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Report of the

Working Group on Oceanic Hydrography

Bergen, Norway
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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK–1261 Copenhagen K Denmark

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1 SUMMARY OF WORKING GROUP ON OCEANIC HYDROGRAPHY 2003

1) A one-day mini-symposium on Climate was co-chaired by Svein Østerhus (Bjerknes Centre for Climate Research, Bergen) and Harald Loeng (Institute of Marine Research, Bergen), on the first day of the meeting. Abstracts of talks are presented in Annex D.

2) National reports were presented on the second day of the meeting, the summaries of these were collected to form the 2002/2003 ICES Annual Ocean Climate Status Summary (IAOCSS). The report was reviewed and approved by the Working Group on Oceanic Hydrography. This is available at http://www.ices.dk/status/

3) In summary, the North Atlantic Oscillation (NAO) index switched back to negative conditions during the winter preceding 2001 having recovered in the previous 4 years from the extreme negative value of 1996 which had brought to an end a period of extreme and persistent positive NAO index in the late 1980s/early 1990s. The 2002 NAO index showed a return to positive which for the winter as a whole was not extreme, but where individual months exhibited extreme and opposing SLP anomaly patterns.

4) Climactic conditions over the northern North Atlantic remained relatively mild during 2002. Upper layers of the ocean were generally warmer and more saline than normal.

5) The membership of the Working Group on Oceanic Hydrography was reviewed prior to the meeting and an updated members list is included in Annex C.

6) A review of surface flux climatology was undertaken, but concluded that the data sources from which this climatology are derived are too scarce in the northern latitudes (>60°N). At high latitudes, the SOC climatology (or an extended subset of COADS) is not very useful as a source of time-series information, although it retains its utility as a long-term mean climatology.

7) The review of the 2001 ICES Symposium on 'Hydrobiological Variability in the ICES Area, 1990–1999' has been completed and the Symposium volume is expected to be published before the ICES Annual Science Conference in September 2003.

8) The Working Group on Oceanic Hydrography received updates from member countries of new projects in the area. The Working Group on Oceanic Hydrography consider that information from the Baltic is of interest to the WG and encourages attendance from members working in this area.

9) Two new Terms of Reference (ToR) were proposed for discussion by the working group in 2004: (I) A review of national monitoring programmes with a view to improve the overall climate monitoring activities. (II) A review of relations between the ICES Working Group on Oceanic Hydrography and other international projects

10) The Working Group will meet next year in Southampton, UK, 29 March – 1 April 2004.

2 OPENING

The Working Group on Oceanic Hydrography was jointly hosted by the Institute of Marine Research and the Bjerknes Centre for Climate Research, Bergen, Norway. The Working Group was welcomed to the Bjerknes Centre by Svein Sundby, the leader of the Ocean Processes Group at the Bjerknes Centre who presented a brief introduction of the activities of the centre.

The Bjerknes Centre for Climate Research (BCCR) is a joint climate research venture between the University of Bergen, the Institute of Marine Research and the Nansen Environmental and Remote Sensing Centre. The BCCR integrates observationalists and modellers in a joint interdisciplinary research effort with the aim of being a world class centre on studies of high latitude climate change. The BCCR is the largest climate research group in Norway and was awarded the status of National Centre of Excellence by the Research Council of Norway on 2002. www.bjerknes.uib.no

3 A MINI-SYMPOSIUM ON CLIMATE

To continue with the recommendations made at the 2001 Reykjavik WG meeting, a mini-symposium on the subject of climate was held. The mini-symposium was co-chaired by Svein Østerhus (Bjerknes Centre for Climate Research, Bergen) and Harald Loeng (Institute of Marine Research, Bergen). Abstracts of the talks are presented as Annex D.

This is the third year that the Working Group on Oceanic Hydrography has commenced with a day of scientific presentations, jointly by members of the Working Group on Oceanic Hydrography, and by scientists from the host organisation. It appears to be a successful development, and encourages a broader interaction between ICES scientists and a wider community, as called for in the ICES strategic plan. The WG recommends that a mini-symposium be arranged for the 2004 meeting.

The Agenda of the symposium ran as follows:

Svein Sundby: Bjerknes Centre for Climate Research

Eugene Colbourne: Decadal Variability in the Ocean Climate of the Northwest Atlantic

Sheldon Bacon: Open-ocean convection in the Irminger Basin

Ross Hendry and John Lazier: Heat and salt budgets of the Labrador Sea

Denis Gilbert: Ocean climate variability in the Gulf of St. Lawrence

Anne Britt Sand, Hjalmar Hatun and Helge Drange: An isopycnic model for the Nordic Seas: Comparison of decadal variations between model results and observations

Tor Eldevik: Ventilation and spreading of Greenland Sea water: Process studies

Tore Furevik, Mats Bentsen, Helge Drange, Johnny Johannessen and Alexander Korablev: Temporal and spatial variability of the sea surface salinity in the Nordic Seas

Helge Drange, Jan Even Nilsen, Yongqi Gao, Tore Furevik and Mats Bentsen: Simulated North Atlantic-Nordic Seas water mass exchanges in an isopycnic co-ordinate OGCM

Waldemar Walczowski and Wieslaw Maslowski: Mesoscale structures in the Nordic Seas (observations and modelling)

Ursula Schauer, Eberhard Fahrbach, Svein Østerhus, Gerd Rohard and Agnieszka Beszczynska-Möller: Arctic warming through the Fram Strait – oceanic heat transport from three years of measurements.

Øystein Skagseth: Wind forcing of the Norwegian Atlantic Current

Kjell Arne Mork: Currents measurements in the northern Norwegian Sea.

Hedinn Valdimarsson: Some process studies in Icelandic waters

Alicia Lavín and César González-Pola: Intermediate water masses variability in the Bay of Biscay

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

4 REVIEW OF MEMBERSHIP

A list of the participants at the 2003 Working Group on Oceanic Hydrography is presented in Annex B. The French national report was prepared by Gilles Reverdin and presented by Yves Morel. It is hoped that Dr Reverdin may attend the 2004 Working Group on Oceanic Hydrography. The following people also attended the meeting to present national reports: John Mortensen (replacement for Jens Meincke) and Agnieszka Beszczynska-Moller (replacement for Eberhard Fahrbach).

Harry Dooley (ICES) renewed the list of membership to the Working Group on Oceanic Hydrography, and some effort was made to recruit new participants. The Working Group on Oceanic Hydrography welcomed several new members at the 2003 meeting; Sarah Hughes (UK), Stephen Dye (UK), Denis Gilbert (Canada), Waldemar Waczowski (Poland) and Kjell Arne Mork (Norway). The updated list of members is presented as Annex C.

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

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

This agenda item was covered by a single full day of presentations, in which an overview of North Atlantic ocean climate during 2002 emerged. The national contributions are summarised to provide input to the ICES Annual Ocean Climate Status Summary (IAOCSS) (ToR B).

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

ANNEX E: THE NAO IN WINTERS 2002 AND 2003

S. Dye, B. Dickson and J. Meincke

The Centre for Environment Fisheries Aquaculture Sciences (CEFAS), Lowestoft, UK.

ANNEX F: OCEANOGRAPHIC INVESTIGATIONS OFF WEST GREENLAND 2002 (AREA 1)

E. Buch and M.H. Ribergaard

Division for Operational Oceanography, Danish Meteorological Institute, Denmark.

ANNEX G: CLIMATIC CONDITIONS OFF WEST GREENLAND – 2002 (AREA1)

M. Stein

Institute for Sea Fisheries, Hamburg, Federal Republic of Germany.

ANNEX H: AREA 2B (LABRADOR SEA) CANADIAN REPORT
ENVIRONMENTAL CONDITIONS IN THE LABRADOR SEA IN SPRING 2002

R.M. Hendry, R.A. Clarke, J.R.N. Lazier, and I.M. Yashayaev

Fisheries and Oceans Canada, Bedford Institute of Oceanography, Nova Scotia, Canada.

ANNEX I: ENVIRONMENTAL CONDITIONS IN THE NORTHWEST ATLANTIC DURING 2002 (ICES AREA 2)

E. Colbourne

Northwest Atlantic Fisheries Centre, St. John's, Newfoundland, Canada.

ANNEX J: AREA 3: ICELANDIC WATERS

H. Valdimarsson and S. Jónsson

Marine Research Institute, Reykjavík, Iceland

ANNEX K: HYDROGRAPHIC STATUS REPORT 2003: SPANISH STANDARD SECTIONS (AREA 4)

A. Lavín, C. González-Pola and J. M. Cabanas

Spanish Institute of Oceanography (IEO), Spain.

ANNEX L: CONTRIBUTION TO THE 2003 MEETING OF THE WORKING GROUP ON OCEANIC HYDROGRAPHY: FRENCH NATIONAL REPORT (AREA 4)

G. Reverdin,

The Laboratory for Dynamical Oceanography and Climatology (LODYC), France

ANNEX M: REPORT ON WOCE/CLIVAR SECTION A1E (NORTHERN NORTH ATLANTIC AREA 5B)

J. Mortensen

Institute of Oceanography, IMF, University of Hamburg, Hamburg, Federal Republic of Germany.

ANNEX N: 2002 RESULTS FROM THE SCOTTISH STANDARD SECTIONS, (AREA 7 AND 8)

S. Hughes and B. Turrell

FRS Marine Laboratory Aberdeen, Scotland, UK

ANNEX O: NORTH SEA SST SINCE 1968: SOME GROSS STATISTICS (AREA 8 AND 9)

P. Loewe and G. Becker

Federal Maritime and Hydrographic Agency of Germany (BSH), Hamburg, Germany.

ANNEX P: THIRTY YEAR TIME-SERIES OF SURFACE TEMPERATURE AND SALINITY IN THE SOUTHERN BIGHT OF THE NORTH SEA (ICES AREA 9)

S. Dye, K. Medler, S. Norris and B. Dickson

The Centre for Environment, Fisheries & Aquaculture Sciences (CEFAS), Lowestoft, UK.

ANNEX Q: AREA 9B: SKAGERRAK, KATTEGAT AND THE BALTIC

K. Borenas

Swedish Meteorological and Hydrological Institute, Sweden

ANNEX R: OCEAN WEATHER STATION MIKE (AREA 10)

S. Østerhus

Bjerknes Centre for Climate Research, Norway

ANNEX S: NORWEGIAN WATERS (AREA 8, 10 AND 11)

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

Institute of Marine Research, Bergen, Norway

ANNEX T: AREAS 10 AND 11 (NORWEGIAN AND BARENTS SEAS) RUSSIAN REPORT RUSSIAN STANDARD SECTIONS IN THE BARENTS AND NORWEGIAN SEAS

V. Ozhigin

Knipovich Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia

ANNEX U: POLISH NATIONAL REPORT (AREA 10, 11, 12)

J. Piechura, W. Walczowski

Institute of Oceanology, Polish Academy of Sciences, Poland.

ANNEX V: HYDROGRAPHIC CONDITIONS IN THE GREENLAND SEA AND FRAM STRAIT (AREA 12)

A. Beszczyńska-Möller, G. Budeus, E. Fahrbach, U. Schauer, A. Wisotzki

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

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

The draft ICES Annual Ocean Climate Status Summary (IAOCSS) was prepared and reviewed by the Working Group, and its contents agreed. Sarah Hughes (UK) must be thanked for helping prepare the 2002/2003 IAOCSS. The text of the report is presented in Annex W.

Harald Loeng (Norway) suggested that having a co-ordinated summary in the front of the IAOCSS report would make it more useful to non expert readers. In the 2001/2002 report there is a brief summary for each of the 12 areas and for the NAO-index, but there is no comparison between areas or comments on how the NAO influence the oceanographic conditions. The suggestion is to compare both the present hydrographic conditions and the observed trend and for example, examine whether the NAO could explain both similarities and differences between areas. An overall summary paragraph was added to the 2002/2003 report and the group agreed to expand the report with an extended summary from 2004.

Vladimir Ozhigin (Russia) suggested also including a simple figure illustrating the development in hydrographic conditions. Eugene Colborne (Canada) showed how the Canadians are summarising their climatic conditions in one single table, and it was agreed to follow the Canadian model. The Working Group Chair will remind the members about the new procedure before the next meeting, including detailed information on how to make the calculations.

The overview of the 2002/2003 report is presented below.

The 2002/2003 ICES Annual Ocean Climate Status Summary

Overview

In most areas of the North Atlantic during 2002, temperature and salinity were higher than the long-term average.

The North Atlantic Oscillation (NAO) index switched back to negative conditions during the winter preceding 2001, having recovered in the previous 4 years from the extreme negative value of 1996, which had brought to an end a period of extreme and persistent positive NAO index in the late 1980s/early 1990s. The 2002 NAO index showed a return to positive which for the winter as a whole was not extreme, but where individual months exhibited extreme and opposing SLP anomaly patterns.

Area Summaries

Area 1: Although summer time temperatures off West Greenland were slightly above average in the summer of 2002, there was cooling during the autumn. Unusually low salinities were observed in the off-slope surface waters during the autumn.

Area 2: Annual mean air temperatures over all areas of the Northwest Atlantic remained slightly above normal during 2002, but have decreased over 2001 values. The amount of sea ice on the eastern Canadian Continental Shelf continued to be below normal for the 7th consecutive year. Ocean temperatures during 2002 remained above normal, thus continuing the warm trend experienced throughout much of the Northwest Atlantic during the past several years. Ocean salinities during 2002 increased to the highest levels observed in over a decade.

Area 2b: Labrador Sea

The 2001–2002 winter over the Labrador Sea was more severe than the previous winter but still milder than normal. Observations in early summer 2002 showed remnants of convective overturning to maximum depths of 1200 -1400 metres, about 400 metres deeper than seen in the preceding two years. Apart from the apparent weak increase in winter convection, the general trend was to warmer and more saline conditions. This was true both in waters shallower than the maximum depth of convection and in the intermediate-depths below 1400m. The net result is that the mean 0–2000 metres salinity was the highest in the past thirteen years of regular spring-summer observations. The corresponding mean temperature was the second highest observed during this period.

Area 3: The hydrographic conditions in 2002 revealed winter and spring values on the shelf north, north-east and east of Iceland below long-term mean for both temperature and salinity. Summer and autumn values in this area were about average and higher. The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years though slightly lower than the peak values in 1998.

Area 4: An extremely anomalous cold atmospheric spring-summer period at the southern Bay of Biscay area have made 2002 the coldest sea surface temperature year from 1992. Upper water (0–300 metres) mean temperature is on the time-series average. Salinity has begun to recover after the minimum found in 2001 resulting in average values for shallower depths.

Area 5a: No data available for 2002

Area 5b: The WOCE/CLIVAR Section A1E, showed relatively high temperatures and salinities in the upper layer in 2002. These suggest that a new positive salinity anomaly is in progress. In the upper 1200 metres of the water column the tendency is towards warmer and more saline conditions. This is due to the deepening and decay of the Labrador Sea Water mass produced in the 1990s.

Area 6: No data available for 2002

Area 7: With respect to the last four decades, Atlantic waters in the Faroe Shetland Channel are generally warming and becoming more saline. This trend continued during 2002.

Areas 8 and 9: Surface waters of the North Sea were higher than average in most areas for the whole of the year. Salinities in the North Sea returned to normal following the extreme low values observed in 2001.

Area 9b: The year of 2002 was characterised by the late summer being unusually warm which resulted in higher than normal sea surface temperatures in Area 9b. Low surface salinities were found in the Kattegat and Skagerrak in April-June due to large outflows from the Baltic.

Area 10: In the Norwegian Sea conditions continued a long term warming trend, and in 2002 the temperature of Atlantic water was the highest since the time series started in 1978.

Area 11: The Barents Sea was warmer than the average during 2002. The temperature increased from average in January and reached maximum temperature anomaly in June, which was the highest observed during the last 30 years. The temperature then decreased to the average at the end of 2002.

Area 12: In the Greenland Sea in summer 2002, the Atlantic waters of the West Spitsbergen Current were characterised by high temperature and salinity, similar to those observed during the last three years. Polar waters in the east Greenland Current were significantly colder and less saline than in summer 2001.

7 REVIEW OF NORTH ATLANTIC CLIMATOLOGIES (TOR C)

A review of the SOC air-sea surface flux climatology was undertaken by Sheldon Bacon (UK).

The SOC air-sea flux climatology is the product of several years of work by the Meteorology Team in the James Rennell Division of SOC – particularly Simon Josey, Liz Kent and Peter Taylor. It is available on the web at http://www.soc.soton.ac.uk/JRD/MET/fluxclimatology.php3. For published references, see for example Josey, Kent and Taylor (1998, 1999 and 2002). The primary data source for the climatology is the Combined Ocean–Atmosphere Data Set (COADS) Release 1a, which contains global Voluntary Observing Ship (VOS) data. The climatology itself uses a subset of COADS (1980–1993) which contains long wave, short wave, latent and sensible air-sea heat fluxes plus surface wind stress on a 1˚ x 1˚ grid. Its utility lies in the fact that it is a high accuracy measurement product, thanks to work on inclusion of metadata, bias identification and removal, re-calibration, bulk formula configuration, etc. Thus it could be more useful than atmospheric model products (like ECMWF or NCEP reanalyses). For the present study, we employed an expanded subset of COADS spanning 1970–1997.

The climatology is designed for use as a source of monthly / seasonal / annual mean data, but plainly the source data contain the potential to provide time series information over decades. Although the climatology is intended to have global coverage, it is most reliable where shipping (and hence data) density is highest: this means approximately 40˚S – 60˚N. Nevertheless, the Norwegian coast, which lies at a higher northern latitude than these limits, is ice-free all year and has a reasonable density of shipping, so it seemed worthwhile trying to see whether a useful time series could be extracted. Liz Kent performed the necessary data extraction on my behalf. It was apparent that the data density was in fact so low (on a monthly basis) that a large area (5˚ x 5˚) had to be inspected in order to obtain meaningful values. Also, much of the shipping is coastal (nearshore), so there is a strong regional bias in the data. In short, at high latitudes, the SOC climatology (or an extended subset of COADS) is not very useful as a source of time-series information, although it retains its utility as a long-term mean climatology. For the purposes of the Working Group on Oceanic Hydrography, it is best to rely for atmospheric flux products on, for example, NCEP reanalysis output.

7.1 References

Josey, S. A., Kent, E. C., and Taylor, P. K.1998: The Southampton Oceanography Centre (SOC) Ocean - Atmosphere Heat, Momentum and Freshwater Flux Atlas. Southampton Oceanography Centre Report No. 6, 30 pp. plus figs.

Josey S. A., Kent, E. C., and Taylor, P. K.1999: New insights into the ocean heat budget closure problem from analysis of the SOC air-sea flux climatology. J. Climate 12 2856–2880.

Josey S. A., Kent E. C., and Taylor P. K. 2002: Wind stress forcing of the ocean in the SOC climatology: Comparisons with the NCEP-NCAR, ECMWF, UWM/COADS, and Hellerman and Rosenstein Datasets. J. Phys. Oceanogr. 32 1993–2019.

8 EVALUATION OF THE ICES INTERACTIVE DATA SUMMARY PRODUCT (TOR D)

Unfortunately Dr H Dooley (ICES) could not attend the 2003 Working Group on Oceanic Hydrography and therefore no progress has been made with this item. The Working Group on Oceanic Hydrography strongly recommend that the ICES oceanographer attend the 2004 meeting or provide a written report to the working group prior to the next meeting to allow the group to evaluate the product.

9 PUBLICATION OF THE PROCEEDINGS OF THE ICES SYMPOSIUM ON HYDROBIOLOGICAL VARIABILITY IN THE ICES AREA, 1990–1999 (TOR E)

The 2nd ICES Decadal Symposium was held at the Royal College of Physicians, Edinburgh on August 8–10 2001 and was highly successful, attracting a full programme of 42 selected talks and 55 posters describing the variability of the plankton, fish, ocean and atmosphere of the ICES area during the 1990s. It was held in partnership with a one day

'Achievements Symposium' on 7 August celebrating 70 years of the CPR Survey. Active canvassing attracted a total of 17 corporate and institutional sponsors to allow the Symposia to be conducted within budget. Around 184 individuals participated overall, with 155 attending the decadal meeting.

It is suggested that by 2011, it might be appropriate to include a session specifically aimed at describing and testing the best of these relationships in stock assessment. The ICES website www.ices.dk/symposia/decadal3 will be made available to receive participants' comments on the success or otherwise of the present format and ideas for the design and content of a 3rd Decadal Symposium in 2011.

The editorial panel formed by Ken Drinkwater (Canada), Alicia Lavín (Spain), Mike St. Johns (Canada) and lead by Bill Turrell (UK) have reviewed the posters and papers. This process was helped by editorial input from Jennifer Watson who took the whole process to conclusion. The proceedings were supplied to ICES in January 2003 in paper and electronic formats. Judith Rosenmeier (ICES Senior Editor) has assured the group that the volume of the ICES Marine Science Symposia series entitled 'Hydrobiological Variability in the ICES Area 1990–1999' will be published before the ICES Annual Science Conference in September 2003.

10 REVIEW TWO PROPOSALS FOR NEW WORK, VIZ:, I) UNDERTAKE LONG TERM STORAGE OF WATER SAMPLES; II) UNDERTAKE AN ISOPYCNAL ANALYSIS OF IN SITU DATA. (TOR F)

1) The group discussed the proposal by Bogi Hansen (Faroes) for the long-term storage of water samples for future analysis. The text of the proposal is included as Annex X of this report. The Working Group on Oceanic Hydrography remain unconvinced of the benefits of this approach. Past experience has shown that many parameters are unstable in long term storage. Further justification would be needed before the Working Group on Oceanic Hydrography can recommend this approach to all members. Sheldon Bacon (UK) has proposed that an expert be invited to speak on the stability of seawater in storage at the next OHWG meeting.
2) The Working Group on Oceanic Hydrography also discussed the proposal by Prof. Tom Rossby (USA) to undertake isopycnal melding of the in-situ data. Some members have included isopycnal analysis in their national reports but no further progress has been made. The text of the proposal is included as Annex Y of this report. The Working Group on Oceanic Hydrography would be grateful if Professor Rossby could attend the meeting in 2004 to develop this proposal further.

11 ANY OTHER BUSINESS

11.1 NEW TECHNOLOGY

Rune Hansen and Helge Minken from Aanderaa Instruments

Aanderaa Instruments is in the final stage in the development phase of the new Recording Doppler Current Profiler RDCP600. The RDCP600 is Aanderaa's most advanced product to date. It has been designed to be used in bottom mounted installations, as well as in ordinary string moorings where it may replace multiple single-point current meter installations. The Aanderaa RDCP600 will include support for additional sensors in the same fashion as the single-point current meters RCM-9 and RCM-11.

They also described a new oxygen sensor based on the principle of the effect of dynamic luminescence quenching by molecular oxygen. The sensor can output data in standards RS-232 format or be fitted onto Aanderaa instruments.

11.2 Status in Nuka Artica by Svein Østerhus

Svein Østerhus (Norway) gave an update of the Nuka Arctica project. This cargo vessel travels between Denmark and Greenland (Nuuk) every 9 days. It is fitted with a Thermosalinograph and Vessel Mounted ADCP and also deploys XBT's and Meteorological balloons during the journey. Data from the project is available via the Nuka Arctica web page http://www.gfi.uib.no/forskning/Nuka_Arctica/. Svein was concerned that the Nuka Arctica line has been dropped from the CLIVAR project.

11.3 'Deep water convection in the Greenland Sea' Johan Blindheim

Johan Blindheim (Norway) gave an update of his work on deep-water convection in the Greenland Sea. No signal of deep convection has been observed in the last decade

11.4 Hendrik van Aken

Hendrik van Aken (the Netherlands) described his planned work in the Irminger Sea using moorings with profiling CTD and ADCP's as well as the re-survey of the WOCE A1E line. Hendrik proposed that the first year of mooring data would be available to present to the Working Group on Oceanic Hydrography in 2005, while the hydrographic survey data would be presented during the 2004 meeting.

11.5 Ross Hendry

Ross Hendry (Canada) presented details of the Davis Strait Flux Experiment, a joint contribution by the University of Washington (USA) and Fisheries and Oceans Canada's Ocean Sciences Division, Bedford Institute of Oceanography (BIO) to the Arctic and Subarctic Ocean Flux (ASOF) programme. Acoustically-tracked CTD gliders, fixed moorings with upward-looking sonar and acoustic Doppler current profilers (ADCP), and ADCP bottom landers will monitor volume, fresh water, and ice fluxes in Davis Strait during 2004–2007. Brian Petrie is the principal contact at BIO.

11.6 Alicia Lavín

Alicia Lavín (Spain) presented details of two EU projects on operational oceanography that the Intituto Español de Oceanografia (IEO) is involved in. The first called GYROSCOPE is lead by France deploying Argo floats in the Atlantic, data is available from the project website: http://www.ifremer.fr/lpo/gyroscope/. The second project FERRYBOX, is lead by Germany, and has installed Thermosalinograph, Fluorometers and other sensors on Ferries servicing routes around European waters. The data from the FERRYBOX project is available from the via the project websites: (http://www.soc.soton.ac.uk/ops/ferrybox_index.php)

11.7 Harald Loeng

Harald Loeng (Norway) gave an update of the new moorings proposed for deployment in the Nordic Seas in April 2003. These measurements are closely linked to the ASOF-N project and the moorings will be recovered in 2003.

11.8 Outcoming from other regions

Correspondence was received from Eberhard Hagen from IO-Warnemuende, Germany regarding participation in the Working Group on Oceanic Hydrography. Although Eberhard is mainly involved in projects in the Benguela Current, he would still be welcomed into the group to provide input about the Baltic. The Working Group on Oceanic Hydrography would also welcome more input from other institutes involved in the Baltic area.

11.9 Session on the 2003 ASC. Presentation and call for papers

The Working Group on Oceanic Hydrography members were reminded of the deadline for submission of papers to the theme session (Session T) on 'The state and stability of the northern North Atlantic: patterns and trends' at the 2003 Annual Science Conference in Tallinn Estonia. Abstracts must be submitted by 5th May 2003.

11.10 New session for 2004 ASC in Vigo Spain

The Working Group proposes for 2004 ICES Annual Science Conference (ASC) in Vigo (Spain) a special theme session on the subject "Processes related to the continental slope in the North Atlantic". Convenors:, Alicia Lavín, Harald Loeng + **and (NW Atlantic Area)**

Justification

The western boundary of the Atlantic Ocean is well known by its intense boundary currents at surface and subsurface levels. Despite the relative low energy levels, the processes bound to the eastern boundary at the ocean may strongly affect the marine circulation and production.

- Upper water advection in a slope bounded current is the main source of water masses of southern origin and increases salinity and heat content from south Portugal to the Northern seas. In some regions, e.g., the Iberian ocean margin, the slope boundary current may show a seasonal variability. The slope current may form a meridional link between different populations of marine species.

- Part of the Mediterranean outflow is guided along the European slope to at least the Porcupine Sea Bight in a slope bound under-current. The high salinity of the Mediterranean outflow strongly influences the salinity of the North Atlantic at intermediate levels.
- Filaments, resulting from upwelling, and mesoscale eddies shedding from the slope current may transport water from the continental shelf, with its dissolved and suspended matter, into the ocean basins and maintain exchange of properties across the ocean margin.
- Internal waves and internal tides are generated at the sloping boundaries of the ocean. The energy transported laterally by these waves will become available for boundary intensified turbulent diapycnal mixing. This intense mixing is required to explain the canonical $K=10^{-4}$ m^2 s^{-1} value, since open ocean measurements come to turbulent diffusion coefficients at least an order of magnitude smaller.
- General processes on continental slopes are also a valid topic for presentation as well as any other processes on continental slope dynamics from modelling and observation.

11.11 New session for 2005 Annual science conference

The Working Group on Oceanic Hydrography considered the following proposal by Hendrik van Aken for a theme session in 2005. "Recent advances in our understanding of marine turbulence in an ecological and climatolgical context"

'The Working Group on Ocean Hydrography considers turbulence and turbulent mixing to be key factors in the understanding of the ocean as a physical and eco-system. Turbulence can be shear driven, convectively driven or driven by double diffusive processes. Convenors: Hendrik van Aken and another convenor (to be arranged).

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

The Working Group on Oceanic Hydrography considers this to be an interesting proposal that would require input from other multidisciplinary groups and would allow discussion of new developments in the understanding of marine turbulence in an ecological and climatological content.

12 DATE AND PLACE OF NEXT MEETING

Sheldon Bacon (UK) kindly extended to the Working Group an invitation to Southampton in 2004. The Working Group will meet there during 29 March – 1 April 2004. It is proposed that a one-day mini-symposium be held to discuss recent work on regional ocean climate variability of relevance to Working Group on Oceanic Hydrography. This meeting will also provide the opportunity to meet with members of international projects based in the Southampton Area (e.g., CLIVAR, GOOS, Argo).

13 RECOMMENDATIONS

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

a) update and review results from Standard Sections and Stations^ALL*;

b) consolidate inputs from Member Countries into the ICES Annual Ocean Climate Status Summary (IAOCSS [HUGHES]);

c) review national monitoring programmes with a view to improve the overall climate monitoring activities [LOENG];

d) review progress on the publication of the proceedings of the ICES Symposium on Hydrobiological Variability in the ICES Area, 1990–1999 [LAVIN];

e) Review relations of ICES Working Group on Oceanic Hydrography to international climate monitoring programmes [BACON].

f) review two proposals for new work, viz:
   i) undertake long term storage of water samples [HANSEN];
   ii) undertake an isopycnal analysis of in situ data [ROSSBY].

Working Group on Oceanic Hydrography will report by 30 April 2004 for the attention of the Oceanography Committee and Advisory Committee on the Marine Environment.

Supporting Information

Priority:	The activities of this group are fundamental to the fulfilment of the oceanography committee's action plan.
Scientific Justification:	a) This is a repeating task established by the Working Group to closely monitor the ocean conditions in the ICES area. The materials presented under this item will be utilised to prepare an overview of the state-of-the-environment in the North Atlantic for 2003. b) The Working Group recognises the need for disseminating climate information in a timely and appropriate manner. The Steering Group on ICES-GOOS has also identified the climate summary as an essential contribution from Working Group on Oceanic Hydrography. This agenda item will allow Working Group OH members to prepare the document during the meeting, thus avoiding delays in the dissemination of the information. c) Most ICES countries have an extensive monitoring activity, but there is no or little co-ordination between nations. This agenda item will therefore critical evaluate the existing activities and look for improvement and better co-ordination efforts d) The Working Group on Oceanic Hydrography will review progress by the Scientific Steering Group and editorial Panel on the publication of the proceedings of the ICES Symposium on Hydrobiological Variability in the ICES Area, 1990–1999, in order to identify any potential problems, help rectify them and provide advice intended for the third Decadal Symposium. e) The visit of the ICES Working Group on Oceanic Hydrography to Southampton Oceanography Centre provides an opportunity for the Working Group on Oceanic Hydrography to interact directly with the representatives of several international climate monitoring programmes (e.g., CLIVAR, GOOS, Argo), and it would be of benefit both to ICES an the international programmes to enhance internal information change. f) These two new business items were proposed by Prof. Hansen (Faroe Islands) and Prof. Rossby (USA) for further discussion by the group (see Annex Y and Z of 2002 report).
Relation to Strategic Plan:	The Working Group on Oceanic Hydrography supports various elements of Goals 1 and 4.
Resource Requirements:	No extraordinary additional resources
Participants:	The Group normally is well attended but lack participation from a number of countries committed to physical oceanographic programmes in the Atlantic, in particular France
Secretariat Facilities:	N/a
Financial:	None apart from b) Publication / reproduction costs
Linkages to Advisory Committees:	ICES Annual Ocean Climate Status Summary available to Advisory Committee on Fishery Management and Advisory Committee on the Marine Environment
Linkages to Other Committees or Groups	Publications Committee; Consultative Committee; ICES/IOC Steering Group on GOOS
Linkages to Other Organisations:	IOC, JCOMM

ANNEX A: AGENDA AND TERMS OF REFERENCE FOR 2003 WORKING GROUP ON OCEANIC HYDROGRAPHY MEETING

The Working Group on Oceanic Hydrography [Working Group on Oceanic Hydrography] (Chair: A Lavín*, Spain) will meet in Bergen, Norway from 31 March - 3 April 2003 to:

a) update and review results from Standard Sections and Stations [ALL];

b) consolidate inputs from Member Countries into the ICES Annual Ocean Climate Status Summary (IAOCSS) [HOLLIDAY];

c) conclude the review of North Atlantic climatologies and their availability and usage, and additional data sources for the ICES Annual Ocean Climate Summary;[BACON]

d) review an evaluation of the interactive data summary product produced by the ICES Service Hydrographique in order to enhance the ICES Annual Ocean Climate Status Summary;[DOOLEY, ROSSBY, TURRELL]

e) review progress on the publication of the proceedings of the ICES Symposium on Hydrobiological Variability in the ICES Area, 1990–1999; [DICKSON]

f) review two proposals for new work, viz:

   i) undertake long term storage of water samples; [HANSEN]
   ii) undertake an isopycnal analysis of in situ data [ROSSBY].

Working Group on Oceanic Hydrography will report by 30 April 2003 for the attention of the Oceanography Committees

Scientific Justification:

a) This is a repeating task established by the Working Group to closely monitor the ocean conditions in the ICES area. The materials presented under this item will be utilised to prepare an overview of the state-of-the-environment in the North Atlantic for 2000.

b) The Working Group recognises the need for disseminating climate information in a timely and appropriate manner. The Steering Group on ICES-GOOS has also identified the climate summary as an essential contribution from Working Group on Oceanic Hydrography. This agenda item will allow Working Group OH members to prepare the document during the meeting, thus avoiding delays in the dissemination of the information.

c) For the past two years the Working Group on Oceanic Hydrography has considered other data sources and climatologies that are of potential use for the Working Group, and in particular the IAOCSS. A document will be produced as an Annex summarising this work, and drawing conclusions from it with respect to developing the IAOCSS.

d) The ICES Oceanographic Data centre is preparing an interactive method of accessing and displaying data it holds. The Working Group on Oceanic Hydrography will review this product, and assess it by conducting case studies intersessionally. These will be reviewed by the Working Group, and an assessment made of the value of this product.

e) The Working Group on Oceanic Hydrography will review progress by the Scientific Steering Group and editorial Panel on the publication of the proceedings of the ICES Symposium on Hydrobiological Variability in the ICES Area, 1990–1999, in order to identify any potential problems, help rectify them and provide advice intended for the third Decadal Symposium.

f) These two new business items were proposed by Prof. Hansen (Faroe Islands) and Prof. Rossby (USA) for further discussion by the group (see Annex Y and Z of 2002 report).

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ANNEX D: ABSTRACTS FROM THE MINI-SYPOSIUM ON CLIMATE

Decadal Variability in the Ocean Climate of the Northwest Atlantic

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Decadal changes in the meteorological and ocean climate of the Northwest Atlantic were presented based on standard station and section data as well as data from fishery resource assessment surveys. The decadal average NAO index increased during the past three decades from the very low value of the 1960s, reaching the highest value in over 100 years by the 1990s. Air temperatures were generally cold prior to the 1920s, warm from the 1930s-1960s, then experienced large amplitude fluctuations superimposed on a general downward trend until the 1990s. Air temperatures warmed throughout the 1990s setting near record highs in Newfoundland and Labrador by the end of the decade. Sea ice extent on the Newfoundland Shelf was generally low during the 1960, corresponding to the below normal trend in the NAO and more extensive during the 1970s-1990s. During the mid-1990s however, sea ice extent decreased from the heavy ice years of the early 1990s to the lightest ice-years since the 1960s by the end of the decade. The analysis of ocean temperatures indicates that the 1950s and particularly the 1960s were the warmest decades during the latter half of the 20th century. During the past three decades however, ocean temperatures experienced sharp annual fluctuations, decadal oscillations and a long-term decline with the 1990s representing the 3rd consecutive decade with below normal temperatures on the Newfoundland Shelf. The decadal mean salinity indicates that the magnitude of negative salinity anomaly on the inner Newfoundland Shelf during the 1990s was comparable to that experienced during the 'Great Salinity Anomaly' of the early 1970s. In addition, the decade of the 1990s has experienced some of the most extreme variations since measurements began during the mid-1940s. Ocean temperatures ranged from record low values during 1991 to record setting highs during 1999 in many areas, particularly on the Grand Bank of Newfoundland. The potential impact of the changes in ocean climate during the past several decades on marine production in Newfoundland waters was also discussed. Coincident with the climate changes during the past three decades, many fish and invertebrate species showed dramatic changes in distribution and abundance. Recruitment in northern cod stocks of Newfoundland, for example, declined during the 1970s and 1980s reaching historical low values by the early 1990s. During the past four decades a regime shift occurred in the fishery in Newfoundland waters, from one dominated by cod during the warmer decades to one dominated by invertebrates during the last decade.

Open-ocean convection in the Irminger Basin

Sheldon Bacon

Hydrography Team, James Rennell Division, Southampton Oceanography Centre

Open-ocean deep convection in the Irminger Sea was recognised as a possibility nearly a century ago in work by Fridtjof Nansen, but with intermittent exceptions has received very little attention until recently, in particular in work by Bob Pickart. Bacon, Gould and Jia (2003) examine recent (1996/7) hydrographic data from ships and profiling floats for evidence of convection. In a hydrographic section from summer 1997 (Discovery cruise 230) running south- east across the Irminger Sea from Cape Farewell, southern Greenland, we find two deep-reaching plumes of fresh water, apparently resulting from convection from the previous winter. One plume is 700 m deep and lies in the centre of the recirculating gyre lying east of Cape Farewell and first identified by Lavender *et al.* (2000). With evidence from float trajectories and model data that the water column in that location is essentially stationary, we can predict the convection depth there over the winter 1996/7 given knowledge of (a) the pre-winter stratification, which we have from a section taken on Discovery cruise 223, and (b) the winter air-sea heat fluxes, which we obtained from NCEP Reananlysis data (NOAA CDC, Boulder, Colorado). Actual and predicted convection depths agree very closely. The other plume is 1000 m deep and lies in a region where stratification precludes its having been generated in situ. We show in the paper that it cannot have originated in the Labrador Sea, and that the only possible area of generation lies a few hundred km west of its observed (summer) location, i.e., south of Cape Farewell. To attempt to support this hypothesis, we search for profiling float data in this general area over the winter 1996/7 and found both a float which captured the 1000 m deep winter mixed layer there (in March 1997), and a July 1997 hydrographic section (from the F/S Meteor) which confirmed the persistence of this convective feature. By referring to the winter of 1996/7 as a year in which Irminger convection to 1000 m was just possible, we can use NCEP fluxes since 1948 to predict that the most likely candidate years for convection in the Irminger Sea were 1976, 1983, 1984, 1989, 1993 and 1994. There is a coincidence, probably imperfect, between Irminger and Labrador Sea convection, and also therefore with the North Atlantic Oscillation.

Heat and Salt Budgets of the Labrador Sea

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An analysis of thirteen annual occupations of the AR7W Labrador Sea section and NCEP/NCAR reanalysis heat fluxes concludes that changes in air-sea exchanges can largely explain observed changes in upper-layer heat content during this decade long period of deep convection and restratification. At the same time, upper layer salt content showed random variability. The upper-layer salt balance is primarily determined by advective effects, with air-sea fluxes playing a relatively minor role. The mechanisms that govern changes in the salt balance are not well understood.

Ocean climate variability in the Gulf of St. Lawrence

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The Gulf of St. Lawrence is a seasonally ice-covered inland sea affected by a large continental freshwater discharge (14000 m^3s^{-1}). In the summer, its water column may be roughly characterized as a three-layer system, 1) a warm (T ~ 6–20 °C) and relatively fresh (S ~ 28–31) surface layer in the top 20 to 30 m, 2) a cold (T < 1 °C, S ~ 32) intermediate layer known as the CIL which is a relic of the winter surface mixed layer, between about 30 m and 100 m depth, and 3) a warm (T ~ 2–5 °C) and salty (S ~ 33–35) deep layer from 100 m to 400 m depth. In the winter, the 3-layer system collapses to a 2-layer system as the surface layer deepens and merges with the CIL.

The T-S-O2 properties of each of the three layers display a large amount of interannual to interdecadal variability. In the CIL, this variability is caused by a combination of local forcings (air-sea-ice heat fluxes, brine rejection) and advection of cold and relatively salty (S > 32.5) waters from the inshore Labrador Shelf waters. The range of values for the various CIL interannual indices are -1 to 1.5 °C for its mid-summer (July 15) minimum temperature, 20 m to 120 m for the thickness of waters colder than 1 °C, and 4 to 12 x 103 km^3 for its volume. In the warm and salty deep layer, Gulf-wide average temperature indices range from 1.5 to 4 ° C in the 100 m to 200 m deep layer, and from 3 to 7 ° C in the 200 m to 300 m deep layer. Interannual to interdecadal variability in this deep layer is caused by changes in the properties of continental slope waters at the mouth of the Laurentian Channel, located in the Northwest Atlantic some 300 km to the south of Newfoundland.

The dissolved oxygen content of the 200 m to 300 m deep waters entering the mouth of the Laurentian Channel undergoes interannual variations ranging between 65% and 80% of the saturation value. As these relatively oxygen-rich waters move landward as part of the Gulf of St. Lawrence's estuarine circulation, respiration of aquatic organisms and remineralization of organic matter consume oxygen. At the head of the Laurentian Channel, at the end of their 1240 km long journey, the dissolved oxygen concentration of the 200 to 300 m deep waters has dropped to about 20–25 % saturation. Historical oxygen data from the 1930s and 1970s suggest there has been a long-term decline in oxygen concentration in the bottom water of the St. Lawrence Estuary. A research program is presently being spun up to look into the possibility that coastal eutrophication may be partly responsible for this observed decline in bottom water oxygen.

An isopycnic model for the Nordic Seas: Comparison of decadal variations between model results and observations

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The continental shelf current flowing between the Faroe Islands and the Shetland is the warmest and most saline of the three current branches, which are crossing the Greenland-Scotland Ridge poleward. This inflow has a large influence on the ecology in the Nordic Seas and the climate in Northern Europe, and it is a driving mechanism of the global thermohaline circulation. A nested version of the Miami Isopycnal Co-ordinate Ocean Model (MICOM) has been set up in the Northern North Atlantic, and its boundary conditions are obtained from a global version of MICOM. The horizontal resolution in the inflow region is 20–25 km and the model has 26 vertical layers. It is forced by

NCAR/NCEP synoptic forcing fields through the integration period 1948–2001, and incorporates realistic river runoffs. The simulated temperature in the Faroe-Shetland Channel has been compared to 30–50-year long hydrographical observations. The variability on decadal time scales compares well to observations, and the potential of using simulated data to improve instrumental records in periods of scarce data coverage and to extrapolate time series backward in time has been studied.

Ventilation and spreading of Greenland Sea water: Process studies

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The Greenland Sea is a 'hot spot' for open ocean convection. The generation and spreading of water thus ventilated play a fundamental role in the Nordic Seas' deep-water flow to the North Atlantic, a main constituent of the global thermohaline circulation. In this paper, a recently compiled Russian hydrographical data base is used investigate the location and extent of the late winter Greenland Sea Gyre mixed patch. The patch area is then tagged and introduced as a passive tracer in an advective-diffusive model of the flow of Greenland Sea water. As adequate current data are unavailable, the corresponding flow field of a 20 km resolution synoptically forced general circulation model of the Nordic Seas is used. The evolution of the tracer field provides estimates for the ventilated water's residence time in the Greenland Sea, and its pathways within and through the Nordic Seas. Comparisons are made with the results of the SF6 tracer release experiment of recent years.

Temporal and spatial variability of the sea surface salinity in the Nordic Seas

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In this paper, the temporal and spatial variability of the sea surface salinity (SSS) in the Nordic Seas is investigated. The data include a Russian hydrographical database for the

Nordic Seas and daily to weekly observations of salinity at Ocean Weather Station Mike (OWSM) (located at 66°N, 2°E in the Norwegian Sea). In addition, output from a medium- resolution version of the Miami Isopycnic Coordinate Ocean Model (MICOM), forced with daily National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data, is used to complement the analysis of the temporal and spatial fields constructed from the observational data sets. The Nordic Seas show a strong seasonal variability in the vertical density stratification and the mixed layer (ML) depth, with a weak stratification and a several hundred meters deep ML during winter and a well-defined shallow ML confined to the upper few tens of meters during summer. The seasonal variability strongly influences the strength of the high~frequency variability and to what extent subsurface anomalies are isolated from the surface. High- frequency variability has been investigated in terms of standard deviation of daily SSS, calculated for the different months of the year. From observations at OWSM, typical winter values range from 0.03 to 0.04 psu and summer values range from 0.06 to 0.07 psu. Results from the model simulation show that highest variability is found in frontal areas and in areas with strong stratification and lowest variability in the less stratified areas in the central Norwegian Sea and south of Iceland. Investigation of the interannual variability over the last 50 years shows a marked freshening of the Atlantic Water in the Norwegian and Greenland Seas. Moreover, the strength of the southern sector of the Polar front, as defined by the 34.8–35.0 psu isohalines along the western boundary of the inflowing Atlantic Water, undergoes significant interannual variability with gradient stretching reaching up to 300 km. In comparison, the variability in the strength of the eastern front and northern sector of the Polar front, seemingly controlled by the shelf break off Norway and the ridge between the Norwegian and the Greenland Seas, typically undergoes stretching only between 60 and 80 km. The investigation also demonstrates that the low-frequency variability in the upper ocean density field in the Greenland Sea, a key factor for the deep water convection, is governed by the variability in the sea surface field. Since the early 1960s, there has been a negative trend in the salinity, probably contributing to the observed decrease in the deep water production in that period.

Simulated North Atlantic-Nordic Seas water mass exchanges in an isopycnic coordinate OGCM

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The variability in the volume exchanges between the North Atlantic and the Nordic Seas during the last 50 years are investigated using a synoptic forced, global version of the Miami Isopycnic Coordinate Ocean Model (MICOM). The simulated volume fluxes agree with the existing observations. The net volume flux across the Faroe- Shetland Channel (FSC) is positively correlated with the net flux through the Denmark Strait (DS; R = 0.74 for 3 years low pass filtering), but negatively correlated with the net flux across Iceland-Faroe Ridge (IFR; R = -0.80). For the Atlantic inflow across the FSC and IFR, the correlation is R = -0.59. For the transports through the FSC and DS, the simulation suggests that an atmospheric pattern resembling the North Atlantic Oscillation is the main driving force for the variations, involving Ekman fluxes and barotropic adjustment. The model also shows a 0.7 Sv reduction of the Atlantic inflow to the Nordic Seas since the late 1950s.

Mesoscale structures in the Nordic seas – observations and modelling

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Institute of Oceanology Polish Academy of Sciences (IO PAS) has been investigating Arctic Seas since 1989. Data collected by the IO PAS in frames of the VEINS project as well as during other cruises conducted by the R.V. “Oceania” into the Barents, Norwegian and Greenland Seas are used. Observed mesoscale structures are be compared with the results from the high-resolution models of the Pan-Arctic region forced with the realistic atmospheric fields. Results from two numerical Coupled Ice-Ocean Models are used. The older one is 1/6° (~18 km) resolution Arctic Ocean Model. The new one is 1/12° (~9 km) Eddy-Permitting, Pan Arctic Model. Both models are evaluated in the Naval Postgraduate School, Monterey. First, based on in situ measurements and models output, regions of high mesoscale activity are specified. There are mainly the Barents Sea Slope, area west of Spitsbergen and the Arctic Front – border between the Atlantic Domain and Greenland Sea Gyre. Comparison between currents pattern, flow energy and the eddy kinetic energy obtained from both models and in situ data is done. Next we describe observed structures as frontal meanders and intrusions, cyclonic and anticyclonic eddies, and dens water plumes. Selected phenomenon are compared with modelled structures. Investigations of the Arctic Front conducted by the IO PAS show that the mesoscale eddies and intrusions play an important role in the transfrontal volume, salt and heat exchanges. Anticyclonic eddies broken from the frontal meanders carry considerable volume of Atlantic Water into the Greenland Sea. Anticyclonic eddies play also an important role in the Atlantic Water recirculation processes. Such eddies form west of Spitsbergen and migrate westward, into the East Greenland Current as the returned Atlantic Water. Observed and modelled processes and pathways of the Atlantic Water recirculation are presented.

Arctic warming through the Fram Strait - oceanic heat transport from three years of measurements

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The estimates of volume and heat transport through Fram Strait for the period 1997 to 2000 from data of moored instruments were presented. Full depth volume transports at 78° 55’N were in the order of 10 Sv both northwards and southwards with an annual mean net transport between 2 and 4 Sv to the south. The temperature of the northward flow of Atlantic Water had a strong seasonality with a minimum in winter. Nevertheless, the northward heat transport was highest in winter caused by the winter maximum of northward volume transport. During the three years of observation, the heat transport in the West Spitsbergen Current increased from 28 to 46 TW as a result of both increased speed and temperature. In contrast to the West Spitsbergen Current, the volume and heat transport of East Greenland Current remained fairly constant. An integration over a subsection of the East Greenland Current showed similar values of volume transport to that obtained by measurements in the1980s. The southward heat transport through modified Atlantic Water weakened slightly between 1997 and 1999 despite increased temperatures. The annual mean net heat transport across 78° 55'N increased from 16 to 41 TW in the late 1990s which - according to longterm hydrographic

observations - represent a phase of change from long-term mean to moderately warm Fram Strait conditions. An increase of this magnitude would have been sufficient to explain the warming of intermediate Arctic layers observed in the early nineties.

Current measurements in the northern Norwegian Sea

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In the EU-project MAIA ("Monitoring the Atlantic Inflow toward the Arctic") three moorings, including current meters and sound sources for tracking underwater drifting floats, were deployed in the Lofoten Basin in May 2001. The 3 moorings were recovered 30 October - 5 November 2001. All moorings included one current meter at 1300 depth and one mooring also included a current meter at 790 m depth. The current meter at 790 m depth unfortunately failed after approximately 1 month after the start. The other current meters recorded successfully for the whole period. All current meters were located in the intermediate layer. Mean speeds for the current meters ranged from 5.2 to 7.4 cm/s. Maximum speed (30 cm/s) (south-westward direction) was found at the most western located current meter, located at the 2600 m isobath. Spectral and wavelet analysis reveal peaks at ~12 days, ~7 days, 24 h (K1), 12.4 h (M2), 8 h and 6 h periods. The 8 and 6 h periods are found at the two current meters where the slope is steepest (bottom depth equals to 1500 m depth), indicating that they topographic generated. The ~7 days period is found to be barotropic topographic waves while the ~12 h period seemed to be baroclinic topographic waves. The semidiurnal tidal current (M2) had major axis of 2–5 cm/s and minor axis of 0–2 cm/s. A persistent northward current (~10 cm/s) that lasted for about 1 month was only seen in one of the mooring.

Some process studies in Icelandic waters

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A description is given on some ongoing process studies in Icelandic waters. Comparison between the MICOM model run by the Nansen Centre in Bergen and observations on the north Icelandic shelf show that the model gives lower temperatures and salinities than observed. An example is shown of modelling work package in EU project Metacod using Vectore ocean model from Hamburg. Results are shown from vessel mounted ADCP measurements are presented suggesting a barotropic jet feeding the Denmark Strait overflow. Introduction of the AU ANIMATE project and results from the Irminger Sea on redfish and environment were also shown.

Intermediate water masses variability in the Bay of Biscay

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The evolution of the intermediate waters masses which occupies the eastern Iberian side of the Bay of Biscay is studied from the shelf-edge and slope stations of an hydrographic standard section northward from Santander (43°30'/43º54' N; 3°47'W). The systematic sampling of the water column have showed a detailed picture of the variability in water masses below the mixing layer during the sampling period, the Eastern NorAtlantic Central Water (ENACW) water mass has suffered a non-uniform deepening of their isopycnal levels inducing a warming trend (0.02 to 0.04 ºC per year on average) for the total heat stored between isobaric levels. On the other hand the Mediterranean Sea Outflow Water (MOW) have been modified along isopycnals increasing both temperature and salinity in a progressive manner from a period ending at 2001, the warming trend maintained within 0.02 to 0.04 ºC, year 2002 represents an inversion for the trend. Both behaviours could accord with a higher than the mean temperature period in the regions of formation of both water masses, the ENACW changes agree with the mild atmospheric forcing on the North Atlantic for the last decade which could have induced a reduction on the mixing layer convection. MOW modifications could be linked to changes on Mediterranean Western basin intermediate and deep waters.

ANNEX E: THE NAO IN WINTERS 2002 AND 2003

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Background

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

It is conventional to use an index of the winter NAO (NAO_{DJFM}) defined by the pressure difference between the two cells of the dipole, as measured at land stations. Hurrell (1995; 1996; Hurrell *et al.* 2003) constructs a time-series of the winter NAO_{DJFM} index of Lisbon−Stykkisholmur SLP, whilst Jones *et al.* (1997) use the SLP difference Gibraltar−Reykjavik. These indices have the benefit that they can be extended back to 1864 (Hurrell, 1995) and 1821 (Jones *et al.* 1997). Whilst an index of the NAO_{DJFM} is normalised to its standard deviation over a base period, it remains a measure of SLP difference between two particular land stations and a diagnostic of the NAO_{DJFM} SLP distribution.

The characteristics of the NAO_{DJFM} and aspects of the relationship to the ocean were discussed in the prior reports to the Working Group on Oceanic Hydrography (Dickson & Meincke, 1999, 2000; Dickson *et al.* 2001) and recently by Visbeck *et al.* (2003). The amplification of the NAO_{DJFM} index from the extremes of negative to positive between the 1960s and the late-1980s/early-1990s underwent a sharp decrease in winter 1996. Following the 1996 winter extreme, the winters of years 1997–2000 showed a return to positive NAO conditions until the winter of 2001 when the Hurrell NAO_{DJFM} index was -1.89 and the Jones NAO_{DJFM} index was -0.5 (see data sources below). At the time of the last report early indications were that the NAO_{DJFM} index for winter 2002 would see a return to weakly positive conditions (Dye *et al.* 2002).

Here we briefly report on the conclusion from winter 2002 and early indications for winter 2003. Though March is still in progress, the NAO_{DJFM} index for 2003 is likely to show a return to negative conditions, where the SLP anomaly distribution shows a strong influence by a Scandinavian anticyclone pattern comparable to EOF-2 (Figure 1).

Winter NAO in 2002

The Jones NAO_{DJFM} index for the winter of 2002 was 0.79 and the Hurrell NAO_{DJFM} index was 0.76 confirming the early indications described in last years report. Figure 2a shows the SLP anomaly field in the North Atlantic for the composite of the 4 winter months (NCEP/NCAR Reanalysis data, Kalnay *et al.*, 1996), and shows little of the typical NAO pattern (Figure 1 EOF-1). The cause of the overall weak positive NAO_{DJFM} index stems from a weak anti-cyclonic anomaly centred on Switzerland showing little zonal extension into the Atlantic. SLP anomaly over Iceland was weak and slightly positive but still small enough to make the difference in SLP with the Iberian Peninsula positive. It is worth noting that a NAO index using SLP at the Azores to indicate the southern centre of action would have produced a weakly negative anomaly.

Overall winter 2002 was a not an extreme NAO_{DJFM} year as shown by the SLP anomaly field and by the two instrument based indices both reporting an index less than one standard deviation from their means. However, of the four months that make up the Jones NAO_{DJFM}, December showed an extreme negative anomaly, -2.25, whilst January and February were both extremely positive, 2.31 and 3.01. Figure 2b) shows the SLP anomaly for the individual winter months and confirms the strength of the anomaly in those months. December is dominated by an anti-cyclonic anomaly south of Iceland, leading to north-easterly wind anomaly over the North Sea and anomalous south-easterly airflow across the Labrador Sea and southern Greenland. The pressure dipole is more east-west than the usual pattern in Jan 2002 with a deep low off southern Greenland. February shows much of the strong zonal character of the EOF-1 NAO positive but with the northern low pressure anomaly centred over Sweden. March has no strong pattern over the north-eastern North Atlantic and is comparable with the composite SLP anomaly for all 4 months. Three of the 4 months exhibited extreme anomalies, at more than 2 standard deviations from the mean Dec, Jan and Feb fall outside 95% of months in the Jones index. Some hydrographic and ecosystem responses to the winter NAO of 2002 may therefore have been strong despite the non-extreme NAO_{DJFM} index.

Early indications of a negative NAO_{DJFM} index for 2003

The Jones NAO index for December 2002 has been published at a value of -0.98, but no further values are available as yet. The SLP anomaly fields for December and January show that the instrumental indices of Jones and Hurrell are likely to record negative anomaly in the pressure difference between Lisbon/Gibraltar and Iceland in those months, and positive in February (Figure 3a-c). In each of the 3 months, no matter the sign of an NAO index, anomalous south-easterly or northerly airflow across the North Sea is likely to have led to enhanced surface cooling.

Two NAO indices based on principal component analysis are available from NCEP-CPC. The first projects the monthly data onto loading patterns of the 700mbar height for each month giving NAO index of -1.3, 0.5 and -0.1 for December 2002 through January 2003. The second NCEP-CPC NAO index projects daily data onto the first REOF of monthly mean 500mbar height and is used to analyse NAO forecasts. This index gives December 2002 to February 2003 NAO values as -0.92, -1.17 and -0.02. The difference in these two principal component NAO analyses highlights sensitivity to the choice of loading pattern.

It seems probable that the overall NAO_{DJFM} will be negative for the winter of 2002. There is not a strong 'classical NAO' in the SLP anomaly which shows a Scandinavian blocking anticyclone and East-West dipole pattern as the overall character for the first three months of this winter.

Autumn 2002

The Jones NAO index is valid mainly as a winter index when the southern high pressure part of the dipole retracts eastward placing Gibraltar close to the centre of action for the NAO pattern. It is worthy of note however that this index was negative throughout the whole of the second half of 2002 (Jul-Dec). The 500mbar NCEP NAO was negative August to December, and the 700mbar NCEP NAO was negative from September to December. This may have had an impact upon the hydrographic conditions in the north-eastern North Atlantic in the latter part of the year. For instance, we show in Figure 4 the 2002 anomaly and climatology of the scalar windspeed for the months September to November. In autumn 2002 windspeeds across the north European shelf seas were some 10–20% lower than average and may have had an impact on, for example, the breakdown of seasonal stratification and shelf sea bottom fronts. A resultant reduction in the latent heat flux from the surface may have enhanced SST in those months and allowed density driven transport pathways to persist for longer than usual.

Data sources

Hurrell (1995) instrumental NAO_{DJFM} index www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html

Jones (1997) instrumental NAO index from www.cru.uea.ac.uk/cru/data/nao.htm

SLP Anomaly data NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center (Kalnay *et al.*, 1996) www.cdc.noaa.gov/Composites

NCEP-CPC 700 mbar principal component NAO index plus other N. Hemisphere teleconnections www.cpc.ncep.noaa.gov/data/teledoc/telecontents.html

NCEP-CPC 500 mbar daily principal component NAO index and forecasts www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao_index.html

Further NAO information and comparison between instruments and principal component indices and alternate seasons www.cgd.ucar.edu/~jhurrell/nao.html

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Visbeck, M., Chassingnet, E. P., Curry, R. G., Delworth, T. L., Dickson, R. R., Krahmann, G. 2003. The Ocean's Response to the North Atlantic Oscillation Variability. In *The North Atlantic Oscillation: Climatic Significance and Environmental Impact.* (Eds. Hurrell *et al.)* Geophysical Monograph 134 (AGU, Washington, DC).

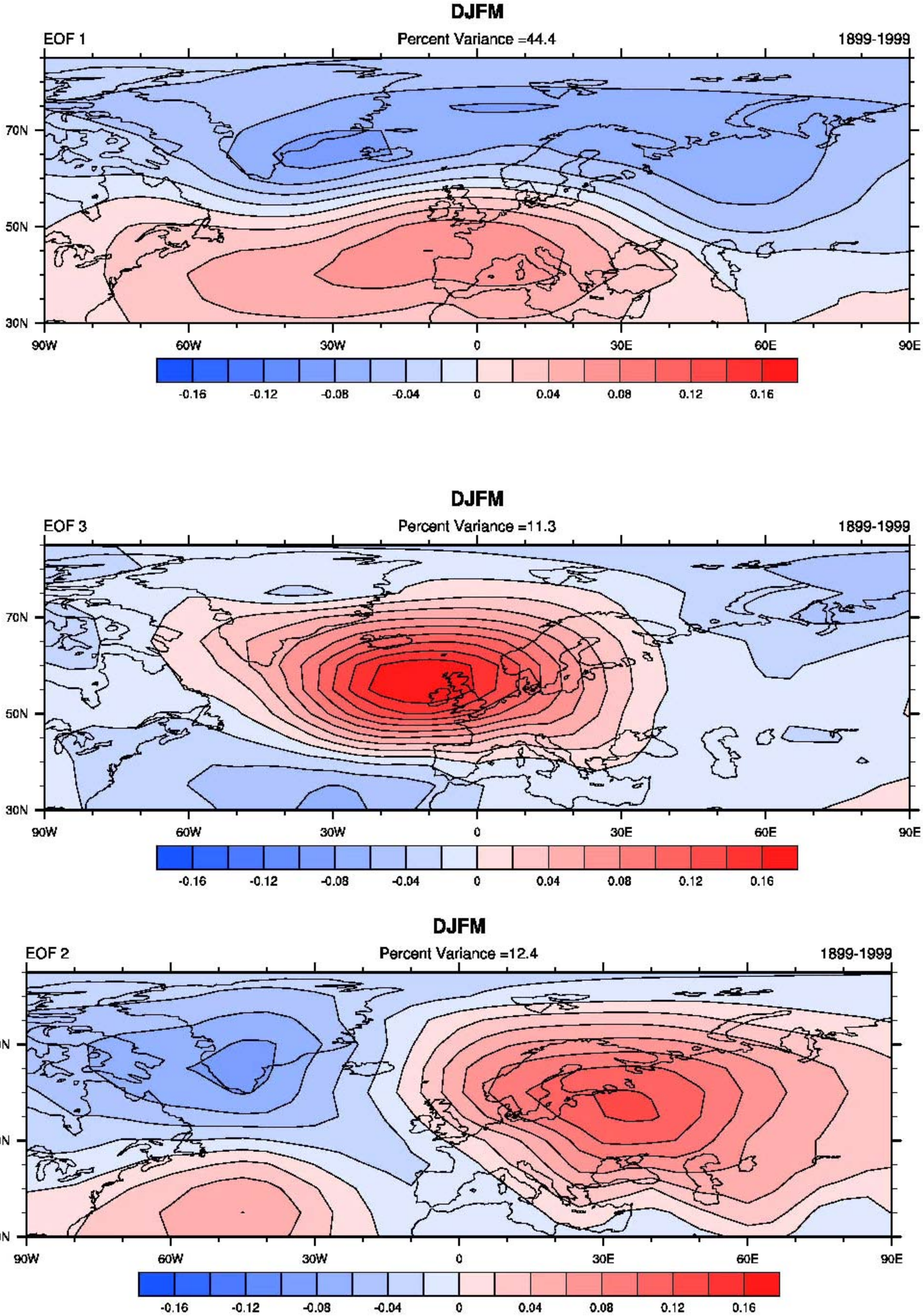
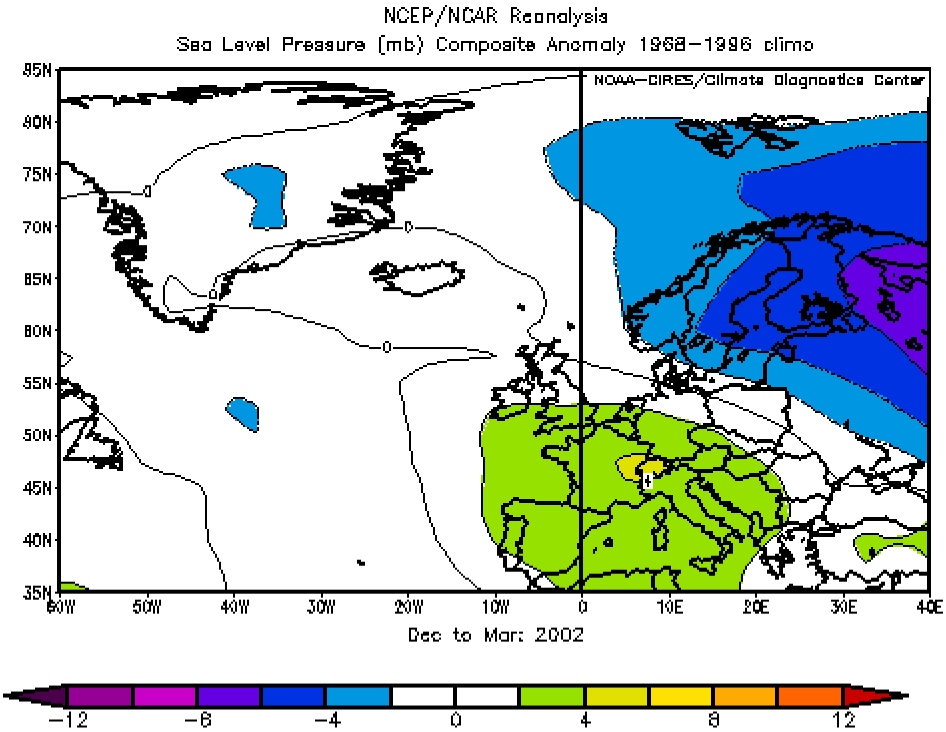


Figure 1. The first three EOFs of winter SLP anomalies over the Atlantic sector describe almost 70% of the variance. Figure courtesy of J. Hurrell, NCAR.

a) 2002



b) 2002 individual months

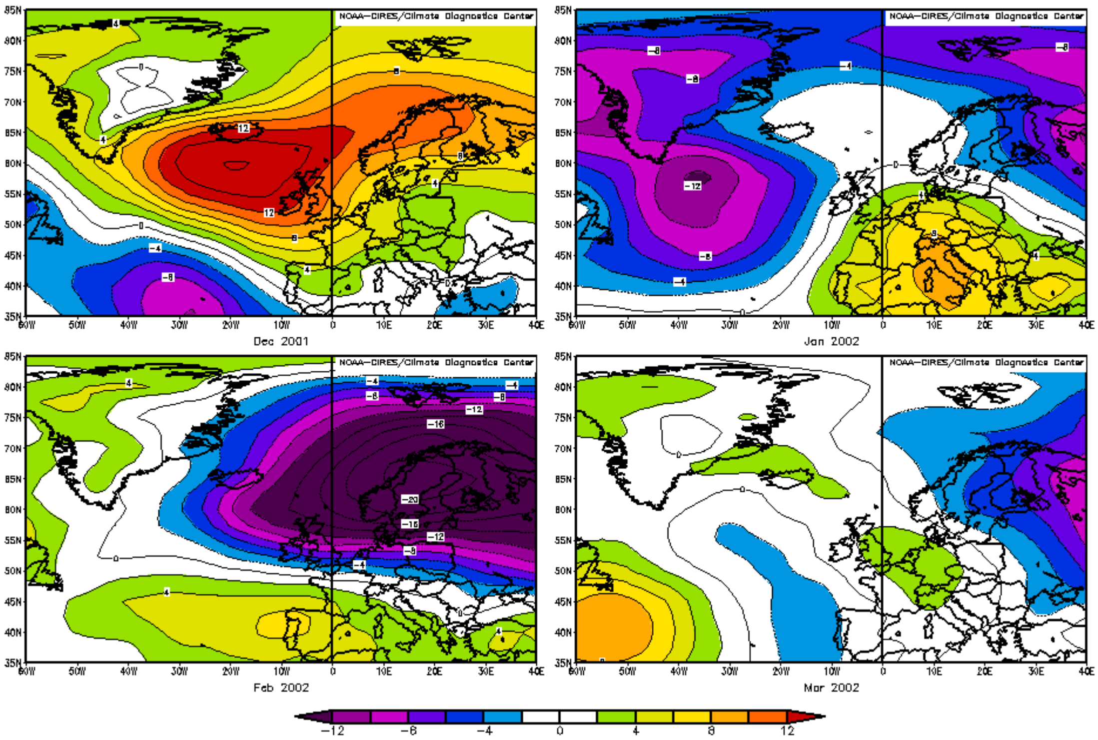


Figure 2. The North Atlantic distribution of SLP anomaly in the North Atlantic for (a) composite of December 2001 to March 2002, (b) individual months Dec 2002 and Jan 2003 upper panels, Feb 2003 and March 2003 below (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

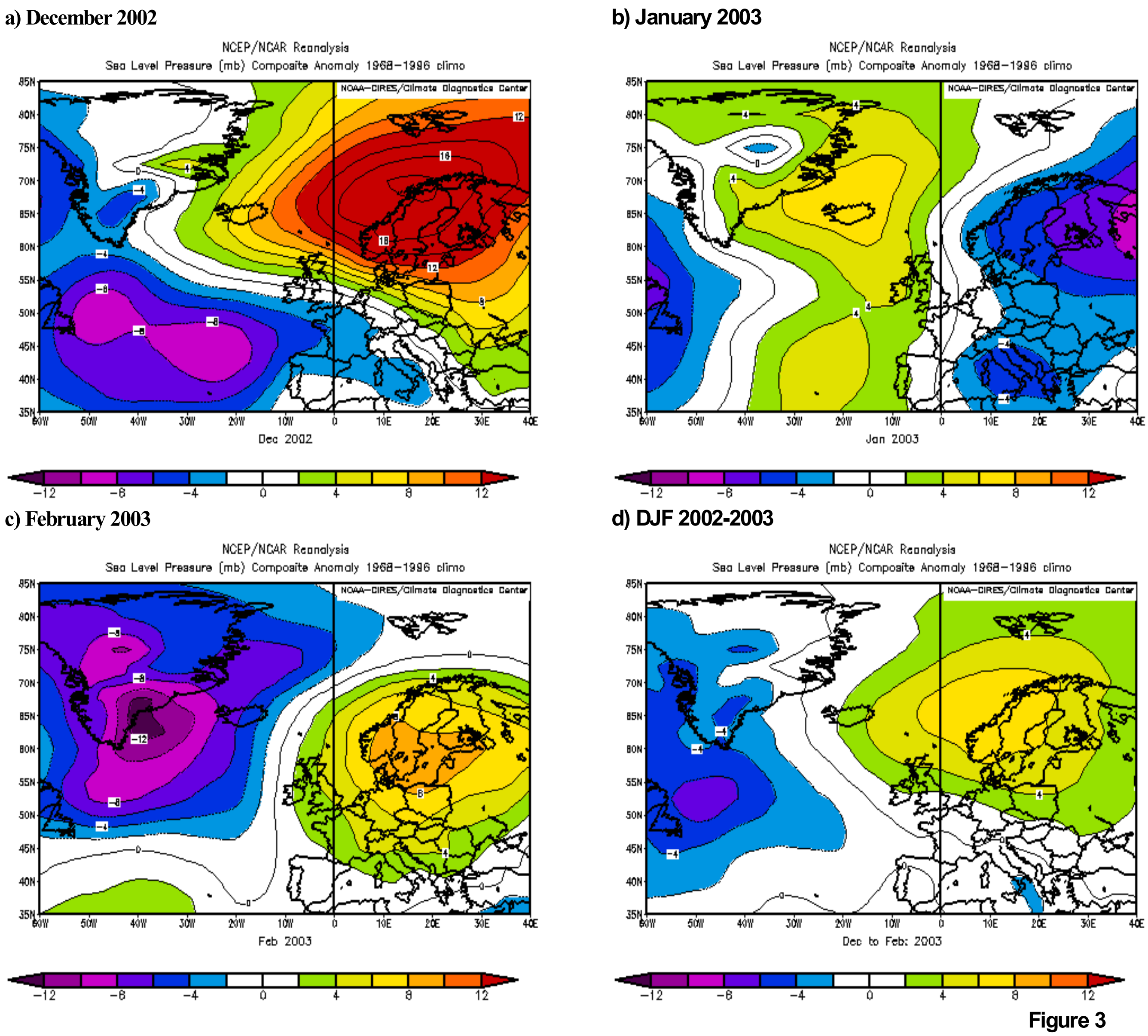
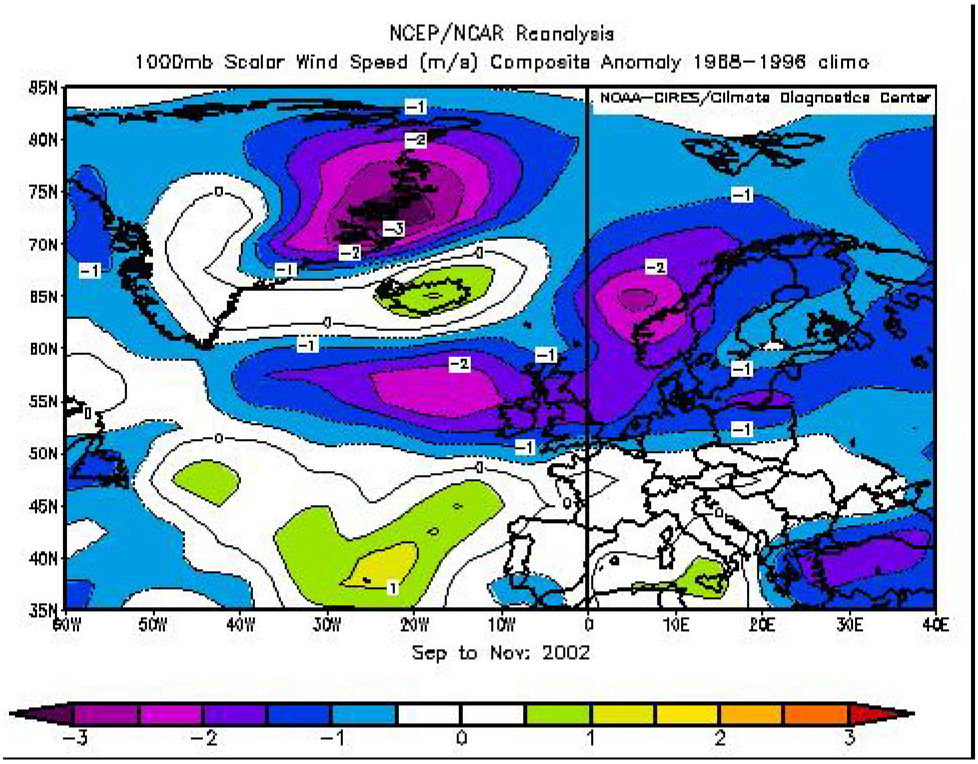
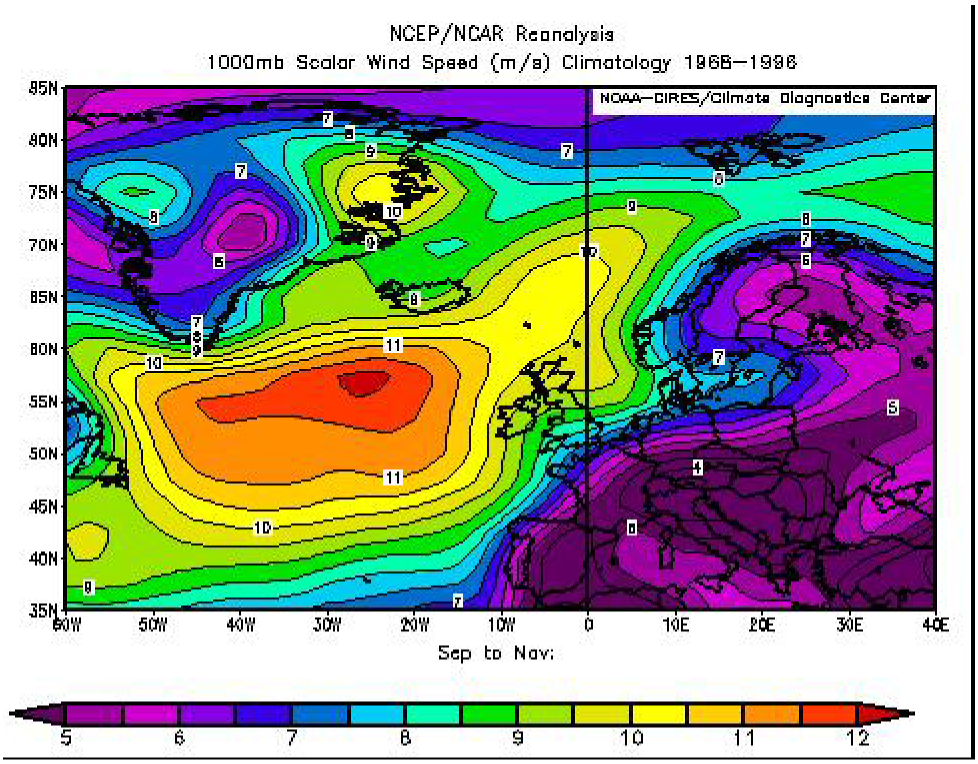


Figure 3. The Atlantic distribution of SLP anomaly in the North Atlantic for (a) December 2002, (b) January 2003, (c) February 2003 and (d) the composite of those 3 months (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

a) 2002 Anomaly





b) Climatology

Figure 4. The North Atlantic September–November composite of surface scalar wind speed a) anomaly in 2002 (b) climatology 1968–1996, (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

ANNEX F: OCEANOGRAPHIC INVESTIGATIONS OFF WEST GREENLAND 2002 (AREA 1)

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Abstract

Results of the summer 2002 standard section cruise along the west coast of Greenland are presented together with CTD data gathered during trawl surveys.

The time series of mid-June temperatures and salinities on top of Fylla Bank showed in 2002 similar conditions as in 2001 i.e., a year close to average conditions.

Pure Irminger Water was observed only at the Cape Farewell Section st.4, and Modified Irminger Water could be traced only as far north as the Fylla Bank section where it barely was present at st. 5. indicating a reduced inflow of Irminger Water to the West Greenland area in 2002. The inflow of Polar Water also seem to be less than normal.

1. Introduction

The North Atlantic marine climate is largely controlled by the so-called North Atlantic Oscillation (NAO), which is driven by the pressure difference between the Azores High and the Iceland Low pressure cells. Here the NAO index is calculated as the pressure difference between Ponta Delgada, Azores and Reykjavik, Iceland and normalised by the period 1961–1990. The NAO index during the 2002 was negative for the second year running although the value was approximately zero, Figure 1.

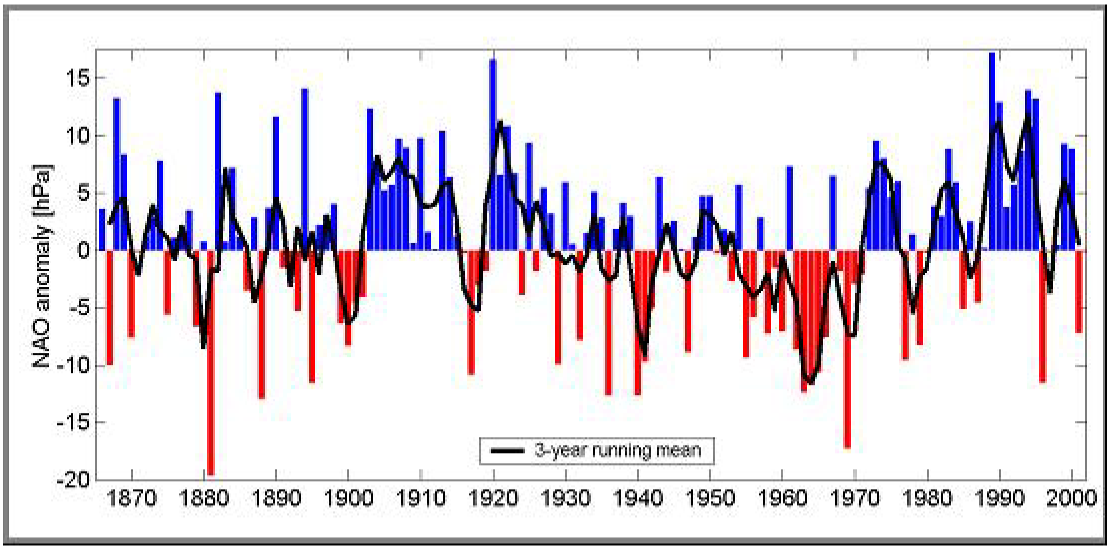

Figure 1. Time series of winter (December–March) index of the NAO from 1865–2002. The heavy solid line represents the meridional pressure gradient smoothed with a 3-year running mean filter to remove fluctuations with periods less than 3 years (Data updated from www.cru.uea.ac.uk/cru/data/nao.htm).

West Greenland lies within the area which normally experiences warm conditions when the NAO index is negative. As can be seen from Figure 2 the annual mean air temperature for 2002 in Nuuk was minus 1.1°C, which is 0.7°C lower than in 2001 reflecting well the increase in the NAO value. The mean air temperature for 2002 was however slightly above normal for most of the North Atlantic region, Figure 3.

Changes in the ocean climate in the waters off West Greenland generally follow those of the air temperatures, exceptions are years with great salinity anomalies i.e., years with extraordinary inflow of Polar Water or water of Atlantic origin. In 2002 the mean temperature on top of Fylla Bank in the middle of June (Figure 4) was 1.77°C which is slightly above the average value of 1.67°C for the whole 50 year period, which correlates well with the slightly negative value of NAO.

