ICES WGOH REPORT 2017

SCICOM STEERING GROUP ON ECOSYSTEM PROCESSES AND DYNAMICS

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Report of the Working Group on Oceanic Hydrography (WGOH)

4-6 April 2017

Torshavn, Faroe Islands

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

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Contents

Executive summary

The Working Group on Oceanic Hydrography (WGOH) meets yearly to review oceanographic conditions in the ICES region and to report on these in the ICES Report on Ocean Climate (IROC). The WGOH 2017 meeting was hosted by the Faroe Marine Research Institute, Torshavn, Faroe Islands, 4–6 April 2017. The highlights for the IROC for 2016 are presented below.

Highlights of the North Atlantic for 2016

Air and sea surface temperatures were higher than normal across most of the region, with the exception of the central subpolar North Atlantic (centred on 50N and including the Irminger and Iceland Basins). In Greenland and the Barents Sea record high air and sea surface temperatures were observed. North of Iceland record high sea surface temperatures were observed.

A cold anomaly in the surface and upper ocean of the central subpolar North Atlantic persisted in 2016, though it weakened through the year.

Heat content in the upper layer of the Norwegian Sea reached a record high value, and bottom temperatures across the northeast US Continental shelf were unusually high.

Salinity in the upper layer of the eastern subpolar North Atlantic and the Norwegian Sea has been decreasing since the late 2000s, and in 2016 a dramatic freshening and record low values were observed in the Faroe Bank Channel and Iceland Basin.

Ice cover in the Barents Sea reached a record low, with the first ice-free July on record. For the second winter in a row the Bothnian Bay was not completely ice covered and ice-cover elsewhere in the Baltic was lower than normal.

Experimental forecasts of sea level pressure and surface air temperature are included here for the first time.

Following recommendations from ICES SGWIDE and the recent publication of the sub polar Gyre Index, we include this data for the first time in the IROC.

Highlights of the north Atlantic atmosphere in winter 2015/2016

The winter North Atlantic Oscillation (NAO) index was positive (+0.98), for the third consecutive winter.

The Azores High was relatively strong with high pressure anomaly extending from Newfoundland across southern Europe, while the Iceland Low strengthened at its southern extent. Weaker winds than average were evident from the southwest of Iceland into the Norwegian Sea extending to Svalbard and the western Barents Sea.

Winter air temperatures were only below average (1981–2010) over the subpolar gyre, elsewhere temperatures were generally higher than normal and particularly so over the Middle Atlantic Bight, Fram Strait and the Barents Sea.

Beyond 2016: initial assessment of the north Atlantic atmosphere in winter 2016/2017

An initial assessment of the North Atlantic atmosphere at the end of the IROC year is included. Atmospheric conditions during winter are a determining factor of oceanic conditions for the following year; therefore, this outlook offers some predictive capability for spring to autumn 2017.

The sea level pressure pattern for December 2016 to March 2017 indicates that it was the 4th consecutive positive NAO index winter but again weaker than those preceding it. As expected for a weak NAO index the sea level pressure (SLP) anomaly is not a clear NAO pattern and there was no strong spatial pattern to the wind speed anomaly.

Air temperatures were cold over the subpolar gyre, including over the Irminger Sea and Iceland Basin. As in the winter 2016 warmer-than-average conditions were evident around the margins of the subpolar gyre, but the colder than average conditions ob-served in 2016 remained over the gyre itself.

1 Administrative details

Working Group name

Working Group on Oceanic Hydrography (WGOH)

Year of Appointment within current cycle

2015

Reporting year within current cycle (1, 2 or 3)

3

Chair(s)

Sarah Hughes, Scotland, UK

Karin Margretha H. Larsen, Faroe, Denmark

Meeting dates and venues

24–26 March 2015; Pasaia, Basque Country, Spain (15 participants)

5–7 April 2016; Sopot, Poland (20 participants)

4–6 April 2017; Tórshavn, Faroe Islands (19 participants)

2 Terms of Reference

a) Update and review results from Standard Sections and Stations;
b) Consolidate inputs from Member Countries to, and continue development of the ICES Report on Ocean Climate (IROC); work with ICES Data Centre to develop web based presentation of IROC data including full meta-data;
c) Explore areas of mutual interest with international climate monitoring, reanalysis & prediction programmes;
d) Provide expert knowledge and guidance to ICES Data Centre on request;
e) Collaborate with regional integrated ecosystem advice Expert Groups, review products of the ICES Regional Groups (WGIBAR, WGINOR, WGIAB, WGINOSE, WGEAWESS, WGNARS)
f) Provide expert knowledge, support and guidance to SCICOM and other Expert Groups requiring information on oceanic hydrography, and working to strengthen the role of physical oceanography within ICES in conjunction with groups such as WGOOFE, including: i) Sup-port SCICOM regarding elements of the EGs' work that are relevant to Marine Strategy Framework Directive activities;
g) Prepare contributions for the annual SSGEPD session during the ASC on the topic areas of the Science Plan – as & when requested by SSGEPD;
h) Evaluation and review of WG actions and purpose.

3 Summary of Work plan

Year 1	a) IROC 2015 production & recommendations for modifications to IROC format and content, including discussion on potential for reanalyses, forecast products to be included and addition of ICES Regional Ecosystem area focussed component, also potential move to purely web based product. b) WG Activities progress report including highlights of North Atlantic hydrographic conditions and any significant events synthesized from the national reports and IROC findings. c) Initial identification of climate monitoring, reanalysis and forecasting programmes.
Year 2	a) IROC 2016 production including first implementation of recommended changes. b) WG Activities progress report including highlights of North Atlantic hydrographic conditions and any significant events synthesized from the national reports and IROC findings. c) Map marine climate reanalysis and forecast parameters to ICES interests.
Year 3	a) IROC 2017 production and review of content and requirement to continue IROC process. b) WG Final report

4 Summary of Achievements of the WG during 3-year term

- Improvement of data delivery on IROC online portal (initiated in 2015 and on-going);
- New team established in 2015 for delivery of Annual IROC;
- New deep-ocean time series added to IROC 2014;
- Delivery of IROC 2013/14 (CRR329);
- Science Plan Mapping Exercise submitted;
- New time series added to IROC 2015;
- Delivery of IROC 2015 (CRR331);
- IROC 2016 on target and new developments in progress.

5 Final report on ToRs, workplan and Science Implementation Plan

Report on the work done in connection to the meeting in 2017: as usual a mini-symposium was held on the first day of the meeting. The mini-symposia usually includes a combination of talks from the host institution and invited WGOH members. At the 2017 meeting, most of the time was spent reporting findings from the different ICES areas, work which addresses ToRs a) and b). The remainder of the meeting was spent working through the other ToRs (c–h) and the last couple of hours were spent working on the upcoming IROC.

ToR a: Update and review results from Standard Sections and Stations

Area Reports were presented to the WGOH and additional scientific work reviewed during a mini-symposium. WGOH were grateful to members whom, although unable to attend the meeting, were still able to offer an area report as this is incredibly useful to the group when preparing the IROC.

Some groups support their presentation with a formal report and these offer valuable comprehensive reviews of the different sea areas within the North Atlantic as covered by members of the WGOH. These reports contain much more detailed information than the ICES Report on Ocean Climate which can only summarise the general conditions. The area reports should therefore be more visible and the group suggested posting them on the WGOH webpage including an archive of previous reports. Table 1 below lists the area reports presented at the meeting.

Table 1. List of Area reports Presented to ICES WGOH in 2017.

Region of Report	**Presenter**	**Country**	**Report/Presentation**
Greenland	Boris Cisewski	Germany	Presentation
USA	Paula Fratantoni	USA	Presentation
Icelandic Waters	Hedinn Valdimarsson	Iceland	Presentation
Eastern Bay of Biscay	Almudena Fontán	Spain	Presentation
Iberian Coast Bay of Biscay	Cesar González-Pola	Spain	Presentation
Western English Channels	Kieran Lyons	Ireland	Presentation
Rockall Trough and Extended Ellet Line	Penny Holliday	UK	Presentation
Faroese Waters	Karin Margretha H. Larsen	Faroe, Denmark	Presentation
Scottish Waters	Sarah Hughes	Scotland, UK	Presentation
North Sea	Holger Klein	Germany	Presentation
Baltic – Sweden	Johanna Linders	Sweden	Presentation (via Skype)
Baltic – Finland	Meri Korhonen	Finland	Presentation
Baltic – Poland	Tycjan Wodzinowski	Poland	Presentation
Norwegian Seas and North Sea	Kjell Arne Mork	Norway	Presentation
Kola Section, Barents Sea	Alexander Trofimov	Russia	Presentation
Fram Strait	Agnieszka Beszczynska-Möller	Poland	Presentation

ToR b: Consolidate inputs from Member Countries to, and continue development of the ICES Report on Ocean Climate (IROC); work with ICES Data Centre to develop web based presentation of IROC data including full meta-data

The WGOH has faced a few challenges regarding the IROC the previous 2-3 years. The editorial group put a large effort in consolidating the inputs from the members and to write and setup the IROC, but despite of this the IROC 2013/14 was not published until March 2016, the main reasons being the editors occupied by other duties and the long design procedure at the ICES office. With the lessons learned in 2015 the editorial group was ready to manage the IROC 2015. The aim was to have it published on the website before summer 2016, but again delays in data and text deliveries slowed down the progress. Additionally, the editorial group found the communication with the ICES designers unhelpful, and as a result there was no time to proof-read the final copy prior to publication. In 2016 the IROC was published in September.

Based on the experience from the two previous years the editorial group has decided to setup the IROC themselves using the program LaTeX. When this is done, the IROC will be handed to the ICES as a finalised PDF document. This first year will be a test to see if this method is achievable and if successful the plan is to continue to develop and publish the IROC within this framework. There were no objections from the meeting participants to moving to this layout. The data providers can still submit regular text and the editors will take care of the input. Additionally, in this format new series can easily be added.

To improve the submission of data for the IROC Hjalte Parner at the Data Centre has established a method to ease the submission process for the contributors. Prior to the meeting reminders are sent by email, but still roughly half of the data was submitted at the time of the meeting. The improvement of the procedures is therefore an ongoing process for future years.

Hjalte Parner provided information about further developments of the IROC web page. The map projection has been changed as agreed in 2016. Meta data are to be submitted for each time series and we will move on with the contribution. Still most contributors are to deliver this information. The metadata can include acknowledgement and citation information. Different details for the metadata were discussed. Sarah Hughes compiles a list of metadata that we can add for each series. When finalised Sarah sends the list to Hjalte for emailing to all data providers. The metadata list will be evaluated at the next meeting.

Hjalte offered the providers to submit time series next year. He will make the calculations of monthly and annual averages, but these can be overruled by the owners own calculations (if submitted). Hjalte showed the group the possibilities of creating all kind of forms on the map on the IROC webpage. E.g. lines and polygons can be added as requested by the data providers. A request was to have the index numbers added to the front page dropdown menu - Hjalte will add the numbers. Areas should be removed as these are replaced with ecoregions. The group wants information on how to cite the most recent IROC on the front page. This information used to be there, but there was some issue. Hjalte will look at this as well as the webpage counter that takes counts of downloads etc.

Plots are already created automatically and can go directly into the IROC. The layout can be changed upon request from the editorial group. This will be very helpful in the production of the IROC. On the IROC webpage "Buttons" can be created for each plot where we can select different add-ons to the plot like std dev, smoothed line, etc.

WGOH agreed that data providers should provide as much additional information as possible, following the metadata template that would be provided by Hjalte. Members were reminded of the need to submit their data in a standard format as this allows the dataset to work efficiently in supporting the development of the summary figures for the IROC. WGOH thanked Hjalte and the ICES Data Centre for their commitment to supporting the IROC.

ToR c: Explore areas of mutual interest with international climate monitoring, reanalysis & prediction programme

WGOH members continue to work in collaboration with researches on other international climate monitoring projects. Members do their best to raise awareness of the outputs from the ICES WGOH and the IROC publication when participating in international conferences and meetings.

ToR d: Provide expert knowledge and guidance to ICES Data Centre on request

No specific actions were taken relating to this ToR at the 2017 meeting. However, Hjalte Parner has attended recent meetings which is incredibly valuable. Bot at the meeting, and in-between meetings the WGOH are working very closely with him in relation to developing the IROC product online and streamlining the process of preparing the IROC.

ToR e: Collaborate with regional integrated ecosystem advice Expert Groups, re-view products of the ICES Regional Groups (WGIBAR, WGINOR, WGIAB, WGINOSE, WGEAWESS, WGNARS)

No specific actions were taken relating to the ToR at the 2017 meeting. The following WGOH members have contributed or have strong links with the regional integrated assessments and have provided a short description on their involvement in the groups. The members are encouraged to give a short presentation of these groups at the WGOH meeting in 2018.

Working Group on the Integrated Assessments of the Norwegian Sea (WGINOR)

WGOH link: Kjell Arne Mork

The Working Group on the Integrated Assessments of the Norwegian Sea (WGINOR) aims to conduct and further develop Integrated Ecosystem Assessments for the Norwegian Sea as a step towards implementing the ecosystem approach. The work is based on international fish-plankton centred surveys in the Norwegian Sea in May and since the mid-90s. In the most recent years these surveys have transitioned into ecosystem surveys that capture most of the key components of the ecosystem. These data sets are a firm foundation for undertaking integrated assessment of ecosystem status in the Norwegian Sea which is yet to be done. At present a multispecies fisheries model and an end to end ecosystem model are being set up for the Norwegian Sea.

Working Group on the Integrated Assessments of the Barents Sea (WGIBAR)

WGOH link: Alexander Trofimov

WGIBAR conducts and develops integrated ecosystem assessments for the Barents Sea as part of the Ecosystem Approach to Fisheries Management. WGIBAR's aim is to summarize and analyse up-to-date knowledge on the state of the Barents Sea ecosystem.. WGIBAR prepares relevant datasets and other relevant information, including pollution, to describe and analyse fluctuations and changes in the Barents Sea ecosystem and prepares an annual report “State and drivers of the Barents Sea”, which is available on the ICES WGIBAR page as a separate document. The Integrated multivariate (PCA, CCA, and NMDS) analyses of the time series, grouped into abiotic, biotic and pressures, are performed by WGIBAR. There are 17 abiotic variables reflecting meteorological and oceanographic conditions, a set of variables including zooplankton biomass in three size fractions and sum total for the Barents Sea, 3 time series of krill, abundance of 0-group fish of 9 species (capelin, cod, haddock, herring, polar cod, long-rough dab, Greenland halibut, redfish, and saithe), 23 variables reflecting stock size, growth and maturation of cod (7 variables), haddock (6 variables), capelin (5 variables), polar cod (2 variables), and herring, long-rough dab and shrimp (1 variable each).

WGIBAR identifies knowledge gaps and priority research items that when addressed, can improve future integrated ecosystem assessments, explores the use of available ecosystem and multispecies models as an analytical tool in integrated ecosystem assessment for the Barents Sea, and provides recommendations to improve the monitoring of the Barents Sea ecosystem for integrated ecosystem assessments.

Baltic Integrated Fish Survey Working Group (WGBIFS)

WGOH link: Tycjan Wodzinowski

It is obligatory to attach the hydrography and meteorology chapter to the after cruise report. The descriptive information consists of water temperature, salinity and oxygen content on the fishing depth for the pelagic trawling and for near bottom water for the bottom trawling (additional for the pelagic trawling). The additional parameters are temperature, salinity and oxygen content on surface water and the same parameters through transection. A transection route is often the same, if it is possible, or similar for all cruises. All parameters are presented in the form of maps and graphs. In the above mentioned chapters additional information is included when some special occurrences such as the Mayor Baltic Inflow take place. The after cruise reports are the part of the year report of the WGBIFS.

The Working Group on Northwest Atlantic Regional Sea (WGNARS)

WGOH link: Paula Fratantoni

The Working Group on the Northwest Atlantic Regional Sea (WGNARS) develops scientific support for Integrated Ecosystem Assessments of the Northwest Atlantic region to support ecosystem approaches to science and management. WGNARS' spatial scope focuses on the Northwest Atlantic continental shelf, extending from Labrador, Canada to Cape Hatteras, North Carolina, USA. Work includes identifying key drivers that influence the Northwest Atlantic continental shelf and characterizing the ecosystem response;

developing representative indicator time series for these drivers and responses; setting thresholds that can be used to quantify ecosystem status; performing ecosystem-level management strategy evaluation to test strategies for achieving management objectives; and developing conceptual models linking ecosystem services to broad-scale drivers in the system. This work relies heavily on ocean observations collected through existing long-term Canadian and U.S. monitoring programs operating on the Northwest Atlantic continental shelf.

The WGOH does not have members linking to the Working Group on Integrated Assessments of the North Sea (WGINOSE), the Working Group on Integrated Assessments of the Baltic Sea (WGIAB) and the Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS). However there are some links through colleagues that make it likely that awareness of the IROC and its products should be adequate within these groups.

