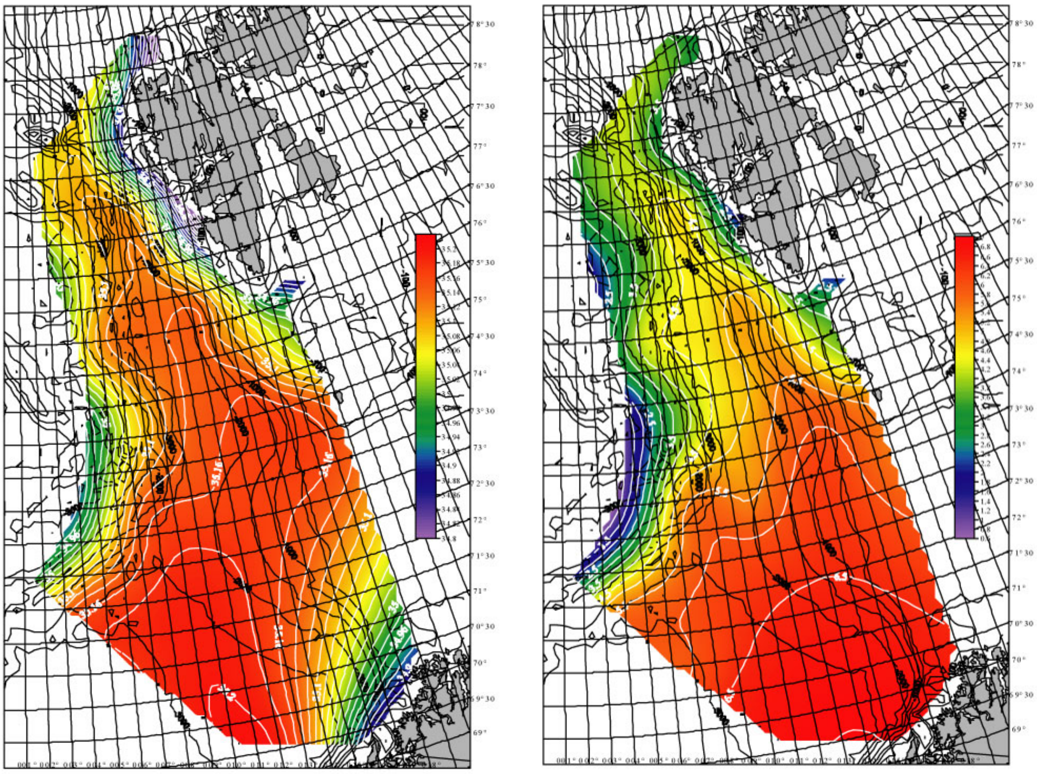

Figure A16.2: June–July 2005. Salinity (left panel) and temperature at 100 dbar.

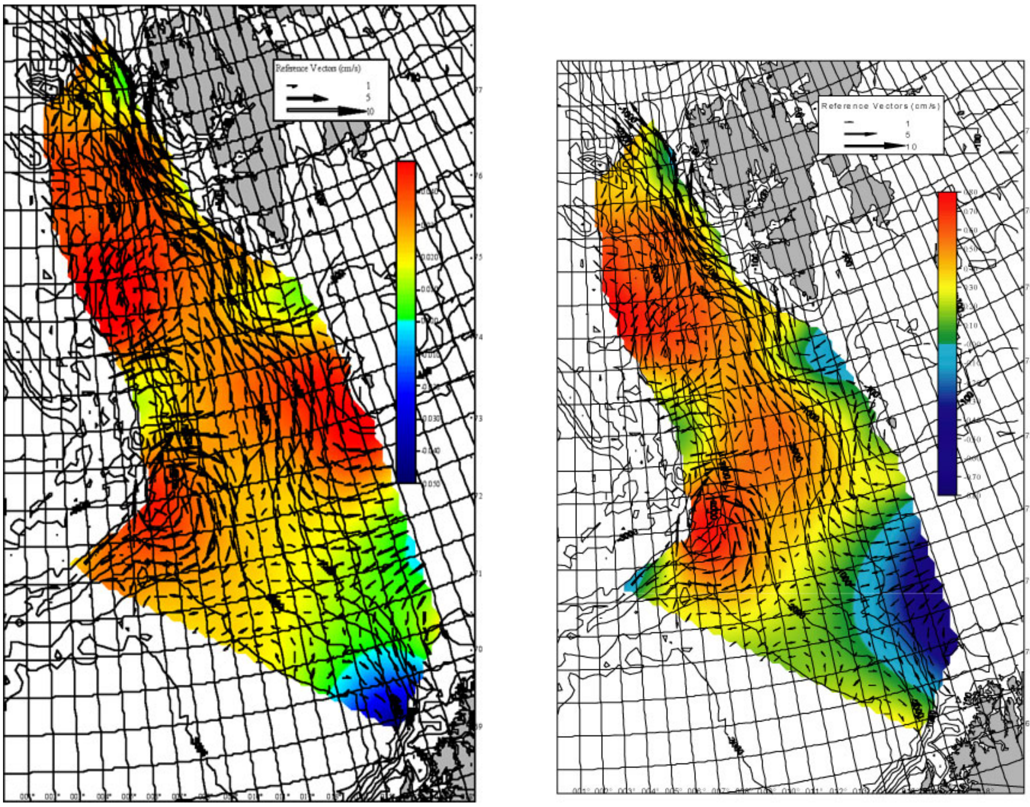

Figure A16.3: June–July 2005. Anomaly of salinity (left panel) and temperature at 100 dbar. Anomalies of geostrophic currents (calculated in reference to 1000 dbar) in background. All anomalies were calculated in reference to summer 2000–2005 mean.

3. Dynamics

Figure A16.5 presents the distribution of temperature, σΘ and baroclinic currents at 100 dbar (currents calculated for the reference level of 1000 m.) during summer 2005. Considerable part of AW flowing along the Norwegian coast proceeds eastward into the Barents Sea. Strict description of currents pattern in the southern part of polygon is impossible due to the spare data distribution. The rest of AW inflow continues northward as two separated branches of the West Spitsbergen Current. The main core (the eastern branch) is related to the Barents Sea and Spitsbergen shelf break and slope. This branch is warmer and more saline than the western one, related to the submarine ridges system (Mohn, Knipovich Ridge). Both branches converged at 77°30 -78°N, then diverged again downstream, forming a multi-path flow structure in the Fram Strait. Part of the AW flowing along the shelf break (the Svalbard Branch) entered the AO along the slope.

In 2005 both branches were very active, also mesoscale activity was intensive. Two large eddies were observed in the western branch: one at latitude 73°20'N, the other at 76°10'N. The southern eddy was 150 km in diameter, AW reached a depth of 900 m, and the density structure was disturbed even below 2000 m depth.

The baroclinic calculations show in summer 2005 a little less intensive inflow of AW across the Fram Strait than in summer 2004 (0.94 Sv of AW in 2005 in comparison to 1.01 Sv in 2004). Also heat transport was smaller (17.82 TW in 2005, 18.72 TW in 2004). However heat transport cross the section 'N' (76° 30' N parallel) was in 2005 higher than in 2004. It probably means that in summer 2005 the warm signal was only approaching the Fram Strait

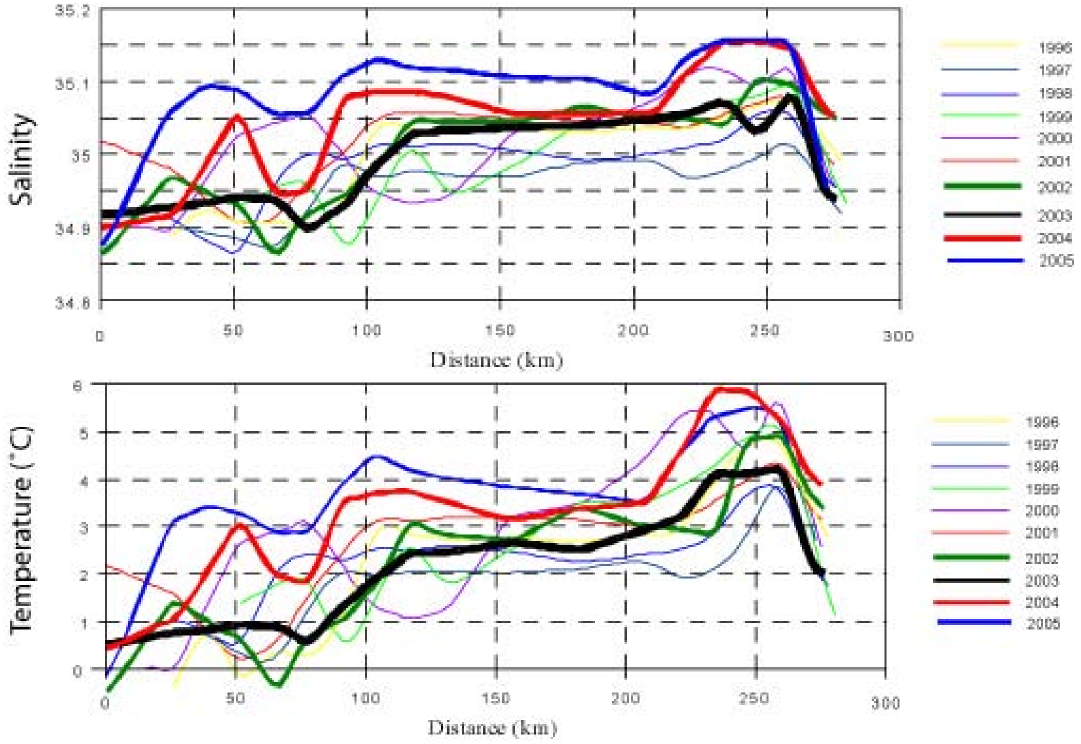

Figure A16.4: Salinity (upper panel) and temperature at section 'N' along 76°30' N parallel, from latitude 004°E to 015°E at 200 m.

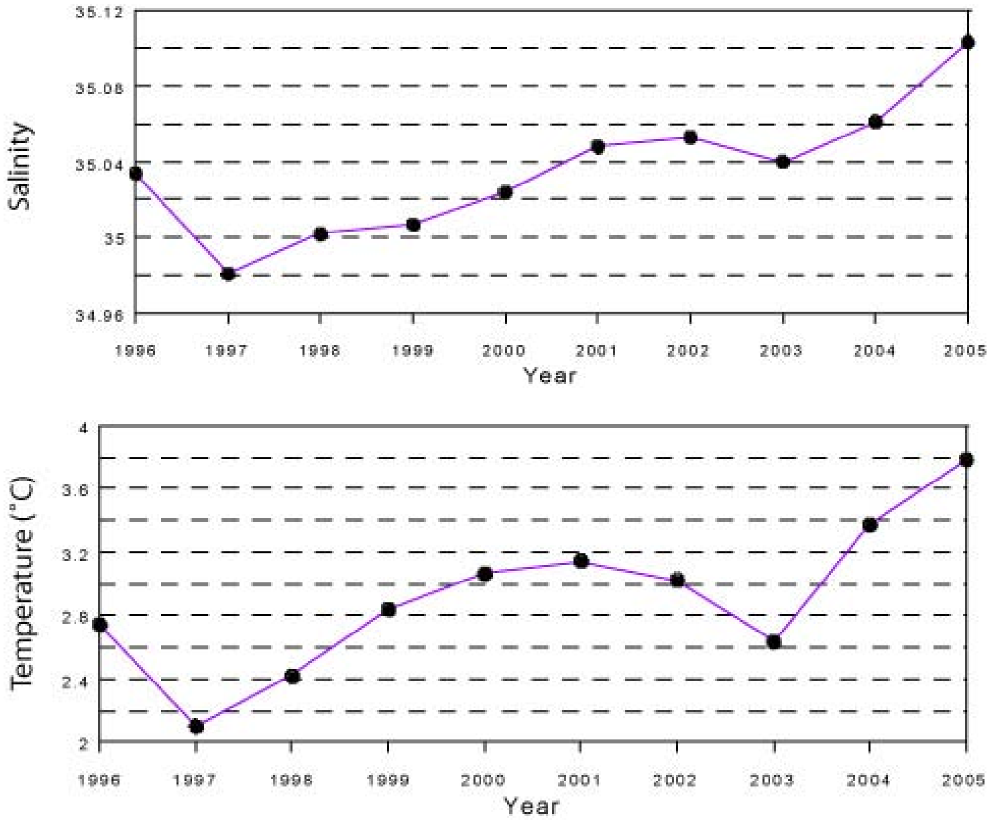

Figure A16.5: (previous page): Mean salinity (upper panel) and mean temperature at section 'N' (76°30' N) at 200 m, between 009°–012° E.

Water density and baroclinic currents vectors. Year 2005, level 100 m. Reference level 1000 m.

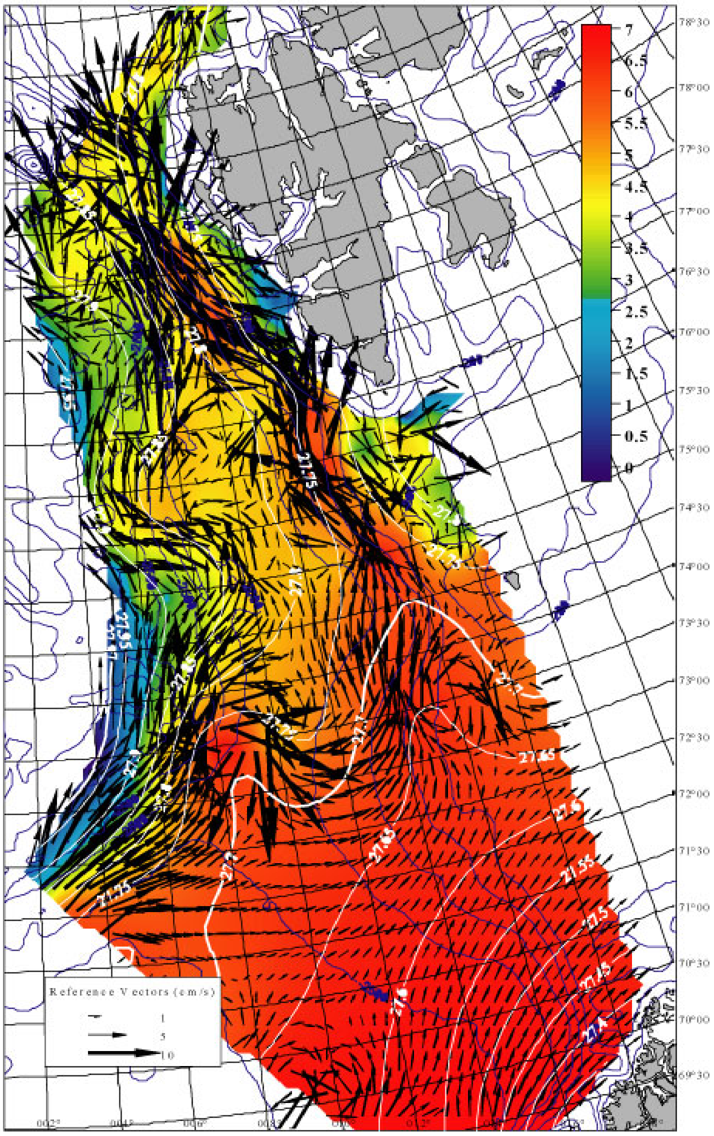

Figure A16.6: June–July 2005. Temperature distribution (colour scale), σΘ (white isolines) and baroclinic currents at 100 dbar. Reference level 1000 m.

Annex 17: Barents, Norwegian and Irminger Seas, 2005

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The Barents Sea

Analysis of oceanographic conditions in the Barents Sea is based on the deepwater observations data in the standard sections and stations done during fish stock assessment surveys. Total number of oceanographic stations carried out by PINRO in 2005 constituted 1556; as well, 39 series of observations in 15 standard sections (327 stations) were performed. In the Kola section, 11 series of observations were done.

Figure A17.1 shows location of main standard sections in the Barents Sea; results of observations done in them in 2005 will be described below. Observations in these oceanographic sections have been carried out since the first half of the previous century (in the Kola section – since 1900, in the North Cape-Bear Island section- since 1935, in sections east of the Bear Island and in the Kanin section – since 1936); and the Kola section and North Cape – Bear Island sections have a status of the age-old sections. The Kola section, centenary of observations in which was celebrated in 1999, has been carried out by now more than 1 000 times (Figure A17.2).

Long-term data obtained in sections of the Barents Sea and summarized in PINRO publications (Bochkov, 1982; Tereshchenko, 1997, 1999; Antsiferov and Guzenko, 2002) were used for the analysis.