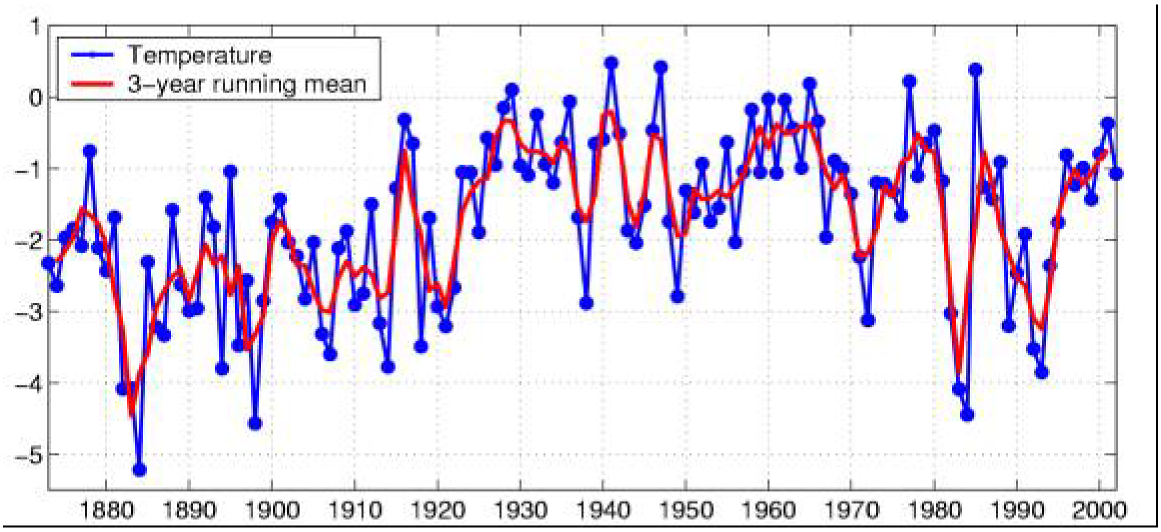

Figure 2. Annual mean air temperature observed at Nuuk for the period 1873 to 2002.

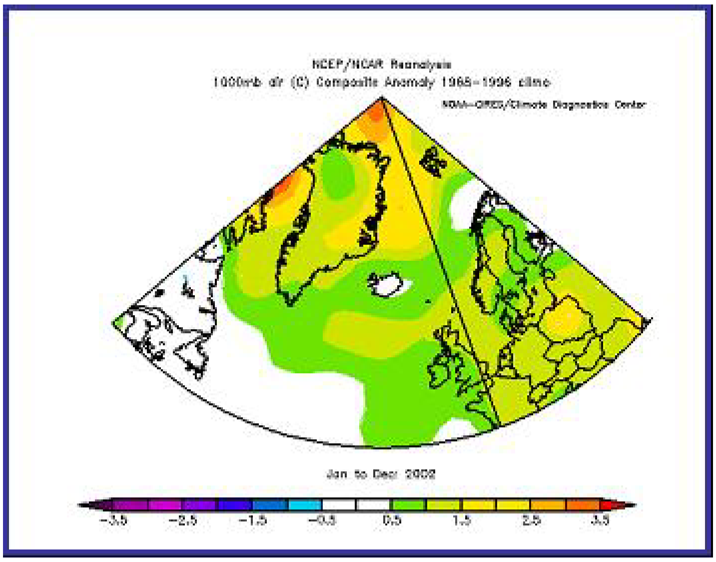

Figure 3**.** Anomalies of the annual mean air temperature in the North Atlantic region –NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov)

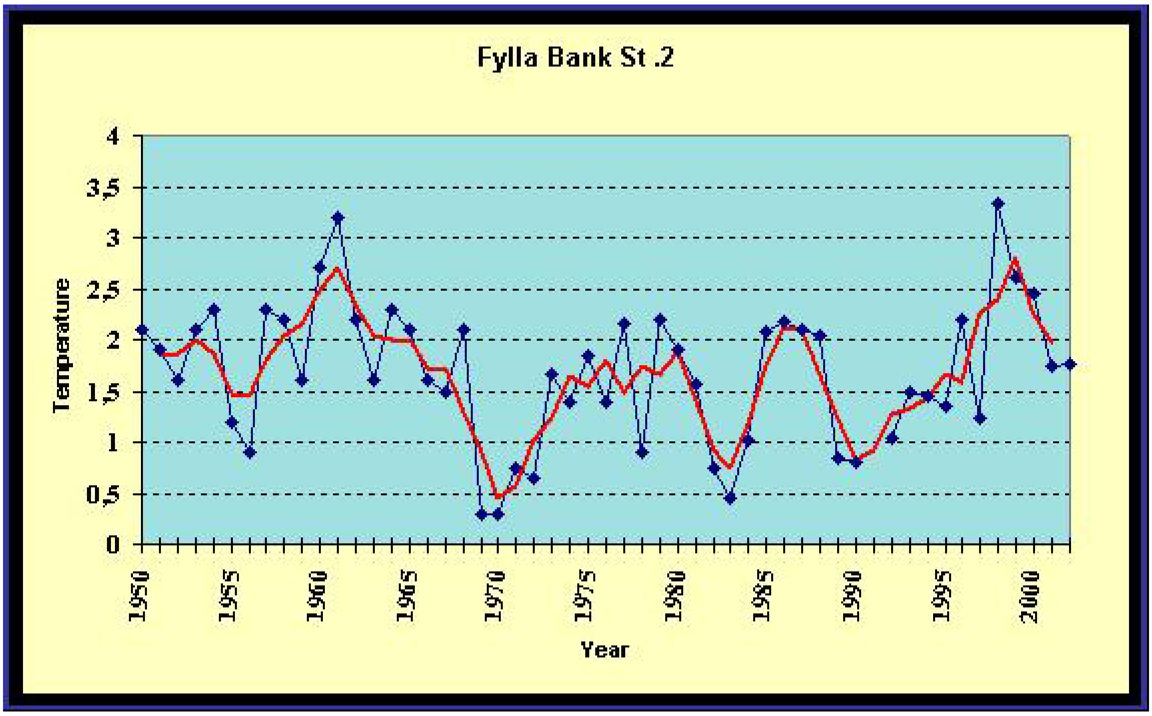

Figure 4. Time series of mean temperature (observations and 3 year running mean) on top of Fylla Bank (0 - 40 m) in the middle of June.

2. Measurements

The 2002 cruise was carried out according to the agreement between the Greenland Institute for Natural Resources and Danish Meteorological Institute during the period July 2 to July 9, 2002 onboard the Danish naval ship **"AGDLEK".** Observations were performed on the following stations (see also Figure 5):

- Cape Farewell St. 1 - 5
- Cape Desolation St. 1 - 5
- Frederikshaab St. 1- 5
- Fylla Bank St. 1- 5
- Sukkertoppen St. 1 - 5
- Holsteinsborg St. 1 – 5
- Additionally 4 stations at Tovssuaq was taken.

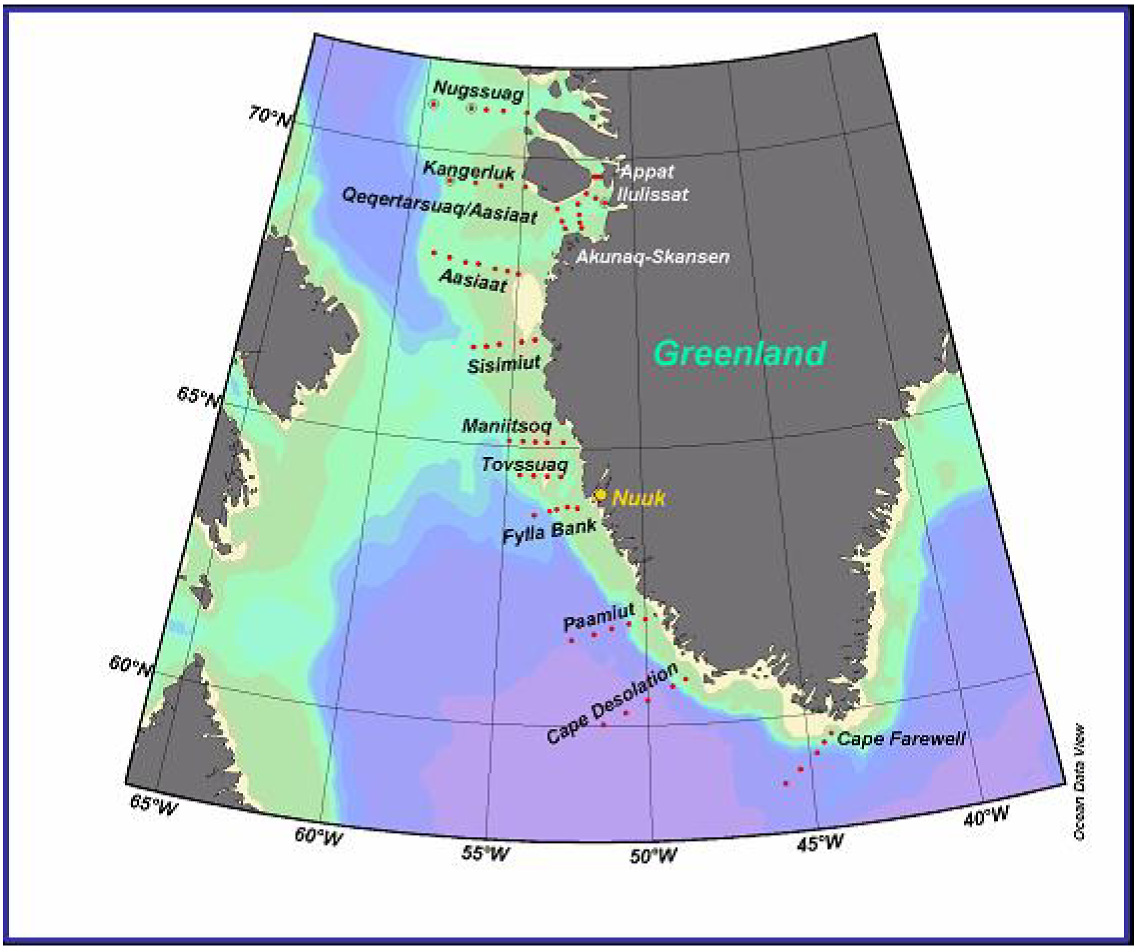

Figure 5. Position of the oceanographic sections off West Greenland where measurements were performed in 2002

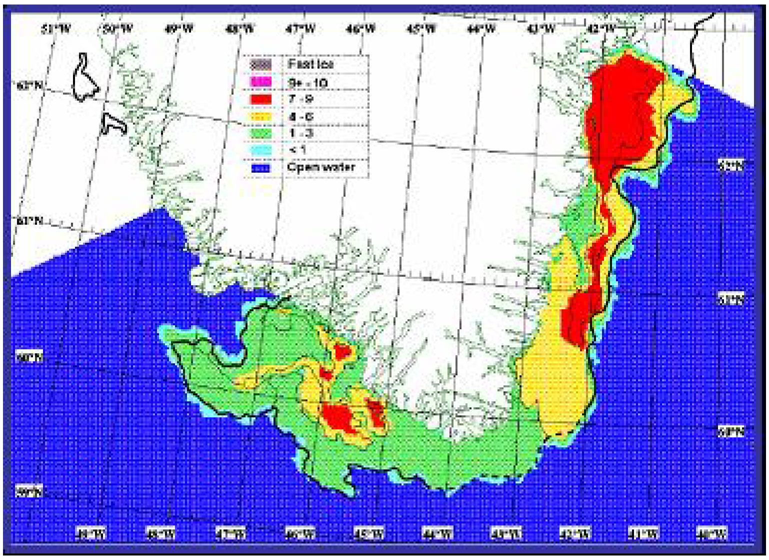

Figure 6. Distribution of sea ice in the Cape Farewell region 9 July 2002.

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

The cruise was blessed with favourable weather and ice conditions. “Vestice” was not present at the Holsteinsborg section. Close to Cape Farewell “Storis” was present, Figure 6, but fortunately not in quantities preventing the measuring program being carried out, only the innermost station was taken about 3 nm from the standard position.

In late July/early August the Greenland Institute for Natural Resources carried out trawl surveys in the Disko Bay area and further North onboard FV “Paamiut”. During this survey CTD measurements were carried out on national oceanographic standard stations.

3. Data handling

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

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

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

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

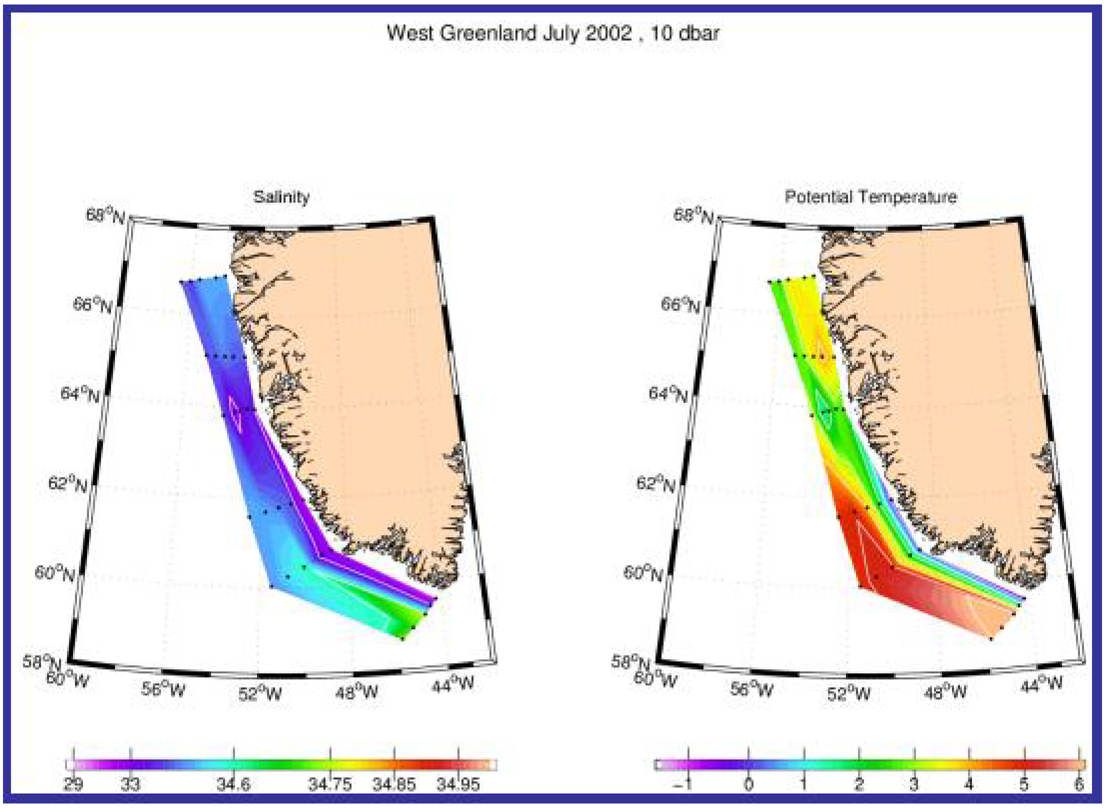

Figure 7. Temperature and salinity at 10m, July 2002.

4. Oceanographic conditions off West Greenland in 2002

The surface temperatures and salinities observed during the 2002 cruise are shown in Figure 7. The cold and low salinity conditions observed close to the coast off Southwest Greenland reflect the inflow of Polar Water carried to the area by the East Greenland Current. Water of Atlantic origin (T> 3°C; S> 34.5) is found at the surface only at the 3 outermost stations on the Cape Farewell Section. The surface salinity seems in general to be relative low especially on the western part of the area.

The 2002 mean salinity value (33.41) on top of Fylla Bank (Figure 8) was similar to the 2001 condition and equal to the average value for the entire period.

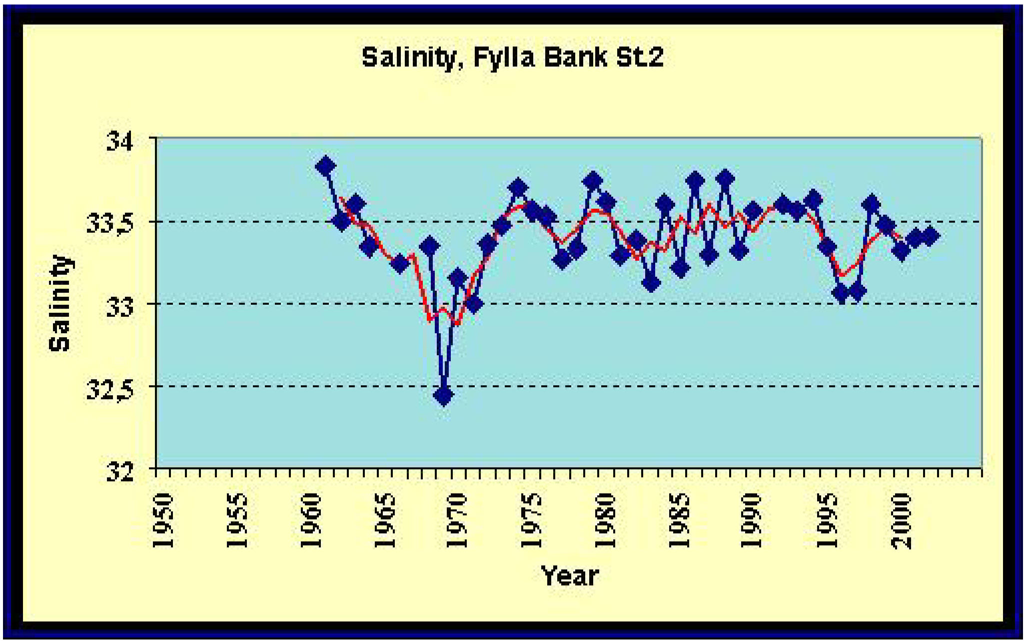

Figure 8. Time-series of the mean salinity (observations and 3 year running mean) on top Fylla Bank (0–40m) in the middle of June.

The vertical distribution of temperature, salinity and density at sections along the West Greenland coastline is given in Figures 9 – 19. In addition to data from the six standard sections obtained during the AGDLEK cruise in early July, data from the Disko Bay and further north obtained during the R/V PAAMIUT cruise in July/August are shown.

In the surface layer (0–100 m) relatively strong gradients between the cold, low-saline Polar Water and the warm, high-saline water of Atlantic origin was observed at the Cape Farewell section only although the gradient also here was less pronounced than previous years. On the sections further north it is remarkable and unusual to see the missing strong gradients between the cold, low saline Polar Water and the warm, saline Atlantic Water. This indicates a low intensity in the East Greenland Current component as well as a lower than normal inflow of water of Atlantic origin.

Normally there is a very pronounced core of Polar Water (revealed by its low temperatures) just west off Fylla Bank at depth of 50 - 100 m, but in 2002 this core was hardly recognisable i.e., another sign of reduced inflow of Polar water in 2002.

From the Aasiat to the Nugssuaq sections a cold layer is found between approximately 40 and 150m with extreme low temperatures at around 75m. This cold water is Polar Water transported to the West Greenland waters by a side branch of the southward flowing Baffin Current.

Temperature and salinity observations at greater depth showed that pure Irminger Water (T ~ 4.5^{o}C, S > 34.95 psu) was hardly present at the Cape Farewell section, and was certainly not observed beyond this point. Modified Irminger Water (34.88 < S < 34.95) was traced only as far north as the Fylla Bank section were it barely was present at Fylla Bank St. 5. Northwest Atlantic Mode Water (3.5 < T < 4.5; 34.5 < S < 34.88) was observed at all sections from Cape Farewell to Nugssuaq.

5. Conclusions

The oceanographic conditions off West Greenland during the summer 2002 was characterised by:

- Climatic conditions – NAO, Nuuk Air Temperatures, medio water June temperature and salinities on top of Fylla Bank – were close to average conditions
- The inflow of Polar Water as well as Irminger Water was in 2002 less than normal reflected by the fact that no strong gradients between the two water masses was observed; that Polar Water could hardly be distinguished at Fylla Bank, that pure Irminger Water was hardly present at the Cape Farewell region and that Modified Irminger Water was observed only as far north as the Fylla Bank Section.

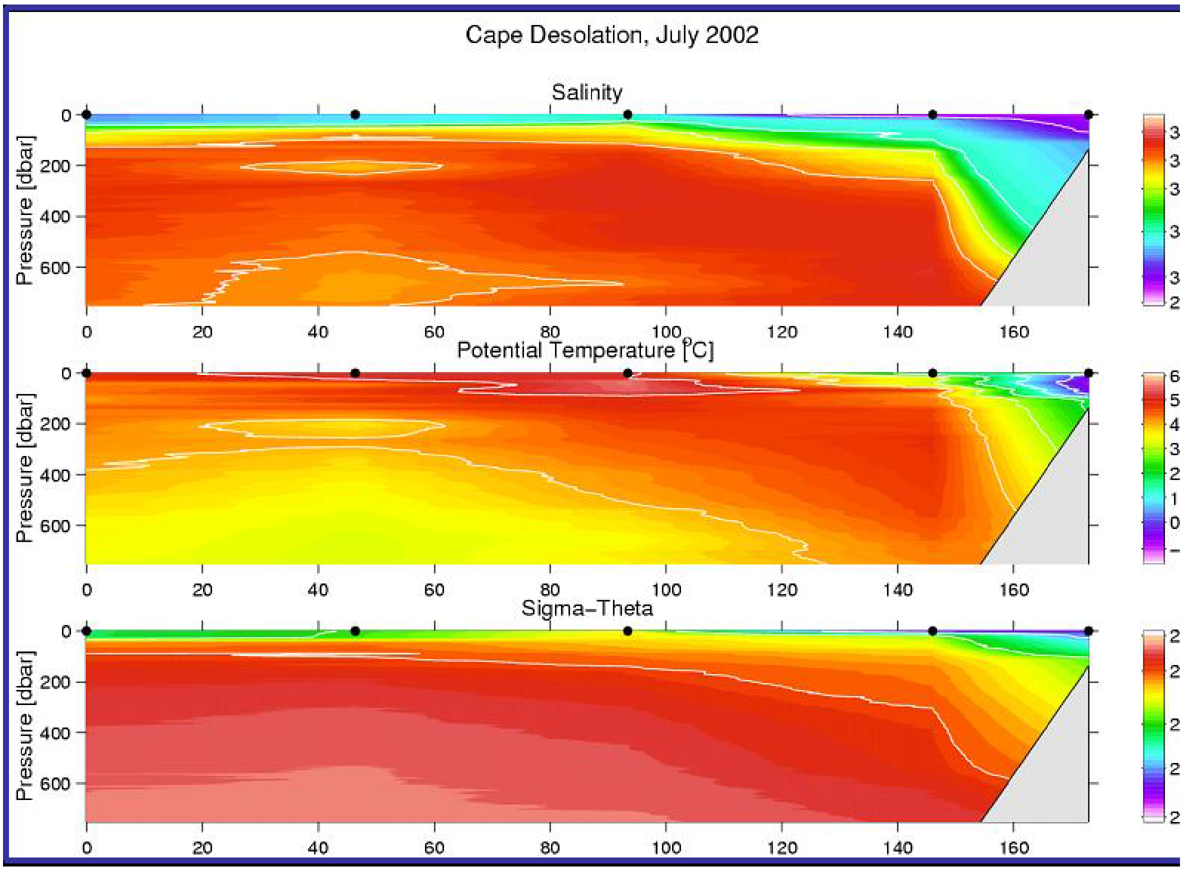

Figure 9**.** Vertical distribution of temperature, salinity and density at the Cape Farewell section, July 2002.

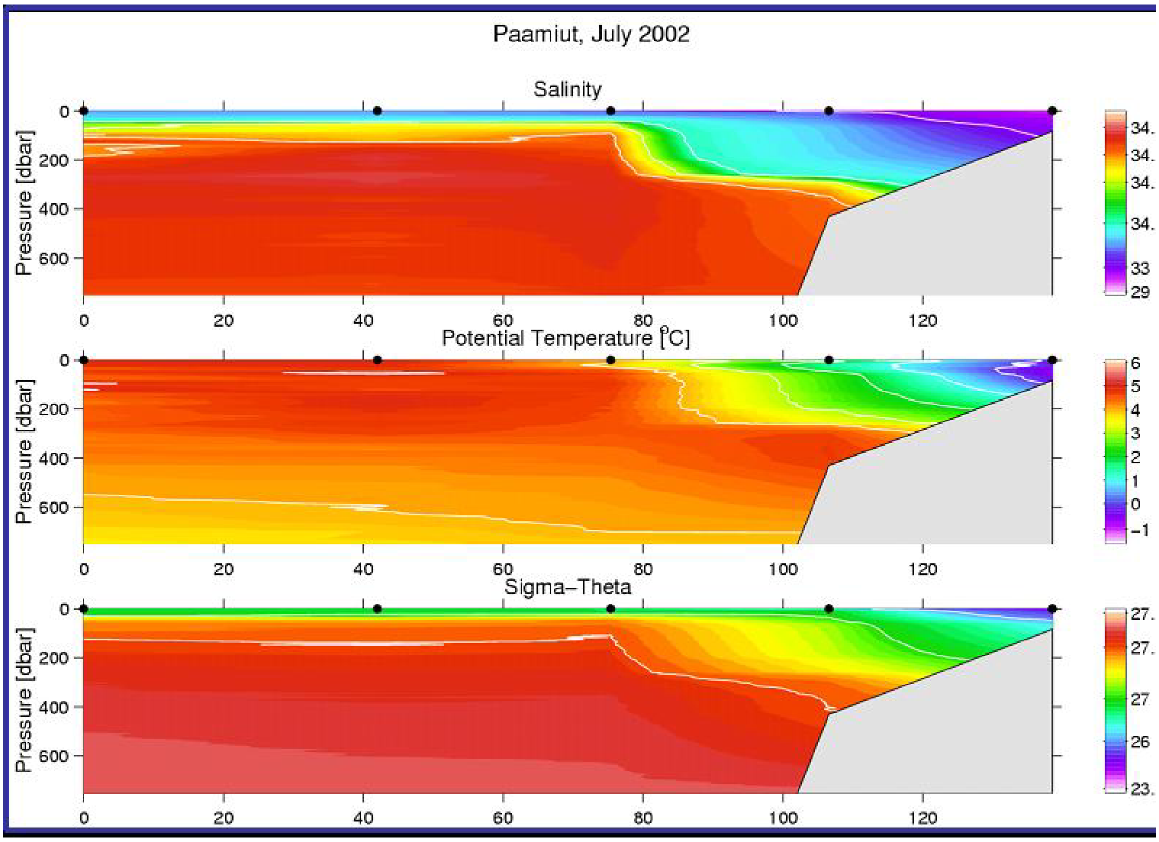
Paamiut, July 2002
Salinity
Pressure [dbar]
0
200
400
600
0
20
40
60
80
100
120
34.
34.
34.
34.
33
29
Potential Temperature [°C]
6
5
4
3
2
1
0
−1
Sigma−Theta
27.
27.
27
26
23.

Figure 10.

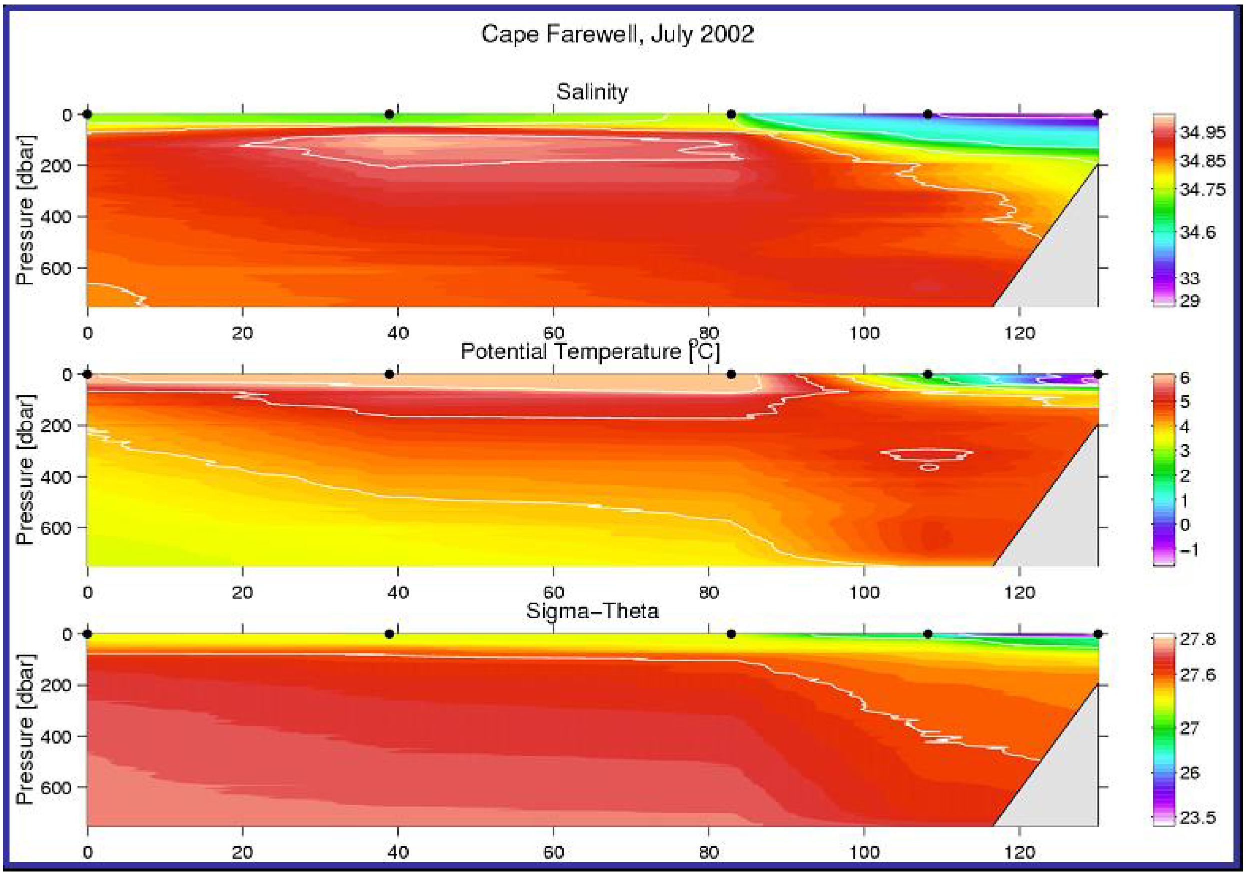

Figure 11. Vertical distribution of temperature, salinity and density at the Frederikshaab Section, July 2002.

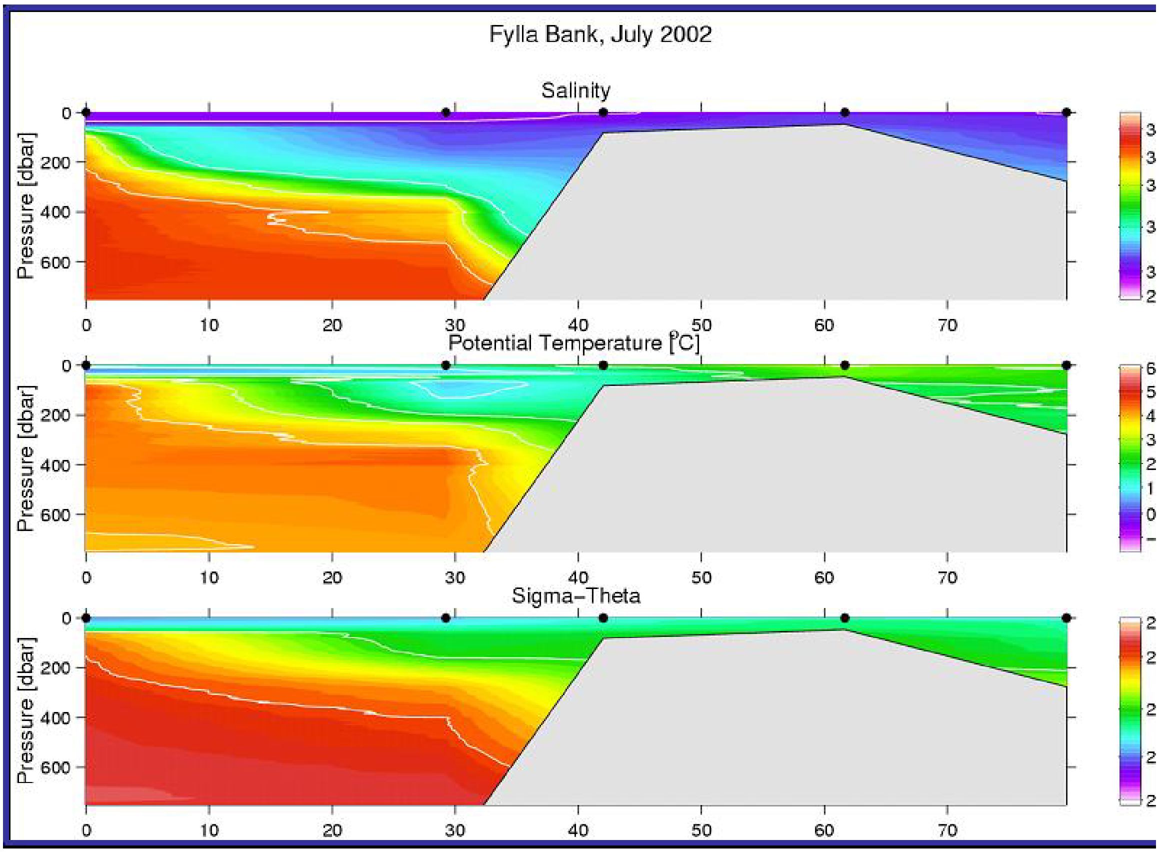

Figure 12. Vertical distribution of temperature, salinity and density at the Fylla Bank Section, July 2002.

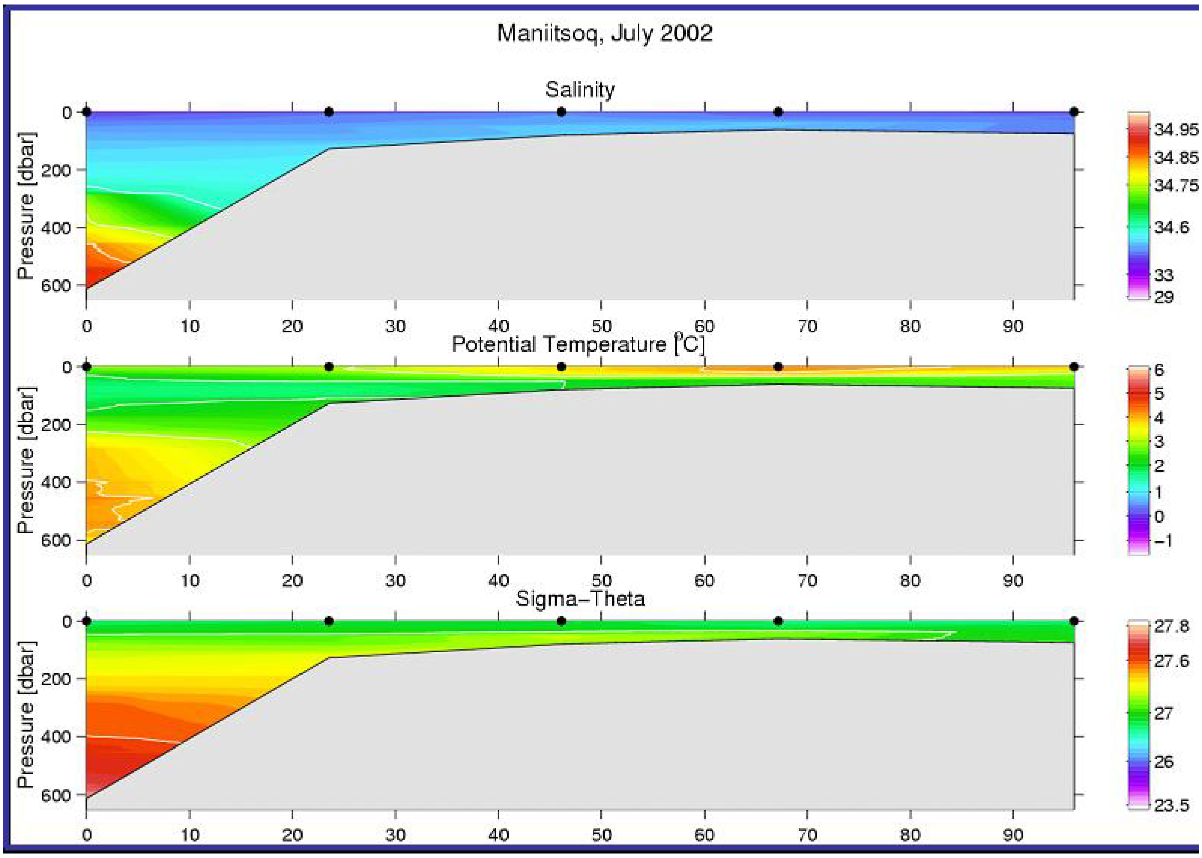

Figure 13 Vertical distribution of temperature, salinity and density at the Lille Hellefiske Bank Section, July 2002.

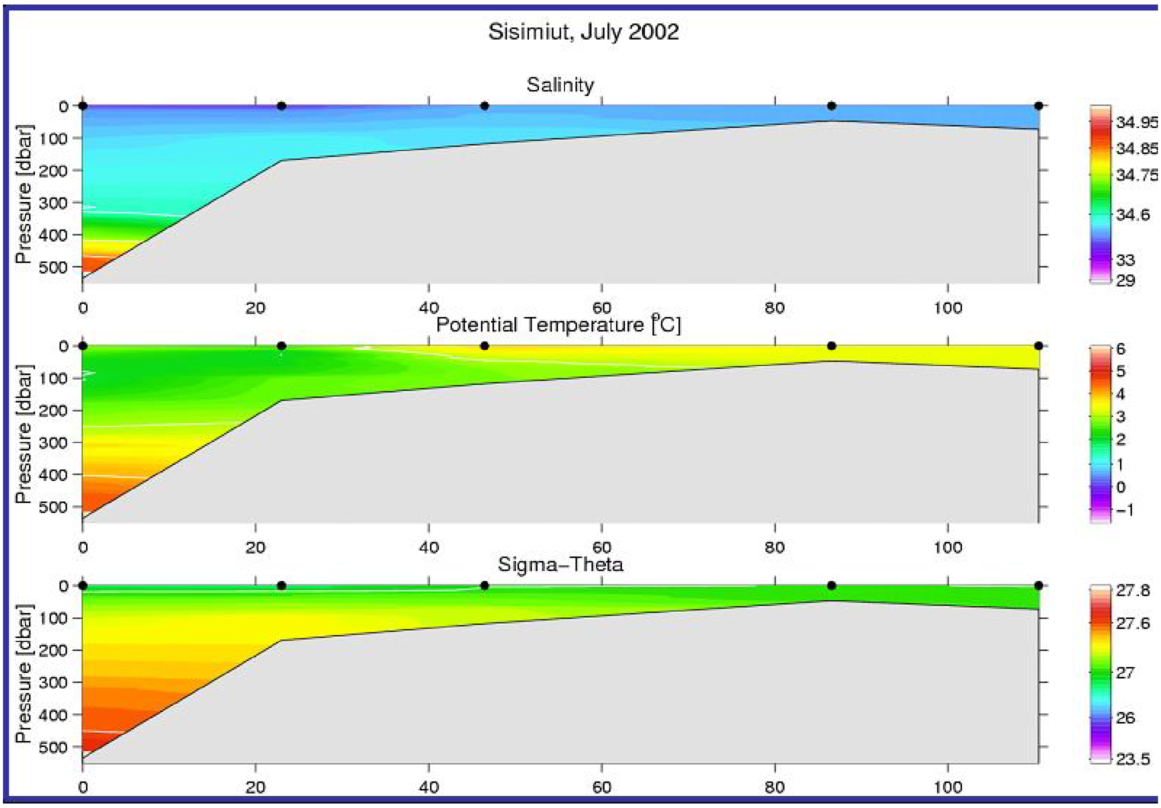

Figure 14. Vertical distribution of temperature, salinity and density at the Holsteinsborg Section, July 2002.

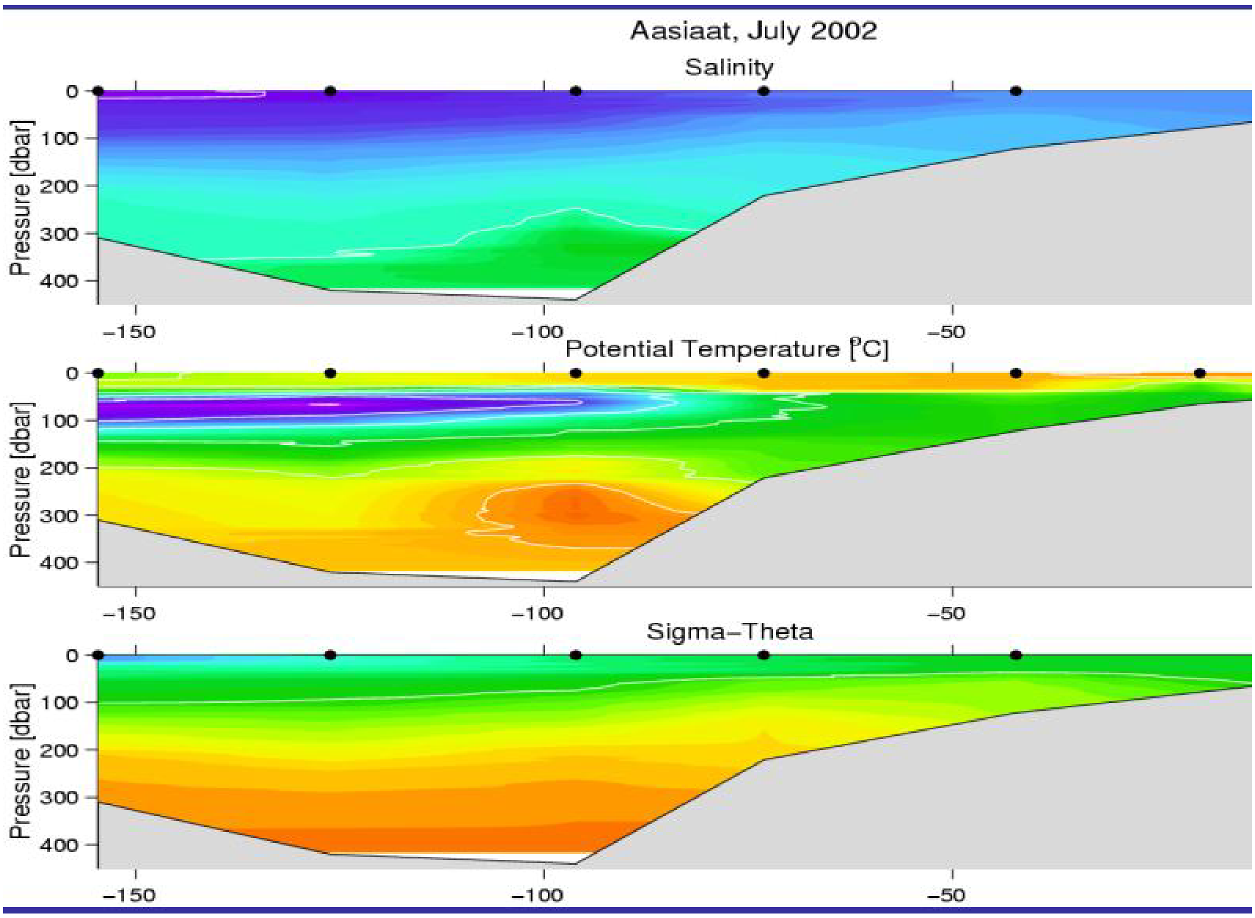

Figure 15. Vertical distribution of temperature, salinity and density at the Aasiat Section, July, 2002.

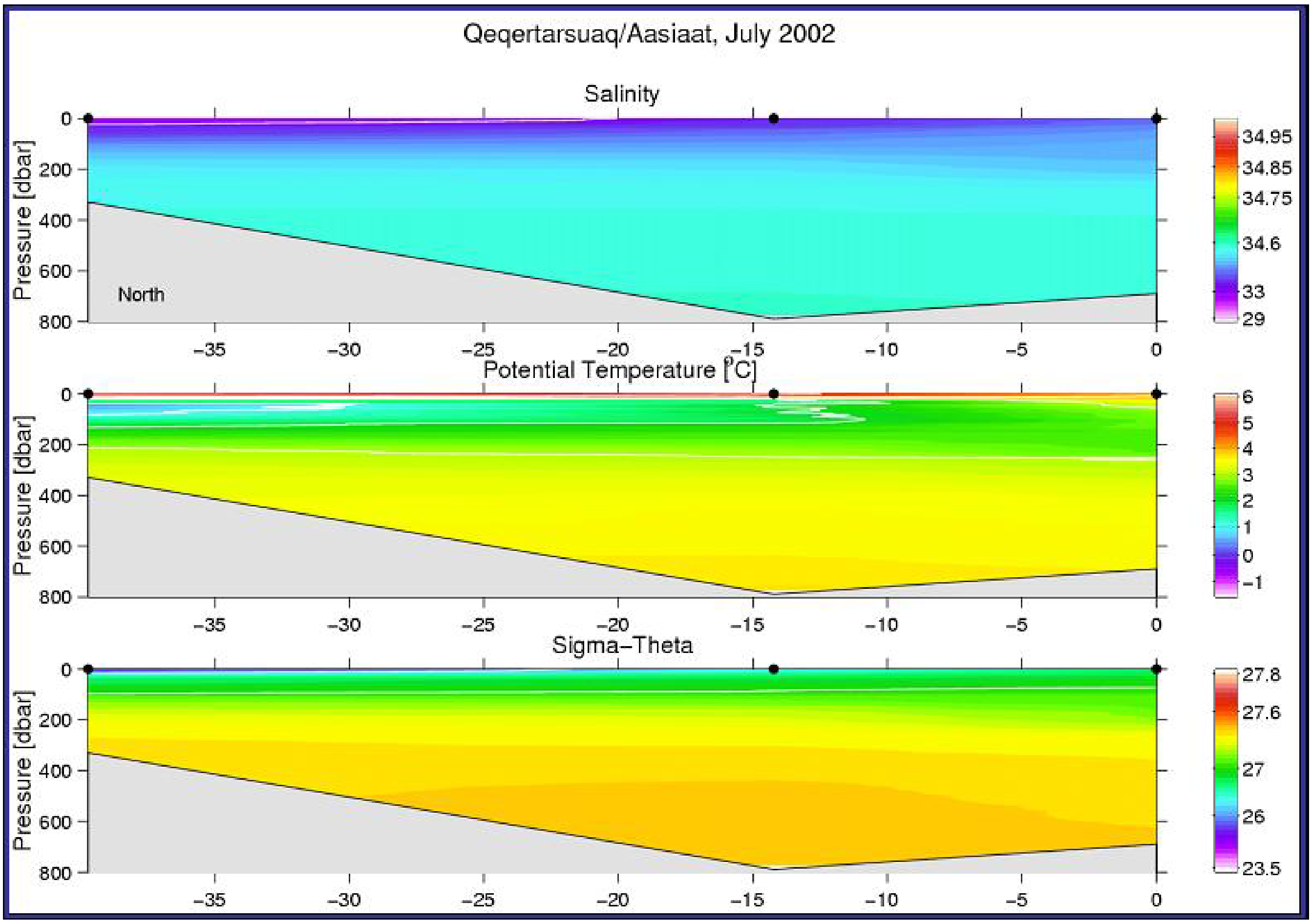

Figure 16. Vertical distribution of temperature, salinity and density at the Qegertarsuaq. Aasiat Section, July 2002

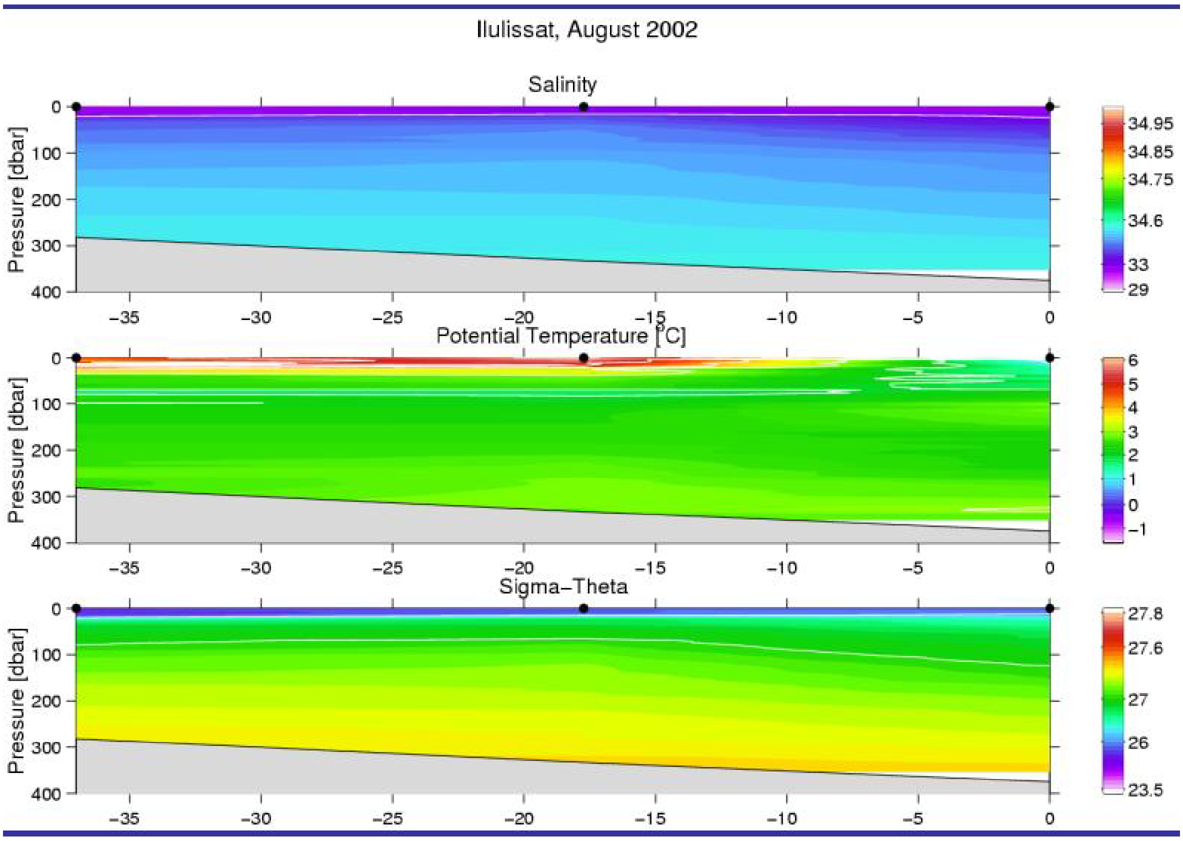

Figure 17. Vertical distribution of temperature, salinity and density at the Ilulissat Section, August, 2002.

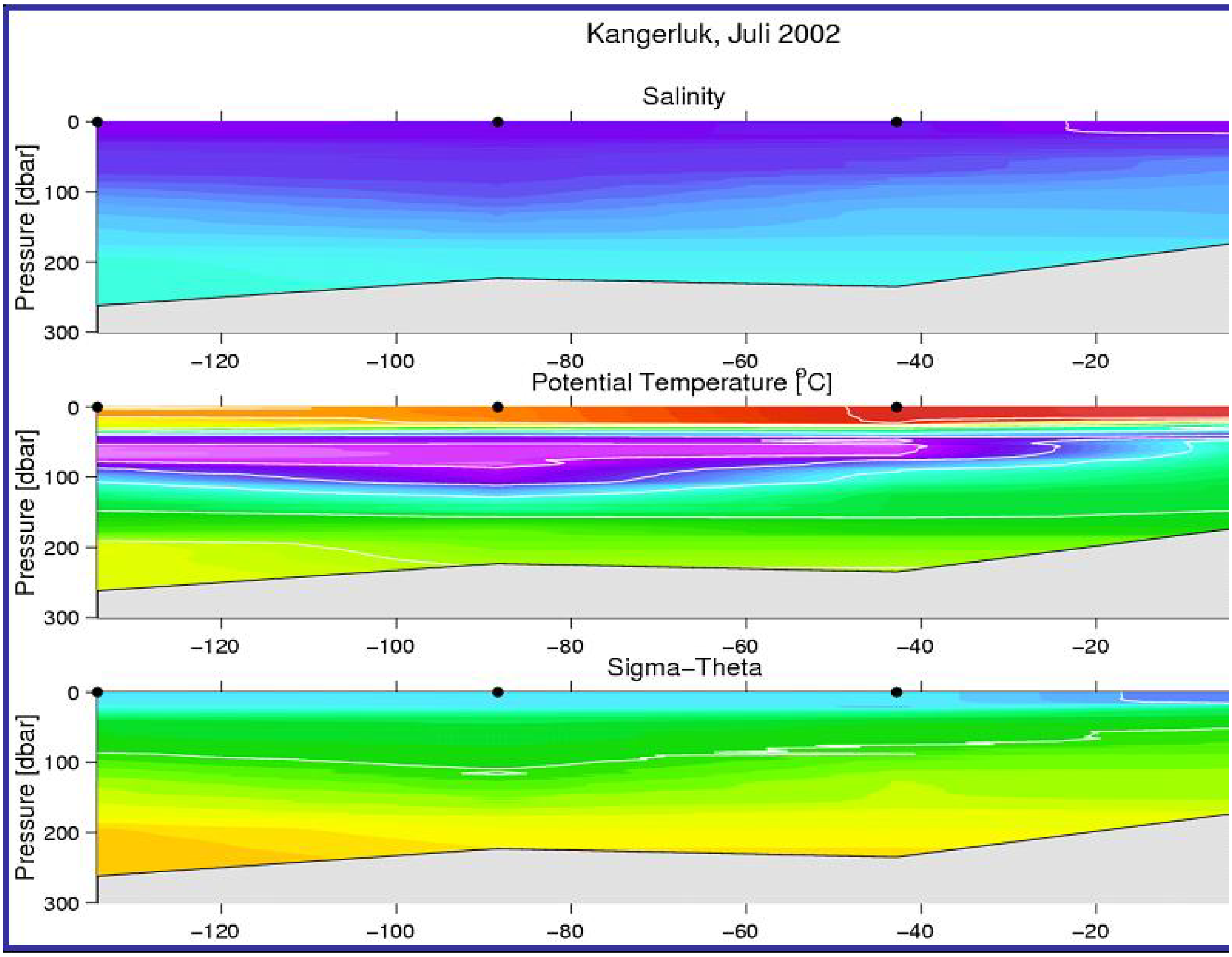

Figure 18. Vertical distribution of temperature, salinity and density at the Disko Fjord (Kangerluk) Section, July, 2002

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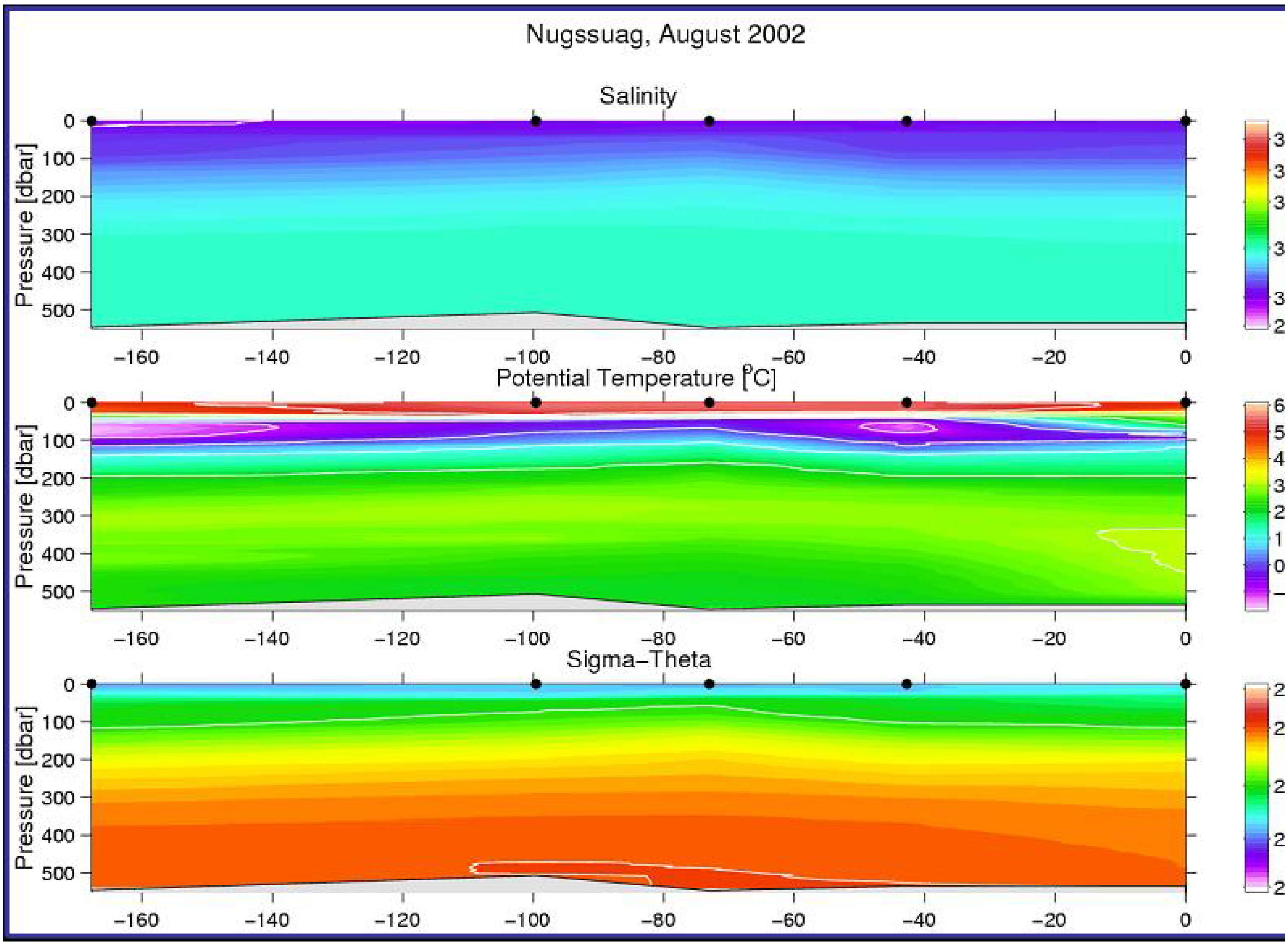

Figure 19. Vertical distribution of temperature, salinity and density at the Nugssuaq Section, August, 2002.

ANNEX G: CLIMATIC CONDITIONS OFF WEST GREENLAND – 2002 (AREA1)

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Institute for Sea Fisheries, Hamburg, Federal Republic of Germany.

Despite warmer than normal climatic conditions off West Greenland during autumn 2002 (Figure 1), the ocean temperatures in this area showed considerable cooling during autumn 2002 at Fyllas Bank station 4 which is at the continental slope west off Nuuk. The upper 200m of the water column indicated cooling of –0.29K (Figure 2) below the climatic mean (1963–1990). This cooling is similar as observed during the early-1970s and early-1980s. Salinity anomaly at station 4 was also anomalous low being -0.54 psu (Figure 3) below the long-term mean. Sea surface temperature anomaly maps, as published by IGOSS (Figure 4) indicate for the month of November a temperature anomaly in the Fyllas Bank area which is in the same range as given for the Fyllas Bank station 4.

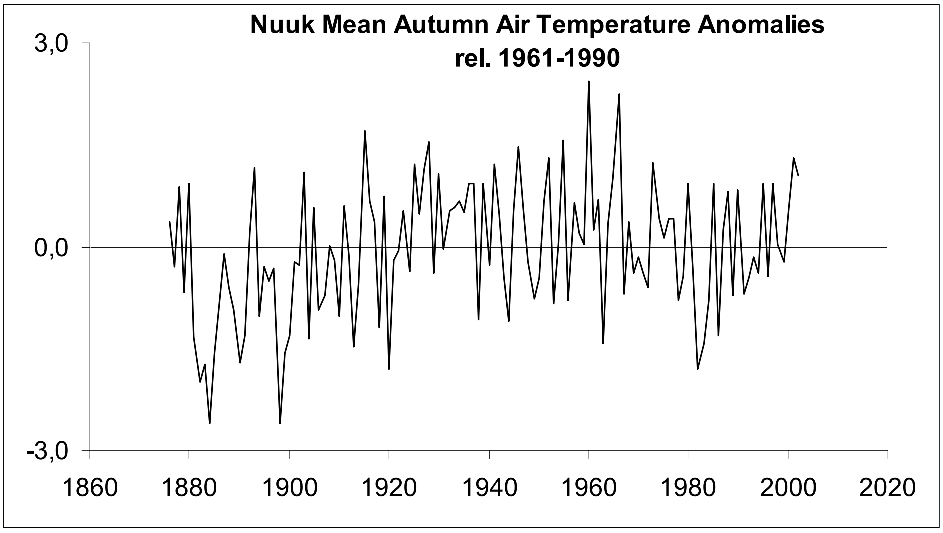

Figure 1. Nuuk mean autumn (Sep-Nov) air temperature anomalies (rel. 1961–1990 climatic mean); data 1876–2002.

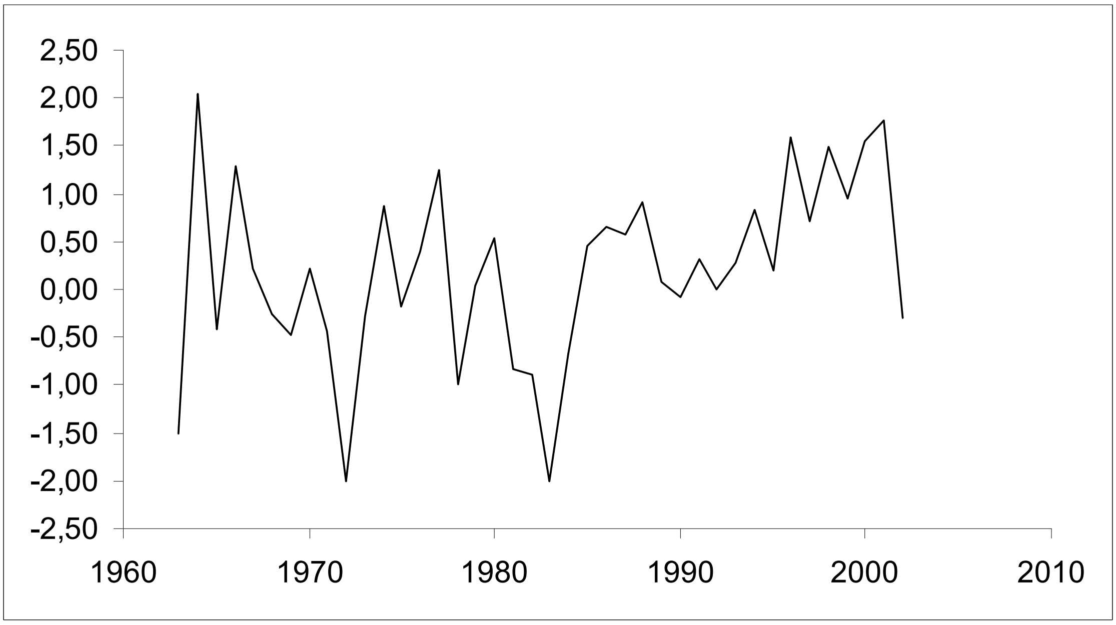

Figure 2. Fyllas Bank Station 4 temperature anomaly autumn, 0–200m; data 1963–2002.

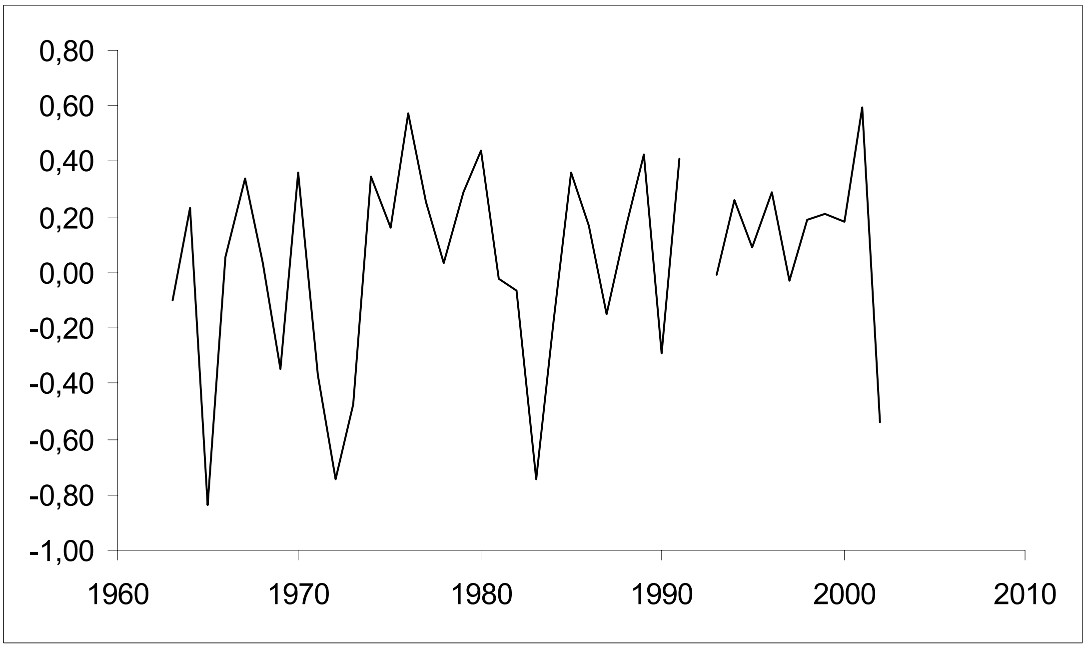

Figure 3. Fyllas Bank Station 4 salinity anomaly autumn, 0–200m; data 1963–2002.

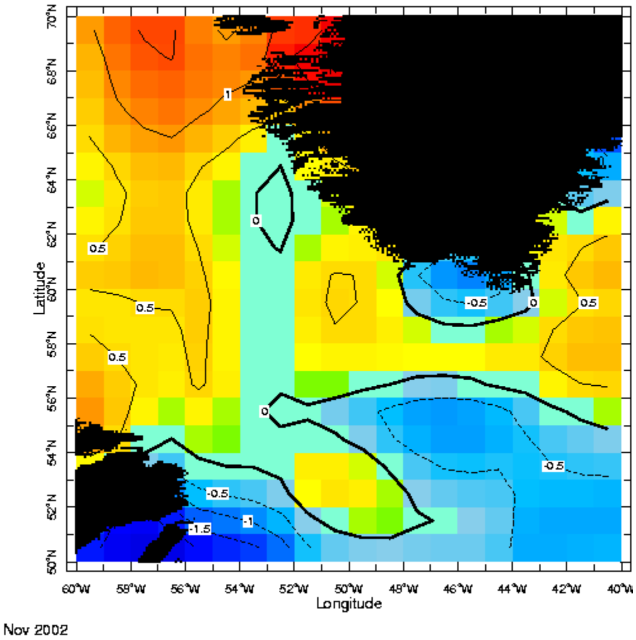

Figure 4. Sea surface temperature anomaly (K)off West Greenland during November 2002 (from: http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS)

ANNEX H: AREA 2B (LABRADOR SEA) CANADIAN REPORT, ENVIRONMENTAL CONDITIONS IN THE LABRADOR SEA IN SPRING 2002

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Abstract

The 2001–2002 winter over the Labrador Sea was more severe than the previous winter but still milder than normal. Observations in early-summer 2002 showed remnants of convective overturning to maximum depths of 1200–1400m, about 400m deeper than seen in the preceding two years. Apart from the apparent weak renewal of winter convection, the general trend was to warmer and more saline conditions. This was true both in the seasonally-active layer shallower than the maximum depth of convection and in the intermediate waters deeper than 1400m. The net result is that the 0–2000m early summer mean salinity was the highest in the past thirteen years of regular observations. The corresponding mean temperature was the second highest observed during this period.

1. Introduction

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

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

Deep convection in the Labrador Sea provides an important pathway for atmospheric gases such as oxygen, carbon dioxide, and the chlorofluorocarbons (CFCs) to pass from the surface mixed layer to intermediate depths. As the convected Labrador Sea Water (LSW) flows to other regions of the ocean (Sy *et al.*, 1997; Lavender *et al.* 2000), it distributes these dissolved gases to a large area of the ocean thereby ventilating the deeper layers. Because of the importance of this process and because of the large variability in the production rate of LSW, the Ocean Sciences Division (Fisheries and Oceans Canada at the Bedford Institute of Oceanography) has occupied a line of CTD stations across the Labrador Sea in the early summer of each year since 1990. This line was designated as line AR7W (Atlantic Repeat Hydrography Line 7) during the World Ocean Circulation Experiment (WOCE). Between 1990 and 1997 the work was a contribution to WOCE. Since 1997, the work has continued as a Canadian contribution to the North Atlantic Oscillation and the Atlantic Thermohaline Circulation Principal Research Areas of the Climate Variability and Predictability (CLIVAR) project of the World Climate Research Programme (WCRP).

The most recent transect of WOCE Line AR7W by was made during June 23 - July 18, 2002, on board CCGS Hudson. Expedition Hudson 2002–032 successfully completed a broad program in physical, biological and chemical oceanography within the Northwest Atlantic and Labrador Sea. R. Allyn Clarke of Ocean Sciences Division was Chief Scientist.

Figure1 shows a map of the Labrador Sea with station positions for the 2002 Hudson expedition, including 101 full depth CTD/rosette stations for temperature, salinity, oxygen, nutrients and other biological and chemical parameters. The Bravo mooring site in the central Labrador Sea near the historical location of Ocean Weather Ship Bravo and ground tracks of the TOPEX/POSEIDON altimetric satellite are also shown.

2. Atmospheric forcing

Monthly-averaged air-sea flux fields produced by the co-operative Reanalysis Project (Kistler *et al.*, 2001) of the U.S. National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) were used to estimate air-sea exchanges of heat, fresh water, and buoyancy for the period January 1948 to November 2002. The heat fluxes discussed here are sums of NCEP short wave radiation flux, long wave radiation flux, sensible heat flux, and latent heat flux. The monthly-averaged NCEP fields were obtained from the NOAA-CIRES Climate Diagnostics Center web site http://www.cdc.noaa.gov/. The grid point at 56.2^{o} N, 52.5^{o} W marked in Figure 1 is about 40 km south of the nearest AR7W station. The fields at this grid point represent an area approximately 115 km in east-west extent and 210 km in north-south extent.

Twelve-month averages from June to May of the heat fluxes over the past 15 years are shown in Figure 2(a). The mean heat flux for June 2001 - May 2002 is approximately 51 Wm^{-2}. This is 14 Wm^{-2} less than the mean for a 31-year period between June 1970 and May 2001 which is used here for a baseline normal period. The 2001–2002 mean heat flux falls at the 26th percentile for this normal period. The mean heat flux for the preceding 12-month period from June 2000 to May 2001 was 32 Wm^{-2}, essentially the same as the value for the1995–1996 average that was the lowest in the 31-year normal period.

Seasonal heat fluxes for the past three years are shown in Figure 2(b). The seasons are defined as Summer = June-August, Fall = September-November, Winter = December-February, and Spring = March-May. For the year leading up to the 2002 AR7W occupation, the winter average heat flux was much less than normal (16th percentile) while summer, fall, and spring averages were near normal. The low values for the 2000–2001 mean reflect the combined influence of a similarly mild winter (17th percentile) and an especially mild spring (0th percentile).

3. Results from 2002

Property distributions in 2002

Contoured gridded sections of potential temperature, salinity, potential density anomaly, potential vorticity, and apparent oxygen utilisation (AOU) for the 2002 AR7W occupation are shown in Figures 3–7. Along-section distance in kilometres increasing from west to east is used as the horizontal co-ordinate. The upper panel of each section plot uses depth as vertical co-ordinate. The lower panel uses potential density anomaly as the vertical co-ordinate for potential density anomalies between 27.7 and 27.8 kg m^{-3}. The mean depth of the 27.7 kg m^{-3} potential density anomaly surface is 269m, with extreme depths of 156m and 753m. The mean depth of the 27.8 kg m^{-3} potential density anomaly surface is 2163m, with extremes of 1663 and 2329m.

Notable in the upper levels of Figure 3(a) (potential temperature) are cold waters (<2^{o}C) over the Labrador Shelf on the western boundary of the Labrador Sea. The shelf waters are separated from the interior by a shelf-break front associated with the southward flowing Labrador Current. Similarly cold waters in the upper few hundred metres at the eastern boundary of the Labrador Sea are bounded to the west by another frontal region associated with the inshore branch of the northward-flowing West Greenland Current. Warmer waters (>4^{o}C) in the upper 500m of the water column on the eastern boundary are associated with the offshore branch of the West Greenland Current and associated recirculation and eddies. A seasonal thermocline with a maximum surface temperature of about 6.6^{o}C was observed in the July 2002 survey.

Figure 3(a) also shows a large area between 600 and 1200m in the central Labrador Sea with potential temperature less than 3.2^{o}C and a reduced vertical temperature gradient, especially for the western half of the section. At about 1300m depths there is a quasi-continuous layer with potential temperature greater than 3.3^{o}C extending from the eastern boundary. This layer deepens to1500m depths at its western limit before finally disappearing near the 300km mark. At still deeper levels, potential temperature decreases with depth to near-bottom values less than 2^{o}C. The prominent slopes of the deep isotherms near the western and eastern boundaries are associated with the deep boundary current that circles the Labrador Sea in a counter clockwise sense.

Figure 3(b) shows that potential temperature is nearly constant on surfaces of constant potential density except at the uppermost levels. Mesoscale eddy features that distort the property fields on surfaces of constant depth have less influence on the distribution of properties on surfaces of constant potential density. For this reason, year-to-year changes in the property fields may be easier to interpret in density space.

We interpret the relative minimum in potential temperature as a remnant of convection that took place during the previous winter. In early July the waters shallower than about 250m depth will have warmed considerably by heating from the atmosphere (Appendix A). The warming of the waters between this near-surface layer and the relative minimum layer can be attributed to horizontal advection and diffusion accompanied by secondary vertical diffusion. The upper of the pair of dashed lines superimposed on each of Figure 3(a) and 3(b) trace the depth or potential density anomaly respectively of the relative minimum in potential temperature. The area enclosed by the 3.2^{o}C potential temperature contour at mid-depths is greater near the western side of the Labrador Sea than the eastern side. The minimum potential temperature layer occurs at somewhat deeper depths and greater potential densities on the western side than on the eastern side. This is compatible with the notion that winter convection occurs predominantly on the western side of the basin, driven by outbreaks of cold, dry air from the north and west.

We interpret the relative maximum in potential temperature near 1400m as the signature of nearly-isopycnal spreading of the relatively warm and saline waters at the eastern boundary of the Labrador Sea. The lower of the pair of dashed lines superimposed on each of Figure 3(a) and 3(b) trace the depth or potential density anomaly respectively of the relative maximum in potential temperature.

The patch near 2000m depths with salinity greater than 34.88 in Figure 4 is a remnant of Deeper Labrador Sea Water (LSW) formed by deep convection in a series of severe winters between 1988 and 1993. The high salinities near 3000m depth or 27.85 kg m^{-3} potential density anomaly mark the influence of Northeast Atlantic Deep Water.

Figure. 5 (potential density anomaly or pressure) is presented for completeness and will not be discussed. Figure. 5 is slightly different from the others: Figure 5(a) shows the change in potential density on pressure surfaces and Figure 5(b) shows the change in pressure on density surfaces.

Figure 6 (potential vorticity) is interesting in that there is a local minimum in potential vorticity that closely follows the relative minimum in potential temperature. There is a layer of relatively high potential vorticity near or just below the potential temperature maximum. Still deeper in the water column near 2000m depth and 27.78 kg m^{-3} potential density anomaly there is another potential vorticity minimum related to the Deep LSW discussed above.

Figure 7 shows the apparent oxygen utilisation (AOU) derived from bottle samples. AOU is defined as the difference between the saturation values of dissolved oxygen concentration at the measured temperature and salinity and the measured dissolved oxygen concentration. It provides a measure of the time elapsed since the water was in contact with the atmosphere, since oxygen concentrations tend to become lower with time because of the biological processes. The waters between the seasonally-heated top few hundred metres and the potential temperature minimum show nearly constant AOU values of about 0.6 ml l^{-1}. Higher values of AOU are observed below the potential minimum, marking waters that have been out of contact with the atmosphere for a longer period of time. The Deeper LSW shows up as a relative minimum in AOU.

4. Changes in properties from earlier years

4.1 Sections showing changes from 2001 to 2002

Contoured gridded sections of the changes in potential temperature, salinity, potential density anomaly or pressure on potential density surfaces, potential vorticity, and apparent oxygen utilisation (AOU) from the 2001 to the 2002 AR7W occupations are shown in Figures. 8–12. The upper panel of each section plot uses depth as vertical co-ordinate. The lower panel uses potential density anomaly as the vertical co-ordinate for potential density anomalies between 27.7 kg m^{-3} and 27.8 kg m^{-3}. Figure 10 parallels Figure5, showing changes in potential density on pressure surfaces in the upper panel and change in pressure on density surfaces in the lower panel.

The changes in the upper 200m are dominated by seasonal effects. T2001 occupation took place in early June. The 2002 occupation took place in early July, one month later in the seasonal cycle.

The depths of the relative minimum and maximum in potential temperature for 2002 are superimposed on all the difference sections as in Figures 2–7. The depths of similar minima and maxima in potential temperature for the 2001 occupation are also marked. In the western part of the transect, the relative minima and maxima in potential for 2002 occur deeper in the water column that was the case in 2001.

In summary, there is a horizontally-coherent layered pattern of property changes. In general, the upper 1000m became warmer, saltier and slightly denser; a layer centred near the 1000m mark in the western two-thirds of the basin became colder and fresher without much change in density; and the waters deeper than this fresher layer became warmer, saltier, and slightly denser.

Changes in the 0–1000m layer

Figure 8(a) and Figure 8(b) (potential temperature change) show a general warming of 0.1 to 0.2°C over much of the water column above the 1000m level. The changes in temperature on surfaces of constant pressure include the effects of transient mesoscale eddies. The warming is seen more clearly in Figure 8(b) on potential density surfaces. Figure 9 shows that this layer also became saltier between 2001 and 2002. Figure 10(a) shows that the salinity increase dominated the temperature increase in terms of density changes: the density of this upper layer increased slightly. Figure 10(b) shows an equivalent shallowing of pressure surfaces by several hundred dbar (equivalent to the change in depth surfaces in metres) of surfaces of constant potential density. Figure 11 suggests that there is an increase in the vertical density stratification in the 0–500m range and a decrease in the density stratification in the 500–1000m range. All these changes are consistent with a greater influence in 2002 of the warm and salty waters originating in the warm branch of the West Greenland Current.

Changes near 1000m

Figure 8(a) and Figure 8(b) show a pronounced cooling of a layer extending from about 800m to 1200m depths over the western two-thirds of the basin. Figure 9 shows that this layer was also fresher in 2002 than in 2001. There is no clear pattern of density change in this layer. However, Figure 11 and Figure 12 show that this layer experienced a decrease in potential vorticity and AOU (increase in dissolved oxygen) from 2001 to 2002. This is consistent with the idea that there was deeper vertical convection in the winter of 2001–2002 than in the preceding winter.

Changes in the deeper waters

Figure 8(a) and Figure 8(b) show a remarkable warming of the deeper waters of the Labrador Sea between 2001 and 2002. The changes are greatest in the 1500–2000m depth range and just above the bottom. The waters in this layer are generally saltier in 2002 than in 2001. The density changes on pressure surfaces or the equivalent pressure changes on density surfaces are directly affected by mesoscale transients and are less spatially coherent. There is a general increase in density, decrease in potential vorticity, and increase in apparent oxygen utilisation in the 1500–2000m range on the western half of the transect. As in the uppermost layer, this suggests a greater influence of waters originating on the eastern boundary. Present estimates of the transit time for waters from the eastern boundary to circulate around the Labrador Sea to the western boundary is of order one year.

4.2 Average profiles from 2002, 2001, and 2000

The vertical structure in potential temperature in 2002 may be seen more clearly in Figure 13(a) and 13(b) which show individual profiles of potential temperature for the11 stations in the distance range 240–700 km plotted with pressure and potential density anomaly respectively as the vertical co-ordinate. An average profile and selected standard deviations are also shown where the averages are taken on pressure surfaces for Figure 13(a) and on potential density surfaces for Figure 13(b). Similar averages in the 240–700km distance range for 2000 and 2001 are included for comparison.

The 2002 average in Figure 13(a) shows a broad relative minimum in potential temperature of 3.15^{o}C centred near 1000 dbar. By comparison, the averages from the two preceding years show weaker relative minima at about 800 dbar for 2000 and 900 dbar for 2001. The 2002 average shows a well-defined relative potential temperature maximum of 3.27^{o}C near 1500 dbar. The averages from the two preceding years show weaker relative maxima centred near 1100 dbar for 2000 and 1150 dbar for 2001.

The 2002 average on potential density surfaces in Figure 13(b) shows the relative minimum in potential temperature centred at 27.74 kg m^{-3}. The relative minima in the averages from the two preceding years are centred near 27.73 kg m^{-3}.The relative maximum for the 2002 average potential temperature on density surfaces appears at a slightly higher density than for the two preceding years, 27.76 kg m^{-3} for 2002 compared to about 27.755 kg m^{-3} for the earlier two cases. The standard deviations near the relative maximum in potential temperature for the 2002 averages on density surfaces are notably less than those for averages on pressure surfaces.

Figure 14(a) and 14(b) show similar averages of AOU. The 800–1200m layer shows a decrease in AOU in 2002 relative to the previous two years. This supports the idea that this water was exposed to the atmosphere during the 2001–2002 winter.

4.3 Changes in heat and salt content 1990–2002

The changes in heat and salt for the 1990–2000 period were discussed by Lazier *et al.* (2002). This section extends the time series to include the most recent AR7W occupations.

Figure 15(a) shows the heat content from spring AR7W occupations averaged over stations in the distance range 320–520 km a function of median station time since the first occupation of AR7W in 1990. Integrals over the depth ranges

150–1000m and 1000–2000m and the sum over these two depth ranges are shown. The units are GJ m^{-2}. A warming of a column of water 1850m thick (equivalent to the 150–2000m depth range) by 0.13°C gives an increase in heat content of about 1 GJ m^{-2}. Figure 15(b) shows a similar plot of salt content. The units are kg m^{-2}. A salinity increase of about 0.005 for the same case gives an increase in salt content of about 10 kg m^{-2}.