ToR f: Provide expert knowledge, support and guidance to SCICOM and other Expert Groups requiring information on oceanic hydrography, and working to strengthen the role of physical oceanography within ICES in conjunction with groups such as WGOOFE including: i) Support SCICOM regarding elements of the EGs' work that are relevant to Marine Strategy Framework Directive activities

At the 2017 meeting it was acknowledged that the collaboration with SCICOM has not been so good. Heðinn Valdimarsson has now become a member of SCICOM and this is expected to improve the collaboration. Heðinn says that the SCICOM intends to have more oceanography in the assessments and we should therefore definitely continue and strengthen the collaboration with the SCICOM and the other Expert Groups. Our role is important in ensuring that physical processes are considered in fishery and ecological research/assessments.

The WGOH members have waved the flag for the WGOH at relevant meetings. Boris Cisewski has presented the group at NAFO meetings, Holger Klein has given presentations and circulated pdf versions of the IROC at various Climate change meetings in Germany and Karin M. H. Larsen has presented the IROC webpage at the OceanSITES meeting 2016.

Paula Fratantoni and Heðinn Valdimarsson expect to attend the upcoming ASC 2017 and they were willing to give presentations of the WGOH at the meeting.

There is some synergy between the data delivered to the IROC and the needs for understanding underlying climate processes (prevailing conditions) in MSFD assessments. As far as possible using links with national MSFD working groups the datasets presented in the IROC are being used for such assessments. In a similar way the data presented here underpin the assessments of environmental conditions made by OSPAR.

ToR g: Prepare contributions for the annual SSGEPD session during the ASC on the topic areas of the Science Plan – as & when requested by SSGEPD

The SSGEPD requested a Science plan mapping exercise early in 2016. The exercise (spreadsheet) was handed to the attending members at the 2016 meeting where after preliminary answers were added to a joint reply. The exercise was completed by the chairs and submitted to SSGEPD.

No request was received for the 2017 meeting.

ToR h: Evaluation and review of WG actions and purpose

WGOH continually review the IROC and the data presented within. The aim is to develop the product to be as useful as possible, whilst remaining a sustainable task for the Working Group. The development of this remains clearly within the existing Terms of Reference.

At the 2017 meeting the WGOH discussed how to develop and improve the IROC in future. It was suggested to

- Include and improve the metadata provided with each dataset.
- Improve the visibility of the underlying national reports by linking directly on the website rather than embedding them into the WGOH report.
- Improving citations and referencing within the IROC.
- Continue work to align the IROC product with marine regions such as the ICES ecoregions and Large Marine Ecosystems.

The group also found it necessary to improve the visibility of the IROC and it was suggested to

- Give presentations at conferences to draw attention to the data within the IROC.
- Develop ideas for further joint publications based on the observations.

The group discussed developing interactions with ICES:

- A planning for future theme sessions is needed.
- Participation in ICES/PICES symposium in June 2018 – Washington.
- Initiate preparations for a next decadal symposium.
- Website still available.
- Stephen knows about registration etc.
- Possible locations to be Galway or Bergen?

AO ICES matters

Heðinn Valdimarsson mentioned the ICES – PICES symposium in June 2018, Washington. He said that in 2008 WGOH submitted a paper to that conference and asked whether the group should contribute to the symposium? A possible topic could be the extreme freshening that is being observed in the North Atlantic. Sarah volunteered to email all regarding this topic.

IROC highlights and key issues from the national reports

This report describes the discussion and outcomes relating to the individual terms of references of the WGOH. The bulk of the science discussed by the WGOH is contained in the area reports (added to the WGOH webpage), which in turn underpin the information presented in the ICES Report on Ocean Climate (IROC).

The IROC represent the scientific highlights of the WGOH meeting, the highlights intended for this report representing the 2016 status are presented here.

Highlights of the North Atlantic for 2016

Air and sea surface temperatures were higher than normal across most of the region, with the exception of the central subpolar North Atlantic (centered on 50N and including the Irminger and Iceland Basins). In Greenland and the Barents Sea record high air and sea surface temperatures were observed. North of Iceland record high sea surface temperatures were observed.

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An initial assessment of the North Atlantic atmosphere at the end of the IROC year is included. Atmospheric conditions during winter are a determining factor of oceanic conditions for the following year; therefore, this outlook offers some predictive capability for spring to autumn 2017.

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Air temperatures were cold over the subpolar gyre, including over the Irminger Sea and Iceland Basin. As in the winter 2016 warmer-than-average conditions were evident around the margins of the subpolar gyre, but the colder than average conditions observed in 2016 remained over the gyre itself.

Election of Chairs

This meeting was the third and final meeting for Sarah Hughes and Karin Margretha H. Larsen as chairs and therefore new chairs were to be elected. Paula Fratantoni (US) and César González-Pola (Spain) approved on request to be candidates. No other member offered to be a candidate. Thus Paula and César were elected with applause.

Next meeting

The WGOH received an invitation from Stephen Dye to host the next meeting in Norwich, UK. The group accepted the invitation with applause and decided to hold the next meeting in Norwich, UK, 20–22 March 2018.

6 Cooperation

Cooperation with other WG

See reply to ToR e)

Cooperation with Advisory structures

WGOH is not an Advisory group as such but the group contributes its advice via the IROC.

Cooperation with other IGOs

WGOH does not have procedures for formal cooperation with other IGOs, but as some WGOH members participate in other IGO meetings, such as NAFO and NEAFC meetings, informal links are developed. These members raise awareness of the work of WGOH at the IGO meetings and feedback relevant information to the WGOH.

7 Summary of Working Group self-evaluation and conclusions

The WGOH contribute very significantly to the first objective of the science plan, "Describe and Quantify the state of North Atlantic Ocean regional systems". We assess the physical state of regional seas and describe changes in the predominant climatic and hydrological processes important for regional ecosystems.

We contribute vital information which can be used by others who wish to try and understand the impacts of climate variability and change on marine ecosystems.

The key output from this working group is the ICES Report on Ocean Climate and its associated website. The Ocean and Atmosphere Highlights from the IROC represent our summary of oceanographic conditions in the latest year and should be used in the Advisory process together with the national reports. Outputs from this working group also feed into assessments for NAFO and regional and national assessments of climate variability.

We believe that the information we prepare is incredibly valuable to ICES and the wider community and we therefore seek to continue with this work. We aim to continue to develop the IROC website and to publish the ICES Report on Ocean Climate each year.

Annex 1: List of participants

Name	Country	Email
Agnieszka Beszczyn-ska-Möller	Poland	abesz@iopan.gda.pl
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Sarah Hughes	Scotland, UK	S.Hughes@MARLAB.AC.UK
Tycjan Wodzinowski	Poland	tycjan@mir.gdynia.pl

Annex 2: Recommendations

Recommendation	Addressed to
1. The WGOH recommends that ICES holds a new decadal symposium in 2021. The WGOH prepared the decadal symposium in Santander in 2011 and the group is willing to help preparing the next symposium as well. It takes time to prepare such a large event and therefore the WGOH recommends initiating the preparations already next year.	WGOH
2. The WGOH continuously tries to improve the IROC and its outreach. An important part of the background material is the national reports from the WGOH members. To improve the visibility of these underlying national reports the group recommends linking them directly on the website rather than embedding them into the WGOH report.	ICES Data Centre
3. The WGOH wish to develop summary publications useful for raising awareness of the IROC, for example a leaflet and/or poster that can be distributed at conferences and meetings.	WGOH

Annex 3: WGOH draft terms of reference 2018–2020

The **Working Group on Oceanic Hydrography** (WGOH), chaired by Paula Fratantoni, USA and César González-Pola, Spain, will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2018	20-22 March	Norwich, UK	Interim report by 1 May to SSGEPD	
Year 2019			Interim report by DATE to SSGEPD	
Year 2020			Final report by DATE to SSGEPD, SCICOM	

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

b) Consolidate inputs from Member Countries to, and continue development of the ICES Report on Ocean Climate (IROC); work with ICES Data Centre to develop web based presentation of IROC data including full meta-data;

c) Explore areas of mutual interest with international climate monitoring, reanalysis & prediction programmes;

d) Provide expert knowledge and guidance to ICES Data Centre on request;

e) Collaborate with regional integrated ecosystem advice Expert Groups, review products of the ICES Regional Groups (WGIBAR, WGINOR, WGIAB, WGINOSE, WGEAWESS, WGNARS)

f) Provide expert knowledge, support and guidance to SCICOM and other Expert Groups requiring information on oceanic hydrography, and working to strengthen the role of physical oceanography within ICES in conjunction with groups such as WGOOFE, including: i) Support SCICOM regarding elements of the EGs' work that are relevant to Marine Strategy Framework Directive activities;

g) Prepare contributions for the annual SSGEPD session during the ASC on the topic areas of the Science Plan – as & when requested by SSGEPD;

h) Prepare Decadal Symposium to be held in 2021;

i) Evaluation and review of WG actions and purpose.

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
	This should capture the objectives of the ToR	Provide very brief justification, e.g. advisory need, links to Science Plan and other WGs	Use codes	1, 2 or 3 years	Specify what is to be provided, when and to whom
a	Examine the hydrographic variability of the North Atlantic and its subpolar seas. Identify events, trends and drivers in the region .	The contributors to the WGOH bring together a wide range of observations taken by various national programmes. Here we annually monitor developments in the environmental conditions that they sample.		3 years	Annual interim reports will include details of national programmes and most up to date findings.
b	Standard Sections and Stations summarized into the production of the IROC report and submitted to IROC data portal.	The Working Group recognises the need for disseminating climate information in a timely and appropriate manner. This agenda item will allow WGOH members to prepare the document during the meeting. We will review proposed new developments in IROC content.		3years	Annual. IROC report for CRR submission. Text and figures to ICES by June 30th each year. Data to portal by 1st September each year.
c	Report on developments within international climate monitoring, multi decadal reanalyses & prediction programmes relevant to ICES	Benefit both to ICES and the international monitoring programmes to enhance internal information exchange. Additionally developments in the capacity to make climate forecasts of hydrographic parameters are being made by the international community, that may have the potential to aid future ICES work.		2 years	Identify the products of potential use to ICES. Report as part of 2nd year progress.

d, e, f	Support for ICES processes on hydrographic data and ocean scale marine climate variability. Including Data Centre, other EGs, and advice programmes where and when requested	As required support for ICES Data centre on hydrographic data. Oceanic hydrography remains a fundamental component of assessing the state of marine ecosystems. WGOH documents interannual to multidecadal variability and trends in the oceanic hydrography for most ecoregions and will review the available 'Ecosystem Overviews' as they become available for each regional sea.	ongoing	Response to requests and reviewing input from Datacentre at WG meetings. Submit review to the annual interations of Ecosystem Overviews.
g	Contribute to objectives, activities of parent science steering group SSGEPD	A flexible ToR to allow WGOH to contribute to SSGEPD requirements as they develop over the term of the current science plan.	3 years	As and when defined by our steering group SSGEPD
h	Prepare a new decadal symposium in 2021	The WGOH has been responsible for previous decadal symposia (e.g. the 2011 symposia in Santander). Such a large event requires thorough preparation and starting the preparation early acts to assure a successful event.	3 years	Progress to be reported annually
i	Ongoing self evaluation of the EGs work.	WGOH is a long established EG within ICES and has ToRs that are closer to an annual workplan. The main product is the annual IROC which has been produced for 15 years, and must be continually developed - through ongoing self evaluation and review	3 years	WGOH Final Report under multiannual TORs 2020

Summary of the Work Plan

Year 1	a) IROC 2018 production & recommendations for modifications to IROC format and content, including discussion on potential for reanalyses, forecast products to be included and addition of ICES Regional Ecosystem area focussed component, also potential move to purely web based product. b) WG Activities progress report including highlights of North Atlantic hydrographic conditions and any significant events synthesized from the national reports and IROC findings. c) Initial identification of climate monitoring, reanalysis and forecasting programmes. d) develop plans for Decadal Symposium
Year 2	a) IROC 2019 production including first implementation of recommended changes. b) WG Activities progress report including highlights of North Atlantic hydrographic conditions and any significant events synthesized from the national reports and IROC findings. c) Map marine climate reanalysis and forecast parameters to ICES interests. e) Prepare for for Decadal Symposium
Year 3	a) IROC 2020 production and review of content and requirement to continue IROC process. b) WG Final report c) Participation and delivery of Decadal Symposium

Supporting information

Priority	Oceanic hydrography remains a fundamental component of assessing the state of marine ecosystems. WGOH documents interannual to multidecadal variability and trends in the oceanic hydrography setting the vital context for prevailing conditions & ecosystem change. The IROC has been cited more than 110 times (http://tinyurl.com/ICES-IROC) demonstrating that it is an important resource for the marine science community within and beyond ICES.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants	The Group is normally attended by about 15–20 members and guests. SSGEPD, ICES Data Centre participant.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	There are no obvious direct linkages.
Linkages to other committees or groups	There is a very close working relationship with all the groups of SSGEPD. The most direct link is to WGOOFE where the activities of the 2 groups are complementary. WGOH focusses on the larger Atlantic space and long term climate scales. Link to PUBCOM for the annual production of the IROC.
Linkages to other organizations	IOC, JCOMM, CLIVAR

Annex 4: WGOH self-evaluation

1) ICES Working Group on Oceanic Hydrography

2) Year of appointment: 2015

3) Current Chairs: Karin Margretha H. Larsen and Sarah Hughes

4) Venues, dates and number of participants per meeting:

San Sebastian, Spain, 24-26 March 2015 (15)

Sopot, Poland, 5-7 April 2016 (20)

Torshavn, Faroe Islands, 4-6 April 2017 (19)

WG Evaluation

5) If applicable, please indicate the research priorities (and sub priorities) of the Science Plan to which the WG make a significant contribution.

The WGOH contribute very significantly to the first objective of the science plan, Describe and Quantify the state of North Atlantic Ocean regional systems. We assess the physical state of regional seas and describe changes in the predominant climatic and hydrological processes important for regional ecosystems.

We contribute vital information which can be used by others who wish to try and understand the impacts of climate variability and change on marine ecosystems.

6) In bullet form, list the main outcomes and achievements of the WG since their last evaluation. Outcomes including publications, advisory products, modelling outputs, methodological developments, etc. *

- The key output from this working group is the ICES Report on Ocean Climate and its associated website. The working group aims to publish this report each year. The 2014 report was published but delayed and the 2015 report was published prior to the Annual Science Conference in Sept 2016. The WGOH are on track to publish the 2016 report in time for the ICES ASC in Sep 2017.
- Many of the members use the data and information provided in the IROC in order to provide advice within their own institutes. In this way each member is able to add considerable value to their own assessments by participating in this working group and understanding how the variability observed in their area fits into the context of broader changes in the North Atlantic. This knowledge exchange is incredibly valuable and can often lead to collaborative research output.
- Outputs from this working group feed into assessments for NAFO and regional and national assessments of climate variability. For example in the UK, it is cited within climate assessments like MCCIP and national reports. In Germany the data in the report is reported to national climate groups. It is also a reference for knowledge of climate variability needed for MSFD assessments and will feed into the next OSPAR intermediate assessment.

- The website holding the data that are contained within the IROC has been developed with cooperation from the ICES Data Centre.
- The IROC is cited multiple times and so in this way is contributing to wider scientific knowledge. To date the collected reports have 118 citations. http://tinyurl.com/ICES-IROC.
- Members of the working group are working collaboratively on a number of related research projects. For example, recently members of WGOH were invited to a workshop on seabirds organised by RSPB and Birdlife. Also WGOH members make a large contribution to EU projects such as Blue-Action and NaClim. Participation in the ICES working group on Oceanic Hydrography was the underpin to this research.

7) Has the WG contributed to Advisory needs? If so, please list when, to whom, and what was the essence of the advice.

7.1) WGOH is not an advisory group. The group has contributed its advice via IROC.

7.2) The IROC is cited multiple times and so in this way is contributing to wider scientific knowledge. To date the collected reports have 118 citations. http://tinyurl.com/ICES-IROC.

8) Please list any specific outreach activities of the WG outside the ICES network (unless listed in question 6). For example, EC projects directly emanating from the WG discussions, representation of the WG in meetings of outside organizations, contributions to other agencies' activities.

8.1) NAFO, Ocean Sites, Marine strategies meetings and climate change meetings in Germany (Holger), OSPAR intermediate assessment, Mccip and opeg in the uk (Stephen), Scottish ocean climate report, NACLIM, Blue-Action, RSPB birdlife.

9) Please indicate what difficulties, if any, have been encountered in achieving the workplan.

9.1) Money and time. This is a difficult period for sustained time series and we have seen the cancellation of a number of key projects. Many organisation report limitations to ship time which can affect the quantity of data collected and so impact on the uncertainty of the observations

9.2) There have been some difficulties in ensuring continuity with the IROC publications. We continue this work and have confidence that the report will develop and improve further.

Future plans

10) Does the group think that a continuation of the WG beyond its current term is required? (If yes, please list the reasons)

10.1) Yes. We believe that the information we prepare is incredibly valuable to ICES and the wider community and we seek to continue with this work.

11) If you are not requesting an extension, does the group consider that a new WG is required to further develop the science previously addressed by the existing WG.

11.1) Not applicable

(*If you answered YES to question 10 or 11, it is expected that a new Category 2 draft resolution will be submitted through the relevant SSG Chair or Secretariat*.)