Results

The weather over the sea during the year was determined by the cyclonic activity with the increase of intensity of the Icelandic low in the early and end of the year. In January–February, winds of the southern quarter predominated, in the spring-time – northeastern and eastern directions, and in June–December the southern, south-western transference of air masses dominated.

The air temperature was higher than normal during the most part of the year with maximum values of positive anomalies (to 6.0–7.0°C) in January-February. Small negative anomalies of the air temperature were registered only in June-July in the eastern part of the sea (69–77°N, 35–55°E).

Sea surface temperature (SST) in January-February over the major part of the sea was characterized by the increased, relative to the long-term average heat content, with positive anomalies of 0.4–1.3°C. In spring, SST of the central and eastern parts of the sea was higher than normal; in the western part, small negative anomalies were registered. In June-July, negative anomalies of SST were observed in the west and east of the sea. In central areas, the intensive atmospheric heating of the surface layers continued, the peak of which was observed in July. In subsequent months in the central and eastern parts of the sea, the increased SST anomalies lasted out. In the western sea, the SST was close to the long-term mean in the second half of the year.

In early 2005, the air temperature increase in the polar latitudes promoted the decrease of the area covered by the sea ice. In January, the ice edge was along 79°N that was 200–400 mile to the north from the long-term mean location. In February, the area covered by ice appeared to be twice less then normal and the lowest for the recent 70 years. In spring, ice formation in the Barents Sea became more intense. Ice cover in March-May was only by 13–14% less than normal. In summer, the intensive ice melting and melting of ice took place in the Barents Sea. Ice coverage in July constituted 13% that almost two times less than normal. In August and September, the area of the Barents Sea was free of ice, while the long-term mean values of the ice coverage makes up 12 and 9%, correspondingly. The ice edge was located mainly north of 81°N. By the end of year the ice edge located approximately along 78°N, nevertheless, the ice coverage remained at the level much less than normal (Figure A17.3).

Water temperature of the active layer (0–200 m) of the southern part of the Barents Sea in the Kola section was higher than the long-term mean level during the whole year, and in February and December it reached the absolute maximum for the period since 1951. A gradual decrease of the water temperature with the increase in autumn took place in the Main Branch of the Murman Current beginning from February and in the Coastal Branch of the Murman Current beginning from June (Figure A17.4). Water temperature in the 0-200 m layer in the Kola section in all branches was at the level typical of warm and extremely warm years and was lower than in 2004 from May to October. By the end of the year, the positive anomalies increased because of the lowered rate of cooling in autumn; in November and December they were higher than last year (Figure A17.4).

A gradual decrease of the active layer salinity took place during the whole year in all branches of the Murman Current in the Kola section. The positive anomalies of salinity (to 0.08) were observed till June. In August-October salinity was close to the long-term mean, and in November-December the negative anomalies of salinity were observed with minimal values of 0.10-0.11 in the Coastal Branch of the Murman Current (Figure A17.4).

In general, the mean year water temperature of the Coastal and Main Branches of the Murman Current in the Kola section was much higher than normal and close to that in 2004, and salinity corresponded to the long-term average and was lower than in 2004 (Figure A17.5).

In February, June, July and August the observations were carried out in the North Cape – Bear Island section. Temperature in the 0–200 m layer of the North Cape Current (71°33’N 25°02’E – 73°35’N 20°46’E) in the section was characterized by high (above 1°C) positive anomalies. In February, the absolute maximum temperature was registered for the whole period of observations of temperature of the active layer of the North Cape Current with positive anomaly of 1.4°C (Anon., 2006).

In the section west of the Bear Island (along 74°30’) in 2005 three series of observations were carried out. Water temperature of the Eastern Branch of the Norwegian Current (74°30’N, 13°30’E - 15°55’E) in the 0–200 m layer was higher than normal by 0.7°C in February, by 1.1°C in July and by 1.4°C in November.

In the section east of the Bear Island (along 74°30’) during 2005 three series of observations were carried out as well. Temperature of the Northern Branch of the North Cape Current (74°30’N, 26°50’ – 31°20’E) in the 0–200 m layer in February, April and October exceeded the long-term average by more than 1°; in February the positive anomaly constituted 1.4°C and was maximal for the whole period of observations in the section.

Observations in the Kanin section (along 43°15’E) had been carried out only in February and August. Water temperature of the active layer of the Novaya Zemlya Current (71°00’N -

71°40’N, 43°15’E) exceeded the long-term mean by 1.8°C in February and by 0.7° C in August, that is the absolute maximum for February for the whole period of observations.

Near-bottom temperature in the Barents Sea in 2005 corresponded to that typical of warm and extremely warm years. The major part of the sea was occupied by waters with positive temperature anomalies with maximum values of more than 2°C on the Spitsbergen Bank (Figure A17.6). In the east, bottom temperature was by 0.3–0.5°C higher than long-term mean and by 0.5–1.0°C, on average, higher than in 2004. In the utmost southeast of the sea the area with negative anomalies was registered, which extended to the north to 73°N and to the west to 46°E (Anon., 2006).

In general, thermal status of the main currents of the Barents Sea in 2005 was much higher than normal and close to the level of 2004.

The Norwegian Sea

In the Norwegian Sea in 2005 the summer (June-July) oceanographic survey was carried out after two year’s (2003–2004) intermission. In the area from the Faroe-Shetland Channel (FSC) to 71°10’N, 213 CTD stations were performed including stations in seven sections. Standard sections, the location of which is shown in Figure A17.7, have been carried out by PINRO since the early 1950’s. Total number of observations in sections in the Norwegian Sea constituted more than 1400 from 1951 to 2005; 400 of them – during the summer surveys. Most often the sections were done in the central part of the sea 6C (along 65°45’N) and 7C (along 67°30’N). Figure A17.8 shows a number of series of observations performed by PINRO in the standard sections per year (1) and in the period of summer oceanographic surveys (2).

For analysis of oceanographic conditions the long-term data in the standard sections of the Norwegian Sea summarized in PINRO publications (Anon., 1997; Sentyabov *et al.*, 2003)) were used.

Results

The most part of the year the small-gradient baric field was located over the sea. Winds of the southwestern direction predominated. The air temperature was close to normal and 1°C lower than in 2004.

Sea surface temperature (SST) over the major part of the sea in the first half of the year exceeded the long-term mean. In summer the SST of the Norwegian Current (NWAC) was close to normal, and in the west of the sea (in the area of the East-Icelandic Current (EIC)) it was lower than the long-term average by 0.3–0.5°C. Compared to three preceding years, when SST was maximal for the whole period of observations, a tendency appeared in 2005 to the lowering of temperature to the average level.

In summer 2005, the Atlantic waters flowed into the Norwegian Sea through the eastern part of the FSC in the 0-400 m layer. Their temperature in the section 2C was higher than normal by 0.6°C and salinity – by 0.05. In the south of the sea (section 5C) temperature and salinity were close to the long-term mean in the upper 200-meter layer. In deeper layers, temperature was more than 1°C and salinity 0.08 lower than usually because of the wide penetration of cold waters eastwards. Between 63 and 65°N the core of the NWAC was shifted eastwards to the continental slope compared to the long-term mean location. North of 65°30’N the Atlantic waters distributed 30-50 miles farther to the west than usually. In the central part of the sea the water temperature of the Norwegian Current in the upper 200-m layer in sections 6C and 7C was warmer than normal by 0.4–0.8°C. In the northern part of the surveyed area (sections 8C and 9C) thermal status of the Norwegian Current was also increased. The positive anomalies of water temperature constituted 0.7–1.0°C. Temperature of mixed waters in the central part of the Norwegian Sea in both sections 6C (65°45’N, 04°00’W - 02°30’W) and 7C (67°30’N, 04°00’W-01°45’W) was higher than normal by 0.4–0.6°C. Salinity of both Atlantic and mixed waters in 2005 was by 0.07–0.13 higher than the long-term mean.

Figures A17.9 and A17.10 show anomalies of both temperature and salinity in the most often performed sections in the central part of the Norwegian Sea. Water temperature of the Norwegian Current in 2005 corresponded to that typical of warm years, but was somewhat lower than in the extremely warm 2002–2003. During recent five years temperature of mixed waters remained also at the increased level after considerable cooling in 1993–2000 (Sentyabov *et al.*, 2003). Salinity for the recent five years increased both in Atlantic and mixed waters to the level before the Great Salinity Anomaly (Dickson *et al.*, 1988).

The influence of the East-Icelandic Current in the west and southwest of the sea was enforced compared to the long-term average (1971–2000) and 2003–2004, when it was weakened. Negative anomalies of temperature in sections “Kryuchok” (“hook”) and 5C constituted 1.0–1.5°C, and that of salinity – 0.10. In the southern part of the sea between 62°30’N and 65°30’N cold and relatively freshened waters penetrated to the east to 1°W in the 50–200 m layer and to 2°E deeper than 200 m. However, in the upper 400-m layer these Arctic waters did not distribute south of 62°30’ N and were separated from the Atlantic waters by very strong frontal zone. In the western part of the surveyed area the boundary separating the cold waters from warm Atlantic and mixed waters was shifted 30–40 miles westwards than usually (Anon., 2006).

The Irminger Sea

PINRO conducts regular oceanographic investigations in the Irminger Sea from the moment of opening of fishery for Sebastes mentella in 1981. Observations in the standard sections over the Reykjanes Ridge have been carried out since 1968. At present the Institute continues a series of observations in summer (June) only in the section 3K, which crosses the Reykjanes Ridge approximately at 60°N. It had been performed annually since 1990 till 1997, and since 1999 the section has been carried out every second year. Data of observations in the section reflects well the interannual variations of oceanographic conditions in the Irminger Sea. They are used in the analysis of spatial/temporal variability of oceanographic factors in the Irminger Sea in addition to data of observations in the area of Russian and international trawl-acoustic surveys of redfish stock.

Results

The weather in the area in 2005 was characterized by the increased number of days with storm winds of, mainly, western direction in winter and summer. High positive anomalies of the air temperature and SST were registered. The air temperature over the sea was higher than long-term mean during the whole year. The positive anomaly of the mean annual temperature constituted 1.4°C and was close to maximum in 2003. During the year SST in the Irminger Sea and in the adjacent areas was 0.5–2.0°C higher than long-term average. Positive anomalies of mean annual values of SST in the Irminger Sea and adjacent areas in 2005 caused low ice coverage of the Danish Strait and fishing grounds of the East Greenland (Anon., 2006).

It was revealed during the observations in the 3K section in June that temperature and salinity in waters of Sub-Polar Gyre in the upper 500-m layer were maximal for the period of 1990-2005; in waters of the Irminger Current their values were also anomalously high, but lower than maxima in June of 2003 by 0.1–0.4°C and 0.02–0.04 (Sigurdsson *et al.*, 2003). Interannual dynamics of mean temperature and salinity in 200–500 and 500–1000 m layers at stations 1–6 in the 3K section (west of the Reykjanes Ridge) is presented in Figure A17.11.

By data of deepwater observations the temperature of the Irminger Sea waters between 51° and 63°N from 28° to 43°W was higher than long-term mean (1954–2003). The positive anomalies of water temperature dominated at depths from the surface to 500 m, and the largest values were registered at 200 m (Figure A17.12). The negative anomalies to 0.3–0.5°C were registered at depths more than 500 m in local areas in waters of the Irminger Current over the Reykjanes Ridge and south west of the Farewell Cape.

Conclusions

By the level of the thermal status of air and water masses of the Barents Sea, the year of 2005 should be considered as anomalously warm year and close to the previous year. It caused a significant decrease in the area covered by ice. Mean annual ice coverage of the Barents Sea in 2005 was the lowest for recent 50 years.

Thermal status of Atlantic waters in the Norwegian Sea in 2005 was increased, but lower than in anomalously warm 2002–2003, temperature of mixed waters remained at the high level and that of waters of the East-Icelandic Current in the western sea decreased to the level typical of cold years.

Data obtained during investigations in the Irminger Sea shows that thermal status of waters in the upper 500-m layer in open areas of the North Atlantic remains increased during last ten years.

Under complicated economical conditions of reforms, PINRO continues to carry out observations in the standard sections of the Barents, Norwegian and Irminger Seas, supporting the unique series of deepwater observations necessary to study marine climate variations. To our opinion, the necessity has arisen to perform the unification of standard oceanographic sections in the North Atlantic 0, to single out the most durable series of observations and to regulate the order of their fulfilment for conservation and continuation of these time-series.

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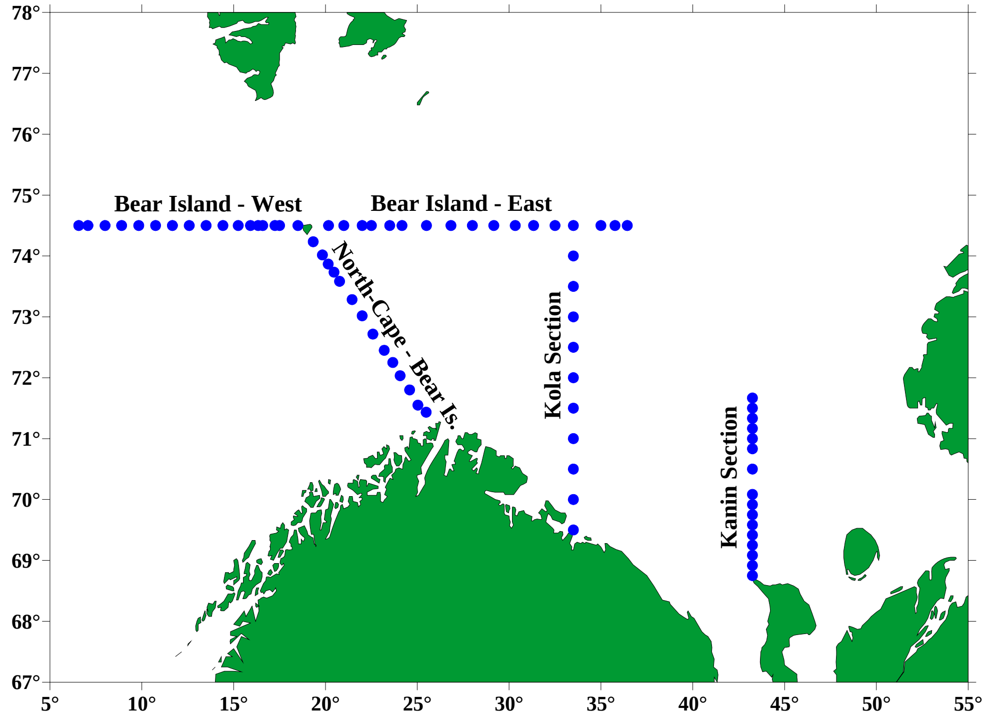

Figure A17.1: Main Russian standard sections in the Barents Sea.

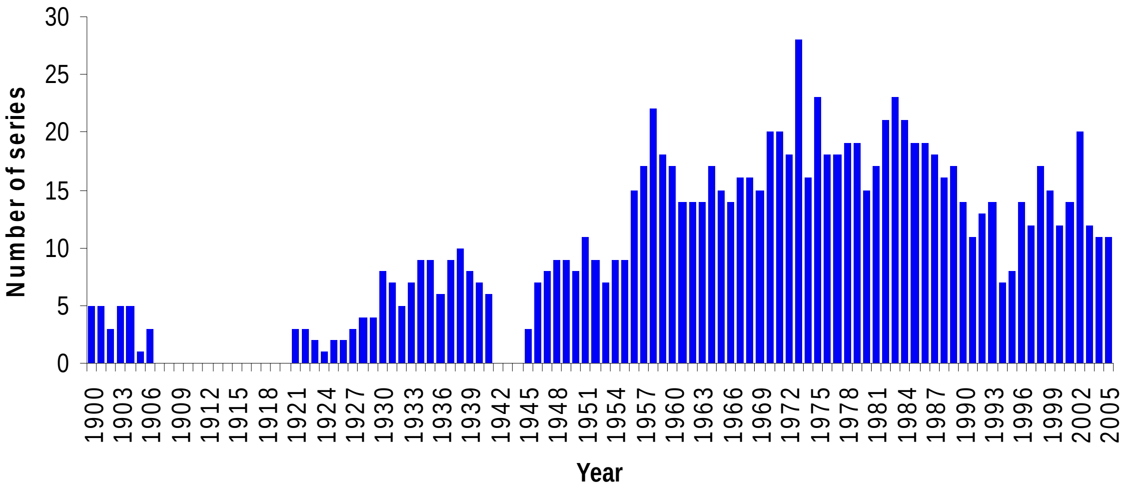

Figure A17.2: A number of series of observations in the Kola section in 1900–2005.