The heat content in the 150–1000m layer increased in each of the last two years. This layer was considerably fresher than the 13-year mean in 2001 and somewhat saltier than the mean in 2002. The high-frequency variability in 150–1000m salt content was noted by Lazier *et al.* (2002).

The remarkable increasing trends in heat and salt content in the 1000–2000m layer were noted by Lazier *et al.* (2002). Both trends continued through 2001. In 2002, the heat content increased again while salt content decreased slightly.

The net result is that the 150–2000m early-summer 2002 mean salinity was the highest observed in the past thirteen spring-summer periods for which measurements are available. The corresponding mean temperature was the second highest observed during this period. The density of seawater decreases with increasing temperature and increases with increasing salinity. The 2002 survey showed slightly denser waters in the 150–1000m depth range and slightly less-dense waters in the 1000–2000m depth range compared with results from 2001. The net effect was a small decrease in 150–2000m mean density, equivalent to a rise in steric sea level of the order 0.01m.

There is a strong seasonal signal in the properties in the 0–150m layer. Appendix A summarizes an analysis of the seasonal cycle in the central Labrador Sea from historical data.

5. Sea level changes from TOPEX/POSEIDON altimetry and hydrography

Time series of sea level at the site of the central mooring were extracted from the TOPEX/POSEIDON (T/P) Maps of Sea Level Anomaly (MSLA) altimeter data product produced by the French Archivage, Validation et Interprétation des données des Satellites Océanographiques (AVISO) (http://www-aviso.cls.fr/). Data were available for the period October 1992 through February 2002. A seasonal signal was estimated by a least-squares fit to annual and semi-annual harmonics and the residuals were low-pass filtered. Additional data from the nearby crossover point of T/P Tracks 098 and 243 referred to the same datum were used to extend the time series to the end of the T/P coverage in its original orbit on August 11, 2002.

Figure 16 shows the time series of the low-passed altimetric measurements with and without the seasonal signal. Also shown are the time changes in geopotential height relative to 2000 dbar calculated from AR7W measurements since 1900 relative to the mean of spring values during the T/P measurement period. Each value is an average of approximately 4 stations in the 320 - 520 km distance range. Sample standard deviations for each cruise are also shown. The seasonal signal has a range of just less than 9 cm. There is reasonable agreement between the changes in geopotential height relative to 2000 dbar and the changes measured by the altimeter when seasonal effects are included. This is true in particular for the changes from 2001 to 2002. Both the 0–2000dbar geopotential heights and the low-frequency sea level time series show an increase of 1–2 cm between the 2001 and 2002 AR7W occupations.

6. Summary

Since the winter of 1994–1995, mild winters have produced only shallow wintertime convection. This pattern persisted through the winter of 2001–2002. Annual sea-air heat fluxes (June 2001-May 2002) in the central Labrador Sea estimated from the NCEP Reanalysis Project were about 14 W m^{-2} less than the mean for the 31-year normal period June 1970 to May 2000, placing the 2001–2002 12-month average in the 26th percentile of cases for the normal period. Wintertime (December-February) heat fluxes were nearly 60 W m^{-2} less than the winter normal but were balanced by higher than normal spring (March-May) heat fluxes.

A July 2002 transect of the Labrador Sea showed evidence of vertical overturning during the previous winter to depths of 1200–1400m. This evidence consisted of remnants of a vertically-mixed layer with high dissolved oxygen and relative minima of potential temperature and vertical density stratification. The inferred winter mixed layer had potential temperature 3.15 °C, salinity 34.83, and potential density anomaly 27.74 kg m^{-3}. In contrast, the deep mixed layers observed in the early 1990s had potential density anomalies near 27.78 km m^{-3}.

Apart from the apparent weak renewal of winter convection, the general trend was to warmer and more saline conditions. This was true both in the layer shallower than the maximum depth of convection and in the intermediate waters deeper than 1400m. The net result is that the 150–2000m early-summer mean salinity was the highest in the past thirteen years of regular observations. The corresponding mean temperature was the second highest observed during this period.

In spite of a cooling and freshening near 1000m associated with the moderate 2001–2002 winter overturning, the upper layers of the Labrador Sea became warmer and saltier. This points to a greater influence of warm, saline waters carried north into the Labrador Sea by the offshore branch of the West Greenland Current. The 150–1000m mean temperature in the central Labrador Sea was the second highest observed in the thirteen-year period of annual surveys, surpassed only by 1999. The salinity of the upper 1000m was greater than observed since the period of deep convection of the early 1990s when higher-salinity waters from deeper levels were entrained into the upper 1000m. The dissolved oxygen content of the warm, salty water observed in 2002 was lower than observed in the preceding two years.

Since the mid-1990s, a notable trend to higher temperature and salinity in the 1000–2000m layer has emerged. In spite of the effects of winter overturning noted above, the mean temperature of this layer in early-summer 2002 was the warmest observed at comparable seasonal times during the past thirteen years. Salinity in this depth range showed a very slight decrease from the record-high conditions of the previous year. The dissolved oxygen content of this intermediate layer decreased compared with the preceding two years.

The net result is that the 150–2000m early-summer 2002 mean salinity was the highest observed in the past thirteen spring-summer periods for which measurements are available. The corresponding mean temperature was the second highest observed during this period. The density of seawater decreases with increasing temperature and increases with increasing salinity. The 2002 survey showed slightly denser waters in the 150–1000m depth range and slightly less-dense waters in the 1000–2000m depth range compared with results from 2001. The net effect was a small decrease in 150–2000m mean density, equivalent to a rise in steric sea level of the order 0.01m. Sea level changes measured by the TOPEX/POSEIDON altimetric measurements are consistent with this result.

Acknowledgments

The altimeter products used were produced by French AVISO/Altimetry operations centre. The MSLA products were produced by the CLS Space Oceanography Division as part of the European Union Environment and Climate project AGORA (ENV4-CT9560113) and DUACS (ENV4-CT96–0357) with financial support from the CEO programme (Centre for Earth Observation) and Midi-Pyrenees regional council.

Appendix A - Annual variability in the central Labrador Sea from OWS Bravo

Temperature and salinity in the upper layers of the Labrador Sea undergo a marked annual cycle (Lazier, 1980). The annual AR7W surveys do not take place at exactly the same time each year, leading to some aliasing of the seasonal changes. To quantify these effects, annual cycles of temperature, salinity, and associated derived parameters in the upper 150m of the central Labrador Sea were estimated by revisiting the hydrographic data from Ocean Weather Ship (OWS) Bravo located at 56.5^{o}N, 51^{o}W discussed in detail by Lazier (1980).

The four-year period from January 1964 to December 1967 showed a relatively stationary seasonal cycle. For this period, potential temperature averaged over 0–150m varied annually from an overall mean of 4.3^{o}C by ±1^{o}C with a minimum in late-February and a maximum in mid-September (Figure A1). During the same period, salinity averaged over 0–150m varied annually from an overall mean of 34.75 by ±0.06 with a minimum in early May and a maximum in mid-November (Figure A2). Potential density anomaly averaged over 0–150m varied annually from an overall mean of 27.55 kg m^{-3} by ±0.2 with a maximum in early April and a minimum in mid-September. Steric sea level (Figure A3) varied annually by ±0.025 m. Minimum sea level corresponds to maximum potential density anomaly and vice versa. Density or steric sea level changes related to temperature variability were a factor of three greater than the changes related to salinity variability.

The changes in measured fields between the 2001 and 2002 early-summer occupations of AR7W can be estimated from the OWS Bravo results. The median date of the 2001 survey was June 6 and the median date of the 2002 survey was July 5, for a 29-day difference. The warming trend during the late spring and early summer would give a change of 0.5^{o}C in 0–150m average temperature using the 1964–1967 annual cycle. This is equivalent to 0.3 GJ m^{-2} heat content. The decreasing trend in upper-layer salinity would give a change of -0.02, equivalent to -3 kg m^{-2} salt. The increasing trend in steric sea level would give a change of about 0.01 m.

As a check on the sensitivity of the annual cycle to the measurement period a similar calculation was carried out for the two-year period June 1972 to May 1974 which showed more salinity variability and greater wintertime heat loss than the earlier period (Lazier, 1980). The 0–150m layer was colder by 0.9^{o}C, fresher by 0.14, and less dense by 0.02 kg m^{-3} during this period than for the 1964–1967 period. The annual cycles for this period are also in Figures A1, A2, and A3. The temperature cycle is comparable to the results from the earlier period but the salinity cycle has double the range and noticeably different phasing compared with the 1964–1967 result. It gives a salinity change of -0.05, equivalent to -8 kg m^{-2} salt, for the 29-day June-July interval. Since density changes are dominated by temperature changes, the annual cycles in steric sea level for the two periods are similar.

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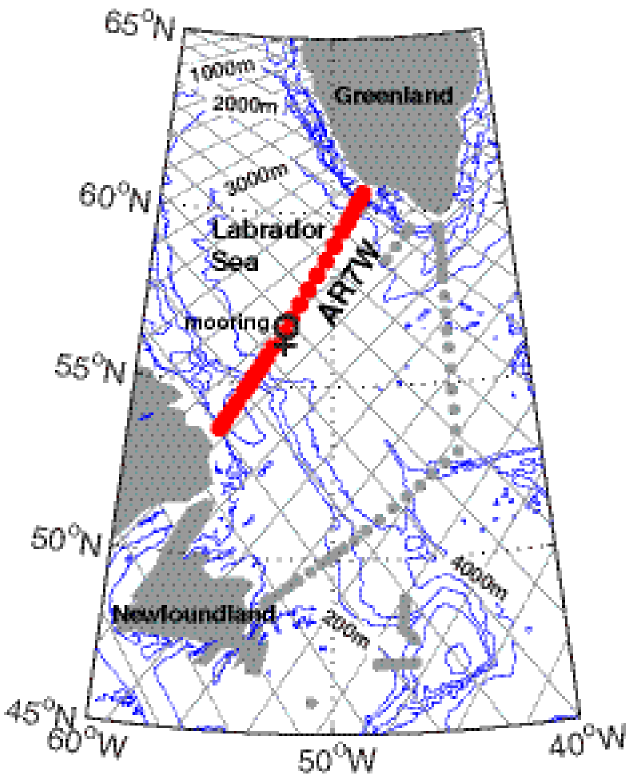

Figure 1 Map of the Labrador Sea showing CTD station positions for Hudson Expedition 2002-032 (large circles - AR7W stations; small circles - additional stations). The Bravo mooring site is marked with an open circle. A nearby NCEP Reanalysis grid point referred to in the text is marked with a cross. TOPEX/POSEIDON ground tracks and selected bathymetric contours are also shown.

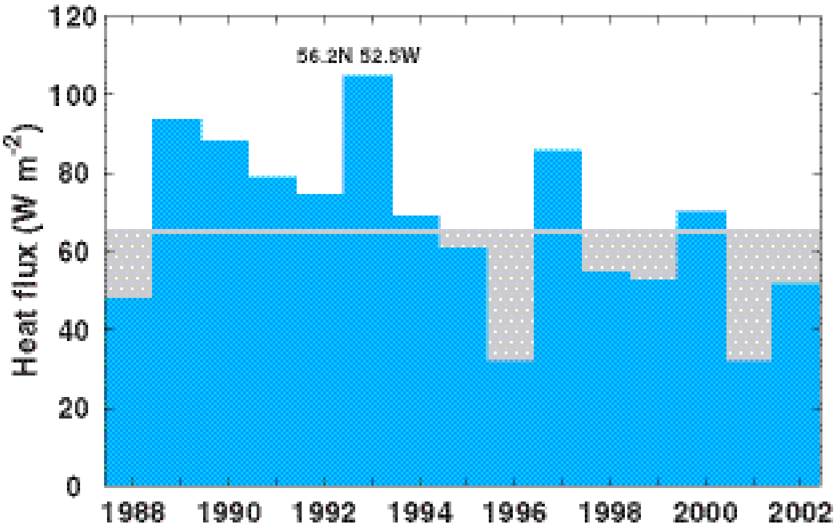

Fig. 2(a) 12-month averages (June-May) of monthly-mean NCEP sea-air heat flux at 56.2°N, 52.5°W in the central Labrador Sea. Values within the shaded area are lower than the mean (65 Wm^{-2}) for the normal period June 1970 to May 2001. Values for the most-recent two 12-month periods were lower than normal: 51 Wm^{-2} (26th percentile) for June 2001 - May 2002 and a near-record low of 32 Wm^{-2} for June 2000 - May 2001.

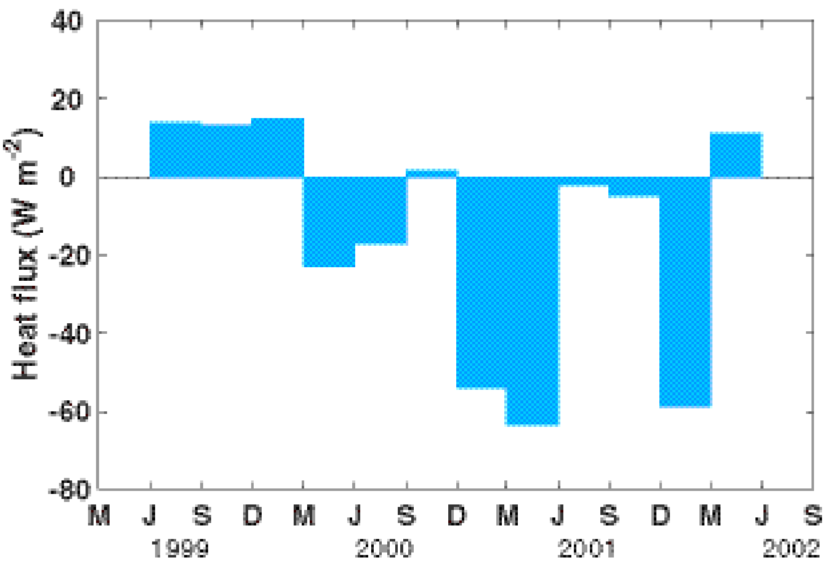

Fig. 2(b) Seasonal averages (summer = JJA, fall = SON, winter = DJF, spring = MAM) of monthly-mean NCEP sea-air heat flux anomalies at 56.2°N, 52.5°W in the central Labrador Sea for the period Summer 1999 - Spring 2002. The anomalies are relative to seasonal means for the normal period June 1970 to May 2001. For 2001-2002, the winter average heat flux was less than normal (16th percentile). Summer, fall, and spring averages were near normal. For 2000-2001, both winter (17th percentile) and spring (0th percentile) fluxes were less than normal.

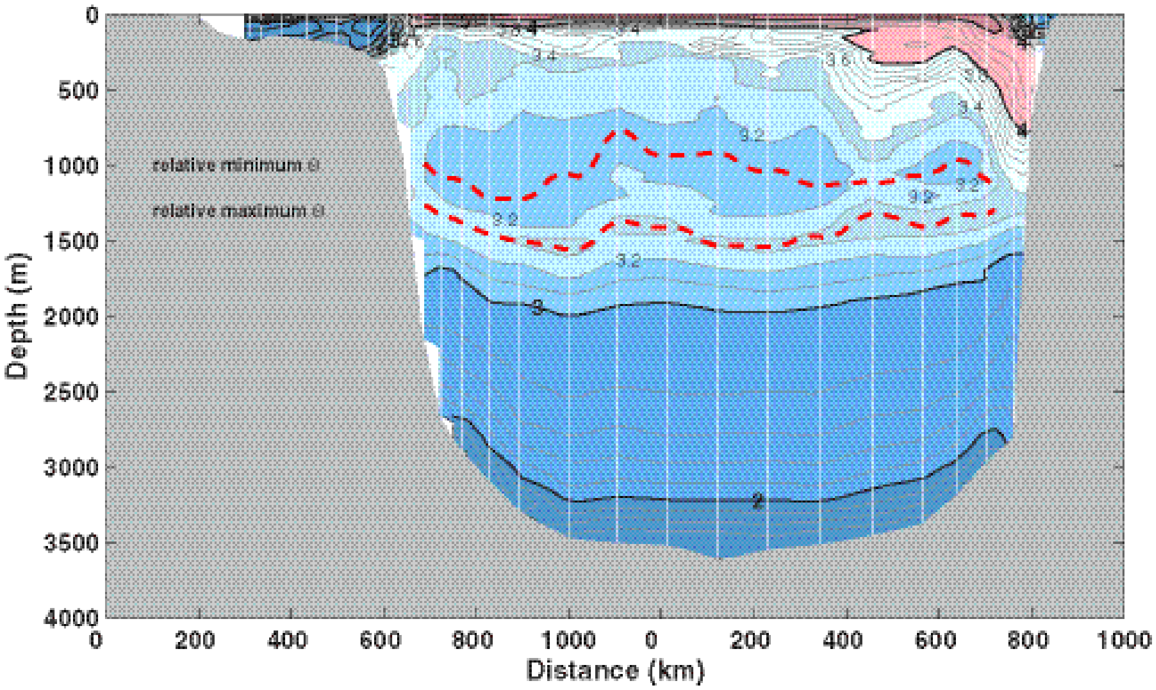

Fig. 3(a) Potential temperature (°C) on AR7W during July 2-9, 2002, from Hudson 2002-032. The dashed lines trace layers of relative minimum potential temperature (< 3.2°C) and relative maximum potential temperature (generally >3.3°C).

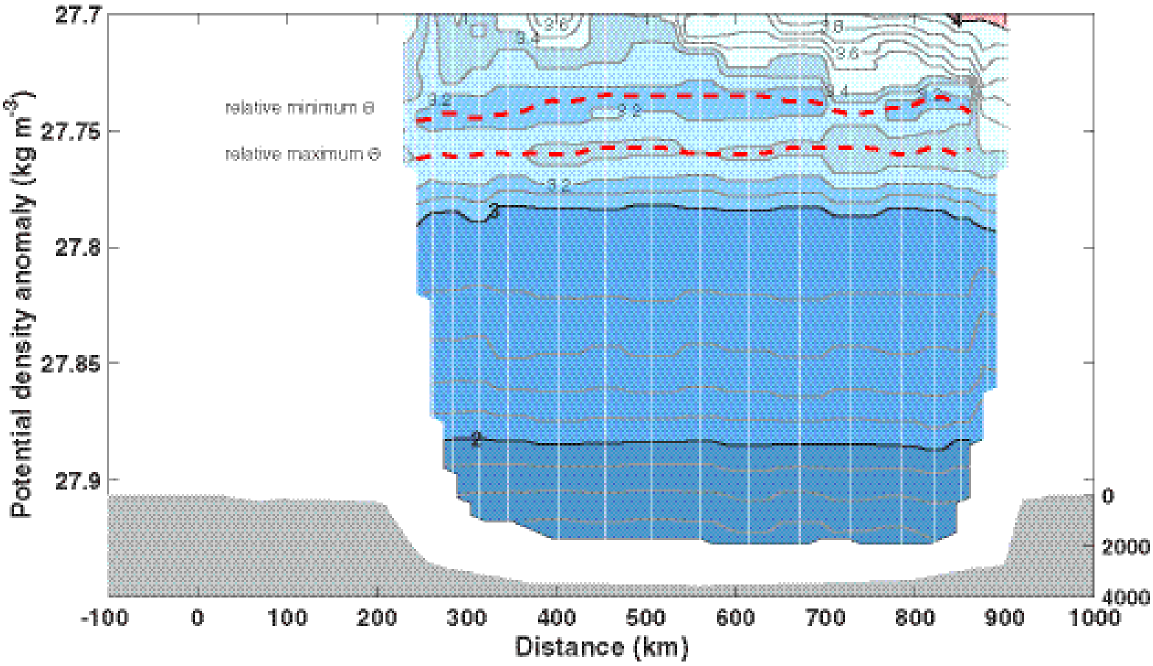

Fig. 3(b) Potential temperature (°C) on AR7W using potential density anomaly as the vertical coordinate for potential density anomalies greater than 27.7 kg m^{-3} during July 2-9, 2002, from Hudson 2002-032. The dashed lines trace layers of relative minimum and maximum potential temperature as in Figure 3(a). An overlay shows the section bathymetry (m). The scale for the bathymetry is at lower right.

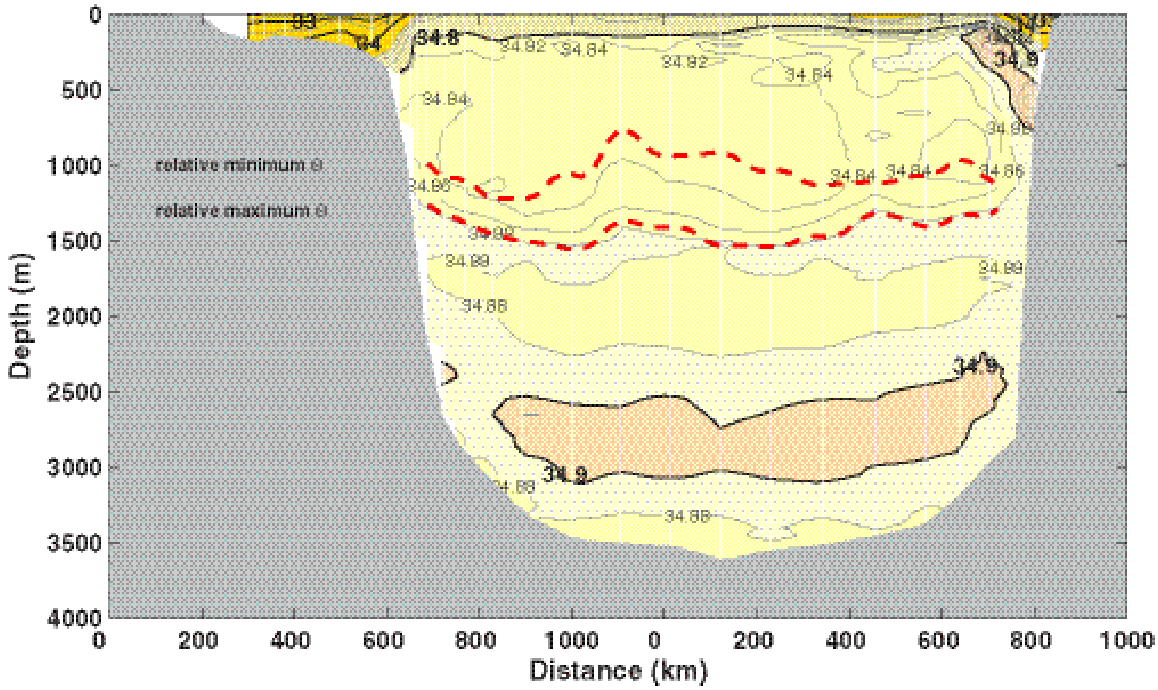

Figure 4(a) Salinity on AR7W during July 2-9, 2002, from Hudson 2002-032. The dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature as in Figure 3(a).

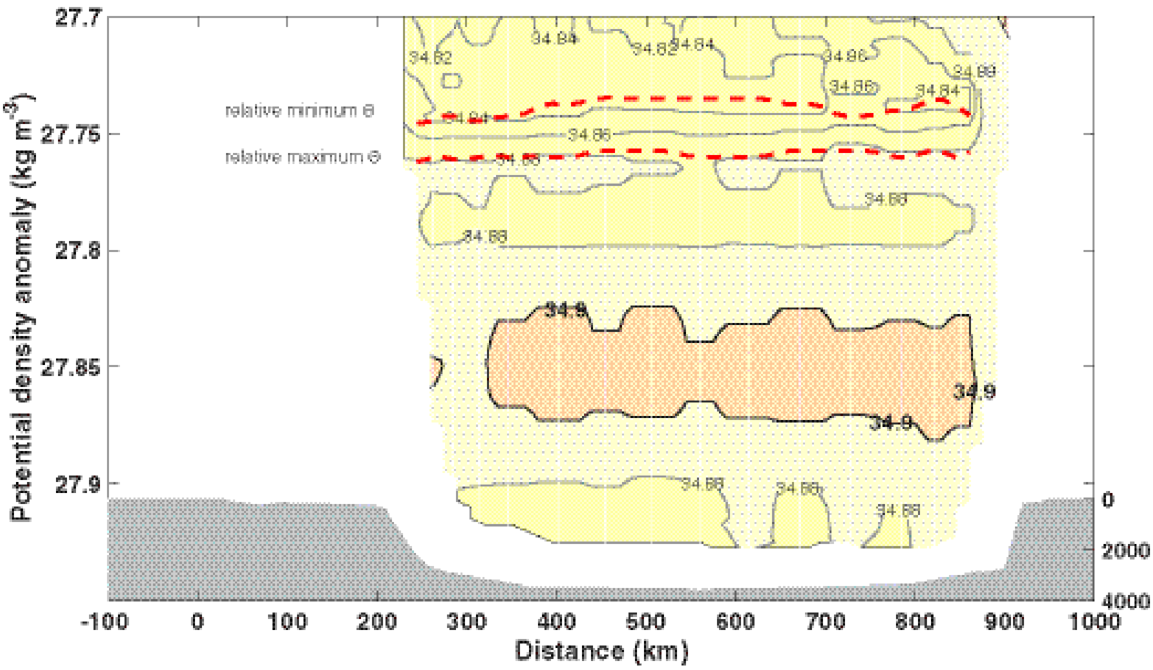

Figure 4(b) Salinity on AR7W using potential density anomaly as the vertical coordinate for potential density anomalies greater than 27.7 kg m^{-3} during July 2-9, 2002, from Hudson 2002-032 as in Figure 3(b).

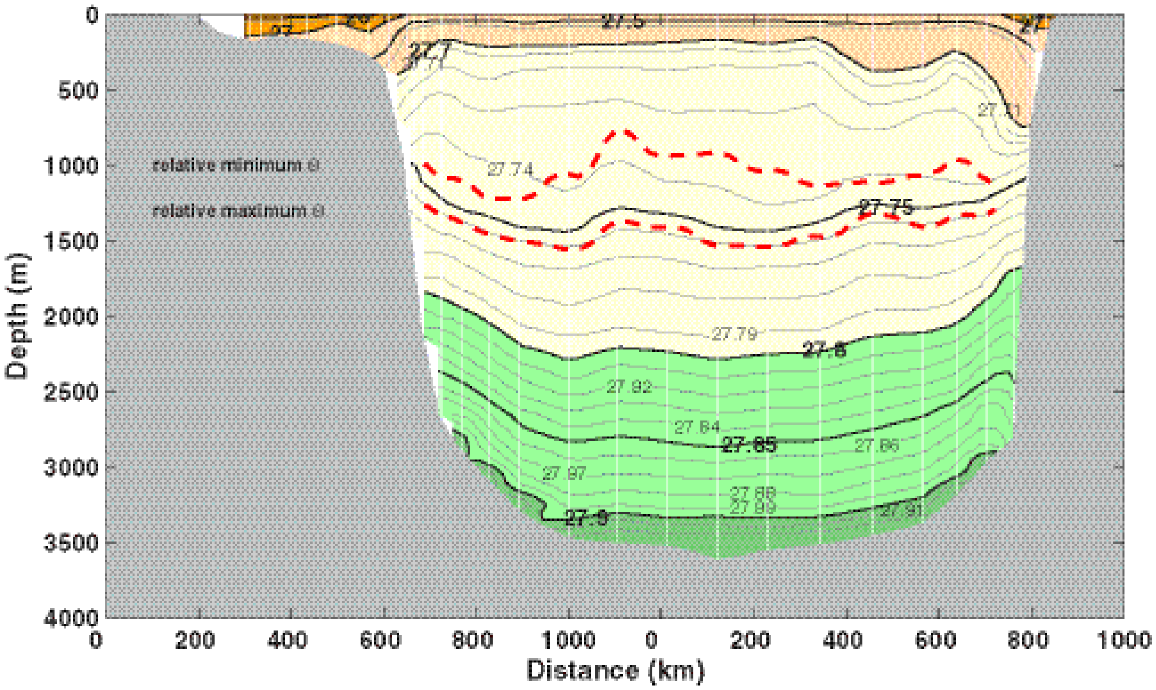

Fig. 5(a) Potential density anomaly (kg/m^3) on AR7W during July 2-9, 2002, from Hudson 2002-032. The dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature as in Figure 3(a).

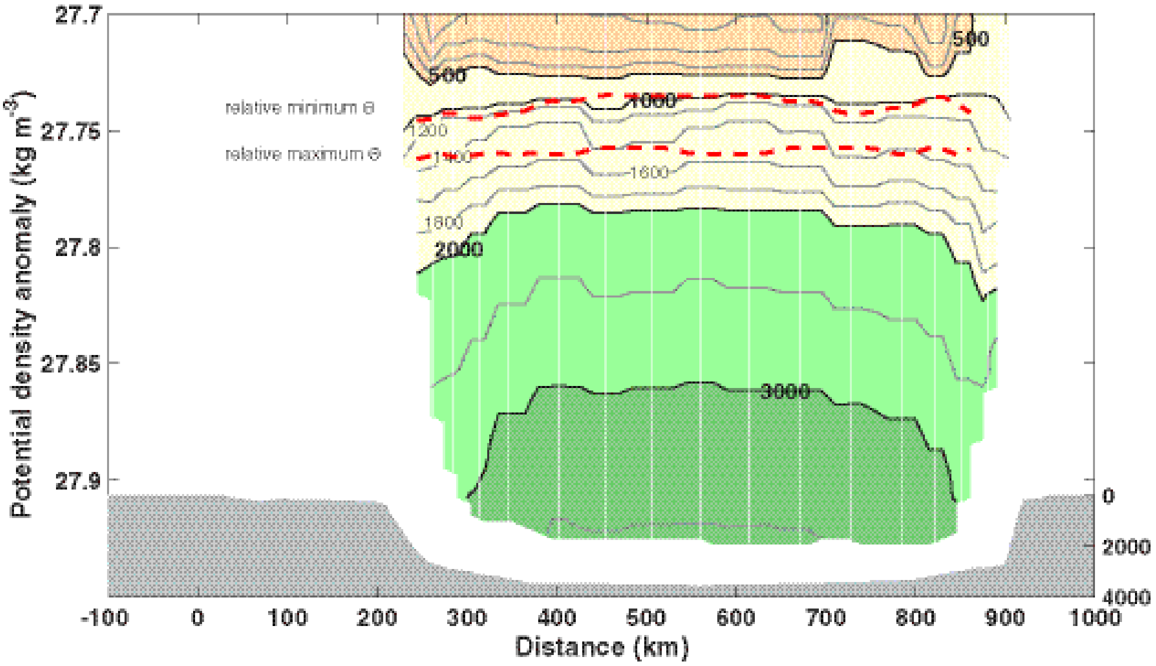

Figure 5(b) Pressure (decibars) on AR7W using potential density anomaly as the vertical coordinate for potential density anomalies greater than 27.7 kg m^{-3} during July 2-9, 2002, from Hudson 2002-032 as in Figure 3(b).

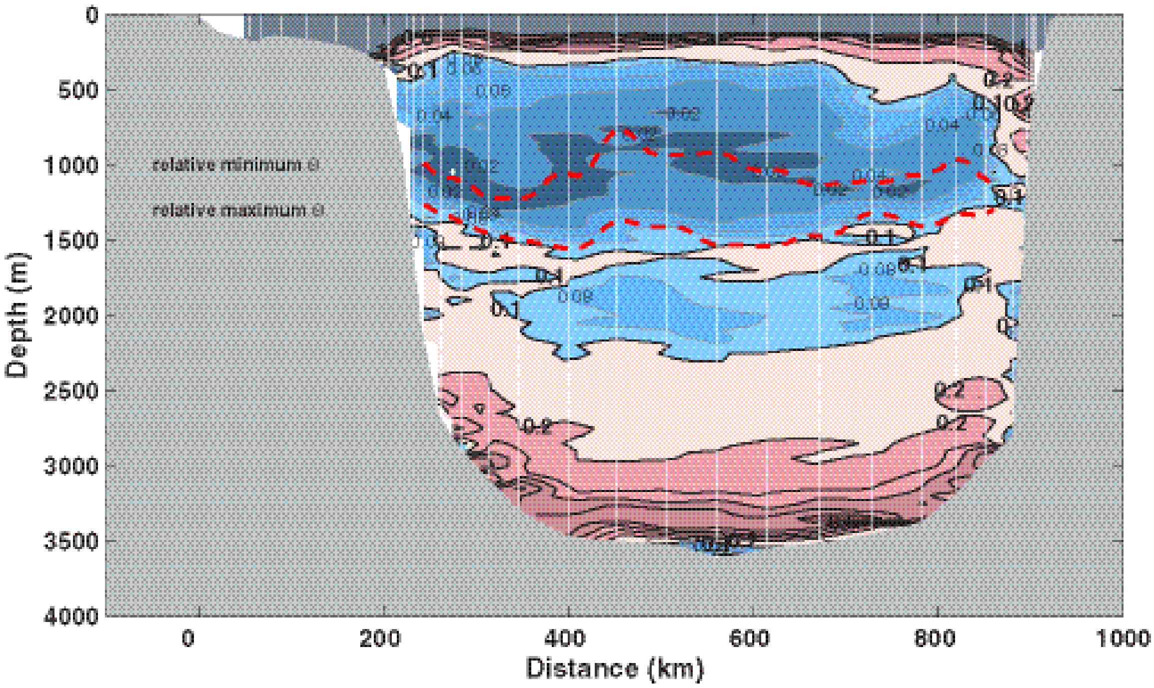

Fig. 6(a) Potential vorticity (10^{-10} m^{-1} s^{-1}) on AR7W during July 2-9, 2002, from Hudson 2002-032. The contoured field was produced from profiles that were smoothed in the vertical with a smoothing scale of 100m. The dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature as in Figure 3(a).

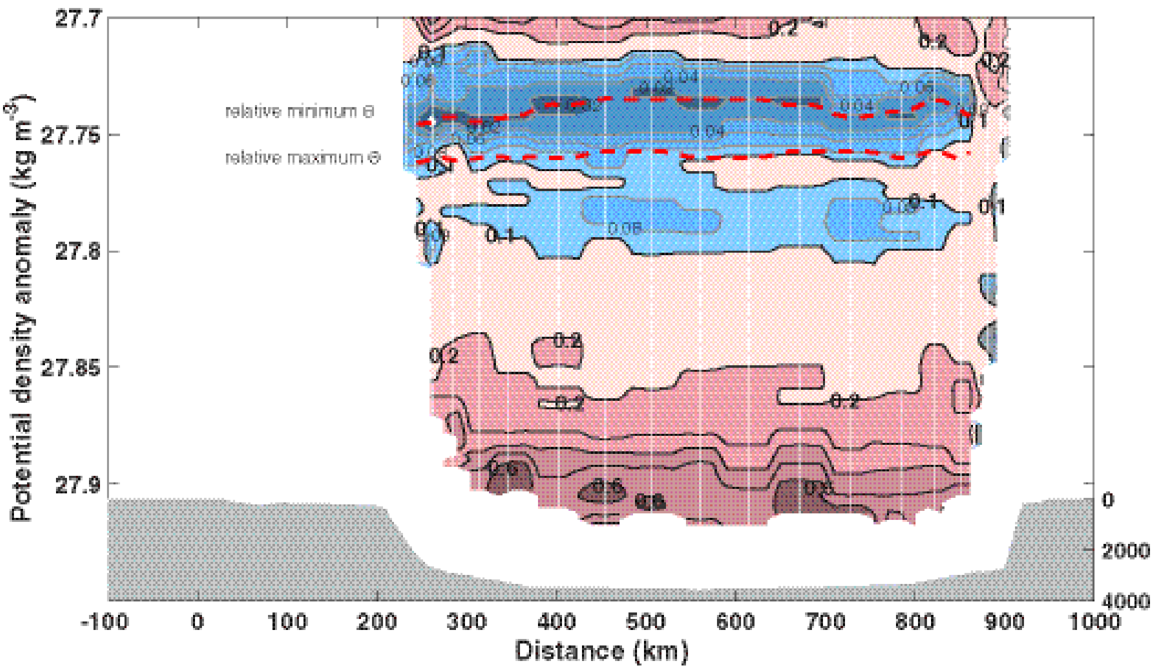

Figure 6(b) Potential vorticity (10^{-10} m^{-1} s^{-1}) on AR7W using potential density anomaly as the vertical coordinate for potential density anomalies greater than 27.7 kg m^{-3} during July 2-9, 2002, from Hudson 2002-032 as in Figure 3(b).

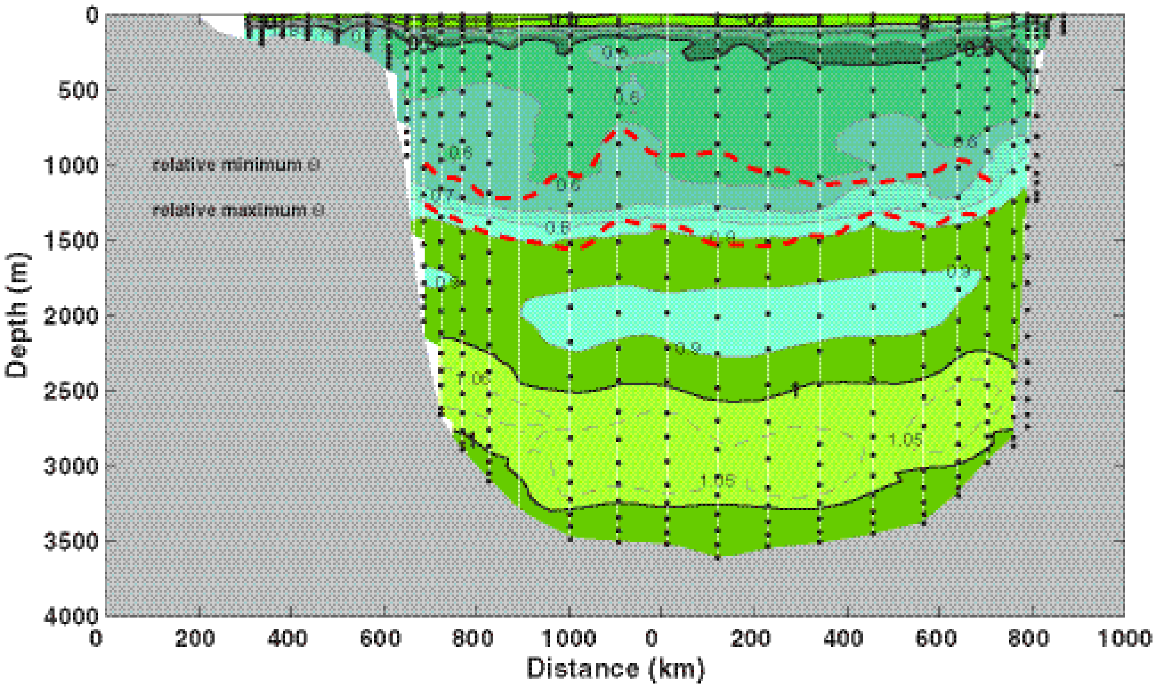

Fig. 7(a) Apparent oxygen utilization (ml l^{-1}) on AR7W during July 2-9, 2002, from Hudson 2002-032 bottle samples (indicated by dots). The dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature as in Figure 3(a).

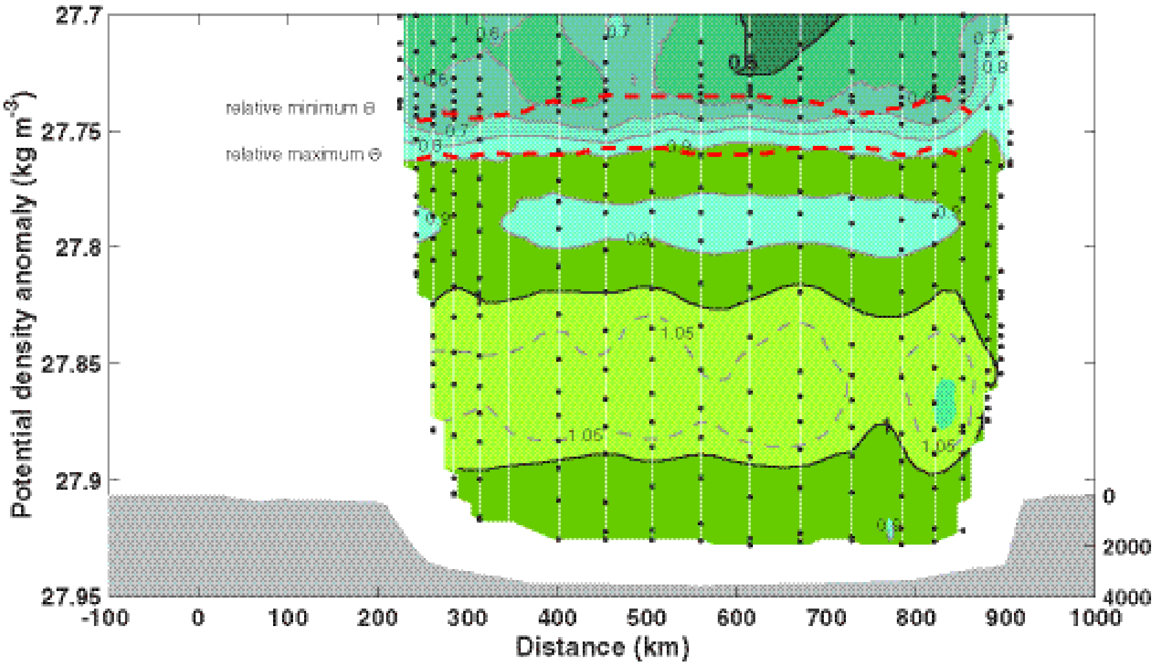

Figure 7(b) Apparent oxygen utilization (ml l^{-1}) on AR7W using potential density anomaly as the vertical coordinate for potential density anomalies greater than 27.7 kg m^{-3} during July 2-9, 2002, from Hudson 2002-032 as in Figure 3(b).

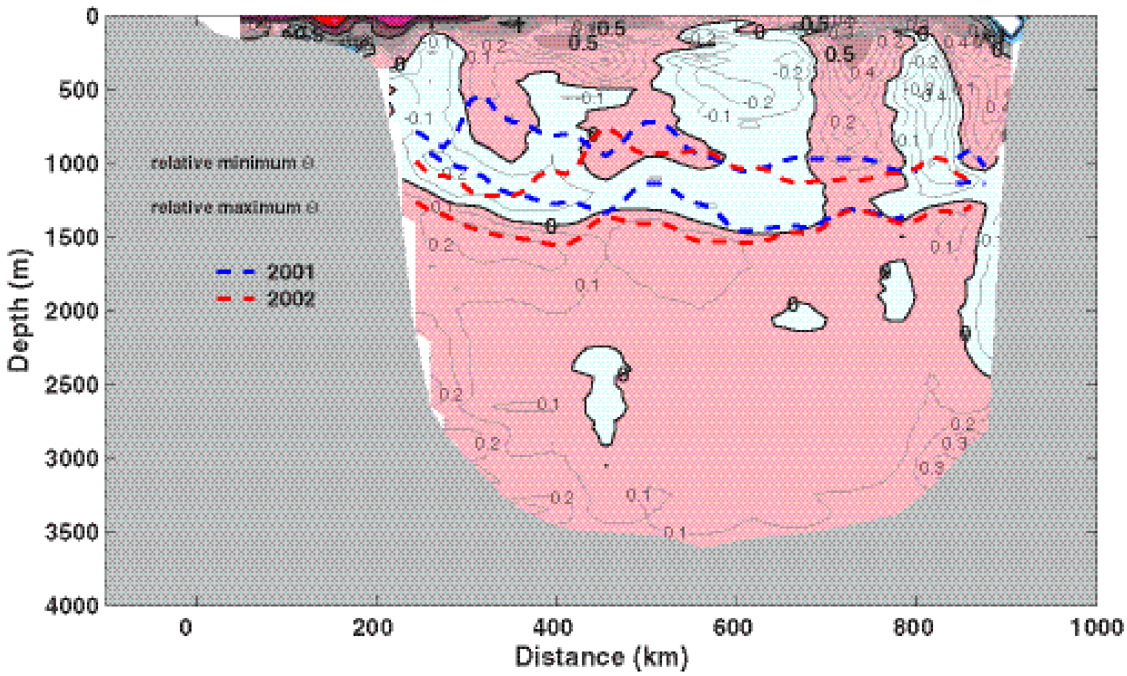

Fig. 8(a) Potential temperature change (^{o}C) on AR7W from June 2001 (Hudson 2001-022) to July 2002 (Hudson 2002-032). The heavy dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature for the individual years.

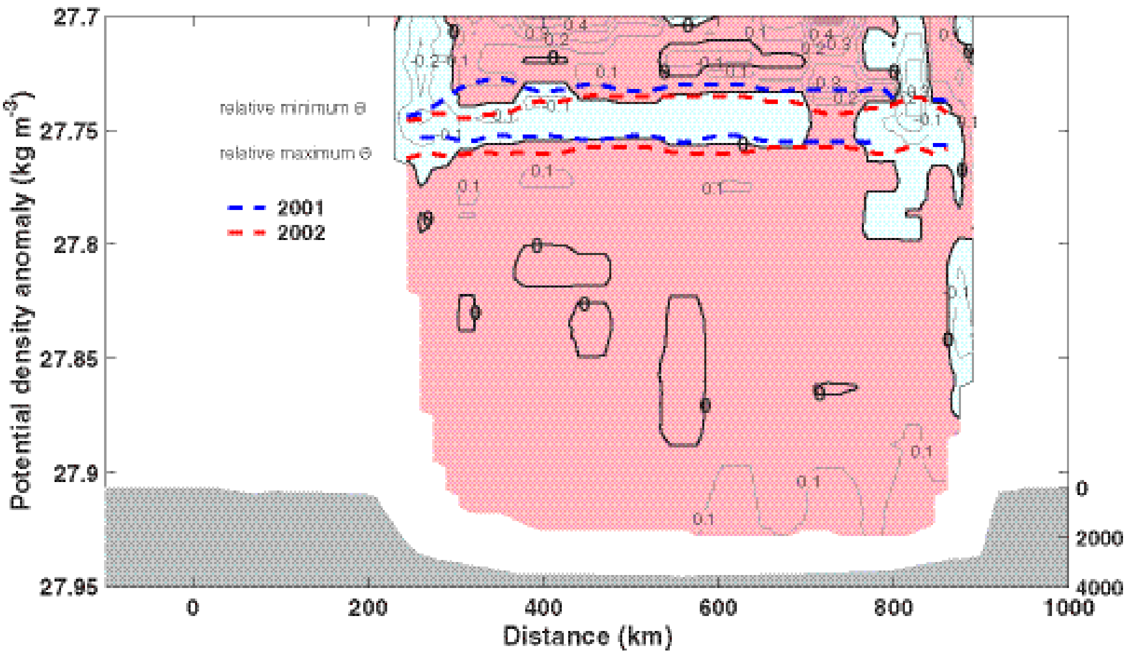

Figure 8(b) Potential temperature change (^{o}C) on AR7W from June 2001 to July 2002 using potential density anomaly as the vertical coordinate for potential density anomalies greater than 27.7 kg m^{-3}. The heavy dashed lines trace layers of relative minimum and maximum potential temperature as in Figure 8(a). An overlay shows the section bathymetry (m). The scale for the bathymetry is at lower right.

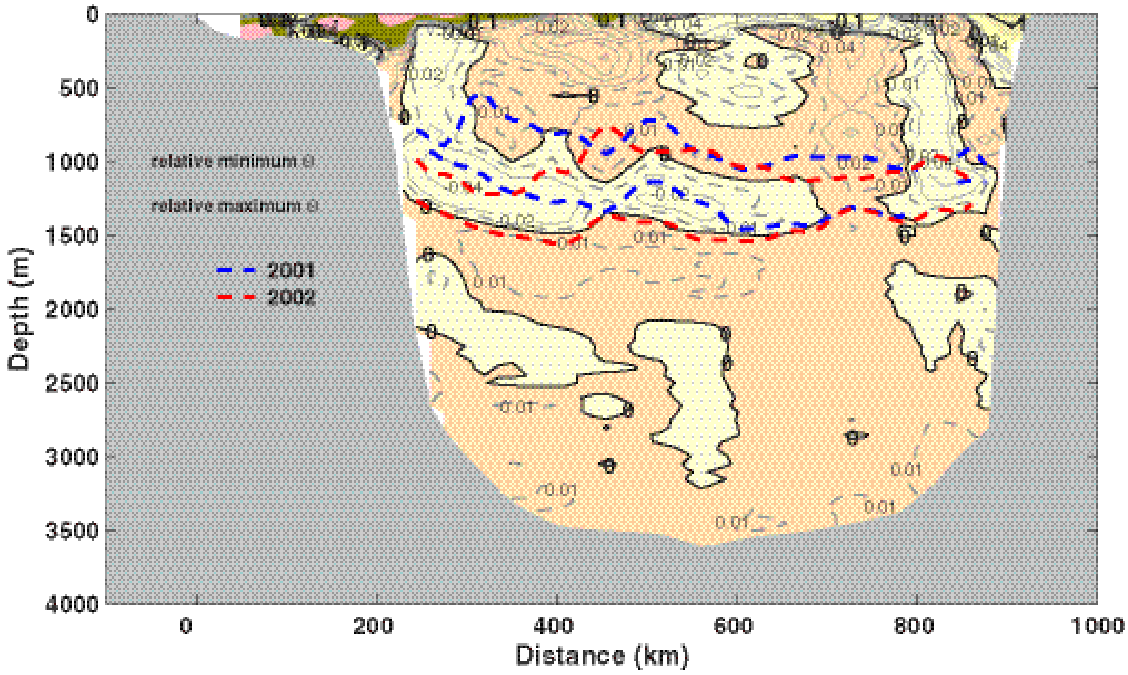

Fig. 9(a) Salinity change on AR7W from June 2001 to July 2002. The heavy dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature as in Figure 8(a).

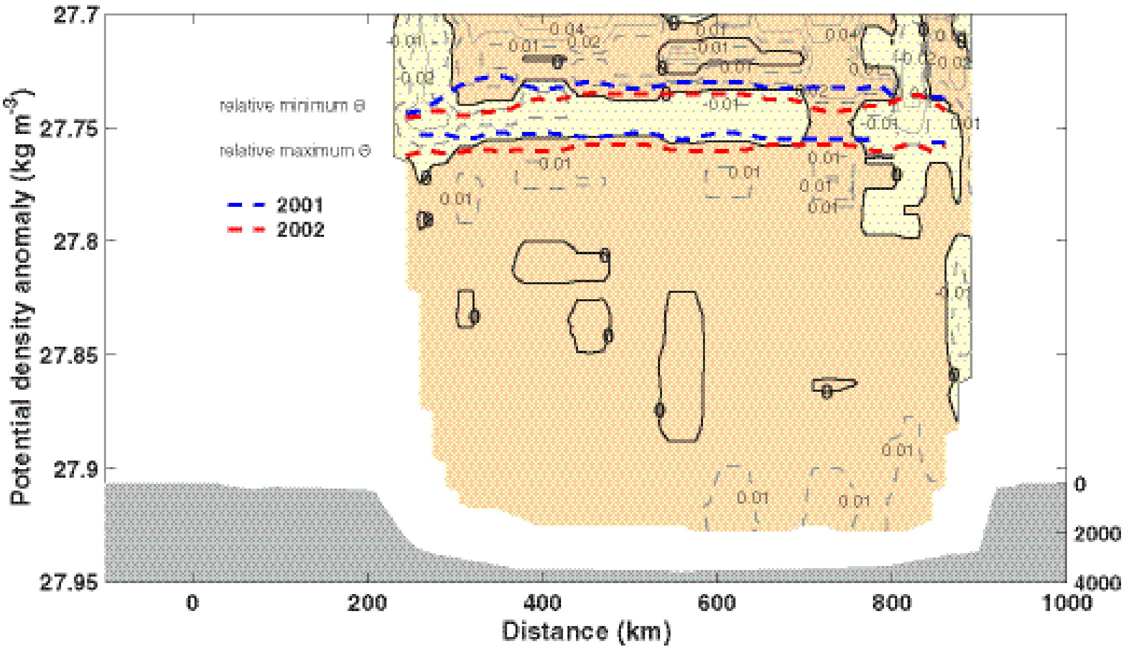

Fig. 9(b) Salinity change on AR7W from June 2001 to July 2002 using potential density anomaly as the vertical coordinate as in Figure 8(b).

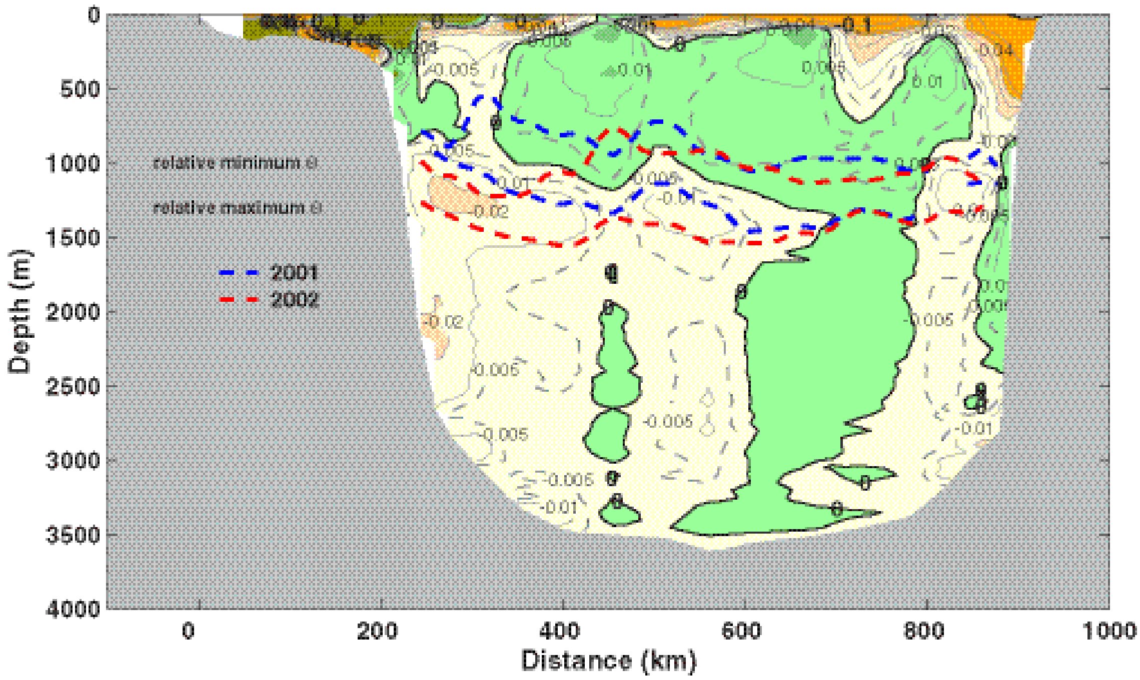

Fig. 10(a) Potential density change (kg m^{-3}) on AR7W from June 2001 to July 2002. The heavy dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature as in Figure 8(a).

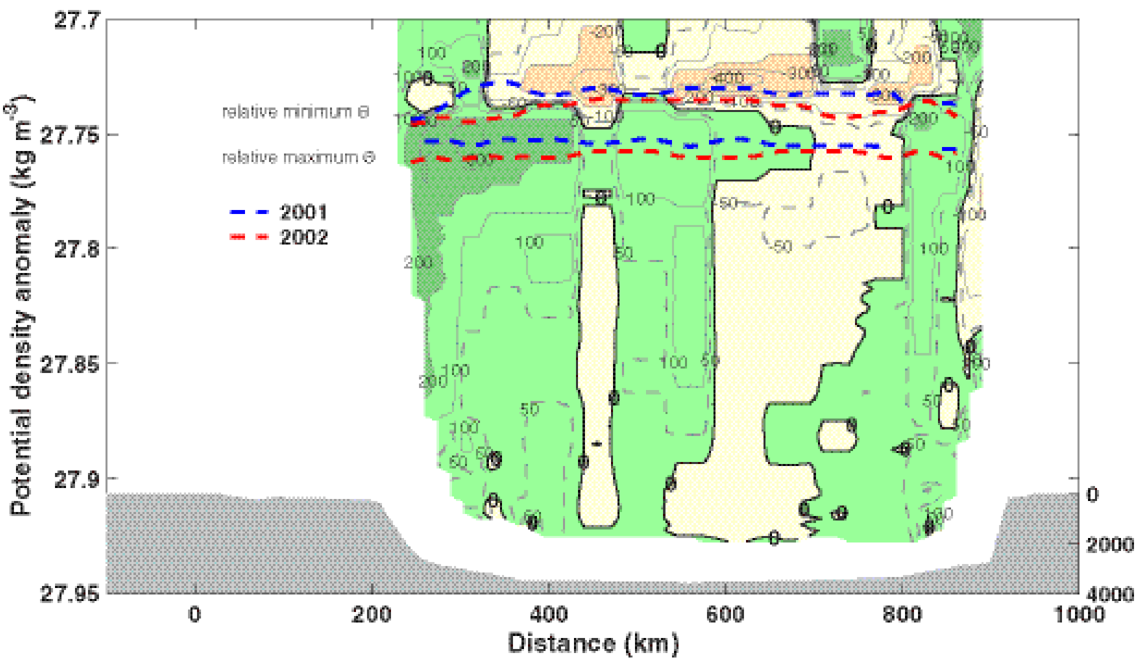

Fig. 10(b) Pressure change (dbar) on AR7W from June 2001 to July 2002 using potential density anomaly as the vertical coordinate as in Figure 8(b).

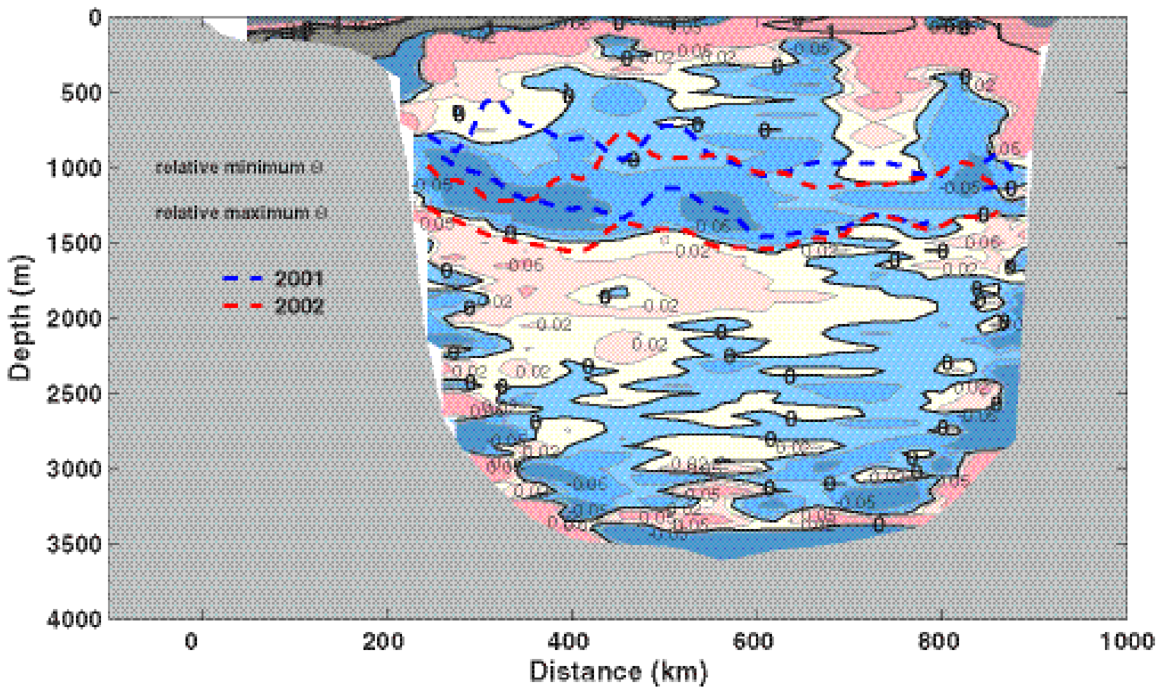

Fig. 11(a) Potential vorticity change (10^{-10} m^{-1} s^{-1}) on AR7W from June 2001 to July 2002. The dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature as in Figure 8(a).

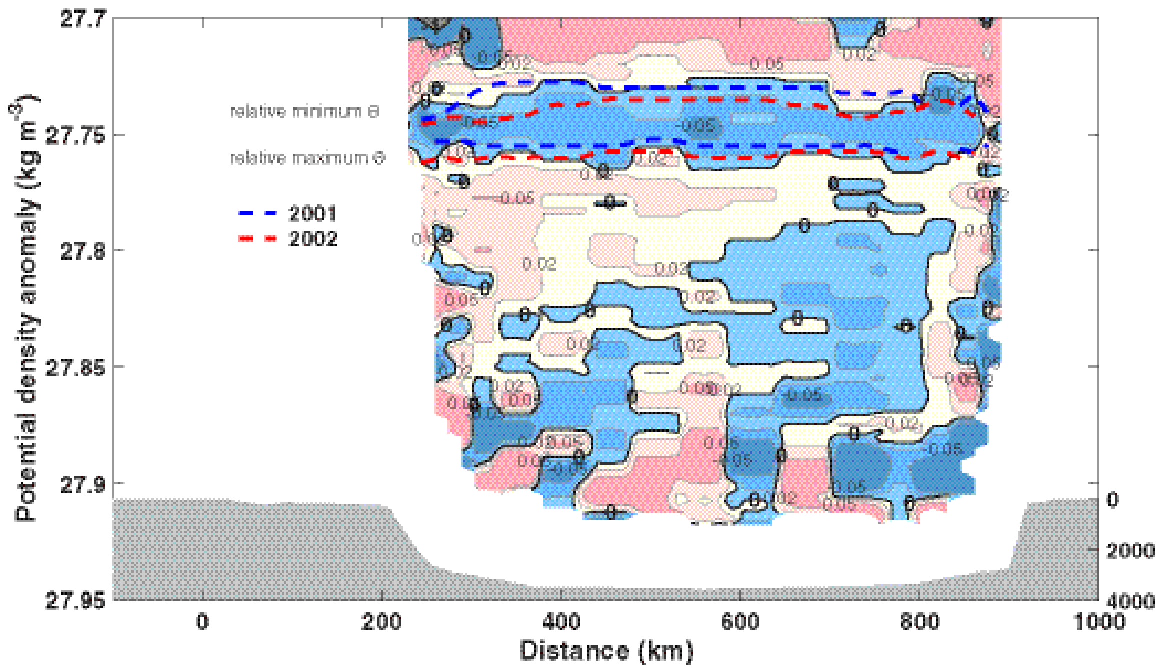

Fig. 11(b) Potential vorticity change (10^{-10} m^{-1} s^{-1}) on AR7W from June 2001 to July 2002 using potential density anomaly as the vertical coordinate as in Figure 8(b).

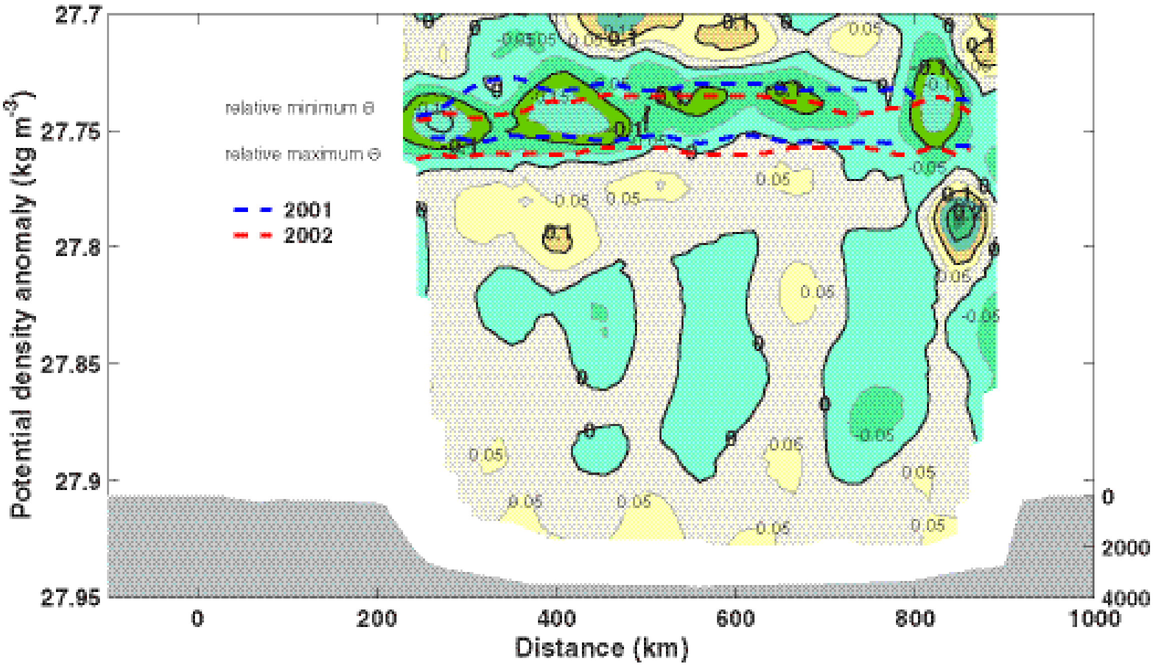

Figure 12(a) Apparent oxygen utilization change (ml l^{-1}) on AR7W from June 2001 to July 2002 using bottle samples. The heavy dashed lines trace layers of relative minimum potential temperature and relative maximum potential temperature as in Figure 8(a).

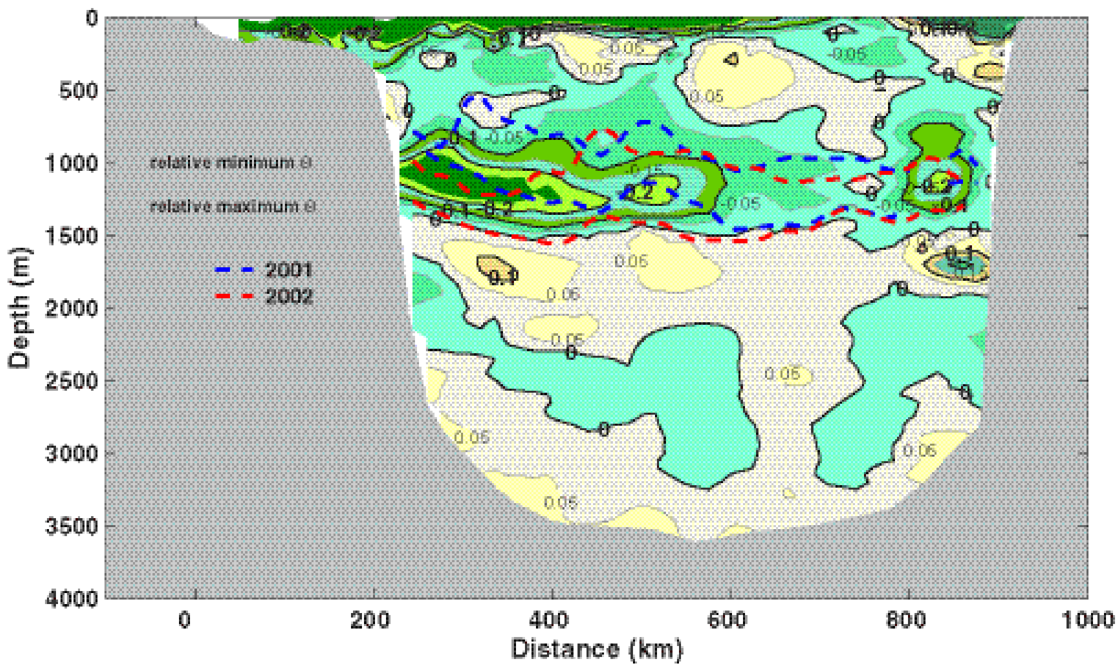

Figure 12(b) Apparent oxygen utilization change (ml l^{-1}) on AR7W from June 2001 to July 2002 using potential density anomaly as the vertical coordinate as in Figure 8(b).

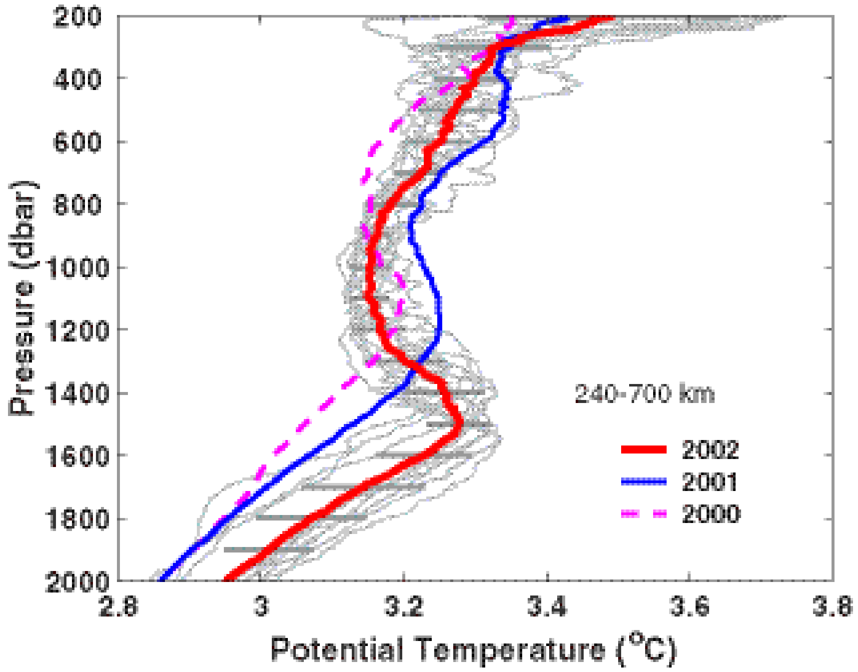

Fig. 13(a) Potential temperature averaged on pressure surfaces for distances in the range 240-700km for 2002, 2001, and 2000 using pressure as the vertical coordinate. Individual profiles and selected standard deviations for 2002 are plotted in the background.

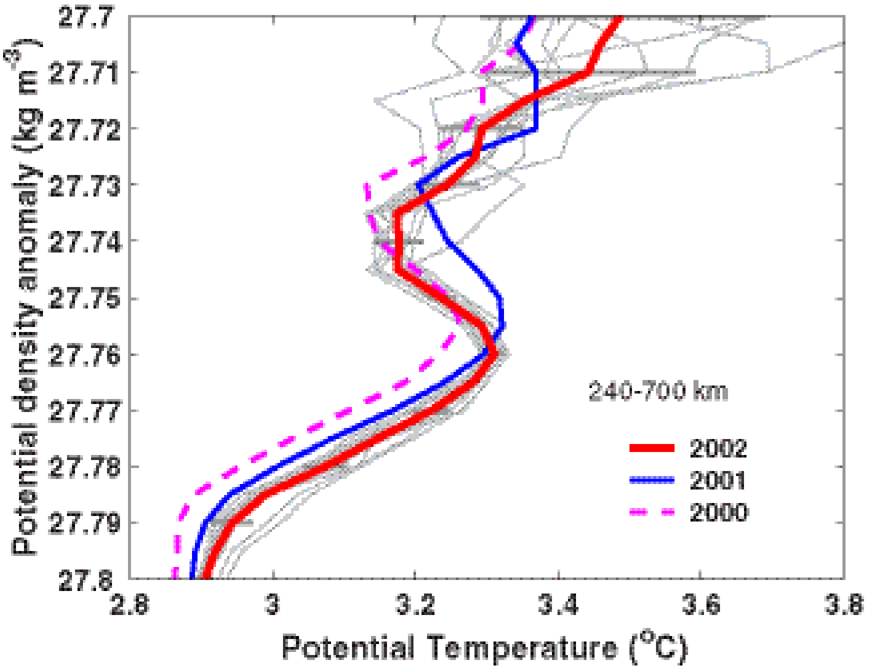

Fig. 13(b) Potential temperature averaged on potential density for distances in the range 240-700km for 2002, 2001, and 2000 using potential density anomaly as the vertical coordinate for potential density anomalies between 27.7 and 27.8 kg m^{-3}. Individual profiles and selected standard deviations for 2002 are plotted in the background.

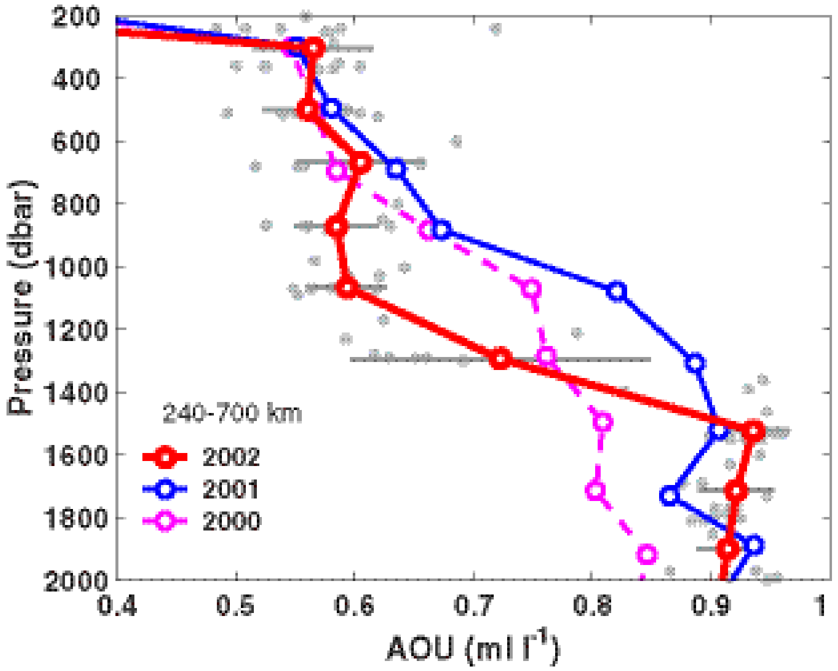

Fig. 14(a) Apparent oxygen utilization (AOU) from discrete bottle values averaged in 200-dbar bins for distances in the range 240-700km using pressure as the vertical coordinate for 2002, 2001, and 2000. Individual values and standard deviations for 2002 are plotted in the background.

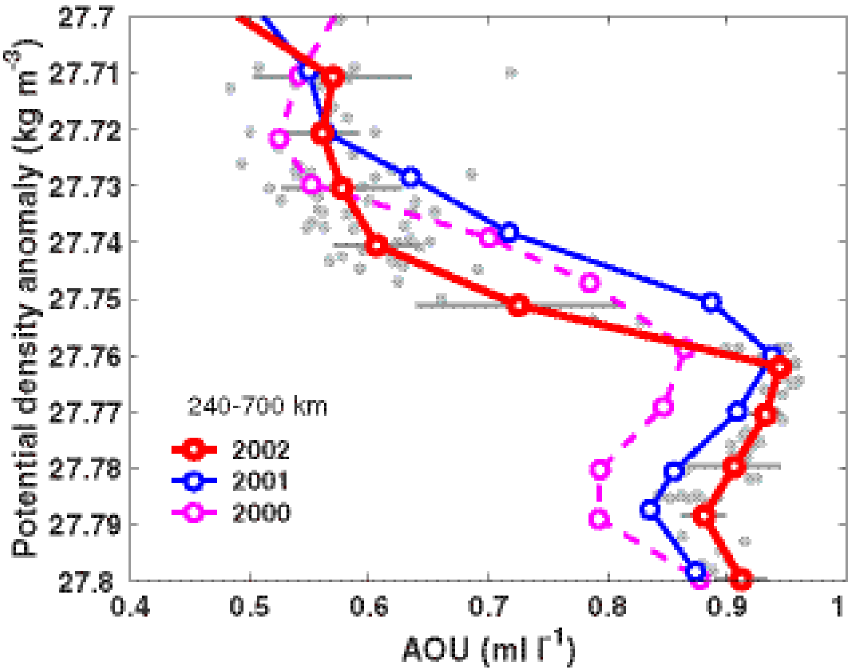

Fig. 14(b) Apparent oxygen utilization (AOU) from discrete bottle values averaged in 0.01 kg m^{-3} potential density bins as a function of potential density anomaly for distances in the range 240-700km for 2002, 2001, and 2000 using potential density anomaly between 27.7 and 27.8 kg m^{-3} as the vertical coordinate. Individual values and standard deviations for 2002 are plotted in the background.

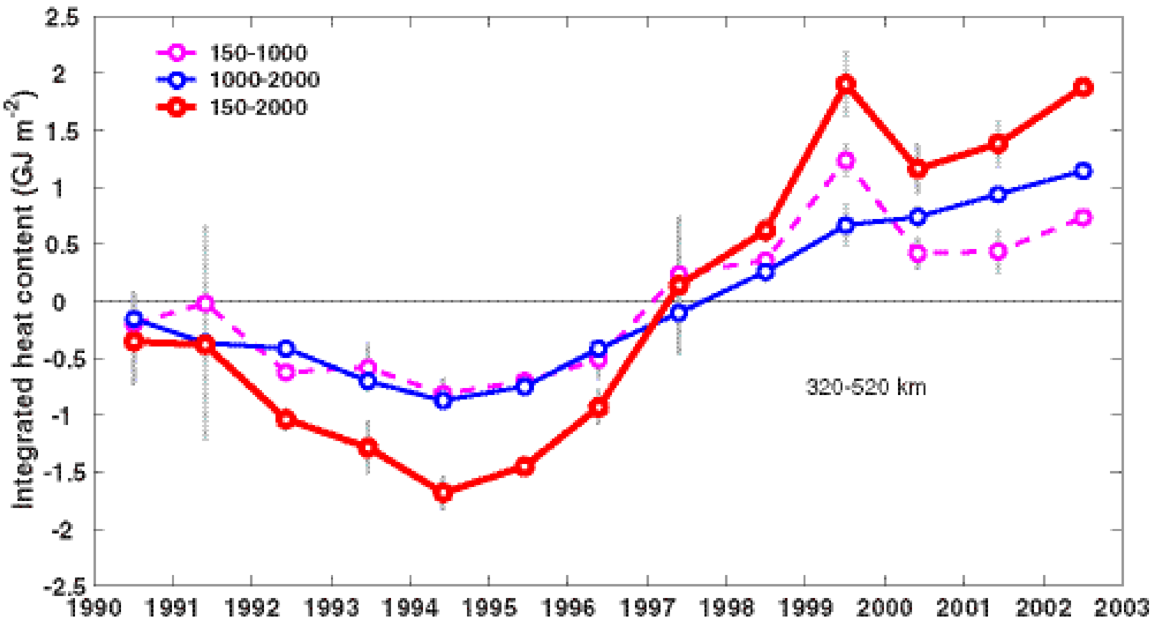

Fig. 15(a) Heat content from spring AR7W occupations averaged over stations in the distance range 320-520km as a function of median station time. Integrals over 150-1000m and 1000-2000m and their sum are shown. The average heat content in the respective depth ranges for the 13 spring occupations has been removed. The error bars are standard deviations.

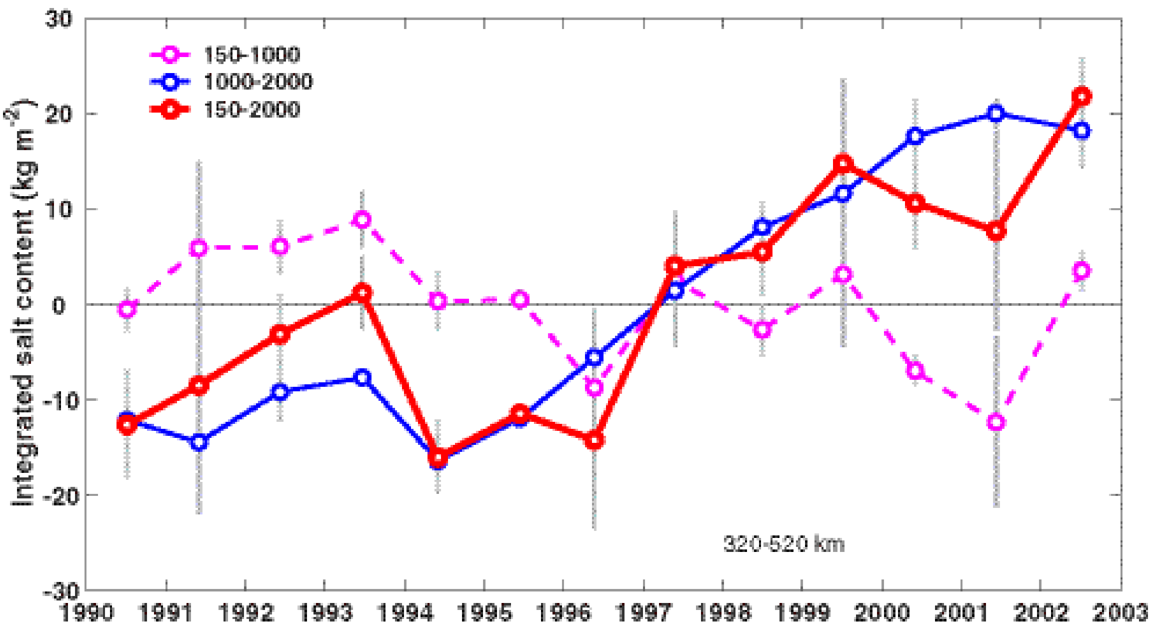

Fig. 15(b) Salt content from spring AR7W occupations averaged over stations in the distance range 320-520km for different depth layers as a function of median station time as in Fig. 16(a).