12) What additional expertise would improve the ability of the new (or in case of renewal, existing) WG to fulfil its ToR?

12.1) We have asked for help from the Data Centre and we got that, this has been extremely helpful for the working group and we hope this will continue.

12.2) We need to ensure we have representation from all of the ICES regions. We have limited representation in some areas (France, Portugal, and Netherlands). Our colleagues from Canada participate by correspondence but often struggle to attend the meetings. In some areas we have lost members due to retirements and have struggled to find a dedicated replacement. This is often due to retirement and we need to seek replacements.

12.3) In 2017 we allowed some participation using Skype which we felt worked quite well and is a useful option to have open for each meeting. Facilities and technology for this are often unreliable though. It is preferable for people to attend in person and the meeting could not continue if purely virtual.

13) Which conclusions/or knowledge acquired of the WG do you think should be used in the Advisory process, if not already used?

13.1) The Ocean and Atmosphere Highlights from the IROC. These represent our summary of oceanographic conditions in the latest year and are a key deliverable for the WGOH.

13.2) The detailed national reports that describe conditions in each region. We recommend more visibility is given to these reports by linking to them online.

13.3) However, the oceanographers who present their data to WGOH also have a wealth of knowledge about oceanographic processes and conditions which could be of great value to other working groups. Unfortunately wider participation of physical oceanographers in ICES is limited by funding and resources.

Annex 5: Agenda WGOH

4-6 April 2016

Faroe Marine Research Institute (Tórshavn, Faroe Islands)

Meeting room: Aulan, Vinnuháskúlin

Day 1, Tuesday 4th April

Start at 0900 (Lunch: 12:30)
1. General information, Membership and Introductions.

0920-1230 Mini-symposium

0920: John Mortensen: Freshwater pathways around Greenland

0940: Igor Yashayaev: Long-term versus decadal-scale variability in deep-water ventilation in the Labrador Sea (presented by Penny Holliday)

1000: Bogi Hansen: Atlantic water flow and heat transport between Iceland and Scotland

1015: Coffe

1045: Hjálmar Hátún: Winter convection blows life - A Bird's-eye view

1115: Sólvá Eliasen: The Faroe Shelf spring bloom is linked to a hydrographical transition

1135: Inga Kristiansen: Phenology changes of Calanus in the south-western Norwegian Sea, 1990-2014, linked to ocean climate.

1255: Boris Cisewski: seasonal variation of diel vertical migration of zooplankton from ADCP backscatter time series data in the Lazarev Sea, Antarctica.

Lunch

1400h
2. IROC
   - IROC 2015 review (Sarah Hughes)
   - Review IROC and IROC web page
   - Suggestions for improvements and any new time series or products
   - Initial overview of contents and contributions received so far
   - Latex-based IROC (Cesar Gonzalez-Pola)

3. ICES Data Centre (Hjalte Parner)
   - Update the data series on the web
   - Review of recent activities and future plans

4. Review of 2016 Atmospheric conditions (Stephen Dye – via Skype)

5. Area reports (latest results from standard sections and stations)

Day 2, Wednesday 5th April
Start at 0900 (Lunch 12:30)

5. Continue area reports

1900: Joint dinner at Bowlingahøllin

Day 3, Thursday 6th April

Start at 0900 (Lunch 12:30)

6. Election of Chairs

7. ICES Matters

- Remaining ToR's
- WGOH self evaluation (requested by ICES)
- AO ICES matters

8. Relations with international climate monitoring programmes (CLIVAR, Argo, etc.)

9. ASC 2017 (Fort Lauderdale, Florida, USA), Theme sessions in 2017. ASC 2018?

10. IROC highlights and key issues from the national reports

11. WGOH website

12. Next Meeting

13. AOB

1400 IROC 2016

Work on the IROC 2016

Annex 6:

Regional report on West Greenland 2016

Regional report on West Greenland 2016 (Area 1)

Boris Cisewski, Thünen Institute of Sea Fisheries, Germany

The water mass circulation off Greenland comprises three main currents: Irminger Current, West Greenland and East Greenland Currents (Figure 1). The East Greenland Current (EGC) transports ice and cold low-salinity Surface Polar Water (SPW) to the south along the eastern coast of Greenland. On the inner shelf the East Greenland Coastal Current (EGCC), predominantly a bifurcated branch of the EGC, transports cold fresh Polar Water southward near the shelf break (Sutherland and Pickart, 2008). The Irminger Current is a branch of the North Atlantic Current. Figure 2 reveals warm and salty Atlantic Waters flowing northward along the Reykjanes Ridge. South of the Denmark Strait (DS) the current bifurcates. While a smaller branch continues northward through the DS to form the Icelandic Irminger Current, the bulk of the current recirculates to the south and transports salty and warm Irminger Sea Water (ISW) southward along the eastern continental slope of Greenland. It makes a cyclonic loop in the Irminger Sea. South of Greenland both currents bifurcate and spread northward as a single jet of the West Greenland Current (WGC). The WGC carries the water northward and consists of two components: a cold and fresh inshore component, which is a mixture of the SPW and melt water, and a saltier and warmer Irminger Sea Water (ISW) offshore component. The WGC transports water into the Labrador Sea, and hence is important for Labrador Sea Water formation, which is an essential element of the Atlantic Meridional Overturning Circulation. The dynamics of the current is monitored yearly in autumn at two standard ICES/NAFO oceanographic sections across the slope off West Greenland (Figure 3). The German groundfish survey off Greenland is conducted since 1981, aiming at monitoring groundfish stocks in particular of cod and redfish. The monitoring is carried out by the Thünen-Institute of Sea Fisheries (TI-SF) from board of R/V 'Walter Herwig III' and reveals significant interannual and long-term variability of both components of the WGC.

Atmospheric conditions

The variability of the atmospheric conditions over Greenland and the Labrador Sea is driven by the large scale atmospheric circulation over the North Atlantic, which is normally described in terms of the North Atlantic Oscillation (NAO). During a positive NAO strong northwest winds bring cold air from the North American continent and cause negative anomalies of the air temperatures over Greenland, Labrador Sea and Baffin Bay (Hurrell and Deser, 2010). During a negative NAO the westerlies slacken and the weather is normally milder over the whole region. According to ICES standards, the Hurrell winter (DJFM) NAO index is used for this study, which is available at *https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based*.

In winter 2015/2016, the NAO index was positive (0.98) for the third consecutive winter but was weaker than these 2 preceding winters (Figure 4). Figure 5a shows the winter sea level pressure (SLP) averaged over 30 years (1981-2010), mainly dominated by the Iceland Low and the Azores High. Both, the Icelandic Low and the Azores High were strengthening resulting in an increased pressure difference over the North Atlantic sector than normal during winter 2015/2016 (Figure 5b). The resulting negative anomalies in the north and the positive in the south reveal a positive NAO character (Figure 5c). Air temperature at Nuuk was used to characterize the atmospheric conditions in 2016. Annual and monthly mean values were obtained from the Danish Meteorological Institute (Cappelen, 2013). In 2016, the monthly mean air temperatures between January and August were higher than the long-term mean (Figure 6). Greenland witnessed its highest June temperature ever recorded on June 9 2016 when the daily air temperature at Nuuk reached 24°C. The resulting annual mean temperature at Nuuk was 0.6°C in 2016, which was 2.0°C above the long-term mean (1981-2010) (Figure 7).

Hydrographic Conditions

The core properties of the water masses of the WGC are formed in the western Irminger Basin where the EGC meets the Irminger current (IC). The EGC transports fresh and cold PSW of Arctic origin. The IC is a northern branch of the Gulf Stream, which makes a cyclonic loop in the Irminger Sea and carries warm and saline ISW. After the currents converge, they turn around the southern tip of Greenland, form the WGC and propagate northward along the western coast of Greenland. During this propagation considerable mixing between two water masses takes place and ISW gradually deepens (Clarke and Gascard, 1983; Myers et al., 2009). The annual sea surface temperature (NOAA OI SST) anomalies for 2016 indicate positive anomalies in the Northwestern Atlantic with highest values occurring northeast of Iceland and along the coast of East Greenland (Figure 8), whereas negative anomalies were observed in the central area of the North Atlantic.

CTD profiles were conducted with a Sea-Bird 911plus sonde attached to a 12-bottle water sampler. The hydrographic database consisted of 36 hydrographic stations sampled between October 22 and November 11, 2016, from R/V 'Walther Herwig III'. Study area and station locations are shown in Figure 3. The Fyllas Bank Section had to be abandoned due to severe weather conditions. For in-situ calibration, salinity samples were analyzed with an OPTIMARE Precision Salinometer (OPS) salinometer immediately after the cruise. The collected data was interpolated to a 1 m grid in the vertical. If data was missing at the top of a profile, we assumed constant properties from the first measurement (normally 2–7 m) up to the surface.

The standard Cape Desolation section spans across the shelf and the continental slope off West Greenland and is situated 300 km northwest from the southern tip of Greenland. There is more than one definition of the water masses carried by the WGC (Clarke and Gascard, 1983; Stein, 2005; Schmidt and Send, 2007; Myers et al., 2009). Here I consider the upper layer down to 700 m water depth and define SPW and ISW following the nomenclature of Myers et al., 2009 (Table 2). At this section a strong surface front separates PSW on the shelf from ISW offshore (Figure 9). In autumn, the temperature of the upper layer is well above zero (Θ_{Min} = 2.88°C) due to the summer heat accumulation, and hence only the salinity can be used as a tracer of the SPW (Figure 9a). A surface salinity of about 31 was observed at station 540 (Figure 9b). The most offshore station of the section done in 2016 (Station 537) corresponds to the standard Cape Desolation Station 3, which was reported in ICES WGOH since 2001 (Stein, 2010). In 2016, the water temperature of the upper 700 meters was lower than its long-term mean, whereas the salinity reveals strong negative anomalies between 20 and 150 m water depth (Figures 10a, b). In 2016, the water temperature and the salinity in the 75-200 m layer at Cape Desolation Station 3 was 5.44°C (Figure 11a) and 34.84 (Figure 11b), which was 0.27°C and 0.08 below the long-term mean, respectively. The properties of the North Atlantic Deep Water (NADW) in the deep boundary current west of Greenland are monitored at 2000 m depth at Cape Desolation Station 3. The temperature and salinity of this water mass underwent strong interannual variability during the 1980s (Figure 12).

Since the beginning of the 1990s, both characteristics were decreasing and reached their minimum values in 1998 and 1997, respectively. After that, the temperature of the NADW revealed a positive trend until 2014, whereas its salinity rather stagnated between 2007 and 2014. In 2016, the temperature increased and salinity stagnated, and were 0.1°C and 0.02 above the long-term mean (Figures 12a and b).

Tables

Table 1. Details on the times series, analysed in this study.

Name	Lat (°N)	Lon (°W)	Type	Source
Nuuk (4250)[1]	64.17	51.75	Weather station	DMI
Nuuk airport (4254)[1]	64.20	51.68	Weather station	DMI
Cape Desolation Station 3	60.47	50.00	Oceanographic station	TI-SF
Fyllas Bank Station 4	63.88	53.37	Oceanographic station	TI-SF

Table 2. Water mass characteristics in the study area.

The water masses in the area	Potential temperature (θ)	Salinity (S)
Surface Polar Water (SPW)	$\theta \leq 0$	$S \leq 34.4$
Irminger Sea water (ISW)	$\theta \geq 4.5$	$S \geq 34.95$

[1] In recent years, Nuuk air temperature was taken from the Nuuk airport synop station 04254 due to a failure on Nuuk synop station 04250 (Cappelen, 2013).

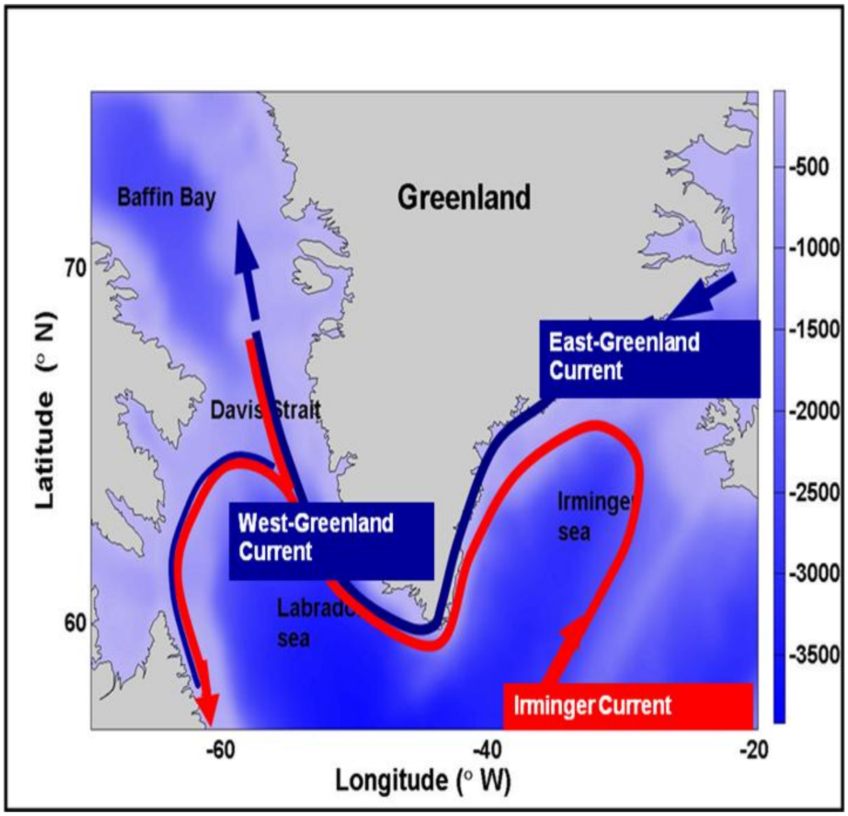


Figure 1. Scheme of the upper ocean circulation in the study area. Red and blue curves show the trajectories of warm Irminger Sea Water and cold Surface Polar Water, respectively.

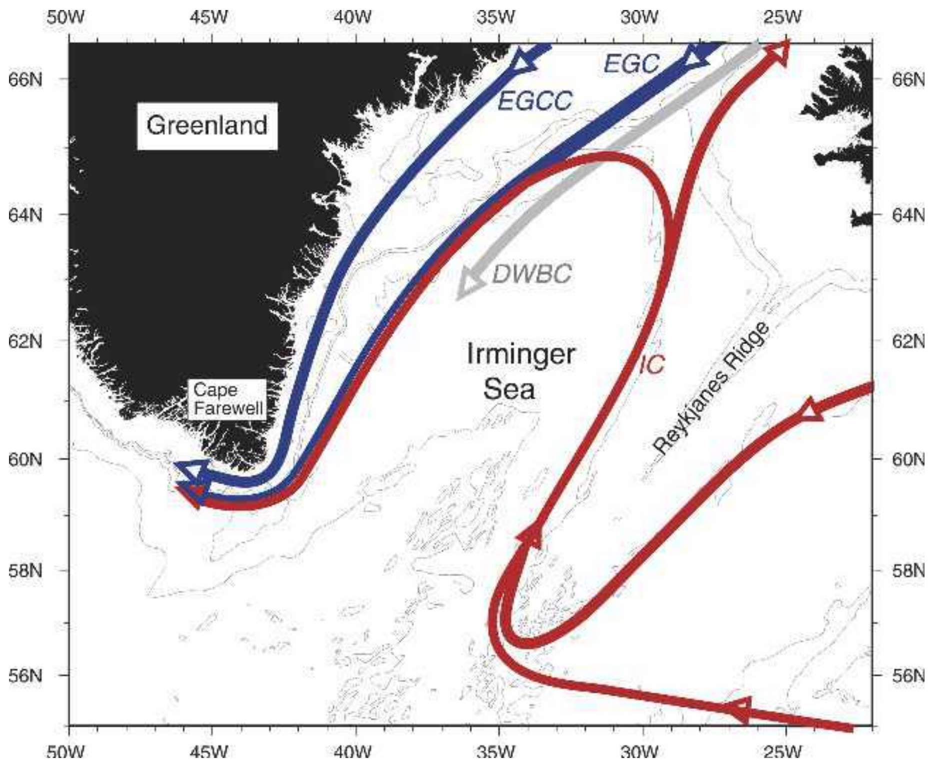


Figure 2. Schematic of the boundary currents of the Irminger Sea (depicted from Pickart et al., 2005)

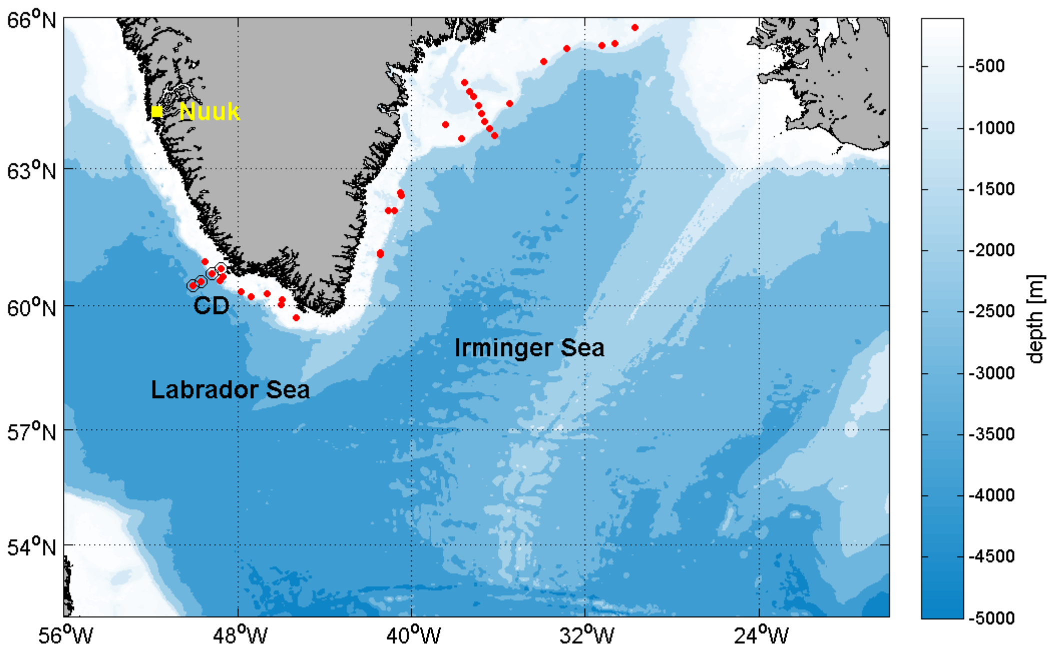


Figure 3. Map and bathymetry of the study region. Meteorological station location is shown in yellow. Red dots show the location of the hydrographic stations, conducted during the survey in 2016. Gray edged dots show the two ICES/NAFO standard sections (CD – Cape Desolation section, FY – Fyllas Bank Section; geographic coordinates are given in table 1).