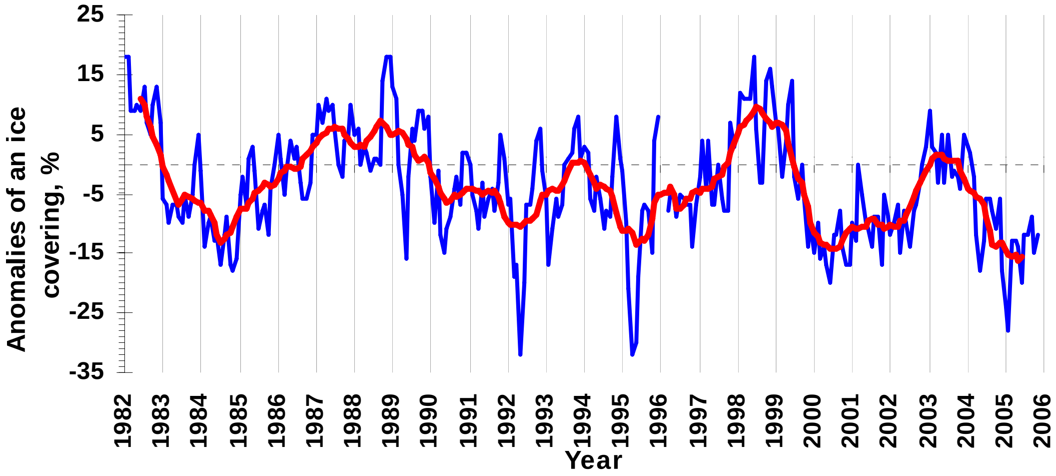

Figure A17.3: Anomalies of mean monthly ice coverage of the Barents Sea in 1982–2005. Blue line means monthly values, red line – moving 11-monthly means (Anon., 2006).

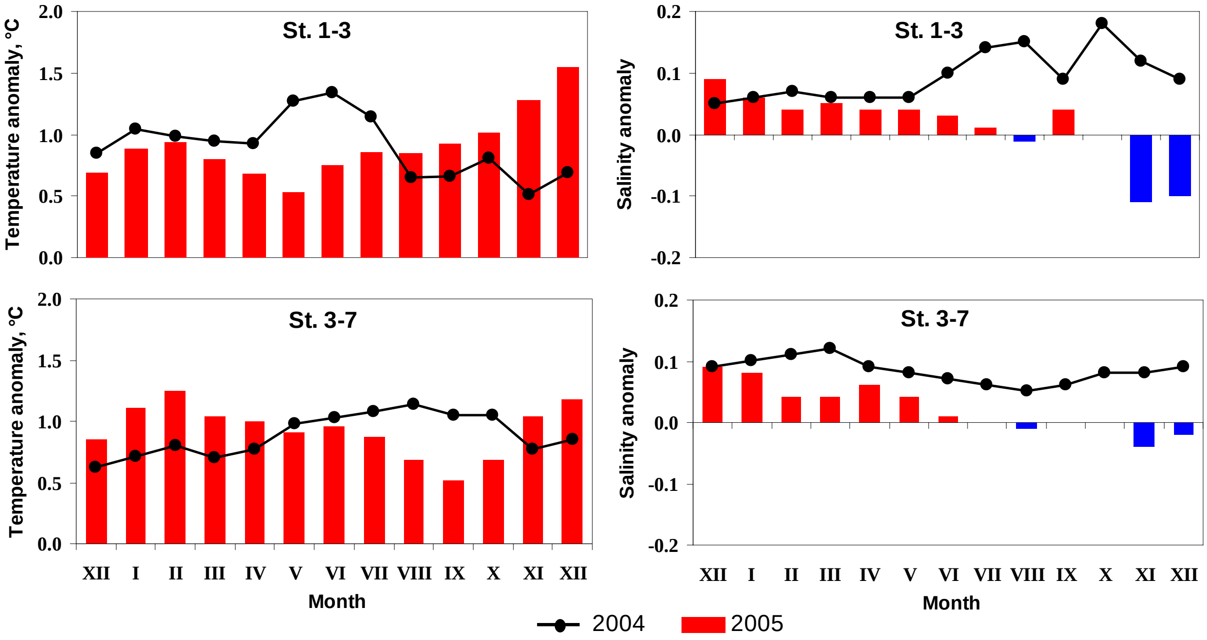

Figure A17.4: Monthly mean temperature (left) and salinity (right) anomalies in the 0–200 m layer of the Kola section in 2004 and 2005. Stations 1–3 – Coastal branch of the Murman Current. Stations 3–7 – Main branch of the Murman Current (Anon., 2006).

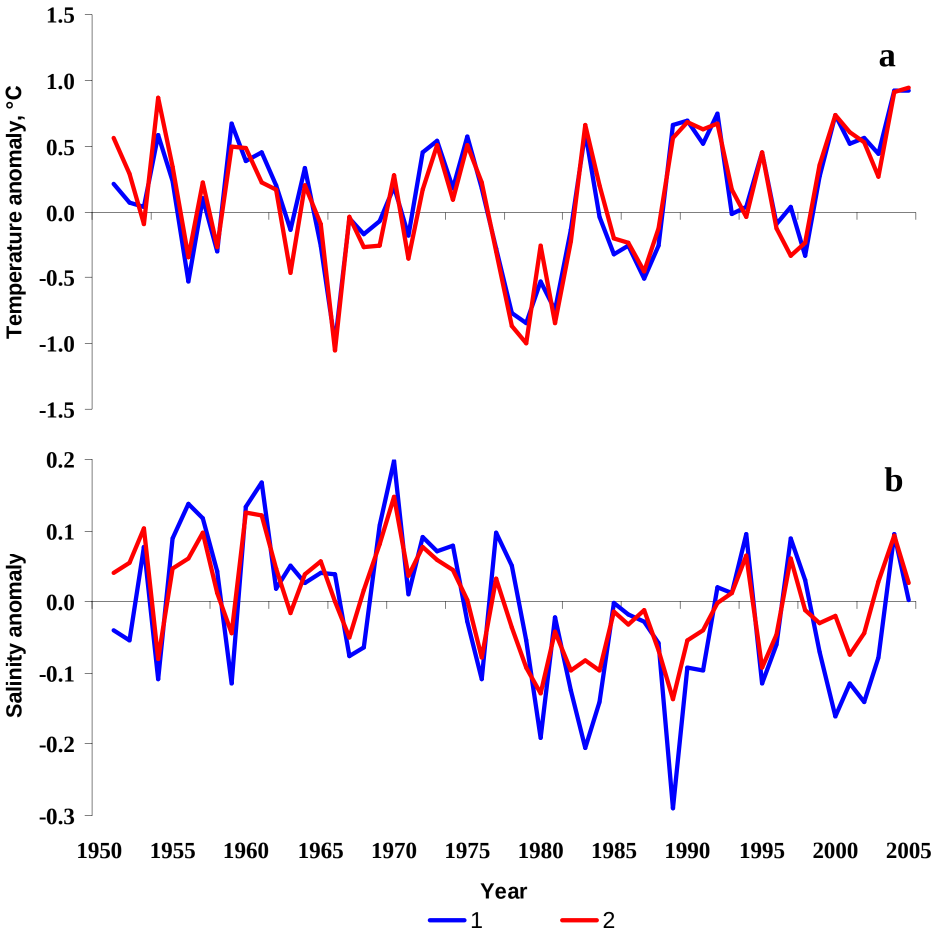

Figure A17.5. Mean yearly temperature (a) and salinity (b) anomalies in the 0-200 m layer in the Kola section in 1951–2005. 1) Coastal branch of the Murman Current, 2) Main branch of the Murman Current (Anon., 2006).

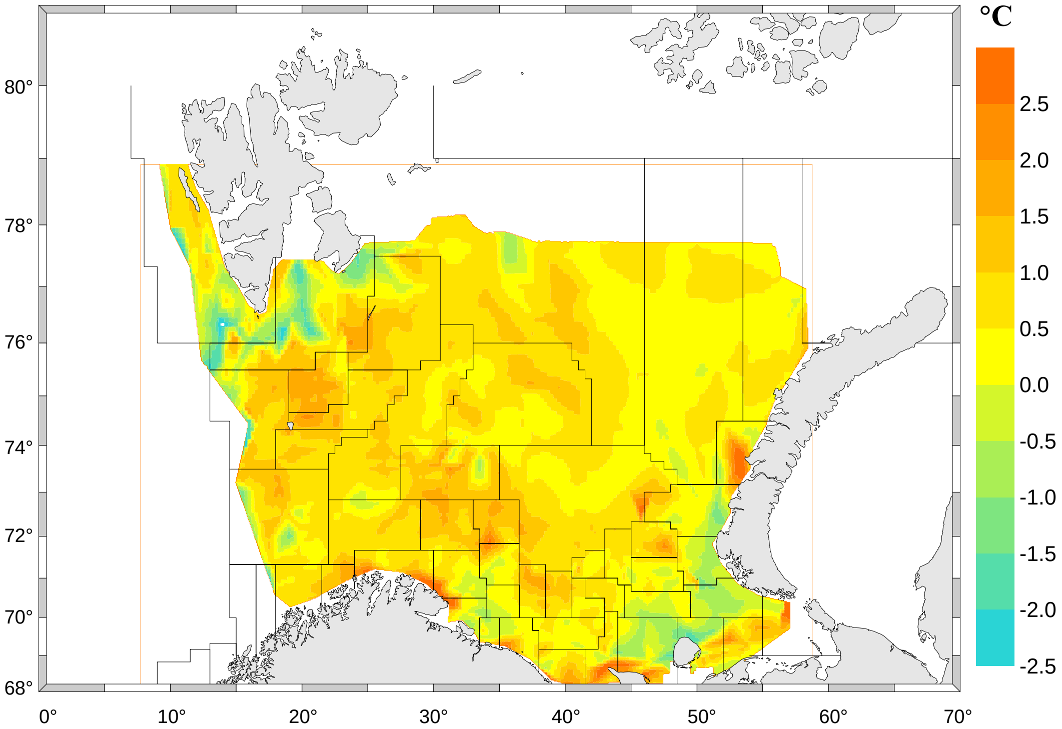

Figure A17.6: Bottom temperature anomalies in the Barents Sea in August–September 2005.

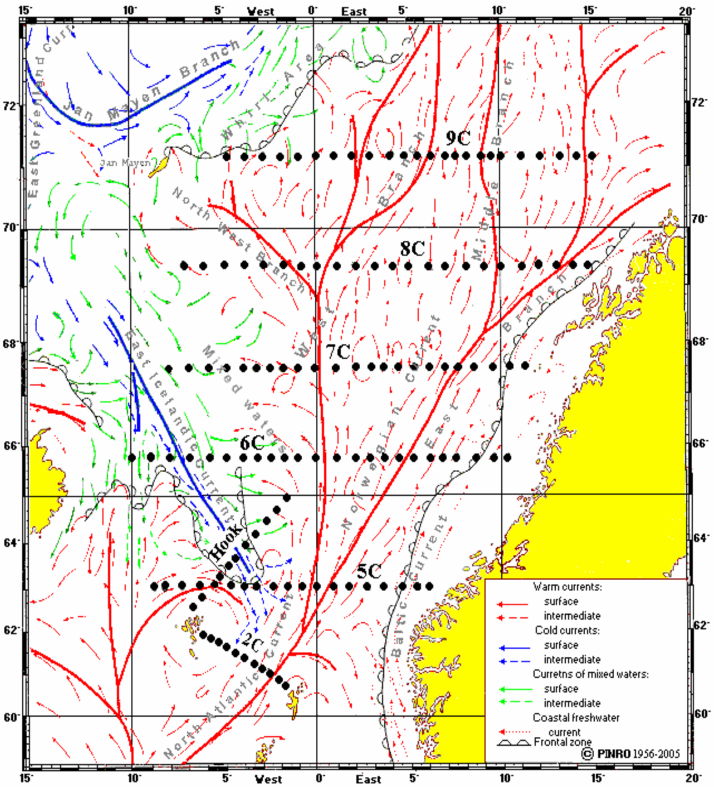

Figure A17.7: Positions of standard sections stations in the Norwegian Sea occupied in June-July 2005 and the currents in the Norwegian and Greenland Seas (Alexeev and Istoshin, 1956).

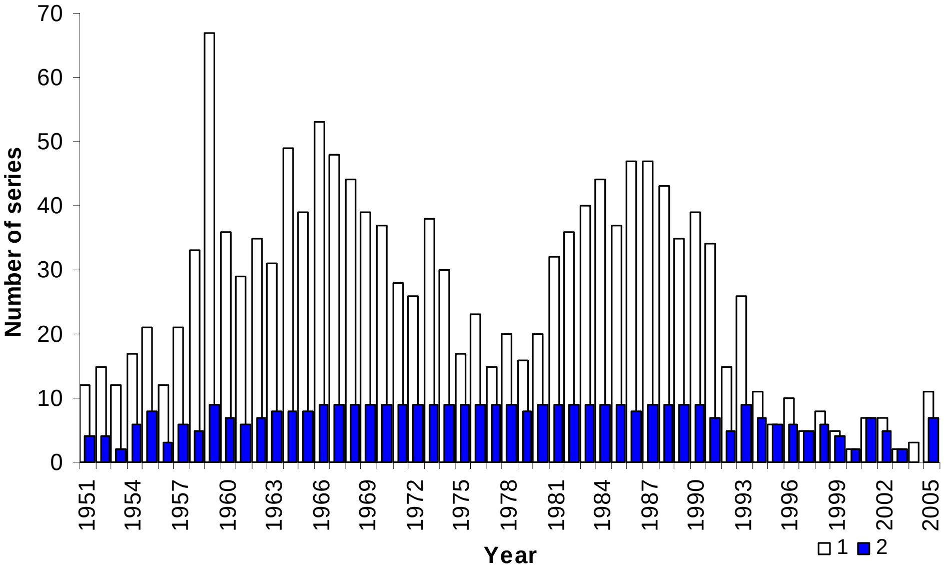

Figure A17.8: Number of observation series in the sections 2C–9C in the Norwegian Sea, which were carried out during year (1) and "Summer Surveys" (2) in 1951–2005.

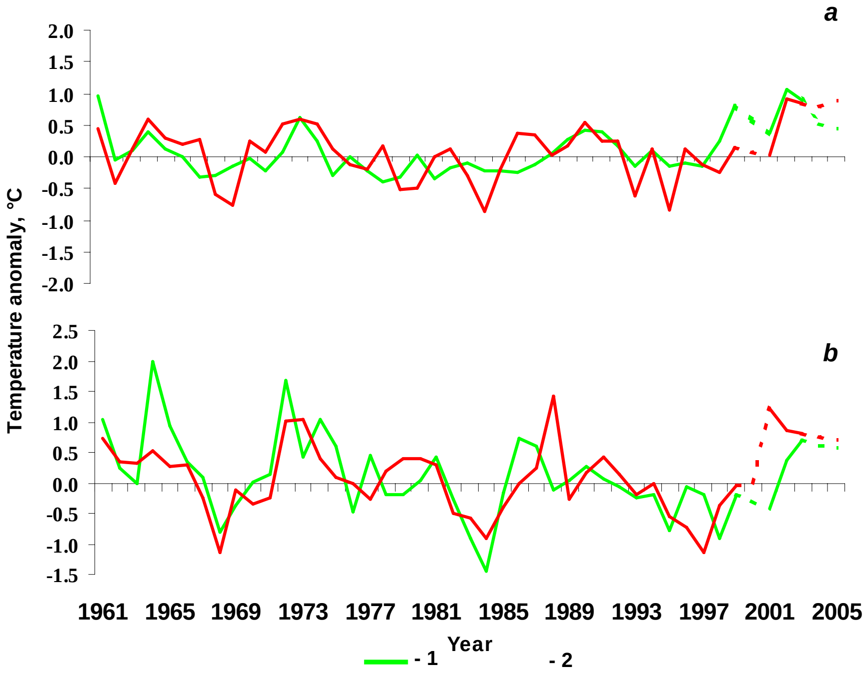

Figure A17.9: Mean temperature anomalies (in comparison 1971-2000 mean) in the upper 200 m layer of the Norwegian Atlantic Current (a) and mixed waters in the central Norwegian Sea (b) in the standard sections 6C (1) and 7C (2) in June 1961–2005.