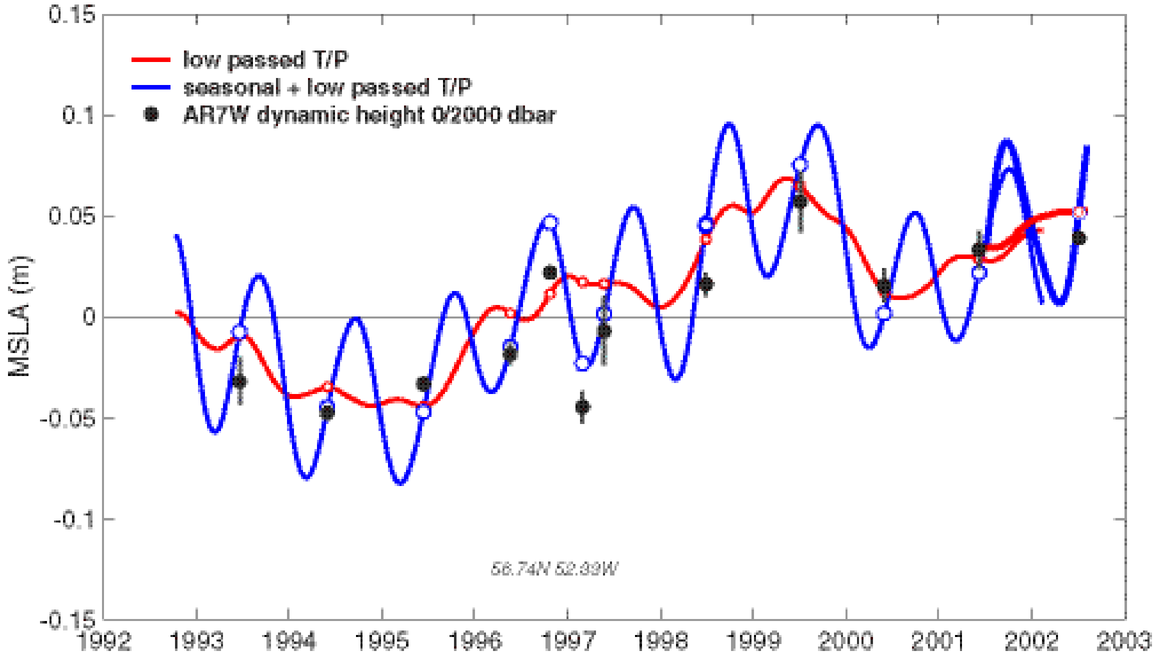

Fig. 16 TOPEX/POSEIDON sea level anomaly near the Bravo mooring site. Low-passed sea-level changes are shown with and without the seasonal cycle. The filled circles show the 0-2000dbar geopotential height from AR7W occupations averaged over stations in the 320-520km distance range, with associated standard deviations. The open circles mark T/P sea level including seasonal changes at the same times. Most of the analysis is based on the AVISO MSLA product. The last, partly overlapping part of the analysis (indicated by slightly heavier lines) is based on crossover time series for Tracks 243 and 098.

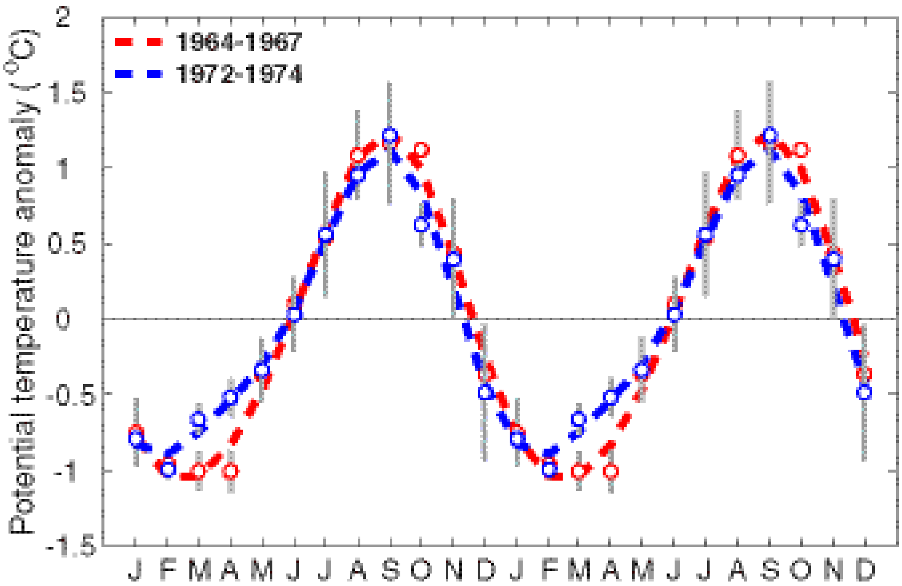

Fig. A1 Annual cycles in 0-150m depth-averaged potential temperature relative to the period means from OWS Bravo for January 1964 - December 1967 and June 1972 - May 1974, repeated for two annual cycles. Means of monthly means (open circles) are plotted against mid-month date. The error bars are standard deviations of the monthly means for the two periods. The dashed curves are least-squares fits of annual and semi-annual harmonics.

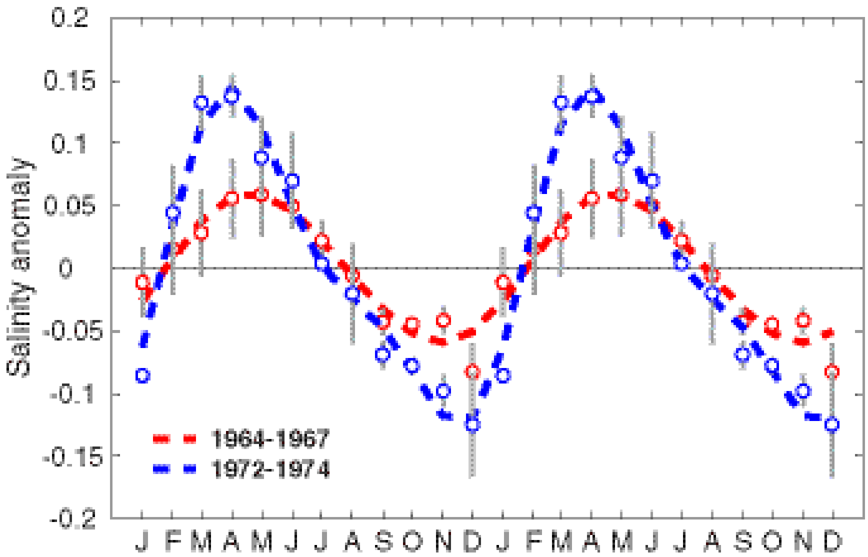

Fig. A2 Annual cycles in 0-150m depth-averaged salinity relative to the period means from OWS Bravo as in Fig. A1.

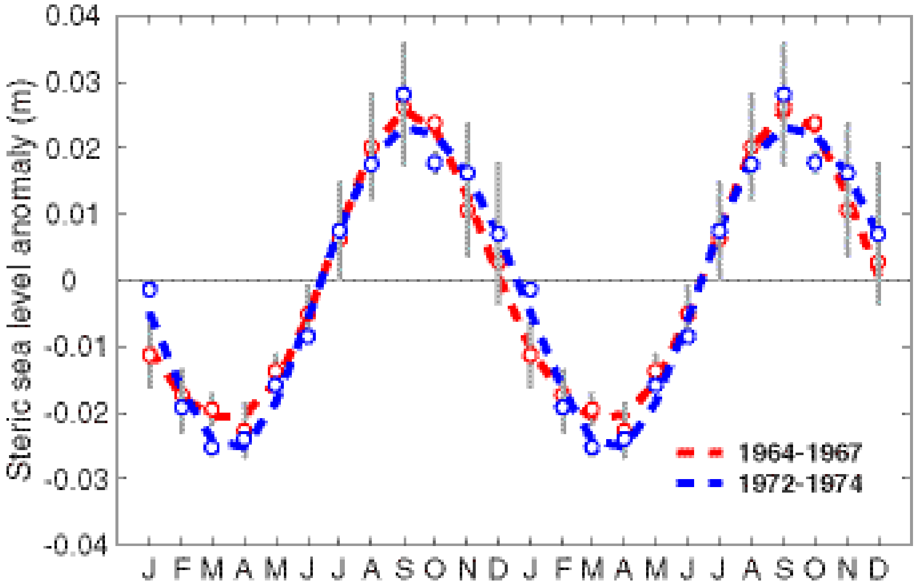

Fig. A3 Annual cycles in 0-150m steric sea level from OWS Bravo as in Fig. A1.

ANNEX I: ENVIRONMENTAL CONDITIONS IN THE NORTHWEST ATLANTIC DURING 2002 (ICES AREA 2)

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Abstract

Meteorological and oceanographic observations from data collected at standard monitoring stations and sections in the Northwest Atlantic during 2002 are presented referenced to their long-term (1971–2000) means. The NAO index for the winter of 2002 was below normal, indicating a reduced Arctic outflow to the Northwest Atlantic resulting in generally warmer than normal air temperatures and reduced ice coverage. The annual water-column averaged temperature at Station 27 for 2002 decreased compared to 2001 values, but remained above the long-term mean over most depth ranges. Water-column averaged summer salinities at Station 27 increased over 2001 values to above normal and to the highest in about 12 years. The cross-sectional areas of <0°C (CIL) water were below normal along all sections from the Grand Bank (Flemish Cap section), to the Seal Island section off southern Labrador. Off Bonavista the CIL area was very similar to 2001, below normal for the 8th consecutive year and among the lowest observed since 1978. In general, over all areas of the Newfoundland Shelf, the near-bottom thermal habitat continued to be warmer than that experienced from the mid-1980s to the mid-1990s. The below-normal trend in water temperature, established in the late 1980s, reached a minimum in 1991, moderated by 1996, reached a maximum in 1999 and has continued above normal up to 2002. Water salinities on the Newfoundland Shelf also reached near-record lows in the early 1990s, remained below normal throughout most of the 1990s and up to 2001, however, during 2002 there was a significant increase with surface values the highest observed in over a decade.

Introduction

Meteorological and oceanographic conditions during 2002 are presented referenced to a standardised base period from 1971–2000 in accordance with the convention of the World Meteorological Organisation. The data were collected by a number of researchers in Canada and compiled into time series for the standard sections and stations (Figures 1 and 2). The meteorological and sea ice data and analysis were provided by K. Drinkwater and I. Peterson at the Bedford Institute of Oceanography in Dartmouth Nova Scotia, Canada.

One of the most widely used and longest oceanographic time series in the Northwest Atlantic is from Station 27, located at latitude 47° 32.8' N and longitude -52° 35.2' W. This monitoring station was first occupied 1946, it is located in the inshore region of the eastern Canadian continental shelf about 8 km off St. John's Harbour Newfoundland (Figure 2), in a water depth of 176 m. The station is occupied on a regular basis mainly by oceanographic and fisheries research vessels at a frequency of about 3–4 times per month on average, with 55 occupations during 2002.

Recognising the usefulness of standard oceanographic indices for monitoring ocean climate variability the Canadian Department of Fisheries and Oceans started occupying a series of cross-shelf hydrographic sections during mid-summer of every year beginning in the late 1940s. In 1976 the International Commission for the Northwest Atlantic Fisheries (ICNAF) adopted a suite of standard oceanographic stations along sections in the Northwest Atlantic from Cape Cod (USA) to Egedesminde (West Greenland) (Anon. 1978). Several of these sections are occupied annually during mid-summer on an oceanographic survey conducted by the Canadian Department of Fisheries and Oceans (Figure 2). In this report the results for the Seal Island section on the Southern Labrador Shelf, the Bonavista section off the east coast of Newfoundland and the Flemish Cap section which crosses the Grand Bank at 47° N are presented for the summer 2002 survey.

Meteorological and sea-ice conditions

Monthly and annual air temperature anomalies for 2002 relative to their 1971–2000 means at four sites in the northwest Atlantic from Nuuk in West Greenland to St. John's Newfoundland are shown in Figure 3. The predominance of warmer-than-normal annual air temperatures at all four sites during 2002 is clearly evident with annual anomalies ranging from a maximum of +0.7°C at Nuuk Greenland to +0.2°C at St. John's Newfoundland. Monthly air temperatures were above normal in 6–8 months of 2002 at these sites. Air temperature however decreased significantly over 2001, with most sites experiencing a decrease of near 1°C. The inter-annual variability in air temperatures since 1960 at Nuuk, Iqaluit, Cartwright, and, to a lesser extent, St. John's, have been dominated by large amplitude fluctuations with minima in the early 1970s, early to mid-1980s and the early 1990s, suggesting a quasi-decadal period. Also note that all sites where data are available, cold conditions (relative to the 1971–2000 mean) existed throughout the late 1800s and early 1990s. Temperatures rose to above normal values between the 1910s and 1950s, the actual timing being site-dependent (Drinkwater *et al.* 2000).

The North Atlantic Oscillation (NAO) Index as defined by Rogers (1984) is the difference in winter (December, January and February) sea level atmospheric pressures between the Azores and Iceland and is a measure of the strength of the winter westerly and north-westerly winds over the Northwest Atlantic. A high NAO index corresponds to an intensification of the Icelandic Low and Azores High, which in most years creates strong north-west winds, cold air and sea temperatures and heavy ice in the Labrador Sea and Newfoundland 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 patterns. The NAO index for 2002 was below normal (by 3 mb) indicating a reduced Arctic outflow to the Northwest Atlantic during the winter months (Figure 4). The spatial extent of the atmospheric sea-level pressure fields during the winter months of 2002 returned to normal, ending the anomalous eastward shift that occurred during 1999 and 2000. These changes in the NAO index fit the pattern of quasi-decadal variability that has persisted since the 1960s.

Information on the location and concentration of sea ice is available from the daily ice charts published by Ice Central of Environment Canada in Ottawa. The time series of the arial extent of sea ice on the Newfoundland and southern Labrador shelves (between 45–55^{o}N) show that the peak extent during 2002 increased slightly over 2001 but remained below average for the 7th consecutive year (Figure 4). The average ice area during both the period of southward advancement (January to March) and northward retreat (April to June) also increased slightly relative to 2001, but again remaining much less than the heavy ice years of the early 1990s (Figure 4). In general, sea ice coverage was lighter-than-average and of a shorter duration than normal during 2002 on the Newfoundland and Labrador Shelves.

Time Trends in Temperature and Salinity at Station 27

Station 27, located in the Avalon Channel off St. John's (Figures 1 and 2), was sampled a total of 55 times (49 CTD profiles, 6 XBT profiles) during 2002. The data from this time series are presented in several ways to highlight seasonal and interannual variations over various parts of the water column. The cold near isothermal water column during the winter months has temperatures ranging from 0^{o} to –1^{o}C. These temperatures persisted throughout the year in the bottom layers. Surface layer temperatures ranged from about –1^{o} to 0^{o}C from January to late-April, after which the surface warming commenced. By mid-May upper layer temperatures had warmed to 2^{o}C and to >12^{o}C by August at the surface, after which the fall cooling commenced. Except for a near surface cold anomaly during the spring these values were about 0.25^{o} to 0.5^{o}C above normal for the winter months over most of the water column. Temperatures at depths from 25–75 m were below normal from July to August and from September to December a significant upper layer negative temperature anomaly developed, which reached to 100 m depth by the end of the year. These values reached 1^{o}C below normal in November and December. Bottom temperatures ranged from 0^{o} to 0.5^{o}C above normal from January to December (Figure 5). Surface salinities reached a maximum of >32.2 by mid-February and decreased to a minimum of <31.2 by September. These values were generally above normal throughout the year in the upper water column, reaching a maximum of about 0.4 above normal during the summer months. In the depth range from 50–100-m, salinities generally ranged from 32.2 to 32.8 and near bottom they varied throughout the year between 32.8 and 33.2. These bottom values were near normal during most of 2002 (Figure 5).

The annual time series of temperature and salinity anomalies generally show three significant colder and fresher-than-normal periods at near decadal time scales since the early 1970s (Figures 6 and 7). At the surface negative temperature anomalies reached a minimum in the early 1990s, began to moderate to near-normal conditions by the summer of 1994 and have continued at normal to above normal up to 2002. Near bottom at 175-m depth, temperatures were generally below normal from 1983 to 1994, the longest continuous period on record. During 1994 and 1995 bottom temperatures started to warm and by 1996 were above the long-term average. Bottom temperatures from 1998 to 2002 have remained above the long-term average, however during 2002 they decreased over 2001 values. Annually, surface temperatures were about normal during 2002, while at the bottom they were either normal or above normal in 8 months of 2002 (Figure 6 right panels).

Near-surface salinity anomalies (Figure 7) show the large fresher-than-normal anomaly that began in early 1991 had moderated to near normal conditions by early 1993 but returned to fresher conditions by the summer of 1995. Salinities approached near normal values during 1996 but decreased to mostly below normal values from 1997 to 2001. In general, during the past several decades cold ocean temperatures and fresher-than-normal salinities, were associated with strong positive NAO index anomalies, colder-than-normal winter air temperatures, heavy ice conditions and larger than average summer cold-intermediate-layer (CIL) areas on the continental shelf (Colbourne *et al.* 1994, Drinkwater 1996). During the past several years (up to 2001) however, salinities have remained below normal during a time period of warm air temperatures and lower than normal ice conditions. During 2002 surface salinities were either normal to above normal for 11 of 12 months, near-bottom however, they were slightly below normal for 6 of 12 months of 2002 (Figure 7 right panels).

The depth averaged (0–175 m) annual temperature and summer salinity anomaly time series at Station 27 are displayed in Figure 8. The temperature time series shows large amplitude fluctuations at near decadal time scales, with cold periods during the early 1970s, mid-1980s and early 1990s. During the time period from 1950 to the late 1960s the heat content of the water column was generally above the long-term mean. It reached a record low during 1991, a near record high during 1996, near normal in 1997 and 1998 and above normal during 1999 to 2001. During 2002 the depth averaged temperature remained slightly above normal (0.2^{o}C) but decreased over 2001 (Figure 8).

The depth averaged (0–50 m) salinity time series (Figure 8) of the July-September values 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 1996 to 2001 summer salinities varied considerably from about normal to below normal. During 2002 salinities increased over 2001 values and were the highest in about 12 years in the upper water column.

Standard Sections

Flemish Cap (47^{o} N)

Near surface temperatures along the Flemish Cap section during the summer of 2002 ranged from 7^{o}-8^{o}C while sub-zero (^{o}C) temperatures were generally found below 60-m depth to the bottom over most of the Grand Bank. The coldest water is normally found in the Avalon Channel and at the edge of the Grand Bank corresponding to the inshore and offshore branches of the Labrador Current (Figure 9). Temperatures were generally above normal over most areas along this section during the summer except for isolated areas near the surface and in the deeper waters of the Flemish Pass. Salinities along the section on the Grand Bank are characterised by generally fresh conditions on the bank (<33), a strong horizontal gradient at the shelf break separating the saltier (>34.5) slope water offshore in the Flemish Pass. Salinity anomalies during 2002 were higher than average in the upper layers and near normal below 50-m depth (Figure 10).

Bonavista

The dominant water mass feature along this section during the summer months is the cold intermediate layer of <0^{o}C water (CIL) which develops during early spring after intense winter cooling. Temperatures along the Bonavista section during the summer of 2002 in the upper water column ranged from 7–8^{o}C. These values were generally above normal (up to 2^{o}C) in the offshore areas and below normal inshore. The offshore area of the Labrador Current appeared warmer-than-normal as did the near bottom areas across most of the eastern Newfoundland Shelf. Intermediate depth waters corresponding to the CIL were colder than normal (Figure 9). Salinities along the Bonavista section generally range from <32.5 near the surface in the inshore region to >34 in the offshore region (Figure 10). Bottom salinities ranged from 32.5 in the inshore regions, to 34.75 at about 325-m depth near the shelf edge. Similar to the Flemish Cap section salinities were generally above normal throughout the section, with the magnitude of the anomalies decreasing with depth. In general, salinities along the Bonavista section increased over values observed in 2001.

Seal Island

The Seal Island section, which crosses Hamilton Bank on the southern Labrador Shelf, was also sampled in July of 2002 (Figure 9). Upper layer temperatures across the shelf in this region ranged from –0.5^{o}C at approximately 50-m depth to between 3^{o}-4^{o}C at the surface. Temperatures below 50-m depth were generally <0^{o}C over most of the shelf, corresponding to the CIL water mass, except near bottom where they range from 0^{o}-1^{o}C due to the influence of warmer slope water. Near the shelf break in Labrador slope water, bottom temperatures increase to 2^{o}-3^{o}C. Temperature anomalies in the surface layer were up to 1^{o}-2^{o}C below normal over most of the shelf, but were up to 2^{o}C above normal offshore of the shelf break. In water generally associated with the CIL, temperatures were above normal by up to 1^{o}C over most of the shelf. Surface salinities along this section ranged from <31 inshore of Hamilton Bank to >34 in the offshore region. Bottom salinities ranged from 32.5 near shore to 34.75 at the edge of the shelf in water depths >400-m. Again, similar to conditions along sections further south, water salinities were saltier-than-normal in most areas over the shelf. Offshore of the shelf break, salinities were near normal at depth and above normal in the upper water column

Cold Intermediate Layer (CIL) Time Series

As shown above in the cross-shelf contour plots, the vertical temperature structure on the Newfoundland Continental Shelf during late spring through to the fall is dominated by a layer of cold <0°C water trapped between the seasonally heated upper layer and warmer slope water near the bottom. This water mass is commonly referred to as the cold intermediate layer or CIL (Petrie *et al.* 1988). The cold, relatively fresh, shelf water is separated from the warmer saltier water of the continental slope by a frontal region denoted by a strong horizontal temperature and salinity gradient near the edge of the continental shelf. The spatial extend of this winter chilled water mass is evident in the section plots of the temperature contours, for example along the Seal Island section (Figure 9) the CIL extends offshore to over 200 km, with a maximum vertical extent of approximately 150 m. This corresponds to a cross-sectional area of around 25 km^2. The annual summer CIL cross-sectional area anomalies defined by the 0°C contour for the Flemish Cap, Bonavista and Seal Island sections are displayed in Figure 11. Along the Flemish Cap section during the summer of 2002 the CIL area was below the 1971–2000 normal, similar to conditions observed during the past 4-years but a slight decrease over 2001. Along the Bonavista section the CIL area was similar to 2001, among the lowest values observed since 1978, continuing the trend of below normal values observed since 1994. Similarly, along the Seal Island section the area of <0°C water decreased over 2001, continuing the below normal trend establish during the mid-1990s. This is in contrast to the near record high values measured during the early 1990s, which was an extremely cold time period on the Newfoundland Shelf.

Geostrophic Circulation and Transport

Temperature and salinity data were used to compute geostrophic currents relative to 300 m along several sections sampled during the summer of 2002 (Figure 12). The geostrophic component of the speed of the southward flowing Labrador Current along these sections generally show distinct inshore and offshore branches. The inshore branch is weaker than the shelf-slope branch and is usually restricted to the inshore troughs within approximately 50–100 km of the coast. Typical current speeds in these regions range from 0.05–0.10 m/s, although some estimates were up to 0.2 m/s along the Seal Island section during 2002. The offshore branch is located at the shelf break in water depths generally greater than 400 m. The offshore distance and the width of the current vary according to the underlying topography. Along the Seal Island section, for example, the core of the offshore branch is about 100 km wide, centred at about 200 km offshore over the 400-m isobath, while further north, on the mid-Labrador Shelf, the width of the current is approximately 50 km centred at about 125 km offshore. In the offshore branch, typical speeds range from 0.05 m/s at 175-m depth to >0.2 m/s in the upper water column. At mid-shelf currents are weak and sometimes reverse direction, with clockwise circulation on Hamilton Bank, for example, current speeds in these areas are less that 0.05 m/s. In general, geostrophic currents along the Labrador Shelf (Seal Island section) appear stronger than those on the eastern Newfoundland Shelf (Bonavista section) with speeds over 0.25 m/s offshore from Hamilton Bank for example (Figure 12).

The historical (1952–2002) summer (July-August) temperature and salinity data along the Seal Island, Bonavista and Flemish Cap sections were used to compute a time series of geostrophic transports. The volume transport was calculated by integrating the speed both vertically through the water column and horizontally through the offshore branch of the current. A common reference level of 135-m was chosen for these calculations since this was the deepest level common to all three sections that did not intersect the bottom, thus eliminating potential problems associated with a bottom reference level. Also, the main interest was to examine variations in volume transport during recent ocean climate changes on the continental shelf. Short-term climate changes generally result in variations in upper layer shelf stratification due mainly to salinity changes resulting from increased ice formation and melt. This determines in part, the magnitude of the shelf-slope density front and hence the strength of the geostrophic component of the Labrador Current. The time series of volume transport of the offshore branch of the Labrador Current for the three sections (Figure 12, right panels) show large inter-annual variations with an average transport of between 0.4–0.5 Sv (1 Sv = 10^6 m^3/s) to the south, relative to 135 m. In general, the time series indicate higher than average transport during the late 1950s and into the 1960s, lower than average values during the cold period of the early 1970s and to a lesser extent during the cold period of the mid-1980s. During the late 1980s the transport increased to above average values, which for the most part continued into the mid-to-late 1990s. Except for the Bonavista section, the transport in the offshore branch of the Labrador Current during 2002 increased slightly over the 2001 values.

Summary

The NAO index for the winter of 2002 was below normal, indicating a reduced Arctic outflow to the Northwest Atlantic resulting in generally warmer than normal air temperatures and reduced ice coverage on the Newfoundland Shelf. Air temperatures however, were lower than those reported during the past several years and the ice extent increased marginally over 2001. The annual water-column averaged temperature at Station 27 for 2002 decreased compared to 2001 values, but remained above the long-term mean over most depth ranges. The annual surface temperature at Station 27 was about normal during 2002, while the annual bottom temperature remained above normal by 0.2°C. Water-column averaged summer salinities at Station 27 increased over 2001 values to above normal and to the highest in about 12 years. Surface salinities at Station 27 were above normal for 11 of 12 months, while bottom salinities were either near normal or slightly below normal.

The cross-sectional area of <0°C (CIL) water on the Newfoundland and Labrador Shelves during the summer of 2002 decreased over 2001 values along northern sections and along southern sections it remained very similar to 2001. The CIL areas were below normal from the Flemish Cap section on the Grand Bank to the Seal Island section off southern Labrador. Off eastern Newfoundland along the Bonavista section the CIL area was very similar to 2001, below normal for the eighth consecutive year. These values are among the lowest observed since 1978 on the eastern Newfoundland Shelf. In general, over all areas of the Newfoundland Shelf, the near-bottom thermal habitat continued to be warmer than that experienced from the mid-1980s to the mid-1990s.

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

Acknowledgements

I thank C. Fitzpatrick, D. Senciall, P. Stead, J. Craig, C. Bromley and W. Bailey of the oceanography section at NAFC for data collection and quality control. I also thank the many scientists and technicians at the Northwest Atlantic Centre (NAFC) for collecting and providing much of the data contained in this analysis and to the Marine Environmental Data Service in Ottawa for providing most of the historical data. I also thank the captain and crew of the CCGS Teleost for three successful oceanographic surveys during 2002.

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Figure 1. Northwest Atlantic showing coastal air temperature monitoring stations.

Figure 2. Location map showing general circulation features of the Northwest Atlantic, the location of Station 27 and the locations of standard monitoring sections on the Newfoundland and Labrador Shelf.

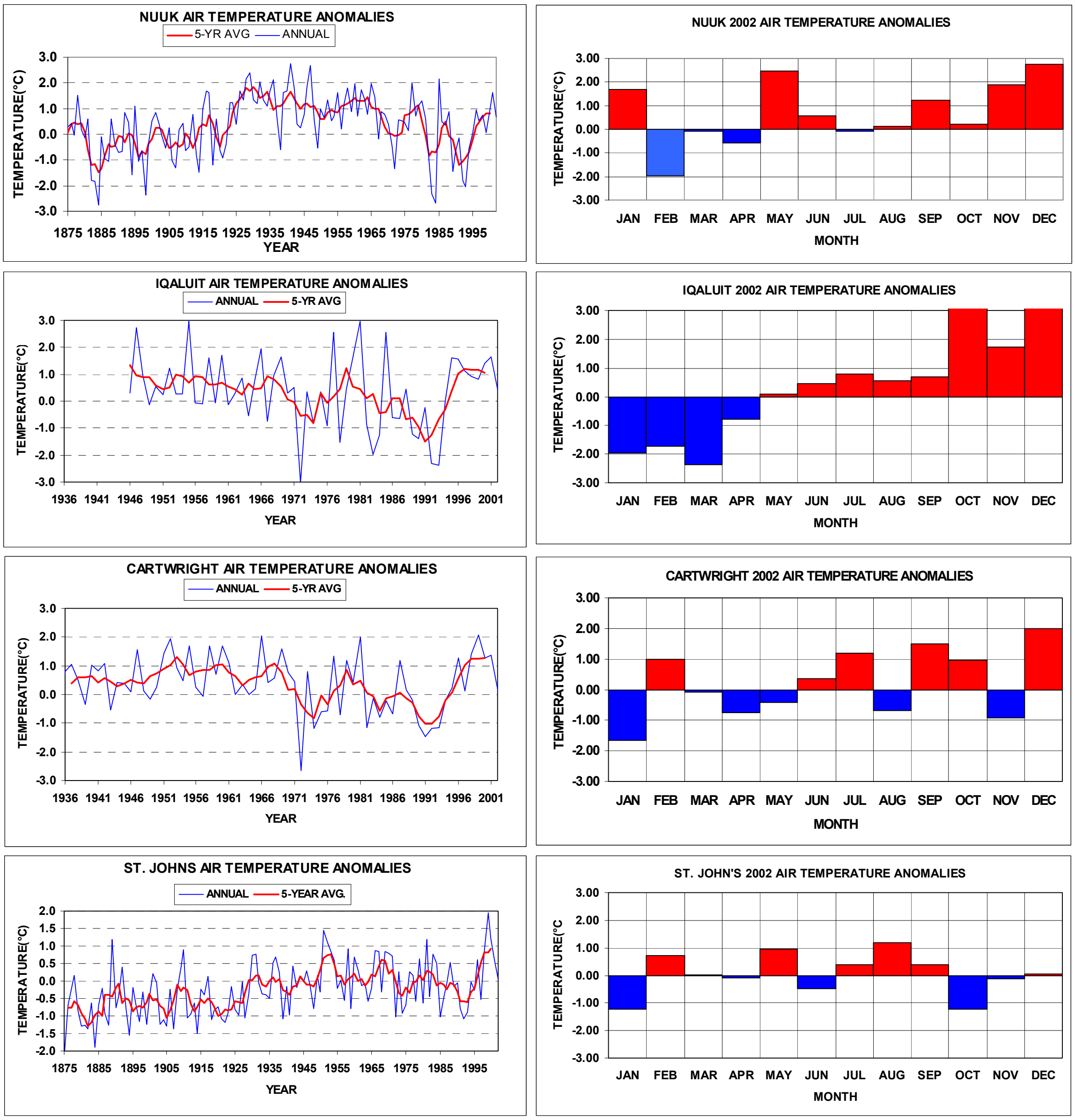

Figure 3. Annual and monthly air temperature anomalies in 2002 at selected coastal sites (see Figure 1 for locations). The anomalies are referenced to their 1971–2000 means.

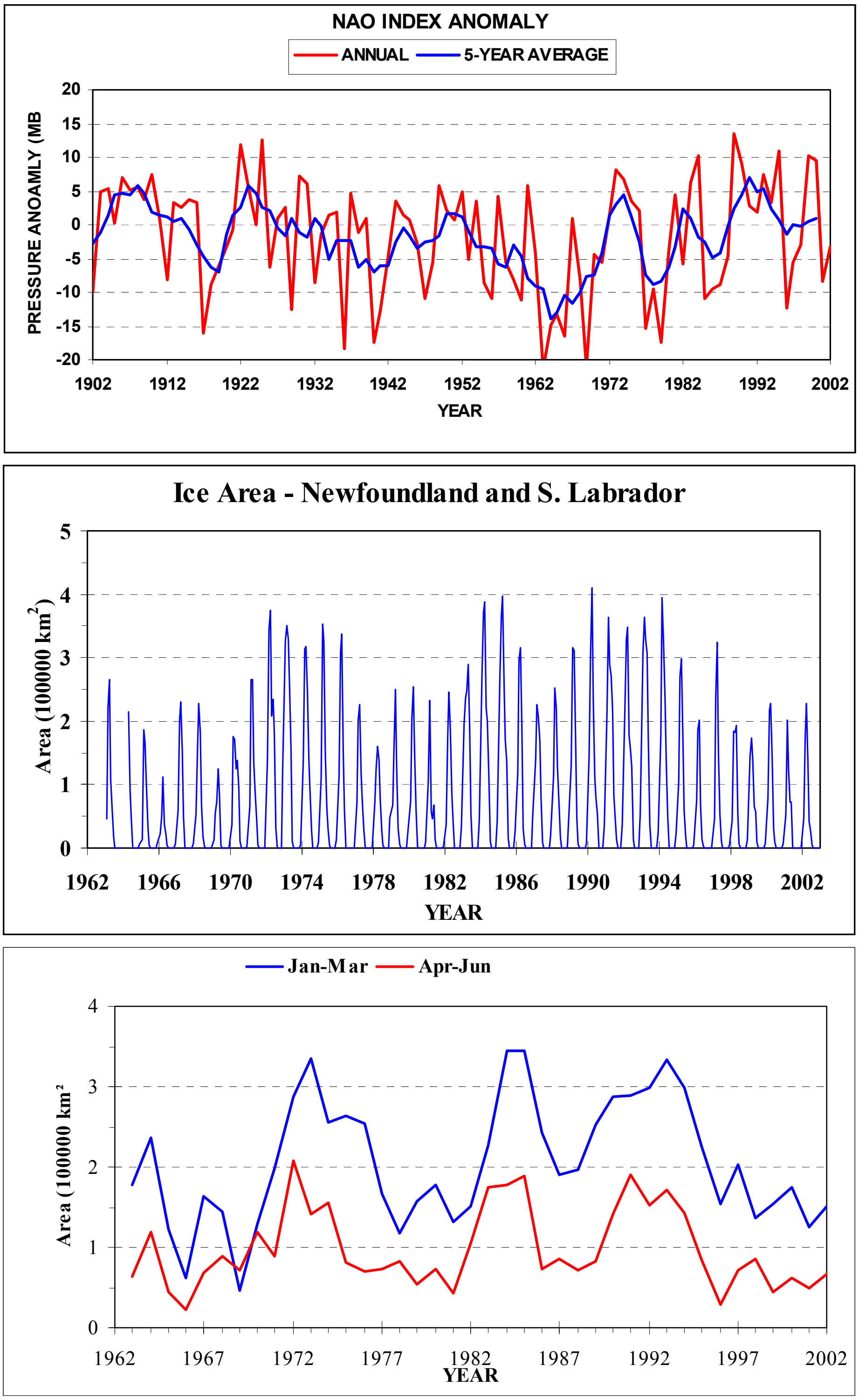

Figure 4. Anomalies of the North Atlantic Oscillation Index relative to the 1971–2000 mean (top panel), monthly mean ice areas off Newfoundland and Labrador between 45°N- 55°N (centre panel) and the average ice area during the normal periods of advancement (January-March) and retreat (April-June) (bottom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

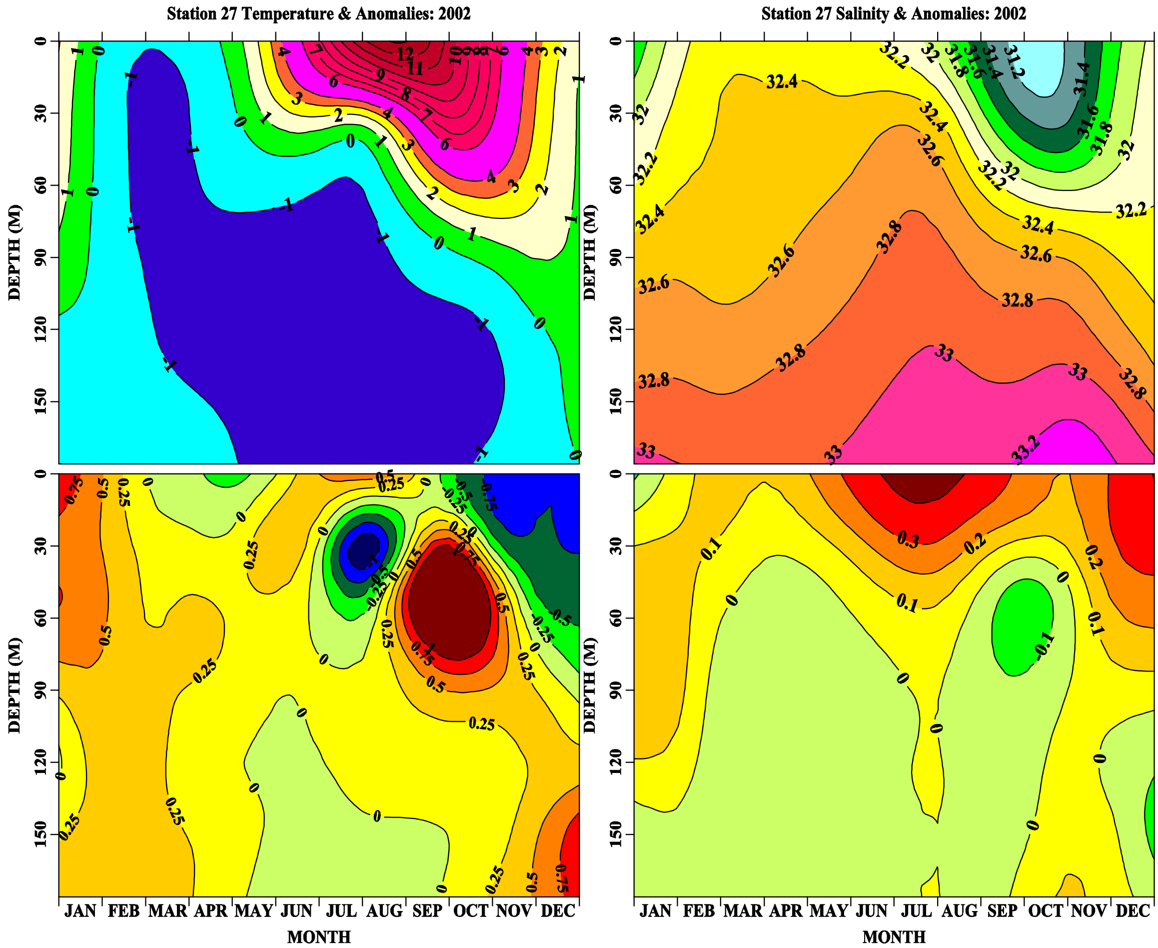

Figure 5. Contours of the annual cycle of temperature and temperature anomalies (in °C) (left panels) and salinity and salinity anomalies (right panels) as a function of depth at Station 27 for 2002.

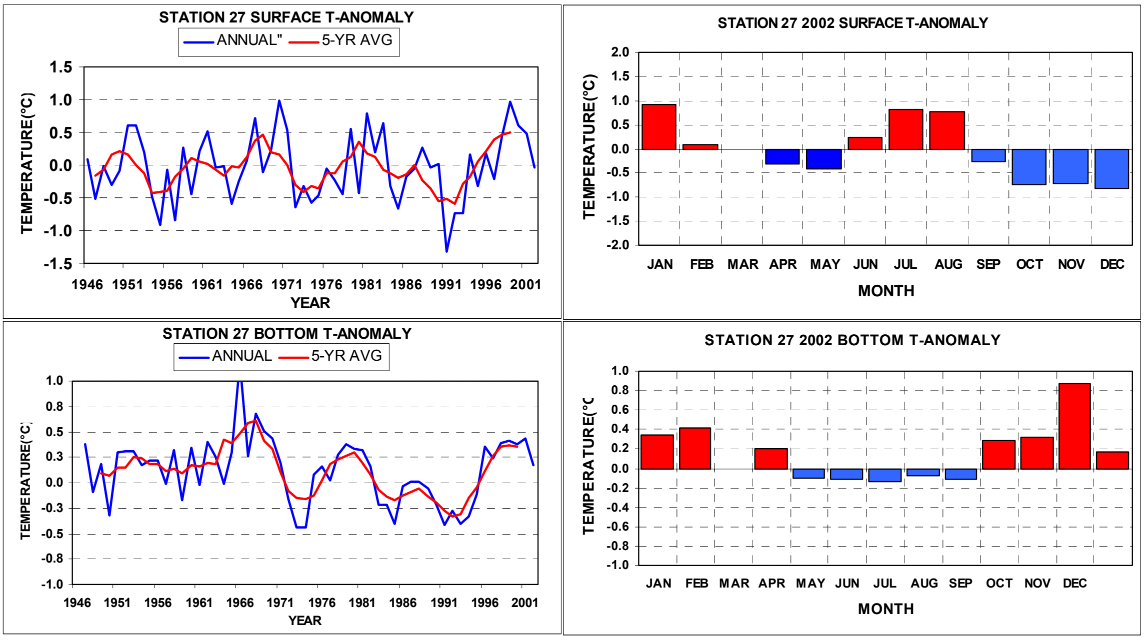

Figure 6. Monthly surface and bottom temperature anomalies at Station 27 during 2002 (right panels) and their annual anomalies with 5-year running means (left panels).

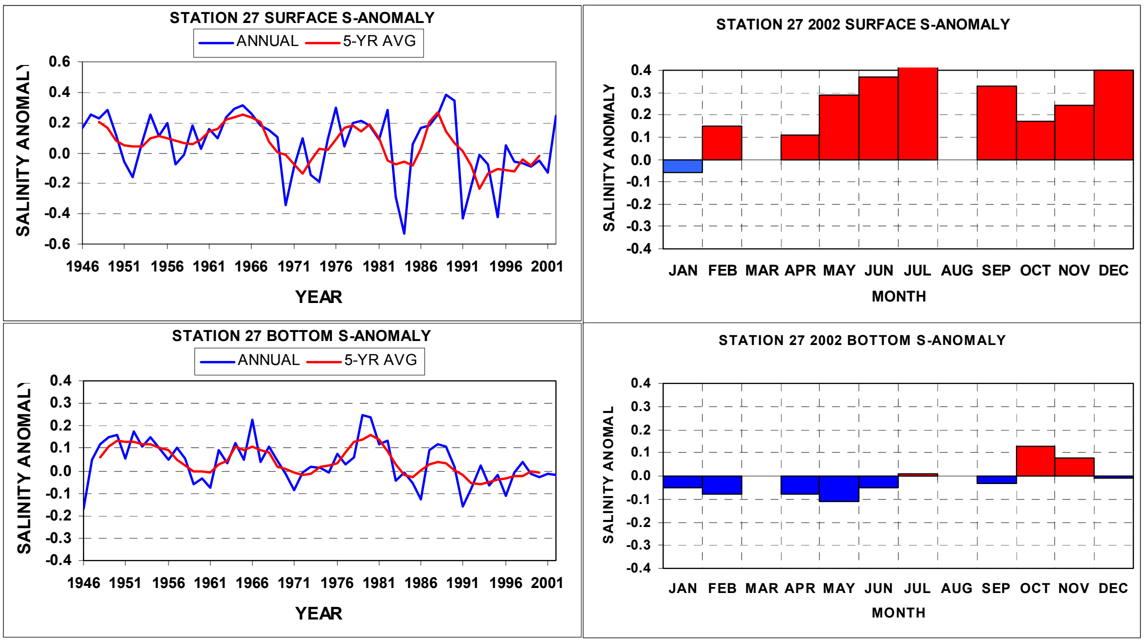

Figure 7. Monthly surface and bottom salinity anomalies at Station 27 during 2002 (right panels) and their annual anomalies with 5-year running means (left panels).

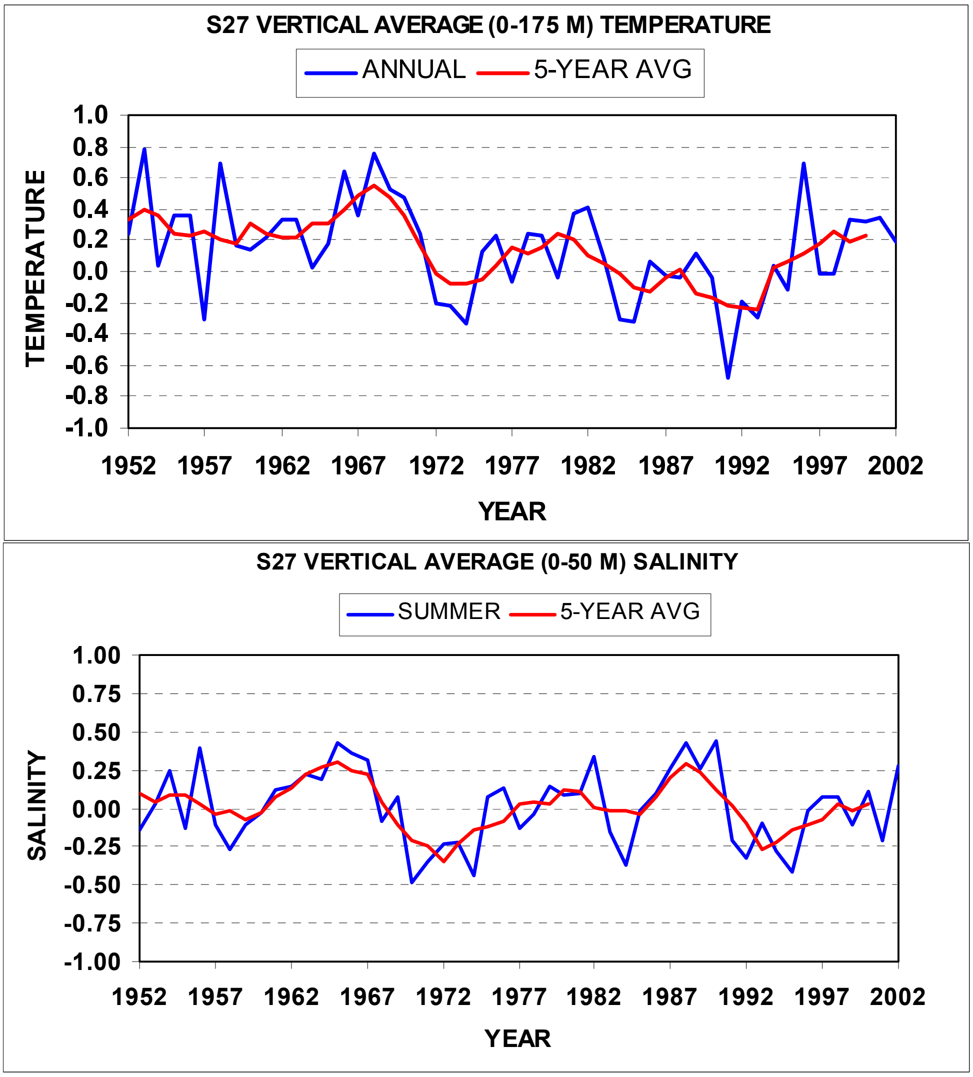

Figure 8. The annual vertically averaged (0–176 m) Station 27 temperature anomalies and the vertically averaged (0–50 m) summer (July-Sept.) salinity anomalies.

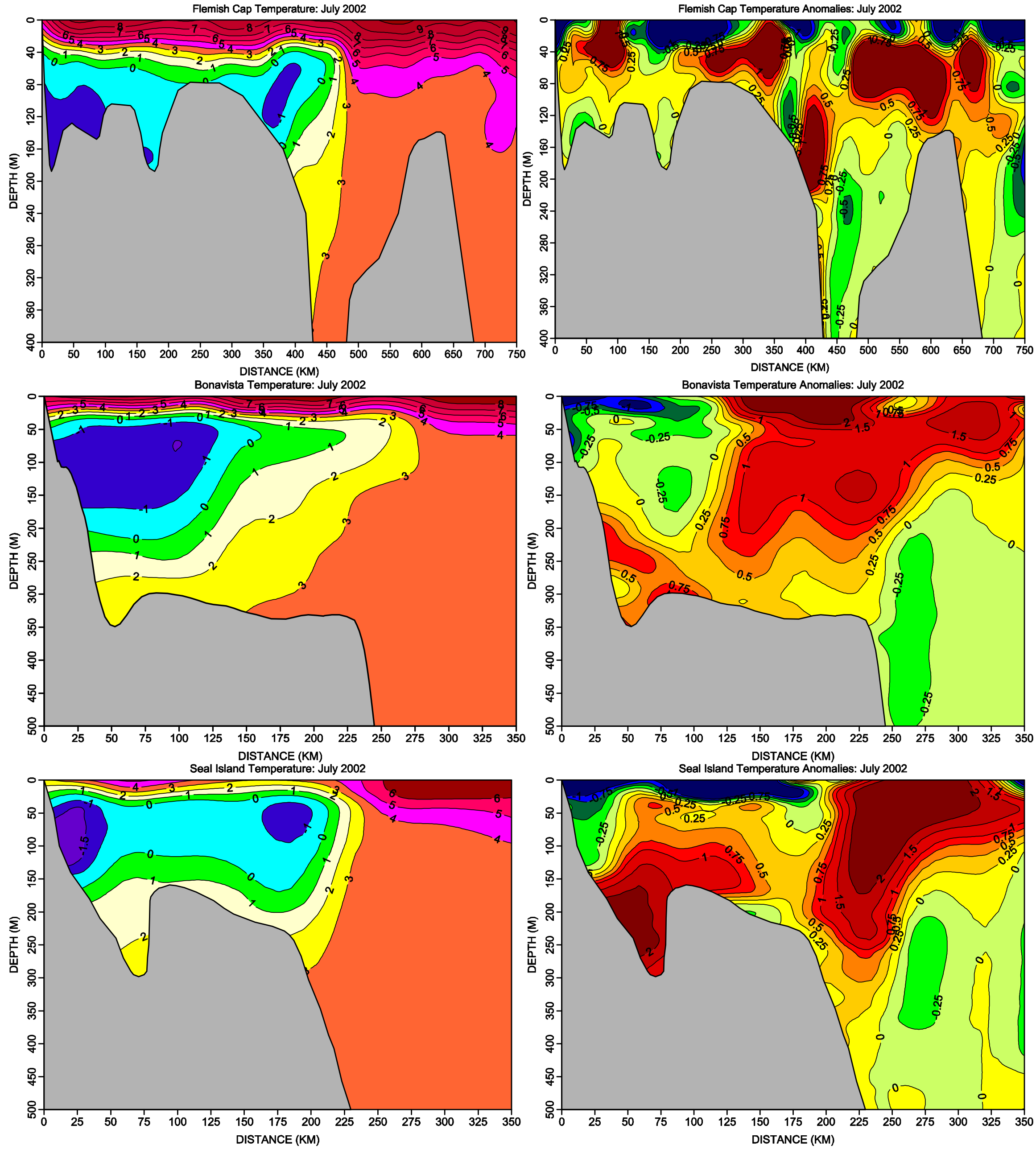

Figure 9. Contours of temperature and temperature anomalies (in °C) along the Flemish Cap, Bonavista and Seal Island sections (Figure 2) during the summer of 2002.

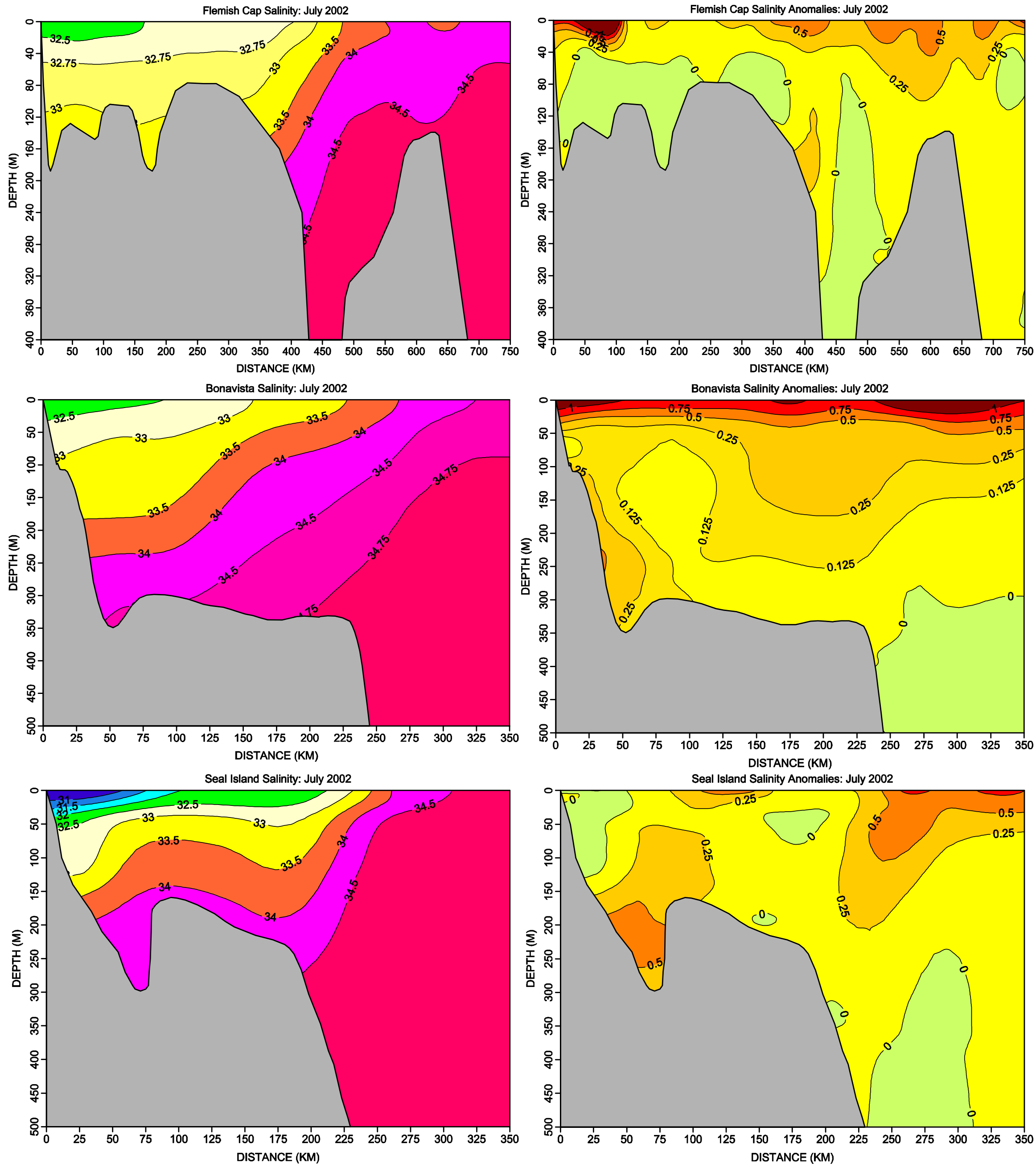

Figure 10. Contours of salinity and salinity anomalies along the Flemish Cap, Bonavista and Seal Island sections during the summer of 2002.

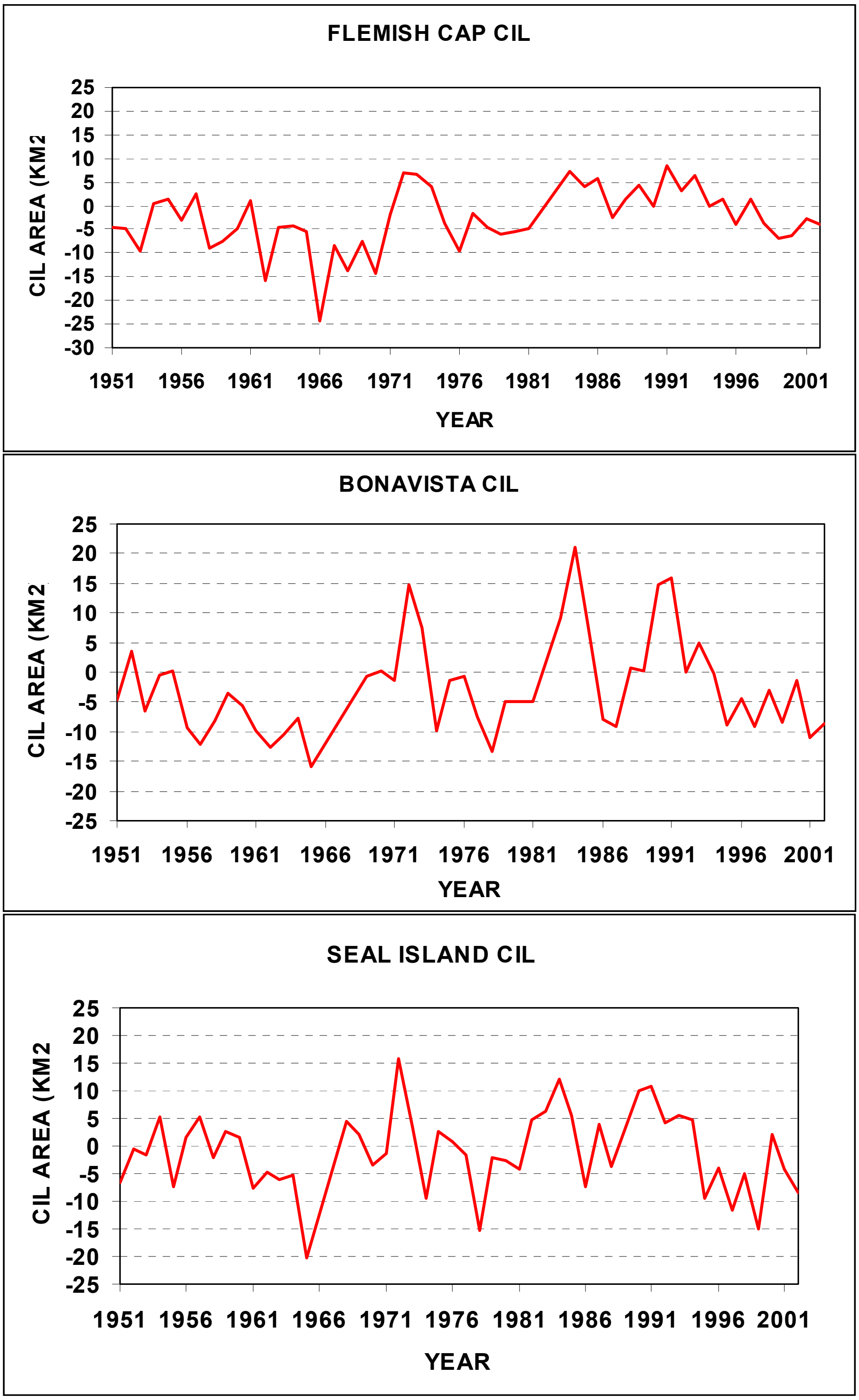

Figure 11.Annual summer CIL cross-sectional area anomalies along the Flemish Cap, Bonavista and Seal Island sections. The anomalies are references to the 1971–2000 means.

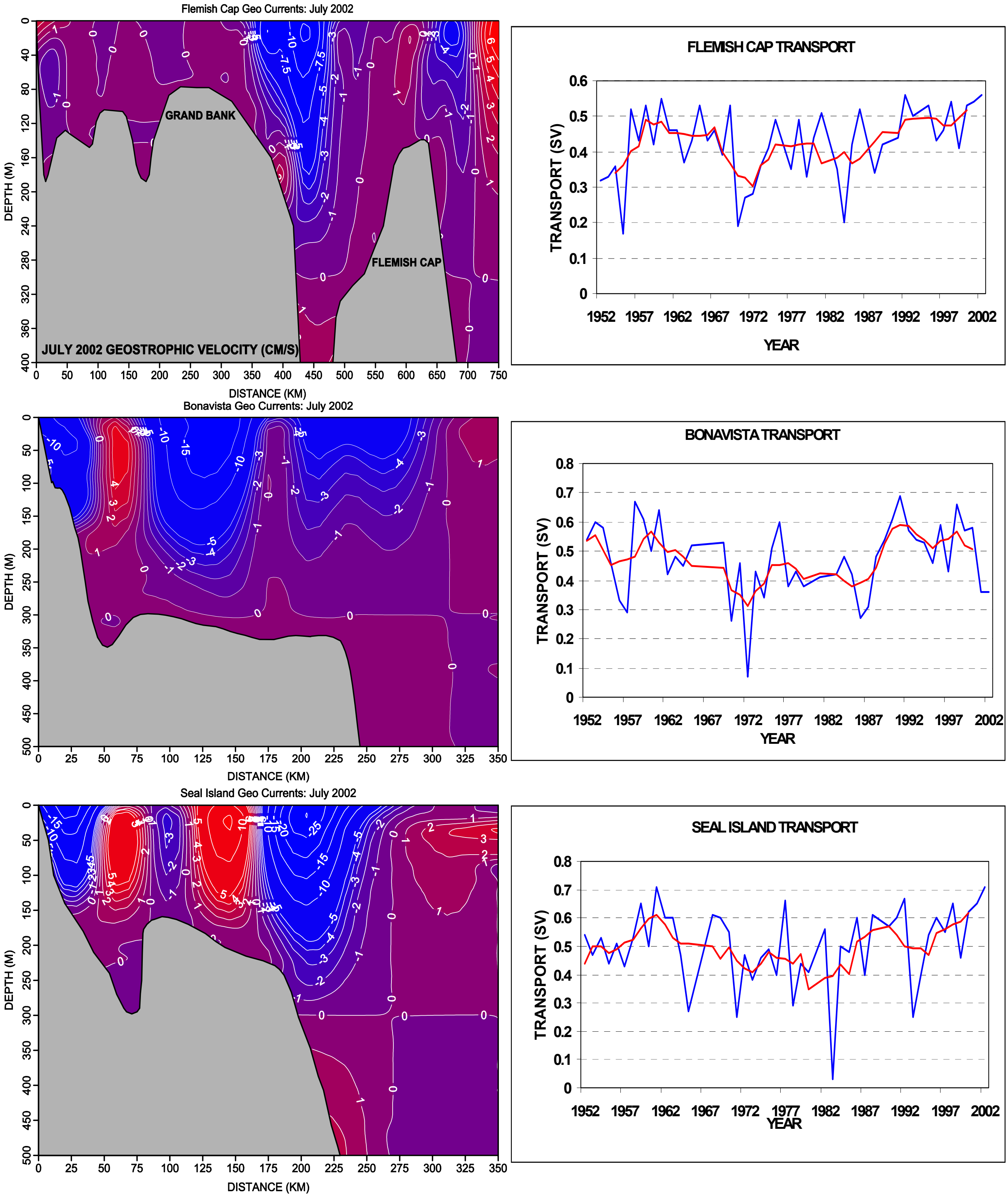

Figure 12. Contours of geostrophic currents (in cm/s) along sections on the Newfoundland and Labrador Shelf (Figure 2) during the summer of 2002 (left panels) and annual estimates of geostrophic transport (10^6 m^3/s) relative to 130-m depth of the offshore branch of the Labrador Current.

ANNEX J: AREA 3: ICELANDIC WATERS

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

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

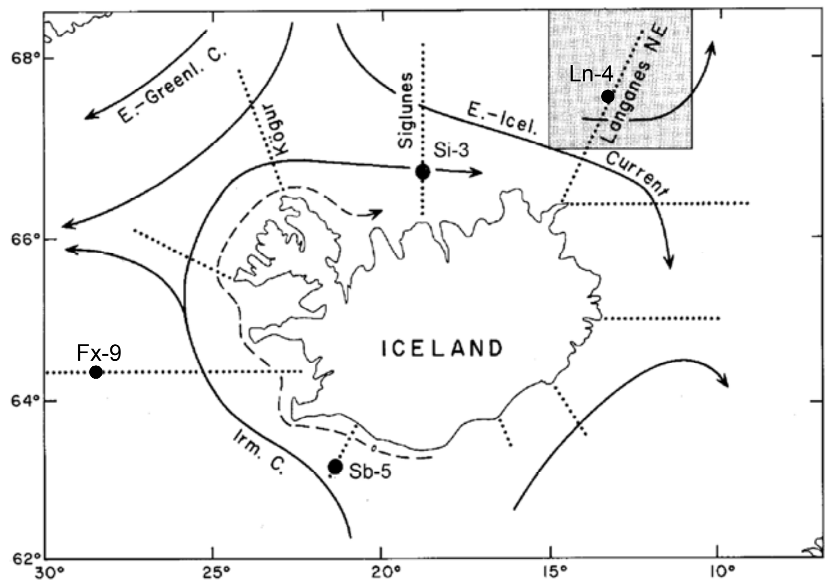


Figure 1. Main currents and location of standard hydro-biological sections in Icelandic waters. Selected areas and stations dealt with in this report are indicated.

Hydrographic conditions in Icelandic waters are generally reflected in the atmospheric or climatic conditions in and over the country and the surrounding seas, mainly through the Icelandic Low and the Greenland High (Figure 2). These conditions in the atmosphere and the surrounding seas have impact on biological conditions, expressed through the food chain in the waters including recruitment and abundance of commercial fish stocks.

The hydrographic conditions in 2002 revealed winter and spring values on the shelf north, northeast and east of Iceland (Figures 2, 3b and 4) below long-term mean for both temperature and salinity. Summer and autumn values in this area were about average and higher.

The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years (Figures 3.a and 5), though slightly lower than the peak values in 1998.

The cold water north, north-east and east of Iceland in the East Icelandic Current was in 2002, especially in winter to autumn, closer to shore than in 1999 to 2001 when it was relatively far offshore. The temperature and salinity in the East Icelandic Current in 2002 were lower than in 2001 (Figures 3 and 5). These mild conditions in Icelandic waters in 1999–2001 (Figure 6) followed extremely cold conditions in 1995, improving in 1996 and 1997, and continued to do so in 1998 and 1999, but showed a slight decrease in 2000. Observations in February 2003 revealed continuous relatively high temperatures and salinities in the warm water south of Iceland (S > 35.15) and values in the north- and northeastern area were lower and similar to what was observed in 1997 and salinities of the surface layers were below the critical 34.7.

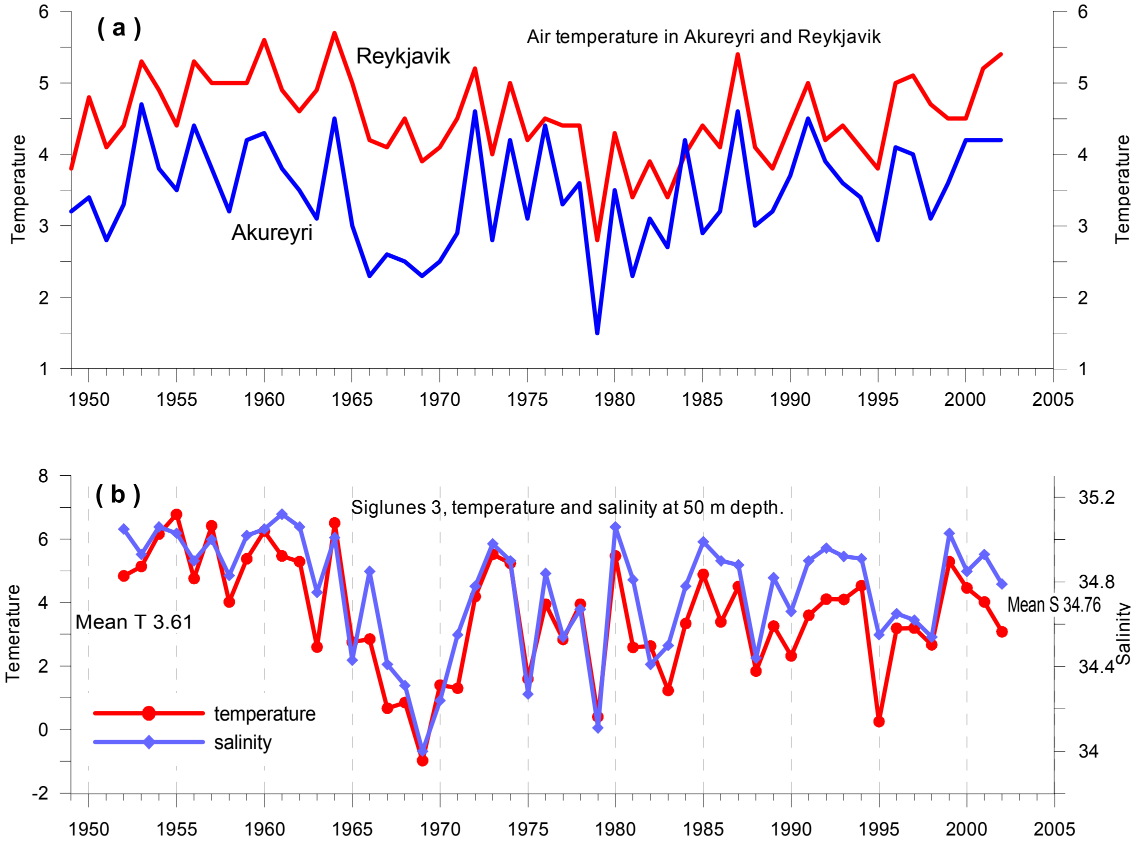


Figure 2

a) Mean annual air-temperatures in Reykjavík and Akureyri 1950–2002

b) Temperature and salinity at 50 m depth in spring at Station Si-3 in North Icelandic waters 1952–2002

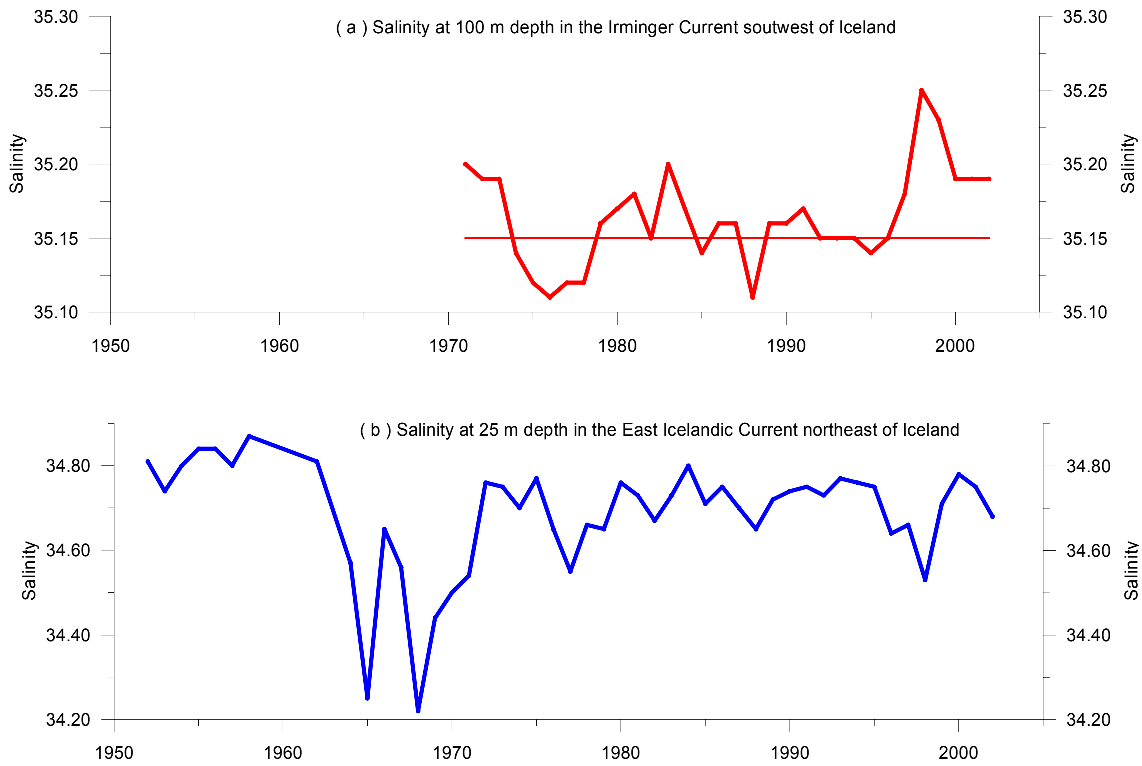


Figure 3. Salinity in spring at:

a) 100 m depth in the Irminger Current south of Iceland (Sb-5) 1971–2002.

b) 25 m depth in the East Icelandic Current north-east of Iceland 1952–2002, mean from shaded area in figure 1.

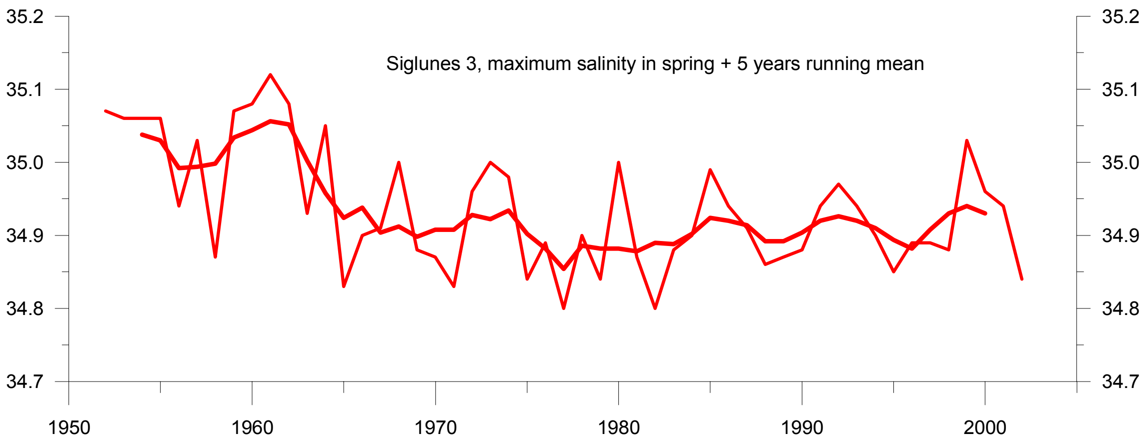


Figure 4. Maximum salinity in the upper 300 m in spring at station Si-3 in North Icelandic waters 1952–2002 and 5 years running mean.

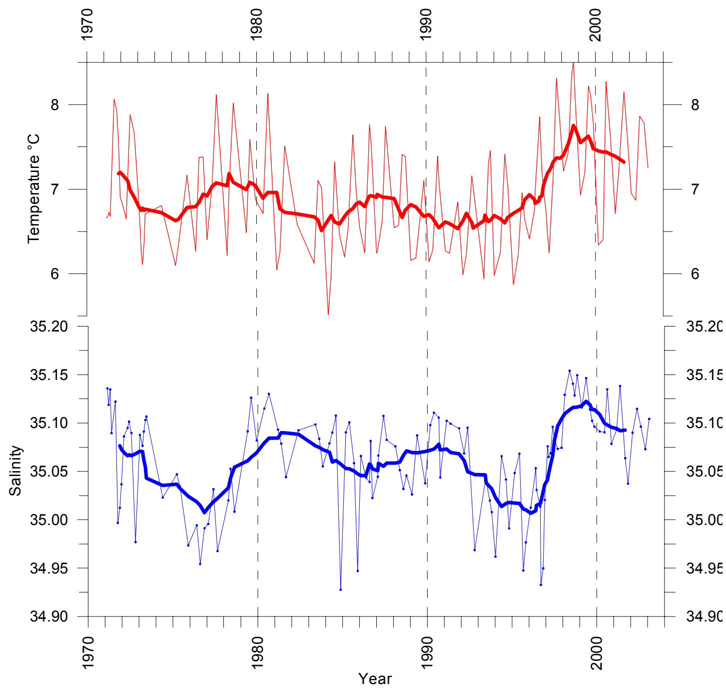


Figure 5. Mean temperature 0–200 m at the shelf brake west of Iceland. Combined data from stations RE8 and FX9, 20 nm apart. Thick line is approx. 3 yrs running mean.

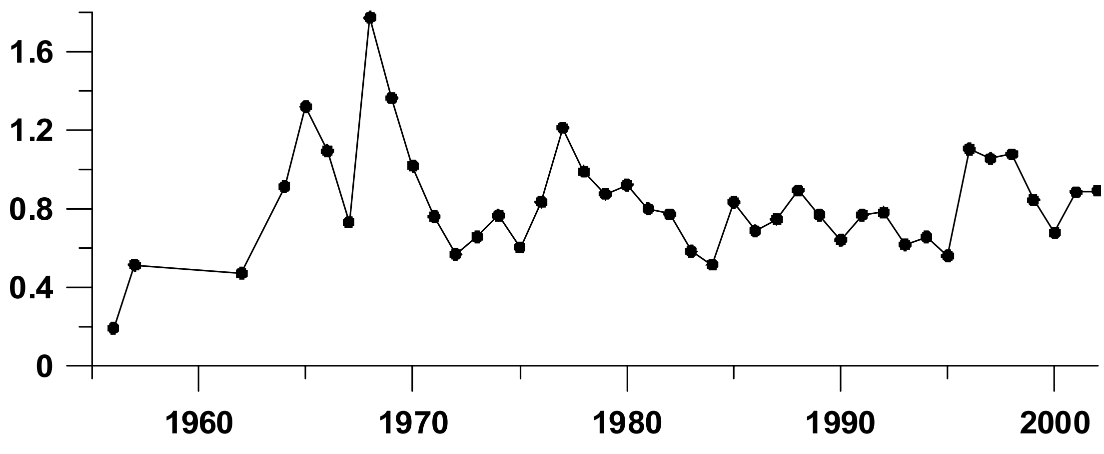


Figure 6. The fresh water thickness at Langanes NE 4 above 150 m, relative to salinity of 34.93 in May/June 1956–2002.

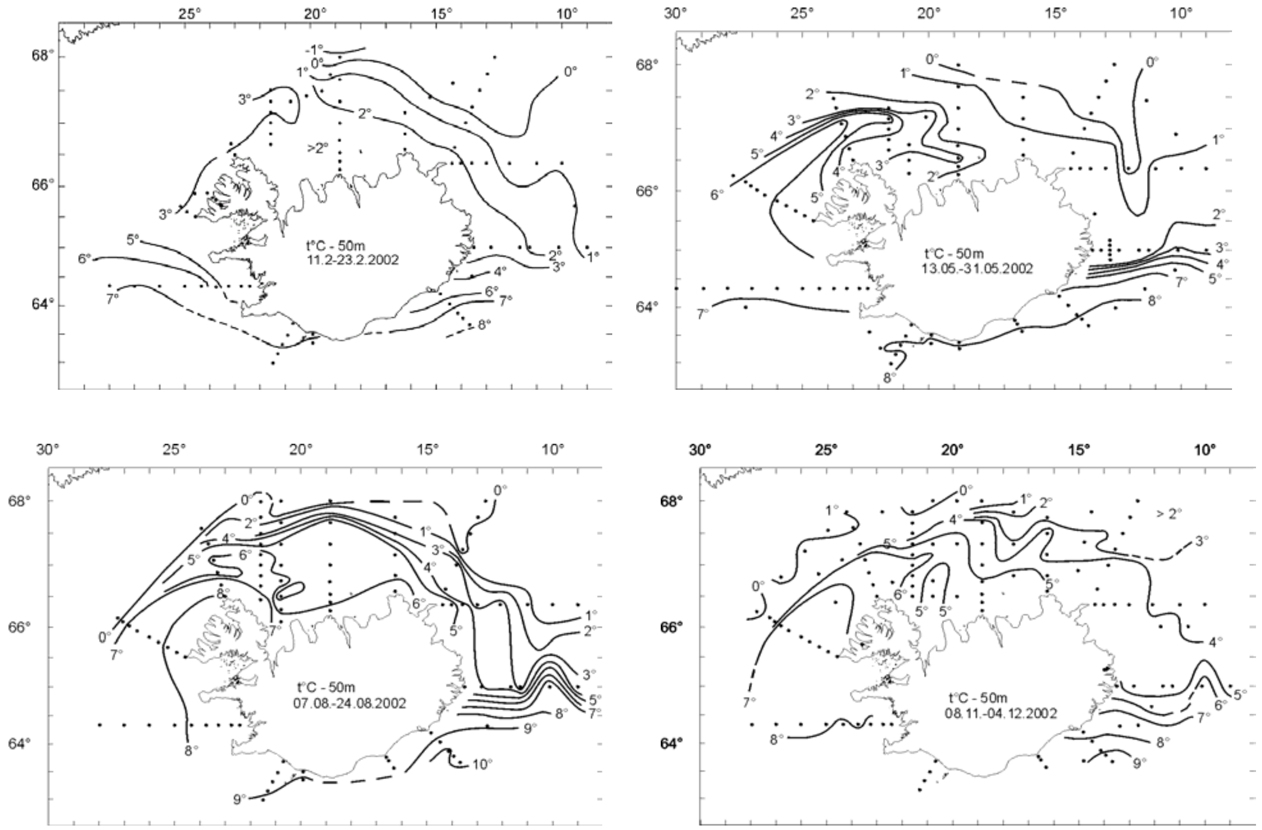


Figure 7. Temperature at 50 m depth in Icelandic waters in February, May, August and November/December 2002.

ANNEX K: HYDROGRAPHIC STATUS REPORT 2003: SPANISH STANDARD SECTIONS (AREA 4).

A.Lavín, C. González-Pola and J. M. Cabanas

Spanish Institute of Oceanography (IEO), Spain.

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), La Coruña (43.40ºN, 8.3ºW) and Vigo (42.1ºN, 9.0ºW). (Figure 1).

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

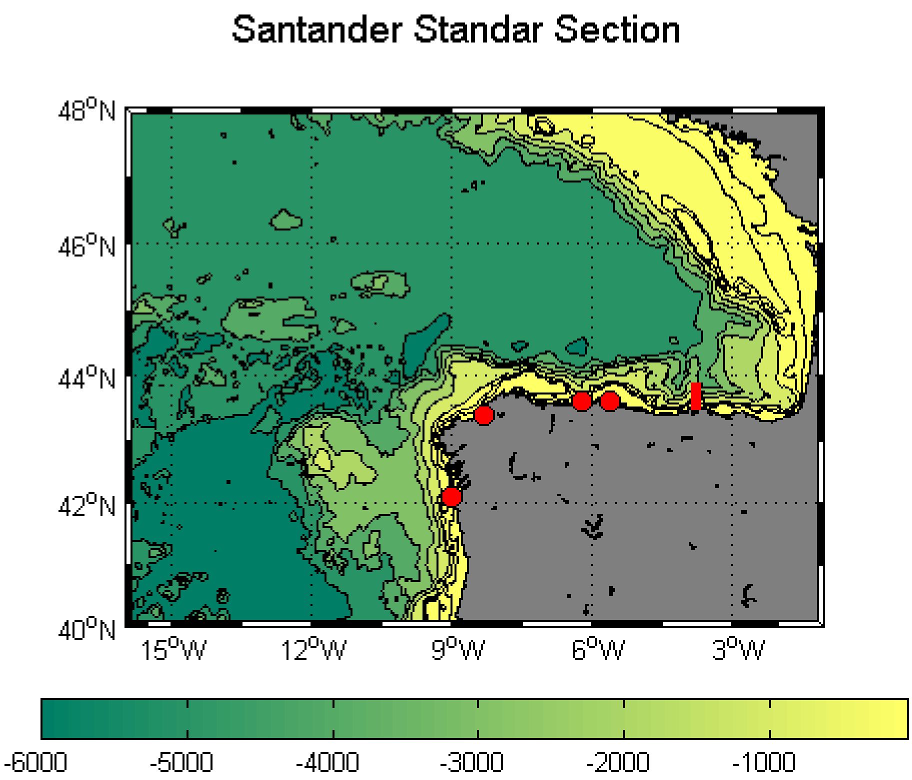


Figure 1. Spanish Standard Sections from the 'Instituto Español de Oceanografía'

Meteorological Conditions

Meteorological conditions in the north of the Iberian Peninsula in 2002 (source: Centro Meteorológico Zonal de Cantabria y Asturias, Instituto Nacional de Meteorología) are similar to those from 1998 to 2001. The annual mean air temperature over the southern Bay of Biscay during 2002 has remained at nearly the same value as during the four preceding years, around 14.9°C, 0.5ºC over the 1961–2002 average. Figure 2 shows the plot of the de-seasoned running mean temperature within annual means and total average.