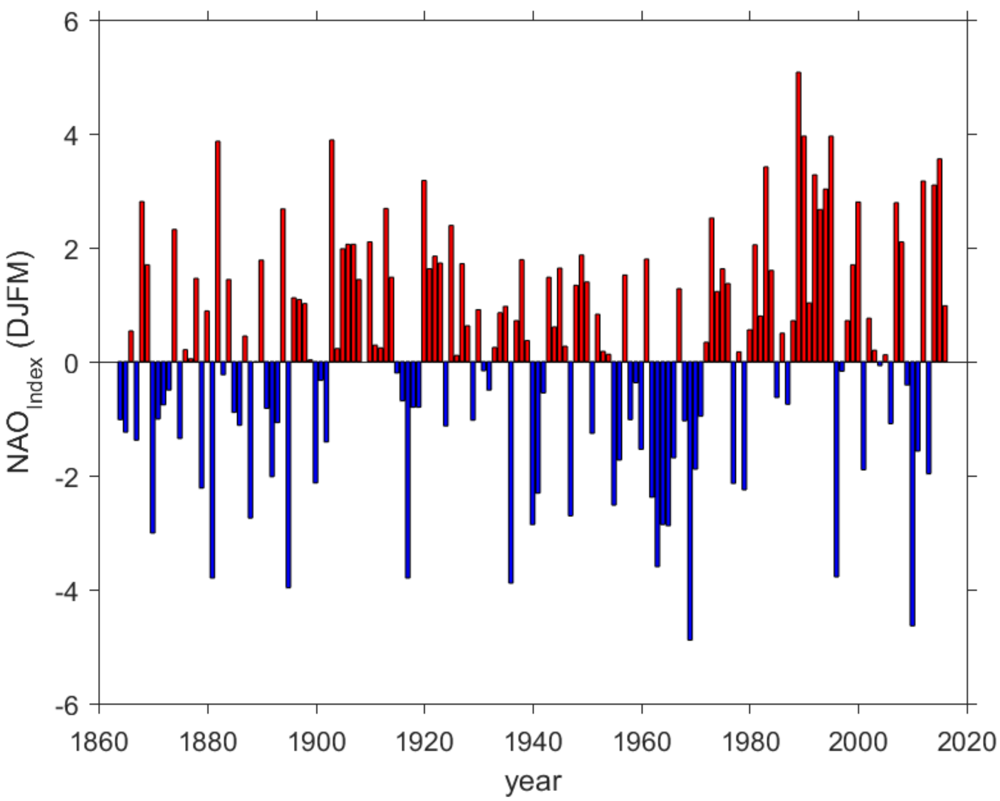


Figure 4. The Hurrell winter (DJFM) NAO index.

Data source: https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based

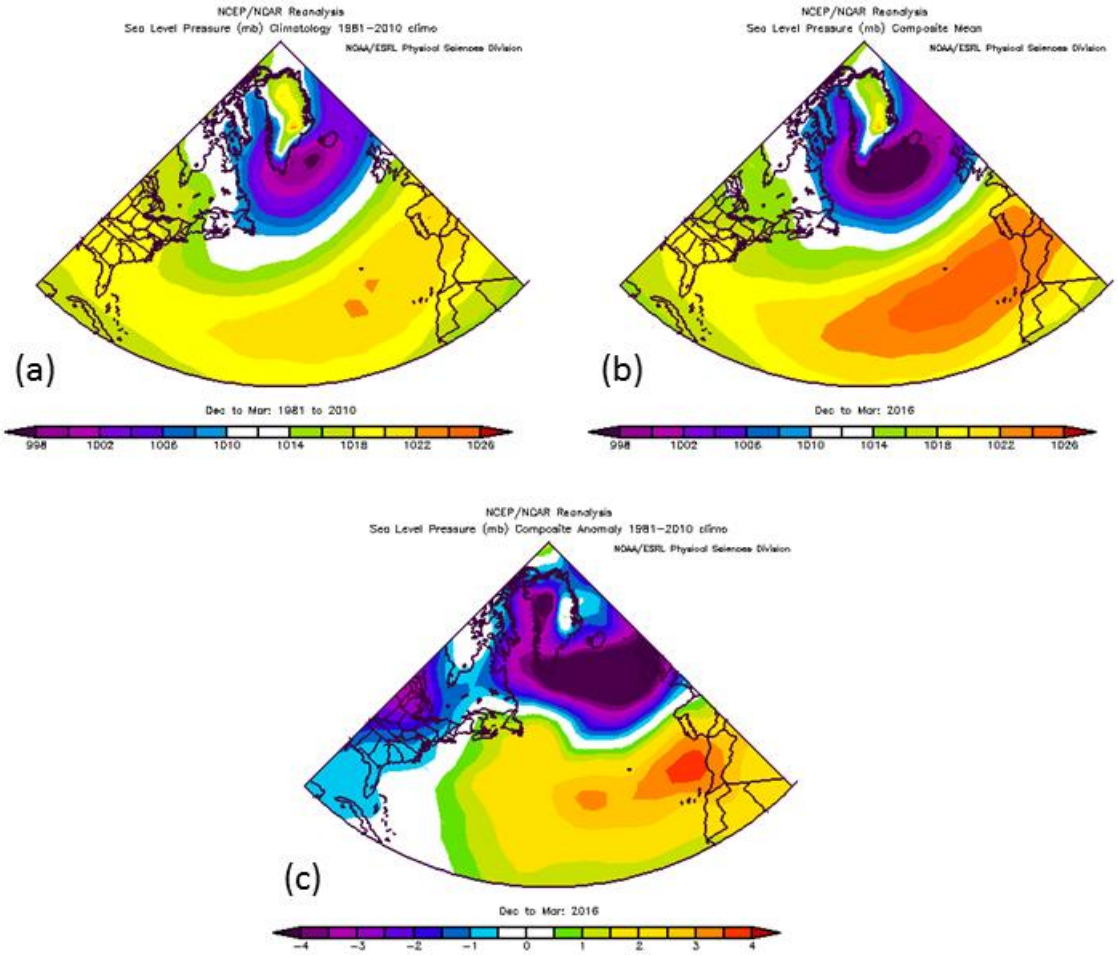


Figure 5. Maps of winter 1981-2010 (DJFM) mean sea level pressure (SLP) **(a)**, winter 2016 SLP **(b)**, and resulting SLP anomaly **(c)** over the North Atlantic. *Images are provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado*

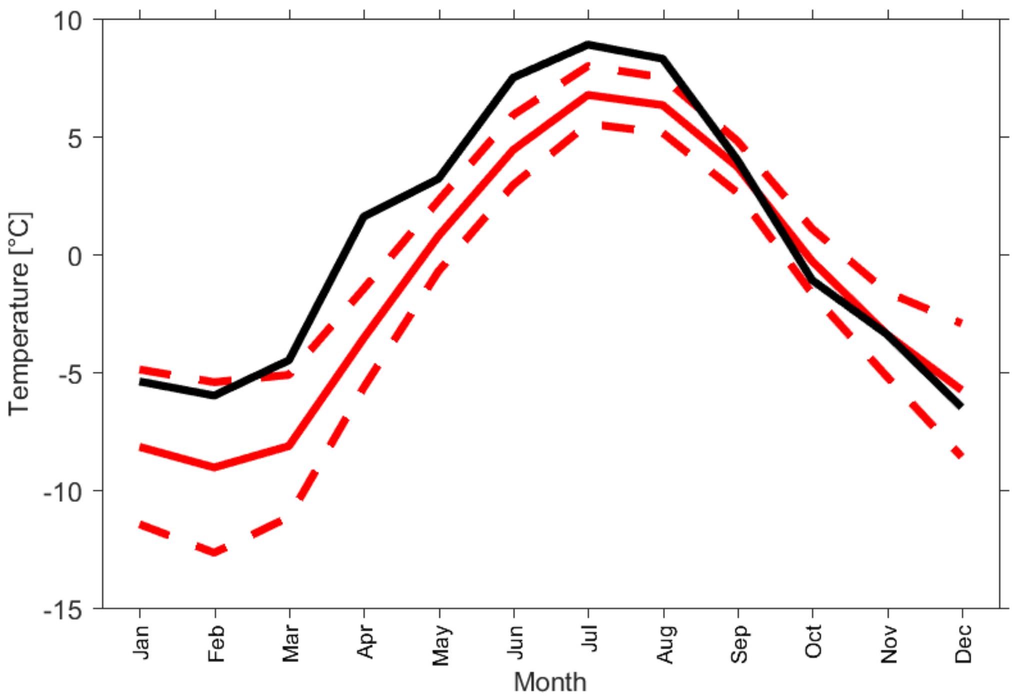


Figure 6. Monthly mean air temperature at Nuuk station in 2016 (black line), long-term monthly mean temperature (red solid line) and one standard deviation (red dashed lines) are shown. Reference period is 1981 to 2010. Data source: Danish Meteorological Institute (DMI)

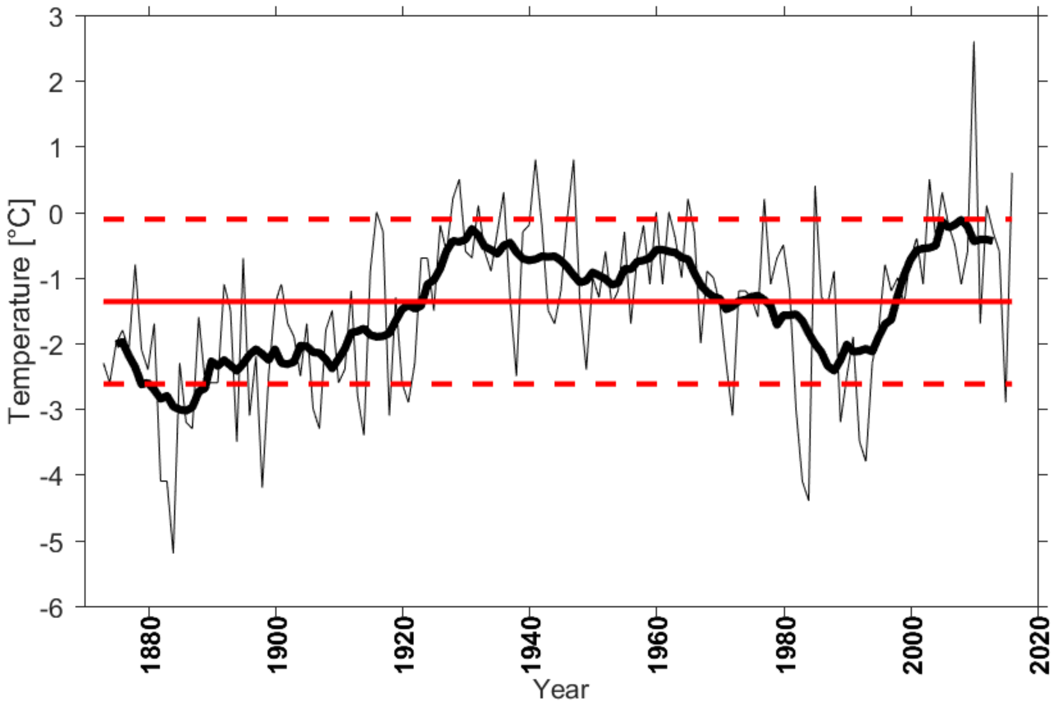


Figure 7. Annual mean air temperature at Nuuk station. Thick black line shows the 5-year smoothed data. Red solid line indicates the long-term mean temperature, referenced to 1981-2010. Dashed red lines mark corresponding standard deviations. Data source: Danish Meteorological Institute (DMI)

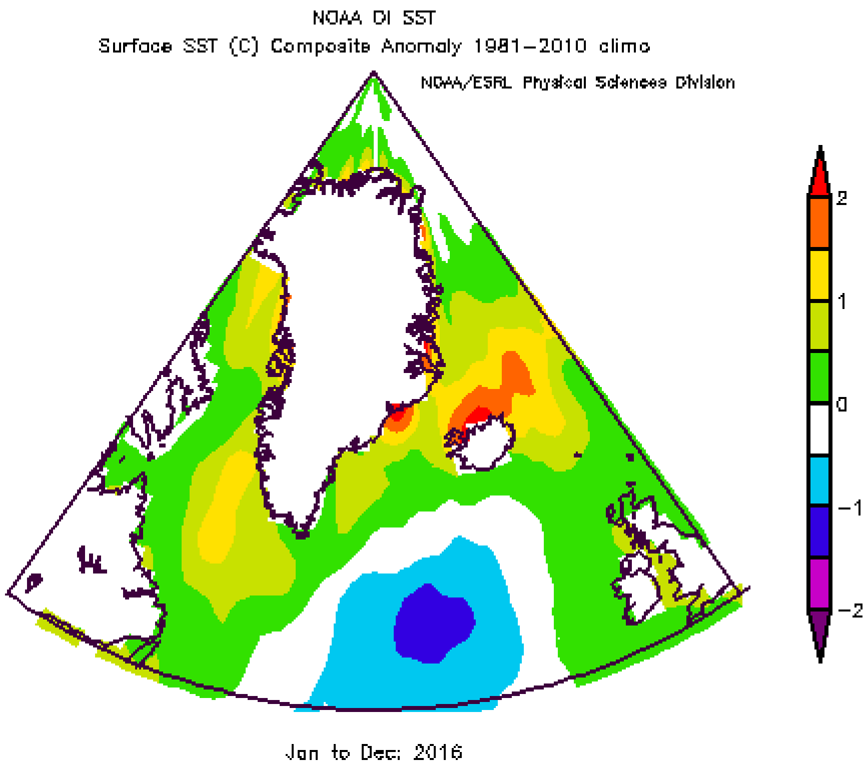
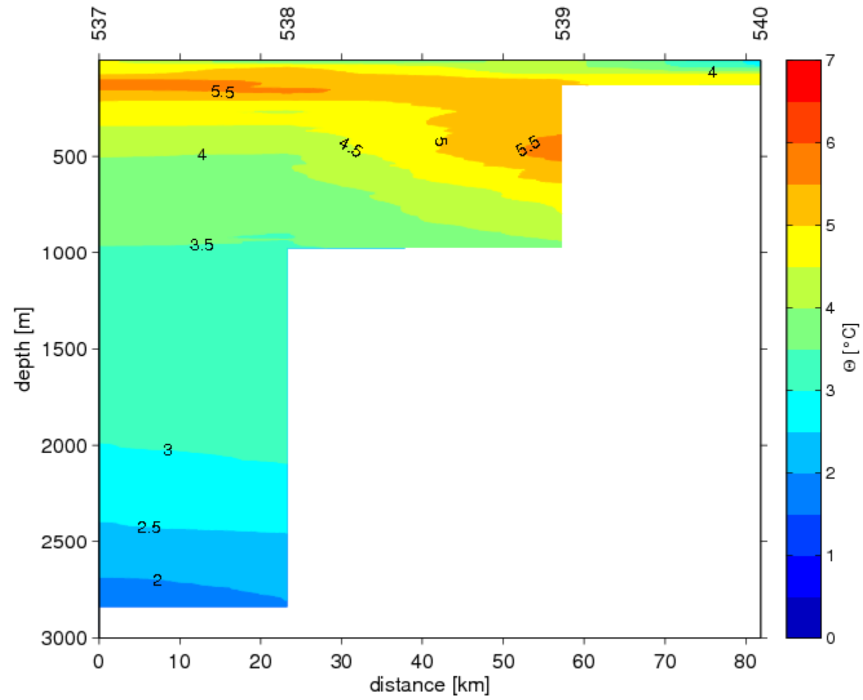
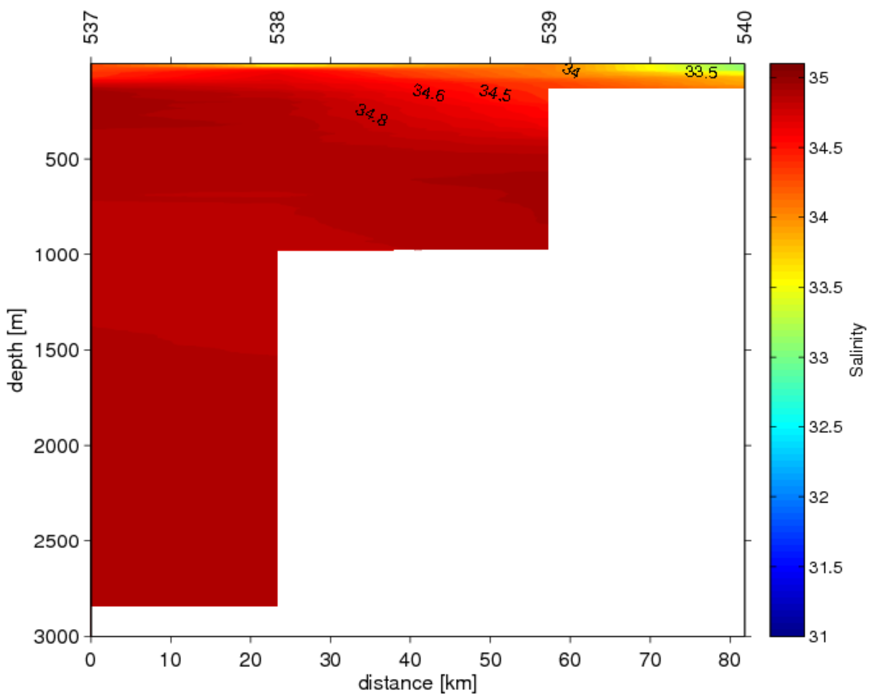


Figure 8. Map of 2016 annual sea surface temperature (NOAA OI SST) anomalies in the study region. The long-term mean corresponds to 1981-2010. *Image is provided by the NOAA/ESRL Physical Science Division, Boulder, Colorado*



(a)



(b)

Figure 9. Vertical distribution of potential temperature **(a)** and salinity **(b)** along the Cape Desolation section in 2016.