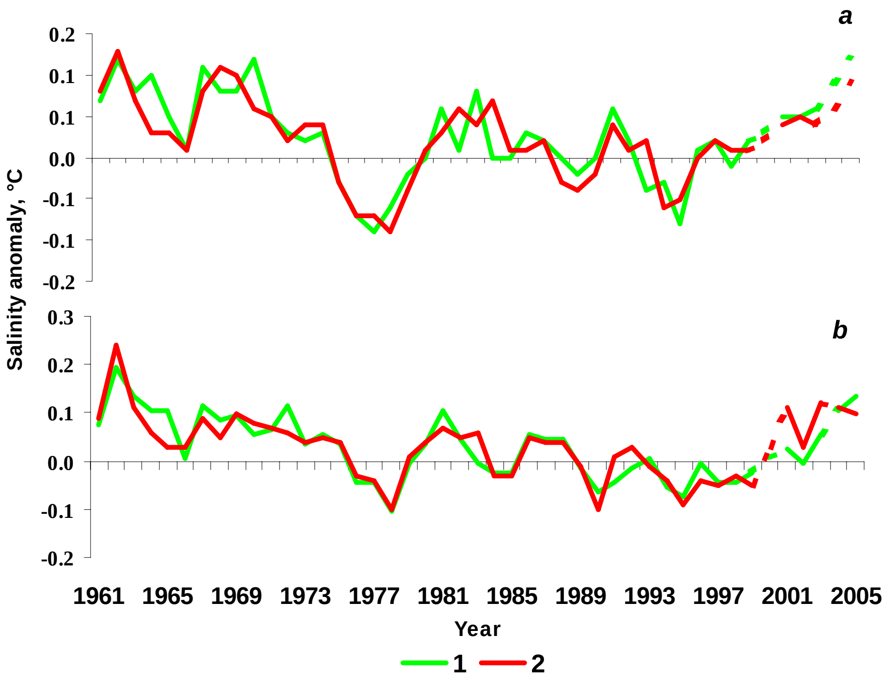

Figure A17.10: Mean salinity anomalies (in comparison 1971-2000 mean) in the upper 200 m layer of the Norwegian Atlantic Current (a) and mixed waters in the central Norwegian Sea (b) in the standard sections 6C (1) and 7C (2) in June 1961–2005.

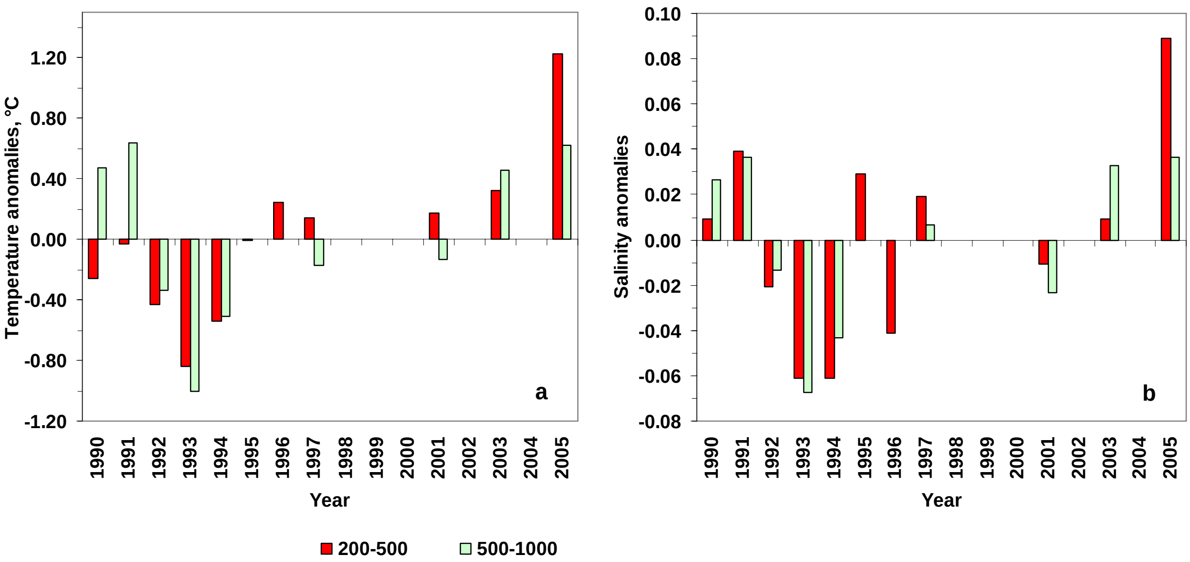

Figure A17.11: Anomalies of temperature (a) and salinity (b) in the 3-K section in June of 1990–2005.

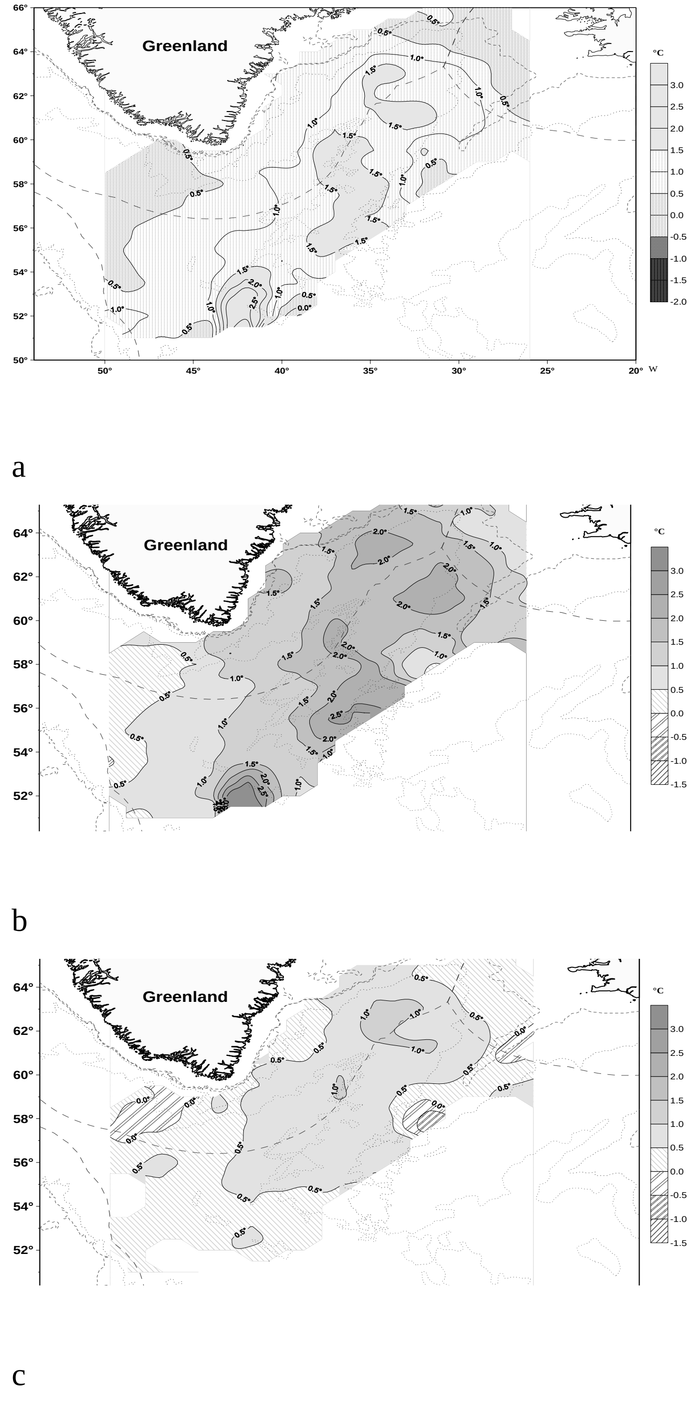

Figure A17.12: Anomalies of water temperature at 200 (a), 300 (b) and 600 m (c) in the area of the international survey of redfish in the Irminger Sea in June–July 2005 (Anon., 2006).

Annex 18: Hydrographic Conditions in the Greenland Sea and Fram Strait, 2005 (ICES Area 12)

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In summer 2005 the hydrographic measurements in the Greenland Sea (section along 75°N) and in Fram Strait (section along 78°50'N) were continued by Alfred Wegener Institute. These two sections allow to monitor 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 Mediterrean. 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 1800 m. However long lived Coherent Vortices (CV) play a special role in ventilation of the Greenland Sea. Within these eddies, winter convection penetrates usually to considerably greater depths (about 2600 m) than in the surrounding waters. The CVs posess a diameter of only 20 km, and as they show no surface signal during summer they are difficult to detect.

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 the northern part of Fram Strait. The size and strength of the different branches largely determine the input of oceanic heat to the inner Arctic Ocean. The East Greenland Current, carrying water from the Arctic Ocean southward has a concentrated core above the continental slope, west of Greenland.

In the central Greenland Sea a long-term zonal CTD section at 75°N was performed in summer 2005 with a regular station spacing of 10 Nm. In August/September 2005 a hydrographic section with a high spatial resolution was carried out across Fram Strait at 78°50'N. The CTD and ADCP measurements were combined with recovery and redeployment of 12 moorings in the eastern and central part of the strait.

The obtained time-series of temperature and salinity in the Greenland Sea and Fram Strait were compiled from the AWI sections combined with the earlier data sets to describe the long-term variability of different water masses. Time-series of the currents, temperature and salinity were also provided by recovering 12 moorings, deployed in autumn 2004. 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 VEINS project. Since 2003 the work has been carried out as a part of international program 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 five moorings in the western part of the strait. Since 2003 the measurements at the array augmented with two new moorings in the recirculation area and an additional level of instruments at the AW lower boundary (ca 700 m) have been continued.

The general situation at the section in the Greenland Sea at 75°N was characterized by summer conditions with with a relatively warm surface layer. The subsurface layer was strongly influenced by Atlantic Water (AW) as the salinities over 34.92 observed much farther to the west than in 2004. The surface layer was characterized by high temperature due to summer heating, except cold Polar waters over the Greenland shelf. The layer above the intermediate temperature maximum showed higher temperatures than in 2004. Since the winter ventilation introduced colder waters in a mixed layer like ventilation process (visible also in the autonomous profiler data), this increase must be attributed to lateral advective processes. An extent of the Return Atlantic Water (RAW) to the east was farther (up to 2°W) and deeper than in 2004. At first sight, convection seems to have affected only the upper 700 m what is even less than the 1000 m of the preceding year. The bottom water temperature increase continued, and amounts again to about 0.01°C between 2004 and 2005.The properties of the Atlantic Water and Return Atlantic Water observed at the section in the Greenland Sea at 75°N have changed since last year, recovering from the extremely low values in 2003. The properties of the Atlantic Water are given as temperature and salinity averages over the depth range from 50 to 150 m of the stations between 10° and 13°E while the Return Atlantic Water is characterized by the temperature and salinity maximum below 50 m averaged over three stations west of 11.5°W. In both domains temperature increased strongly as compared to 2003 and 2004 and exceeded the long term mean. Temperature of the AW reached the maximum for the whole time-series (5.6°C) while temperature of the RAW was the second highest (after maximum in 1995). A significant rise of mean salinity was also found both in the AW and in RAW resulting in highest values since the beginning of observations, 35.16 and 35.0 respectively in the AW and RAW.

Mean profiles of temperature and salinity between 1993 and 2005 reveal continuous shift towards higher values in the whole deep water layer below 2000m. Temperature in the bottom waters decreased from −1.25°C in 1989 to −1.1°C in 2005 and since 1989 a volume of water with temperature below −1.1°C has been successively decreasing and finally disappeared from the section. Increase in salinity of the Greenland Sea deep waters indicates a salt input in deep layer from both sides (lateral advection), low salinity classes disappear at the bottom and mid-depth salinity step descends progressively.

The most outstanding single feature observed in 2005 was the Coherent Vortex. These features represent the deepest convection level observed in recent years. The eddy structure we observed was not vertically homogeneous but showed several vertical layers probably indicating the convection depth of several preceding winters. The eddy core was definitely not rehomogenized during the last winter. This finding gives a hint about the much discussed lifetime of the CV, which can amounts to several years.

In Fram Strait three characteristic areas can be distinguished in relation to the main flows: the West Spitsbergen Current (WSC) between the shelf edge and 5°E, the Return Atlantic Current (RAC) between 3°W and 5°E, and Polar Water in the East Greenland Current (EGC) between

3°W and the Greenland Shelf. In 2005 warming and salinification continued in the entire Fram Strait and especially in the RAC domain. The Atlantic layer in the off-shore branch of the WSC was warmer than in 2004 and the strongest warming was found in the recirculation area in the western, deep part of the strait. This warm anomaly spread down to the bottom and to the west it reached the edge of the East Greenland shelf. A temperature difference at the section between 2004 and 2005 reveals the strong warming in the western part of the deep area extending not only in the AW layer but much down to the bottom. In the WSC an increase of temperature was found mostly in the off-shore branch and was confined to the AW layer. Comparisons between temperature measured in Fram Strait in 2005 and available climatologies (WOA2001, EGW, PHC; picture not shown) in all cases shows the strong warm anomaly in 2005. Mean temperature and salinity in the layer 50–500 m in three domains (WSC, RAC, EGC) were all higher than the long period average and continued the increase observed already in 2003. The strongest increase of salinity occurred in the East Greenland Current while in the WSC and RAC the observed values were the highest since the beginning of time-series.

Hydrographic properties of the Atlantic water in the whole Fram Strait (defined as water mass with T>2°C and S>34.92) reveal the clear trend for last seven years. 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 2005 the mean temperature and salinity of the AW were higher than in 2004. In addition to high temperature and salinity, the areal coverage of the section by the AW occupied also increased as compared with 2004, indicating the largest heat content since the beginning of time-series.

Time-series of temperature and current velocities, recorded at the array of moorings since 1997 were used to calculate volume and heat fluxes through Fram Strait. For the last measured period, 2004–2005, data from the western part are still not available thus volume and heat fluxes were calculated for the West Spitsbergen Current and for the recirculation domains. A high correlation between heat flux in the WSC and heat flux (r=0.8) through the entire strait allows to estimate the latter value. The volume flux in the WSC was characterized by the strong minimum in summer and early autumn 2004, followed by the maximum in winter and early spring 2005. However the heat flux in summer and autumn was still higher than seasonal average due to higher temperatures (warm anomaly), while in winter months it was comparable to the previous year. Winter-centered annual average of the volume flux in the WSC was higher in 2005 than in 2004 (7.5 Sv as compared to 5.6 Sv) while the annual averaged of the heat flux was comparable in both years (55 TW and 52 TW respectively). In the recirculation domain the net volume flux was southward and increased in 2005 as compared in 2004 but the net heat flux (northward) was similar in both years. Temperature and cross-section current velocity at the depth of 250 m (the AW layer) plotted versus time and longitude show that since summer 2004 the warm AW water has been spreading westward and seasonal temperature decrease in spring and early summer was nearly absent both in the WSC and the recirculation area. Since summer 2003 the isotherm 3°C has been constantly shifted westward. The cross-section current distribution reveals that winter peak in the volume flux in 2005 resulted not from higher velocities in the WSC core but from the larger area of the northward flow in the entire WSC, particularly the stronger than average northward flow in the off-shore branch. Preliminary results from Fram Strait array suggest that the observed warming is less visible as an absolute value (extreme temperature) but rather as deviation from the strong seasonal cycle towards the higher temperature in spring and early summer. Observed changes in the flow field support the upstream observations of the stronger activity in the western branch of the Norwegian Atlantic Current and/or can be also related to a shift in the position of the recirculating AW branch in Fram Strait.

List of figures

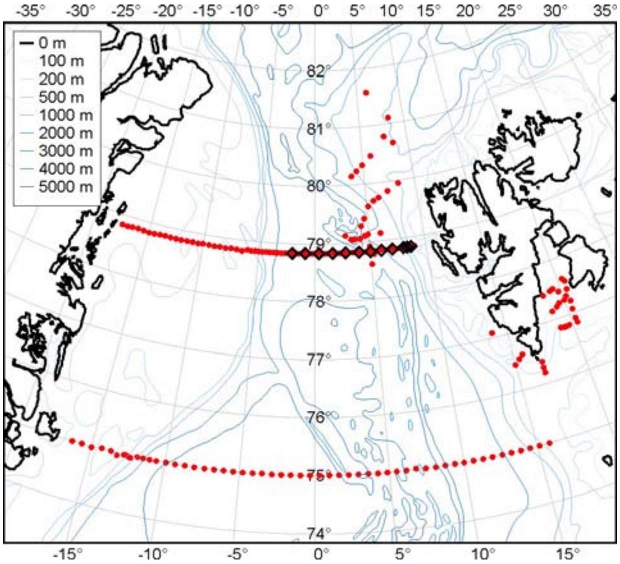


Figure A18.1: Location of sections (dots - CTD stations, squares - moorings redeployed in 2005).