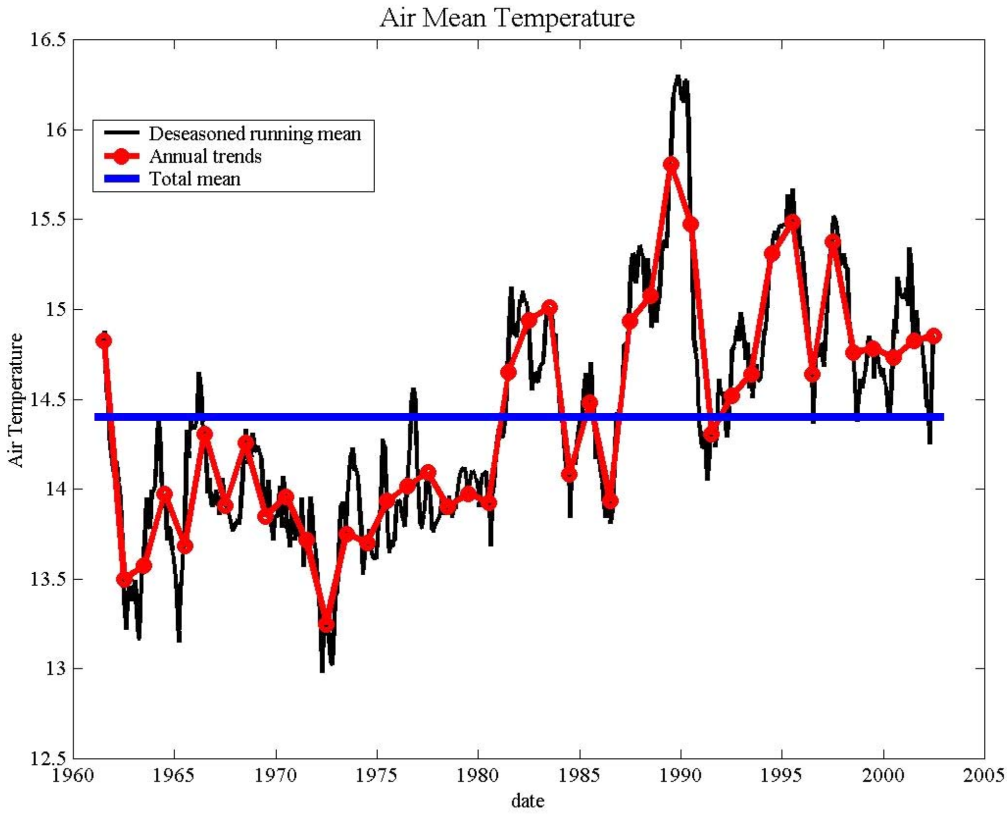


Figure 2. Annual mean temperatures in Santander (43.5ºN, 3.8ºW). *Courtesy of the 'Instituto Nacional de Meteorología'.*

However, positive anomalies in the annual cycle appear in the winter (January to March), and in autumn (Oct-Dec). During summer (May to September) negative anomalous behaviour is really marked. 2001 was the driest year on the historical series, 2002 keeps been dried with only August over the mean monthly value. 2002 summer was the colder since 1987 and one of the colder of the time series. The difference between high summer temperatures and low winter temperatures is substantial, from 11.9ºC (August-December) in 2001 to only 6.7ºC (August-February) during 2002. Figure 3 shows the monthly mean air temperatures superimposed on the annual cycle in Santander ("Instituto Nacional de Meteorología"), this annual cycle was calculated assuming a linear trend plus two harmonics functional form. Both signals are represented, with the trend (3.5 ºC per century since 1961) and without it.

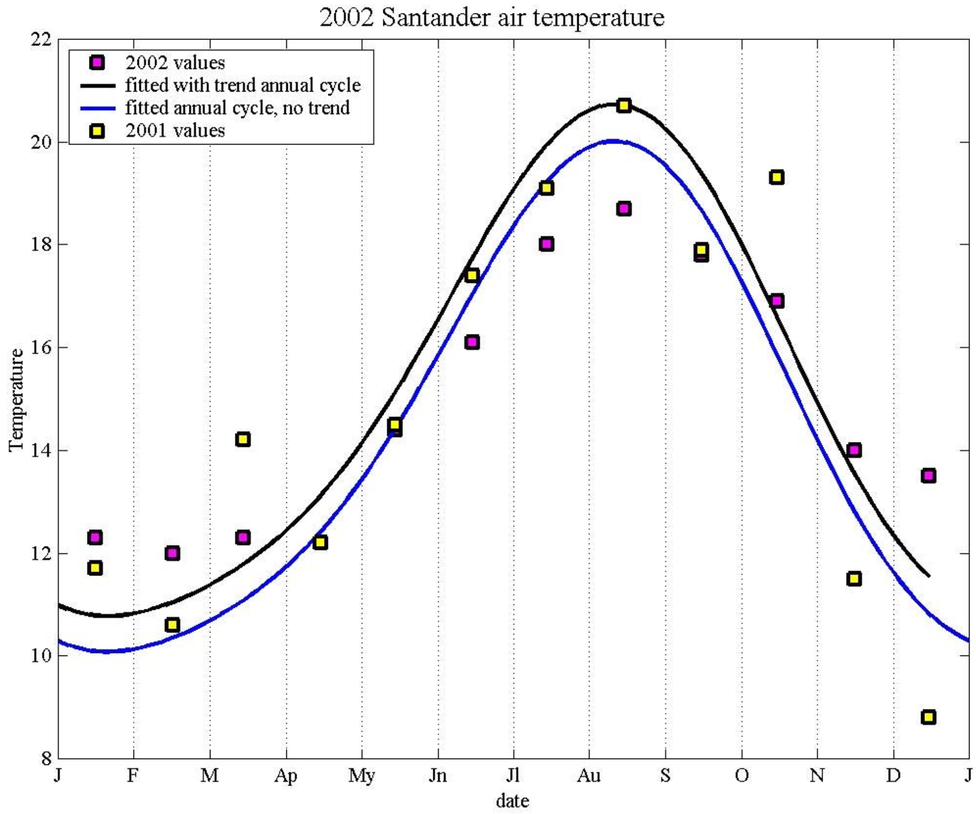


Figure 3. Air temperatures in 2001 in Santander (43.5ºN, 3.8ºW*) Courtesy of the 'Instituto Nacional de Meteorología'*

Hydrography

In order to get a first approximation to the data, contours of temperature, salinity and nitrates (over the shelf, 100 m depth) in the Santander section are shown in Figure 4. 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 2002 presented a shallow picture similar to 2001, and the thermocline reached as much as 30 m depth. The warming period was also reduced, and was the shortest in the time series. Bottom cooling in June and October 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, and in spring due to local river overflow. During 2002 the advection and river overflow was low compared with the previous years. High salinity values over most of the shelf, which appeared from the strong incursion of saltier and warm water in 1997 has reduced since January 2000 to values of the same order as in 1995. The autumn saltier incursion (poleward current) increased salinity over the shelf, but after the episode salinity reduced. With regard to nitrate distributions, high values appeared in the mixed period and due to upwelling events in the stratified part of the year. 2000 and 2001 had a very low influence of upwelling, and only after June did nitrate concentration reach around 6µmol/l below 40 m. During winter 2002 very low nutrient concentration was detected, as corresponds to the old waters of the `poleward current', after which a strong increase in nitrates appeared due to the episodic upwelling with two marked events in June and October.

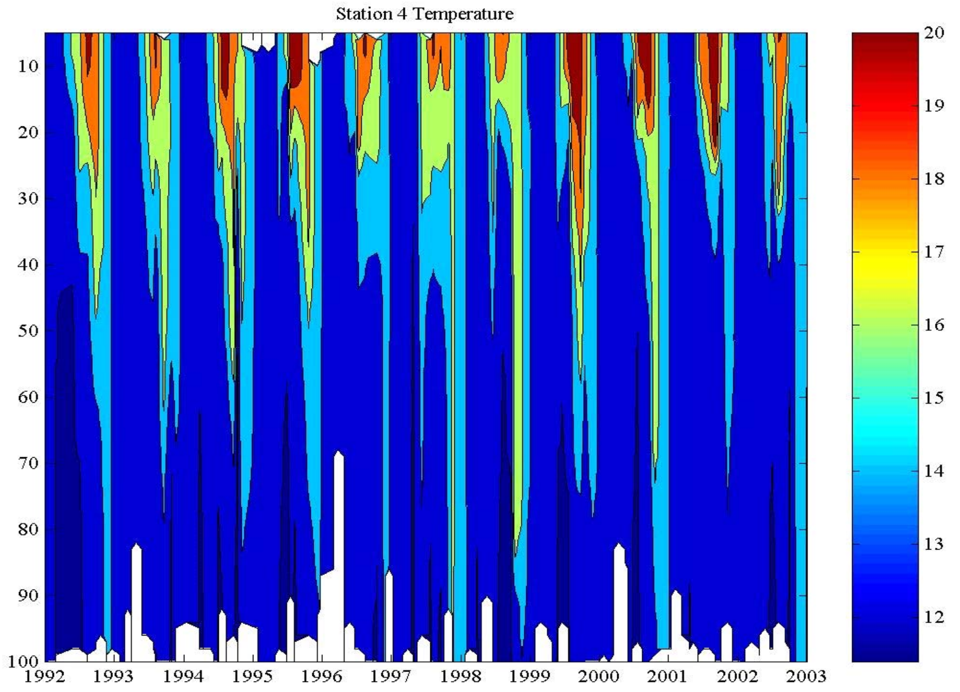


Figure 4a. Temperature evolution at Santander station shelf)

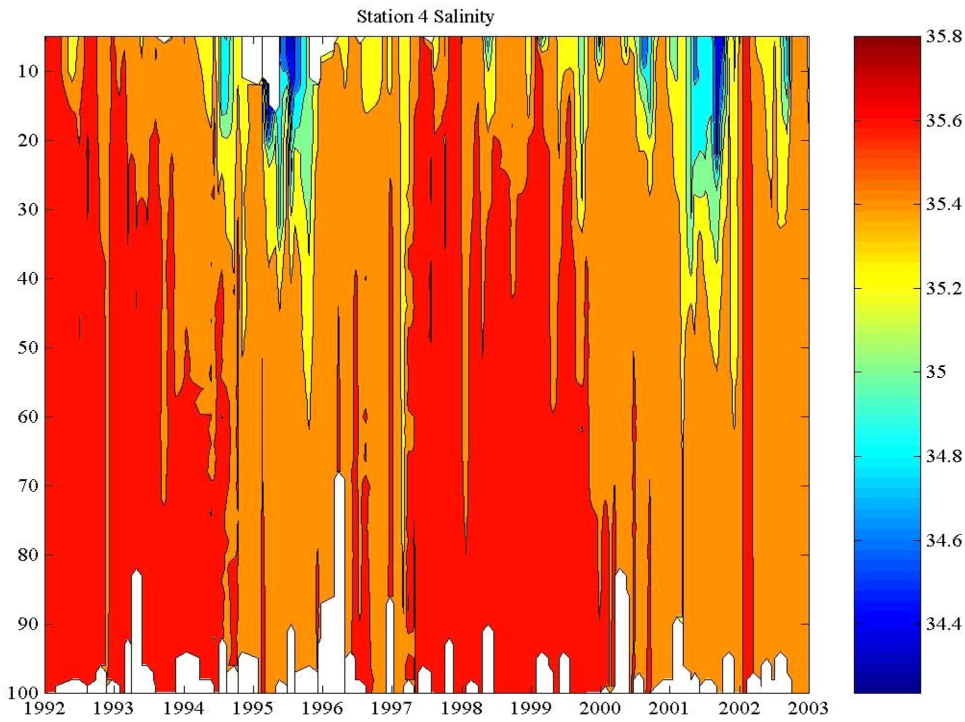


Figure 4b. Salinity evolution at Santander station 4 (shelf)

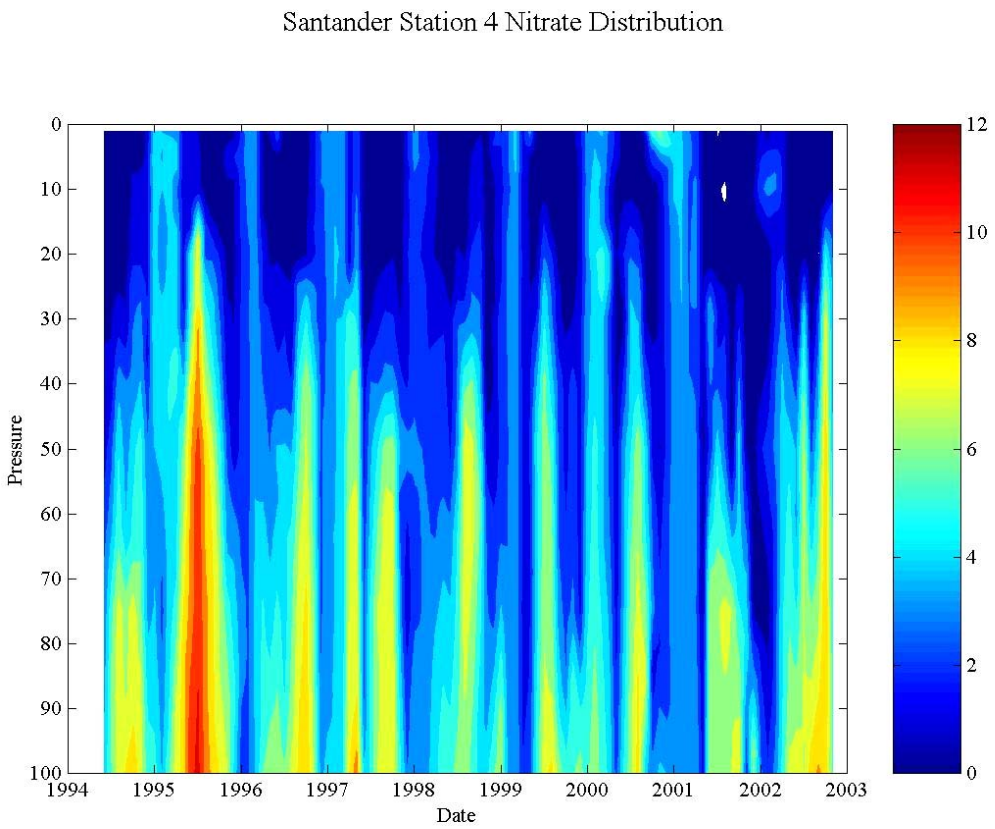
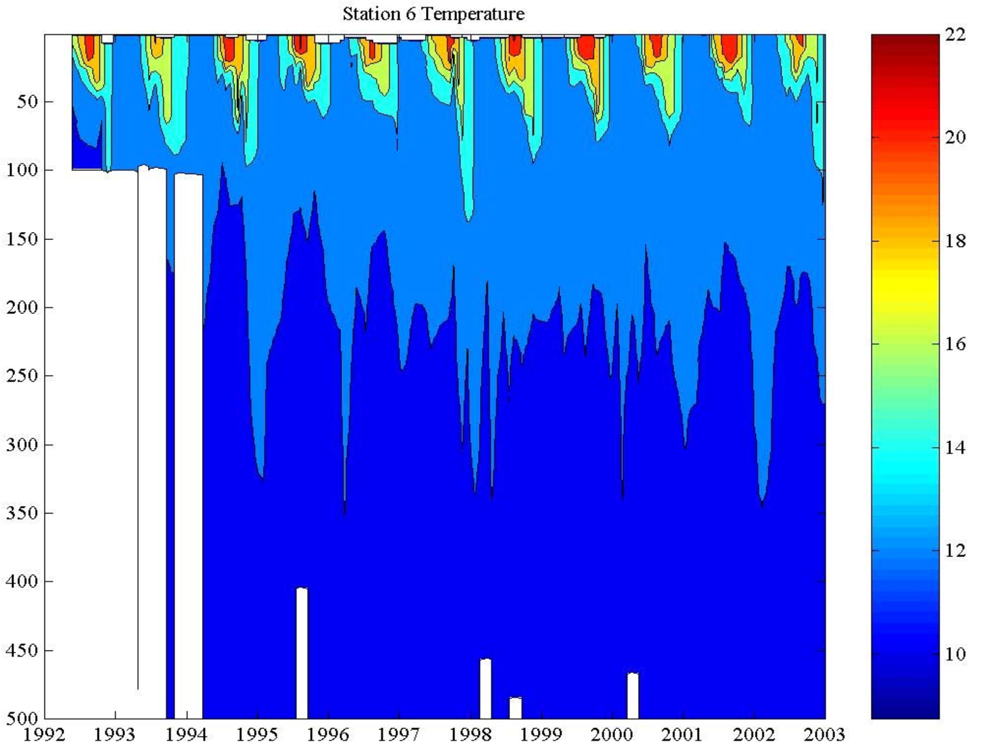
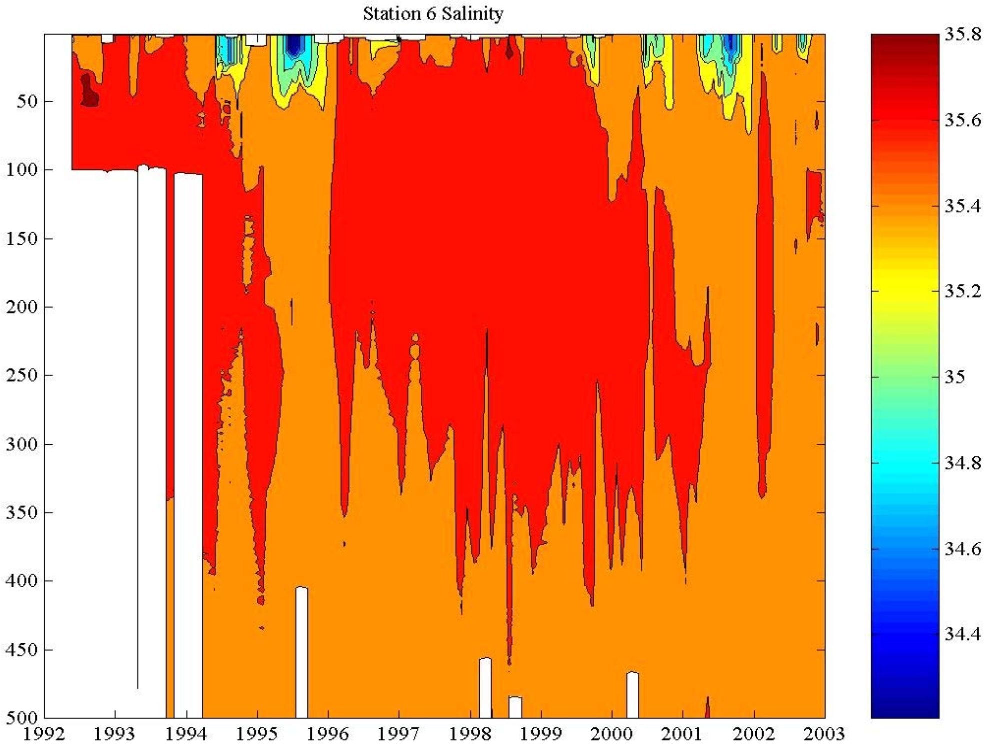


Figure 4c.Nitrate evolution at Santander station 4 (shelf)

Contours of temperature, salinity and nitrates over the shelf-break (600 m depth) in the Santander section are presented in Figure 5. During the first period (1992–1994) only upper layers were sampled. 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. 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. 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, and during the rest of the period the water column is mixed, with the autumn mixing marked even up to 300 m depth.

Salinity contours show high values after the end of the mixing period at the beginning of the winter, the warm period sometimes extending at those depths due to the poleward current. Winter 1996 was a good example, in 1998 it looks strong and in 2002 it was also detected. With respect to nitrate distributions, high values appeared in summer due to upwelling events over the shelf break mainly during 1994 and 1995. After those years, nitrate content has reduced considerably. After some years of low concentration in deep waters in summer, during 2001 and 2002 concentration increased. This increase was due to upwelling in the shelf and advection of upwelled water towards the shelf-break.





Figures 5a,b. Temperature and Salinity evolution at Santander station 6 (shelf-break)

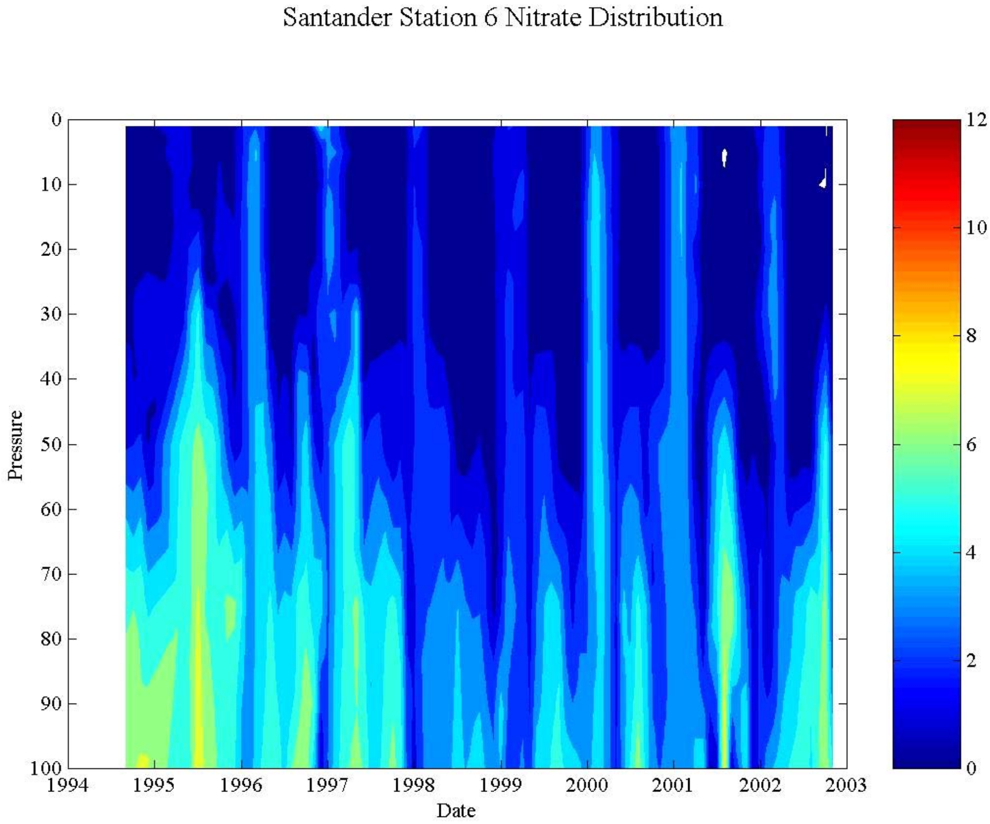


Figure 5c. Nitrate evolution at Santander station 6 (shelf-break)

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

If we look at thin layer superficial waters, we expect to find an approximate mirror of atmospheric forcing. Due to the thermal inertia of the seawater surface, the temperature seasonal cycle does not follow a sinusoidal cycle but presents a rapid warming period in late spring, whereas the autumn cooling is less abrupt. As mentioned previously, superficial salinity presents a seasonal decrease produced by the advection of fresher water from the east of the Bay of Biscay, usually in spring-summer time, when the wind regime is from the first quadrant. The poleward winter signal in February is presented at all depths, but mainly at 200m. This effect is more intense than during the previous poleward episodes in winter 1996 and 1998.

As has been done for air temperature, fitting the temperature signal by two harmonic terms plus a linear trend, we can reproduce the signal approximately. Taking this into account, we can compare the year 2002 with the climatological mean for surface waters finding a slightly cool winter followed by a persistent cool summer for the upper water layer (Figure 7). Winter 2002 seems to be similar to the one in 2001 and warmer than in 2000, the coldest of the decade (Figure 8). Upper water (0–300m) mean temperature is on the time-series average.

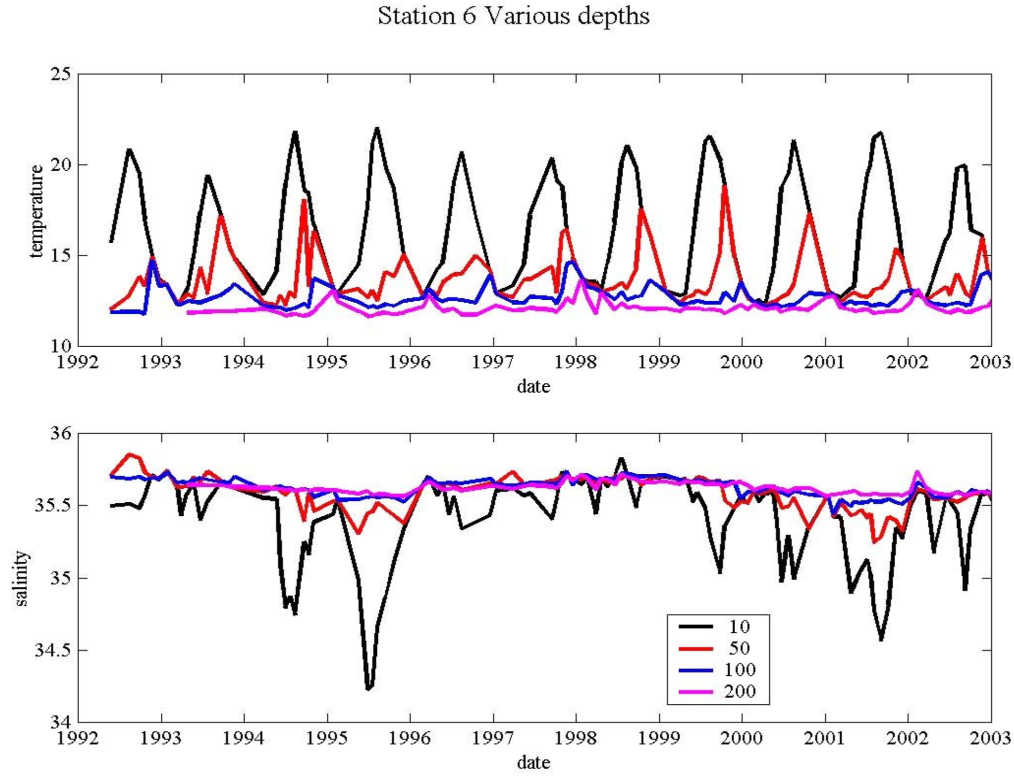
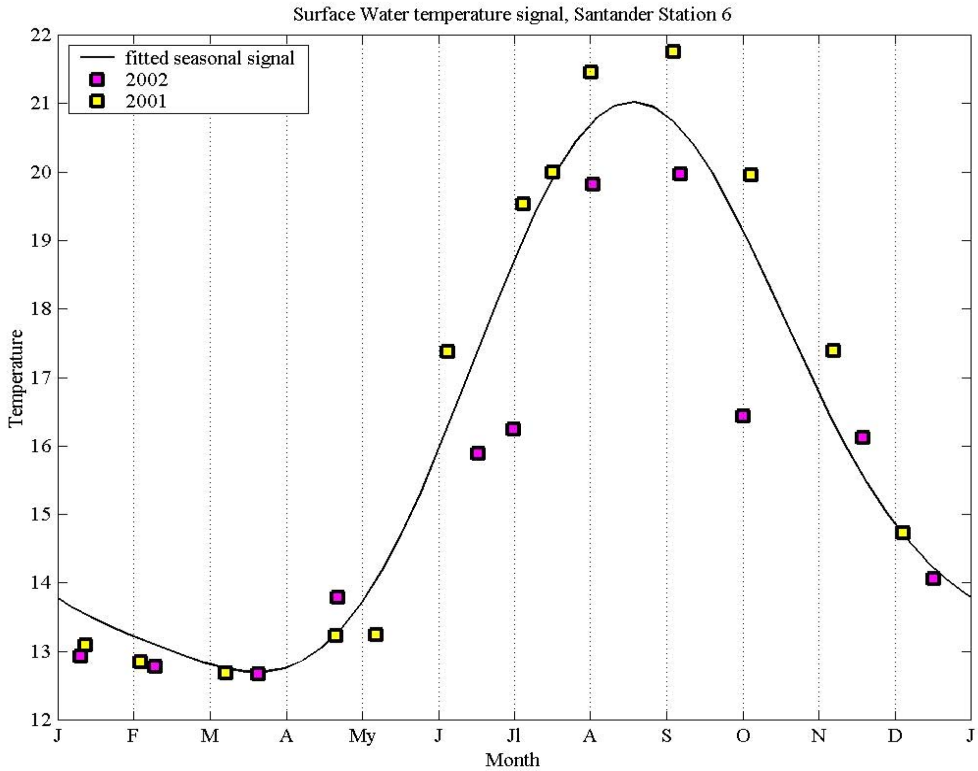


Figure 6.Temperature and Salinity at various depths, Santander station 6 (shelf-break).



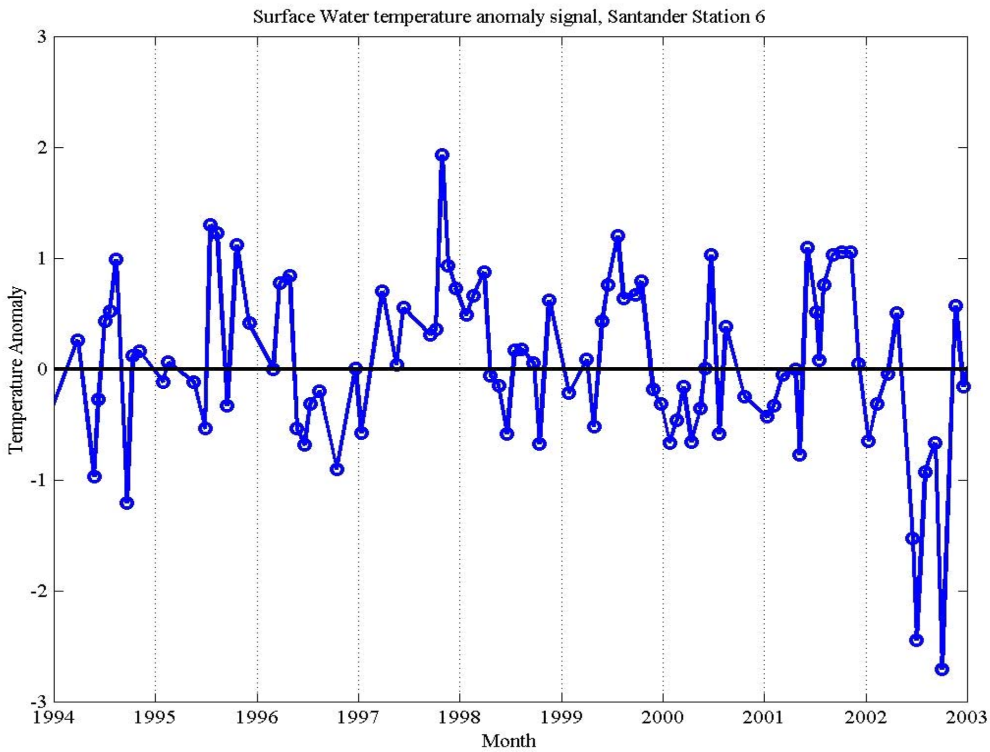


Figure 7. Seawater Surface Temperature at Santander station 6 (shelf-break).

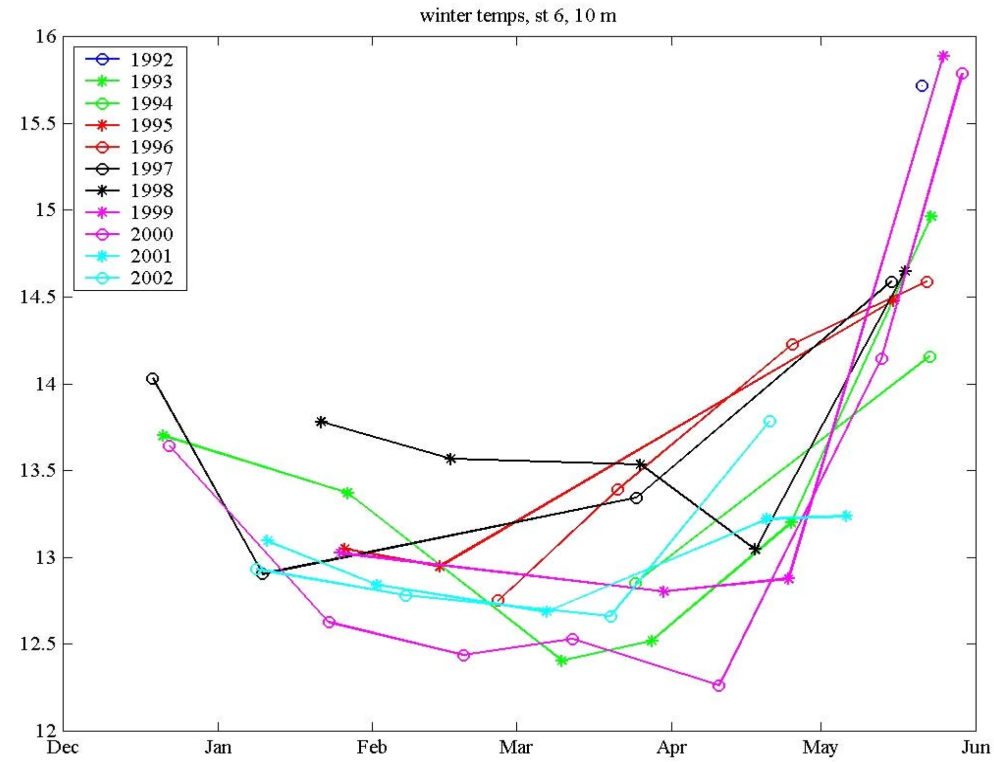


Figure 8. Winter-Spring surface temperatures at Santander station 6.

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 average of this layer (0–300 m) is shown in Figure 9b for station 6. 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). Salinity has begun to recover after the minimum found in 2001 resulting in average values for shallower depths.

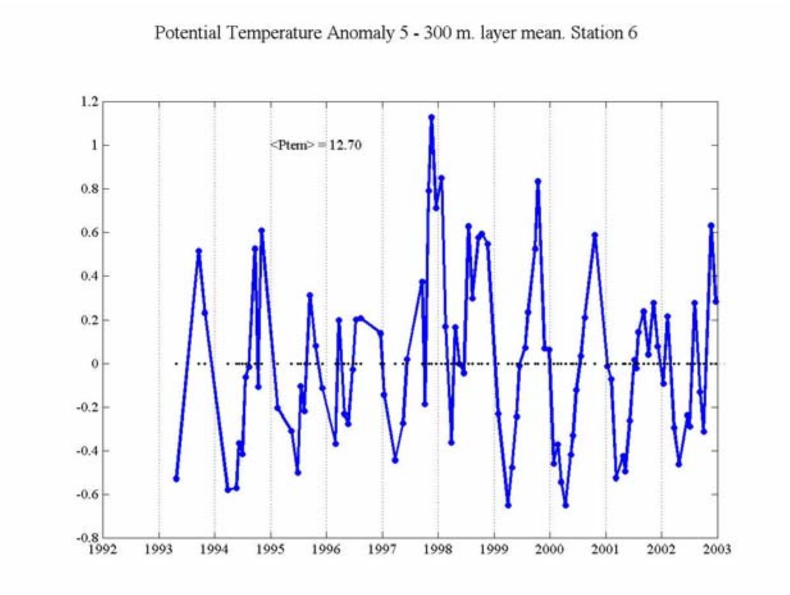


Figure 9a. Potential Temperature anomaly evolution at Santander station 6.

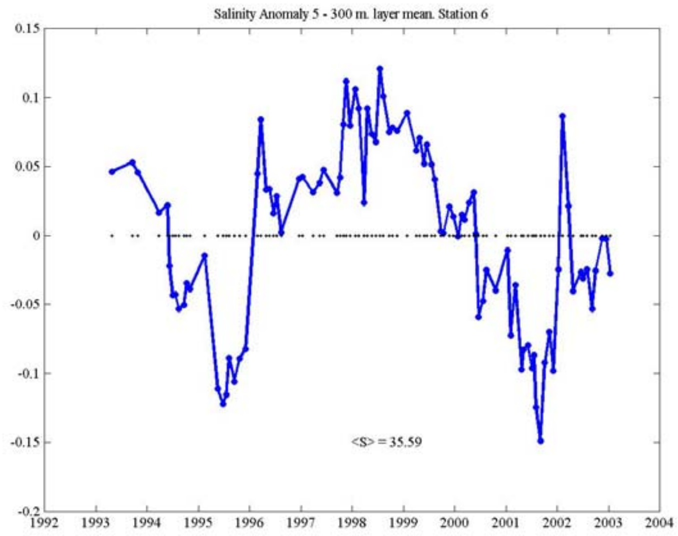


Figure 9b. Potential Temperature anomaly evolution at Santander station 6.

Heat Content

Heat content during 2002 seems to have reduced due to the small contribution of the upper layer during the unusually cool summer. Winter poleward episodes produce high heat content, similar to the 1996 and 1998 values at 200–500m, autumn mixing produces less heat than the previous years but an increase occurs at the end of the year. In Figure 10 we can see evolution in both the mixing layer and NEACW. Total heat content for the whole 500m first layer during the last three years followed a repetitive annual cycle.

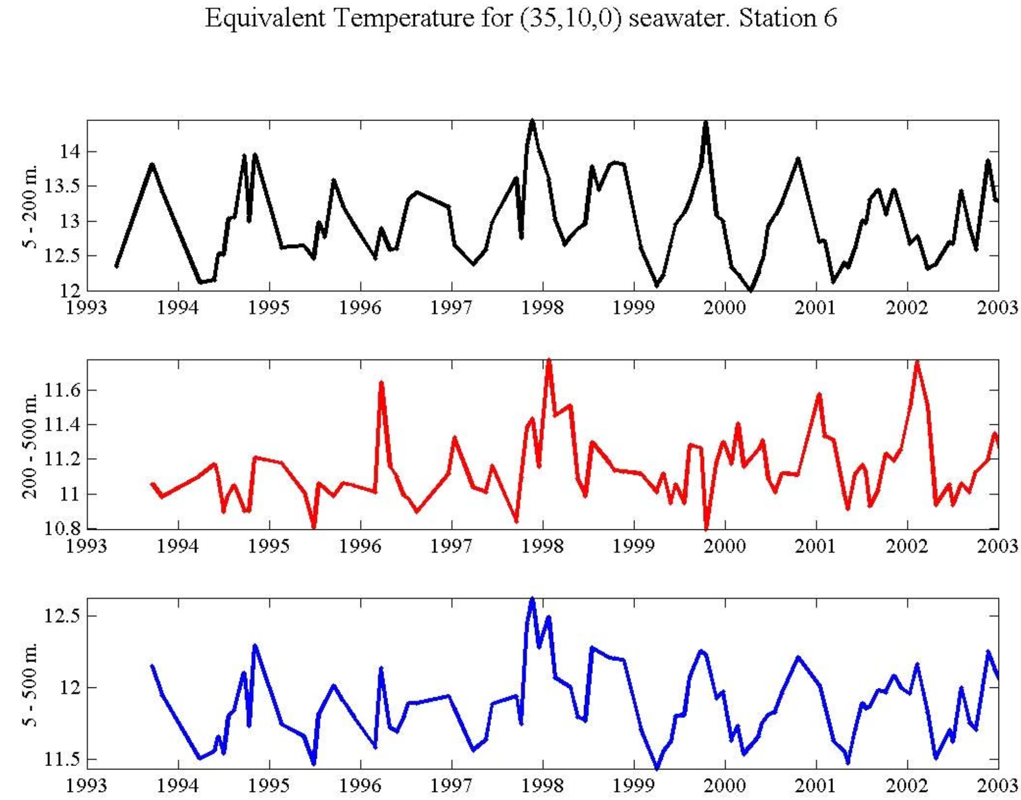


Figure 10. Heat stored in the water column at Santander station 6.

Vigo Standard Section

Contours of temperature, salinity and nitrate over the shelf (94 m depth) in the Vigo section from 1994 to 2002 are presented in Figure 11. The seasonal cycle is marked in temperature in the upper layers and remains during the autumn, usually interrupted by summer upwelling events; autumn 97/ winter 98 was the warmest period of the series. Stratification develops between April-May until October-November, frequently broken by upwelling events. At some depths, salinity contours showed high values all year in 1996, 1997 and 2000; in the remaining years this was only true in winter due to the poleward current. Nitrate values follow the upwelling (high) /poleward current (low) events. Considering upwelling/poleward current timing and intensity, the year 2002 was within the average of the mean of the last 10 years.

Station 3

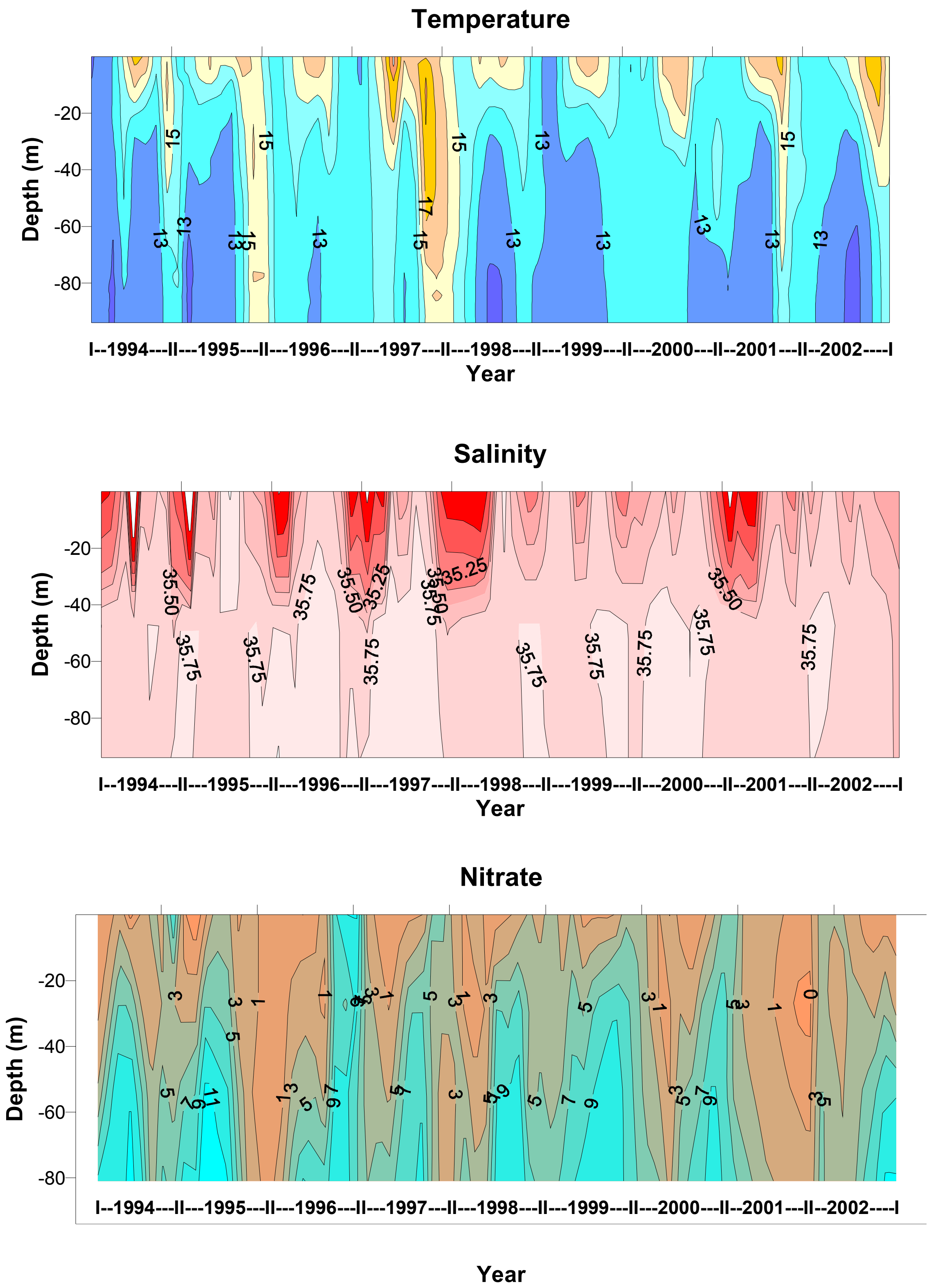


Figure 11a,b,c. Seawater evolution at Vigo (42.1ºN, 9.0ºW) station.

ANNEX L: CONTRIBUTION TO THE 2003 MEETING OF THE WORKING GROUP ON OCEANIC HYDROGRAPHY: FRENCH NATIONAL REPORT (AREA 4)

G. Reverdin,

The Laboratory for Dynamical Oceanography and Climatology (LODYC), France

Repeated hydrography

LPO (Brest) conducted a cruise from Cape Farewell and Portugal in July 2002 (Figure 1). This cruise is expected to be repeated every two years until 2010 as part of the French contribution to the international program on climate variability (CLIVAR), and is referred to as OVIDE. It nearly overlays in the Irminger Sea the section committed every two years by the Inst. of Oceanography of the University of Hamburg (Germany) providing in this area annual resolution of the water masses and transports. The objective is to contribute to the monitoring of the meridional overturning and associated transports. Oceanographic stations were conducted from the surface to the bottom with CTD, L-ADCP as well as with sampled measurements of CFCs, nutrients and dissolved inorganic and organic carbon (in cooperation with colleagues in Vigo, Spain). In addition, 17 profiling floats were deployed as part of the E.U. project GYROSCOPE, mostly on the way from Brest to Greenland.

A CTD section across the Gulf of Cadix has been repeated once a year (SHOM/ LPO) along 8 20'W since 1999. The last repeat was in July 2002, with hope to restart sampling in 2005. The section includes CTD, L-ADCP stations from surface to bottom, and was aimed at a survey of the water masses and their circulation in this region close to the Straits of Gibraltar. Not having at least a seasonal sampling however implies that it is difficult to separate the effect of mesoscale variability from the signals relevant for climate. An experiment possibly starting in 2005 or 2006 will be designed for the monitoring of the Mediterranean water entering in the Atlantic Ocean (EMA).

Coastal surveys are carried every year since 1992 on parts of the French continental shelf of the Bay of Biscay (IFREMER and EPSHOM) with a tendency to be particularly common in the spring and the autumn seasons. Some of the results of the cruises have been analysed and presented in Puillat *et al.* (2002) and Puillat *et al.* (2003) which illustrate strong variability of near surface salinity at the mesoscale and on seasonal to interannual time scales with the occasional presence of fresh water lenses and upwelling patterns (Figure 2). They are associated to variations of fresh water influx by the rivers (in particular, Loire and Gironde) as well as of wind forcing.

Profiling floats

France contributes to the ARGO project of profiler floats with more than 100 floats already deployed in the North Atlantic with further deployments (50 each year 2003–2004) planed in the tropical and southern Atlantic as well as in the other world oceans. The floats are currently mostly with FSI temperature and conductivity sensors. Current tests suggest that the salinity can be retrieved with accuracy on the order of 0.01 psu based on careful pre-cruise calibration. There is no clear experience of long-term behaviour of the sensor accuracy. They are expected to live three-four years and to profile every 10 days from their parking depth usually near 2000m to the surface where they transmit the data through Argos. The processing, data validation and data archiving are done at the CORIOLIS center in Brest (www.ifremer.fr/coriolis)

Surface data

France contributes to the surface water sampling of the Atlantic Ocean by equipping ships-of-opportunity with thermosalinographs (TSG) and taking on selected transits surface samples for later analyses of nutrients, dissolved inorganic carbon or plankton. Some of these vessels also drop XBTs. Currently, 8 merchant vessels providing data in the Atlantic are part of this world-wide network supervised by IRD. All the ships call in Le Havre (France) or other northern European ports:

- 1 vessel (Waterberg) Europe to South Africa
- 1 vessel (Pasteur) between Europe and Buenos Aires
- 2 vessels between Europe and Cayenne (French Guyana), sometimes also to Italy or Florida (Colibri and Toucan).
- 3 vessels on a round-the-world route crossing the Mediterranean and calling in northern European ports before sailing to the eastern USA (Contships London, Rome and Washington)
- 1 vessel between Aalborg (Denmark) and West Greenland (Nuka Arctica).

In addition, LEGOS (Toulouse) is also involved with the surface sampling on the Skogafoss between Iceland and North America (the main ports of call are Reykjavik, Argentia in Newfoundland, Boston and Norfolk) to calibrate the TSG data from that ship (figure 3). The sampling with thermosalinographs has started on the different lines between 1992 and 1997, but surface sample collection for salinity has been done for a much longer time on some of these lines (in particular for IRD since 1977). Observers taking samples embark roughly every three months on the Skogafoss, and occasionally on some other vessels, and surface samples continue to be collected by the crews (in particular on the Nuka Arctica) for calibration of the TSG salinity data. In addition, three French research vessels operating part of the time in the Atlantic are transmitting data (R/V Atalante, Thalassa and Suroit) with occasional additional data from a fourth research vessel (Marion Dufresne). Furthermore, CMM (French Met Office) deploys occasional surface drifters equipped with salinity or other sensors, usually for identified projects. Four Carioca drifters (LODYC) were deployed during the POMME experiment between Portugal and the Azores in early 2001, which have been recovered after drifting for 6 months to 13 months. Nearby data and postcalibration results suggest that the drifts in their salinity remained small throughout their time at sea (the conductivity cells are SEABIRD microcats which are poisoned, and water circulates in the cell only once each hour). However, attempts with other drifters have not provided usable results. Two more drifters with conductivity cells are deployed in 2003, one near Iceland in January (but with just a month of usable data, followed by an unexplained failure), and one to be deployed west of France in early April.

A significant part of the issue with the near-surface TSG data is making sure that drifts are corrected and that the data are of a reasonable quality. After checking the data for obvious problems (due for example to closed water circuits, the presence of bubbles or objects stuck in the vicinity of the cell, or to large and variable bio-fouling), the main issue is to correct the data for biases. This is not done yet systematically in France, but is planned for the near future (at LEGOS). Methods are being developed to try to assess those in a general way, by intercomparing near surface salinity data of various sources. Nonetheless, even with this data set of still reduced data quality, it seems that this effort is fairly successful to monitor at least long-term variations of the hydrographic conditions (Figure 5). For the time series centered on 10W/42–43N, one notices for example the episodes of high salinity in 1990 as well as in 1998, which are typical of a large area of the northeast Atlantic extending at least from 42N to 48N and across the Bay of Biscay. The low salinity in 2001 seems also to be present in a large area that is probably related to anomalously high rainfall extending from northwest Spain to the British Channel in late 2000-early 2001.

I should also mention the international IOC effort (GOSUD) to link the individual national efforts, and that we had access to data from the CAVASSOO EU project (two lines started in 2002, but the project also includes research vessel data from the R.V. Hesperides (Spain), and the J.C. Ross (UK)). There is also a current effort proposed within the EU integrated project MERSEA to access data from various research vessels, collected, but not yet easily accessible (data from many WOCE cruises are however accessible on: http://www.ifremer.fr/orstom/sss/sss_dac/sss_dac.html)

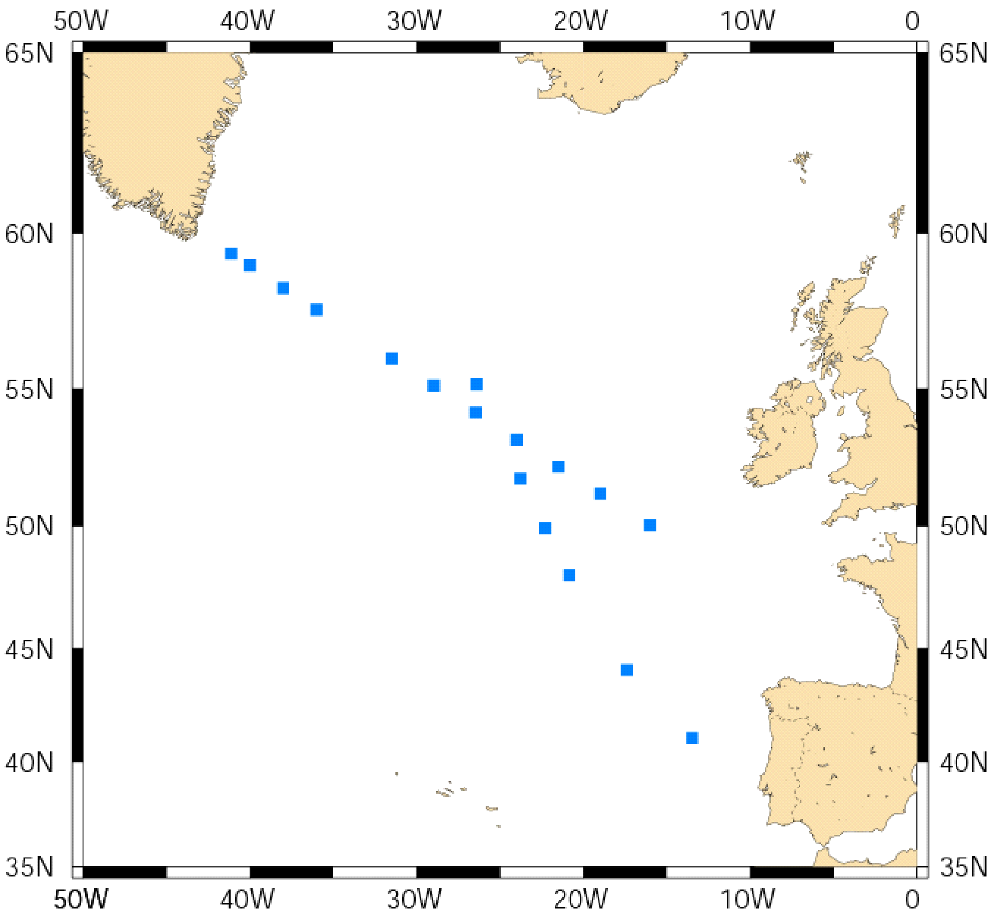


Figure 1: Stations occupied during the Ovide cruise (June-July 2002) (round black circles). The squares correspond to deployments of profiling floats.

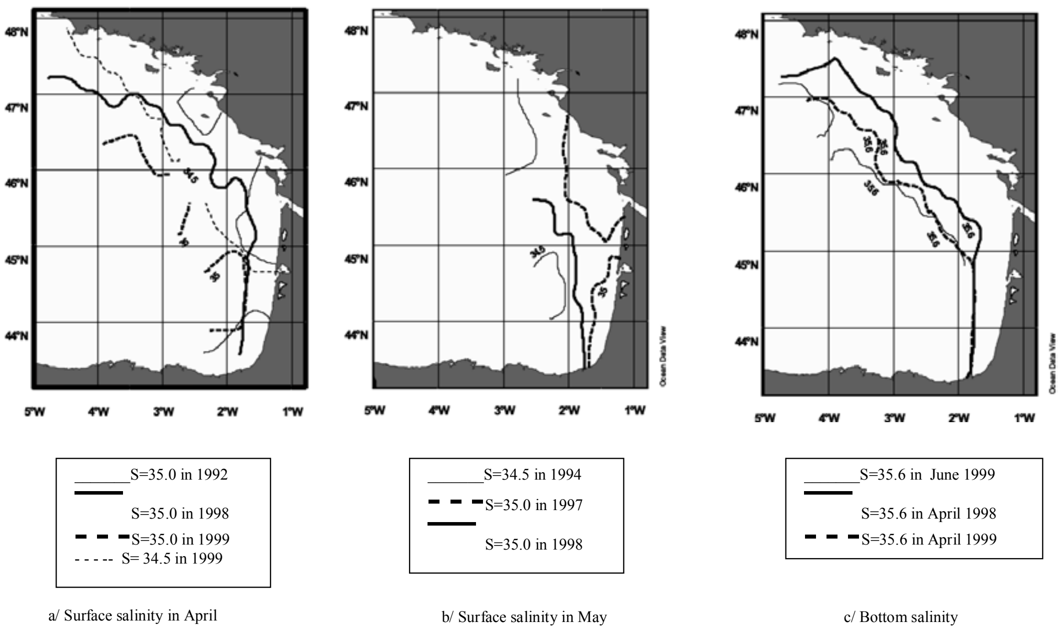


Figure 2. Interannual variability of salinity on the French continental shelf in the Bay of Biscay from Hydrological surveys in the 1990s (communication of I. Puillat).

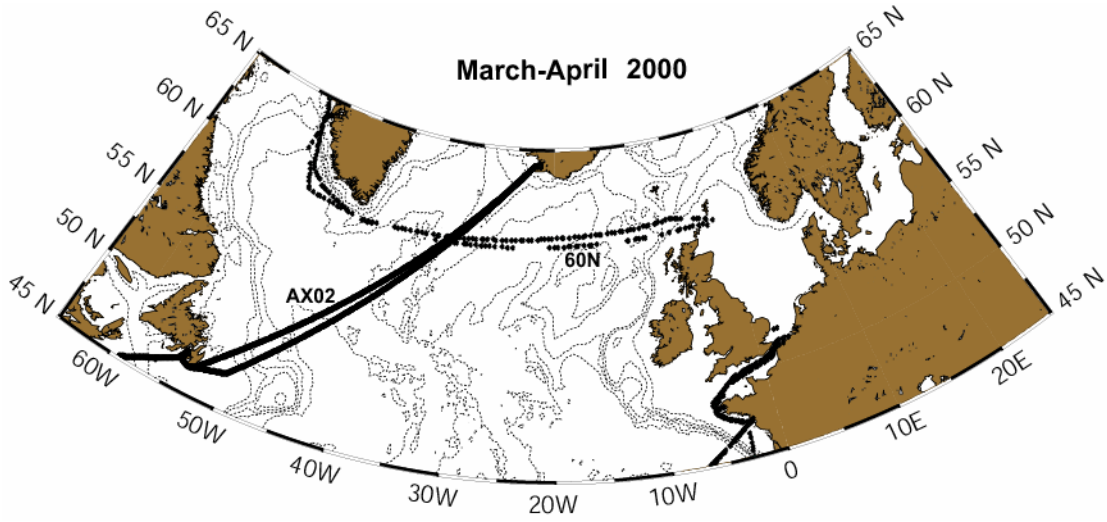


Figure 3: Real-time surface sampling in the subpolar gyre in March-April 2001 from the ships Nuka Arctica and Skogafoss (in March, the Nuka Arctica went between Rotterdam and Algeciras, and in April between Aalborg and west Greenland).

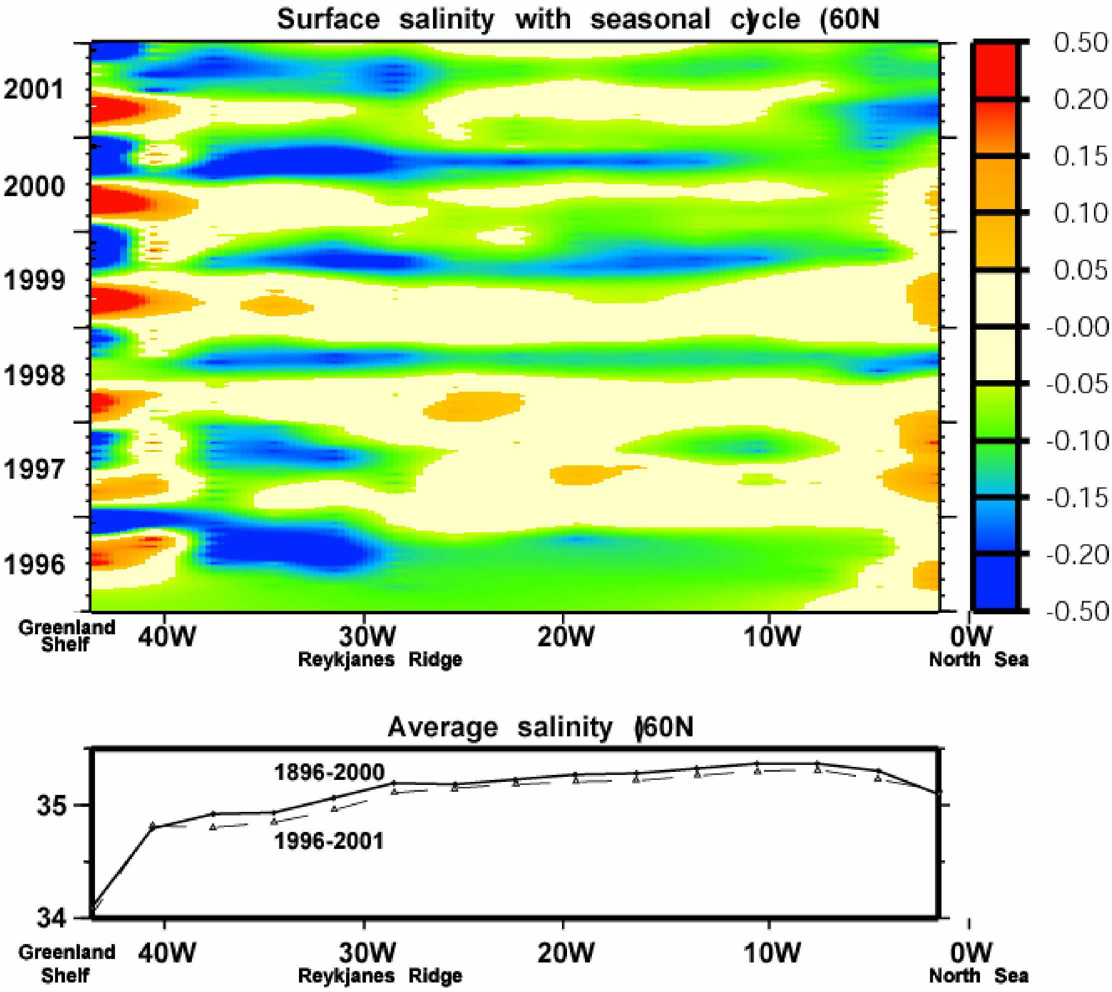


Figure 4. Hovmuller diagram (longitude-time) of surface salinity along 60N between the Shetland shelf and the Greenland shelf off Cape Farewell. At each longitude, the average salinity from 1896 and 2000 has been removed (the lower panel shows the average difference between this climatology and the data for the period 1996–2000). Data are not common before the autumn 1996 and during January-March of each year. The Nuka Arctica regularly provides data along this latitude band since July 1997.

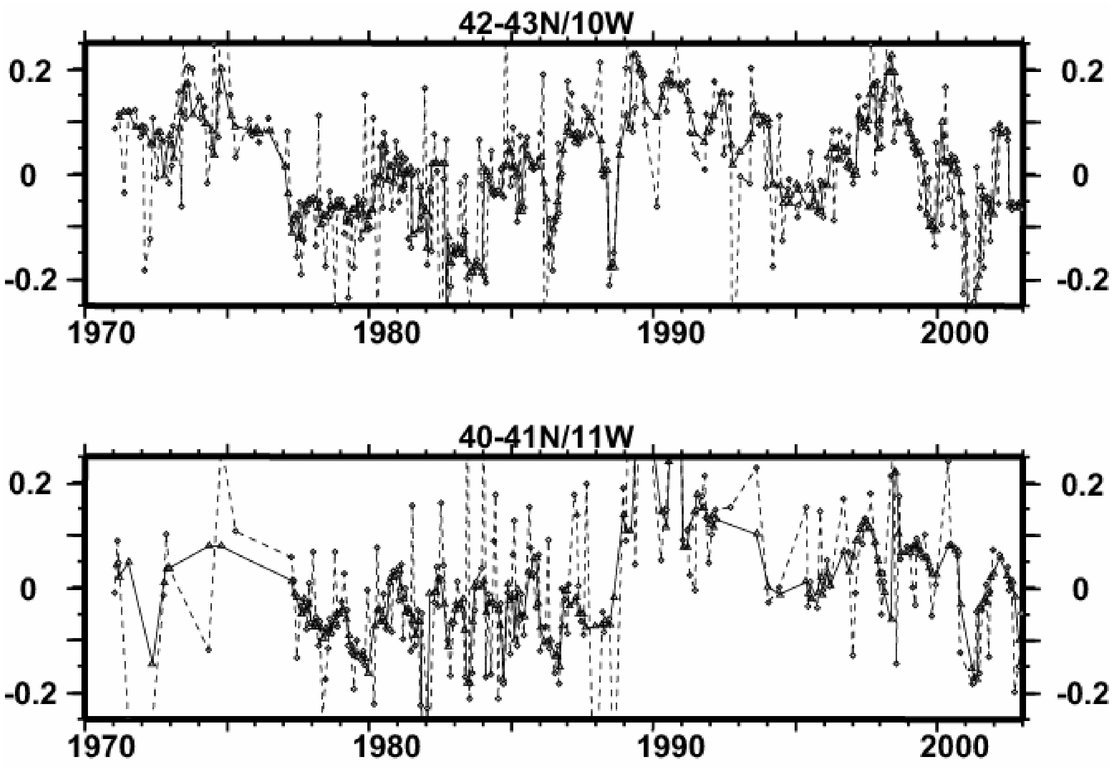


Figure 5. Time series of monthly salinity anomalies in two areas of the northeast Atlantic. Dashed line for the monthly anomalies, full line for filtered data, after removing suspiciously large anomalies and averaging over three months. The average salinity for the upper panel is maximum in December-January (35.84) and minimum in May-June (35.69), and for the lower panel with maximum in Dec-Jan (35.95) and minimum in July (35.81)

ANNEX M: REPORT ON WOCE/CLIVAR SECTION A1E (NORTHERN NORTH ATLANTIC AREA 5B)

John Mortensen

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Summary

The WOCE/CLIVAR Section A1E, showed relatively high temperatures and salinities in the upper layer in 2002. These suggest that a new positive salinity anomaly is in progress. In the upper 1200m of the water column the tendency is towards warmer and more saline conditions due to the deepening and decay of the Labrador Sea Water mass produced in the 1990s.

The ongoing work on the WOCE/CLIVAR section A1E (Figure 1) is reported here. This section has been repeated 9 times since 1991 with approximately 54 CTD-stations between Cape Farvel (Greenland) and Porcupine Bank (SW-Ireland). The eastern part of the section is occupied by warm and saline waters of the North Atlantic Current (NAC) whereas the western part of the section is occupied by less warm and saline waters of the Subpolar gyre. The boundary between these two waters/systems is the Subpolar Front..

The recent 11 years variation of the position of the Subpolar Front along section A1E is illustrated in Figure 2. The position of the Subpolar Front is highly linked to the NAO index. During positive NAO the location of the Front is more easterly hampering the north-westward transport of the warm and saline waters of the NAC. During negative NAO the situation is reverse giving rise to northward progress of warm and saline anomalies. The timing of these anomalies is illustrated in Figure 3, which shows the temporal changes of the mean salinity in different regions of section A1E in the upper 1200m between 1991 and 2002. The positive salinity anomaly is first observed in the Iceland Basin and Rockall Trough and arrives the Irminger Sea about 2 years later.

The 2002 data set suggest that a warm and saline anomaly is in progress, seen as rising salinities (and temperatures) in the upper layer in all three regions in Figure 3 and a westerly position of the Subpolar Front.

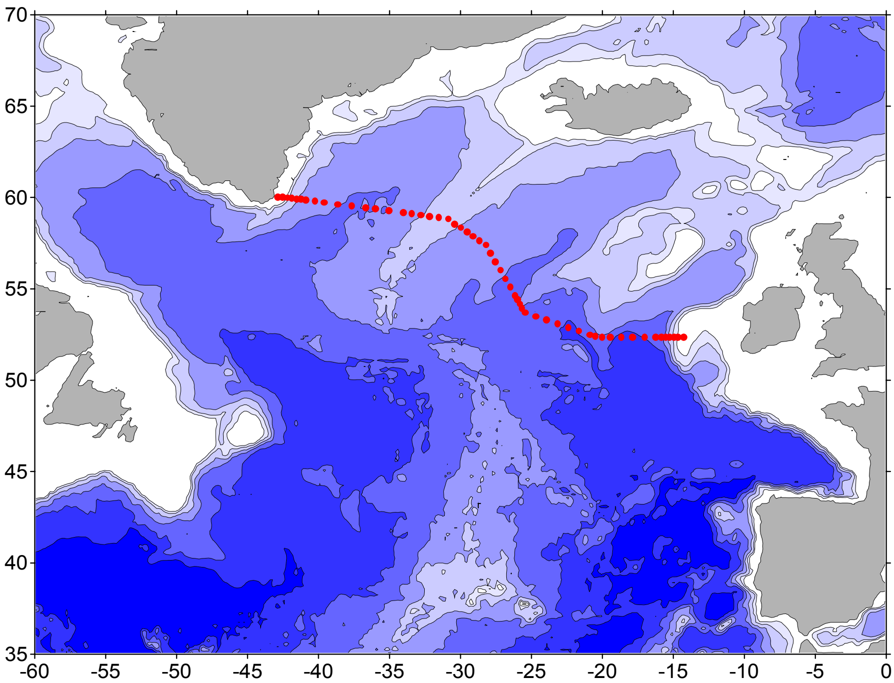

Figure 1. Location of the WOCE/CLIVAR hydrographic section A1E and bottom topography in the northern North Atlantic.

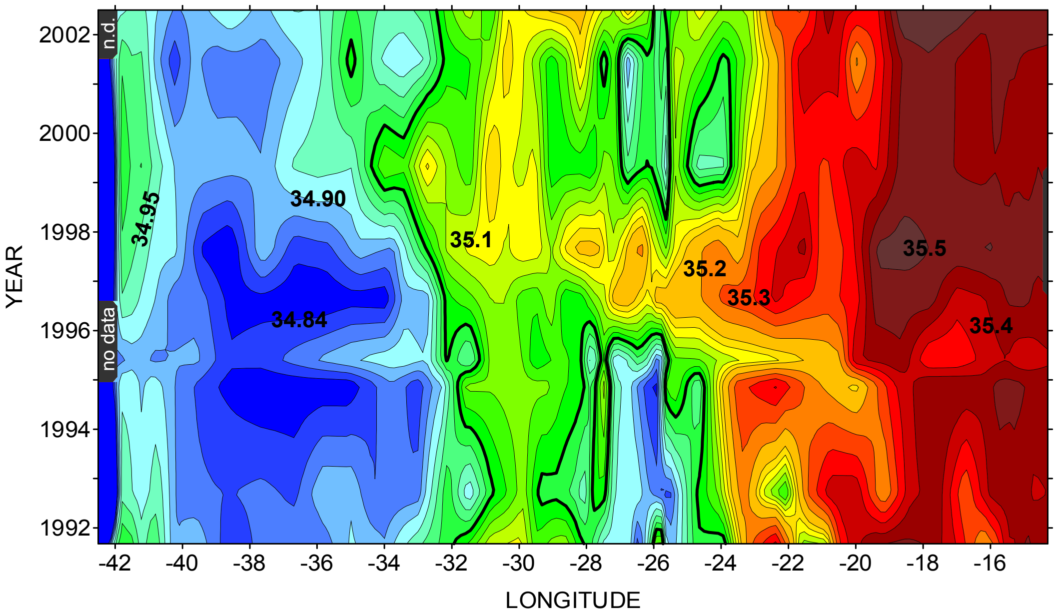

Figure 2. Temporal changes of the mean salinity of the upper 600m along section A1E, recorded nine times between September 1991 and July 2002.

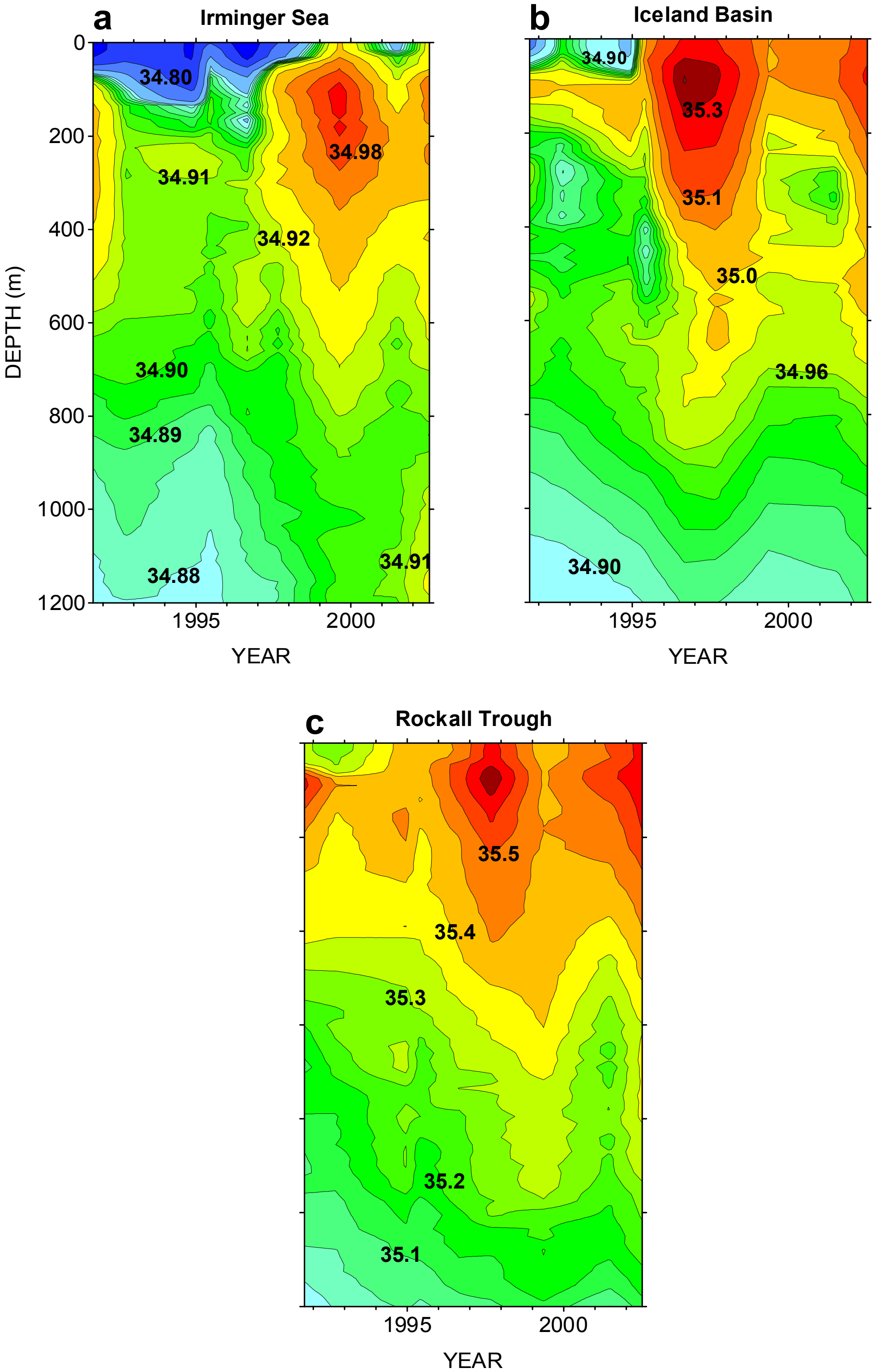

Figure 3. Temporal changes of the mean salinity in different regions of section A1E in the upper 1200m between 1991 and 2002: (a) Irminger Sea (30.8 to 41.8°W), (b) Iceland Basin (24.0 to 28.0°W), and (c) Rockall Trough (15.2 to 20.0°W). Notice that different colour codes are used in the different regions.

ANNEX N: 2002 RESULTS FROM THE SCOTTISH STANDARD SECTIONS, (AREA 7 AND 8)

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Introduction

The two standard Faroe-Shetland Channel sections (Nolso (Faroe) -Flugga (Scotland) and Fair Isle (Scotland) - Munken (Faroe)) and the North Sea JONSIS section have been occupied by the Marine Laboratory Aberdeen on three occasions during 2002; in May; October and December. Figure 1 shows the location of these sections.

Summary of Results

The data are presented in Figures 2 to 10 as anomalies observed during a particular cruise as well as smoothed data calculated as a 3-year running mean. Unless specifically stated, the text refers to the trends observed in the smoothed dataset rather than the individual data points.

Surface Waters

North Atlantic Water (NAW) at the Scottish shelf edge (Figure 2) has been warming since 1987 at a rate of 0.5°C/decade. During 2002 temperatures were higher than average, although not as high as those observed during 1982.

The salinity of NAW demonstrated an almost cyclically variability since the end of the low salinity anomaly (GSA) years in the late 1970s. Salinity increased during 2002 to reach the highest values observed in the last 40 years.

In the Modified North Atlantic Water (MNAW), at the Faroese shelf edge, both temperature and salinity have increased during 2002 to reach values above average.

Bottom Water

The temperature and salinity of Faroe Shetland Channel Bottom Water (FSCBW) has remained fairly stable in the last two years, although salinity values are still well below those in the period before the freshening commenced in the mid-1970s (Figures 6, 7 and 8).

North Sea

In the North Sea the salinity variability in the past has been well correlated with that of NAW, Since 1977 the cyclical variability is very evident, in both salinity and temperature. During 2001 the salinity of mixed oceanic water flowing into the North Sea within the Fair Isle Current (Fair Isle Current Water - FICW) was the lowest observed since the measurements began. (Figure 9), values increased during 2002 back towards more normal conditions. There has been a warming trend in these waters since 1994, temperatures during October 2002 were the highest observed since 1976.

The properties of Cooled Atlantic Water (CAW), which typifies water lying within the central northern North Sea below the seasonal thermocline, may be more closely tied to those of NAW (Figure 10). Temperature and salinity of CAW remained higher than the long term mean in 2002, and showed a slight increase relative to conditions measured in 2001.

Time Series Definitions

Time series from 5 characteristic water masses which occupy the Faroe Shetland Channel are presented in Figures 2–8 and for 2 North Sea water masses in Figures 9 and 10. The methods employed to define the water masses, and to derive the time series are described below.

Surface Waters:

North Atlantic Water (NAW) (Figure 2) - The temperature and salinity at the standard pressure level which exhibits the maximum salinity within an individual survey of the most south-easterly two stations, on both standard sections, on the Scottish side of the Channel.

The criteria was designed to produce the characteristics of the North Atlantic water lying within the Slope Current at the Scottish shelf edge. North Atlantic Water is typified by a salinity maximum on a θ-S diagram. This water most probably originates west of the UK, in the Rockall Trough, and hence may be most closely related to North East Atlantic Water (NEAW).

Modified North Atlantic Water (MNAW) (Figure 3) - The temperature and salinity at the standard depth which exhibits the maximum salinity within an individual survey of the first two stations, on both standard sections, on the Faroese side of the Channel.

These criteria were defined in order to characterise Modified North Atlantic Water, the water mass which composes much of the surface waters of the Channel, and encompasses the anti-cyclonic flow of warm, surface water around the Faroe plateau. These waters most probably originate in the sub-tropical gyre, west of Rockall, and hence may more closely follow conditions in areas influenced by the North Atlantic Current. This water again is identified on a θ-S diagram as a salinity maximum for waters on the Faroese side of the Channel.

Removal of seasonal cycles: As the surveys over the past century have been done at quite different times of the year, the effect of the seasonal cycle in the surface waters has been removed using the monthly mean t and S derived over the period 1960–1990. These means have been calculated for each individual station and at each standard pressure level, and subtracted from the individual observations resulting in plots of t and S anomaly from the mean seasonal cycle.

Intermediate Waters:

Modified East Icelandic Water MEIW (Figure 4) - The average salinity at standard pressures which exhibit potential temperatures in the range 3.5°C >θ< 5.5°C, at stations 7 - 10 along the standard sections. These stations lie between the centre of the Channel and the Faroese plateau.

This criteria is designed to examine the mean characteristics of water hugging the Faroese slope, whose characteristics fall within the stated potential temperature range on a θ-S curve. Within this range an inflection in the slope of the curve is generally observed, indicating the presence of MEIW formed North of Iceland and along the northern slopes of the Iceland - Faroe Ridge. The water circulates around Faroe, partly leaving the Faroe Shetland Channel through the Faroe Bank Channel, and partly recirculating back into the Norwegian Sea. The water which satisfies this criteria generally lies within the pressure range 300–400 dbar. The MEIW temperature time series cannot be used due to the present definition employed. *Note this water was previously named as Arctic Intermediate/North Icelandic Water (AINIW)*

Norwegian Arctic Sea Intermediate Water (NSAIW) (Figure 5) - The salinity at the standard pressure which exhibits the minimum salinity within an individual survey of both standard sections, within the temperature range 0°C > θ < 1°C. Obviously the time series of temperature for this definition has little meaning.

This criteria is designed to examine the characteristics of the intermediate water mass created north of the Arctic front in the Iceland and Greenland Sea, which then subducts beneath the front forming a large salinity-minimum layer throughout the Norwegian Sea. The salinity minimum marking this water has not always been apparent due to changing properties of the water mass, but it has always been marked as a silicate minimum, and has been located between the stated temperatures.