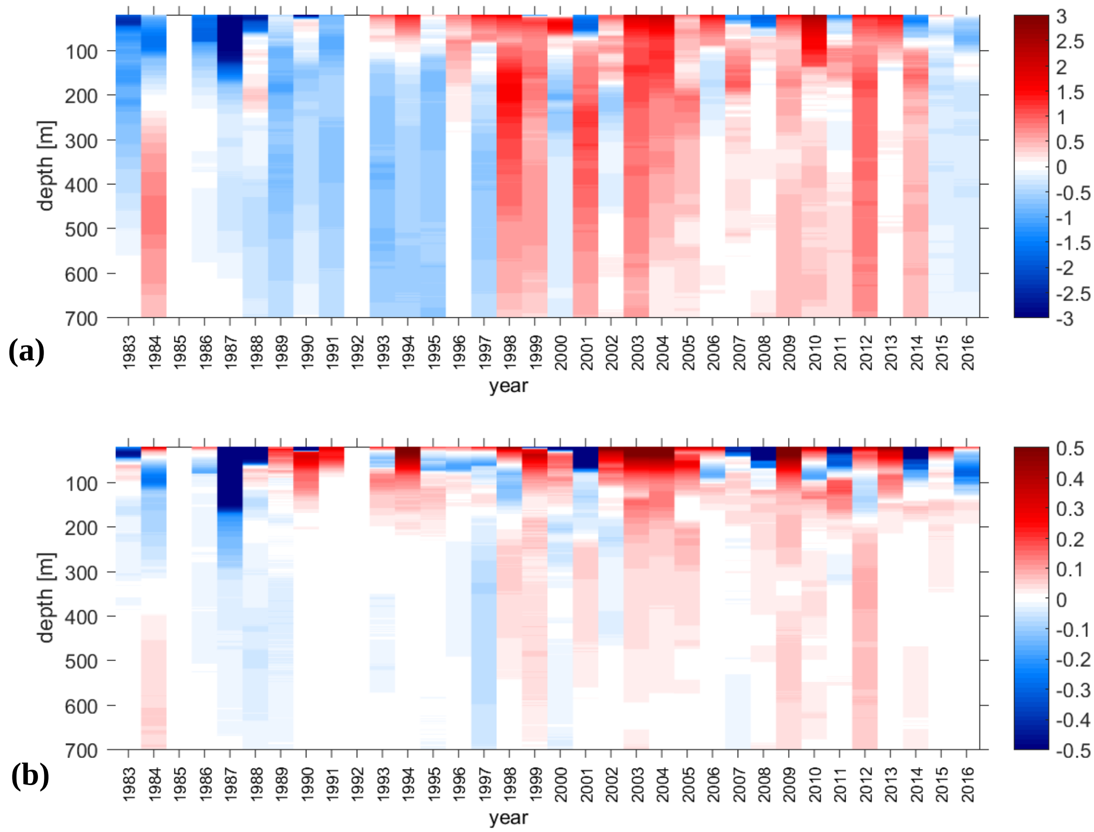
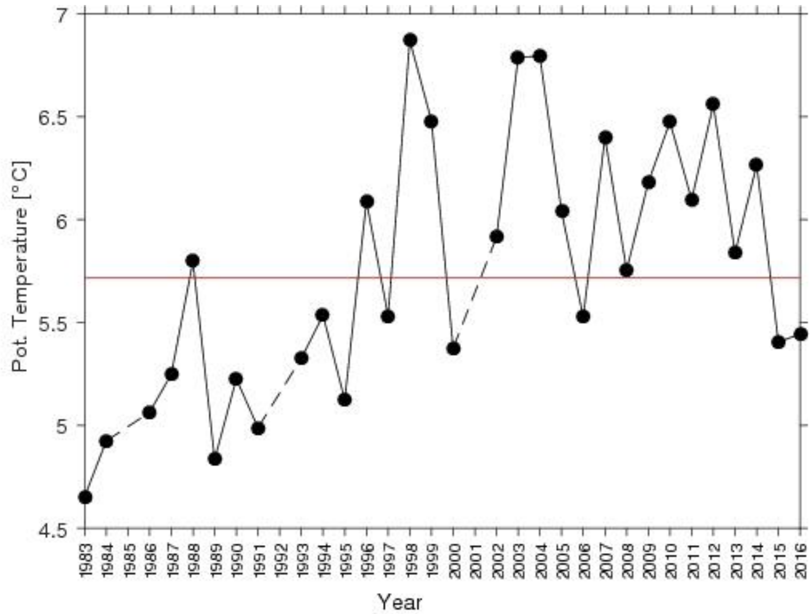
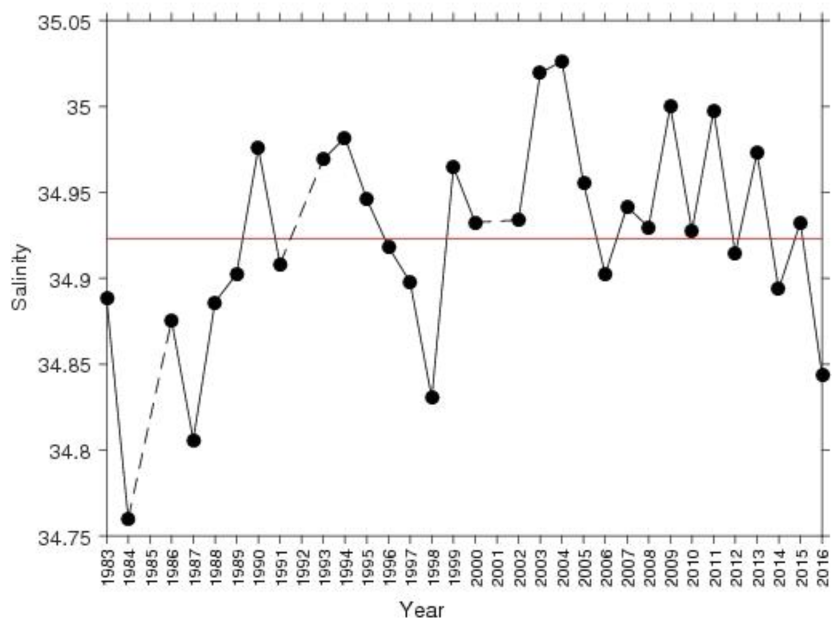


Figure 10. Hovmoeller diagram of the potential temperature anomalies **(a)** and salinity anomalies **(b)** in the upper 700 m at Cape Desolation Station 3. Reference period is 1983-2010.



(a)



(b)

Figure 11. Potential temperature **(a)** and salinity **(b)** in 75-200 m water layer at Cape Desolation Station 3 (60.47°N, 50°W). Red lines indicate the long-term mean potential temperature and salinity, referenced to 1983-2010.

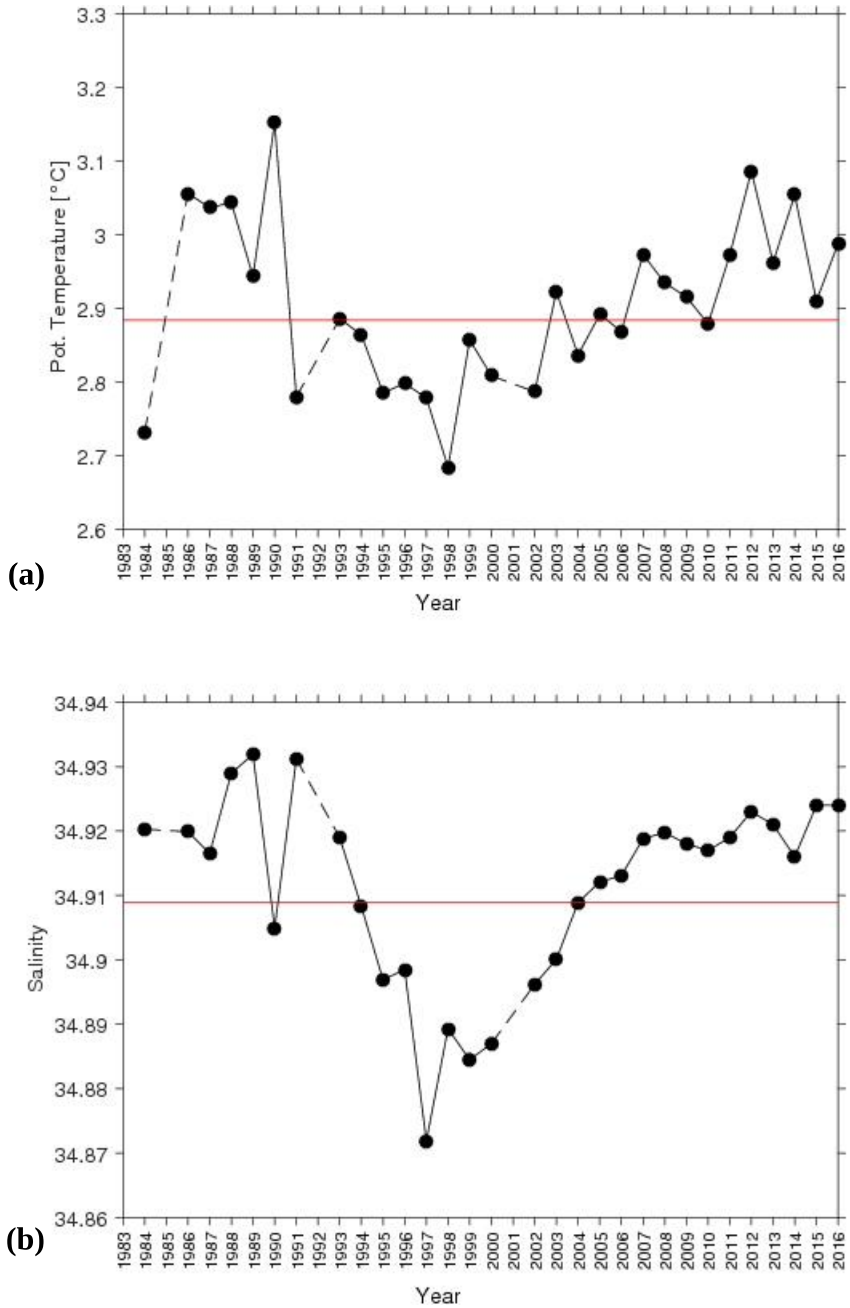


Figure 12. Potential temperature **(a)** and salinity **(b)** at 2000 m water depth at Cape Desolation Station 3 (60.47°N, 50°W). Red lines indicate the long-term mean potential temperature and salinity, referenced to 1983-2010.

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Annex 7:

Regional report –
Hydrographic Conditions on the Northeast United States Continental Shelf in 2016

Area 2c: Hydrographic Conditions on the Northeast United States Continental Shelf in 2016

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Background

The Northeast United States (NEUS) Continental Shelf extends from the southern tip of Nova Scotia, Canada, southwestward through the Gulf of Maine and the Middle Atlantic Bight, to Cape Hatteras, North Carolina (Fig. 1). Contrasting water masses from the subtropical and subpolar gyres influence the hydrography in this region. Located at the downstream end of an extensive interconnected coastal boundary current system, the NEUS shelf is the direct recipient of cold/fresh arctic-origin water, accumulated coastal discharge and ice melt that has been advected thousands of kilometers around the boundary of the subpolar North Atlantic. Likewise, subtropical water masses, advected by the Gulf Stream, slope currents and associated eddies, also influence the composition of water masses within the NEUS shelf region. The western boundary currents of the subpolar and subtropical gyres respond to variations in basin-scale forcing through changes in position, volume transport and/or water mass composition and it is partly through these changes that basin-scale climate variability is communicated to the local NEUS shelf.

To first order, hydrographic conditions along the NEUS shelf are determined by the relative proportion of two main sources of water entering the region: cold/fresh arctic-origin water advected by the coastal boundary current from the north and warmer, more saline slope waters residing offshore of the shelf break. The source waters first enter the NEUS shelf region through the Gulf of Maine, a semi-enclosed shelf sea that is partially isolated from the open Northwest Atlantic by two shallow banks, Browns and Georges Banks. Below 100 meters, exchange between the Gulf of Maine and the deeper North Atlantic is restricted to a single deep channel, the Northeast Channel, which bisects the shelf between the two banks. This deep channel interrupts the continued flow of cold, fresh arctic-origin water along the coast, redirecting the majority of this flow into the Gulf of Maine. In the meantime, denser slope waters enter the basin through the same channel at depth, gradually spreading into a network of deep basins within the Gulf of Maine (Fig. 1b). In the upper layers of the Gulf of Maine, the shelf waters circulate counter-clockwise around the basin before continuing southwestward through the Middle-Atlantic Bight (Fig. 1b). The shelf water is progressively modified by atmospheric fluxes of heat and salt and through mixing with both deeper slope waters and the discharge of several local rivers. In this way, the Gulf of Maine represents the gateway to the NEUS shelf region, responsible for setting the initial hydrographic conditions for water masses entering the Middle Atlantic Bight further downstream.

The pronounced seasonal cycle of heating and cooling over the region drives seasonal variations in water mass composition that are typically larger than interannual variations. During fall and winter, intense cooling at the surface removes buoyancy, resulting in overturning and vertical homogenization of a significant portion of the water column. During spring and summer, surface heating re-stratifies the surface layer, isolating a remnant of the previous winter's cold/fresh mixed water at depth. Variations in these seasonal processes (e.g. less intense cooling in the winter or shifts in the timing of springtime warming) can result in interannual variations in the composition and distribution of water masses. In addition, fluctuations in the composition and volume of source waters entering the Gulf of Maine may also drive interannual variations in water properties relative to this seasonal mean picture.

The slope water that enters the Gulf of Maine is a mixture of two water masses: warm, saline, relatively nutrient-rich Warm Slope Water (WSLW) originating in the subtropics and cold, fresh, relatively nutrient-poor Labrador Slope Water (LSLW) originating in the subpolar region. Seaward of the Gulf of Maine, the relative proportion of these two water masses varies over time. However, in general, the volume of each decreases with increasing along-slope distance from their respective sources; LSLW (WSLW) volume decreases from north to south (south to north). Decadal shifts in the position of the Gulf Stream appear to be closely tied to changes in slope water temperature offshore of the NEUS shelf and to the composition of slope water entering the Gulf of Maine (Pers. Comm. T. Joyce and Y-O. Kwon.) Cooling in the slope water offshore is accompanied by a southward shift in the Gulf Stream and a predominance of northern source water (LSLW) in the deep layers of the Northeast Channel.