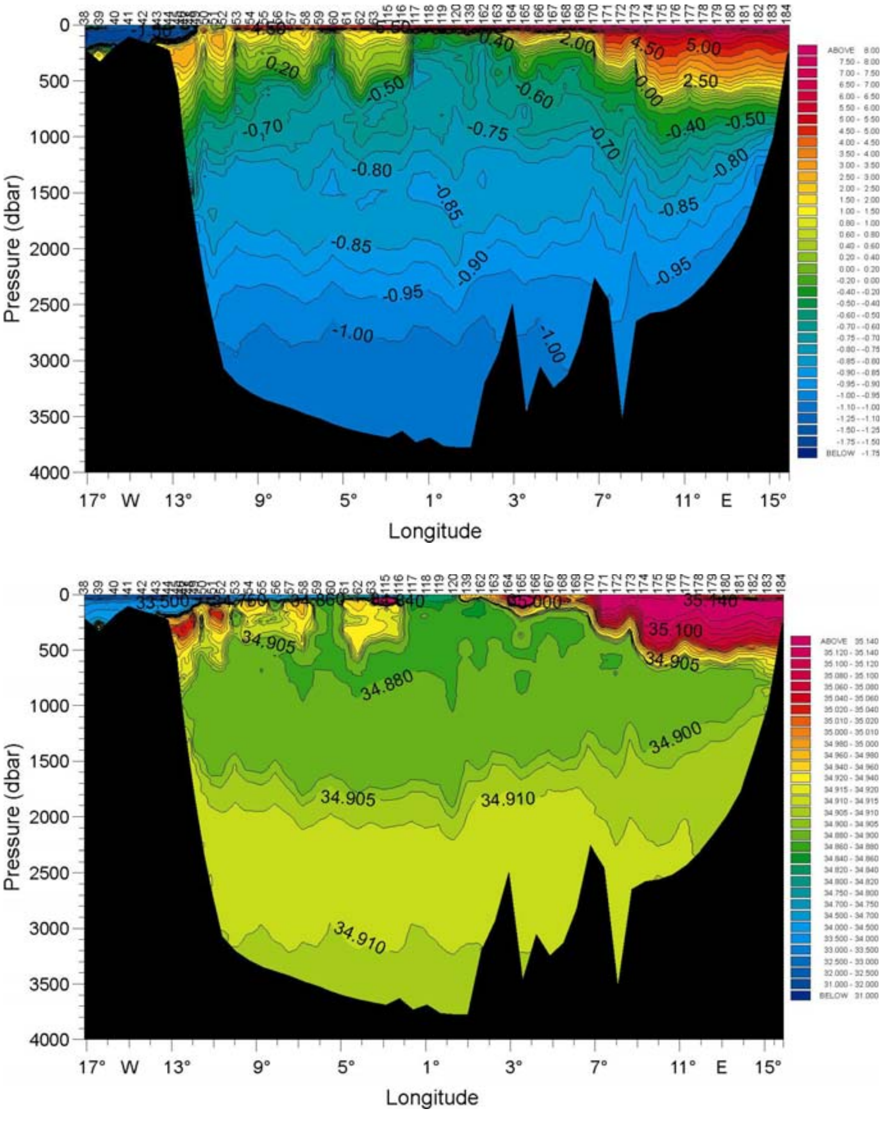
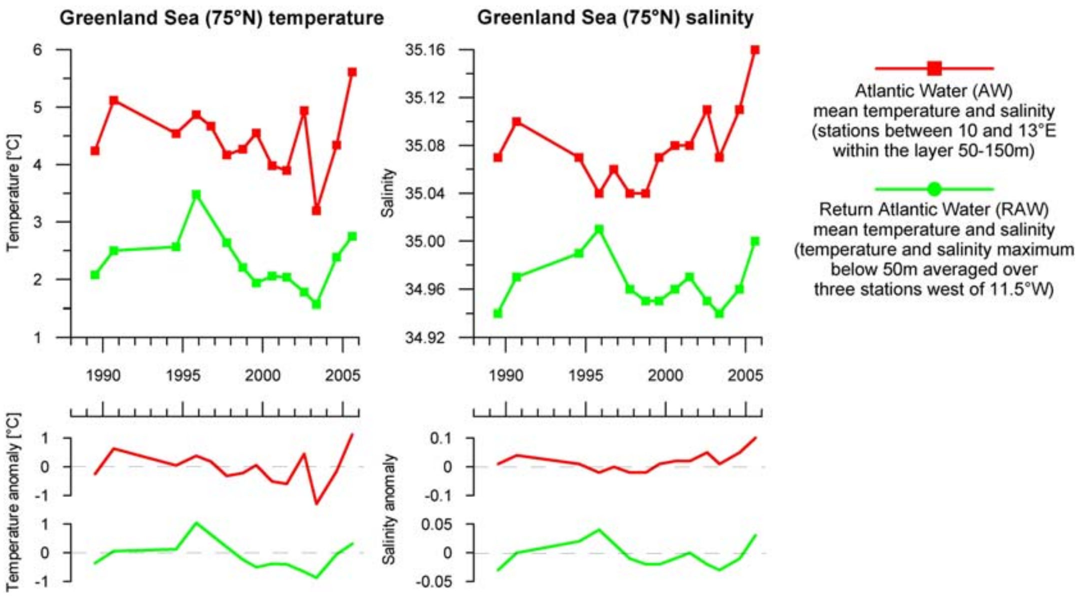


Figure A18.2: Distributions of potential temperature (upper figure) and salinity (lower figure) at the section across the Greenland Sea measured in summer 2005 (G. Budeus, S. Ronski).



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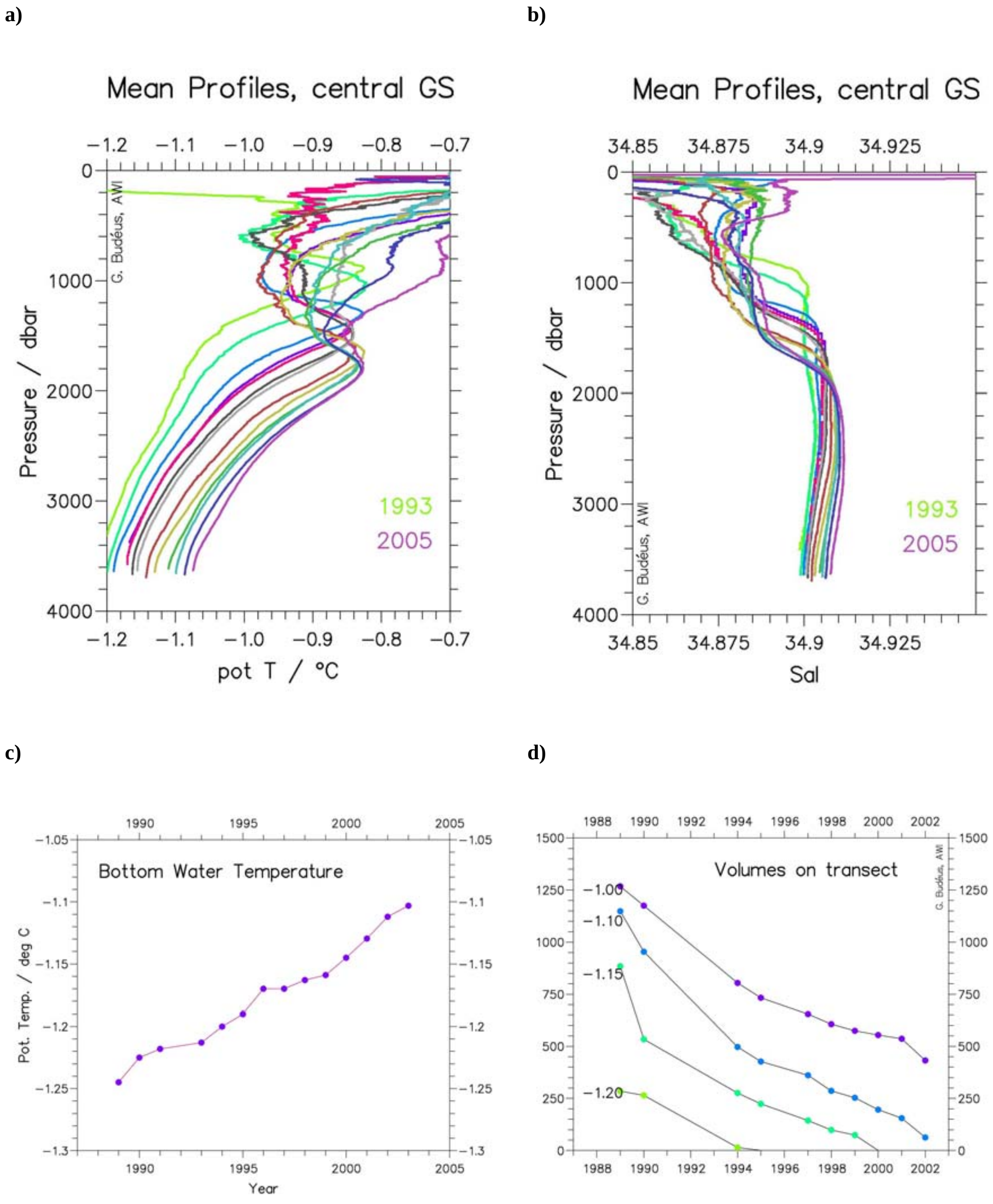

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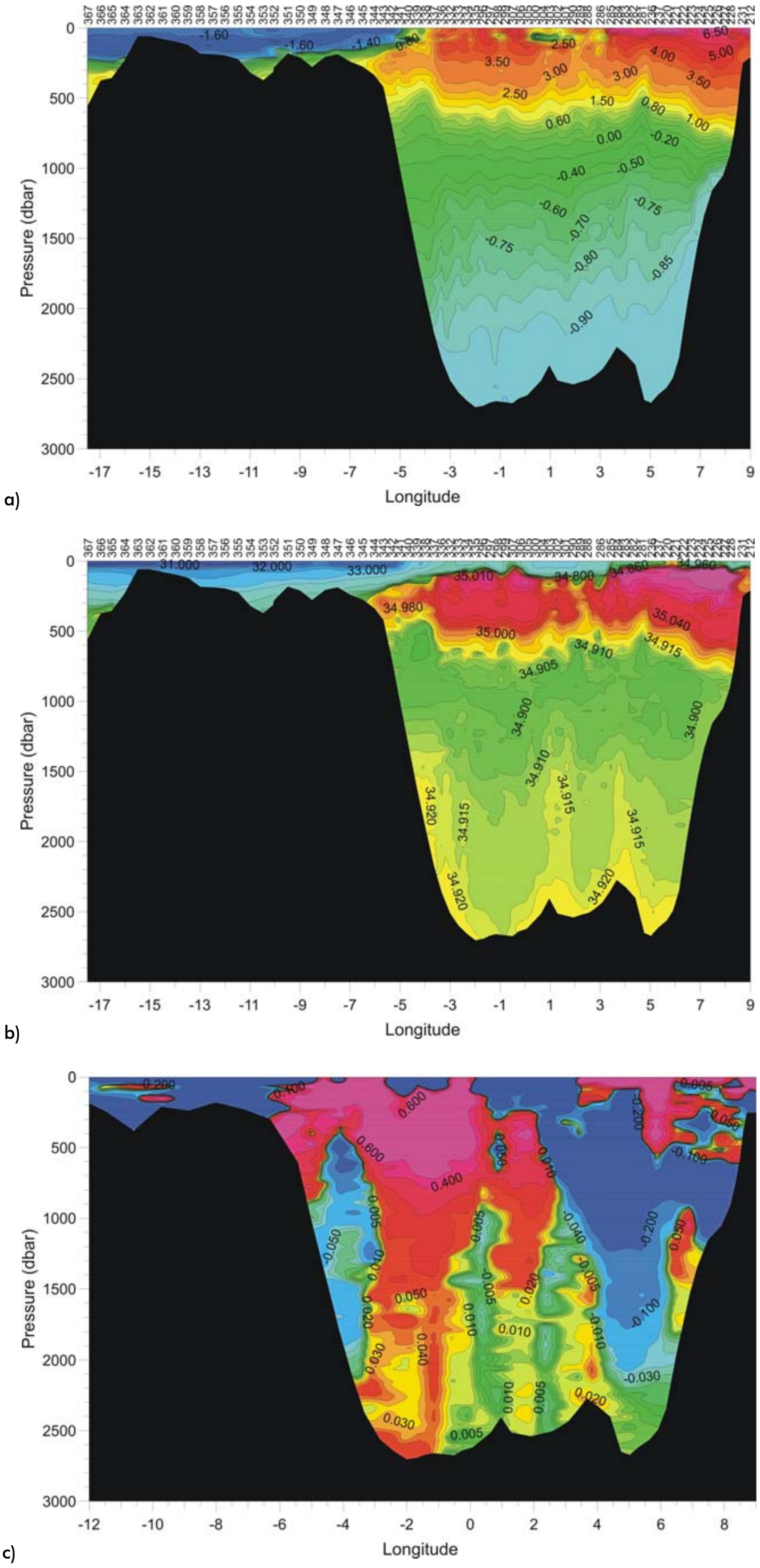

Figure A18.5: Vertical distribution of (a) potential temperature and (b) salinity at the section through Fram Strait at 78°50'N measured in 2005 and (c) temperature difference between 2004 and 2005.

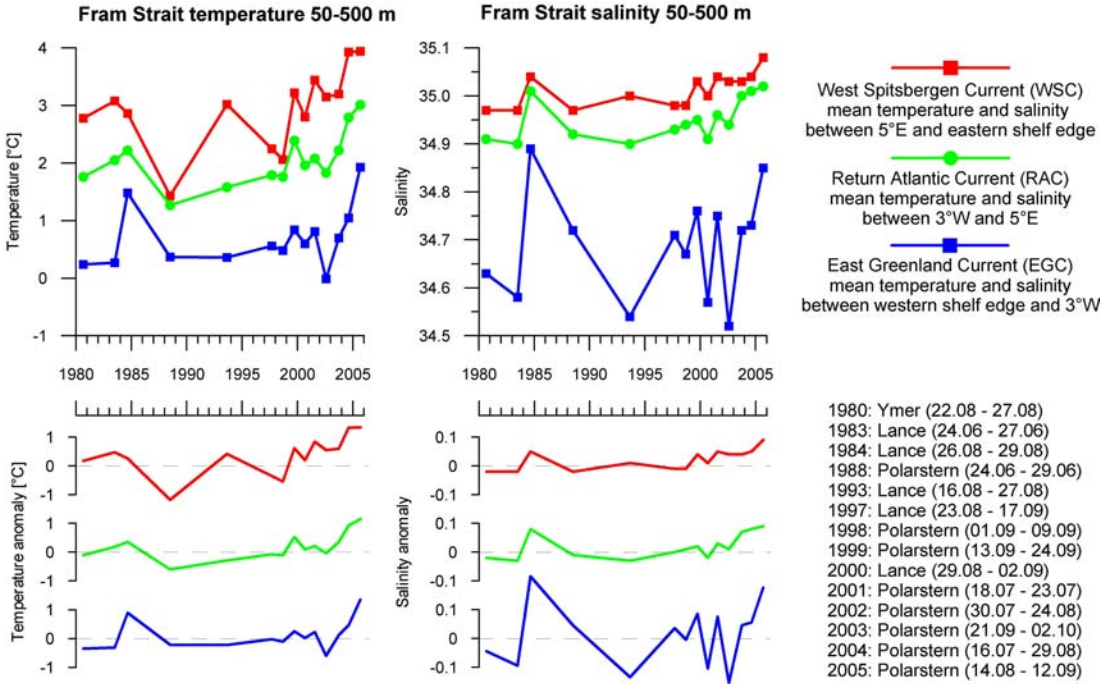

Figure A18.6: The variations of the mean temperatures and salinities in Fram Strait in the West Spitsbergen Current (WSC), Return Atlantic Current (RAW) and East Greenland Current (EGC) in the layer 50–500 m. Anomalies from the long term averages (1980–2000) shown at the bottom plots.