Deep Waters:

Standard Pressure Levels (Figures 6–8) - Mean potential temperature and salinity at a standard pressure levels, averaged over all values on that pressure level recorded during an individual survey of both standard sections.

This method of deriving time series for the bottom waters in the Faroe Shetland Channel acknowledges that the characteristics of the water have changed considerably during the century, sometimes displaying the characteristics of true Norwegian Sea Deep water, while at other times being occupied by predominantly intermediate water.

North Sea Waters:

Fair Isle Current Water (FICW) (Figure 9) - The mean temperature and salinity at all standard pressures, averaged over the first two stations at the west end (Scottish) of the JONSIS standard section.

This criteria captures the characteristics of water entering the North Sea through the Fair Isle Channel. This water originates west of Scotland, and is a mixture of coastal water and Atlantic water that has come onto the shelf from the Slope Current.

Cooled Atlantic Water (CAW) (Figure 10) - The mean temperature and salinity at all standard pressures below 50 dbar, averaged over the first six stations at the east end (Norwegian) of the JONSIS standard section.

This criteria is designed to examine the characteristics of the cool dense lens of Atlantic water which forms in the centre of the North Sea during the summer months. During period of vertical stratification in the northern North Sera, this water mass retains the characteristics of the mixed North Sea during the previous winter, until the dense lower layer is eventually eroded through autumnal wind mixing, and again takes on the properties of the northern North Sea as a whole. Thus it generally represents water of Atlantic origin, modified by mixture with North sea coastal waters to a varying extent.

Removal of seasonal cycles: As the surveys over the observational period have been done at quite different times of the year, the effect of the seasonal cycle in the surface waters has been removed using the monthly mean t and S derived over the period 1970–1990. These means have been calculated for each individual station and at each standard pressure level, and subtracted from the individual observations resulting in plots of t and S anomaly from the mean seasonal cycle.

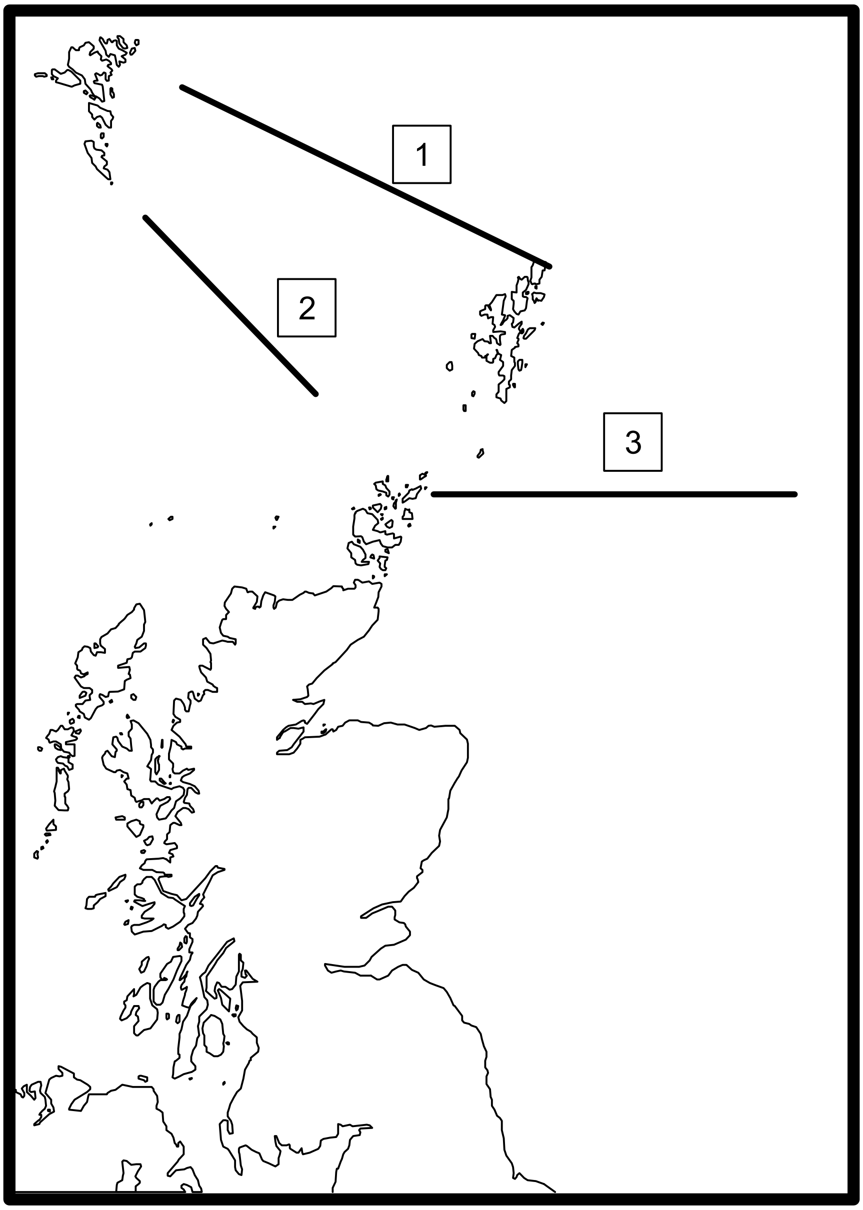


Figure 1. Position of Standard Sections occupied by FRS Marine Laboratory in 2002. Nolso –Flugga Section, 2) Fair Isle – Munken Section, 3) JONSIS Section.

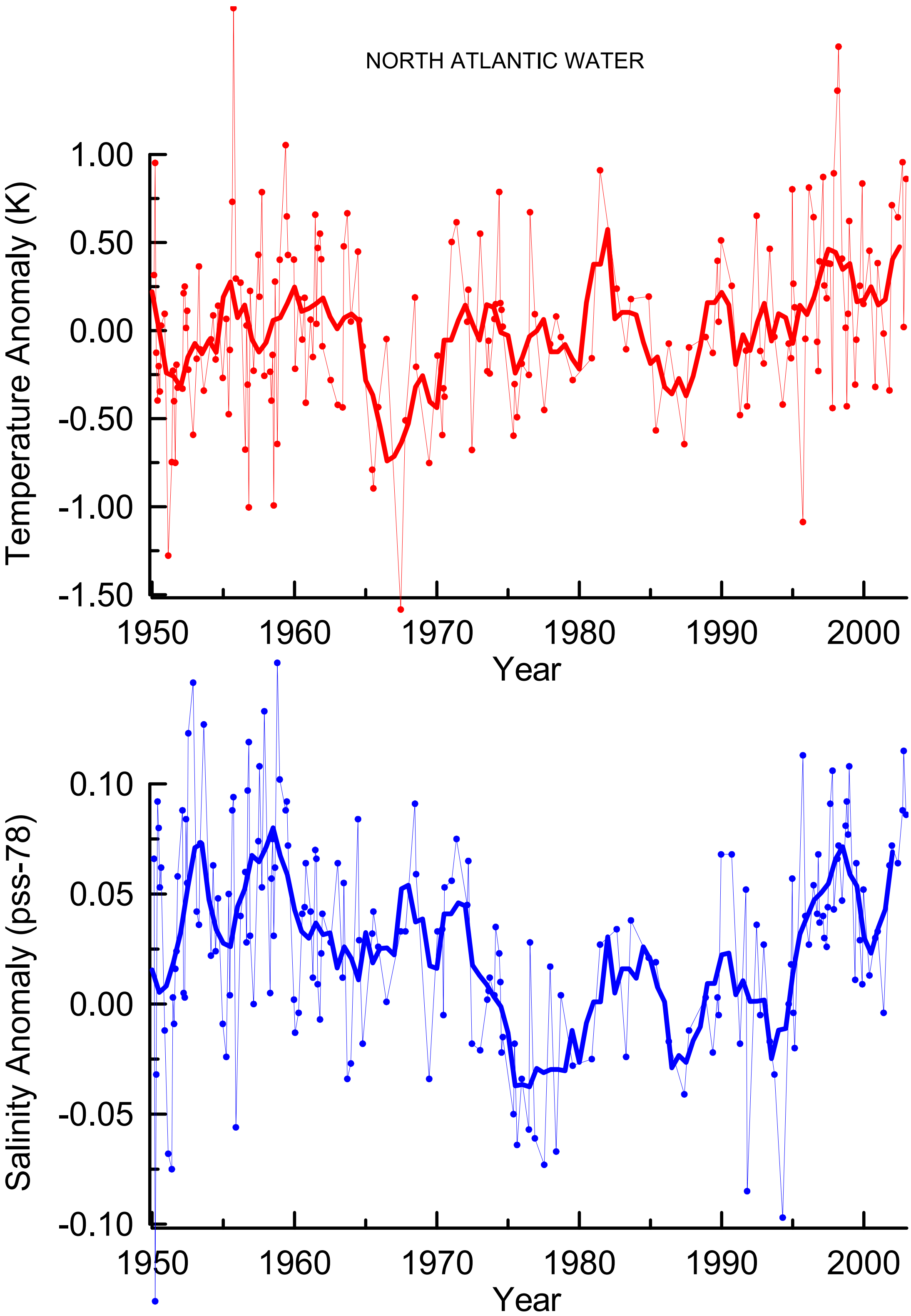
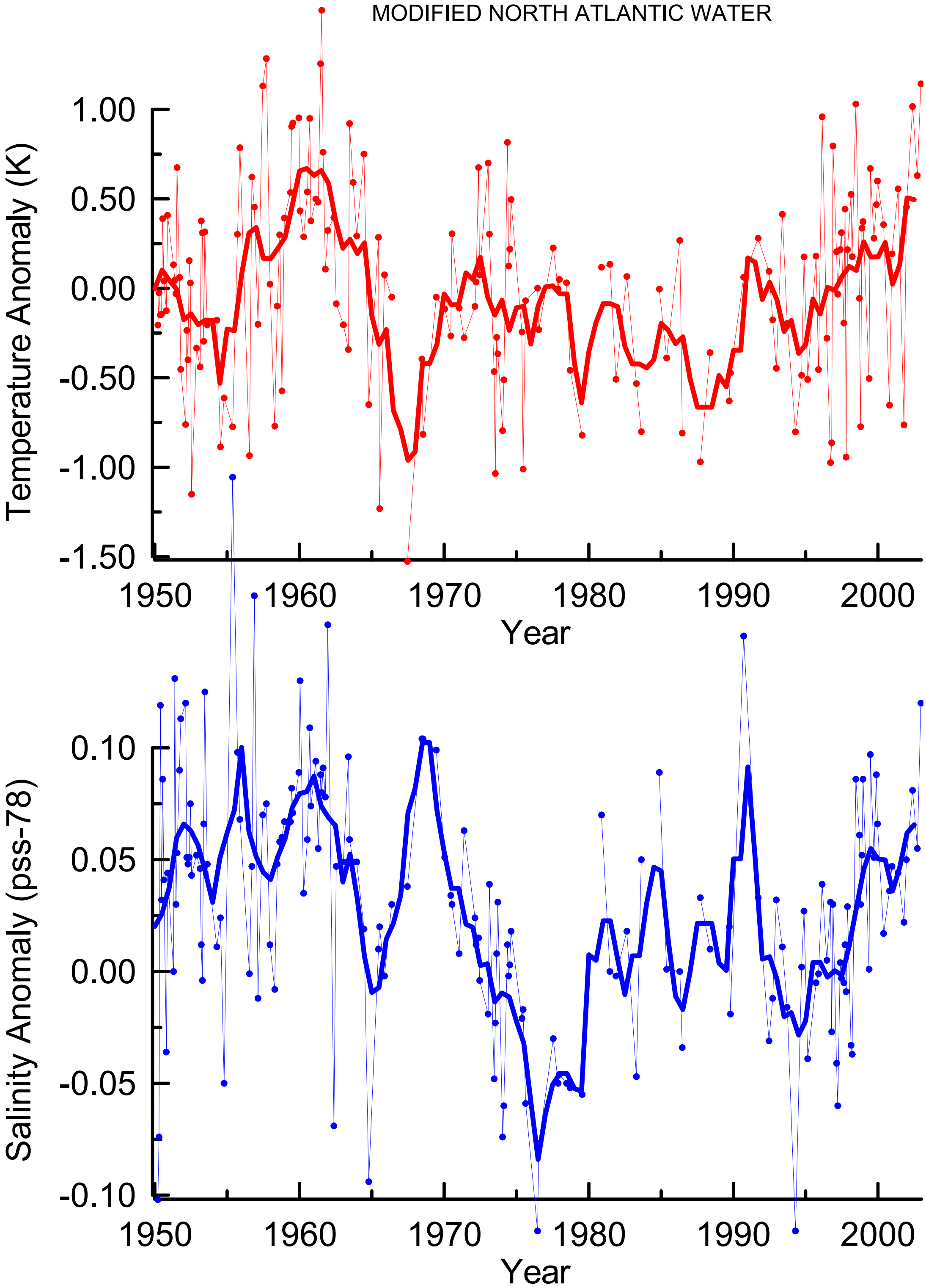

NORTH ATLANTIC WATER
1.00
0.50
0.00
-0.50
-1.00
-1.50
Temperature Anomaly (K)
1950
1960
1970
1980
1990
2000
Year
0.10
0.05
0.00
-0.05
-0.10
Salinity Anomaly (pss-78)
1950
1960
1970
1980
1990
2000
Year

Figure 2



MODIFIED NORTH ATLANTIC WATER
Temperature Anomaly (K)
1.00
0.50
0.00
-0.50
-1.00
-1.50
1950
1960
1970
1980
1990
2000
Year
Salinity Anomaly (pss-78)
0.10
0.05
0.00
-0.05
-0.10
1950
1960
1970
1980
1990
2000
Year

Figure 3

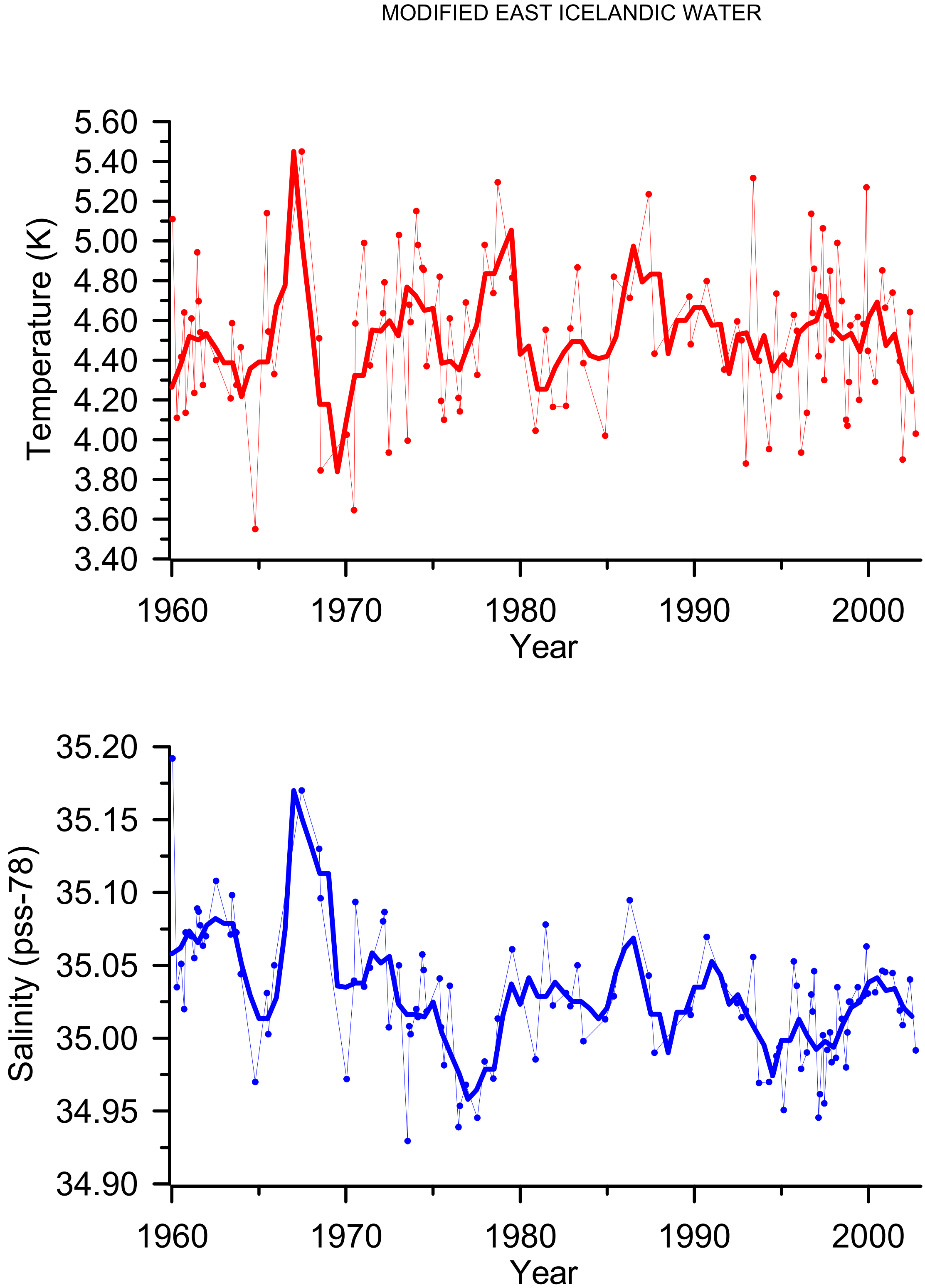
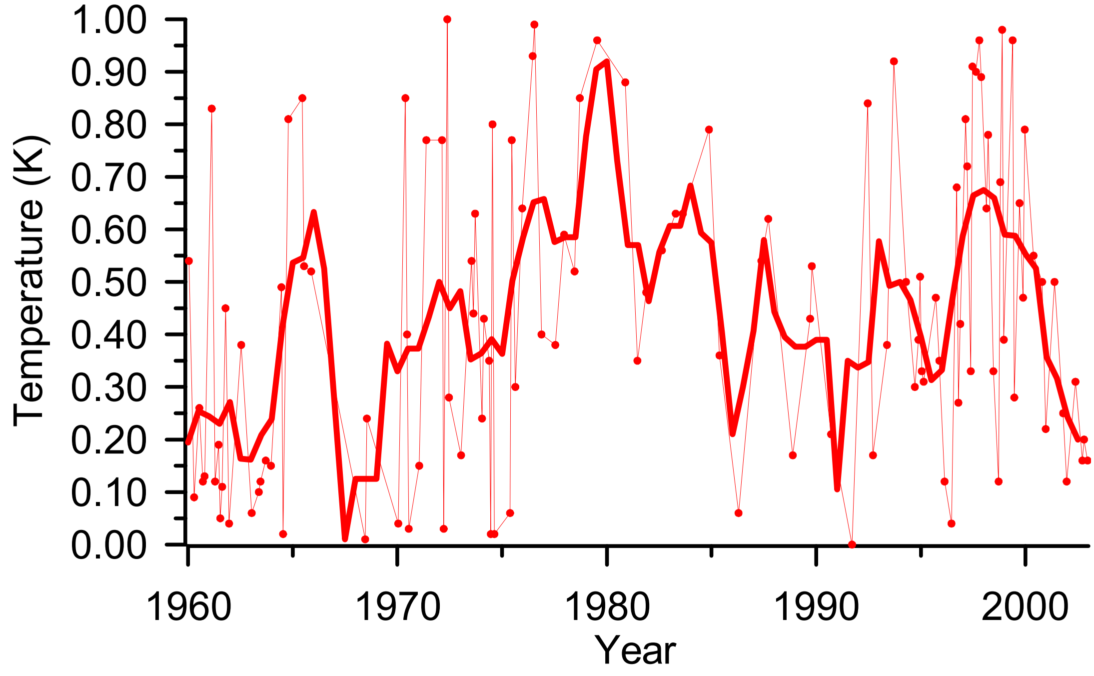

MODIFIED EAST ICELANDIC WATER
Temperature (K)
5.60
5.40
5.20
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
1960
1970
1980
1990
2000
Year
Salinity (pss-78)
35.20
35.15
35.10
35.05
35.00
34.95
34.90
1960
1970
1980
1990
2000
Year

Figure 4

NORWEGIAN SEA ARCTIC INTERMEDIATE WATER



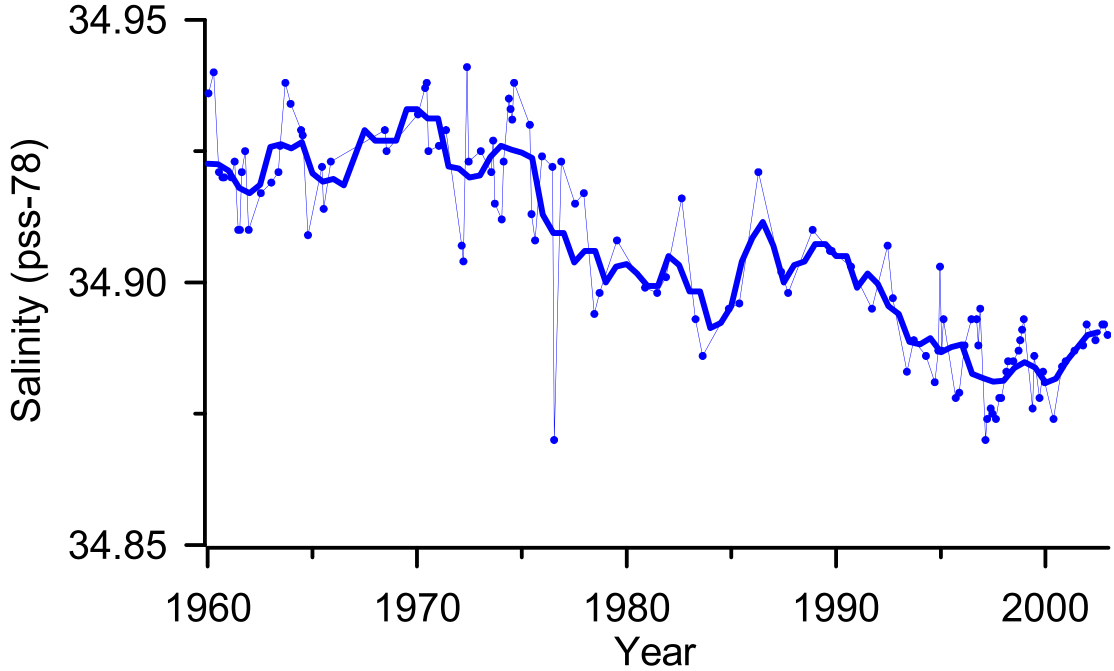


Figure 5

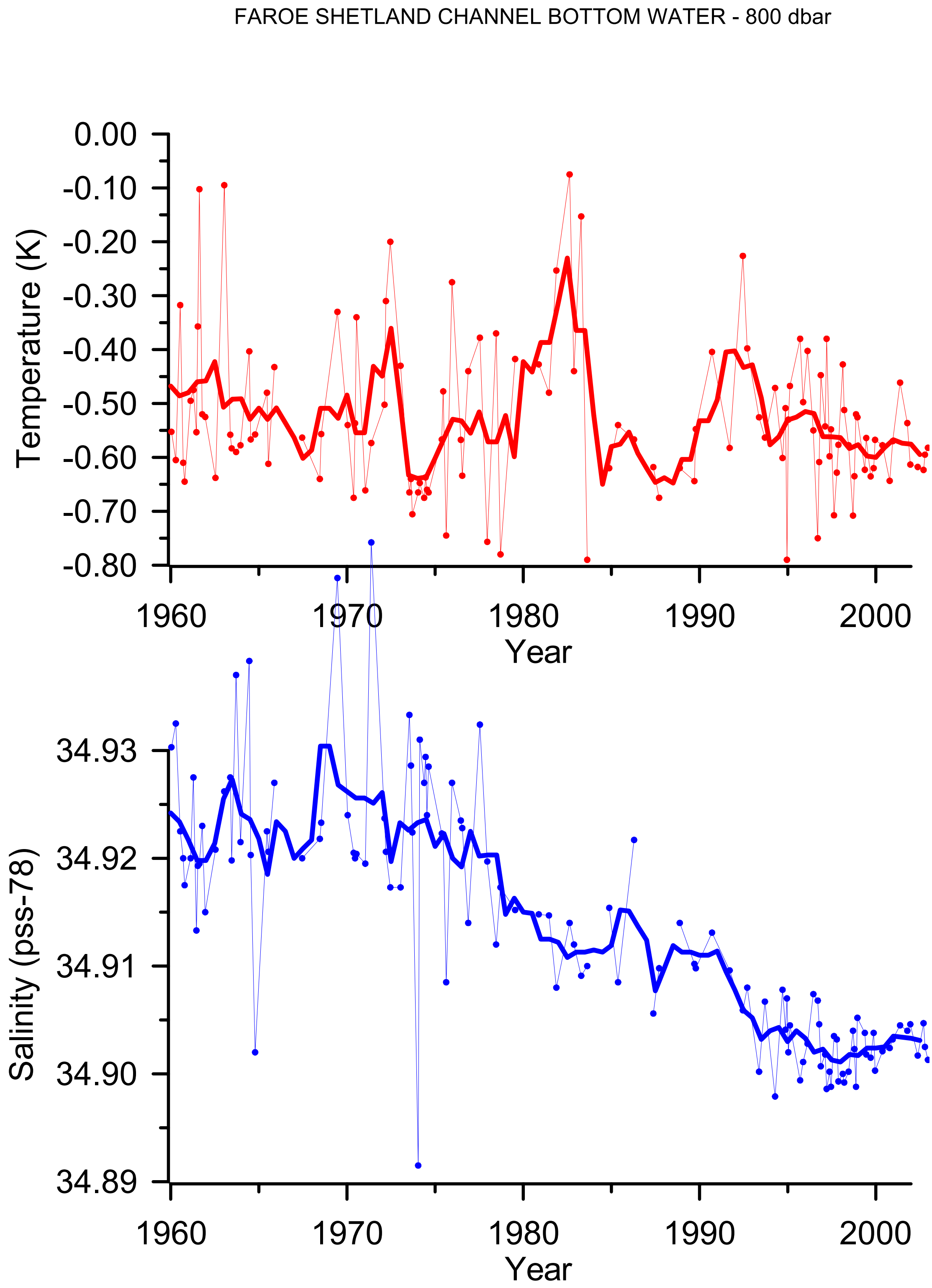

FAROE SHETLAND CHANNEL BOTTOM WATER - 800 dbar
Temperature (K)
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
-0.80
1960
1970
1980
1990
2000
Year
Salinity (pss-78)
34.93
34.92
34.91
34.90
34.89
1960
1970
1980
1990
2000
Year

Figure 6

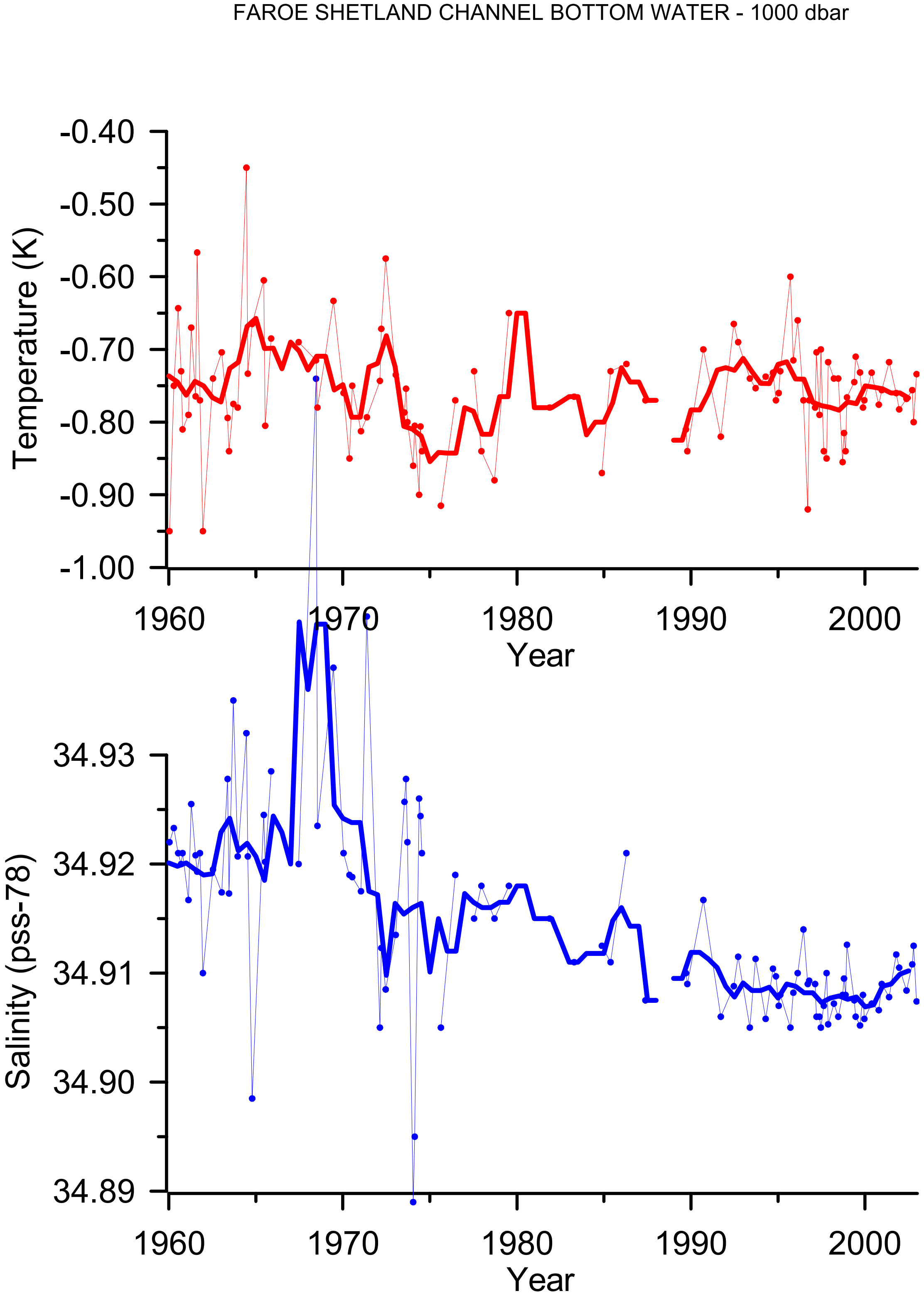

FAROE SHETLAND CHANNEL BOTTOM WATER - 1000 dbar
Temperature (K)
-0.40
-0.50
-0.60
-0.70
-0.80
-0.90
-1.00
1960
1970
1980
1990
2000
Year
Salinity (pss-78)
34.93
34.92
34.91
34.90
34.89
1960
1970
1980
1990
2000
Year

Figure 7

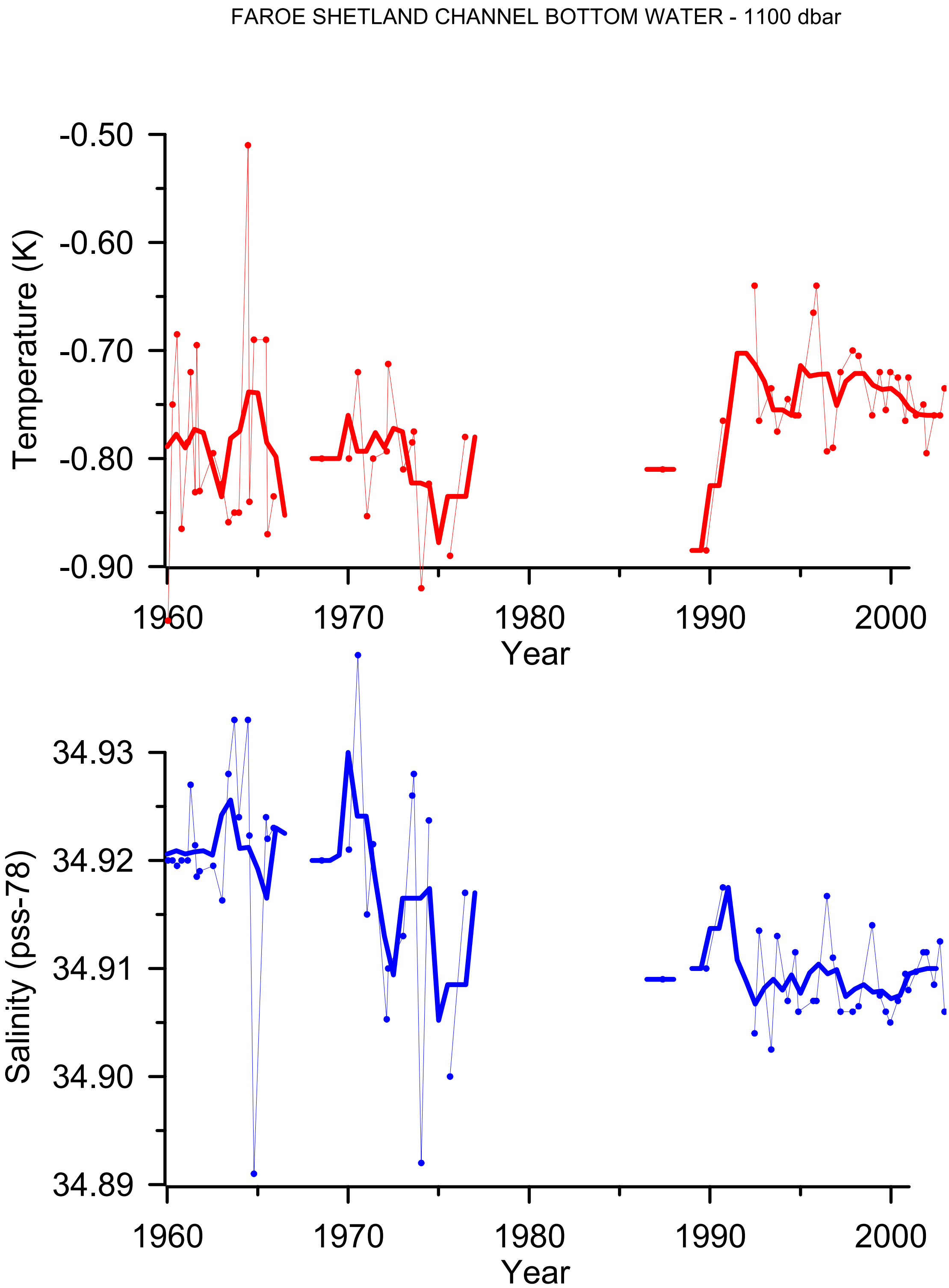

FAROE SHETLAND CHANNEL BOTTOM WATER - 1100 dbar
-0.50
-0.60
-0.70
-0.80
-0.90
Temperature (K)
1960
1970
1980
1990
2000
Year
34.93
34.92
34.91
34.90
34.89
Salinity (pss-78)
1960
1970
1980
1990
2000
Year

Figure 8

FAIR ISLE CURRENT WATER

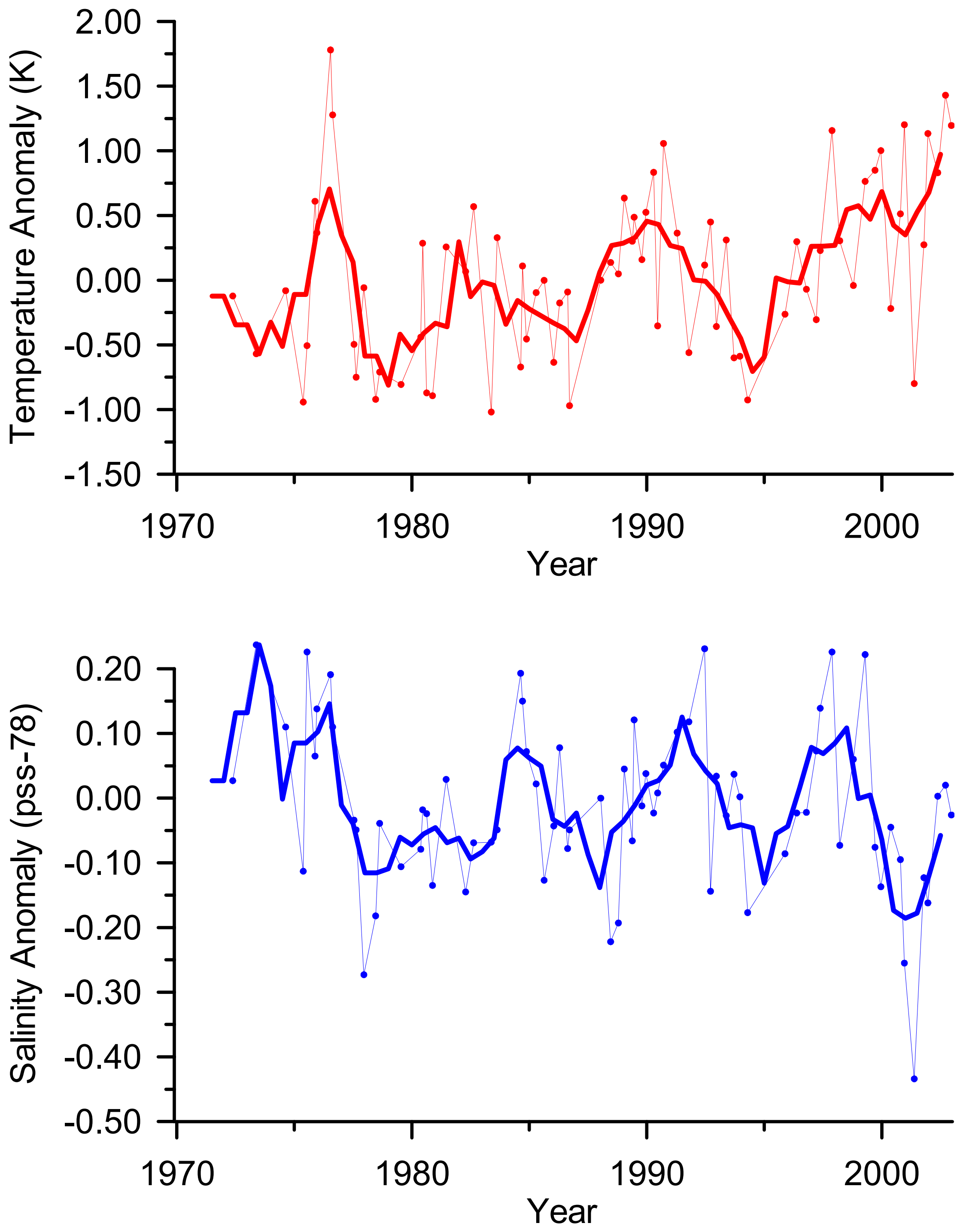
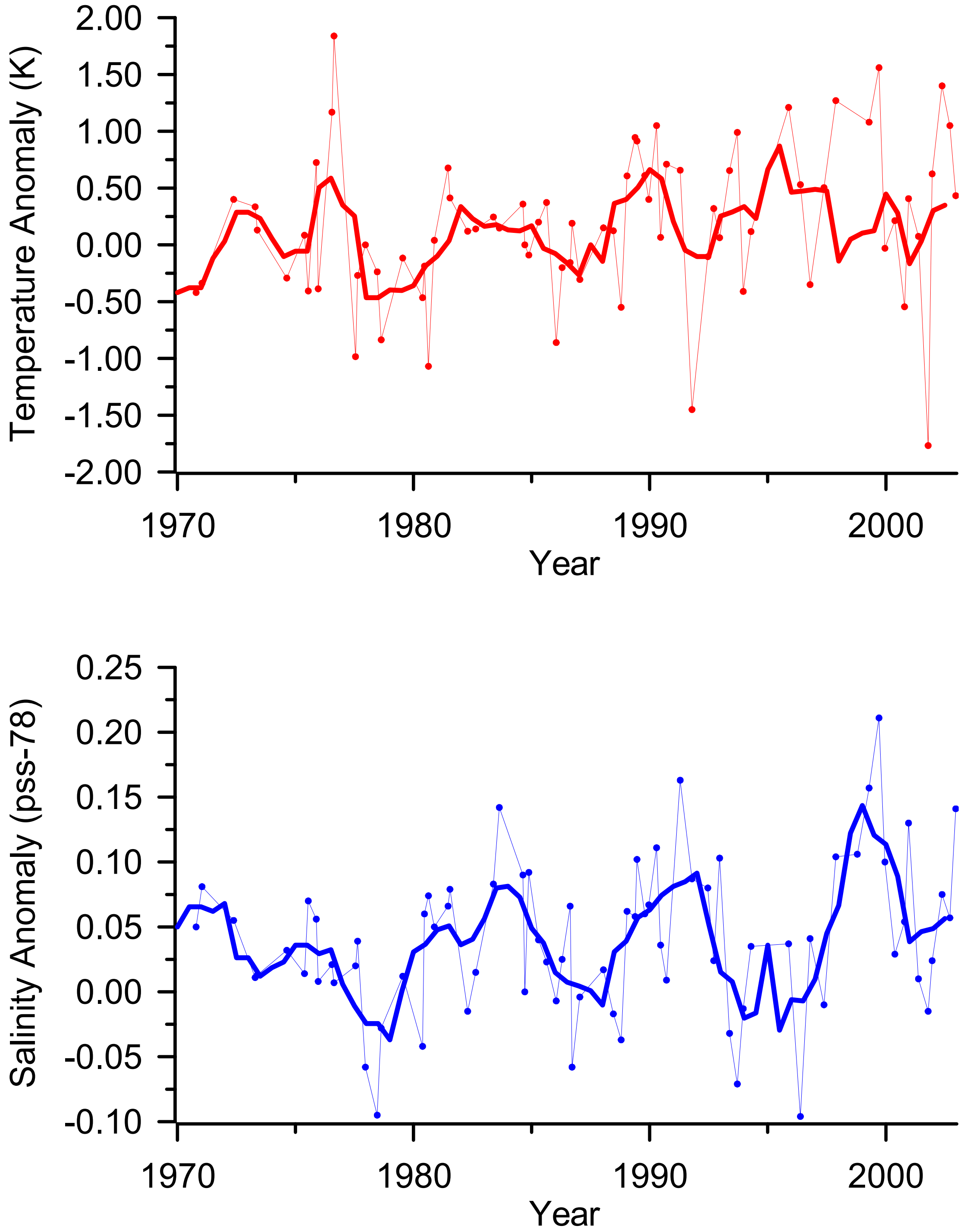


Figure 9



Temperature Anomaly (K)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
1970
1980
1990
2000
Year
Salinity Anomaly (pss-78)
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
1970
1980
1990
2000
Year

Figure 10

ANNEX O: NORTH SEA SST SINCE 1968: SOME GROSS STATISTICS (AREA 8 AND 9)

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1 Introduction

Weekly North Sea SST analyses have been produced at BSH since September 1968. This archive of SST grids not only affords insights into the spatio-temporal evolution over the past several decades of a key parameter of physical ocean state. As SST is an integrator of meteorological forcing this dataset also proofs useful in climate change assessments in the North Sea region.

By presenting some of the gross statistical features of North Sea SST this short note contributes to the latter.

2 Basics

In order to identify and rate anomalous states in geographical SST distributions a climatology was calculated together with interannual standard deviations for each month from weekly SST grids of the base period 1971–1993. *Anomalies* are deviations of a monthly SST distribution from the corresponding climate "normal" month, while *standardized anomalies* measure these departures in units of standard deviations from the normal. The latter actually form a Z statistic with any realization z (z-score) defining an ordinate that subdivides the unit area under a normal probability density curve. The value corresponding to the fractional area to the left of such ordinate is called *percentile* and is indicative of the frequency of occurrence or significance of the anomaly at hand. By way of example, a p-value below <1% (>99%) would identify an extreme or centennial cold (warm) event.

The complete set of monthly distributions of SST, SST anomalies, and associated percentiles may be inspected at http://www.bsh.de/aktdat/mk/M54ANOMe.html.

Gross temporal characteristics of North Sea SST may be derived from the time series of spatially averaged monthly means. The analysis here again is based on the definition of a normal annual cycle (base period 1971–1993) and associated interannual standard deviations as to afford an objective rating of anomalous SSTs.

3 2002

An annual average temperature of 11.0° C made 2002 the warmest year on record.

Another record was set in September (16.2°C), while the months of April, August, and October were the second warmest after 1990, 1997, and 2001, respectively. As is apparent from Figure 1, SSTs exceeded climate normals nearly basin-wide and throughout the year. Spatially averaged anomalies were significant at p-levels > 95% during F-M-A and >99% during A-S-O.

The 12 warm anomalies of 2002 form part of a run of warm anomalies of unprecedented duration. This run started in July 2001 and continued at the time of writing. Even though some elongation of sequences of positive (or negative) anomalies can be expected as a consequence of autocorrelation among months, the difference in probabilities for observing 20+ positive anomalies in a row and a 20 heads run in tossing a fair coin (0.5^{20}) would appear marginal. Other anomaly runs of comparable length (e.g., 12/1978–04/1980=17, 11/1985–11/1986=13, 06/1997–06/1998=13 and 12/1998–05/2000=17) hint to the presence of prolonged across-season cooling and warming trends that are hard to explain by chance.

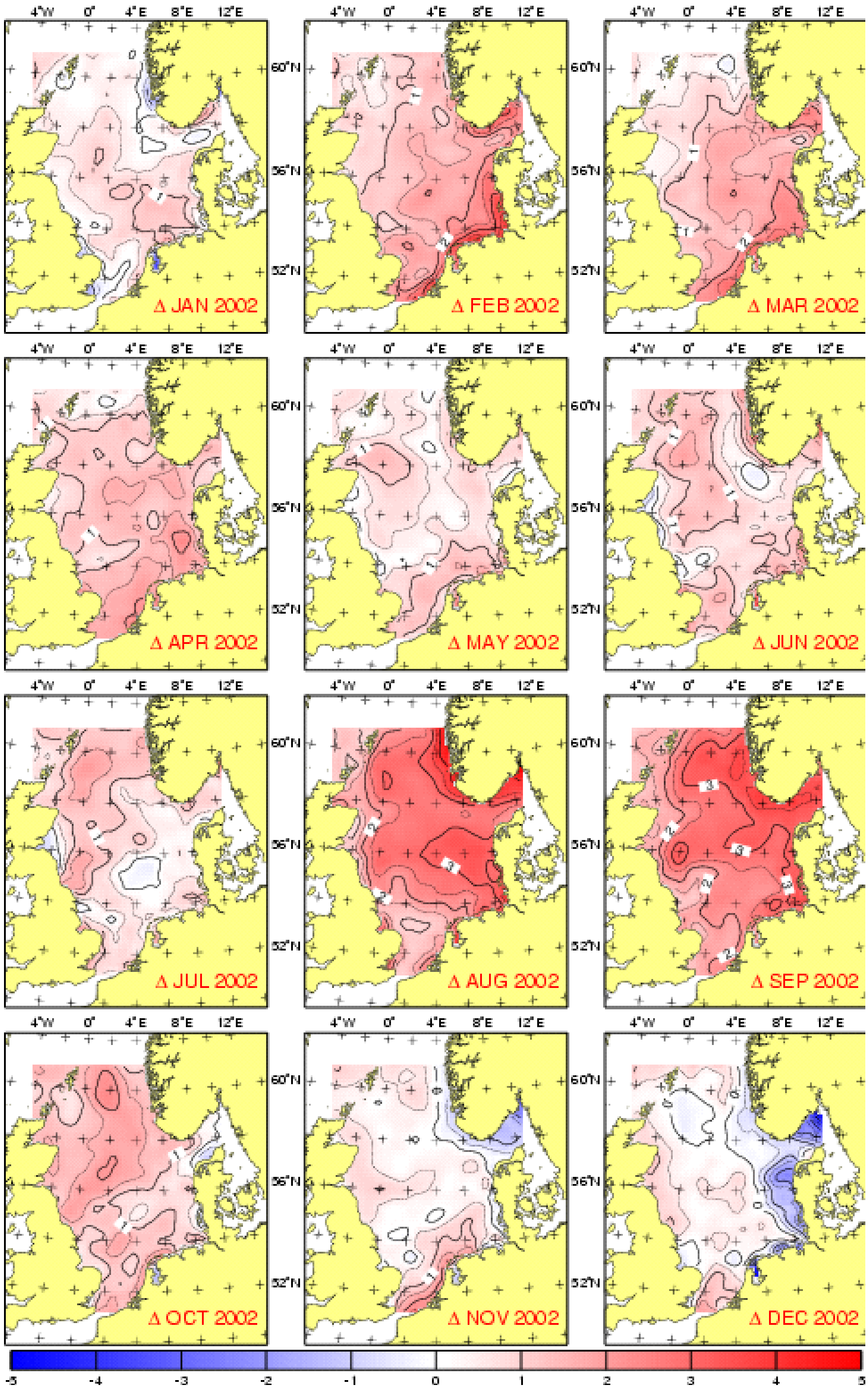

Figure 1. Monthly SST anomalies (°K) in 2002.

4 1968–2002

Some basic temporal features of North Sea SST over the past 35 years are evident from spatial mean monthly time series (Figure2). To emphasize these properties a 1D lowpass filter was applied to each series displayed here in a pseudo-2D time domain.

SSTs range from 3 to 18 °C and assume their extremes at the end of February and in mid-August. The seasonal/annual time sections suggest a quasi-periodicity of 8+/-1 yrs in winter (1970,1979, mid1980s, 1996). This quasi-cycle is detectable in many geophysical time series of the area and may be attributed to the North Atlantic Oscillation (Loewe and Koslowski, 1998).

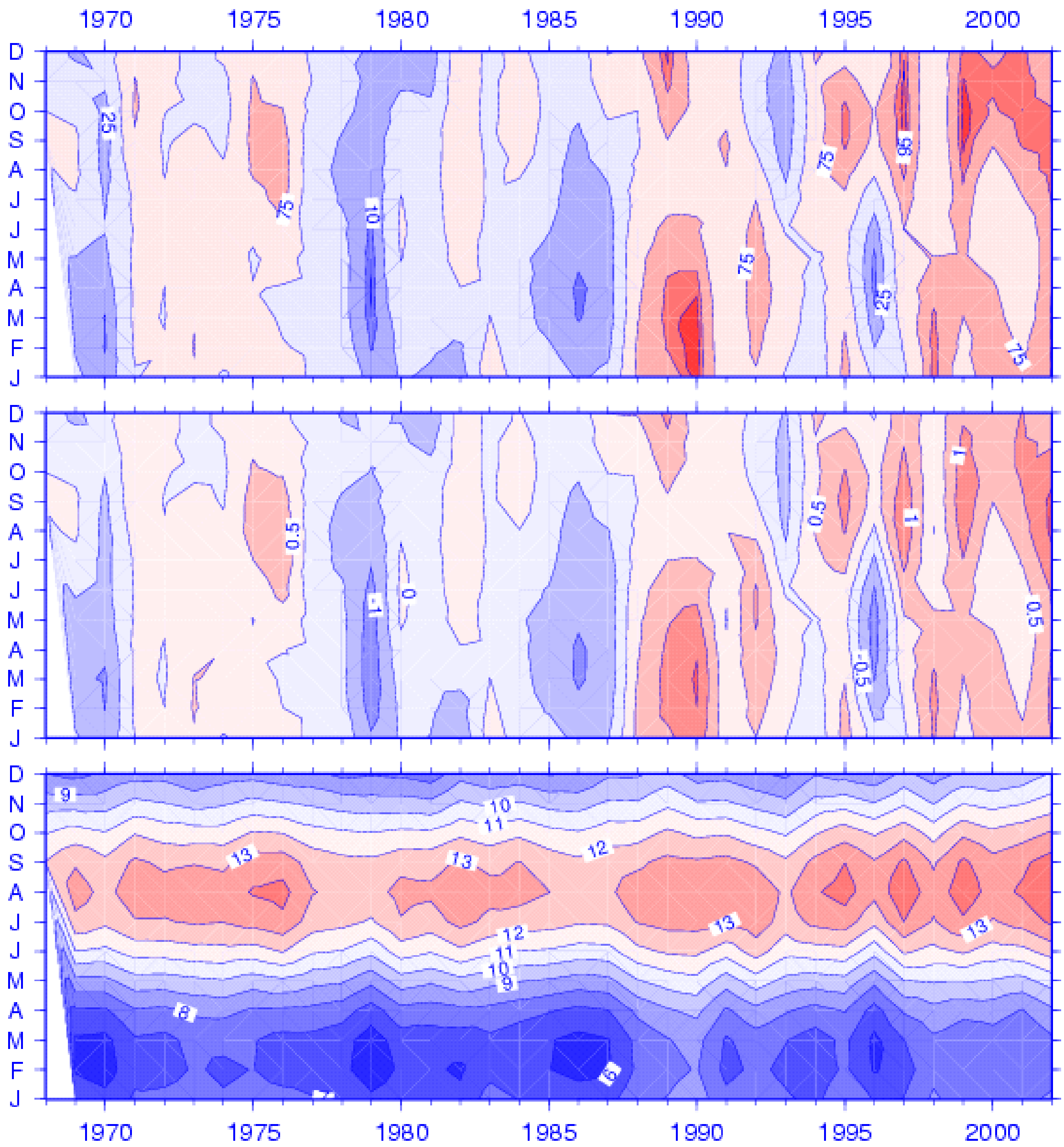

Figure 2. Monthly mean SST (bottom), SST anomalies (°K), and associated Gaussian percentiles. All time series smoothed using a Gaussian filter of width 9 months.

Another notable feature is the predominance of long-lasting and excessive warm anomalies since the late 1980s. These anomalies are most significant in fall but are of notable size in winter and spring as well. The last major rupture of this anomalously warm phase occurred in 1996 when the North Atlantic Oscillation was locked for an extended spell in its negative mode.

The current warm phase could be somewhat disturbing if one lost sight of the fact that it was preceded by a persistent cold spell of comparable length and that opposing anomalies during both these periods are compensating to some large extent. What is more interesting about this decade-long cold period is not only its coming into existence right after the until then hottest summer events in 1975–1976, but also its abrupt termination in late 1987 after a final extreme cold event. The more conventional presentation of serial monthly SST anomalies of Figure 3 illustrates this point even better.

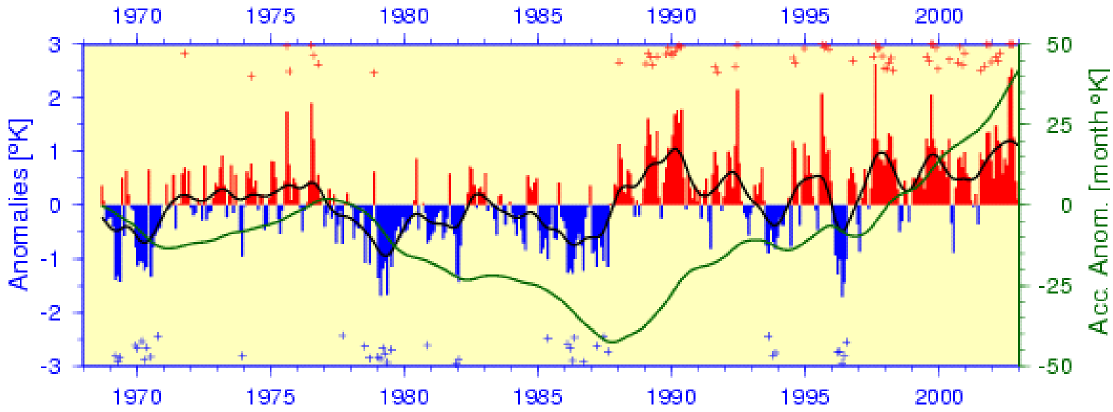

Figure 3. Serial monthly SST anomalies. Percentiles (+) given when <10% or >90% (use right scale +50). Gaussian filter of width 24 months (black). Accumulated filtered anomalies (green).

While it is possible to determine a linear trend of 0.9°C for the entire period of observations, this would promote the conception of gradual warming, which actually did not take place. From the course of accumulated anomalies in Figure 3 it is easy to identify 3 distinct and trend-free phases (viz. 1971–1976 (overall mean 10.1°C), 1978–1987 (9.5°C), and 1989–2001 (10.3°C)) which are separated from one another through sharp jumps. A t-test on the differences of means suggests that the cold period stems from a different population than the warm ones (p>99%).

It is apparent from the filtered anomalies of Figure 3 that a large fraction of SST variance is accounted for by quasi-biennial oscillations (most prominent since 1990) and significant power in the 5–10 yrs periodicity range. Both these frequency bands were shown to stand out in the spectrum of the index of the winter North Atlantic Oscillation (Loewe and Koslowski, 1998). Though the NAO is characterised by two modes, the positive mode clearly is the one preferably assumed (otherwise the terms Icelandic Low / Aleutian High were not very useful). This behaviour results in a skewed, bimodal probability distribution which may be approximated by a linear mixture of 2 Gaussians. Inasmuch as the NAO is accepted as the dominant forcing in North Sea SST variability (e.g., Loewe 1996), the detected differences in mean SST (for the 3 time sections defined in the previous paragraph) are expected to reflect the contemporaneous prevalence of opposite NAO modes (+,-,+).

5 Rank Statistics

Exceedingly long warm runs replaced prevalent cold runs in the late 1980s. The objective here is to proof significant the resulting differences in SST between adjacent time sections 1971–1986 and 1987–2002.

To this end a simple analysis is presented in Figure 4. For the period 1971–2002 annual mean SSTs were ranked by descending temperature. If historical SST had evolved at random one would expect a uniform population density of about 8/quadrant. The actually realised distributions show departures of +/-50% which can be proven significant using combinatorial analysis.

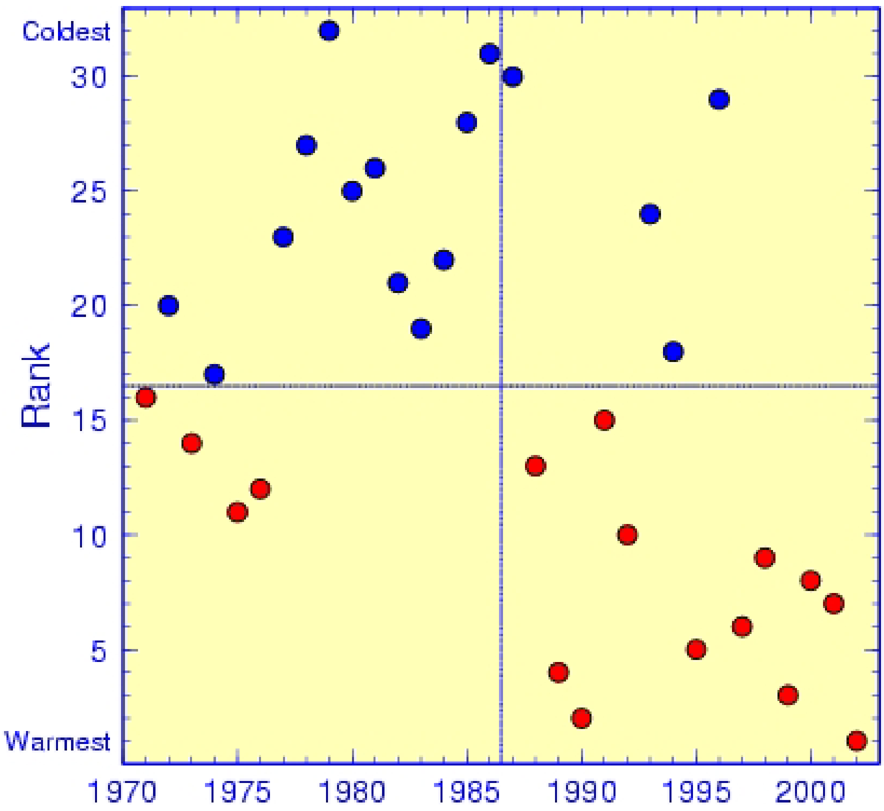

Figure 4. Ranked annual mean North Sea SST.

Note that the curious symmetry in quadrantal population is a mathematical necessity: the joint population of two adjacent quadrants must add to 16. It is therefore sufficient to show that the population of an arbitrary quadrant is unlikely to have resulted from chance.

Consider a box containing 16 red and another 16 blue objects representing the warm and cold annual SST data of Figure 4. Next select 16 objects out of the lot of 32 at random and without replacement. This is possible in $_{32}C_{16} = 32!\,/\,(16!(32–16)!) = 6x10^8$ different ways. Similarly, the number of combinations to select 4 red objects out of 16 red objects is given by the *binomial coefficient* $_{16}C_4 = 1820$, while the remainder of the selection (necessarily 12 blue objects) can be realised in $_{16}C_{12} = {}_{16}C_4$ different ways. Let *X* be the chance variable “number of red objects selected”. The probability that *X=4* follows as the proportion of successes: $p(X=4) = {}_{16}C_4\ {}_{16}C_{12}\,/\,{}_{32}C_{16} = 0.55\%$.

4 warm and 12 cold years would thus be expected to occur in the long run just once in about 200 trials.

It is worth noting that *X* has the *hypergeometric distribution* with probability mass function

$$p(X = x) = f(x \mid n_s, n_r, n_b) = \binom{n_r}{x}\binom{n_b}{n_s - x}\binom{n_r + n_b}{n_s},$$

parameters n_{sample}, n_{red}, n_{blue}, and the property $f(x|n_s,n_r,n_b) = f(n_s-x|n_s,n_b,n_r)$. Mean and variance are $\mu = n_s\, n_r / (n_r + n_b)$ and $\sigma^2 = n_s\, n_r\, n_b\, (n_r + n_b - n_s) / (n_r + n_b)^2(n_r + n_b - 1)$ such that for $n_s = n_r = n_b = 16$, $\mu = 8$, $\sigma^2 = 2.06$, and $X = 4 = \mu - 2.83\sigma$.

Below, the probabilities of half the possible realisations of *X* are tabulated together with those from the cumulative distribution function $\sum_{i=0}^{x} p\left(X = i\right)$.

Hypergeometric Distribution

x	0	1	2	3	**4**	5	6	7	8
$_{16}C_x$	1	16	120	560	**1820**	4368	8008	11440	12870
$p(X=x)$	$1.7E^{-9}$	$4.3E^{-7}$	$2.4E^{-5}$	$5.2E^{-4}$	**0.0055**	0.0317	0.1067	0.2177	0.2756
$p(X<=x)$	$1.7E^{-9}$	$4.3E^{-7}$	$2.4E^{-5}$	$5.5E^{-4}$	**0.0061**	0.0378	0.1445	0.3622	0.6378

Finally, applying this analysis to all calendar months yields that the observed numbers of warm months from 1971 to 1986 – in all seasons except summer – are highly unlikely to have occurred at random.

Number of warm months (rank<=16) during 1971–1986

	D	J	F	M	A	M	J	J	A	S	O	N
x	6	**5**	**4**	**4**	**4**	**5**	7	6	6	**5**	**5**	**5**

6 Final Remarks

The prevalence of positive temperature anomalies since the late 1980s is not regionally confined to the North Sea. Not only is the same phenomenon observed in surface air temperatures from the network of meteorological stations in Germany (Deutscher Wetterdienst, 2001). It also shows in the serial monthly anomalies of global temperature for the period 1961–2001 (cf. Figure 6 in Waple *et al.*, 2002).

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ANNEX P: THIRTY YEAR TIME-SERIES OF SURFACE TEMPERATURE AND SALINITY IN THE SOUTHERN BIGHT OF THE NORTH SEA (ICES AREA 9)

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The Centre for Environment Fisheries Aquaculture Sciences (CEFAS), Lowestoft, UK

Background

Near surface hydrography has been collected by a ship-of-opportunity along a route along 52°N between Felixstowe and Rotterdam since 1971. Temperature and salinity samples are collected weekly at 9 standard stations by the *Stena Freeway* providing an insight to the seasonal, interannual and decadal variability of surface water in the Southern Bight of the North Sea. Here we show data collected at the six standard stations most isolated from high variability coastal processes (Figure1) in order to put the conditions seen in 2002 in the context of those of the past 30 years. Samples were not available over the late summer/early autumn period as the ferry route changed operator and administrative headquarters in 2002, fortunately only 3 months (August-October) were lost to the time-series, and the sample collection recommenced in November.

Surface Temperature and Salinity in 2002

Conditions in 2001 saw an extreme freshening take place during spring across the entire section which persisted into December. SST was high through the summer of 2001 with some delay of the cooling part of the seasonal cycle into November. Figure 2 shows the seasonal cycles of SST and salinity at 3 of the stations on the standard section and compares the conditions of 2002 to those in 2001 and the climatology (1971–2001). Notable are the high winter-spring temperatures in 2002 compared to the climatology and 2001. On average February and March are the coolest months of the year; however very little cooling appears to have taken place after January 2002, and the late winter minimum in temperature was not present. This is likely to have been forced by anomalous atmospheric conditions either by increased wind driven flow of warmer waters eastward through the Dover Straits (strong westerly anomaly in February) or by reduced surface heat flux (warm air temperature anomaly - Feb and March; low wind speed anomaly - March).

Salinity across the section stayed below average until June 2002 and above average from then on. Figure 3 shows an independent measure of the salinity and temperature at the 'CEFAS Gabbard Smart Buoy' close to the position of standard station 4. This verifies the gradual increase in salinity at that station from its minimum in June 2001 to values above 35.0 in June 2002. The comparison with Smartbuoy salinities and regular research vessel samples suggest that the samples taken by the ferry are reliable. Temperature measurements appear less than reliable and possibly more sensitive to the measurement method. The mooring was moved in August 2002 so could not be used to cover the data gap in the standard section time-series.

Figure 2 illustrates that variability of salinity differs from station to station, making a comparison of raw salinity anomaly across the section difficult. In order to make the salinity anomaly time-series across the section comparable we have normalised the anomaly to the standard deviation of the data at each station. In Figure 4 are the time-longitude plots of the normalised temperature and salinity over the last 10 years, and Figure 5 shows time-series of the seasonal section means of the normalised temperature and salinity compared to the NAO_{DJFM} index.

Further explanation is required as to the cause of the periodic salinity anomalies that are apparent from this section (Figures 4 & 5), the lows of 1994–96 being followed by high salinity in 1997–1999, and return to low salinity 2001-summer 2002. Variations in precipitation and output of the large catchments around the Southern Bight is a process by which salinity variability could take place, these would generally be only weakly correlated with the NAO in this region. Variations in flow through the Dover Strait would affect the salinity of the Southern Bight, either through changes in the volume transport (likely to be wind-driven and related to the NAO) or properties of the water transported out of the Channel. Initial evidence from limited data in the eastern English Channel does show that 2001 was a year of low salinity there too, the cause of which could again be precipitation based or transport based.

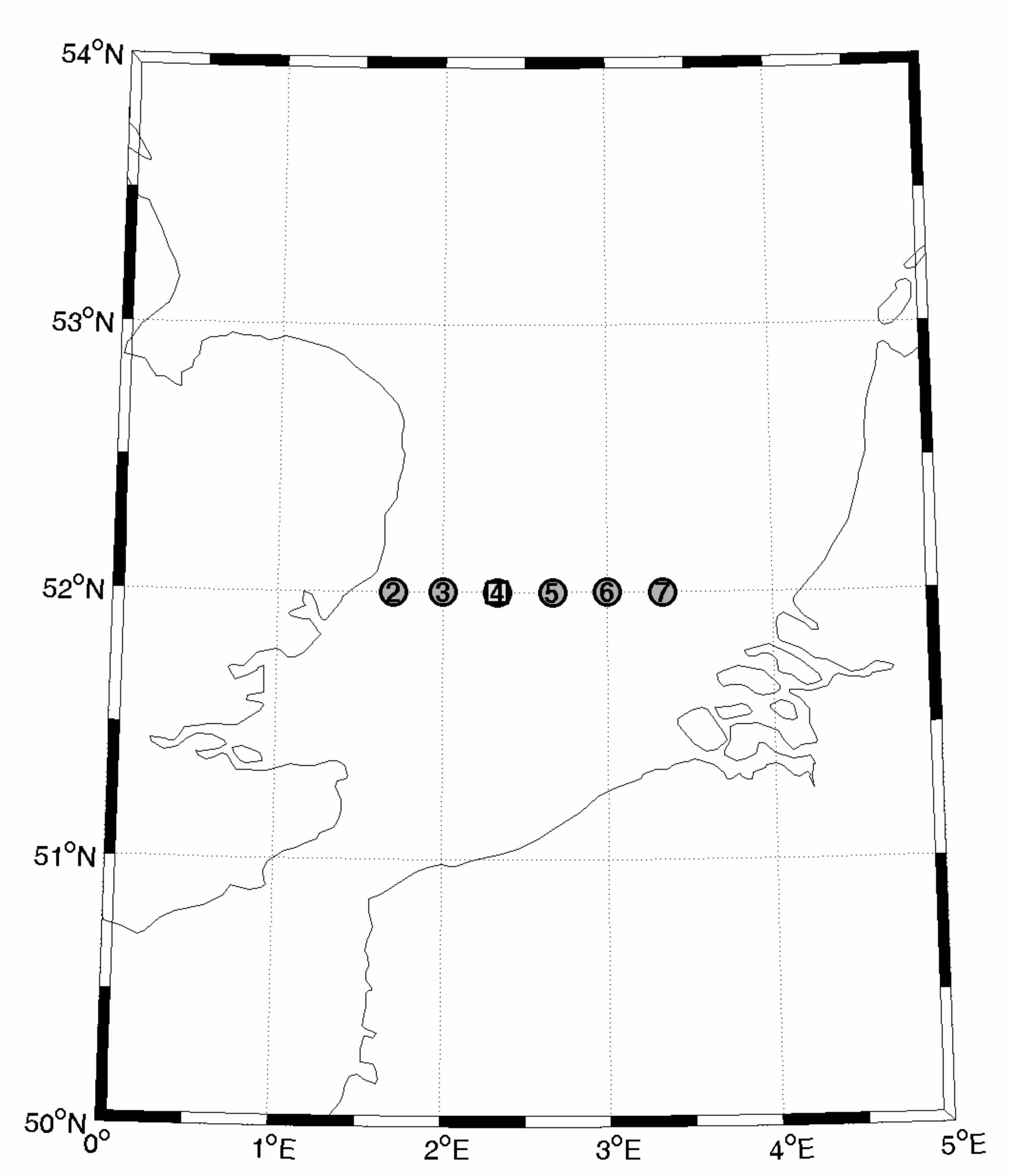


Figure 1. Positions of the six standard stations described here on the 52°N Felixstowe-Rotterdam Route, Station 4 is boxed and circled to show the position of the CEFAS Gabbard Smartbuoy as well as a station on the ferry route.

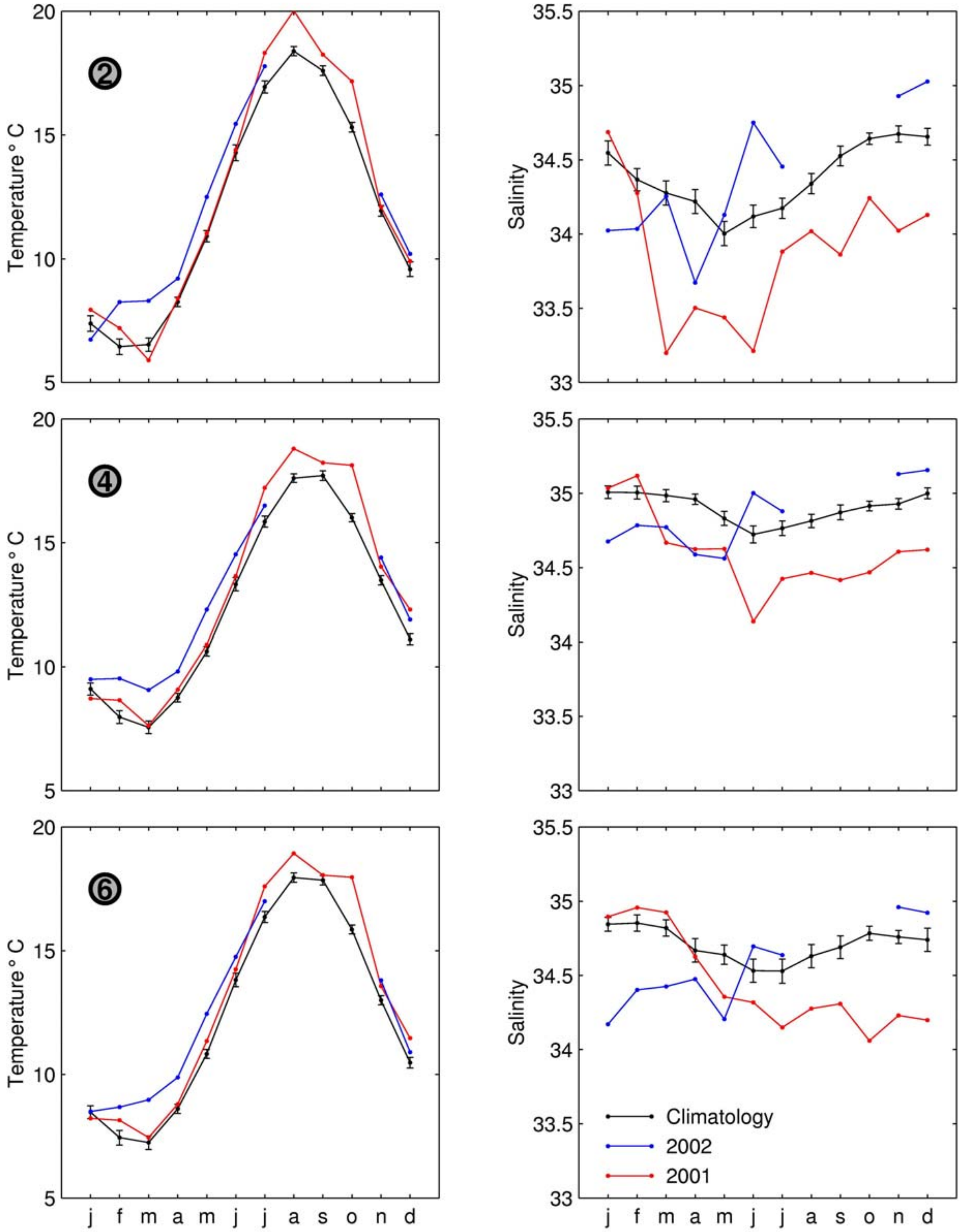


Figure 2. The annual cycle of temperature and salinity at stations 2, 4 and 6 of the 52°N Felixstowe-Rotterdam Route. The climatology in black is constructed from the full database of monthly means at each station, with the errorbar showing the standard error.

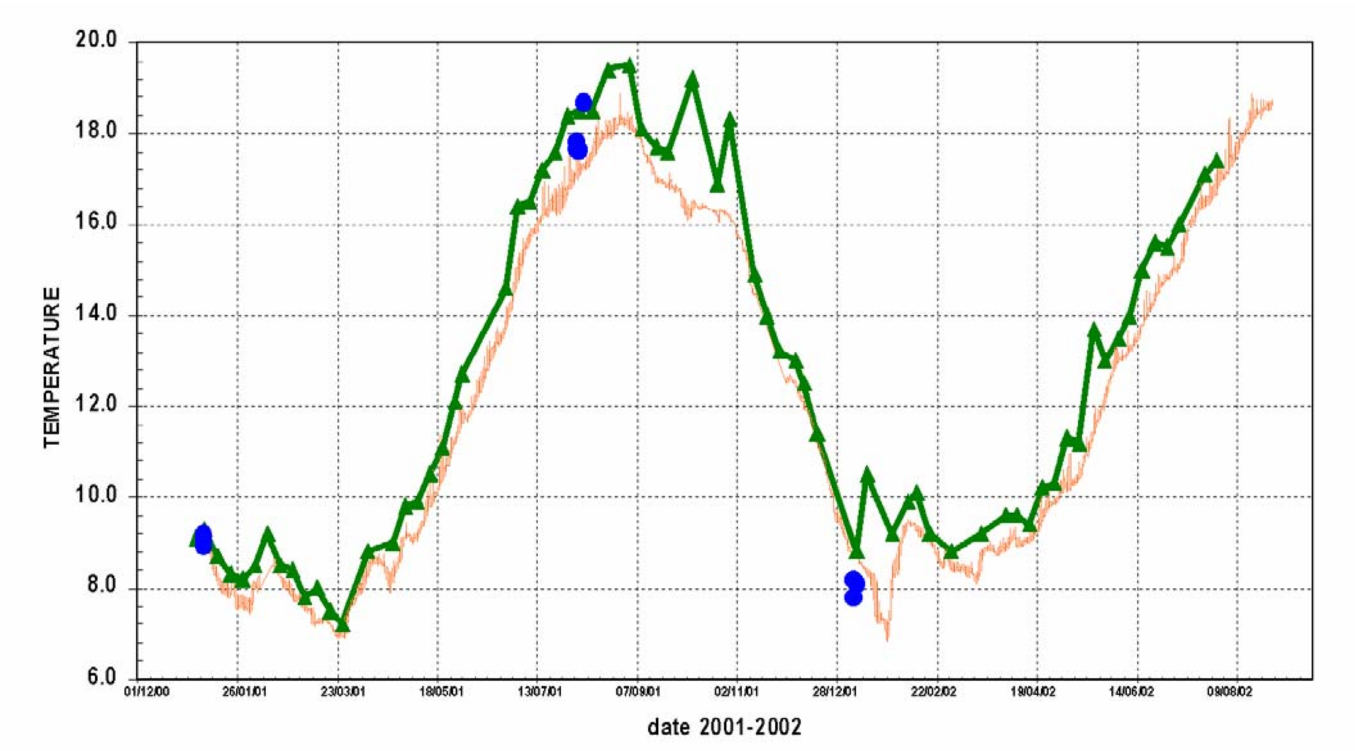
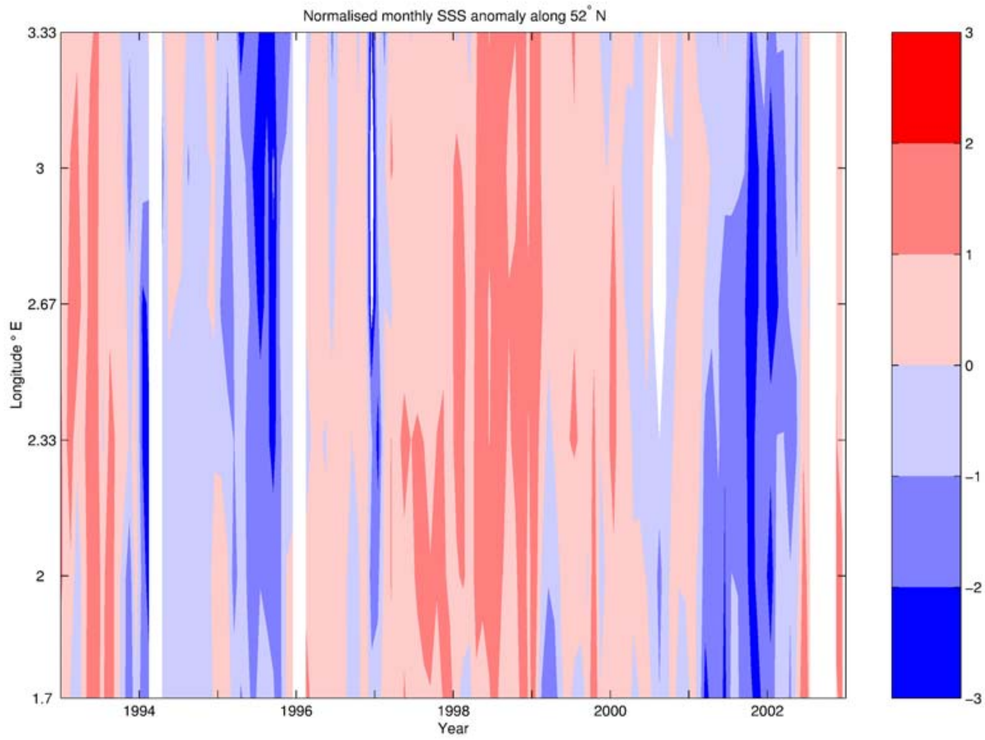


Figure 3. Comparison of a) salinity b) temperature at standard station 4 (green) with the semi continuous salinity from successive deployments of the of the CEFAS Gabbard Smartbuoy (orange line) and R/V CTD data (pink, blue, purple symbols). Data for the period Jan 2001 to August 2002 when the Smortbuoy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

a) Temperature



b) Salinity

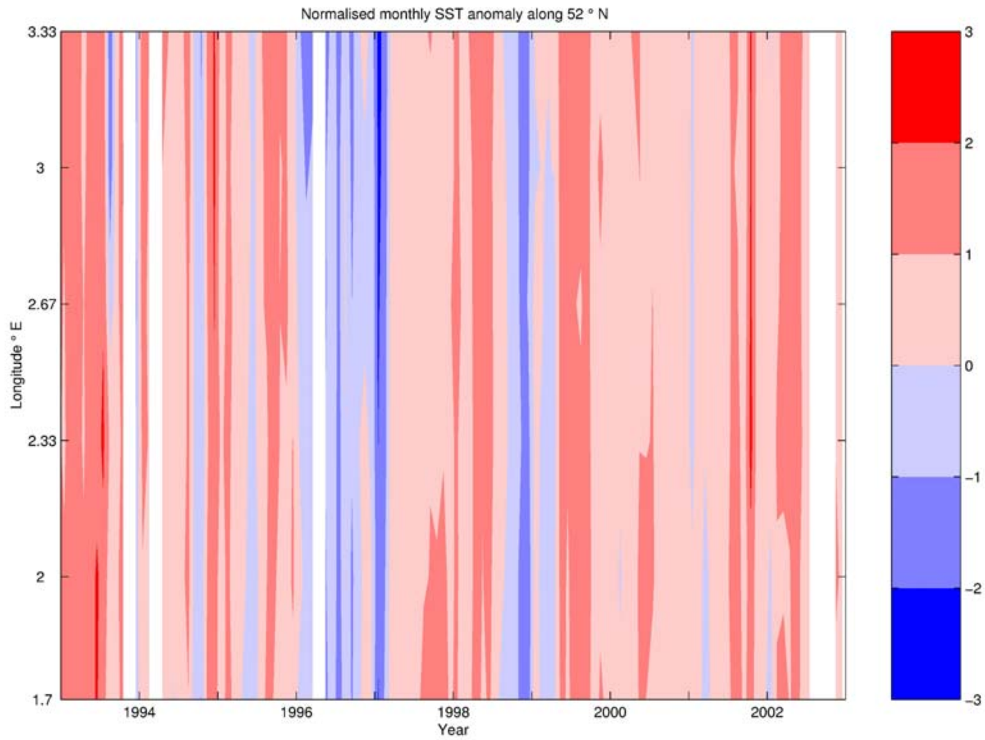


Figure 4. Normalised monthly a) Temperature b) Salinity anomaly along the 52°N Felixstowe-Rotterdam Route. Contours show the number of standard deviations that a particular month is from the monthly mean at that station.