Basin-Scale Conditions in 2016

Surface air temperatures were warmer than average (1981-2010) everywhere but the central basin during winter, summer and fall. During spring, an area of colder air temperatures extended from the central basin over northern North America and the Canadian Archipelago (Fig. 2). Overall, the seasonal range of regional average air temperatures over the northeastern U.S. continent and adjoining shelf was near normal. Sea surface temperature mirrored these patterns, with cooler than average SST in the central basin and Labrador Sea during winter/spring and persistent warming over the NEUS shelf throughout the year (Fig. 3). Annually, the magnitude of the warming was comparable to that observed in the 1950s, however 2016 was characterized by enhanced warming in summer and fall (Fig 4).

Hydrographic Conditions in 2016

The U.S. National Oceanic and Atmospheric Administration's Northeast Fisheries Science Center (NEFSC) conducts multiple shelf-wide surveys every year in support of its mission to monitor the NEUS ecosystem. Monitoring efforts have been ongoing since 1977. Typically, the NEFSC completes six full-shelf hydrographic surveys per year, in addition to several more regionally focused surveys – the minimum required to resolve the dominant seasonal cycle in this region. However, budget cuts and ship maintenance issues led to the elimination and/or truncation of two of these six surveys in 2016 so that overall roughly half as many stations were occupied in 2016 over just three seasons, leading to a critical loss of seasonal resolution.

Relative to historical values, regional ocean temperatures across the NEUS shelf were warm during 2016 (Fig. 5). Annually, waters in the upper 30 meters were between 1.0-1.5°C warmer than normal everywhere, with the largest anomalous occurring in the southern Middle Atlantic Bight, Georges Bank and eastern Gulf of Maine. Of the seasons sampled, warming was most pronounced during spring in the southern Middle Atlantic Bight where regional temperature anomalies exceeded 2°C all the way to the bottom (Fig. 6). Extremely warm conditions were also observed near the bottom in the northern Middle Atlantic Bight during spring, with comparatively weaker warming in the upper layers. By contrast, regional temperature anomalies were large throughout the water column during fall in the northern Middle Atlantic Bight (Fig.6) In the Gulf of Maine, temperatures were roughly 1°C warmer than average at both the surface and bottom throughout the year. The details of the seasonal differences are revealed in synoptic maps, showing warmer temperatures across the entire shelf in spring and fall, but with the largest anomalies observed during fall at the shelf edge near the surface and in shallow regions near the bottom (Fig 7).

Annually, surface waters in the upper 30 meters were saltier than normal in 2016, particularly in the Middle Atlantic Bight (Fig. 8). Large anomalies were observed during spring in the southern Middle Atlantic Bight, where anomalies approached 0.7 psu, and during fall in the northern Middle Atlantic Bight where anomalies were at the upper limit of the historical range, reaching

2.0 psu (Fig. 9a). Saline conditions were also observed near the bottom, although the magnitude of the anomalies was modulated compared to upper layers (Fig. 8 and 9b). Synoptically, the large regional salinity anomalies observed at the surface in the Middle Atlantic Bight during fall were strongest near the shelf edge aligned with regions of warming (Fig. 7), although a tongue of saline water extended inshore between Georges Bank and the eastern tip of Long Island, NY (Fig 10). The salinity within this shoreward protrusion was > 34, suggesting that the anomaly was caused by an intrusion of slope waters onto the shelf. Satellite derived observations of sea surface temperature indicate that several large amplitude Gulf Stream meanders and warm core rings were impinging on the shelf during this time (Fig 11).

Deep inflow through the Northeast Channel continues to be dominated by Warm Slope Water (Fig. 12). Springtime temperature-salinity and temperature-depth profiles indicate the presence of a very weaker Cold Intermediate layer in the western Gulf of Maine during spring 2016, a mid-depth water mass formed seasonally as a product of convective mixing driven by winter cooling (Fig. 13 & 14). In fact, the remnant winter water in the Cold Intermediate Layer is over 1.5°C warmer and slightly fresher than average in 2016, suggesting that convective mixing was suppressed in the preceding winter (Fig. 13). Correspondingly, the bottom water observed in Wilkinson Basin is cooler and fresher than average (Fig. 14 & 15). This is not surprising considering the fact that air temperatures over the Northeastern U.S were more than 2°C warmer than normal in winter 2016 (Fig 2). Vertical mixing during winter is an important process in the Western Gulf of Maine. Deeper mixing has greater potential to tap into nutrient rich slope water at depth resulting in a thicker intermediate layer during spring, both potentially having an impact on the timing or intensity of spring phytoplankton blooms.

Fisheries Implications

Our observations suggest that the Northeast U.S. Continental Shelf has been warming at a rate of ~.02-.05 °C/year since 1977, with signification interannual variations in temperature and salinity superimposed on this trend. As a result, the habitats of fish and invertebrate species in this region have experienced change on a variety of temporal and spatial scales, driving changes in distribution and abundance. Observations suggest that the Northeast US Continental Shelf is being influenced more frequently by the Gulf Stream and that the increased interactions may be related to changes in the meandering character of the current (Andres, 2016). Extreme diversions and meanders in the Gulf Stream's path (e.g. Gawarkiewicz et al., 2012) and detached Gulf Stream Warm Core Rings (e.g. Zhang and Gawarkiewicz, 2015) directly and indirectly influence the hydrography on the shelf, often leading to intrusions of comparatively warm and salty water onto the shelf. These episodic intrusions have the potential to cause significant changes in the ecosystem, for instance leading to significant changes in nutrient loading on the shelf, the seasonal elimination of critical habitats such as the cold pool and shelf-slope front, disruption of seasonal migration cues, and an increase in the concentration of offshore larval fish on the shelf.

Andres, M. (2016), On the recent destabilization of the Gulf Stream path downstream of Cape Hatteras, Geophys. Res. Lett., 43, doi:10.1002/2016GL069966.

Gawarkiewicz, G. G., R. E. Todd, A. J. Plueddemann, M. Andres, and J. P. Manning (2012), Direct interaction between the Gulf Stream and the shelf break south of New England, Sci. Rep., 2, 553, doi:10.1038/srep00553.

Zhang, W. G., and G. G. Gawarkiewicz (2015), Dynamics of the direct intrusion of Gulf Stream ring water onto the Mid-Atlantic Bight shelf, Geophys. Res. Lett., 42, 7687–7695, doi:10.1002/2015GL065530.

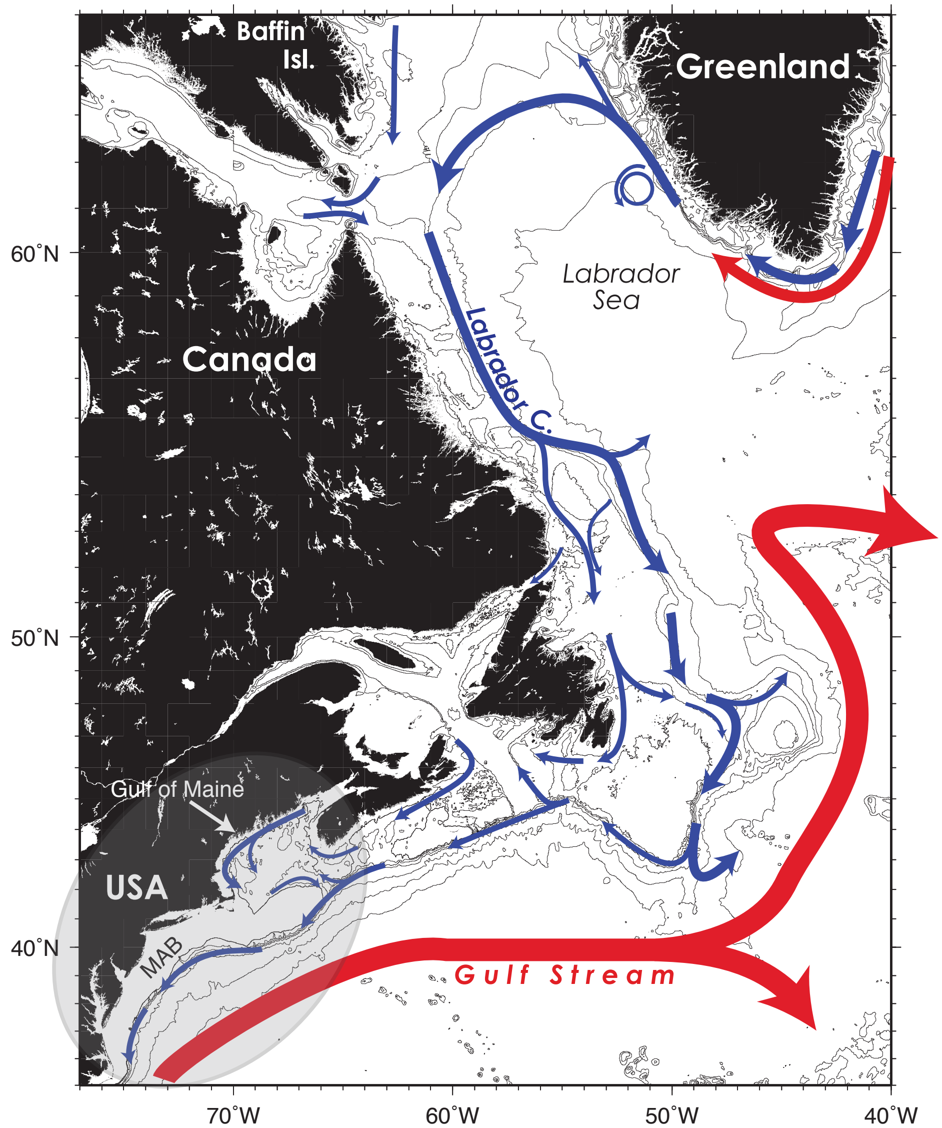

Figure 1a: Circulation schematic of the western North Atlantic. The Northeast U.S. Shelf region is identified by the shaded oval. The 100, 200, 500, 1000, 2000, 3000 and 4000 meter isobaths are shown.

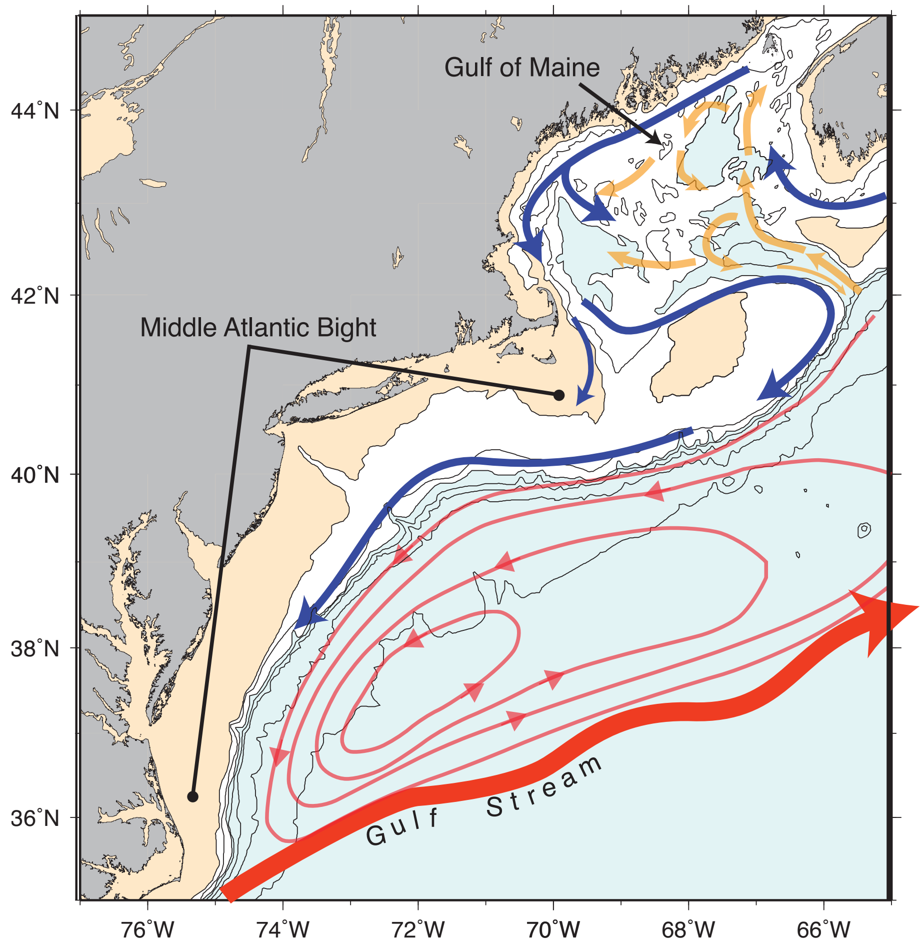

Figure 1b: Circulation schematic for the Northeast U.S. Shelf region, where blue arrows represent shelf water circulation and orange arrows represent deeper slope water circulation pathways. Water depths deeper than 200 meters are shaded blue. Water depths shallower than 50 meters are shaded tan.

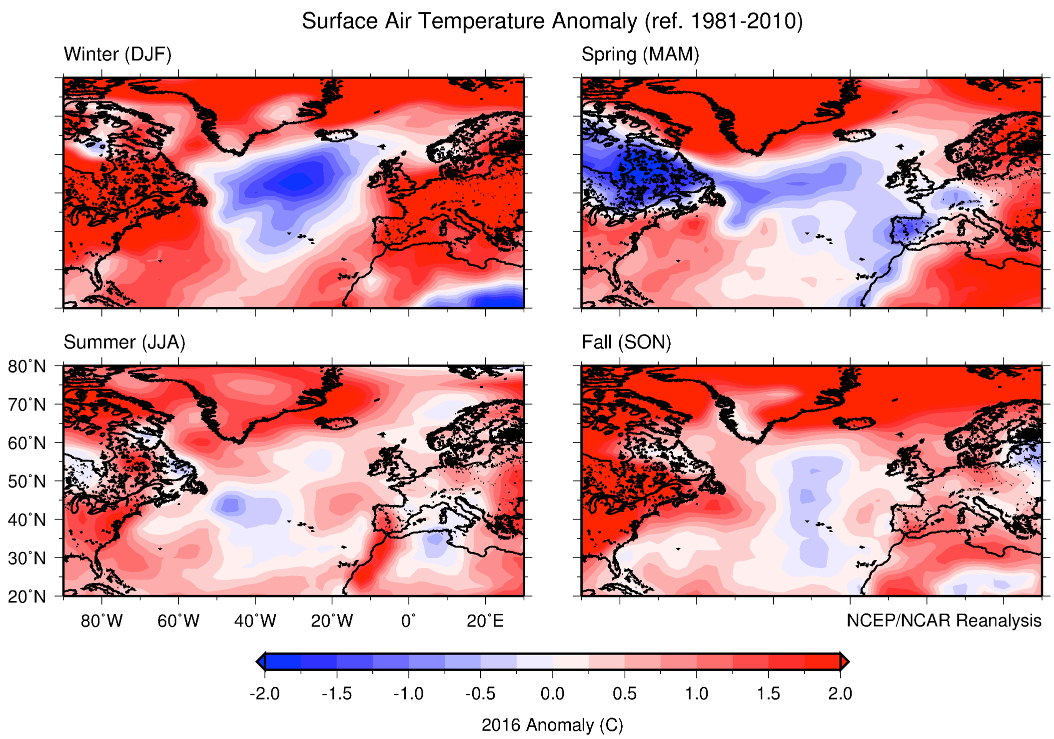

Figure 2: Surface air temperature anomaly derived from the NCEP/NCAR Reanalysis product (http://www.esrl.noaa.gov/psd/data/composites/day/). Seasons are made up of 3-month periods where winter spans December-February. Positive anomalies correspond to warming in 2016 relative to the reference period (1981-2010).

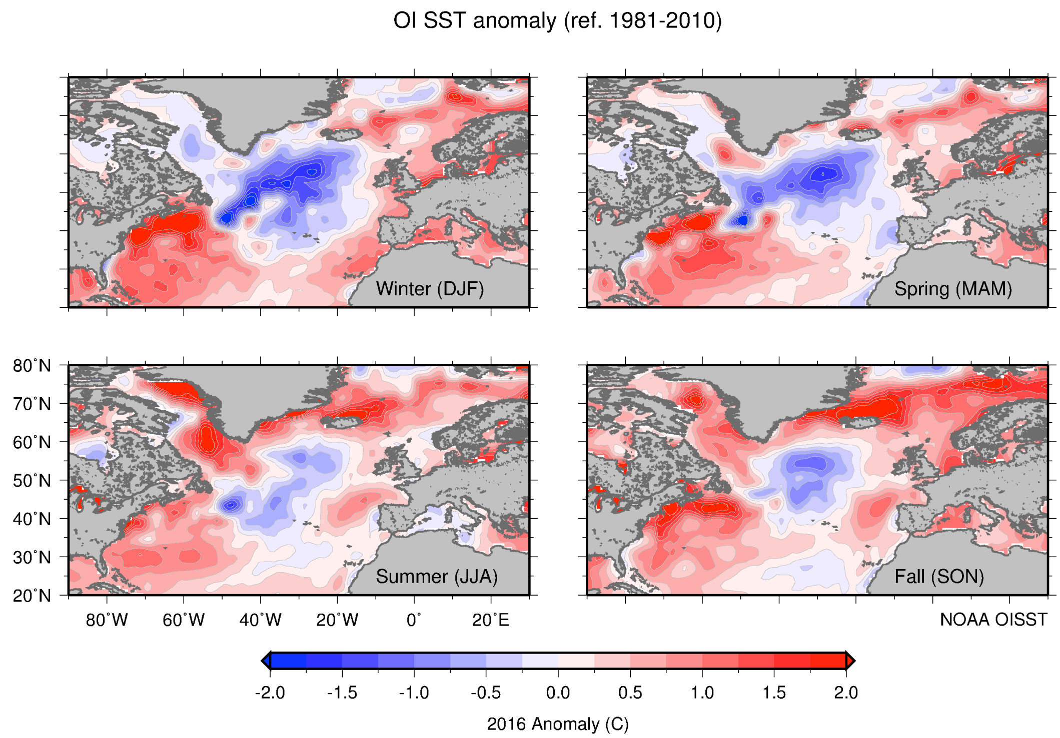

Figure 3: Sea surface temperature anomaly derived from the NOAA's Optimum Interpolation (OI) SST product (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html). Seasons are made up of 3-month periods where winter spans December-February. Positive anomalies correspond to warming in 2016 relative to the reference period (1981-2010).