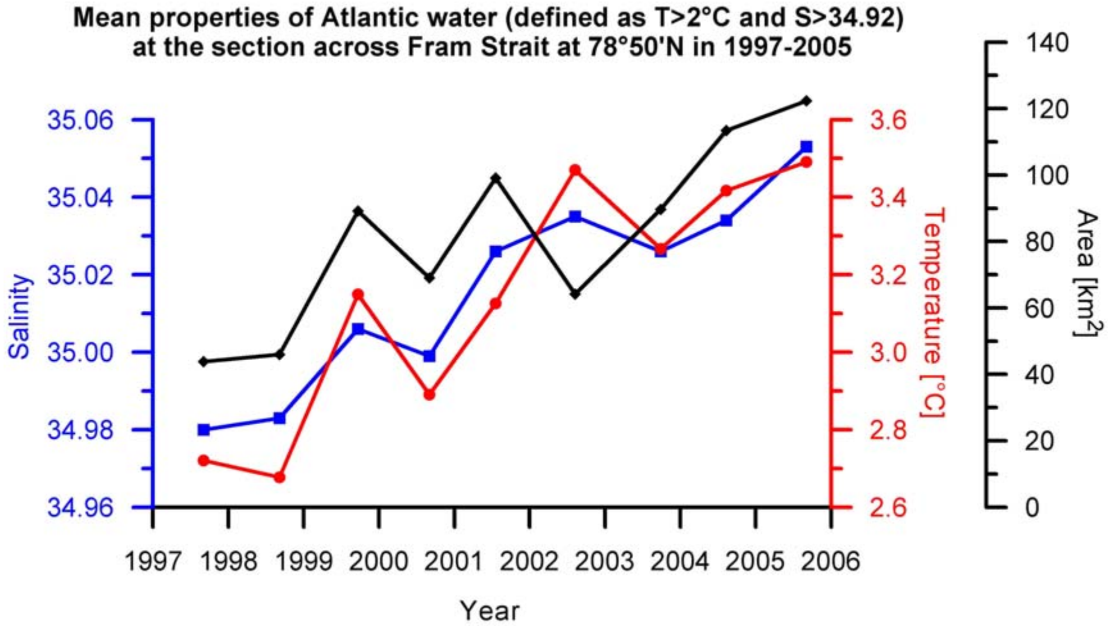

Figure A18.7: Mean properties of Atlantic Water (T>2°C, S>34.92) based on CTD sections in 1997–2005.

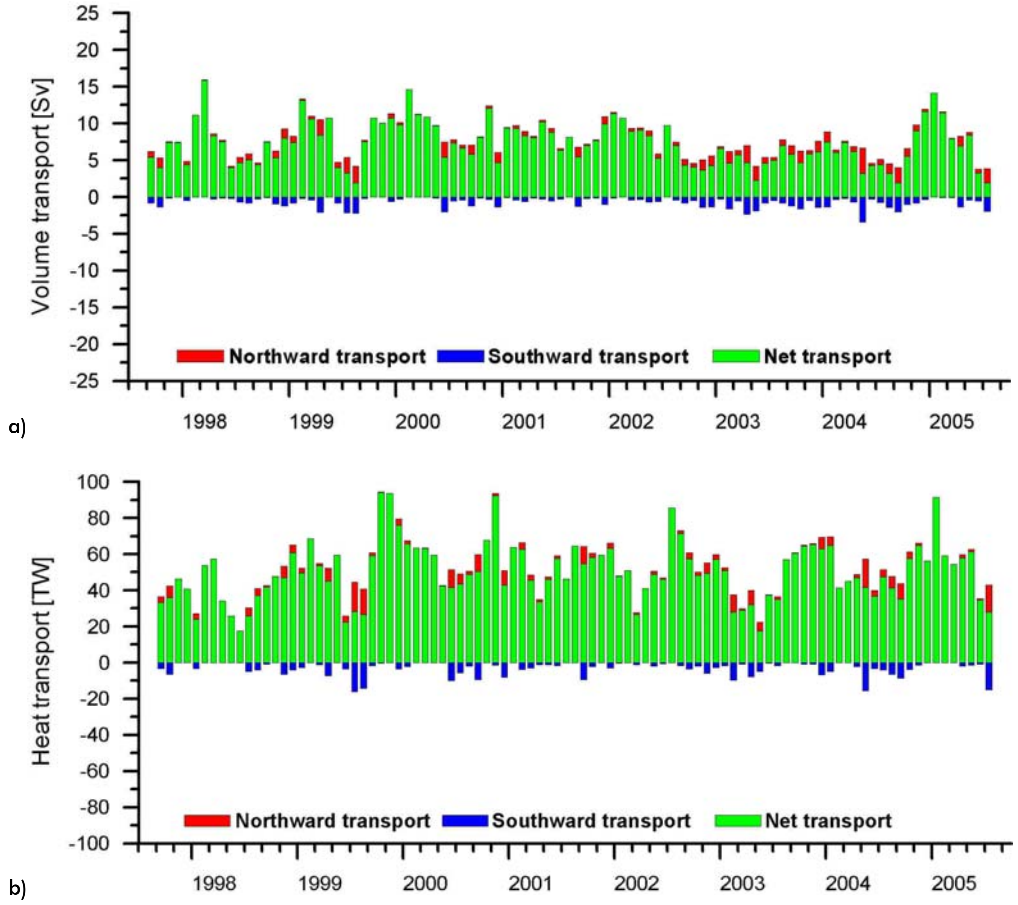

Figure A18.8: Monthly means of the northward, southward and net volume (Figure a) and heat (Figure b) fluxes in the West Spitsbergen Current based on results from the array of moorings in 1997–2005.

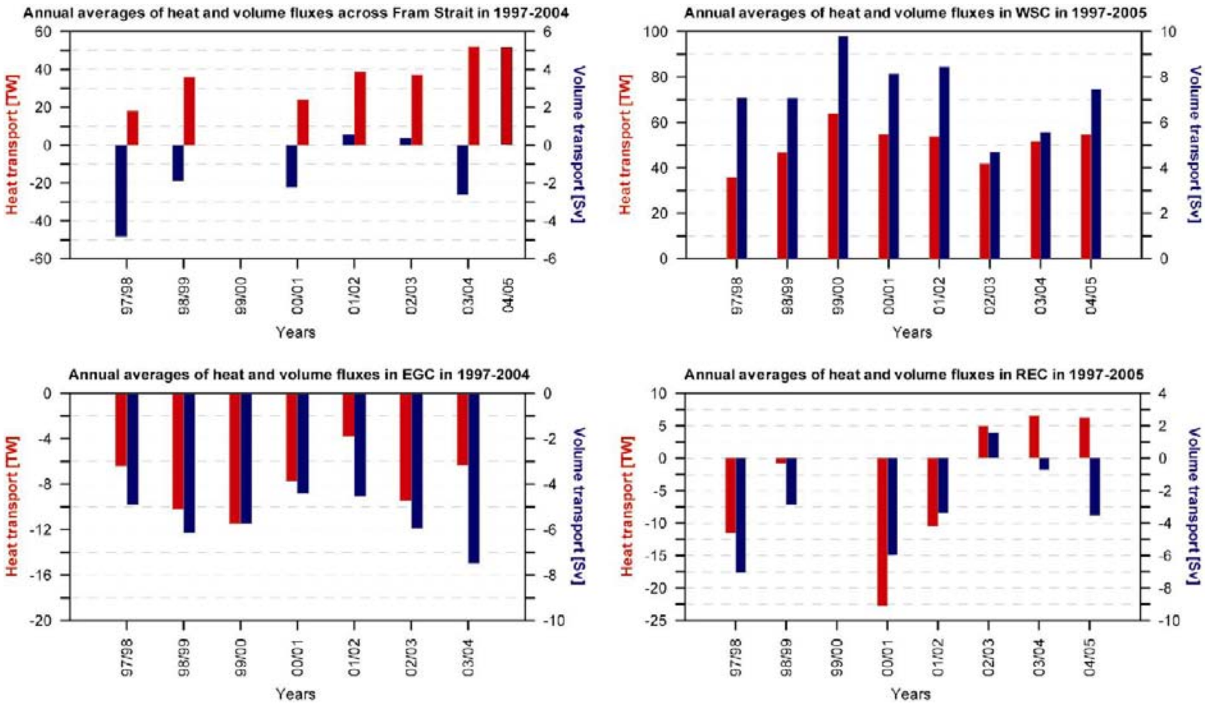

Figure A18.9: Annual averages of net volume and heat fluxes through Fram Strait (upper left figure) and separately in three domains: WSC (lower left figure), RAC (upper right figure) and EGC (lower right figure) based on results from the array of moorings in 1997–2005.

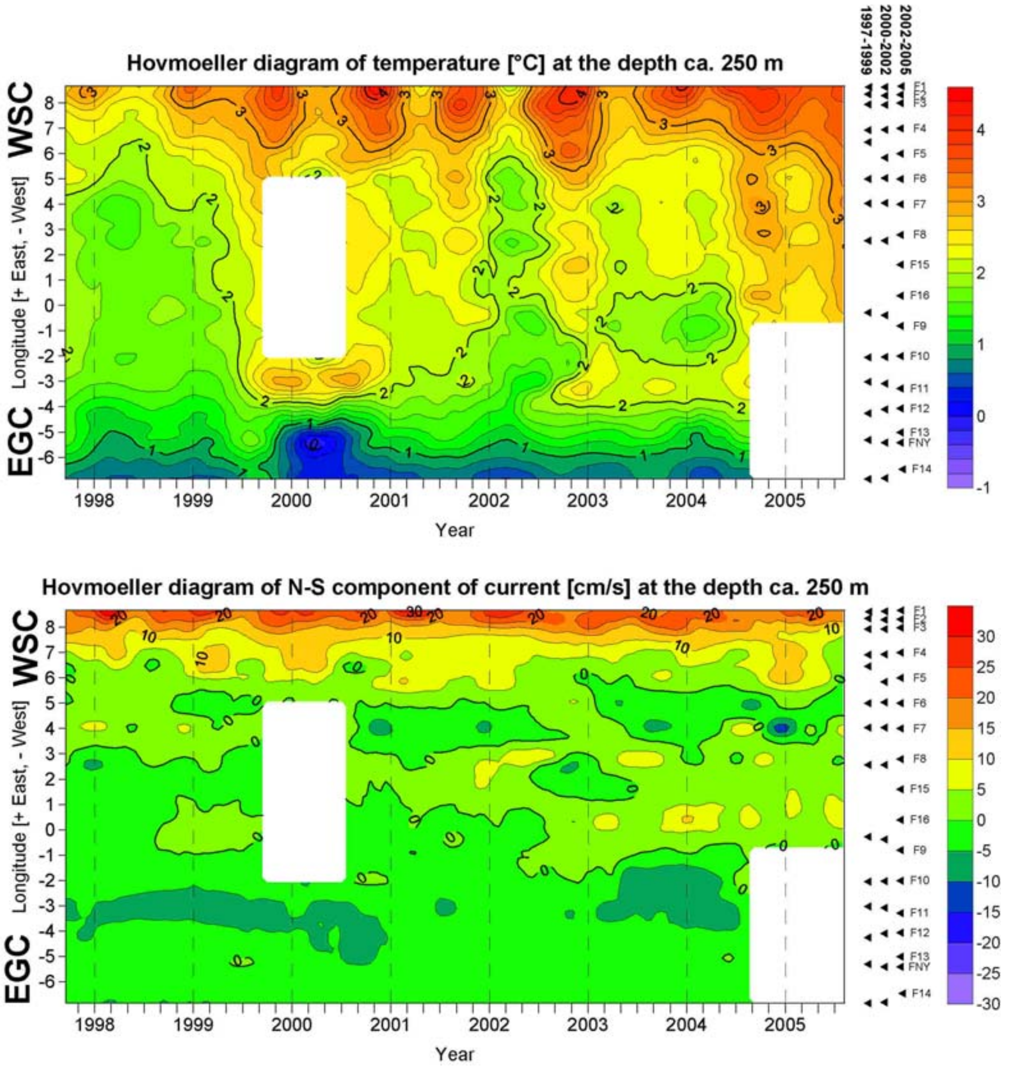

Figure A18.10: Hovmöller diagrams of temperature (upper figure) and meridional component of current (lower figure) in the AW layer at the depth 250 m in 1997–2004. Monthly means of the measured values used.

Annex 19: Environmental conditions in the Labrador Sea in 2005 (Area 2B)

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Summary

Annual mean surface air temperatures from representative land stations bordering the Labrador Sea were about 2°C warmer than normal in 2005, similar to conditions in 2004 and continuing a decade-long period of warmer than normal conditions. Many winter months during recent years show monthly average surface air temperatures more than 5°C warmer than normal.

Mean 2005 sea surface temperatures from the UK Met Office Hadley Centre HadISST 1.1 Global Sea Surface Temperature data were more than 1°C warmer than normal in the Labrador Sea and adjacent northwest Atlantic, similar to conditions in 2004. Relative to 2004, there was a slight cooling in the northern Labrador Sea and a warming to the southeast.

Annual mean sea-air heat fluxes in the west-central Labrador Sea from the NCEP/NCAR Reanalysis project have been lower than normal since 1998. The 2005 annual mean was slightly higher than the previous year's but still the third lowest since 1987. The 2005 value of 44 W/m^2 was 23 W/m^2 lower than the 30-year mean for 1971–2000 of 66 W/m^2, representing a one-third reduction from normal conditions.

Sea level in the west-central Labrador Sea based on TOPEX/POSEIDON and JASON-1 altimetry was nearly 8 cm higher in 2005 than during the cold period 1993-1995. Most of this change can be related to changes in hydrographic conditions. There has been relatively little change in annual-mean sea level during the past eight years. Mean sea level in the southern Labrador Sea and adjacent North Atlantic was slightly higher in 2005 than in 2004, but in the northern Labrador Sea this pattern was reversed.

The 16th annual Fisheries and Oceans Canada AR7W survey took place from late May to early June 2005. Between 1990 and 2005 the upper layers of the Labrador Sea have become warmer and saltier. Changes in temperature and salinity averaged over the upper 150 m during this period amount to about 1°C and 0.1 respectively.

The upper 2000 m of the water column in the west-central Labrador Sea have become steadily warmer over the past six years. By this measure, conditions in 2005 were the warmest in the 16 years of annual AR7W surveys. Salinity has shown a more complex behaviour during this time period. For the past four years, salinity has been higher than during the previous decade, with conditions in 2005 slightly fresher than in 2004. Density changes during the past few years have been relatively small, with changes linked to temperature and salinity nearly in balance.

The 2005 survey encountered warm and saline waters in the offshore branch of the West Greenland Current, with maximum salinities greater than 34.95.

The 2005 observations suggest that vertical mixing in the west-central Labrador Sea during the winter of 2004–2005 was confined to the upper 700 m and restricted to potential density anomalies of less than approximately 27.72 kg/m^3.

Introduction

Labrador Sea hydrographic conditions depend on a balance between heat lost to the atmosphere and heat gained from warm and saline Atlantic Waters carried northward into the Labrador Sea by the West Greenland Current. Severe winters under high North Atlantic Oscillation (NAO) conditions lead to greater cooling: in exceptional cases, the resulting increases in the surface density can lead to convective mixing of the water column to depths of 2 km. Milder winters under low NAO conditions lead to lower heat losses and an increased presence of the warm and saline Atlantic Waters. A sequence of severe winters in the early 1990s led to the most recent period of deep convection, which peaked in 1993-1994. Recent winters have been generally mild.

Figure A18.1 shows a map of Labrador Sea and surrounding land areas. The map shows the locations of selected meteorological stations discussed below, the position of Ocean Weather Station Bravo which operated in the area from 1963 to 1974, and stations locations for the annual AR7W surveys. The circled area in the west-central Labrador Sea marks the region where convection to depths as great as 2000 m was observed during the cold period of the early 1990s (Lazier *et al.*, 2002). Wintertime convection to depths as little as 200 m and as great as 1500 m was observed in the OWS Bravo record (Lazier, 1980).

Figure A19.1: Map of the Labrador Sea showing the AR7W section, selected meteorological stations, and OWS Bravo. The circled area is referred to in the text as the west-central Labrador Sea.

General environmental indicators

Surface air temperature

Figure A19.2(a) shows time-series of annual mean surface air temperature anomalies for 1960–2005 relative to the 30-year 1971–2000 normal for Cartwright, Labrador; Iqaluit, Nunavut; and Nuuk, Greenland. The Cartwright and Labrador data were obtained from Environment Canada while the Nuuk data were obtained from the Danish Meteorological Institute, largely from Cappelen *et al.* (2005). All three stations showed temperatures continuing about 2°C warmer than normal in 2005. Figure A19.2(b) shows time-series of monthly mean surface air temperature anomalies for 2003-2005 for these three stations. The normal annual average air temperature at Iqaluit is more 9°C colder than at Cartwright and about 8°C colder than at Nuuk, but the magnitude and patterns of variability at these three stations bordering the Labrador Sea are remarkably similar. At each site, the annual mean temperature was 1-2˚C warmer than normal over the past three years. The greatest variability occurs during winter months. Warm conditions were observed in January and February 2005 at all three sites: monthly mean temperatures were about 3°C warmer than normal at Cartwright and more than 5°C warmer than normal at Iqaluit and Nuuk.