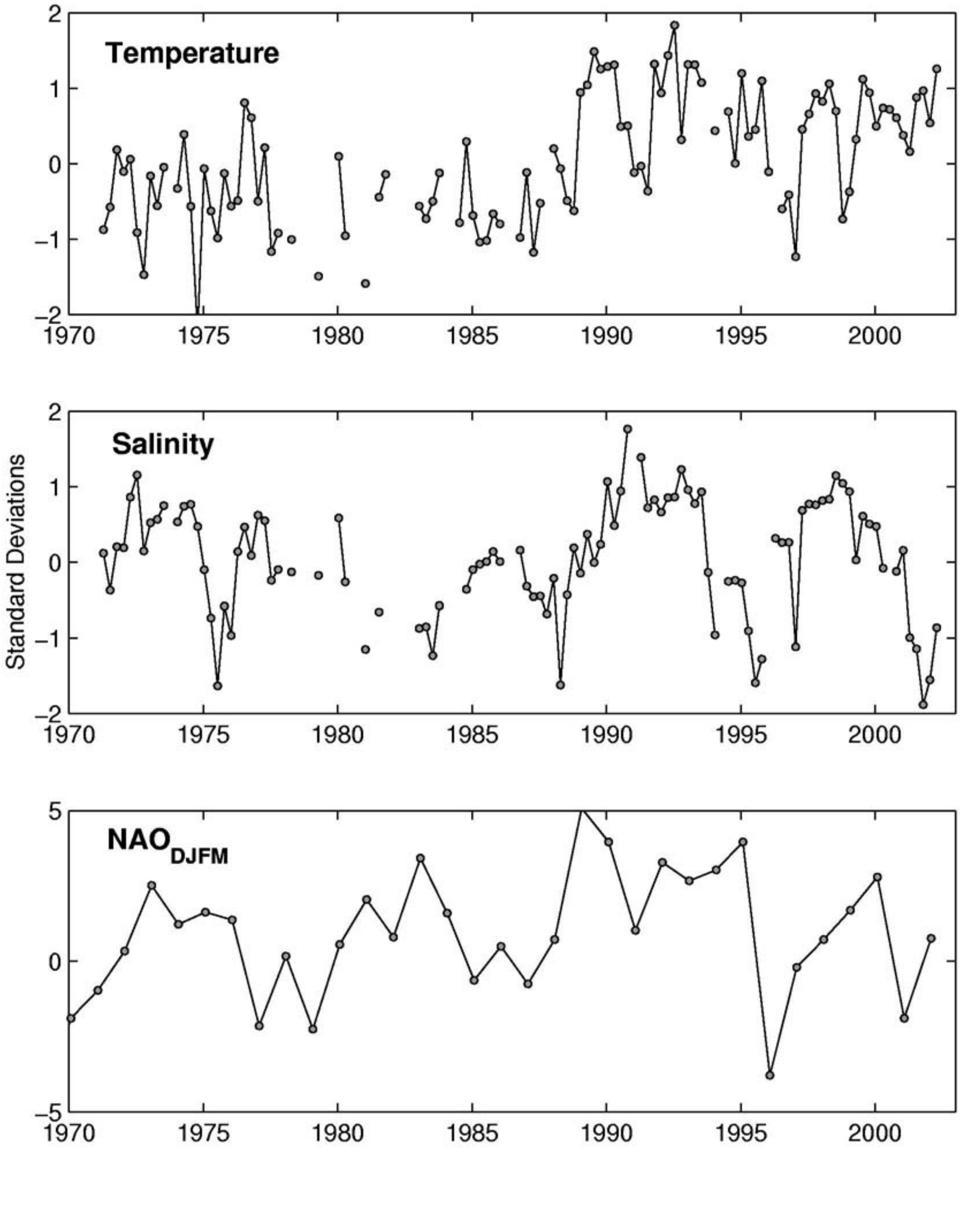


Figure 5. Normalised seasonal a) Temperature b) Salinity anomaly along the 52°N Felix-Rotterdam Route. c) Hurrell NAO$_{DJFM}$ index www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html

ANNEX Q: AREA 9B: SKAGERRAK, KATTEGAT AND THE BALTIC

K. Borenas

SMHI, Sweden

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

The year of 2002 was characterized by the late summer being unusually warm. Higher than normal sea surface temperatures were recorded for the whole area in August and early September. This state of affairs is demonstrated in the temperature record from station P2 in Skagerrak displayed in Figure 1. The diagram also depicts high values in the beginning of June, a feature representative for the situation in Kattegat as well. The weather changed rapidly in the autumn; on the Swedish west coast, for example, the transition from swimming conditions to a 10 cm thick snow cover took a little bit more than a month.

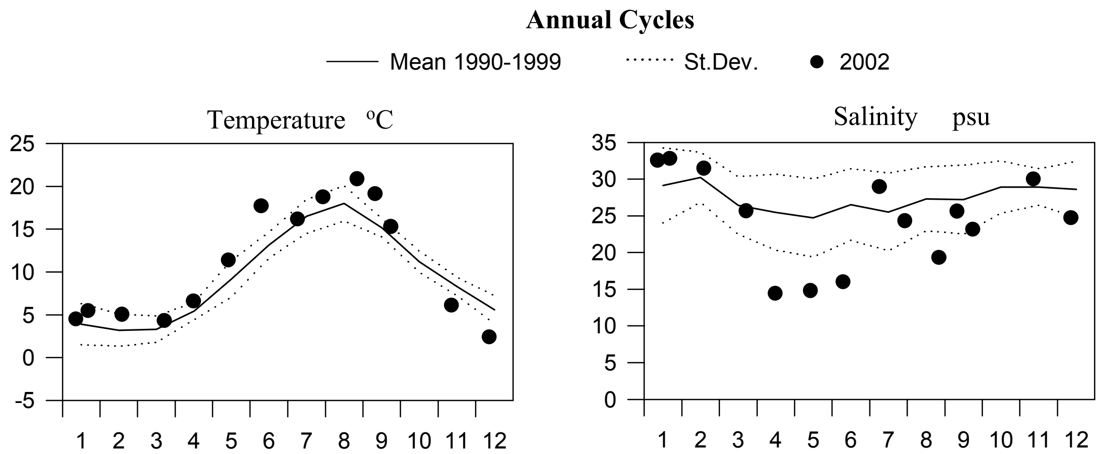


Figure 1. Annual cycles of surface temperature and salinity at station P2 in the southern part of Skagerrak. The data were collected by R/V Argos within the Swedish National Monitoring Programme.

For 2002 the outflow from the Baltic into Kattegat was less than normal until the middle of March when a longer period with sizeable outflows took place. This feature is illustrated in Figure 2 showing the accumulated inflow through Öresund for 2002. The diagram also includes the values for 2001 and 1993 as well as the maximum, minimum and mean values obtained from measurements during the period 1977–2001. The effect of large volumes of low saline water entering into Kattegat-Skagerrak is clearly visible in Figure 1, showing the salinity at P2 for 2002. No major inflows of high-saline water to the Baltic took place during the year.

The ice cover in the Baltic during the winter 2001/2002 had its maximum extent on March 14 2002. The ice winter was considered fairly mild. The onset of cold weather during the late fall 2002 caused an early start of the Baltic freeze up.

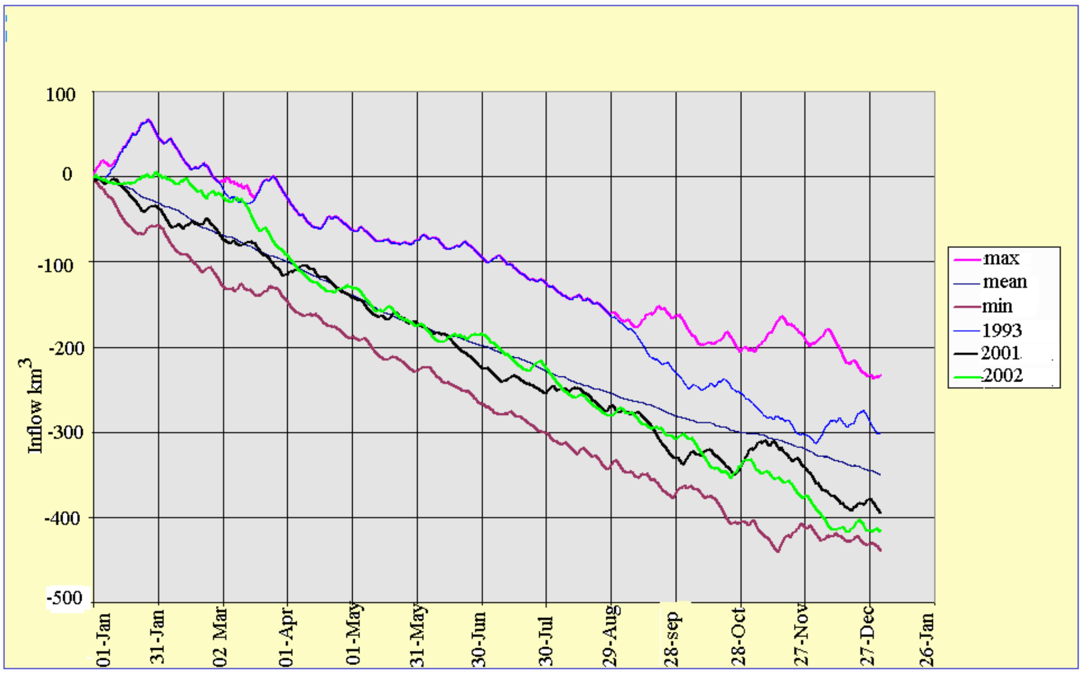


Figure 2. Accumulated inflow in km^3 through Öresund 1993, 2001 and 2002 compared with the period 1977–2001. The map was constructed by SMHI.

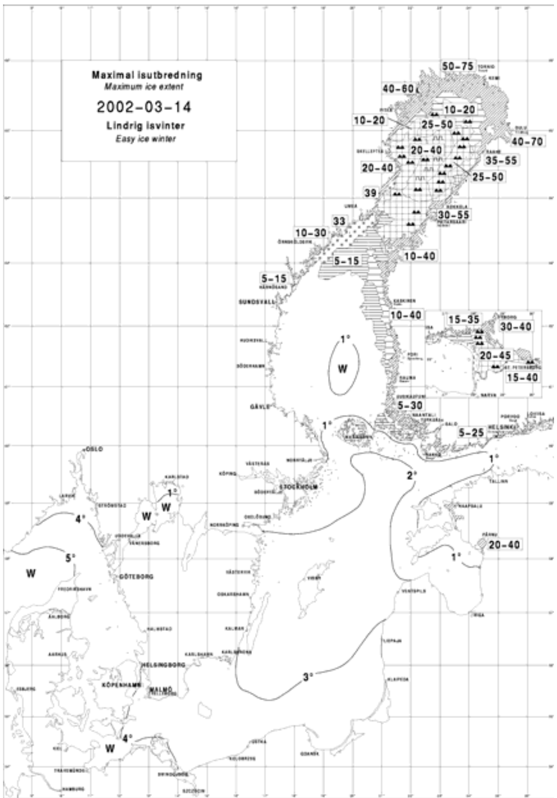
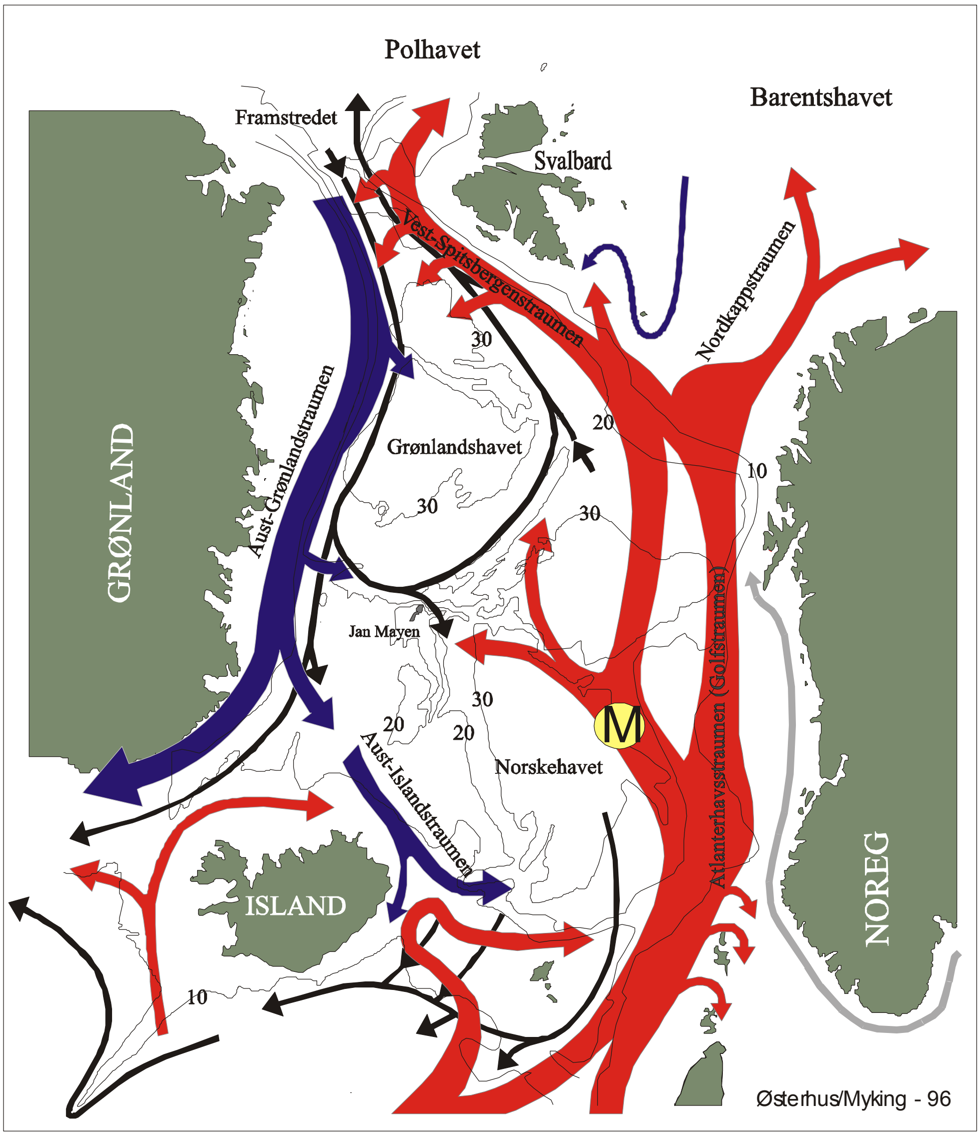


Figure 3. The maximum ice extent in the Baltic during the winter 2001/2002. The map was constructed by SMHI.

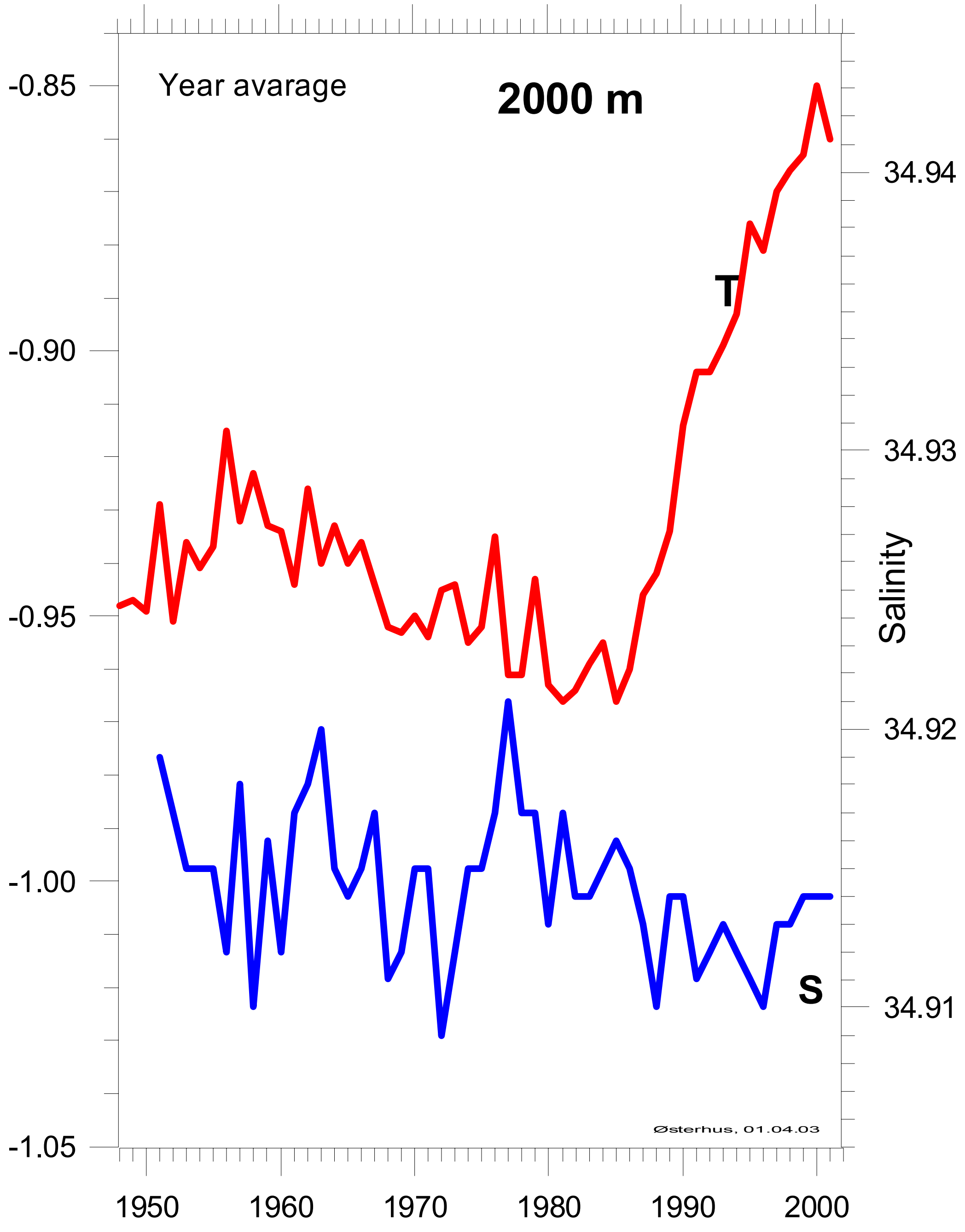
ANNEX R: OCEAN WEATHER STATION MIKE (AREA 10)

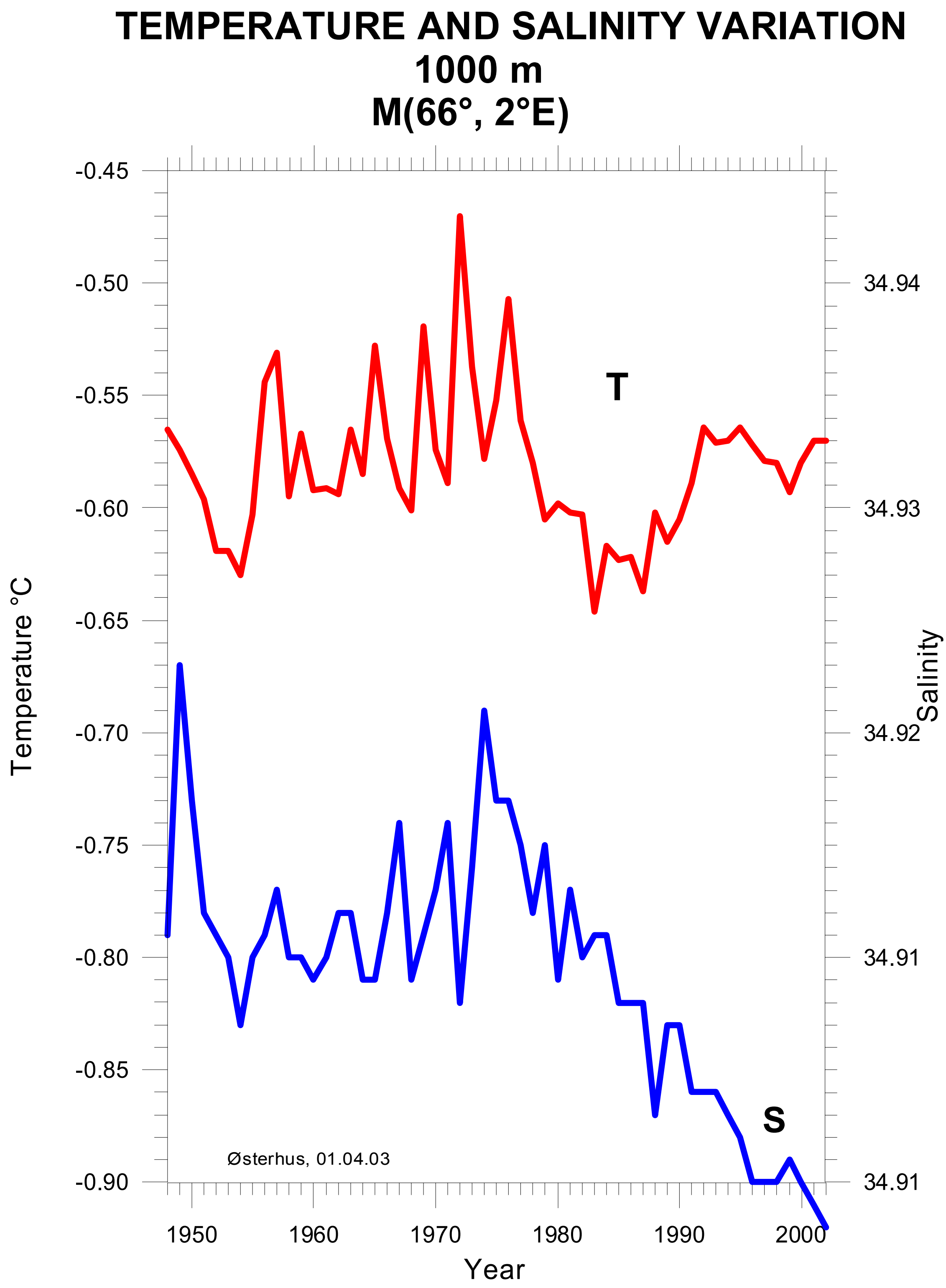
S. Østerhus

Bjerknes Centre for Climate Research, Norway



TEMPERATURE AND SALINITY VARIATION
2000 m
M (66°, 2°E)




TEMPERATURE AND SALINITY VARIATION
1000 m
M(66°, 2°E)
-0.45
-0.50
-0.55
-0.60
-0.65
-0.70
-0.75
-0.80
-0.85
-0.90
Temperature °C
34.94
34.93
34.92
34.91
34.91
Salinity
T
S
Østerhus, 01.04.03
1950
1960
1970
1980
1990
2000
Year

ANNEX S: NORWEGIAN WATERS (AREA 8, 10 AND 11)

Harald Loeng, Kjell Arne Mork and Einar Svendsen

Institute of Marine Research,, P.O. Box 1870 Nordnes, 5817 Bergen, Norway

Summary

The Barents Sea temperature was higher than average during summer of 2002. At the end of 2002, the temperature was just above the long-term mean. In 2002 there was, in the upper layer, an increased temperature in central part of the Norwegian Sea. In the North Sea, the temperature was high in 2002.

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

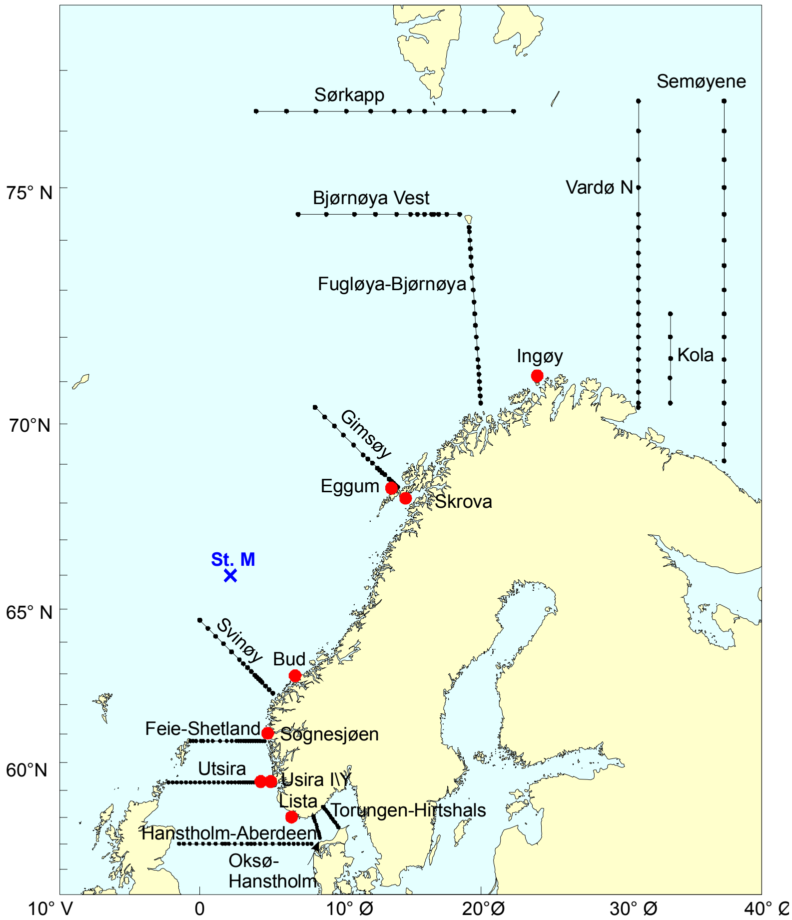


Figure 1. Standard sections and fixed oceanographic station worked by Institute of Marine Research, Bergen. The University of Bergen is responsible for station M, while the Kola section is operated by PINRO, Murmansk (Anon. 2002)

The Norwegian Sea

The inflow of warm Atlantic water to the eastern part of the Norwegian Sea increased in 2002 compared to 2001. The western part of the Norwegian Sea is still influenced by relatively fresh and cold Arctic water. There is, however, an increased influence of Atlantic water in the upper layer of the central and northern parts of the Norwegian Sea.

Figure 2 shows the development in temperature and salinity in three different sections from south to north in the Norwegian Sea (Figure 1). During the last 6 years the temperature and salinity in the Svinøy section have been above the long-term-mean while they were about average in the Gimsøy and Sørkapp sections. In 2002 there was a large increase in both temperature and salinity in the Svinøy section. The temperature was then the largest value in the time series, about 1.3°C above the normal, while the salinity was the next largest, 0.07 above the normal. Only in 1983 was the salinity higher. This increase in temperature and salinity was not seen further north in the Sørkapp section. Unfortunately there were no observations in Gimsøy section that summer.

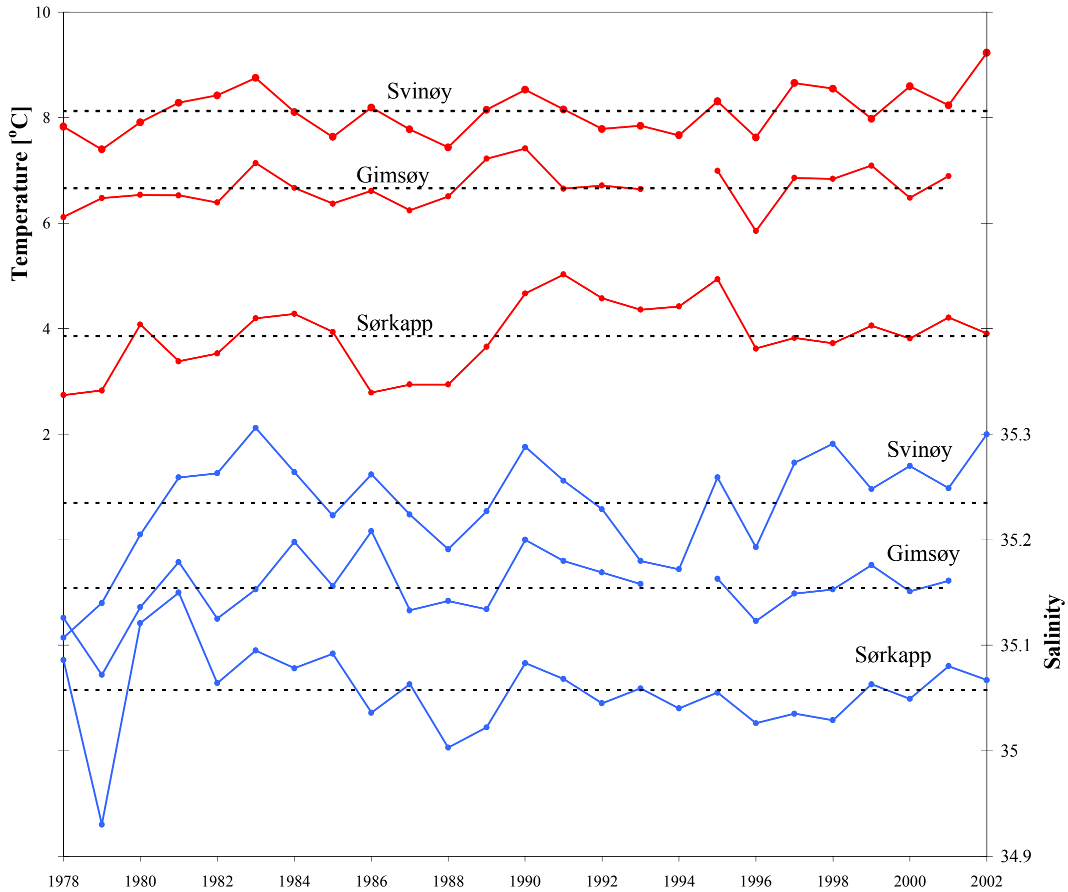
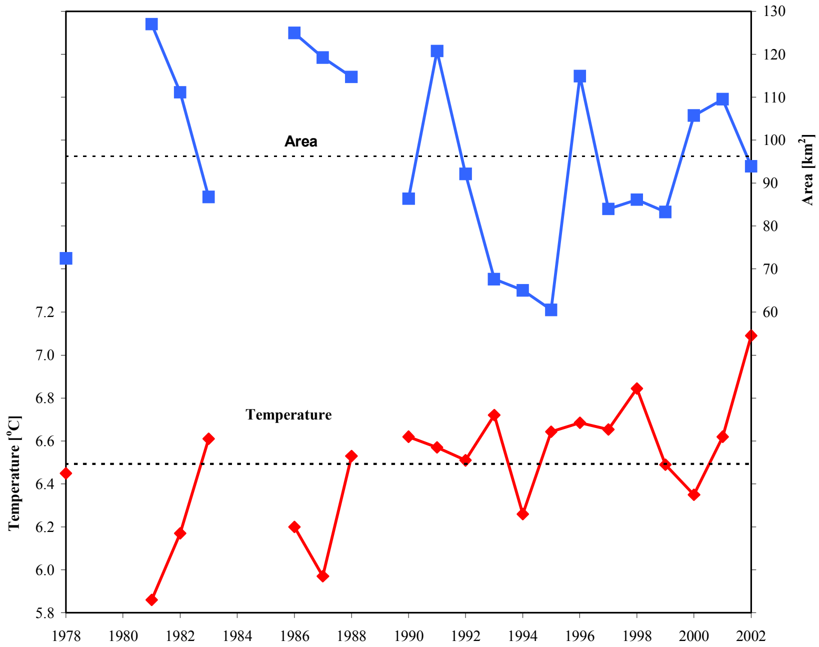


Figure 2. Temperature and salinity, observed in July/August in the core of Atlantic water in the sections Svinøy-NW, Gimsøy-NW and Sørkapp-W, averaged between 50 and 200 m depth. (Anon. 2003).

The area of Atlantic water (defined with S>35.0) in the Svinøy-section has been calculated. The mean temperature within the limited area has also been calculated, and the results for both spring and summer are shown in Figure. 3. There are considerable variations both in the area of Atlantic water distribution and its temperature. The distribution area of Atlantic water has decreased since the beginning of 1980s, while the temperature has shown a steady increase. Since 1978 the Atlantic water has been about 0.5°C warmer. During the years 1992–1995 the area was much lower than average for both seasons. In 1997–1999 there was a warm period followed by a substantial drop in temperature in 2000. Then in 2002 the temperature increased considerable and had the largest values in both time series. The temperature was in 2002 0.7°C higher than the long-term-mean for both spring and summer. While the temperature increased significantly the area of Atlantic water in 2002 was close to normal.



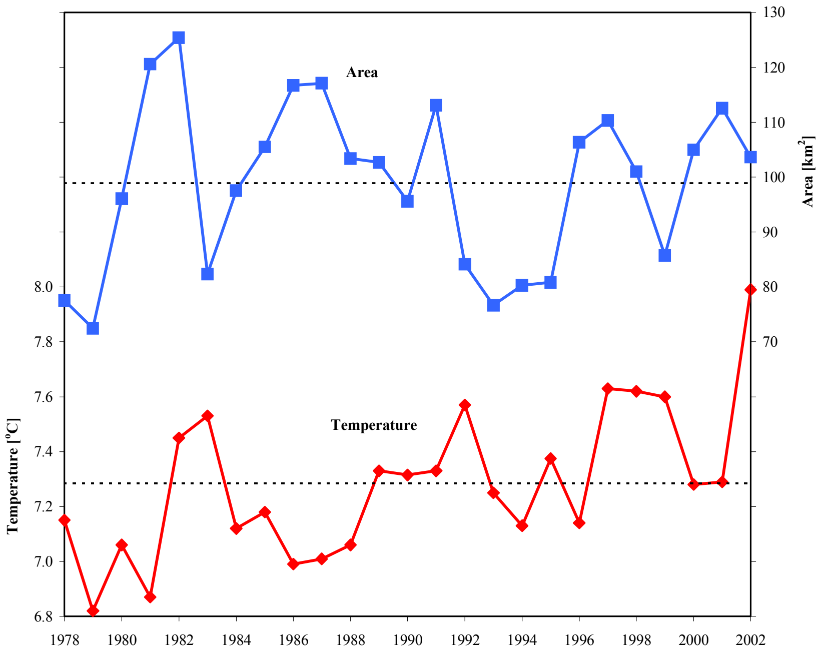


Figure 3. Time series of area (in km^2) and averaged temperature (red) of Atlantic water in the Svinøy section, observed in March/April (upper figure) and July/August(lower figure) 1978–2001 (Anon. 2003).

During research cruises in May and July/August with the aim of estimating the pelagic stock hydrographic observations are also taken, covering most of the Norwegian Sea. From the data volume of Atlantic water in the Lofoten Basin is calculated and presented in Figure 4. Since 1995 the volume has increases every year except for 1997 when there was a decrease. The increase from 1995 to 2002 is over 40%. The average temperature of the Atlantic water in the Lofoten Basin (not shown) was about the same in 2002 as in 2001.

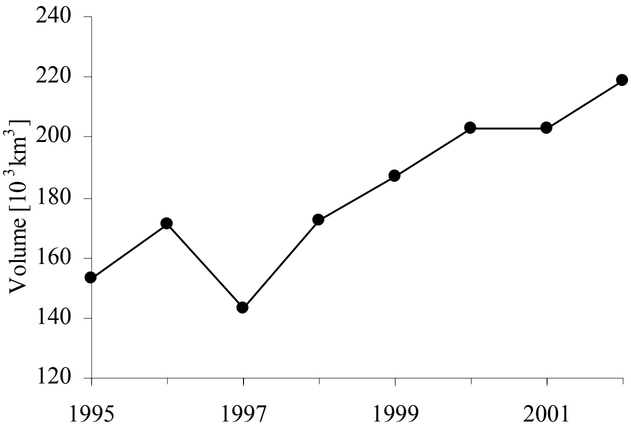


Figure 4. Volume of Atlantic water in the Lofoten Basin, from 68°N to 72°N.

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 observation, and in addition, current measurements have been carried out in the Fugløya- Bear Island section continuously since August 1997.

Figure 5 shows the temperature and salinity anomalies in the Fugløya-Bear Island section in the period from 1977 to January 2003. Temperatures in the Barents Sea were relatively high during most of the 1990s, and with a continuous warm period from 1989–1995. During 1996–1997, the temperature was just below the long-term average before it turned warm again at the end of the decade. Even the whole decade was warm, it was only the third warmest decade in the 20th century (Ingvaldsen *et al.* 2002).

In January 2003 the temperature was just above the long-term average in the whole Barents Sea, but from April the temperature raised quickly. In June the temperature was 1°C above the long term average, and the highest observed since the regular observations started in 1977. The temperature decreased slowly during summer, and in October the temperature was 0.6°C above the average. Then the temperature was decreasing rapidly and in January 2003 the temperature was exactly on the average.

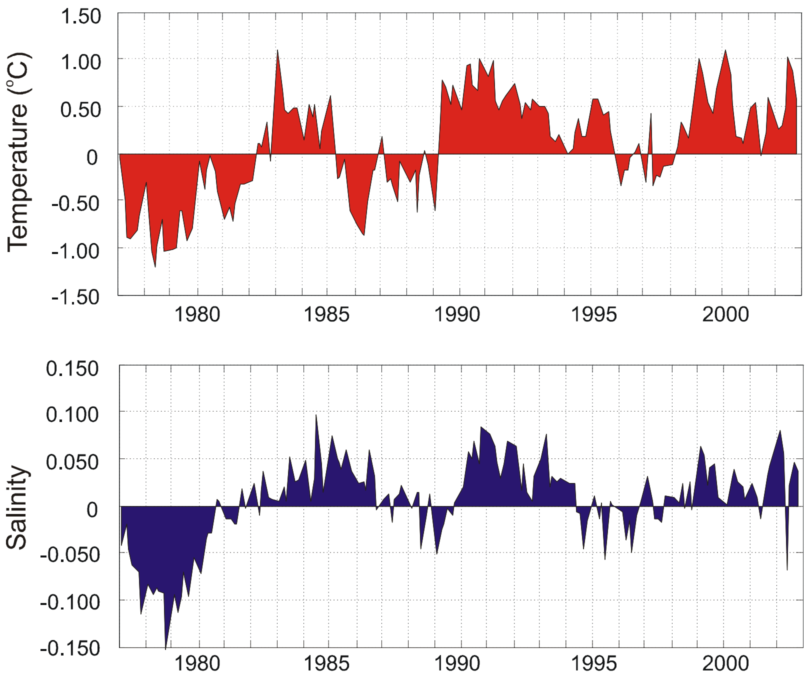


Figure 5. Temperature anomalies (upper panel) and salinity anomalies (lower panel) in the section Fugløya – Bear Island (Anon. 2003).

Figure 6 shows the ice index for the Barents Sea. The variability in the ice coverage is closely linked to the temperature of the inflowing Atlantic water. The ice has a relatively short response time on temperature change (about one year), but usually the sea ice distribution in the eastern Barents Sea respond a bit later than in the western part. 2003 had a positive ice index, which means little ice. During the winter of 2001 there was slightly more ice than the year before, but the ice melt during summer was extremely high and beat the record from 1984.

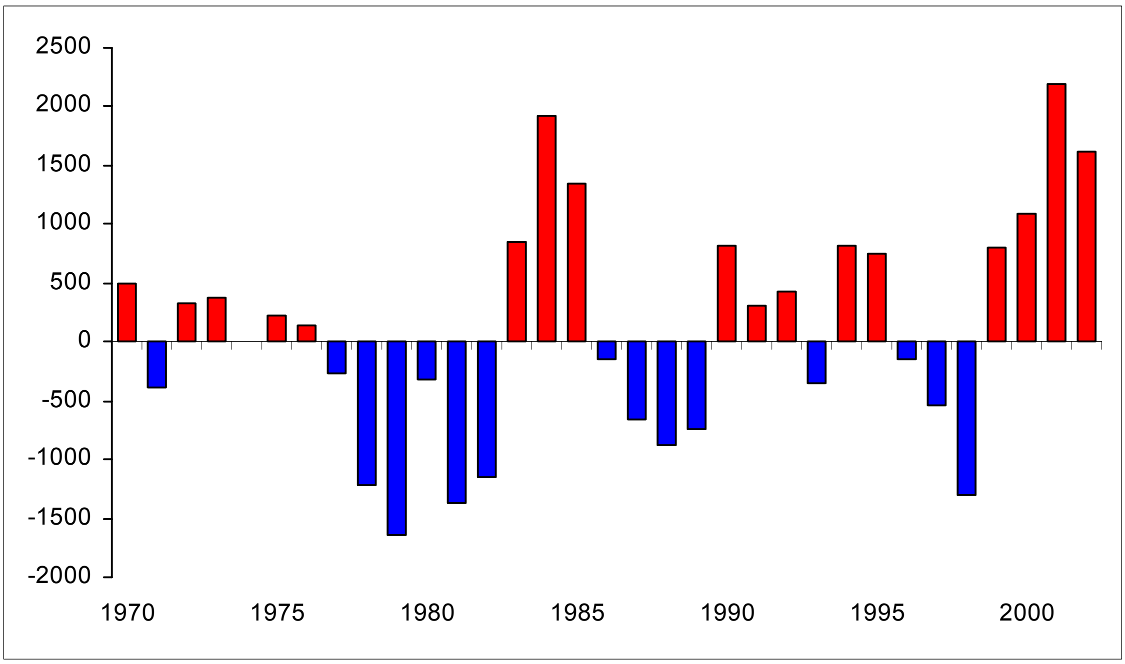


Figure 6. Ice index for the period 1970–2002. Positive values means less ice than average, while negative values show more severe ice conditions (Anon. 2003).

The observed current in the section Fugløya-Bjørnøya is predominantly barotropic, and reveals large fluctuations in both current speed and lateral structure (Ingvaldsen *et al.,* 1999, 2000). Based on several years of hydrographic observations, and also by current measurement from a 2-month time series presented by Blindheim (1989), it was believed that the inflow usually take place in a wide core located in the area 72°30'-73°N with outflow further north. The long-term measurements that started in August 1997 showed a more complicated structure of the current pattern in the area. The inflow of Atlantic water may also be split in several cores. Between the cores there might be a weaker inflow or a return flow. The outflow area may at times be much wider than earlier believed, stretching from 73°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 either by accumulation of water or by an atmospheric low or high.

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

The time series of volume and heat transports reveal fluxes with strong variability on time scales ranging from one to several months (Figure 7). The monthly mean volume flux is fluctuating between about 5.5 Sv into and 6 Sv out of the Barents Sea, and with a standard deviation of 2 Sv. The strongest fluctuations, especially in the inflow, occur in late winter and early spring, with both maximum and minimum in this period. The recirculation seems to be more stable at a value of something near 1 Sv, but with interruptions of high outflow episodes. High outflows occurred in April both in 1998 and 1999 and in 2000 there were two periods with strong outflow, one in January and a second one in June. In January and March 2002 there were two peaks of high inflow. The same peaks were observed in the Svinøy-section two months earlier (Skagseth, pers.com.). The intensity of the flow was reduced during spring and summer. Figure 8 shows the variability in the inflow as calculated from a wind driven numerical model. The inflow during the first two s were stronger than average, while the model showed close to average inflow during rest of the year, except the last two months when the flow was reduced. This is linked to variations in the atmospheric pressure field as indicated by (Ådlandsvik and Loeng, 1991, Ingvaldsen *et al.* submitted).

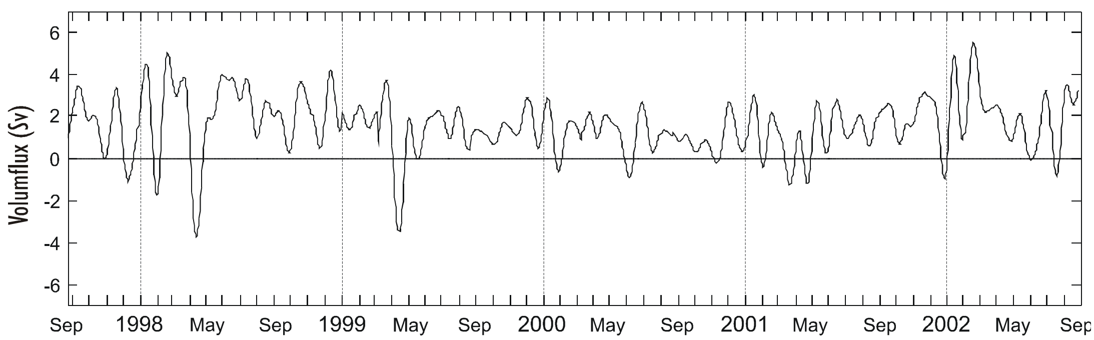


Figure 7. Total volume flux across the section Norway-Bear Island All data have been low pass filtered over 30 days (Anon. 2003)

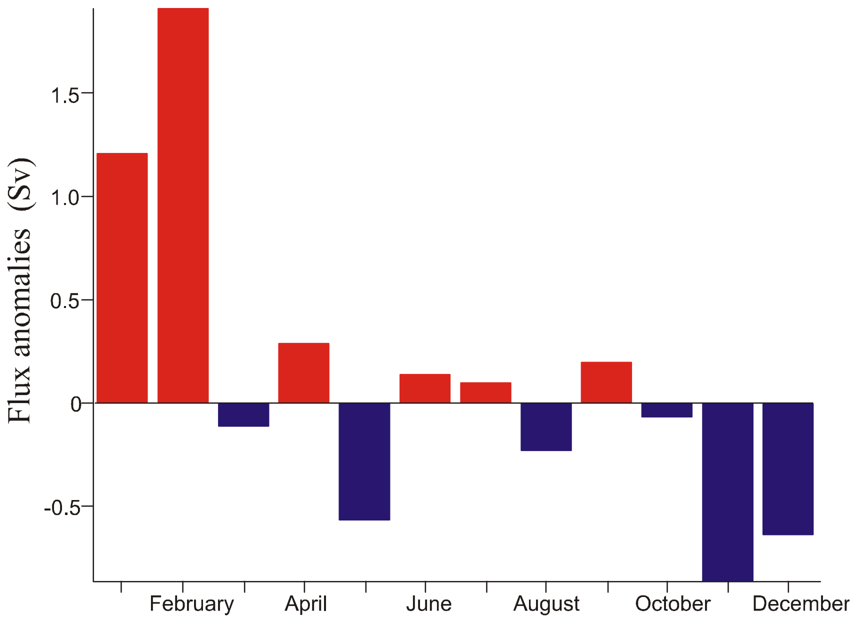


Figure 8. Modelled flux anomalies in 2002 through the section between Norway and Bear Island (Anon. 2003).

The North Sea

The temperature of the upper layer of most of the North Sea was about one degree Celsius warmer than normal during most of 2002. However in August and September it was about 2.5 degrees warmer, and along the Norwegian west-coast it was the warmest September since the monitoring began in 1942. Figure 9 shows the development of temperature and salinity at two positions, one (A) near bottom in the north-western part of the North Sea and the second (B) in the core of Atlantic water at the western shelf edge of the Norwegian Trench. The measurements are carried out during summer and represent the last winter situation. The average temperature at the plateau is 1–2°C lower than in the core of the inflowing Atlantic water (Figure 9). Also the salinity is slightly lower at the plateau. At the plateau, there has been a continuous increase both in temperature and salinity from 1996 to 1999, while decreasing values were observed in 2000. The development is relative similar in the core of the Atlantic inflow. At both positions, the values from 2000 and 2001 were rather close to the long-term average, while in 2002 we see a certain increase in temperature.

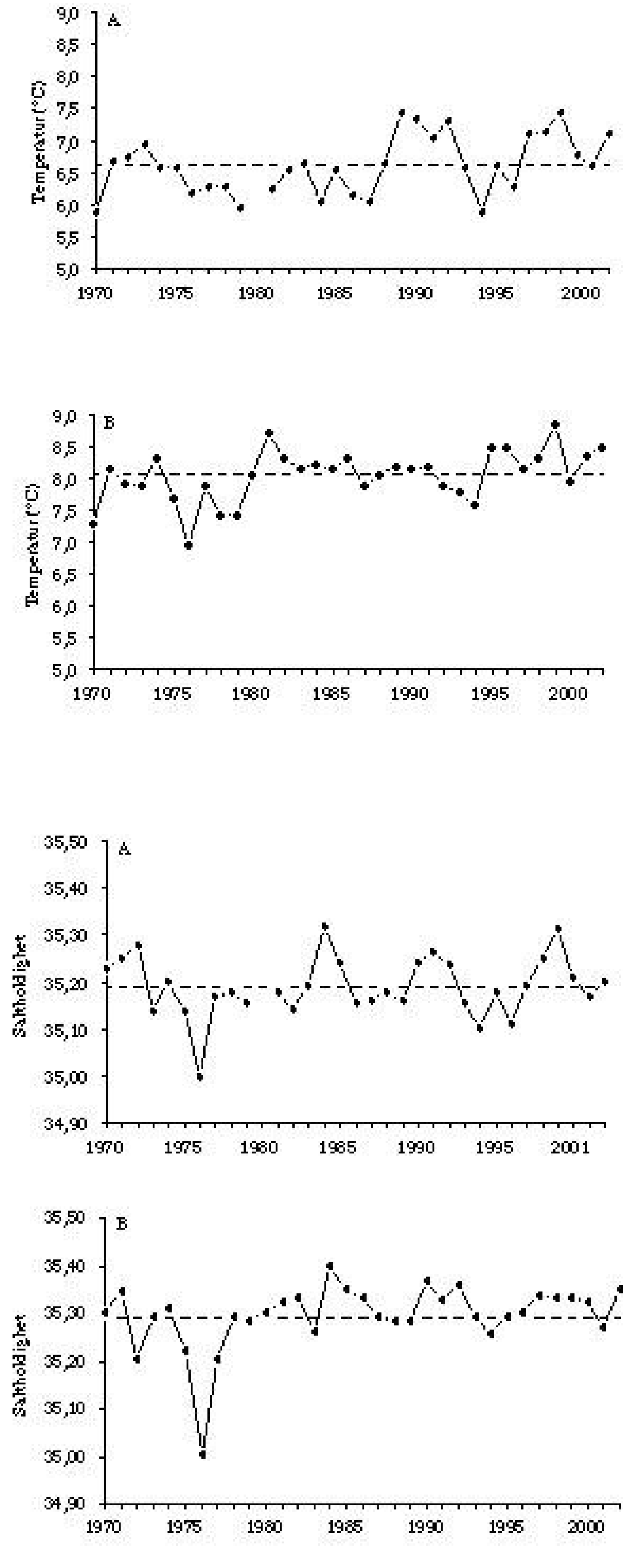


Figure 9. Temperature and salinity near bottom in the northwestern part of the North Sea (A) and in the core of Atlantic water at the western shelf edge of the Norwegian Trench (B) during the summers of 1970–2002 (Anon. 2003).

Estimates from a numerical ocean circulation model showed that the circulation in the North Sea was quite normal throughout 2002. However the net inflow during the first half of the year through the English Channel was the second largest since the start of the simulation period in 1955. The inflow of Atlantic water in the north was generally quite normal (Figure 10), except for the second quarter with somewhat stronger than normal inflow. This inflow of Atlantic water introduced more nutrients in the North Sea system than usual (at a time when there are lack of nutrients) and lead to a stronger (10–20 $gCm^{-2,}$ model based) annual primary production in large areas of the North Sea.

The catches of horse mackerel during the autumn in the North Sea, have for many years been strongly linked with the northern modelled inflow of Atlantic water during winter (1. quarter) approximately half a year earlier. In 2002 the model prognosis was 38.000 ton while the following catches was 32.000 ton.

The Skagerrak coastal water is defined with salinity between 25.0–32.0. Water with lower salinity is defined as brackish water. Along the coast of southern Norway, the thickness of the Skagerrak coastal water was most of the year about 10–30 m. The brackish water was found in the upper 10–15 m from April to June, significantly thicker than in previous years. The transition between Skagerrak water (with salinity between 32–35) and the Atlantic water was found generally deeper than 75 m. The winter of 2002 was quite mild with temperatures at about 5 ^{0}C down to about 75 m from January to mid April. A very warm summer (mid July to mid September) resulted in the warmest surface temperatures since measurements began in 1924, but with a rapid cooling at the end of the year. In 2002 we experienced no exchange of the Skagerrak deep water.

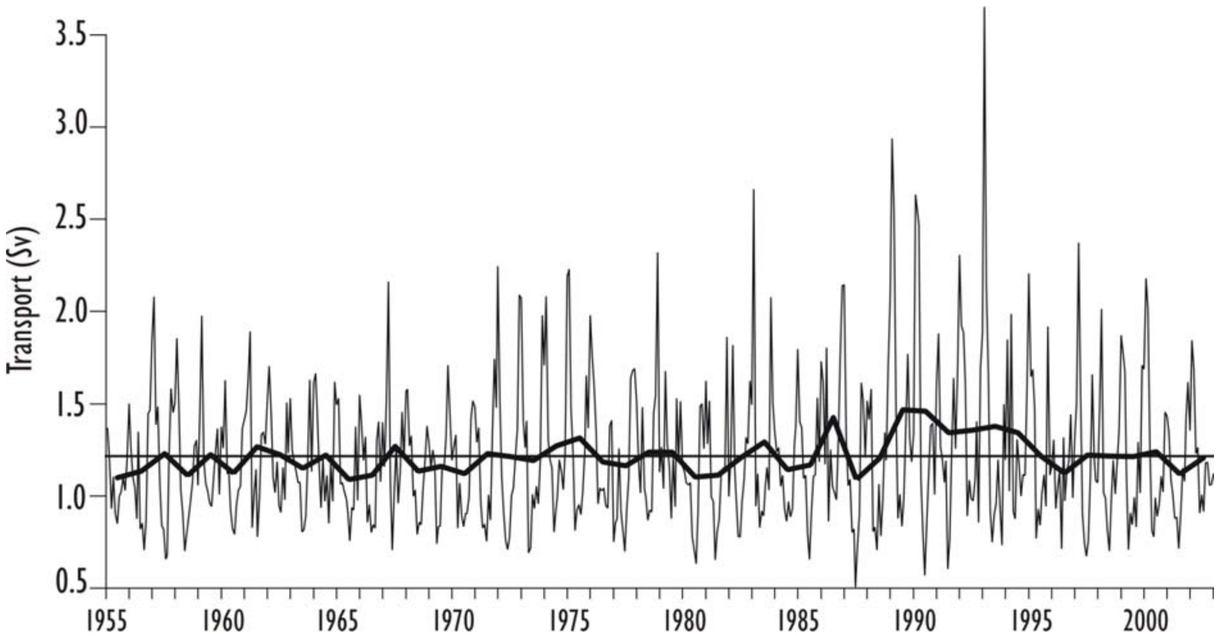


Figure 10. Time series (1955–2002) of modelled annual mean (bold) and monthly mean volume transport of Atlantic water into the northern and central North Sea southward between the Orkney Islands and Utsira Norway. 1 Sv = $10^6 m^3 s^{-1}$. (Anon. 2003)

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ANNEX T: AREAS 10 AND 11 (NORWEGIAN AND BARENTS SEAS) RUSSIAN REPORT, RUSSIAN STANDARD SECTIONS IN THE BARENTS AND NORWEGIAN SEAS

V. Ozhigin

PINRO, Murmansk, Russia

The Barents Sea

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

In winter and spring 2002, low pressure dominated over the Barents Sea with southwesterly winds prevailing over its southern part. In summer, air pressure patterns were dominated by the Azores High, and light winds prevailed over the Barents Sea. Such conditions were favourable for an increased atmospheric and solar heating, especially in the western Barents Sea. In autumn, atmospheric circulation over the sea was under the influence of a low-pressure cell centred over the northwestern Siberia, which lead to the prevalence of moderate northerly winds.

Air temperatures averaged for the western Barents Sea (70–77°N, 15–35°E) were generally warmer-than-normal throughout the year with a peak in April and two minima in March and September. However, warmer-than-normal air temperatures did not persist in the eastern Barents Sea (69–77°N, 35–55°E) throughout the year. Positive temperature anomalies prevailed in January-May with a peak in April. During the latter part of 2002 monthly anomalies were below normal.

Sea surface temperature (SST) in the southwestern Barents Sea (70–74°N, 20–40°E) was close to normal in the very late 2001. A considerable temperature increase took place in winter and spring of 2002. In July, SST anomaly was as high as 1.5°C. In October, temperature dropped to the long-term mean. November and December were above normal. In the southeastern Barents Sea (69–73°N, 42–55°E) monthly sea surface temperatures were close to the long-term average throughout the year.

Increased air and sea temperatures resulted in much lower-than-normal ice coverage (% of the total Barents Sea area) during the first half of 2002 (10–15% less than normal). In August-December, monthly anomalies decreased rapidly to the long-term average. 2002 was the fourth year in succession with light ice conditions in the Barents Sea.

Figure 1 shows main Russian standard sections in the Barents Sea. The Kola section runs from the Kola fjord mouth northwards, along 33°30'E, and crosses the coastal and main branches of the Murman Current. In 2002, the Kola section was occupied in 10 months out of 12. Measurements along other sections were done 2–4 times during the year.

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

In January, the temperature was close to normal both in coastal water and in the main branch of the Murman Current. During late winter and spring the temperature increased gradually, and in summer positive temperature anomalies ranged from 0.7 °C to 0.9 °C. Warm period in the coastal water lasted from April to October, while in the main branch of the Murman Current was 2 months shorter (from May to September). During autumn and early winter the temperature decreased to the long-term mean in January and February 2003.

The annual mean temperature in the main branch of the Murman Current was 0.5 °C above normal (Figure 3). 2002 was the fourth warm year since 1999. The annual mean temperature in the upper 200 m layer in the Kola section in 2003 is expected to be close to the long-term average.

The section Bear Island - West (along 74°30´N) was occupied 5 times in 2002. The temperature in the Norwegian current (74°30´N, 06°34´-15°55´E) in the layer 0–200 m was warmer-than-normal by 1.1 °C in May and October. However, in June-August positive temperature anomalies ranged from 0.4 °C to 0.6 °C. Figure 4 shows temperature variations in the section Bear Island – West in August-September 1966–2002.

The section Bear Island - East (along 74°30´N) was occupied in September and November. A positive temperature anomaly in the northern branch of the North Cape Current (74°30´N, 26°50´-31°20´E) in the layer 0–200 m decreased from 0.9 °C in September to 0.6 °C in November.

Measurements in the Kanin section (along 43°15´E) were performed only in August. The temperature of Atlantic water (71°00´-71°40´N, 43°15´E) in the upper 200 m layer was 0.8 °C above normal.

In the near bottom layer positive temperature anomalies prevailed over most of the Barents Sea throughout the year. Figure 5 shows bottom temperature anomalies in August-September. The anomalies were calculated using the data acquired during joint IMR/PINRO 0-group fish and pelagic fish surveys. Most of the bottom was dominated by warmer-than-normal temperatures. The warmest anomalies ranging between 1.0 °C and 3.0 °C spread over the northwestern Barents Sea and some locations along the Murman and Novaya Zemlya Currents.

The Norwegian Sea

Large-scale sea level pressure patterns and atmospheric circulation lead to the prevalence of the southerly and southwesterly winds over most of the Norwegian Sea throughout the year. The southerly winds were most frequent in April-May.

The air temperature over the Norwegian Sea was warmer-than-normal throughout the year except February and March. Maximum positive anomalies of air temperature (2–3°C) spread over the northern and eastern sea in June.

In January, the sea surface temperature (SST) in the Norwegian Sea was close to the long-term mean. The temperature increased gradually in February-April. In summer, SST was warmer-than-normal practically over the entire Norwegian Sea. In June-August, positive SST anomalies ranged from 1.0 to 1.5°C in the southern Norwegian Sea, while in the central and eastern regions SST was above normal by 2.5–3.0 °C. By the end of the year, SST decreased to the to the long-term average.

Figure 6 shows standard sections occupied in June-July 2002 in the Norwegian Sea.

A considerably warmer-than-normal temperature in the Norwegian Current and colder-than-average temperature in the East Icelandic Current was the main feature of hydrographic conditions in the Norwegian Sea in summer 2002.

The vertically averaged temperature in the upper 200 m layer in the Norwegian Current in the sections 6C (65°45´N, 01°45´W-05°00´E) and 7C (67°30´N, 01°00´W-08°30´E) was above normal by 0.8–1.2 °C and by 0.7 °C higher than last year (Figure 7a).

The temperature of mixed waters in the central Norwegian Sea was above normal (by 0.4–0.8 °C) in both Section 6C (65°45´N, 04°00´W-02°30´W) and 7C (67°30´N, 04°00´W-01°45´W) (Figure 7b).

In the southwestern Norwegian Sea, water temperature in the East Icelandic Current in 0–200 m layer in Section 5C (63°00´N, 04°45´W-02°30´W) was lower than long-term mean by 0.9°C. The core of cold water in Section 6C (65°45´N, 10°45´W-05°00´W) shifted almost 50 miles westward of its long-term mean position.

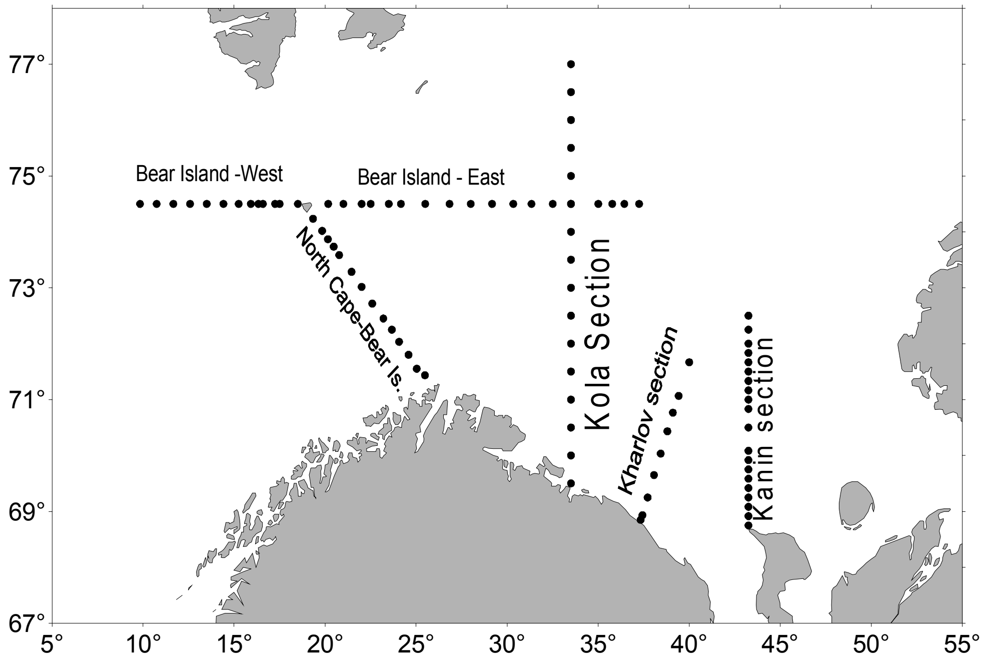
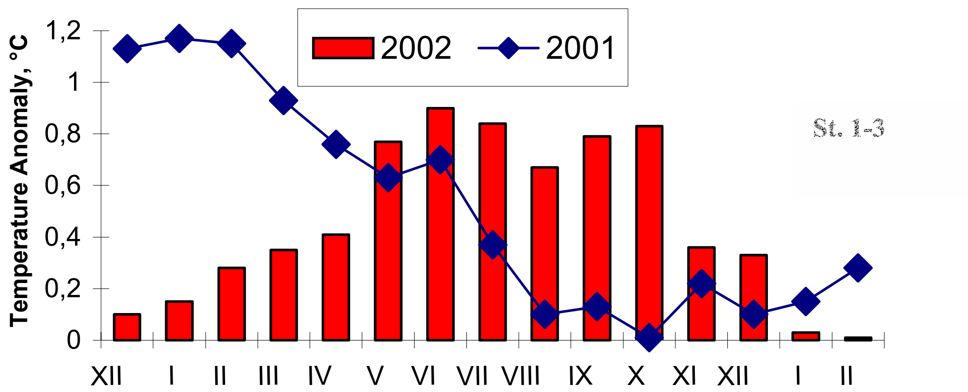


Figure1. Main Russian standard sections in the Barents Sea.



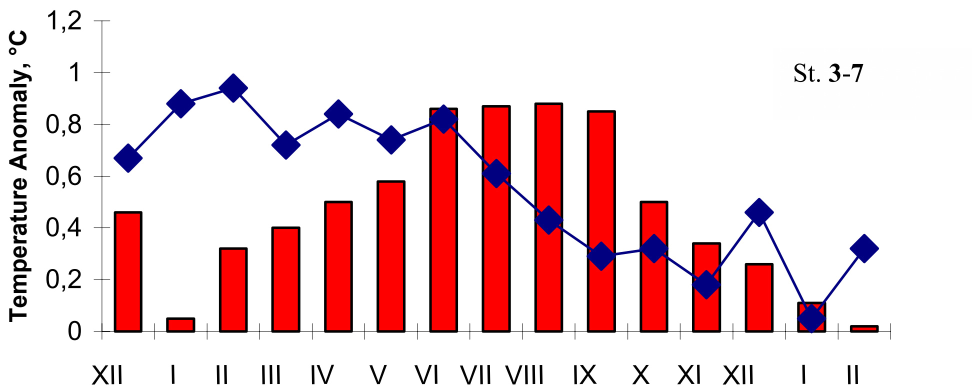


Figure 2. Monthly mean temperature anomalies in the 0–200 m layer of the Kola section in 2001 and 2002. St. 1–3 – Coastal branch of the Murman Current. St. 3–7 – Main branch of the Murman Current.

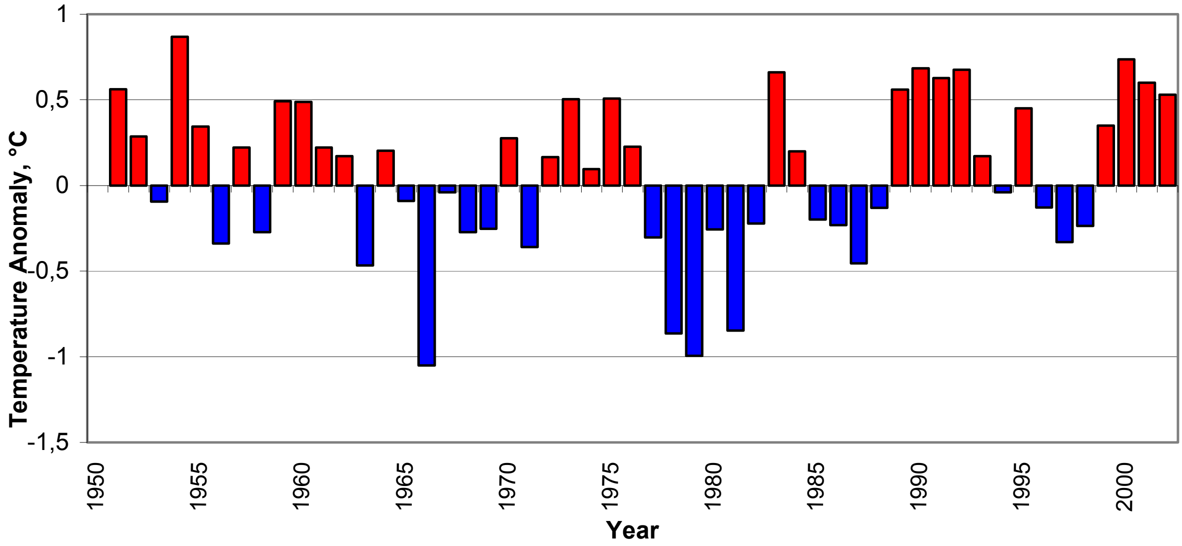


Figure 3. Mean yearly temperature anomalies in the 0–200 m layer in the Kola section in 1951–2002

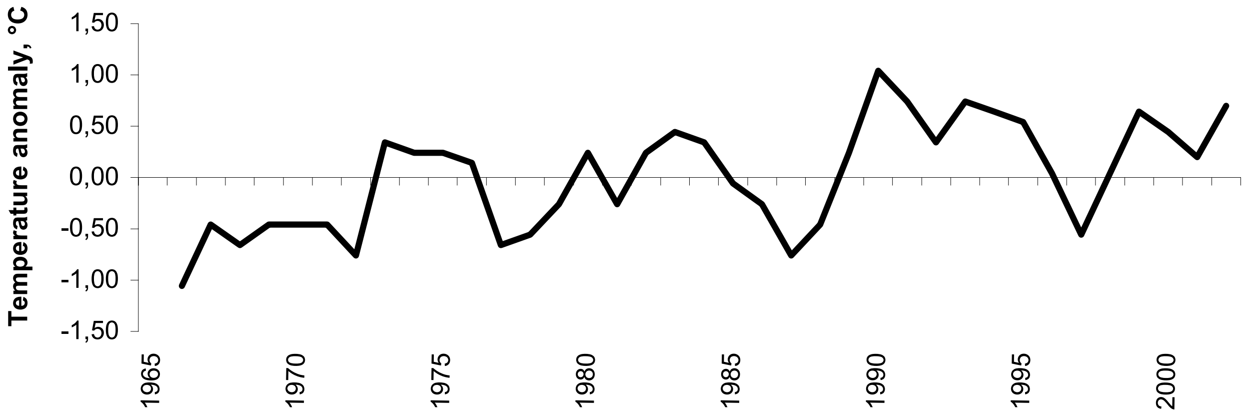


Figure 4. Temperature anomalies of Atlantic water in the section Bear Island - West (74°30´N, 06°34´-15°55´E) (0–200 m) in August-September 1966–2002.

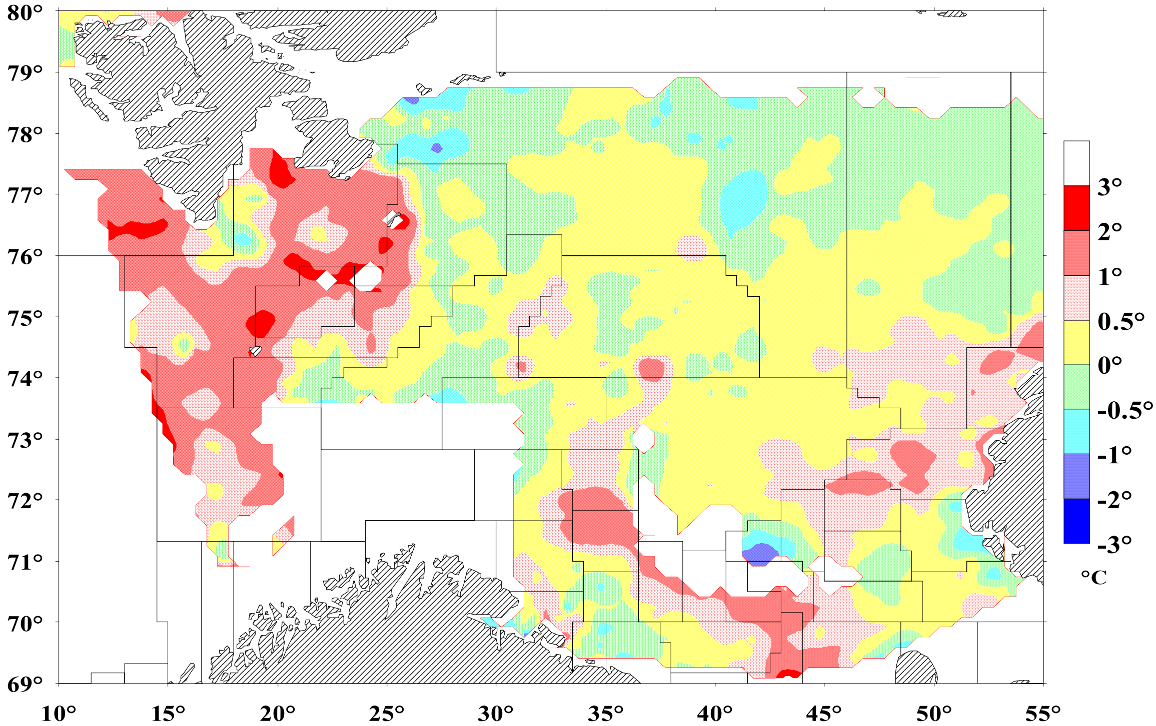


Figure 5. Bottom temperature anomalies in the Barents Sea in August-September 2002.

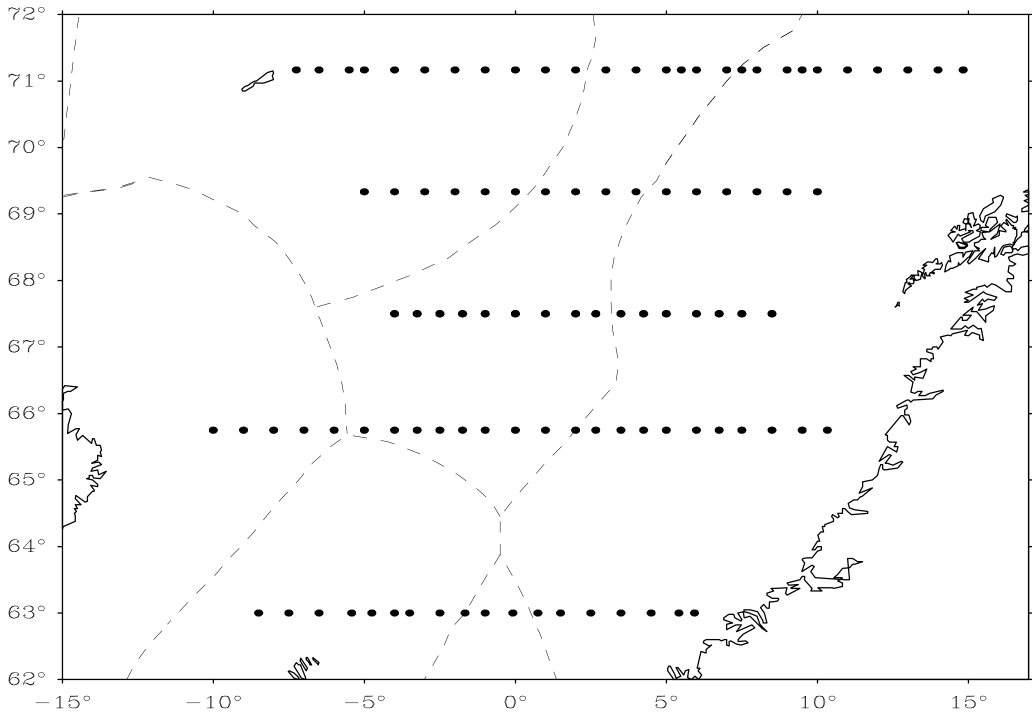


Figure 6. Standard sections in the Norwegian Sea occupied in June-July 2002.

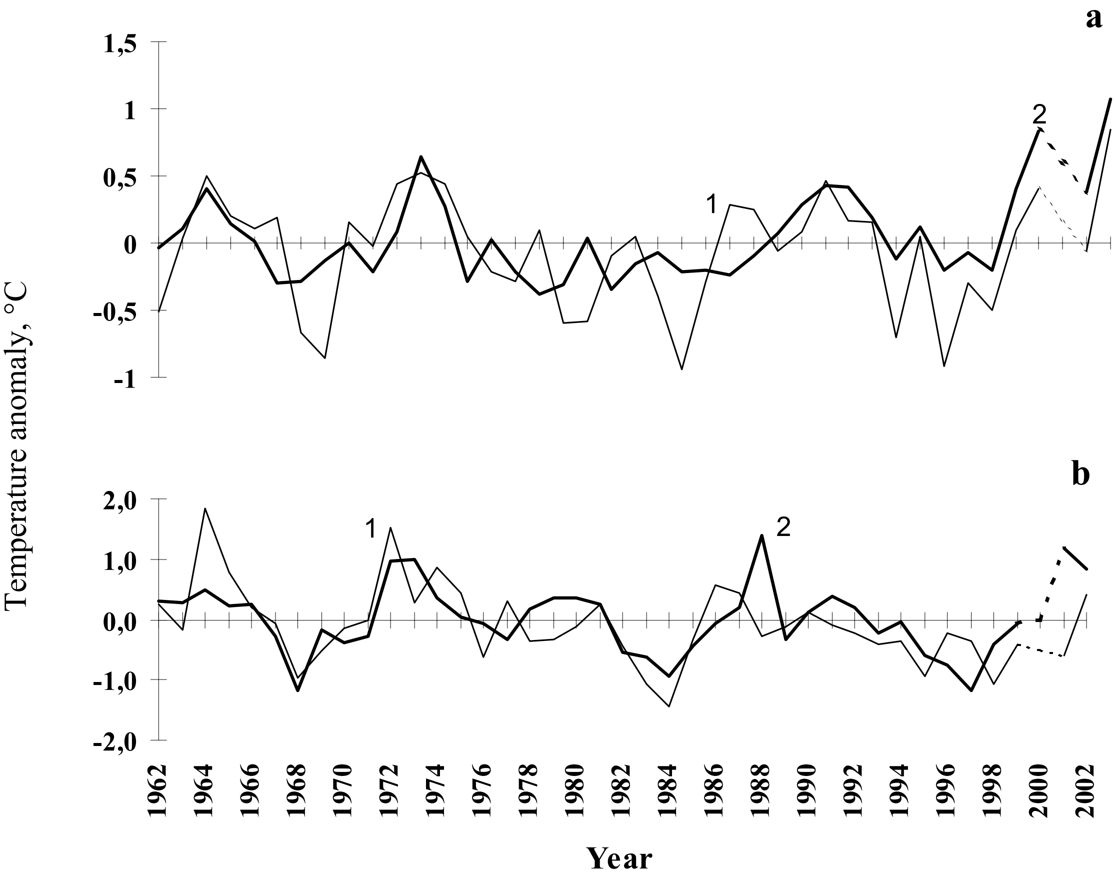


Figure 7. Temperature anomalies in the upper 200 m layer of the Norwegian Current (a) and mixed waters in the central Norwegian Sea (b) in sections 6c (1) and 7c (2) in June 1961–2002.

ANNEX U: POLISH NATIONAL REPORT (AREA 10, 11, 12)

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In summer 2002 IO PAS has performed hydrographic measurements in the Norwegian, Greenland and Barents Seas as a continuation of the previous years work. The main goal of the study was to investigate Atlantic Water (AW) properties and its transport into the Arctic Ocean (AO). CTD stations grid is shown at Figure 1. Area of investigations covers large part of the Atlantic Domain and allows to examine horizontal and vertical distributions of water properties, indirect AW inflow through the Barents Sea Opening as well as direct AW inflow into AO through the Fram Strait. ADCP measurements were conducted during whole cruise of R.V. Oceania.

Figure 2 presents horizontal distribution of the water temperature at the depth of 100 m. Vectors represent baroclinic current which were calculated with reference of no motion level 1000 m. Main portion of AW comes to the Barents Sea through the Norway-Bear Island section. Smaller volume of AW inflows into Barents Sea between Bear Island and Spitsbergen. West of the Spitsbergen coast both, northward flow and recirculation of AW are visible. Within the West Spitsbergen Current flow is less intensive, but occupies thicker layer (Figure 3) than in case of the inflow into Barents Sea, and finally in summer 2002 bigger volume of AW flow through the Fram Strait then through the Barents Sea Opening (Figure 5).

High horizontal and vertical resolution of measurements conducted at sections allows to examine structure of the water column, mesoscale activity etc. Figure 3 shows section 'N', located along the 76° 30' parallel. Atlantic Water is distributed between sea surface and depth of 600 m. Maximal depth AW reaches over the Spitsbergen slope, in the zone of intensive northward jet streams, where calculated baroclinic velocities reaches 60 cm/s. The second zone of the flow intensification is related to the front separated Atlantic and Arctic Waters (stations N7-N3).

Results obtained from some sections are combined with previous data collected by IO PAS into time series. The data set is incomplete and does not allows to investigate seasonal and interannual AW properties variability, however limited studies of long-term variability of the AW properties and transport are possible. Figure 4 presents variability of water temperature at depth 200 m measured in summers 1996–2002. In summer 2002 temperature of AW was close to upper limit of previously observed temperature range. Figure 5 presents trends of AW temperature and transports through Fram Strait and Barents Sea Opening. In summers 1997–2002 increasing of mean AW temperature in the Barents Sea Opening region is observed, while the transport of AW into the Barents Sea decreases, reaching minimal values in summer 2000. During the same time period, baroclinic transport of AW through the Fram Strait increases, reaching maximum in summer 2001.

Some surveys in the region will be continued in 2003 and farther.