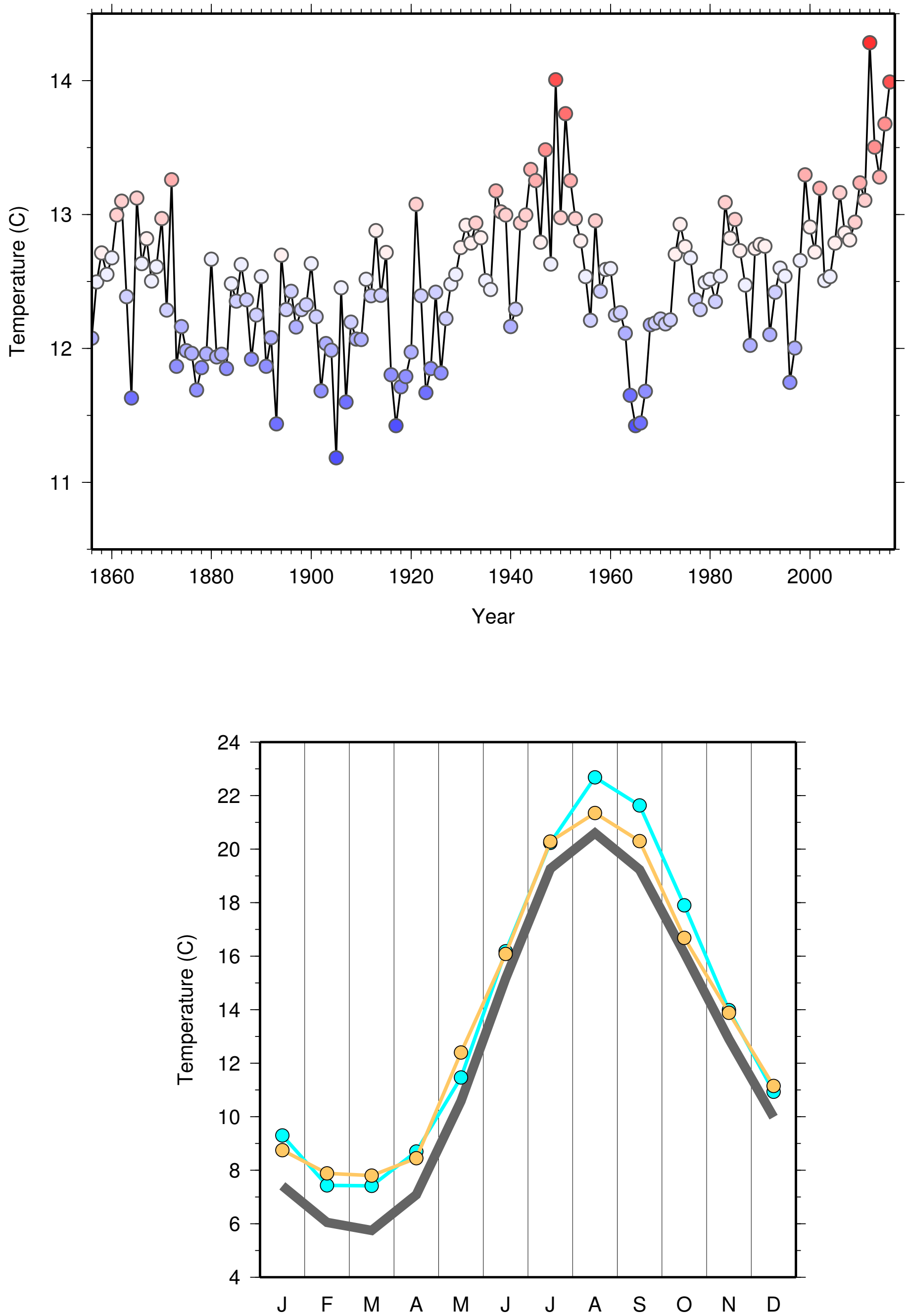

Figure 4: Top: Regional average annual sea surface temperature for the NEUS shelf region calculated from NOAA's extended reconstructed sea surface temperature product (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html). Colors correspond with the anomaly scale in Figure 3. Bottom: Regional average monthly mean SST for the NEUS shelf for 2016 (cyan), 1950 (orange) and 1981-2010 (gray).

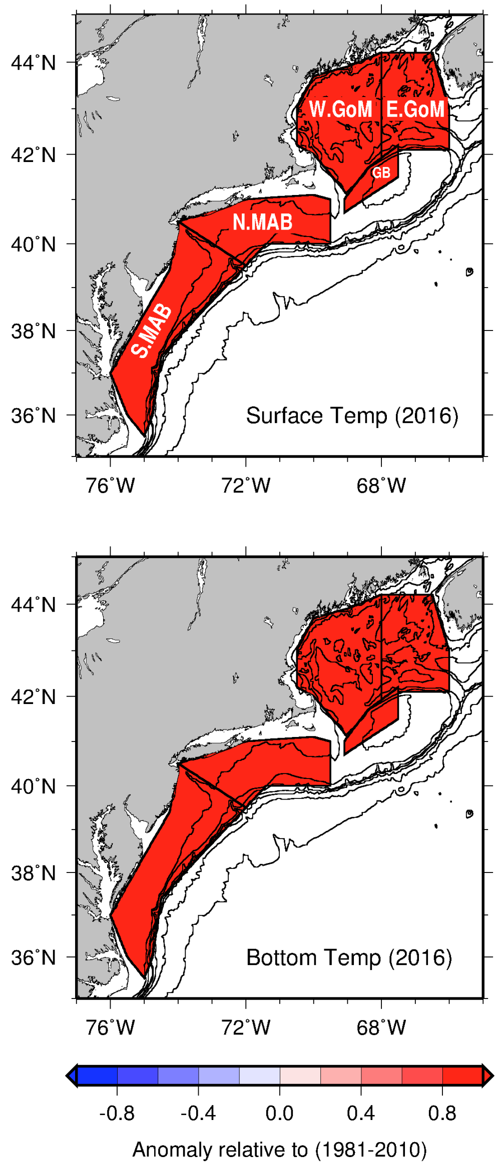

Figure 5: Surface (upper panel) and bottom (lower panel) regional annual temperature anomaly (°C). Positive anomalies correspond to warming in 2016 relative to the reference period (1981-2010). The region labels correspond to the panels in Figure 6.

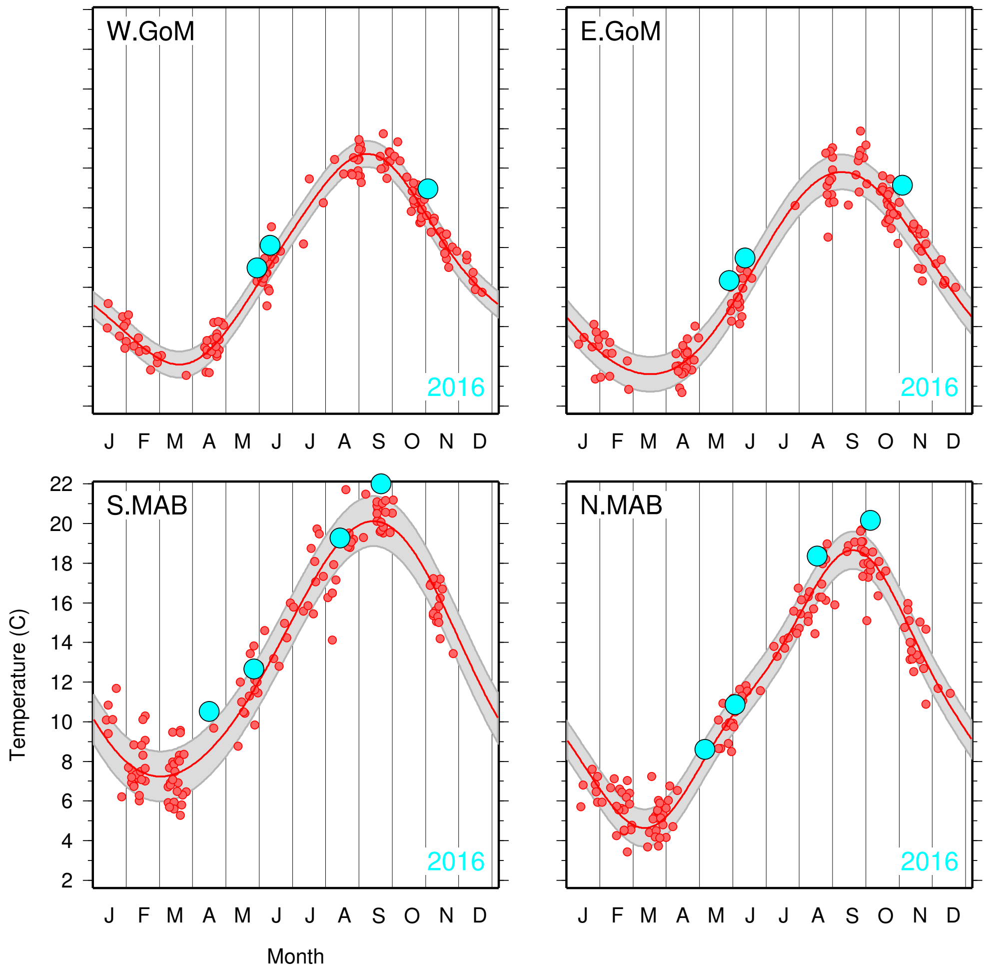

Figure 6a: Regional average 0-30 meter temperature (°C) as a function of calendar day. Each dot represents a volume-weighted average of all observations from a single survey falling within the regions delineated in Fig. 5. An annual harmonic fit to the regional average temperatures from 1981-2010 is shown by the red curve with the points contributing to the fit also shown in red. The gray shading depicts one standard deviation around this fit. The regional average temperatures from 2016 surveys are shown in cyan.

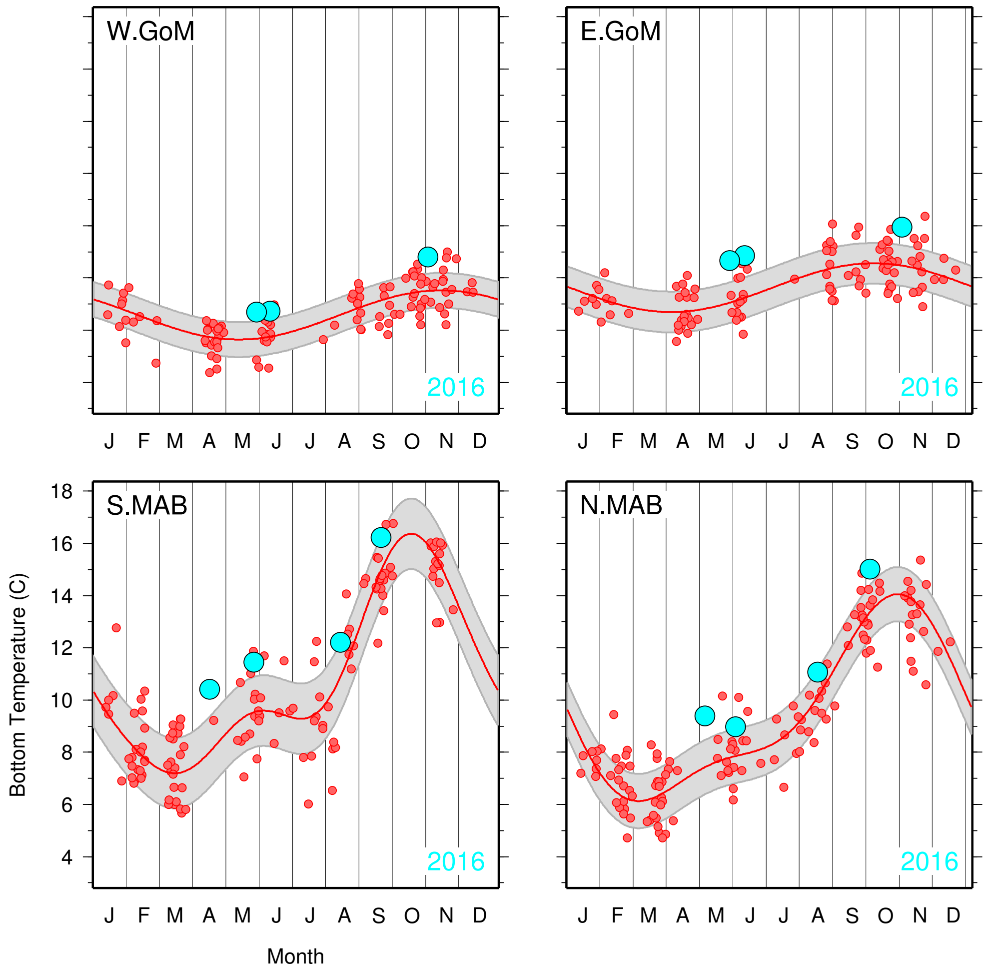

Figure 6b: As in Fig. 6a, but for bottom temperatures.

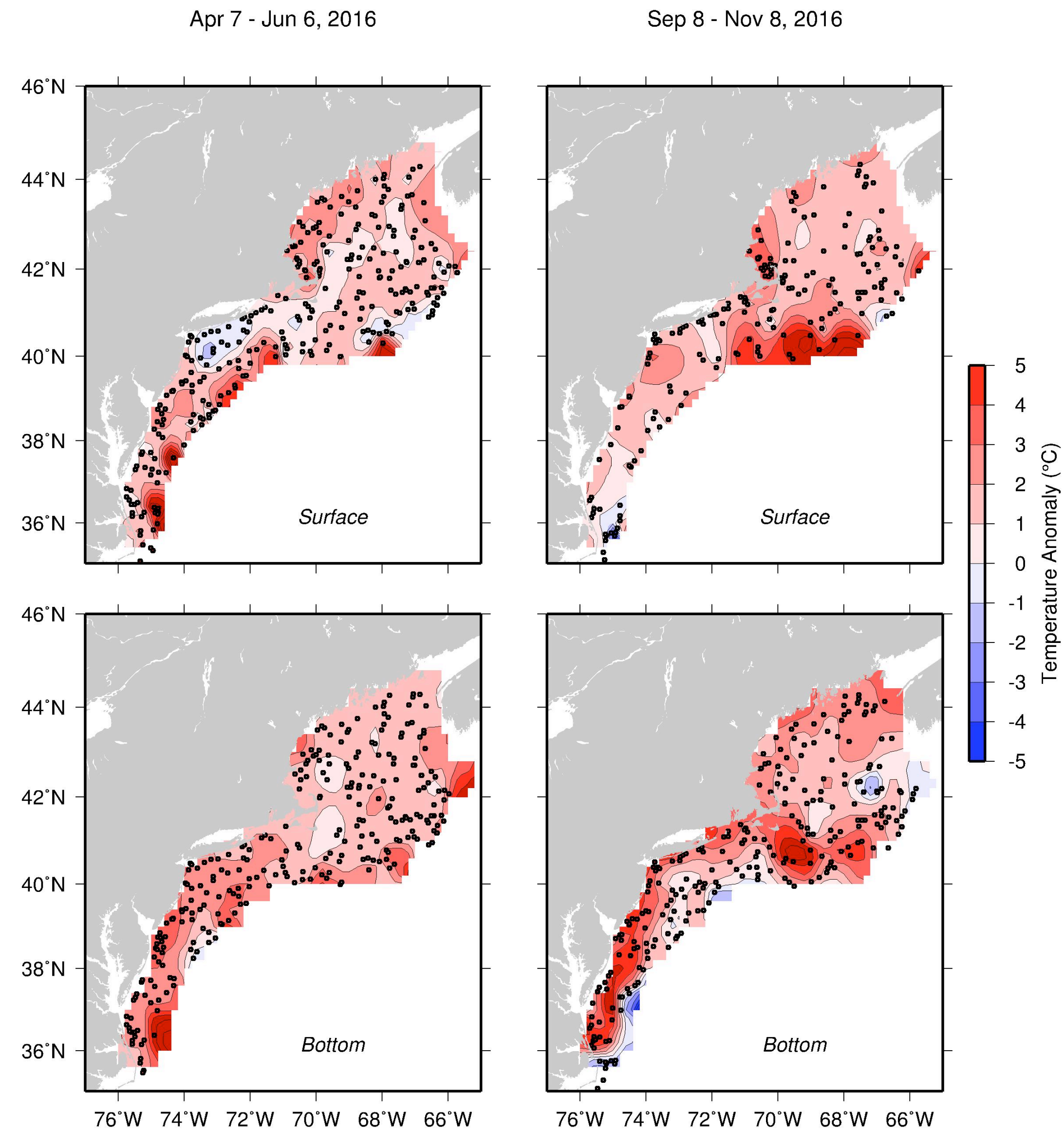

Figure 7: Surface (upper panels) and bottom (lower panels) temperature anomaly from the spring (left) and fall 2016 (right) ground fish surveys. Positive anomalies correspond to warming in 2016 relative to the reference period (1977-1987).