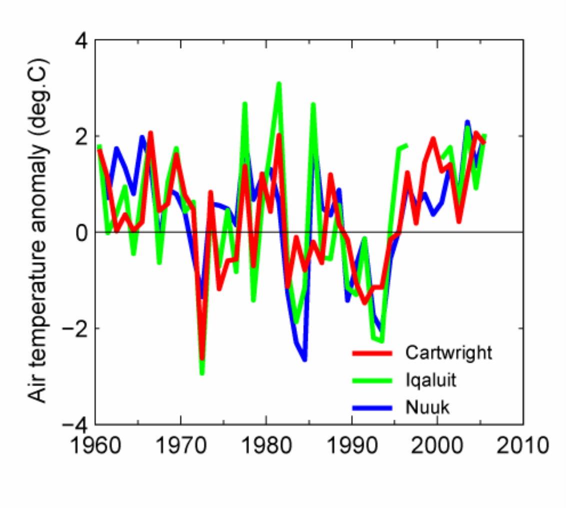

Figure A19.2(a): Annual mean air temperature anomalies for 1960-2005 relative to a 1971–2000 normal for Cartwright, Labrador; Iqaluit, Nunavut; and Nuuk, Greenland.

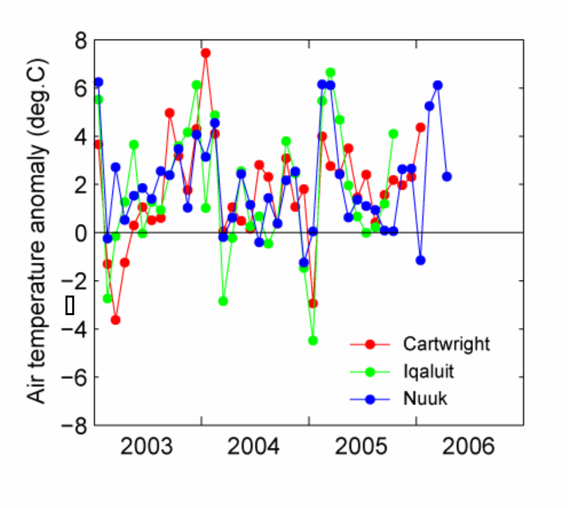

Figure A19.2(b): Monthly mean air temperature anomalies for 2003–2005 as in Figure A19.2(a).

Sea surface temperature

Monthly averages sea surface temperature (SST) data for the Labrador Sea were extracted from the global HadISST1 data set produced by the UK Met Office Hadley Centre on a 1-degree latitude-longitude grid. Figures A19.3(a) and 3(b) show maps of SST anomaly relative to the 30-year normal period 1971–2000 for 2004 and 2005. The 2004 and 2005 anomaly maps both show values more than 1°C warmer than normal. Figure A19.3(c) shows the change from 2004 to 2005. SST values in the west-central Labrador Sea were virtually identical for 2004 and 2005. Conditions were slightly cooler in the northern Labrador Sea, but warmer to the south and east. Figure A19.3(d) shows a time-series of annual SST anomalies averaged over nine grid points centred at 56.5N, 52.5W. The normal value is 4.34°C. Annual mean SST at this location has been warmer than normal since the mid-1990s. The 2004 annual mean was a record high for post-1960 conditions. The 2005 value was virtually identical to the 2004 value.

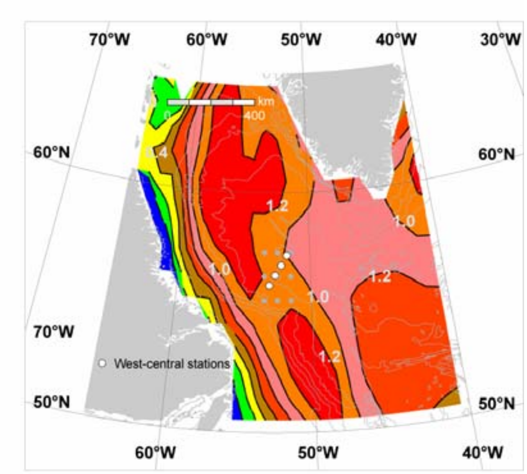

Figure A19.3(a): Mean 2004 HadISST1 Labrador Sea SST anomaly (°C). Hollow circles mark positions of four AR7W stations discussed in the text. Light grey circles are selected HadISST1 grid points.

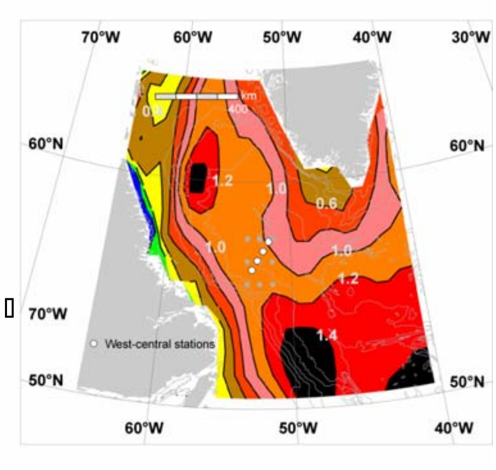

Figure A19.3(b): Mean 2005 Labrador Sea SST anomaly (°C) as in Figure A19.3(a).

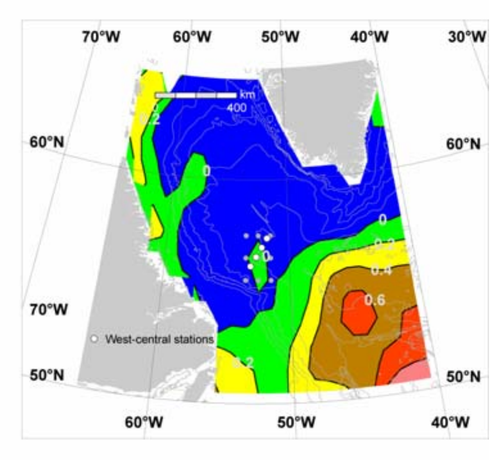

Figure A19.3(c): Changes in annual mean Labrador Sea SST from 2004 to 2005 as in Figures A19.3(a) and 3(b).

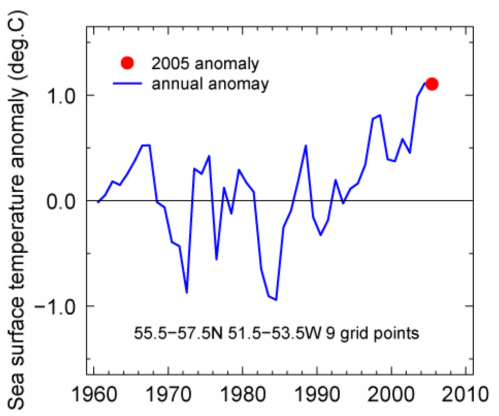

Figure A19.3(d): Time-series of annual SST anomaly averaged over 9 HadISST1 grid points centred at 56.5N, 52.5W in the west-central Labrador Sea marked in Figures A19.3(a)–3(c). The normal value is 4.22oC.

Sea-air heat flux

On an annual average, the Labrador Sea loses heat to the overlying atmosphere. The greatest heat losses occur in January and February. Monthly-averaged air-sea flux fields are available from 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).

Figure A19.4(a) shows a map of 2004 mean NCEP Reanalysis sea-air heat flux anomalies for the Labrador Sea. Positions of the NCEP grid points are superimposed on the map. Figure A19.4(b) shows a similar map of 2005 mean sea-air heat flux anomalies. The anomalies are computed relative to a 1971-2000 normal. The anomalies in the central Labrador Sea show similar values 20-30 W/m^2 less than normal for both 2004 and 2005.but the 2005 map features an area of reduced heat flux south of Greenland. A map of the change in annual mean sea-air heat flux from 2004 to 2005 in Figure A19.4(c) shows that this feature is part of a notable reduction in annual mean heat loss in the northern Labrador Sea. Figure A19.4(d) shows a time-series of annual mean sea-air heat flux anomaly in the west-central Labrador Sea at the NCEP Reanalysis grid point at 56.2N, 52.5W. The normal value is 66 W/m^2. Annual mean heat losses at this location have been less than normal for the past eight years. The 2005 annual mean of 44 W/m^2 was slightly greater than the 39 W/m^2 value for 2004 but was still the third lowest since 1987.

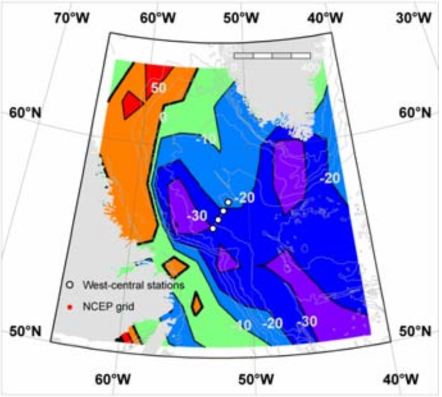

Figure A19.4(a) 2004 annual mean Labrador Sea sea-air heat flux anomaly (W/m2) from monthly mean NCEP/NCAR Reanalysis flux fields on a T62 Gaussian grid. Open circles mark selected AR7W stations.

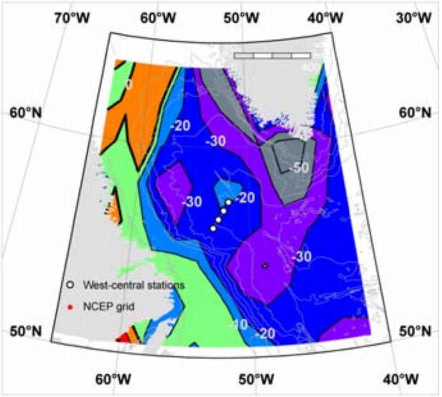

Figure A19.4(b) 2005 annual mean Labrador Sea sea-air heat flux anomaly as in Figure A19.4(a).

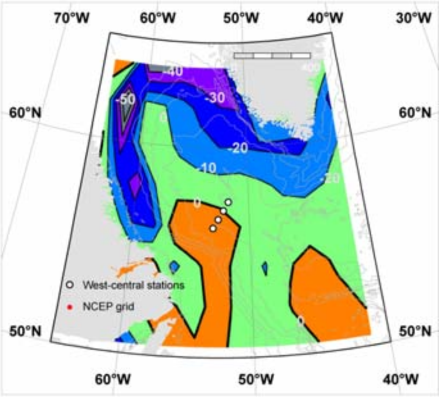

Figure A19.4(c) Change in annual mean Labrador Sea sea-air heat flux from 2004 to 2005 as in Figures A19.4(a) and 4(b).

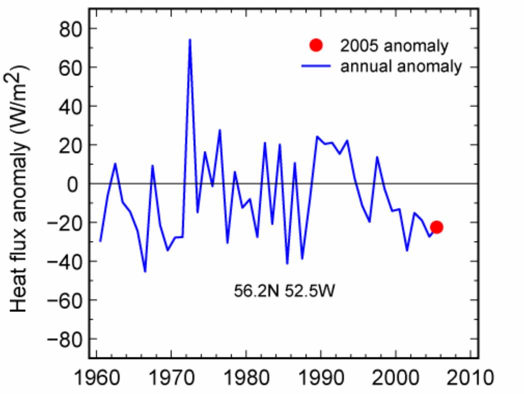

Figure A19.4(d) Time-series of annual sea-air heat flux anomaly from the NCEP/NCAR Reanalysis grid point at 56.2N, 52.5W in the west-central Labrador Sea. The normal value is 66 W/m2.

Sea level

The French SSALTO/DUACS group uses TOPEX/POSEIDON and JASON-1 altimetric sea level measurements to produce weekly gridded Maps of Sea Level Anomalies (MSLA) with near-global geographic coverage on a 1/3^{o} Mercator grid. These are distributed by the French AVISO group with support from the French national space agency CNES. Data coverage begins with the TOPEX/POSEIDON mission in late 1992 and continues to the present. The gridded MSLA are produced by a statistical interpolation that is most reliable at points close to the measurements (Le Traon, *et al.*, 1998).

Figure A19.5(a) shows a map of annual mean Labrador Sea sea level anomaly (SLA) for 2004 from this source annotated with selected AR7W stations positions. The original MSLA product gives anomalies with respect to the 1993–1998 mean but here they are shown relative to the 1993–2005 mean. Figure A19.5(b) shows the same field for 2005. The patterns are similar for the two years. Figure A19.5(c) shows the change in annual mean SLA from 2004 to 2005. There was a slight decrease in sea level in the northern Labrador Sea and a slight increase in the southern Labrador Sea and the adjacent North Atlantic. Figure A19.5(d) shows a time-series of annual mean SLA from a spatial average over 25 grid points centred at 56.7N, 52.3W near an orbit crossover point. Sea level showed a marked rise at this location from the mid-1990s to 2000 but has remained relatively constant since then. The time-series shows a rise in sea level of about 0.01 m from 2004 to 2005, consistent with the difference map in Figure A19.5(c).

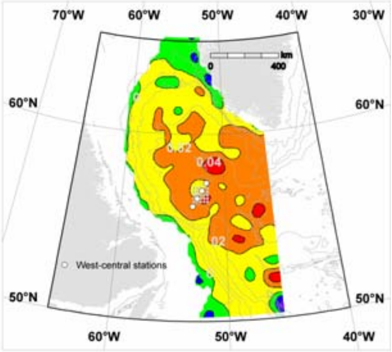

Figure A19.5(a) 2004 mean Labrador Sea sea level anomaly (m) from the Aviso gridded MSLA product.

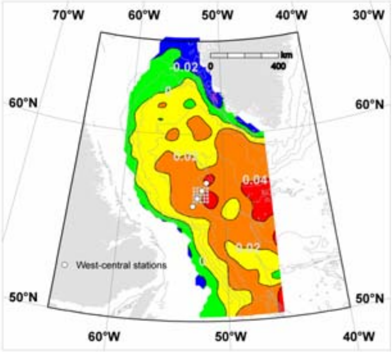

Figure A19.5(b) 2005 mean sea level anomaly for the Labrador Sea as in Figure A19.5(a).

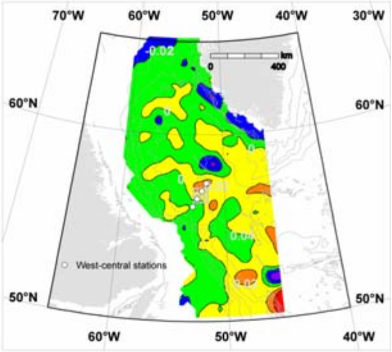

Figure A19.5(c): Change in annual mean Labrador Sea sea level anomaly from 2004 to 2005 as in Figures A19.5(a) and 5(b).

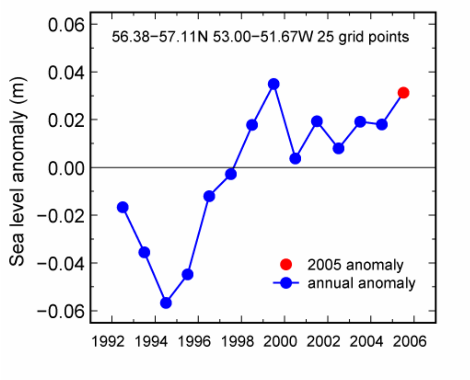

Figure A19.5(d): Time-series of spatially averaged annual mean SLA averaged near 56.7N, 52.3W relative to the 1993–2005 mean value.

AR7W Hydrography

Since 1990, Ocean Sciences Division at the Bedford Institute of Oceanography has carried out annual occupations of a hydrographic section across the Labrador Sea (Figure A19.1). The section was designated AR7W (Atlantic Repeat Hydrography Line 7) in the World Ocean Circulation Experiment (WOCE). This effort continues as a regional monitoring and research program with associated chemical and biological components that contributes to the Climate Variability (CLIVAR) component of the World Climate Research Programme (WCRP) and the international Global Climate Observing System (GCOS).