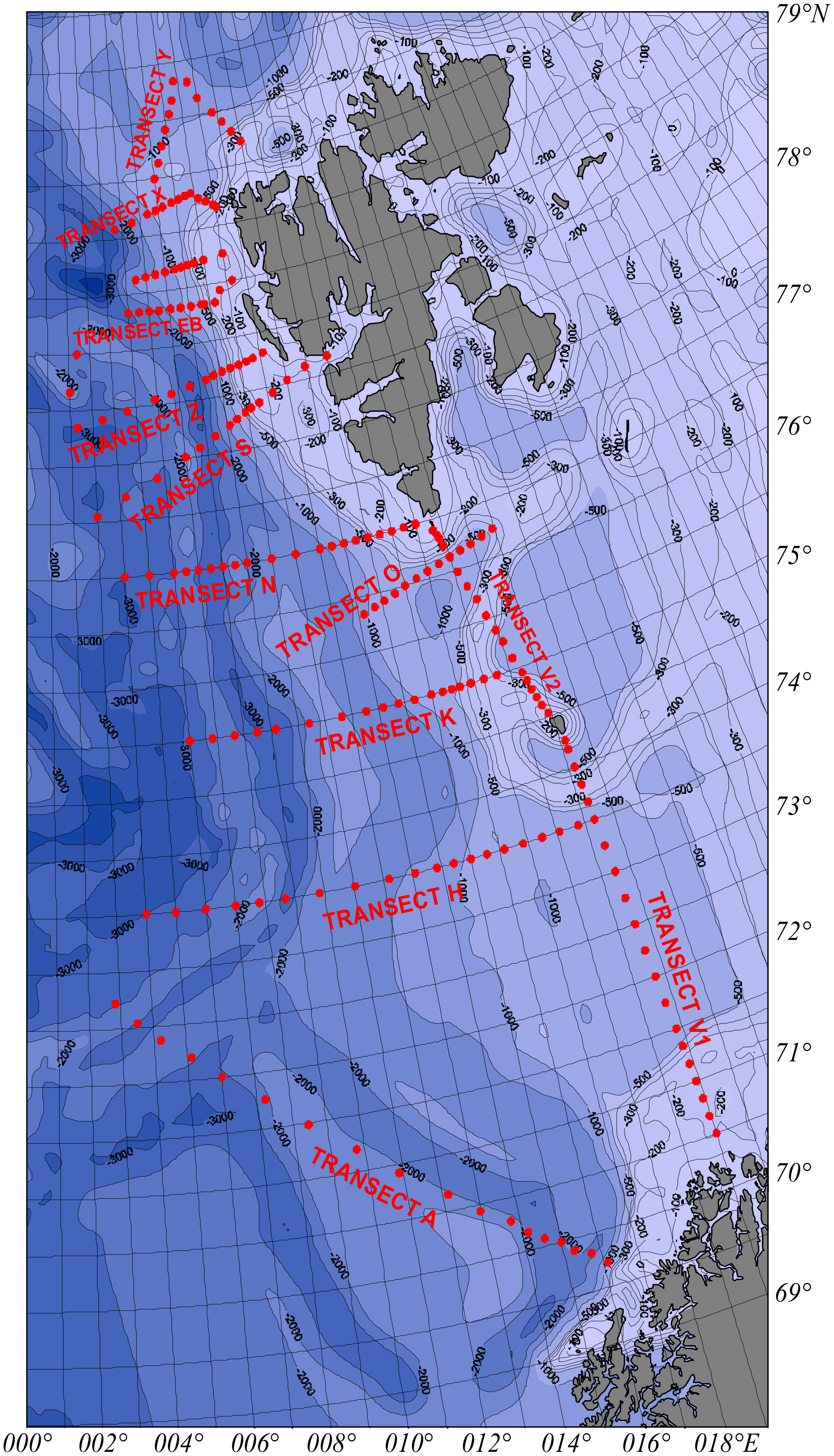

Figure 1. Map with the positions of the CTD stations investigated by IO PAS at the Nordic Seas during summer 2002.

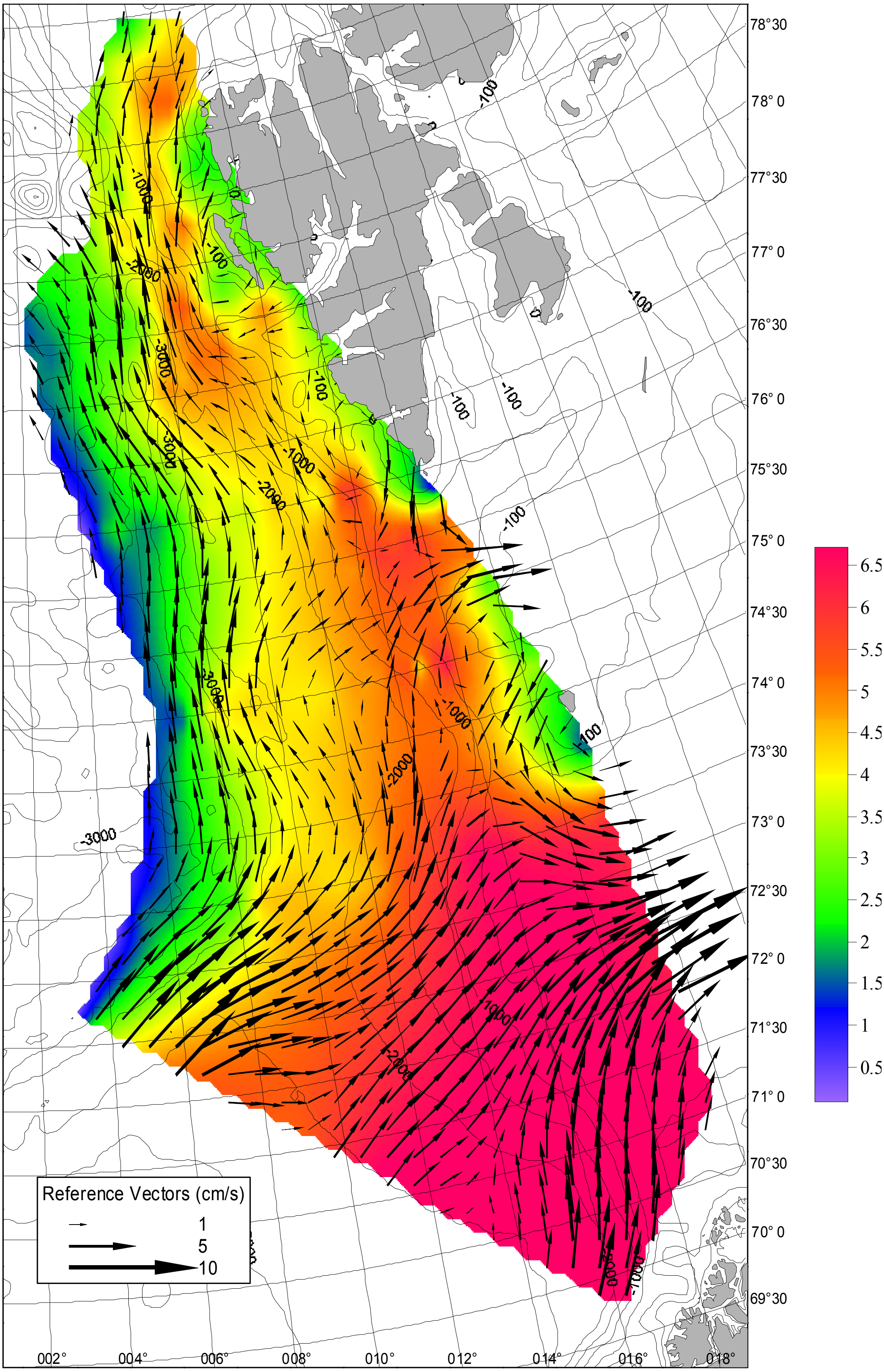

Figure 2. July 2002. Horizontal temperature (°C) distribution (colour scale) and baroclinic current vectors at depth of 100 m.

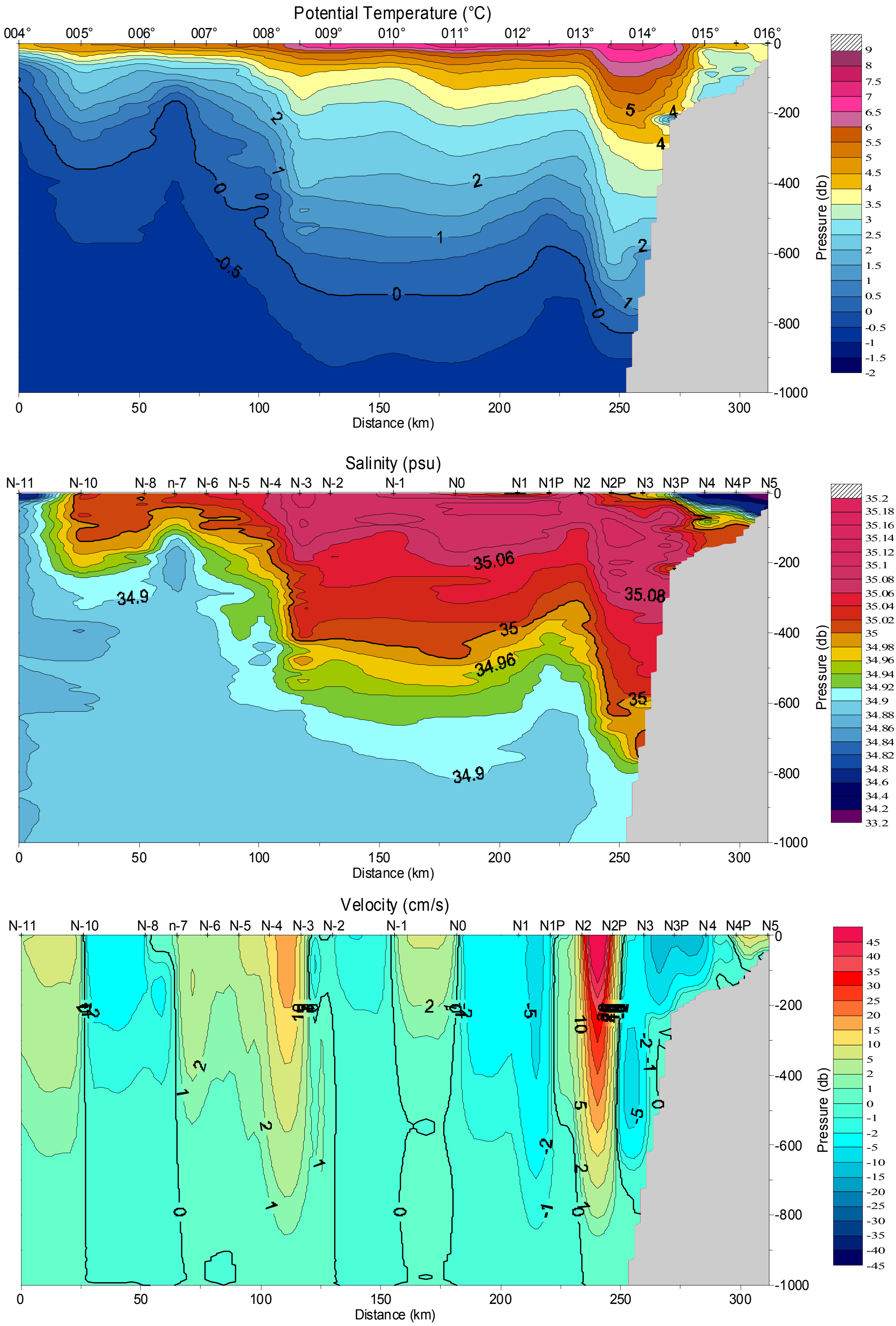

Figure 3. July 2002. Potential temperature (°C), salinity (psu) and baroclinic currents (cm/s) in upper 1000 m of section 'N' along 76°30' parallel.

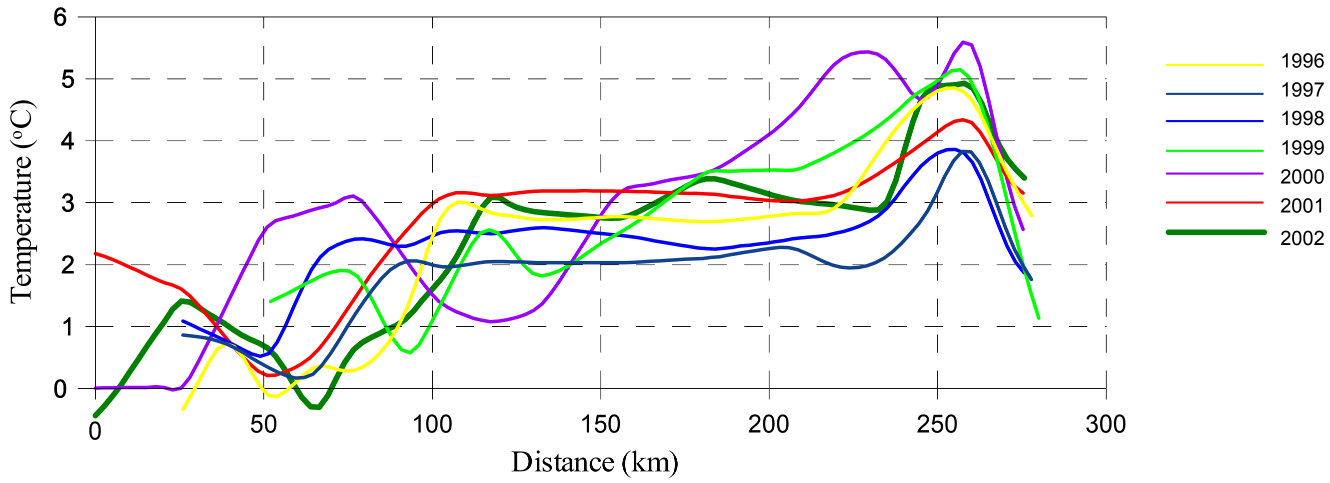

Figure 4. Temperature at depth 200 m along the section ‘N’ (76°30’) in summers 1996–2002.

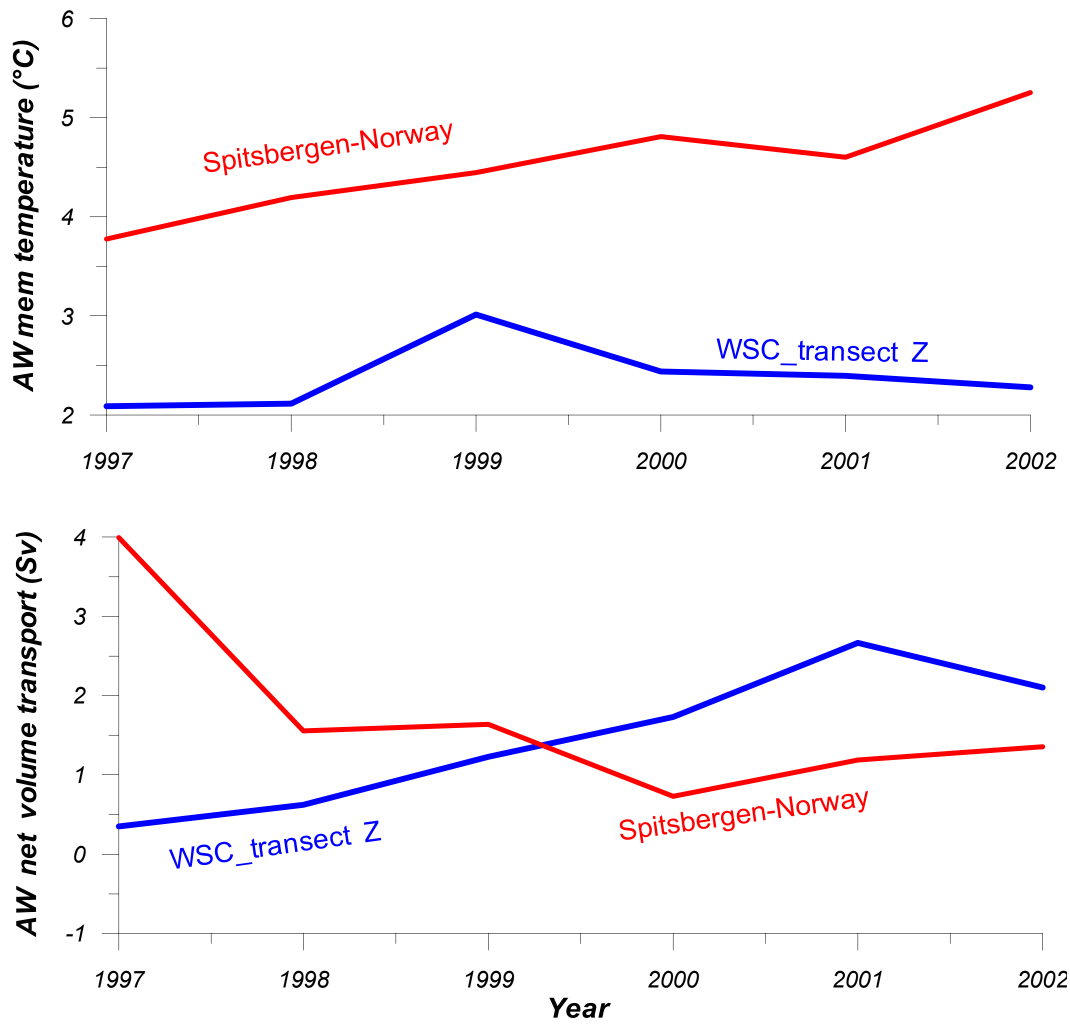

Figure 5. Atlantic Water (S>34.92 psu) mean temperature and volume transports through the Barents Sea Opening (red lines) and by the West Spitsbergen Current (blue lines).

ANNEX V: HYDROGRAPHIC CONDITIONS IN THE GREENLAND SEA AND FRAM STRAIT, (AREA 12)

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In summer 2002 the hydrographic measurements in the Greenland Sea (along 75°N, G. Budeus) and in the Fram Strait (along 79°N/78°50'N, U. Schauer) were performed by the AWI. 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. Obtained time series were compiled from the AWI sections combined with the earlier data sets to describe the long-term variability of the Atlantic Water properties. In the central Greenland Sea the amount of local water mass, its modification and renewal were also investigated. It is planned to continue both hydrographic sections during the cruises scheduled in 2003.

Time series of the current, temperature and salinity fields were provided by recovering of 10 out of 14 moorings, deployed in summer 2000 (some in summer 2001). Regarding the necessity of increased coverage at the western boundary of the West Spitsbergen Current, a new array of 12 moorings was deployed for another year (Figure 1). Data from the last recovery are under processing now. The measurements (CTD sections and moorings) are expected to be kept in the cooperation with the partners in the ASOF-N project, which started on January 1, 2003.

The properties of the Atlantic Water (AW) and Return Atlantic Water (RAW) observed at the CTD section along 75°N have changed since last year (Figure 2). The properties of the Atlantic Water are given as temperature and salinity averages over the depth range from 50 to 150 m of the stations between 10° and 13°E, which have a spacing of 10 Nm. The Return Atlantic Water is characterized by the temperature and salinity maximum below 50 m averaged over 3 stations west of 11.5°W with space interval less than 5 Nm. In 2002 mean temperature of AW in the Greenland Sea was significantly higher as compared to last years. A rise in the AW salinity continued, reaching the highest value for the whole observation period. A subsurface inflow of warm and high saline Atlantic Waters resulted in the higher temperature and salinity of the ventilated layer. Winter convection was confined mostly to about 1500 m except the area of a small-scale eddy, where the temperature maximum was shifted downward to the depth of 2800 m. A general increase of the depth of temperature maximum was observed between 2001 and 2002 as well a rise of the lowest temperatures in the bottom waters.

The temperature and salinity sections across the Fram Strait are shown in Figure 3. with the main core of the West Spitsbergen Current visible at the eastern slope. Time series of mean temperatures and salinities for two depth intervals (5 ÷ 30 m and 50 ÷ 500 m) reveal the variations of the water mass properties in the Fram Strait (Figure 4). Three characteristic areas were distinguished in relation to the main flows: the West Spitsbergen Current (WSC) between the shelf edge and 5°E, the Return Atlantic Current (RAC) between 3°W and 5°E, and Polar Water in the East Greenland Current (EGC) between 3°W and the Greenland Shelf. Mean salinities observed in the West Spitsbergen Current were close to the last year values while the mean temperature in the surface layer increased slightly. Similar changes were found in the Return Atlantic Current with a small drop in the mean salinities of both layers. A strong decrease of the mean salinities was observed in the East Greenland Current, especially in the lower layer (50 ÷ 500 m) where the mean salinity (34.52) as well as the mean temperature (-0.01°C) was the lowest since 1980. At the same time the mean temperature in the EGC surface layer was significantly higher than in previous years. Because the data from the Fram Strait were collected in different seasons from spring to autumn, they are affected by the annual cycle which is most pronounced in the upper layers. Therefore, the observation time has to be taken into account when comparing particular years.

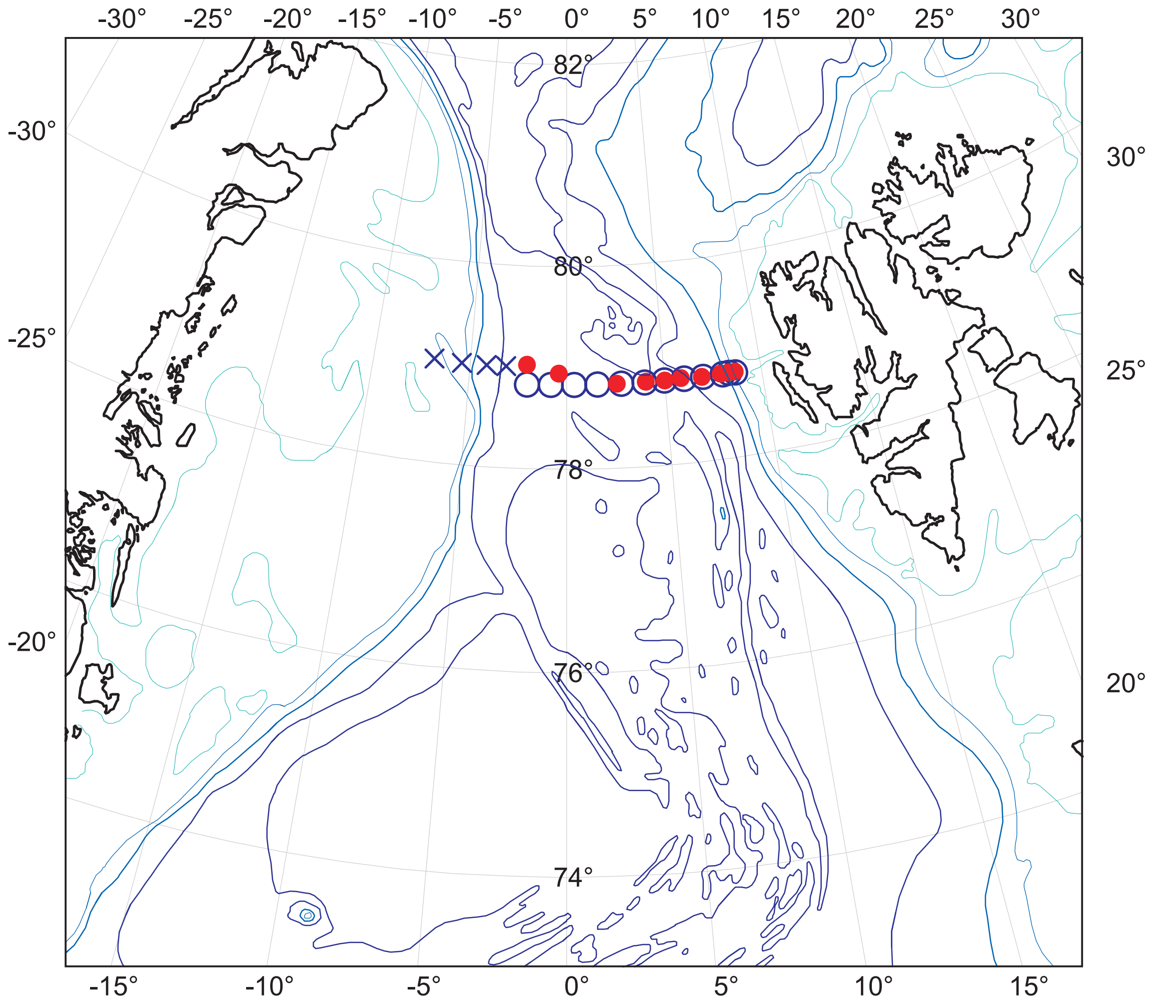
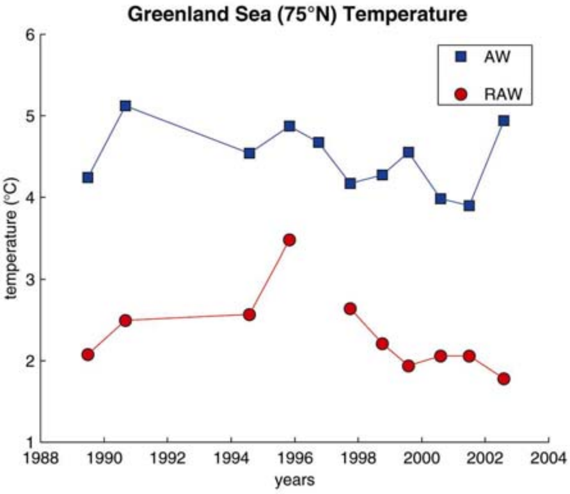


Figure 1. Map with the positions of moorings recovered in 2002 (filled red circles) and newly deployed for another year (empty blue circles).



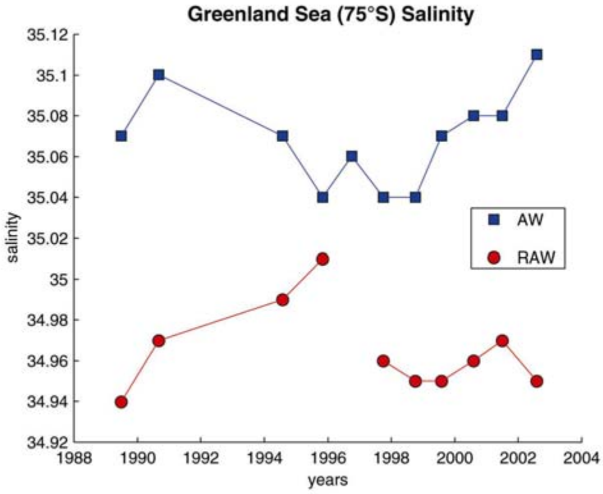
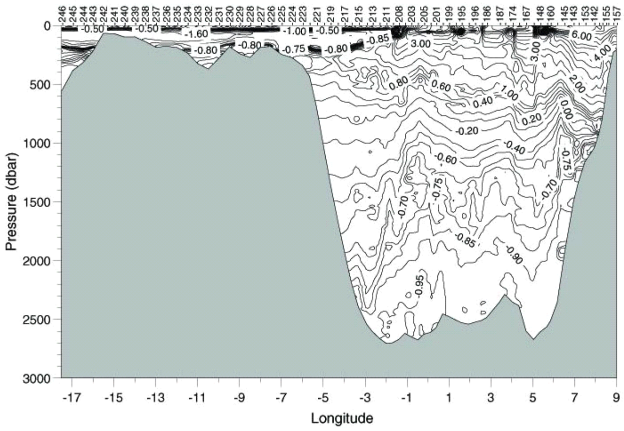


Figure 2. Properties of the Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea observed at the CTD transect along 75°N (G. Budeus).



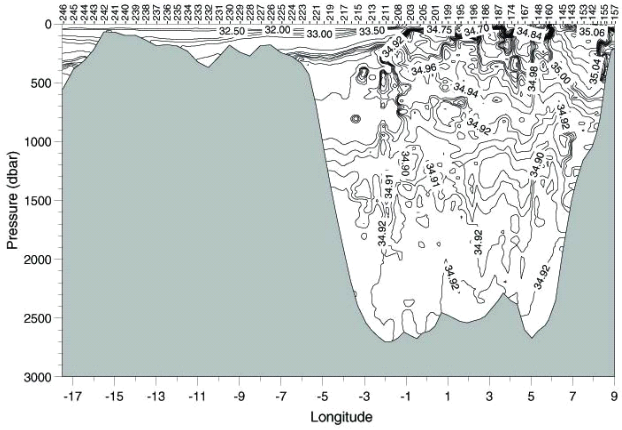


Figure 3. Vertical transects of potential temperature (left figure) and salinity (right figure.) across the Fram Strait measured in summer 2002.

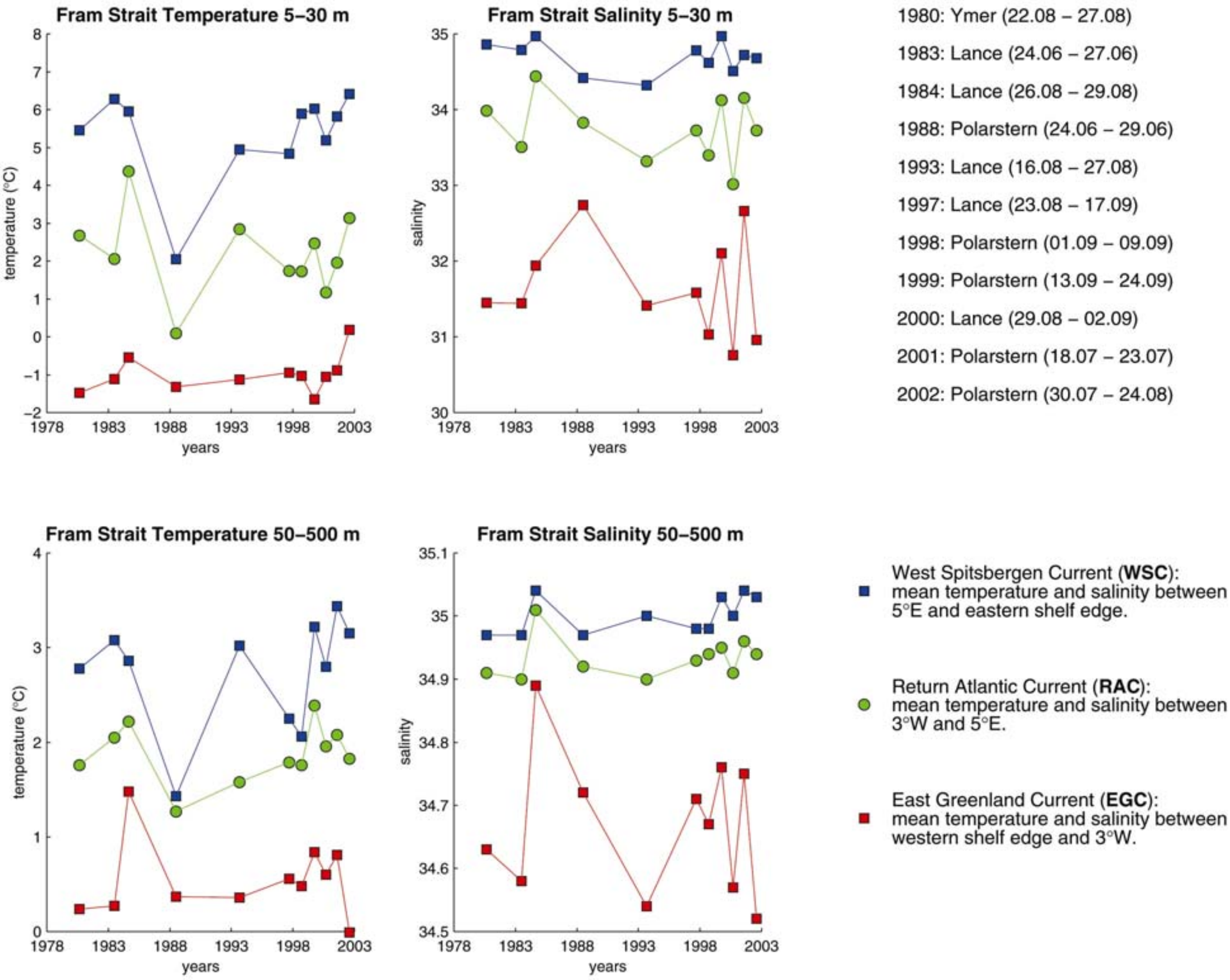


Figure 4. The variations of the mean temperatures and salinities in the Fram Strait in the West Spitsbergen Current (WSC), Return Atlantic Current (RAW) and East Greenland Current (EGC). The values for the last years were calculated by A. Wisotzki, U. Schauer and H. Rohr. Earlier values supplied by M. Marnela and B. Rudels from the FIRM. Additional data obtained from the ICES Data Centre in Copenhagen.

ANNEX W: THE 2002/2003 ICES ANNUAL OCEAN CLIMATE STATUS SUMMARY

Overview

In most areas of the North Atlantic during 2002, temperature and salinity were higher than the long-term average.

The North Atlantic Oscillation (NAO) index switched back to negative conditions during the winter preceding 2001, having recovered in the previous 4 years from the extreme negative value of 1996, which had brought to an end a period of extreme and persistent positive NAO index in the late 1980s/early 1990s. The 2002 NAO index showed a return to positive which for the winter as a whole was not extreme, but where individual months exhibited extreme and opposing SLP anomaly patterns.

Area Summaries

Area 1: West Greenland

Although summer time temperatures off West Greenland were slightly above average in the summer of 2002, there was cooling during the autumn. Unusually low salinities were observed in the off-slope surface waters during the autumn.

Area 2: Northwest Atlantic, Scotian Shelf, Newfoundland and Labrador Shelf

Annual mean air temperatures over all areas of the Northwest Atlantic remained slightly above normal during 2002, but have decreased over 2001 values. The amount of sea ice on the eastern Canadian Continental Shelf continued to be below normal for the 7th consecutive year. Ocean temperatures during 2002 remained above normal, thus continuing the warm trend experienced throughout much of the Northwest Atlantic during the past several years. Ocean salinities during 2002 increased to the highest levels observed in over a decade.

Area 2b: Labrador Sea

The 2001-2002 winter over the Labrador Sea was more severe than the previous winter but still milder than normal. Observations in early summer 2002 showed remnants of convective overturning to maximum depths of 1200 -1400 metres, about 400 metres deeper than seen in the preceding two years. Apart from the apparent weak increase in winter convection, the general trend was to warmer and more saline conditions. This was true both in waters shallower than the maximum depth of convection and in the intermediate-depths below 1400m. The net result is that the mean 0-2000 metres salinity was the highest in the past thirteen years of regular spring-summer observations. The corresponding mean temperature was the second highest observed during this period.

Area 3: Icelandic Waters

The hydrographic conditions in 2002 revealed winter and spring values on the shelf north, north-east and east of Iceland below long-term mean for both temperature and salinity. Summer and autumn values in this area were about average and higher. The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years though slightly lower than the peak values in 1998.

Area 4: Bay of Biscay and Eastern Atlantic

An extremely anomalous cold atmospheric spring-summer period at the southern Bay of Biscay area have made 2002 the coldest sea surface temperature year from 1992. Upper water (0–300 metres) mean temperature is on the time-series average. Salinity has begun to recover after the minimum found in 2001 resulting in average values for shallower depths.

Area 5: Rockall Trough

No data available for 2002.

Area 5b: Northeast Atlantic

The WOCE/CLIVAR Section A1E, showed relatively high temperatures and salinities in the upper layer in 2002. These suggest that a new positive salinity anomaly is in progress. In the upper 1200 metres of the water column the tendency is towards warmer and more saline conditions. This is due to the deepening and decay of the Labrador Sea Water mass produced in the 1990s.

Area 6: Faroe Bank Channel and Faroe Current

No data available for 2002.

Area 7: Faroe Shetland Channel

With respect to the last four decades, Atlantic waters in the Faroe Shetland Channel are generally warming and becoming more saline. This trend continued during 2002.

Areas 8 and 9: Northern and Southern North Sea

Surface waters of the North Sea were higher than average in most areas for the whole of the year. Salinities in the North Sea returned to normal following the extreme low values observed in 2001.

Area 9b: Baltic, Kattegat and Skagerrak

The year of 2002 was characterised by the late summer being unusually warm which resulted in higher than normal sea surface temperatures in Area 9b. Low surface salinities were found in the Kattegat and Skaggerak in April-June due to large outflows from the Baltic.

Area 10: Norwegian Sea

In the Norwegian Sea conditions continued a long term warming trend, and in 2002 the temperature of Atlantic water was the highest since the time series started in 1978.

Area 11: Barents Sea

The Barents Sea was warmer than the average during 2002. The temperature increased from average in January and reached maximum temperature anomaly in June, which was the highest observed during the last 30 years. The temperature then decreased to the average at the end of 2002.

Area 12: Greenland Sea

In the Greenland Sea in summer 2002, the Atlantic waters of the West Spitsbergen Current were characterised by high temperature and salinity, similar to those observed during the last three years. Polar waters in the east Greenland Current were significantly colder and less saline than in summer 2001.

The North Atlantic Oscillation (NAO) Index

Since the NAO is known to control or modify three of the main parameters which drive the circulation in the ocean area covered by this climate summary (i.e. wind speed, air/sea heat exchange and evaporation/precipitation), a knowledge of its past and present behaviour forms an essential context for the interpretation of observed ocean climate change in 2002/2003.

The NAO alternates between a “high index” pattern, characterised by strong mid-latitude westerly winds, and a “low index” pattern in which the westerly winds over the Atlantic are weakened. High index years are associated with warming in the southern North Atlantic and north-west European shelf seas, and with cooling in the Labrador and Nordic Seas. Low index years generally show the reverse.

When we consider the NAO index for the present decade, and the last 10 years in the context of the last 100 years (Figure 1), the 1960s were generally low-index years while the 1990s are high index years. There was a major exception to this pattern occurring between the winter preceding 1995 and the winter preceding 1996, when the index flipped from being one of its most positive values to its most negative value this century. The index subsequently rose from the extreme low of 1996 until 2001 when the NAO Index again became negative.

The winter of 2002 showed an overall positive index, which for the winter as a whole was not extreme, but where individual months exhibited extreme and opposing sea level pressure anomaly patterns. Whilst the simple index for 2002 suggested weakly positive NAO conditions, the winter sea level pressure anomaly was not dominated by the NAO pattern and conditions in the west were more consistent with conditions associated with a negative NAO pattern.

Prognosis for 2003 Winter NAO Index

It appears likely that the winter 2003 NAO index will be negative overall although March 2003 data is not available at the time of writing. The sea level pressure anomaly pattern does not appear to be that of a typical NAO year as anti-cyclonic conditions over Scandinavia dominate.

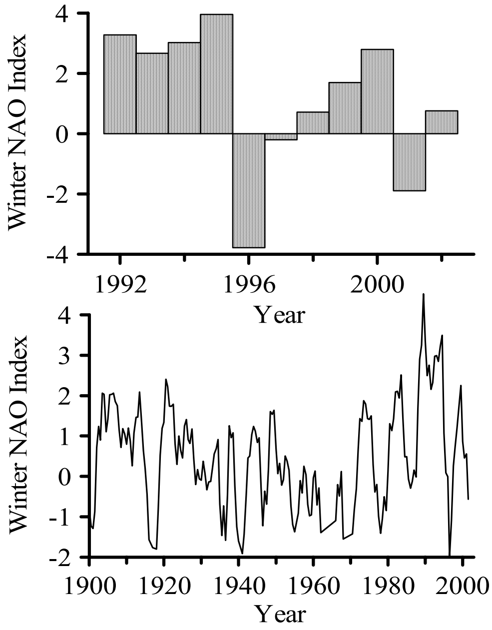


Figure 1. The winter NAO index in terms of the present decade (upper figure) and the last 100 years (lower figure - a 2 year running mean has been applied).

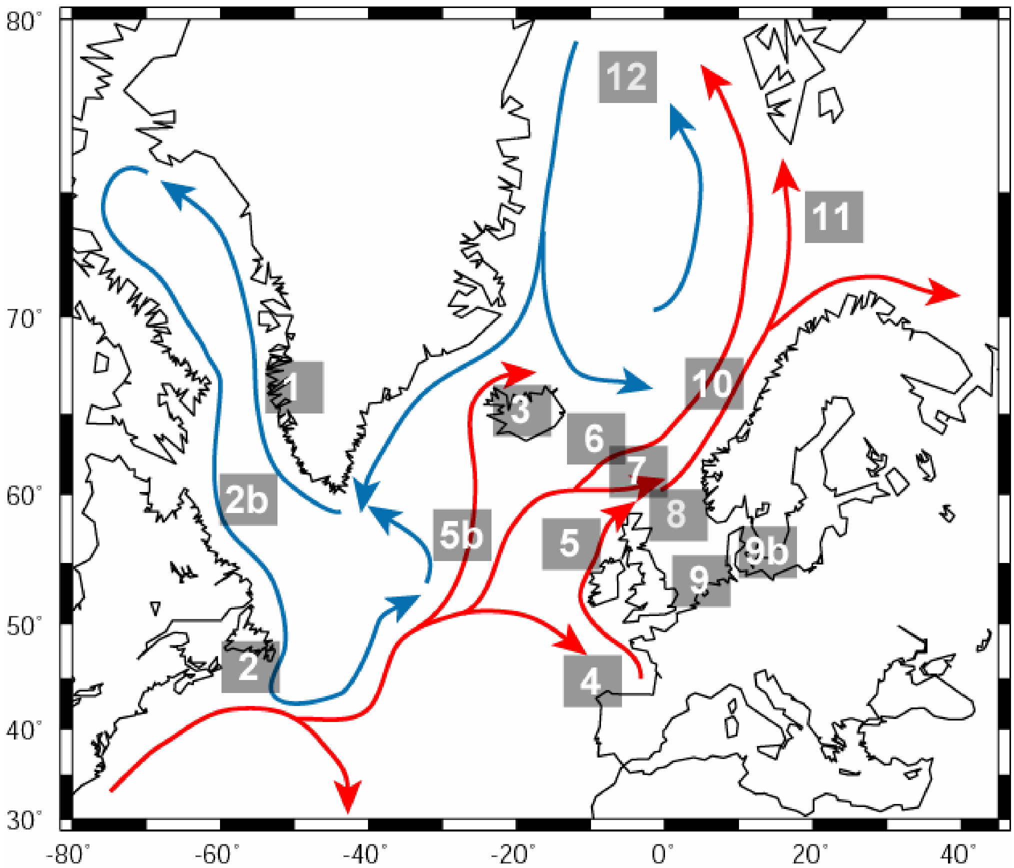


Figure 2. Schematic of the general circulation of the North Atlantic in relation to the numbered areas presented in the 2002/2003 Annual ICES Ocean Climate Status Summary. The blue (light grey) arrows indicate the cooler waters of the sub-polar gyre. The red (dark grey) arrows show the movement of the warmer waters in the sub-tropical gyre.

Text Box 1 - The NAO in winter 2002

Background

Following a long period of amplification from its most extreme and persistent negative phase in the 1960s to its most extreme and persistent positive phase during the late 1980s and early 1990s, the NAO index underwent a large and rapid decrease during the winter preceding 1996. Recent IAOCSS describe the recovery of the NAO to positive conditions in the years following 1996 until a further reversal occurred over the winter preceding 2001. Here we report that the NAO over the winter months preceding 2002 exhibited opposing extremes resulting in an overall positive (but not extreme) NAO index.

Winter NAO in 2002

The Jones NAO_{DJFM} index (www.cru.uea.ac.uk) for the winter of 2002 was 0.79 and the Hurrell NAO_{DJFM} index (www.cgd.ucar.edu/~jhurrell/nao.stat.winter.html) was 0.76. Figure 1a shows the SLP anomaly field in the North Atlantic for the composite of the 4 winter months (NCEP/NCAR Reanalysis data) with little of the typical NAO pattern. The cause of the overall weak positive NAO_{DJFM} index stems from a weak anti-cyclonic anomaly centred on Switzerland showing little zonal extension into the Atlantic. SLP anomaly over Iceland was weak and slightly positive but still small enough to make the difference in SLP with the Iberian Peninsula positive.

Overall the winter 2002 was a not an extreme NAO_{DJFM} year as shown by the SLP anomaly field and by the two instrument based indices both reporting an index less than one standard deviation different from the mean. However, of the four months that make up the Jones NAO_{DJFM}, December showed an extreme negative anomaly, -2.25, whilst January and February were both extremely positive, 2.31 and 3.01. Figure 3b shows the SLP anomaly for the individual winter months. December is dominated by an anti-cyclonic anomaly south of Iceland, leading to north-easterly wind anomaly over the North Sea and anomalous south-easterly airflow across the Labrador Sea and southern Greenland. The pressure dipole is more east-west than the usual pattern in Jan 2002 with a deep low south of Greenland. February shows much of the strong zonal character of the NAO positive but with the northern low pressure anomaly centred over Sweden. March shows no strong pattern over the northeastern North Atlantic and is comparable with the composite SLP anomaly for all 4 months.

Early indications for the winter 2003 are for a decrease in the NAO index with the overall SLP anomaly (Figure 4) this year showing an east-west dipole featuring a Scandinavian anti-cyclone.

Figure 3: NAO

The North Atlantic distribution of SLP anomaly in the North Atlantic for (a) composite of December 2001 to March 2002, (b) individual months Dec 2002 and Jan 2003 upper panels, Feb 2003 and March 2003 below (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

Figure 4: NAO

The Atlantic distribution of SLP anomaly in the North Atlantic for (a) December 2002, (b) January 2003, (c) February 2003 and (d) the composite of those 3 months (NCEP/NCAR Reanalysis data from NOAA-CIRES Climate Diagnostics Center: www.cdc.noaa.gov/Composites).

Regional Descriptions

Area 1 - West Greenland

West Greenland lies within the area which normally experiences warm conditions when the NAO index is negative. Atmospheric conditions off West Greenland during the summer of 2002 were slightly warmer than normal following even warmer conditions during 2001 (Figure 5). The 2002 summertime temperatures at Fylla bank, on the continental slope west of Nuuk, were slightly above the average for the past 50 years. In the summer, the 2002 mean salinity values on top of Fylla Bank were similar to the 2001 conditions and equal to the average value for the entire period.

There was considerable cooling and freshening during autumn 2002 at Fylla Bank station 4. The upper 200 metres of the water column indicated cooling of 0.29°C (Figure 6) below the climatic mean (1963-1990). This cooling is similar to that observed during the early 1970s and early 1980s. The salinity anomaly at station 4 was also unusually low being 0.54 psu (Figure 6) below the long-term mean. Sea surface temperature anomaly maps, as published by IGOSS (Figure 7) indicate, for the month of November, a temperature anomaly in the Fylla Bank area that is in the same range as given for the Fylla Bank station 4.

Figure 5: Area 1, West Greenland

Annual mean air temperature observed at Nuuk for the period 1873-2002.

Figure 6: Area 1, West Greenland

Fylla Bank Station 4 temperature (upper) and salinity (lower) anomaly autumn, 0-200 metres; data 1963-2002.

Figure 7: Area 1, West Greenland

Sea surface temperature anomaly (K) off West Greenland during November 2002 (from: http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS)

Area 2 - North West Atlantic: Scotian Shelf, Newfoundland and Labrador Shelf

Oceanographic conditions in this region are to a large degree determined by the strength of the winter atmospheric circulation over the Northwest Atlantic. In general, when the normal cyclonic circulation is weak during the winter months, corresponding to a negative NAO index, warm saline ocean conditions predominate.

Scotian Shelf

The continental shelf off the coast of Nova Scotia is characterised by complex topography consisting of numerous offshore shallow (< 100 metres) banks and deep (> 200 metres) mid-shelf basins. It is separated from the southern Newfoundland Shelf by the Laurentian Channel and borders the Gulf of Maine to the south-west. The surface circulation is dominated by a general south-westward flow interrupted by clockwise movement around the banks and counterclockwise around the basins with the strengths varying seasonally. Temperature and salinity conditions over the Shelf are largely determined by advection of water from southern Newfoundland and the Gulf of St. Lawrence as well as offshore "Slope" waters.

In 2002, annual mean air temperatures over the Scotian Shelf as represented by those recorded at Sable Island remained above average (based upon 1971-2000) but continued their decline from the record high set in 1999 (Figure 8). The higher-than-normal annual mean temperature is consistent with annual air temperature anomalies from West Greenland to Cape Hatteras. Seasonally, air temperatures from winter to summer declined from warmer than normal during the first 5 months of 2002 to below normal during June and July. For the remainder of the year, air temperatures varied near to and about the long-term mean.

The amount of sea ice on the Scotian Shelf, as measured by the area of ice seaward of Cabot Strait between Nova Scotia and Newfoundland, remained low in 2002. These conditions have persisted for the past five years. The number of days of ice seaward of Cabot Strait was the third lowest in the 41 year record and integrated ice area (sum of the area of ice over all days) was the 2nd lowest on record.

Topography separates the north-eastern Scotian Shelf from the rest of the Shelf. In the north-east, the bottom tends be covered by relatively cold waters (1°- 4°C) whereas the basins in the central and south-western regions have bottom temperatures that typically are 8°-10°C. The origin of the latter is the offshore Slope waters whereas in the north-east their source is principally from the Gulf of St. Lawrence. The interannual variability of the two water masses differs. Misaine Bank temperatures at 100 metres capture the changes in the north-east. They show warmer-than-normal conditions in 2002 and an increase from the below average temperatures in 2001. These followed an extended period from 1985 to 1997 of below average temperatures and generally above normal temperatures from 1998 to 2000. In Emerald Basin, temperatures in 2002 were slightly above average and continue a trend that has existed since the mid 1980s except for the exceptional cold period in 1998. The latter occurred when cold Labrador Slope Water replaced Warm Slope Water at the edge of the continental shelf. These cold waters subsequently penetrated onto the Scotian Shelf and into Emerald Basin. The presence of the Labrador Slope Water was caused by an increase in the volume transport of the Labrador Current, which in turn is believed to have been a delayed response to the large decline in the NAO index in 1996.

Sea surface waters over the entire Scotian Shelf were warmer and saltier than average during 2002. The higher temperatures have persisted for several years and are believed to be associated with the warmer atmospheric conditions. The higher salinities are a change from previous years. Surface salinity conditions on the Shelf are primarily related to upstream conditions off Newfoundland. The higher salinities led to a decrease in the stratification over the shelf in 2002 to levels below the long-term mean.

Newfoundland and Labrador Shelf

The Rogers North Atlantic Oscillation (NAO) index for 2002 was slightly below normal indicating a weak Arctic outflow to the Northwest Atlantic during the winter months. As a result annual air temperatures throughout most of the Newfoundland and Labrador Region were still slightly above normal during 2002, but decreased over 2001 values. Annual mean air temperatures at Cartwright for example, on the southern Labrador Shelf cooled over 2001 values from 1.4°C above normal to 0.2°C above normal in 2002 (Figure 9). Seasonally, air temperatures were either near normal, or above normal in 7 to 9 months of 2002. Sea ice on the Newfoundland and Labrador Shelves during 2002 generally appeared late, resulting in a shorter duration of ice than normal. The total ice coverage during 2002 however, increased over conditions in 2001 during both winter and spring, but remained below average for the seventh consecutive year.

Off eastern Newfoundland, the depth-averaged ocean temperature ranged from a record low during 1991 (high NAO index), a near record high in 1996 (near record low NAO index), and above the long-term (1971-2000) average in 1999 through to 2002, although the 2002 value decreased over 2001. Summer salinities on the Newfoundland Shelf, which were below normal throughout most of the 1990s, increased to above normal conditions during 2002, the highest values observed in about 12 years (Figure 10).

A robust index of the general oceanic environmental conditions off the eastern Canadian continental shelf is the extent of the cold intermediate layer (CIL) of <0°C water. This winter cooled water remains trapped between the seasonally heated upper layer and the warmer shelf-slope water throughout the summer and autumn months. During the 1960s, when the NAO was well below normal and had the lowest value ever in this century, the volume of CIL water was at a minimum, and during the high NAO years of the early 1990s, the CIL volume reached near record high values. During 2002, the CIL remained below normal on the Newfoundland Shelf for the eight consecutive year and among the lowest observed since the late-1970s.

In general, ocean temperatures in the Northwest Atlantic during 2002 remained above normal, thus continuing the warm trend experienced in much of the Northwest Atlantic during the past several years. Temperatures however have been decreasing since the near-record highs of 1999. Salinities in the Northwest Atlantic during 2002 increased to the highest observed values in over a decade, compared to the fresher-than-normal trend experienced throughout most of the 1990s.

Figure. 8. Area 2, North West Atlantic: Scotian Shelf.

Annual air temperatures at Sable Island on the Scotian Shelf, monthly means of ice area seaward of Cabot Strait and the near-bottom temperature anomalies in the north-eastern Scotian Shelf (Misaine Bank, 100 metres) and central Scotian Shelf (Emerald Basin, 250 metres). The vertical line in the plot of air temperatures represents the long-term (1971-2000) average.

Figure. 9. Area 2, Northwest Atlantic: Newfoundland and Labrador Shelf.

Annual air temperature anomalies at Cartwright on the Labrador Coast (top panel) and sea-ice area off Newfoundland and Labrador between 45°N-55°N for the winter (solid line) and for spring (dashed line).

Figure. 10. Area 2, Northwest Atlantic: Newfoundland and Labrador Shelf.

Annual depth-averaged Newfoundland Shelf temperature (ºC) summer salinity anomalies and the time series of cold intermediate layer (CIL) on the Newfoundland (solid line) and Labrador (dashed line) Shelves.

Area 2b - The Labrador Sea in 2002

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

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

Since the winter of 1994 -1995, mild winters have produced only shallow convection. This pattern persisted through the winter of 2001-2002. Annual sea-air heat fluxes (June 2001 - May 2002) in the central Labrador Sea estimated from the NCEP Reanalysis Project were about 14 Wm^{-2} less than the mean for the 31-year normal period June 1970 to May 2001 (Figure 11). This places the 2001-2002 12-month average in the 26th percentile for the normal period.

Wintertime (December-February) heat fluxes were nearly 60 Wm^{-2} less than the winter normals but were balanced by higher than normal spring (March-May) heat fluxes. A July 2002 transect of the Labrador Sea showed evidence of vertical overturning during the previous winter to maximum depths of 1200-1400 metres. This evidence consisted of remnants of a weakly stratified layer at these depths with relative minimum potential temperature and higher dissolved oxygen than in the preceding years. The inferred winter mixed layer had potential temperature 3.15 °C, salinity 34.83, and potential density anomaly 27.74 kg m^{-3}. In contrast, the deep mixed layers observed in the early 1990's had potential density anomalies near 27.78 kg m^{-3}.

In spite of a cooling and freshening near 1000 metres depths associated with the moderate 2001-2002 winter overturning, the upper layers of the Labrador Sea became warmer and saltier. This suggests an increased input of warm, saline waters from the offshore branch of the West Greenland Current. The mean 0-1000 metres temperature in the central Labrador Sea was the second highest in thirteen recent annual surveys, surpassed only by 1999. The salinity of the upper 1000 metres were greater than observed since the period of deep convection of the early 1990's when higher-salinity waters from deeper levels were entrained into the upper 1000m. In addition, the dissolved oxygen content of this warm and saline water was lower than observed in the preceding two years.

Since the mid-1990s, a notable trend to higher temperature and salinity in the 1000-2000 metres layer has emerged. In spite of the effects of winter overturning noted above, the mean temperature of this layer in early summer 2002 was the highest observed at comparable seasonal times during the past thirteen years. Salinity in this depth range showed a very slight decrease from the record high conditions of the previous year. The dissolved oxygen content of this intermediate layer also decreased compared with the preceding two years.

The net result is that the mean 0-2000 metres salinity in early summer 2002 was the highest observed in the past thirteen spring-summer periods. The corresponding mean temperature was the second highest observed during this period. The density of seawater decreases with increasing temperature and increases with increasing salinity. The 2002 survey showed slightly denser waters in the 0-1000 metres depth range and slightly less dense waters in the 1000-2000 metres depth range, compared with results from 2001. The net effect was a small decrease in 0-2000 metres mean density, equivalent to a rise in steric sea level by less than 0.01 metre. The TOPEX/POSEIDON altimetric satellite measured a consistently small increase in sea level over the corresponding period.

Figure 11: Area 2b, the Labrador Sea

12-month averages (June-May) of monthly-mean sea-air heat flux at 56.2 °N, 52.5°W in the central Labrador Sea from the co-operative Reanalysis Project of the U.S. National Centres for Environmental Prediction (NCEP) and National Centre for Atmospheric Research. Values within the shaded area are lower than the mean (65 Wm^{-2}) for the 31-year normal period June 1970 - May 2001. Values for the most recent two 12-month periods were lower than normal: 51 Wm^{-2} (26th percentile) for June 2001 - May 2002 and a near-record low of 32 Wm^{-2} for June 2000 - May 2001.

Area 3 - Icelandic Waters

Iceland is situated at a meeting place of warm and cold currents which meet in an area of submarine ridges (Greenland-Scotland Ridge, Reykjanes Ridge, Kolbeinsey Ridge), which form natural barriers against the main ocean currents (Figure 12). To the south is the warm Irminger Current which is a branch of the North Atlantic Current (6° – 8°C), and to the north are the cold East Greenland and East Icelandic Currents (-1° – 2°C).

The hydrographic conditions in 2002 revealed winter and spring values on the shelf north, north-east and east of Iceland, below the long-term mean for both temperature and salinity (Figure 13). Summer and autumn values in this area were about average and higher. The salinity and temperature in the Atlantic water from the south remained at high levels similar to previous years (Figure 14), though slightly lower than the peak values in 1998.

Figure 12: Area 3, Icelandic Waters

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

Figure 13: Area 3, Icelandic Waters

Temperature and salinity at 50 metre depth in spring at Station Si-3 in North Icelandic waters 1952-2003.

Figure 14: Area 3, Icelandic Waters

Salinity in spring at:

a) 100 metres depth in the Irminger Current south of Iceland (Sb-5) 1971-2002.
b) 25 metres depth in the East Icelandic Current north-east of Iceland 1952-2002, mean from shaded area in figure 1.

Area 4 - Bay of Biscay and Eastern Atlantic

The Bay of Biscay is located between the eastern part of the sub-polar and sub-tropical North Atlantic gyres. The general circulation in the area mainly follows the subtropical anti-cyclonic gyre in a relatively weak manner (1-2 cms^{-1}). At the southern part of the Bay of Biscay east flowing shelf and slope currents are common in autumn and winter due to westerly winds whereas in spring and summer easterly winds are predominant and coastal upwelling events are frequent.

Summer 2002 presents the colder air temperatures since 1987 and one of the colder of the meteorological time series (1960-2002) of the INM. Comparing year 2002 with the climatological mean from 1991 for surface waters, we found a slightly cool winter followed by a persistent cool summer for the upper water layer (Figure 15). The warming period is short being the shortest in the time series. Upper water (0-300 metres) mean temperature is on the time-series average. Salinity has begun to recover after the minimum found in 2001 resulting in average values for shallower depths.

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 with two marked events in June and October. During 2002 the advection and river overflow was low compared to the previous years. Between 1998 and 2001, the evidence of a decline in salinity was found up to a depth of 300 metres. In 2002 this tendency has been inverted, especially during the poleward episode at the beginning of the year (Figure 16).

Thermosalinograph measurements (TSG) in the Eastern Atlantic and Bay of Biscay show some strong coherency of the surface salinity anomaly evolution over an extended area (in particular around Cape Finisterre). This shows this signal is associated with large-scale processes. A strong coherency has also been found with integrated measurements from 5 - 300 metres in the Southern Bay of Biscay, which proves this process affects a significant part of the water column

For the time series centred on 10W/42-43N, one notices for example the episodes of high salinity in 1990 as well as in 1998, which are typical of a large area of the north-east Atlantic extending at least from 42N to 48N and across the Bay of Biscay (Figure 17). The low salinity in 2001 seems also to be present in a large area that is probably related to anomalously high rainfall extending from north-west Spain to the English Channel in late 2000-early 2001.

Figure 15: *Area 4, Bay of Biscay and Eastern Atlantic*

Sea Surface Temperature anomaly at Santander station 6 (shelf-break).

Figure 16: *Area 4, Bay of Biscay and Eastern Atlantic*

Salinity anomaly evolution (5 – 300 m) at Santander station 6.

Figure 17: *Area 4, Bay of Biscay and Eastern Atlantic*

Surface salinity anomaly evolution at 42-43ºN, 10ºW. Dashed line from monthly anomalies, plain line for three month averages.

Area 5 - Rockall Trough

No data available for 2002.

Area 5b - North East Atlantic

The ongoing work on the WOCE/CLIVAR section A1E (Figure 18) is reported here. This section has been repeated nine times since 1991 with approximately 54 CTD stations between Cape Farvel (Greenland) and Porcupine Bank (SW-Ireland). The eastern part of the section is occupied by warm and saline waters of the North Atlantic Current (NAC) whereas the western part of the section is occupied by less warm and saline waters of the sub-polar gyre. The boundary between these two waters is the Sub-polar Front.

The recent 11 years variation of the position of the Sub-polar Front along section A1E is illustrated in figure 19. The position of the Sub-polar Front is highly linked to the NAO index. During positive NAO the location of the front is more easterly hampering the north-westward transport of the warm and saline waters of the NAC. During negative NAO conditions the situation is reversed giving rise to northward progress of warm and saline anomalies. The timing of these anomalies is illustrated in figure 20, which shows the temporal changes of the mean salinity in different regions of section A1E in the upper 1200 metres between 1991 and 2002. The positive salinity anomaly is first observed in the Iceland Basin and Rockall Trough and arrives in the Irminger Sea about two years later.

The 2002 data set suggests that a warm and saline anomaly is in progress, seen as rising salinity (and temperature) in the upper layer in all three regions in figure 20 and a westerly position of the sub-polar front.

Figure 18 Area 5b, Northeast Atlantic

Location of the WOCE/CLIVAR hydrographic section A1E and bottom topography in the northern North Atlantic.

Figure 19 Area 5b, Northeast Atlantic

Temporal changes of the mean salinity of the upper 600 metres along section A1E, recorded nine times between September 1991 and July 2002.

Figure 20 Area 5b, Northeast Atlantic

Temporal changes of the mean salinity in different regions of section A1E in the upper 1200m between 1991 and 2002: (a) Irminger Sea (30.8° to 41.8°W), (b) Iceland Basin (24.0° to 28.0°W), and (c) Rockall Trough (15.2° to 20.0°W). Notice that different colour codes are used in the different regions.

Area 6 – Faroe Bank Channel and Faroe Current

No data available for 2002.

Area 7 - Faroe Shetland Channel

The continental Slope Current flows along the edge of the north-west European shelf, originating in the southern Rockall Trough. It carries warm, saline Atlantic water into the Faroe Shetland Channel. A proportion of this Atlantic water crosses onto the shelf itself and enters the North Sea, where it is diluted with coastal water and eventually leaves that area in the Norwegian Coastal Current. The remainder enters the Norwegian Sea to become the Norwegian Atlantic Current. Cooler, less saline Atlantic water also enters the Faroe Shetland Channel from the north, after circulating around the Faroe Islands. This second branch of Atlantic water joins the waters originating in the Slope Current, and also enters the Norwegian Sea.

Atlantic water in the Slope Current is generally warming and becoming more saline (Figure 21). Temperatures have been rising from a minimum in the late 1960s at a rate of approximately 0.3°C/decade. Salinity has increased from minimum values in the mid 1970s, with the trend showing a decadal scale variability associated with the NAO. In 2000 and 2001, the temperature and salinities decreased slightly. During 2002, the trend has reversed and the values are increasing once again.

Trends in the cooler, fresher modified Atlantic water flowing around Faroe and entering the Channel from the north are similar to those in the Atlantic water of the Slope Current (Figure 22). The warming trend is slightly less in the modified water, while the mid 1970s low salinity period was more extreme. During 2002, temperature and salinity continued to increase slightly from the values observed in 2000 and 2001.

Figure 21: Area 7 – Faroe Shetland Channel.

Temperature and salinity anomalies in the North Atlantic Water (NAW) in the Slope Current.

Figure 22: Area 7 – Faroe Shetland Channel.

Temperature and salinity anomalies in the Modified Atlantic Water (MNA) entering the Faroe Shetland Channel from the north after circulating around Faroe.

Areas 8 and 9, Northern and Southern North Sea

The North Sea oceanographic conditions are determined by the inflow of saline Atlantic water mainly through the northern entrances (Fair Isle Current) and to a lesser degree through the English Channel. The Atlantic water mixes with the run-off mainly from the continent and the lower salinity Baltic outflow along the Norwegian coast. The temperature of the North Sea is mainly controlled by the local solar heating and heat exchange with the atmosphere. Both the salinity and the temperature of the North Sea reflect the influence of the NAO on the movement of Atlantic water into the North Sea and the meteorological forcing of the ocean-atmosphere heat exchange. The balance of tidal mixing and local heating force the development of a seasonal stratification from April/May to September in most parts of the North Sea. Numerical model simulations show strong differences in the North Sea circulation depending on the state of the NAO.

In the Fair Isle Current (Figure 23), temperature increased during 2002 to reach the highest values since the data set began in 1972. The Fair Isle current also appears to be freshening, the lowest values observed since 1972 were seen during 2001 but these values increased to more normal levels during 2002.

In terms of the surface temperatures of the whole North Sea in 2002, the area averaged annual mean SST of 11.0° C made 2002 the warmest year on record. Another record was set in September (16.2°C), while the months of April, August, and October were the second warmest after 1990,1997 and 2001, respectively. As is apparent from figure 24, sea-surface temperatures exceeded the climactic normal nearly basin-wide and throughout the year. The warm period observed throughout 2001 and 2002 form a long period of positive sea-surface temperature anomalies that point to an overall warming trend.

The temperature of the upper layer of most of the North Sea was about one degree Celsius warmer than normal during most of 2002. Along the Norwegian west-coast it was the warmest September since the monitoring began in 1942. Figure 25 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. At both positions, the values from 2000 and 2001 were rather close to the long-term average, while in 2002 we see a certain increase in temperature. Due to the warmer and deeper upper mixed layer and the warmer bottom layer the total heat content of the North Sea in summer 2002 was definitely above the normal.

Low salinities persisted during the first half of 2002 across the Southern Bight following the extreme low salinity year of 2001 (Figure 26). By mid year a positive anomaly was observed at the Smartbuoy deployment (not shown here) and persisted into the autumn. SST in winter and spring months of 2002 was above normal without much of the cooling usually occurring in February and March.

Oceanographic measurements made in summer 2002 (RV GAUSS July) show an increasing influence of Atlantic water in the northern North Sea compared with the previous year. In larger parts the Sea Surface Salinity (SSS) anomaly distribution (Figure 27) shows only insignificant deviations from the long-term mean (Janssen et. al., 1999). Above the western flank of the Norwegian Trench SSS anomalies of up to 1 PSU point to a stronger Atlantic water inflow. In the German Bight and off the Danish coast a stronger than normal run-off led to negative SSS anomalies

German Bight

The temperature data (Figure 28) from the MARNET station "German Bight" support the results of the area averaged North Sea SST data. The whole year the SST in the German Bight was above (or close to) the long-term mean. The salinity data show the normal high variability in the German Bight. The sharp drop of the salinity in September 2002 is caused of the river Elbe exceptional flood in August 2002, which arrived the German Bight station in September 2002.

Figure 23. Areas 8 and 9, Northern and Southern North Sea.

Temperature and salinity anomalies in the Fair Isle Current (FIC) entering the North Sea from the North Atlantic.

Figure 24. Areas 8 and 9, Northern and Southern North Sea.

North Sea area averaged SST annual cycle, monthly means based on operational weekly North Sea SST maps. green dots - climatology 1971-93; blue line – 2001 data, red line - 2002 data; black thin lines - individual years.

Figure 25. Areas 8 and 9, Northern and Southern North Sea.

Temperature and salinity near bottom in the north-western part of the North Sea (A) and in the core of Atlantic water at the western shelf edge of the Norwegian Trench (B) during the summers of 1970-2002.

Figure 26: Areas 8 and 9, Northern and Southern North Sea

Normalised seasonal a) Temperature b) Salinity anomaly along the 52°N Felix-Rotterdam Route.

Figure 27. Areas 8 and 9, Northern and Southern North Sea.

Sea Surface Salinity anomalies based on thermosalinograph data taken in July 2002, (Climatology taken from Janssen *et al.,* 1999)

Figure 28. Areas 8 and 9, Northern and Southern North Sea.

Annual cycle 2002 temperature and salinity from MARNET station “German Bight” temperature climatology taken from weekly SST maps, salinity climatology from data taken at the island of Heligoland.

Area 9b - Skagerrak, Kattegat and the Baltic

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

The year of 2002 was characterised by the late summer being unusually warm. Higher than normal sea surface temperatures were recorded for the whole area in August and early September. This state of affairs is demonstrated in the temperature record from station P2 in Skagerrak displayed in figure 29. The diagram also depicts high values in the beginning of June, a feature representative for the situation in Kattegat as well. The weather changed rapidly in the autumn; on the Swedish west coast, for example, the transition from swimming conditions to a 10 cm thick snow cover took a little bit more than a month.

For 2002 the outflow from the Baltic into Kattegat was less than normal until the middle of March when a longer period with sizeable outflows took place. This feature is illustrated in figure 30 showing the accumulated inflow through Öresund for 2002. The diagram also includes the values for 2001 and 1993 as well as the maximum, minimum and mean values obtained from measurements during the period 1977–2001. The effect of large volumes of low saline water entering into Kattegat-Skagerrak is clearly visible in figure 30, showing the salinity at P2 for 2002. No major inflows of high salinity water to the Baltic took place during the year.

The ice cover in the Baltic during the winter 2001/2002 had its maximum extent on March 14 2002. The ice winter was considered fairly mild. The onset of cold weather during the late fall

2002 caused an early start of the Baltic freeze up.

Figure 29: *Area 9b, Skagerrak, Kattegat and the Baltic*

Annual cycles of surface temperature and salinity at station P2 in the southern part of Skagerrak. The data were collected by R/V Argos within the Swedish National Monitoring Programme.

Figure 30: *Area 9b, Skagerrak, Kattegat and the Baltic*

Accumulated inflow in km3 through Öresund 1993, 2001 and 2002 compared with the period 1977-2001. The map was constructed by SMHI.

Figure 31: *Area 9b, Skagerrak, Kattegat and the Baltic*

The maximum ice extent in the Baltic during the winter 2001/2002. The map was constructed by SMHI.

Area 10 - Norwegian Sea

The Norwegian Sea is characterised by warm Atlantic water on the eastern side and cold Arctic water on the western side. The border zone between these two water masses is known as the Arctic Front. Atlantic water enters the Norwegian Sea through the Faroe Shetland Channel and modified Atlantic water enters between the Faroes and Iceland, flowing eastward along the Iceland Faroe Front, into the Norwegian Sea. A smaller branch, the North Icelandic Irminger Current, enters the Nordic Seas on the western side of Iceland. The Atlantic water that flows northward along Norway as the Norwegian Atlantic Current splits when it reaches northern Norway. One part enters the Barents Sea while the other part continues northward into the Arctic Ocean as the West Spitsbergen Current. Arctic waters are transported into the Norwegian Sea from the southward flowing East Greenland Current mainly via the East Icelandic and Jan Mayen Currents. Fluctuations in fluxes and water-mass properties in this current system are of decisive importance for the distribution and structure of the water masses in the Norwegian Sea.

In the southern Norwegian Sea there is a long-term trend towards higher temperature in the Atlantic Water. The temperature has since 1978 increased by 0.5°C. In 2002 the temperature was the highest observed in the time series. The area occupied by Atlantic water has shown a long-term decrease. However, since the mid 1990s with several years of low values in the area there has been a positive trend.

Over the slope, east in the Norwegian Sea, a warming has taken place since 1996 (Figure 32). In 2002 the warming continued in the southern section (63°N) while a cooling occurred in the northern section (76°N). Unfortunately, there were no observations in the central section (69°N). The northern section has long-term trends toward higher temperature and lower salinity. Since 1996, the temperature in that section was however close to the long-term average. The vertically averaged temperature in the upper 200 metre layer in the Norwegian Atlantic Current was 0.8°–1.2°C above normal during summer 2002.

The SST was for 2002 higher than normal practically over the entire Norwegian Sea. At the Ocean Weather Station "M" it reached record high values. The thickness of the intermediate water mass is still increasing but the temperature increase at 2000 metres depth has stopped.

Figure 32: *Area 10, Norwegian Sea.*

Average temperature and salinity above the slope at three sections, Svinøy (approx. 63°N – upper figures), Gimsøy (approx. 69°N – central figures) and Sørkapp (approx. 76°N – lower figures), representing the southern, central and northern Norwegian Sea.

Area 11 - Barents Sea

The Barents Sea is a shelf sea, receiving an inflow of warm Atlantic water from the west. The inflow demonstrates considerable seasonal and interannual fluctuations in volume and water mass properties, particularly in heat content and consequently ice coverage. Regular measurements of the Atlantic inflow to the Barents Sea started in 1997. During the first three months of 2002 there was a relatively high inflow, while the inflow was below average during the last months of the year.

After a period with high temperatures in the first half of the 1990s, the temperatures in the Barents Sea dropped to values slightly below the long-term average over the whole area in 1996 and 1997. From March 1998, the temperature in the western area increased to just above the average (Figure 33), while the temperature in the eastern areas stayed below the average during 1998 (Figure 34). From the beginning of 1999 there was a rapid temperature increase in the western Barents Sea, which also spread to the eastern part of the Barents Sea, and the temperature has stayed above average since then.

In January 2002 the temperature was close to the long-term average in the whole Barents Sea. However, there was a rapid temperature increase during spring, most likely due to the increased inflow during the first three months. The increased heat content was observed both in the north-western and eastern Barents Sea. The highest positive anomaly of depth-averaged temperature both in the Atlantic and coastal waters (to 0.9° – 1.0°C) was observed in June. During autumn and early winter the temperature decreased rapidly, and reached to the long-term mean in January and February 2003 in the whole Barents Sea. The mean annual heat content in the southern Barents Sea is expected to be close to normal in 2003.

Figure 33: *Area 11, Barents Sea*

Temperature anomalies (upper panel) in the section Fugløya – Bear Island (ANON 2003).

Figure 34: *Area 11,The Barents Sea.*

Temperature and salinity anomalies in the Kola section (0-200 metre).

Area 12 - Greenland Sea

The Greenland Sea and its northern border, the Fram Strait, form one of the pathways that the Atlantic water takes before entering the Arctic Ocean. Part of the Atlantic water also re-circulates within Fram Strait and returns towards the south in the East Greenland Current. Besides the advection, water mass modification such as deep-water renewal, determined the hydrographic conditions in the region.

At the eastern side of the Greenland Sea, within the West Spitsbergen Current, there was a significant increase in temperature and salinity of the Atlantic water along 75°N (between 10°E and 13°E and in 50-150 metre depth) when compared to previous years (Figure 35).

The returning Atlantic water on the western side of the Greenland Sea, characterised by the temperature and salinity maxima below 50 metre averaged over three stations west of 11.5°W along 75°N, was slightly colder and less saline in summer 2002 than in the previous summer.

In the central Greenland Sea during the winter of 2001-2002 convection was confined mostly to about 1500 metre except the area of a small-scale eddy, where the temperature maximum was shifted downward to the depth of 2800 metre. A tendency to increase in the depth of maximum temperature was observed between 2001 and 2002 as well a rise of the lowest temperatures in the bottom waters.

In the eastern part of the Greenland Sea (at 76°30'N) mean temperature and salinity of the Atlantic Water (defined as a layer with salinity higher than 34.92) were a little lower than observed in summer 2001 but still significantly higher than minimum values found in 1997 and 1998 (Figure 36).

Further north, within the Fram Strait, at 79°N, a mean salinity observed in the West Spitsbergen Current was close to the last year value while the mean temperature decreased slightly (from 3.44°C in 2001 to 3.15°C in 2002). Nevertheless, both values remained similarly high as observed during last three years. A small drop in temperature and salinity of the Return Atlantic Current was noticeable. A strong decrease was noticed in the East Greenland Current in the layer 50 ÷ 500 m, where the mean salinity (34.52) as well as the mean temperature (-0.01°C) were the lowest since 1980 (Figure 37).

Figure 35: *Area 12, Greenland Sea.*

Temperature (left Figure) and salinity (right Figure) in the Returning Atlantic Water (RAW) in the East Greenland Current and the Atlantic Water in the West Spitsbergen Current at 75°N.

Figure 36: *Area 12, Greenland Sea (Eastern).*

Mean temperature (left Figure) and salinity (right Figure) of the Atlantic Water (layer with salinity higher than 34.92) in the West Spitsbergen Current at 76°30'N.

Figure 37: *Area 12, Greenland Sea (Northern).*

Averaged temperature and salinity at 50-500 metre depth in the Fram Strait (at 78°50'N / 79°N). The West Spitsbergen Current data (between 5°E and eastern shelf edge) shown in blue, the Return Atlantic Current data (between 3°W and 5°E) shown in green, the East Greenland Current data (between western shelf edge and 3°W) shown in red.

ANNEX X: A PROPOSAL TO THE ICES WORKING GROUP ON OCEANIC HYDROGRAPHY FOR SAMPLING AND LONG-TERM STORING OF WATER FOR FUTURE TRACER ANALYSIS

At the Faroese Fisheries Laboratory, we have recently initiated a routine where we on each of our quarter-annual standard cruises sample water from a few key- locations and depths for permanent storing. The inspiration for doing this was recent developments in the iodine isotope analysis. This technique offers great promise in distinguishing between water masses of different origins in some areas and it can be applied to small-volume samples collected and stored like conventional salinity samples. At present, the analysis of each sample is costly, but that may change, funds may become more available, and analytical techniques for other tracers may improve.

Whenever the technical and financial conditions for analysing a certain tracer in an area are met, the main problem will be samples, and usually, you will want a time series of the tracer concentration in each area or water mass. This is especially important when the tracer has a pulse-like or variable source function. Often, you will, however, only realise the utility of these samples long afterwards. This has been our motivation for initiating this procedure. The fact that no special sample preparation or preservation is carried out will, of course, limit the utility, but, as demonstrated by the iodine example, important parameters can still be determined. We expect future technical developments to increase the utility.

In our procedure, we have decided to sample water from two standard stations, one in the Faroe Bank Channel and one north of the Faroes. At each location, we sample from two depths in order to sample four different water masses. From each depth we draw four samples from a 5-liter Niskin bottle for long term storage. From the same bottle, we draw two additional samples for immediate salinity analysis. This information, together with the CTD data from the sample, is stored with the samples.

At present, we have no specific plans for analysis of these samples, but with very little extra man-power and expenses, we obtain samples that we believe to have large future potential. We propose that other laboratories that run standard cruises, consider a similar procedure.

Bogi Hansen, Tórshavn 8th March 2002

ANNEX Y: A PROPOSAL TO THE ICES WORKING GROUP ON OCEANIC HYDROGRAPHY FOR ISOPYCNAL MELDING OF HYDROGRAPHIC SURVEYS

The hydrographic database for the North Atlantic and Nordic Seas is enormous reflecting the many surveys that have been taken over the last 100 years. Given that most surveys consist of individual sections, it is quite natural that one should focus on the vertical structure of these and examine their evolution over time. Significant changes to the hydrographic make-up of the region have taken place over the years, but it is not always easy to quantify these because the data sets may come from slightly different regions, with different sampling densities, and with survey patterns dictated by the particular requirements of a project. So the question then arises how best to examine these data sets to search for and chart patterns of change in a systematic way. A method that allows for the consistent presentation and intercomparison of observations wherever they come from is to plot the observations on isopycnal surfaces. More specifically, we suggest the construction of a climatology of temperature and salt for a few key isoycnal surfaces. This climatology will define a 'mean state'. As new data for a given time window become available, changes in the hydrographic state of the region should show up clearly by plotting the departure of the observations from this climatology.

Waters move around the ocean along isopycnal surfaces, in response to the forces acting on the fluid. In some areas these motions may be relatively simple, perhaps reflecting a constraint imposed by topography, whereas in other areas more complex eddy motions might dominate, perhaps due to instabilities along fronts. Vertical movement consists of two parts, displacements due to the heaving of isopycnals, which is substantial, and motions due to diapycnal mixing. The latter, so far as we know, is quite small except in the presence of convection. As a result fluid parcels undergo three-dimensional, time-dependent trajectories, but their physical properties change only gradually since they are constrained to move and mix along surfaces, and not between surfaces. It is the vertical motions that tend to dominate the variability one sees in section plots of hydrographic data. The properties on the isopycnals, on the other hand, tend to be much more stable. Thus, an efficient way to display hydrographic information is to show the depths of the isopycnals as a first indication of the dynamic state of the system, and to show properties, such as temperature and oxygen, as a function of sigma-theta or specific volume anomaly to determine the hydrographic state of the system. This has become an increasingly common mode of data presentation in the literature. But we can take the process one step further, particularly for areas with extensive spatial and temporal coverage.

We propose to create a base climatology for the depth (pressure) and properties of chosen key isopycnals. This base state will define the properties of a region for the period in question. Given this climatology, surveys for a given period can then plot their properties relative to this 'base' state. This provides a framework for coherent use and melding of observations from separate surveys. Such a climatology would consist of two parts, maps showing the mean pressures of a given sigma-theta surface, and the properties on that surface. These will be relatively smooth fields as a result of all the data used to construct it. The observations would be binned into regions as small as possible consistent with data availability. This gives essentially equal weight to all regions included in the climatology. These bin-averages would then be mapped to map create the climatology. For the surfaces chosen, we would have pressure, temperature, salt, oxygen and any other property of interest (stratification, nutrients, and the variances of all).

To test the above ideas I propose that we conduct a pilot study of the Norwegian-Greenland Sea along the above lines. After an initial study to select a couple of isopycnals, one to represent the inflow of Atlantic Waters, and another to tag the spreading Arctic Intermediate Waters, I (in collaboration with anyone who might be interested in taking part) will take all available hydrographic station data and compute the pressure and properties on these isopycnals. We will not ask for all data, and in fact we would prefer that various groups prepare these subsampled data sets directly from their own archives. Each Nansen cast consists of samples of temperature and salinity as a function of pressure. We propose that the pressure and properties for a given surface be obtained by linear interpolation between adjacent bottles. The resulting data files would consist of location, time, Nx(pressure, temperature, salt, oxygen?) where N represents the number of sigma-t surfaces to be mapped. These will become the input data to the geographic binning process.

The objective here will be to construction the 'base' climatology which would consist of the mean pressure of the selected isopycnals and the mean properties on those surfaces. Once these are ready, we can look for anomalies that might exist for certain periods or in certain areas by the appropriate subdivision of the data. This framework emphasizes the horizontal dimension: The depth of the isopycnal surface - which is of dynamical interest - and the properties on that surface - which tells us about the movement of water mass anomalies. The latter may have a stronger signature since many times T and S anomalies tend to cancel such that the dynamical impact is minor.

If these data sets could be prepared over the next six months, I think the remaining step of preparing the mean state of these surfaces can be prepared quite quickly and made available to the Working Group on Oceanic Hydrography members, and other interested parties. The expectation is that we would report on this effort at the next Working Group on Oceanic Hydrography meeting in Bergen. Hopefully, by making the climatology available in good time, we could coordinate this year's surveys to look for developing patterns in time for next year's report.