The 31 AR7W stations shown in Figure A19.1 were occupied during the period 29 May–3 June 2005 on CCGS Hudson Mission 2005016 under the scientific direction of Dr Allyn Clarke and Dr Glen Harrison. The section spans approximately 880 km from the 130 m contour on the inshore Labrador shelf to the 200 m contour on the West Greenland shelf. Sea ice sometimes limits coverage at the ends of the section but light ice conditions were encountered in 2005 and all planned stations were occupied.

A contoured gridded section of potential temperature from the 2005 survey is shown in Figure A19.6. Along-section distance in kilometres increasing from southwest (Labrador) to northeast (Greenland) is used as the horizontal coordinate. The four stations within the 320–520 km distance range are chosen to represent conditions in the west-central Labrador Sea.

Notable in the upper levels of Figure A19.6 are cold waters (<2°C) over the Labrador Shelf associated with the Labrador Current and similarly cold waters in the upper few hundred metres over the outer edge of the West Greenland shelf 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. Stations and depth ranges with Irminger Mode Water properties following Buch (2000) (potential temperatures between 4°C and 6°C and salinities between 34.85 and 34.95) and Irminger Atlantic Water properties following Lee (1968) (potential temperatures between 4°C and 6°C and salinities between 34.95 and 35.10) are highlighted in Figure A19.6.

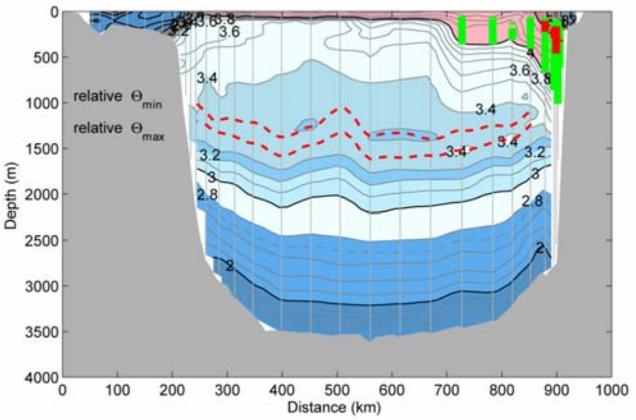

Figure A19.6: Potential temperature (°C) on the AR7W section in late May–early June 2005. Station positions are indicated by vertical lines. The dashed lines trace layers of relative minimum and maximum potential temperature. Colour highlighting marks stations and depth ranges showing Irminger Mode Water (green) and Irminger Atlantic Water (red) as defined in the text.

In the central Labrador Sea, water at depths between 600 m and 1200 m below the seasonal thermocline has reduced vertical temperature gradients that mark vertically-mixed Labrador Sea Water (LSW) formed by winter convection in recent years. The LSW layer creates a relative minimum in potential temperature with core values near 3.2–3.3°C. The section plots are annotated with the pressure of this relative minimum in potential temperature. The LSW layer extends over much of the section, but it is most prominent in the west-central Labrador Sea. The Irminger Waters in the upper 500 m on the Greenland side are notably warmer than waters at the same depths on the Labrador side. Denser components of the warm and saline Irminger Water influence a layer centred at about 1500 m below the LSW with a relative maximum in potential temperature near 3.4°C. The pressure of this intermediate-depth potential temperature maximum is also marked in Figure A19.6.

Changes in upper level properties

Near-surface seasonal warming is apparent in Figure A19.6. There is a regular upper ocean seasonal cycle in both temperature and salinity in the Labrador Sea, with the strongest changes concentrated in the upper 150 m of the water column. Survey times during the 16-year period varied from late May to late July. Climatological hydrographic data from the U.S. National Ocean Data Center (Conkright *et al.*, 2002) were used to model seasonal changes in 0–150 m potential temperature and salinity and remove them from the AR7W survey data. Figures A19.7(a) and 7(b) show time-series of the resulting deseasoned 0-150 m potential temperature and salinity for stations in the 320–520 km distance range for the 16 spring and early summer AR7W occupations from 1990 to 2005. Standard deviations of individual station values for each survey are indicated on the plots. The 2005 anomalies are 0.7°C in potential temperature and 0.08 in salinity relative to the 1990–2005 mean.

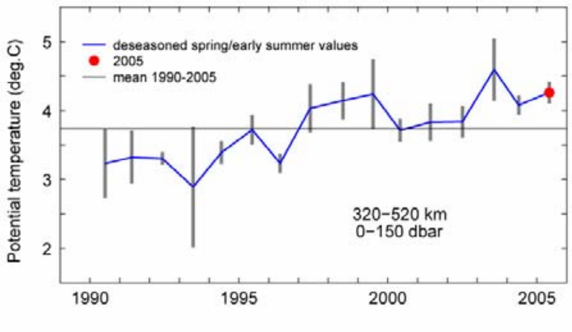

Figure A19.7(a): Deseasoned 0–150 m potential temperature from the 320-520 km distance range for spring and early summer AR7W occupations. Error bars are among-station standard deviations for each survey.

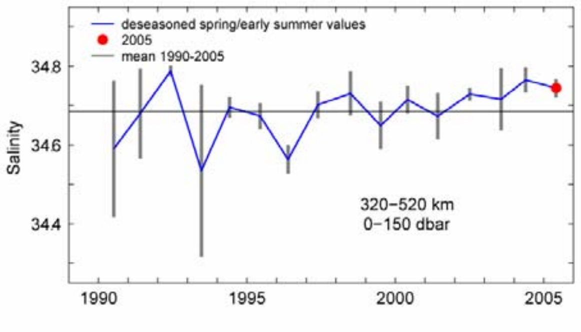

Figure A19.7(b): Deseasoned 0-150 m salinity from stations in the 320-520 km distance range for spring and early summer AR7W occupations as in Figure A19.7(a).

Interannual changes in winter convection

Figure A19.8 gives an overview of interannual variability from AR7W surveys since 1990. It shows a time-series of the pressure on selected potential density anomaly surfaces from average profiles in the 320–520 km distance range for each survey as a function of the median station time. This is an update of Figure A19.4 in Lazier *et al.* (2002).

The deep convection of the early 1990s is reflected in the 1993–1995 maximum in the separation of the 27.77 and 27.79 kg/m^3 potential density anomaly surfaces bounding the deeper shaded layer in Figure A19.8. The volume of water in this potential density range decreased steadily from 1995 to 2000. Pressures corresponding to the minimum potential temperature in the 27.77–27.79 kg/m^3 layer for each survey are noted in the figure. The prominent relative minimum in potential temperature in this layer created by the deep convection that peaked in the winters of 1992–1993 and 1993–1994 persists until at least 1999. Changes in the separation of these isopycnals have been small since 2000.

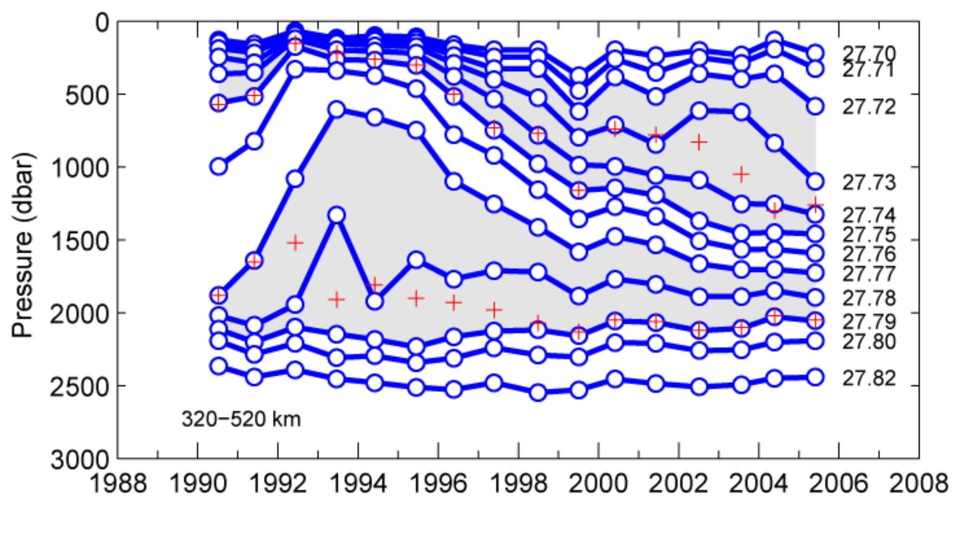

Figure A19.8: Time-series of pressure on selected potential density surfaces averaged over stations in the 320-520 km distance range for spring and early summer AR7W surveys from 1990 to 2005. Crosses mark pressures at minima in potential temperature in two shaded layers 27.72–27.75 kg/m^3 (upper) and 27.77–27.79 kg/m^3 (lower).

Starting in 1999 or 2000 and especially from 2001 to 2003 there was an increase in the separation of isopycnals with potential density anomalies in the range 27.72–27.75 kg/m^3 that define the shallower shaded layer in Figure A19.8. In 2000, this layer developed a prominent relative minimum in potential temperature with core potential temperature 3.2°C, salinity 34.83, and potential density anomaly 27.73 kg/m^3. A relative minimum in potential temperature is also present in 2002 and 2003 at increasing values of potential density anomaly. This feature can be interpreted as a remnant of intermediate-depth winter convection in the west-central Labrador Sea during recent years. In 2004 and 2005 the minimum potential temperature in the 27.72–27.75 kg/m^3 layer is found near the bottom of the layer.

Interannual changes in heat, salt, and geopotential

The changes in heat and salt from 1990 to 2000 were discussed by Lazier *et al.* (2002). Time-series of the changes in heat, salt, and geopotential in selected pressure layers from spring and early summer AR7W surveys from 1990 to 2005 are shown in Figures A19.9(a)–9(c). Each series is plotted as an anomaly relative to its 1994 value. Seasonal changes have been removed from the 0–150 dbar pressure range as discussed above.

The ranges of heat and salt content in the 0–2000 dbar layer in Figures A19.9(a) and 9(b) are approximately 5 GJ/m^2 and 100 kg respectively. A heat gain of 1 GJ/m^2 by this layer would increase its mean temperature by about 0.12°C. An increase of 20 kg/m^2 of salt in the same layer would raise its mean salinity by about 0.01.

The heat content in all layers in the 0–2000 dbar range increased from 2004 to 2005. Following a six-year increasing trend, the 2005 the 0–2000 dbar heat content was the greatest in the 16 spring and early summer AR7W surveys.

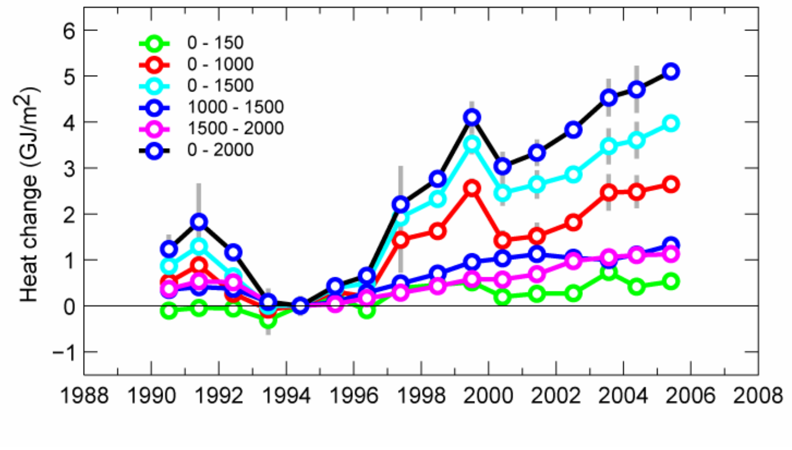

Figure A19.9(a): Heat content in selected layers relative to 1994 from spring and early summer AR7W occupations. Values are averages over stations in the 320–520 km distance range. The legend gives the pressure ranges for each layer in dbar. Climatological seasonal effects in the 0–150 dbar pressure range have been removed.

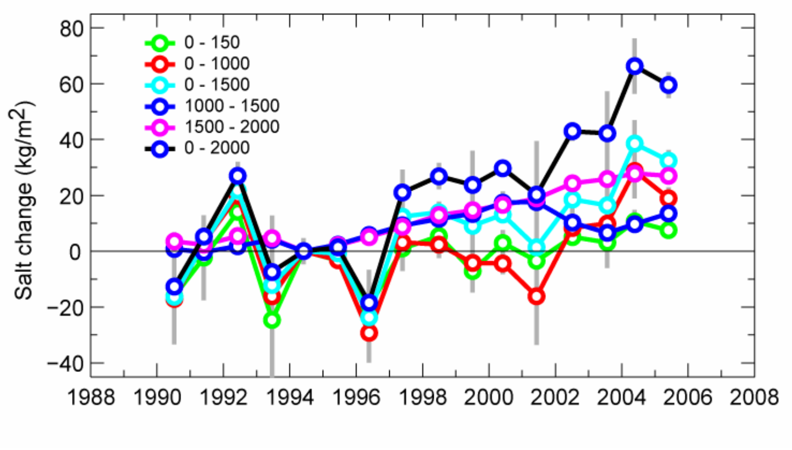

Figure A19.9(b) Salt content in selected layers relative to 1994 from spring and early summer AR7W occupations averaged over stations in the 320-520 km distance range as in Figure A19.9(a).

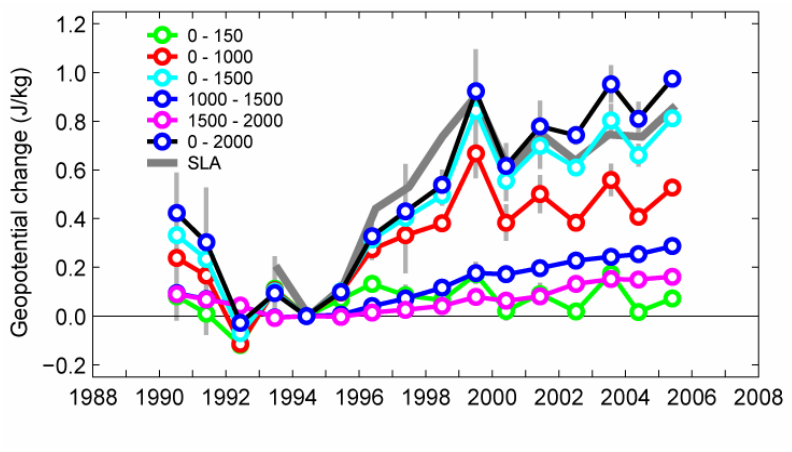

Figure A19.9(c): Geopotential changes for selected layers from spring and early summer AR7W occupations as in Figure A19.9(a) and geopotential changes associated with annual mean altimetric sea level anomalies (SLA) as in Figure A19.5(d), all relative to 1994.

The upper layer salt content shows more vertical structure and higher frequency variability than the heat content. The 0–2000 dbar salt content decreased in 2005 compared to 2004 because the upper 1000 dbar layer was fresher, but 2005 still gave the second highest salt content in the 16-year record.

Higher temperatures correspond to lower water densities and increases in buoyancy and geopotential. Higher salinities correspond to greater water densities and decreases in buoyancy and geopotential. Figure A19.9(c) shows the changes in geopotential relative to 1994 associated with the pressure layers in Figures A19.9(a) and 9(b). A large increase in buoyancy and geopotential took place from 1994 to 1999–2000 as the upper 1000 dbar layer warmed while salinity remained relatively constant. Recent years have seen generally warmer and saltier upper-layer conditions, with only a weak residual positive trend in buoyancy or geopotential. The observed warmer and freshening in the upper 1500 dbar in 2005 both contribute to lower density and greater buoyancy and geopotential. Figure A19.9(c) also shows the equivalent changes in geopotential associated with altimeter observations of sea level. The sea level changes are largely explained by steric effects in the upper 2000 m of the water column, with changes in the upper 1500 m having the greatest effect.

Acknowledgments

Monthly mean surface air temperatures for Cartwright and Labrador data were provided by the Canadian National Climate Data and Information Archive, operated and maintained by Environment Canada. [http://climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html]

Nuuk monthly mean surface air temperatures up to 2004 were provided by the Danish Meteorological Institute [http://www.dmi.dk/dmi/tr05_05_recommended2004.zip] as documented in Technical Report No. 05-05 by Cappelen *et al.* (2005).

http://www.dmi.dk/dmi/index/viden/dmi-publikationer/tekniskerapporter.htm

Recent monthly mean surface air temperatures for Nuuk were provided by the Danish Meteorological Institute. [http://www.dmi.dk/dmi/index/gronland/verdensvejr-gron.htm]

The HadISST1 Global Sea Surface Temperature data set was provided by the Hadley Centre for Climate Prediction and Research, Met Office, Bracknell, UK. [http://www.metoffice.com/research/hadleycentre/obsdata/HadISST1.html]

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