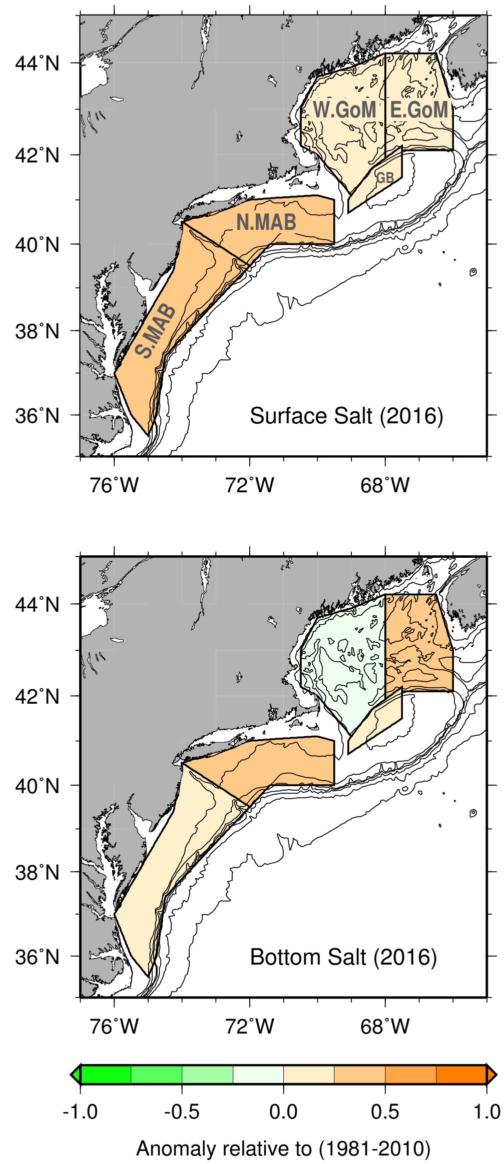

Figure 8: Surface (upper panel) and bottom (lower panel) regional annual salinity anomaly. Positive anomalies correspond to more saline conditions in 2016 relative to the reference period (1981-2010). The region labels correspond to the panels in Figure 6.

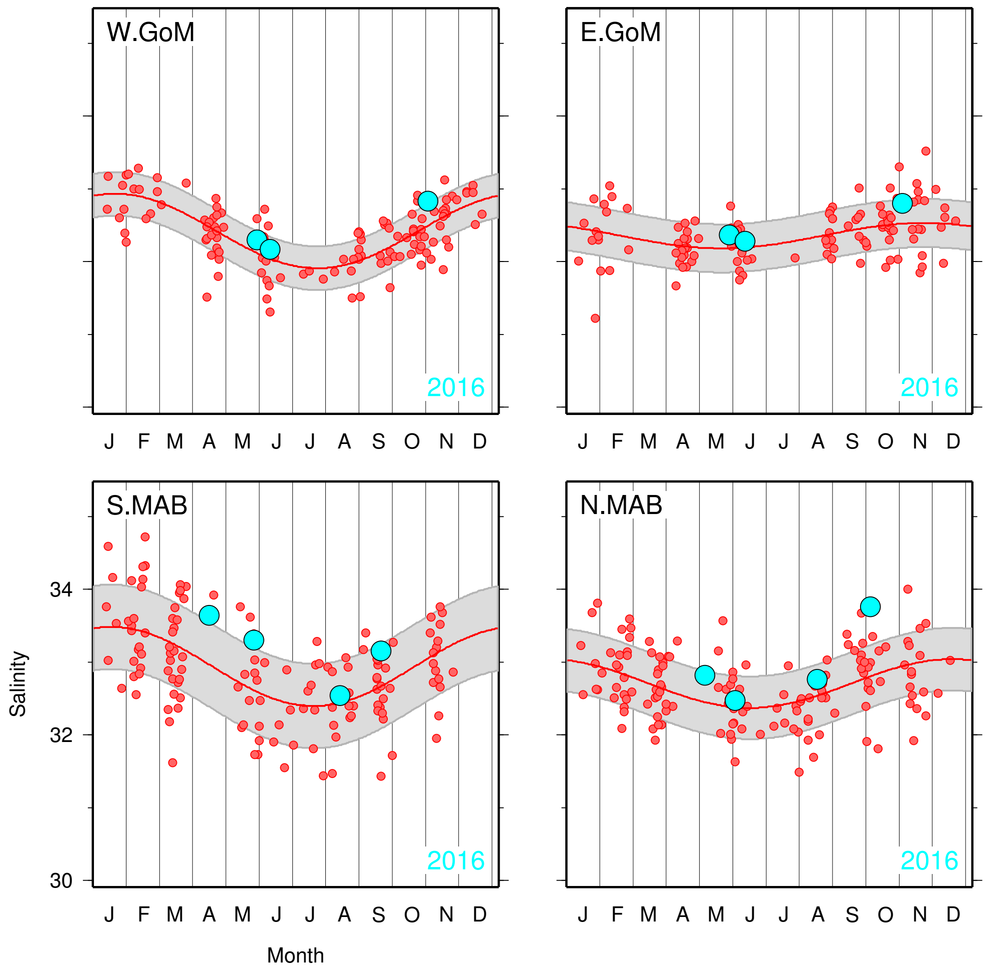

Figure 9a: Regional average 0-30 meter salinity as a function of calendar day. Each dot represents a volume-weighted average of all observations from a single survey falling within the regions delineated in Fig. 5. An annual harmonic fit to the regional average salinities from 1981-2010 is shown by the red curve with the points contributing to the fit also shown in red. The gray shading depicts one standard deviation around this fit. The regional average salinities from 2016 surveys are shown in cyan.

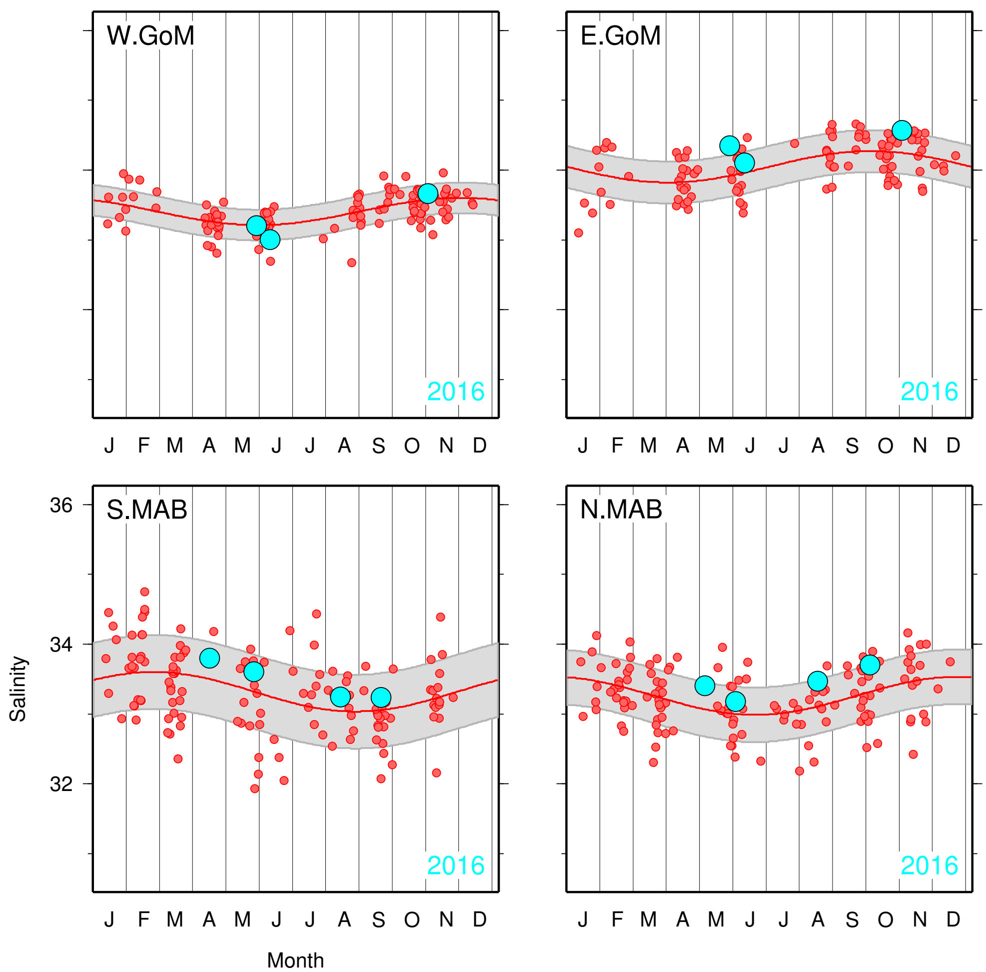

Figure 9b: As in Fig. 9a, but for bottom salinity.

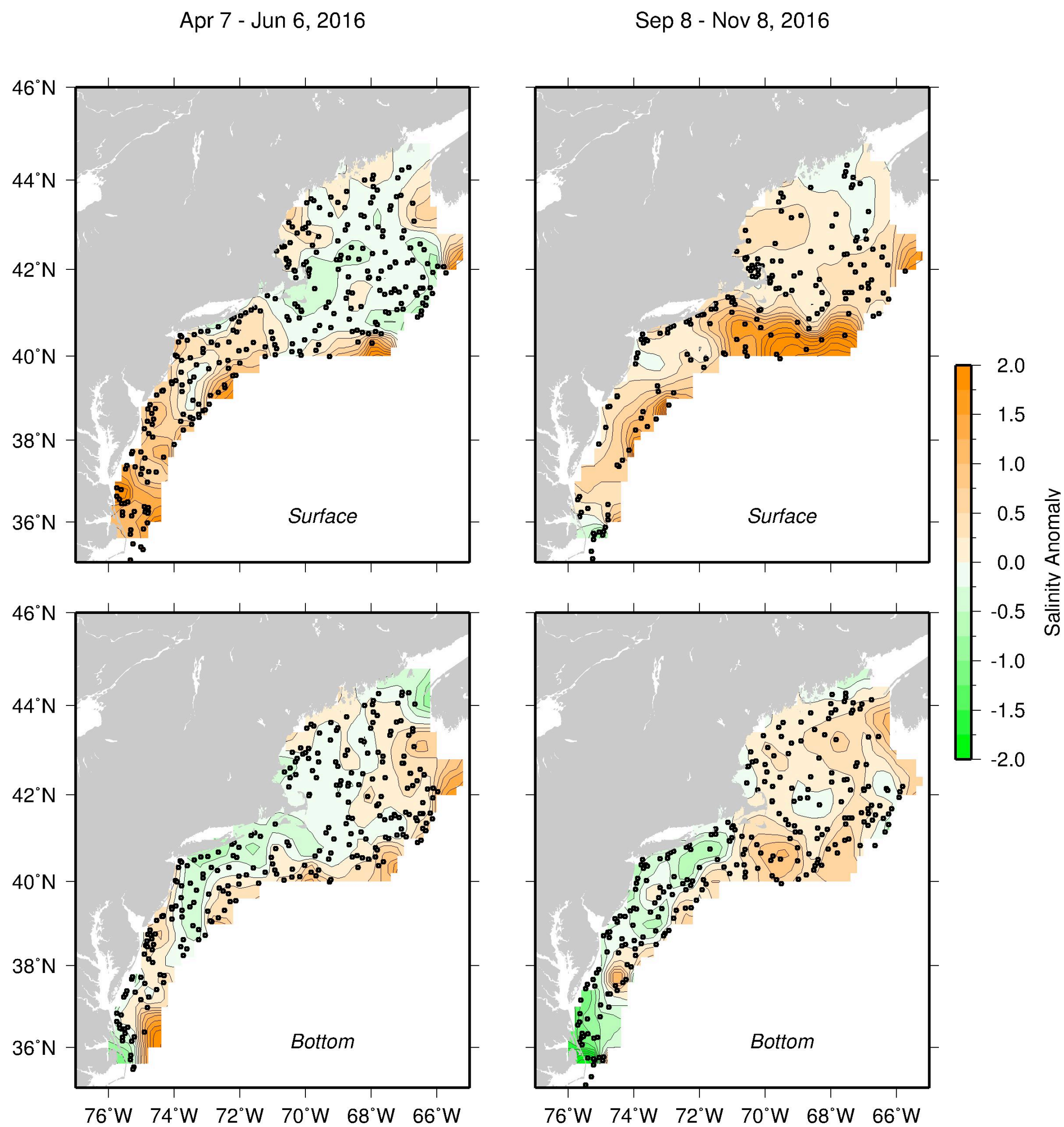

Figure 10: Surface (upper panels) and bottom (lower panels) salinity anomaly from the spring (left) and fall 2016 (right) ground fish surveys. Positive anomalies correspond to more saline conditions in 2016 relative to the reference period (1977-1987).

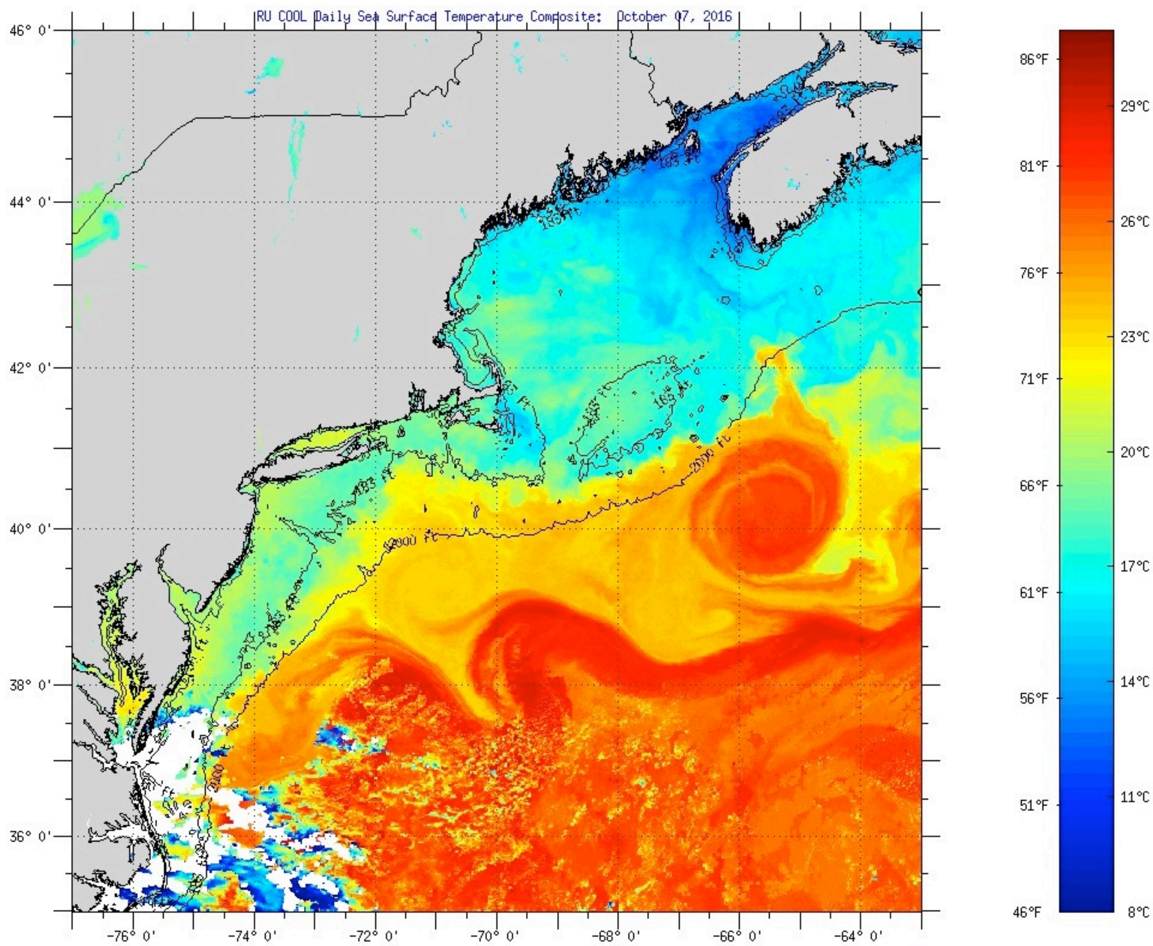

Figure 11: Daily composite sea surface temperature derived by the Coastal Ocean Observations Lab, Rutgers University, from data collected by the Advanced Very High Resolution Radiometer on October 7, 2016.

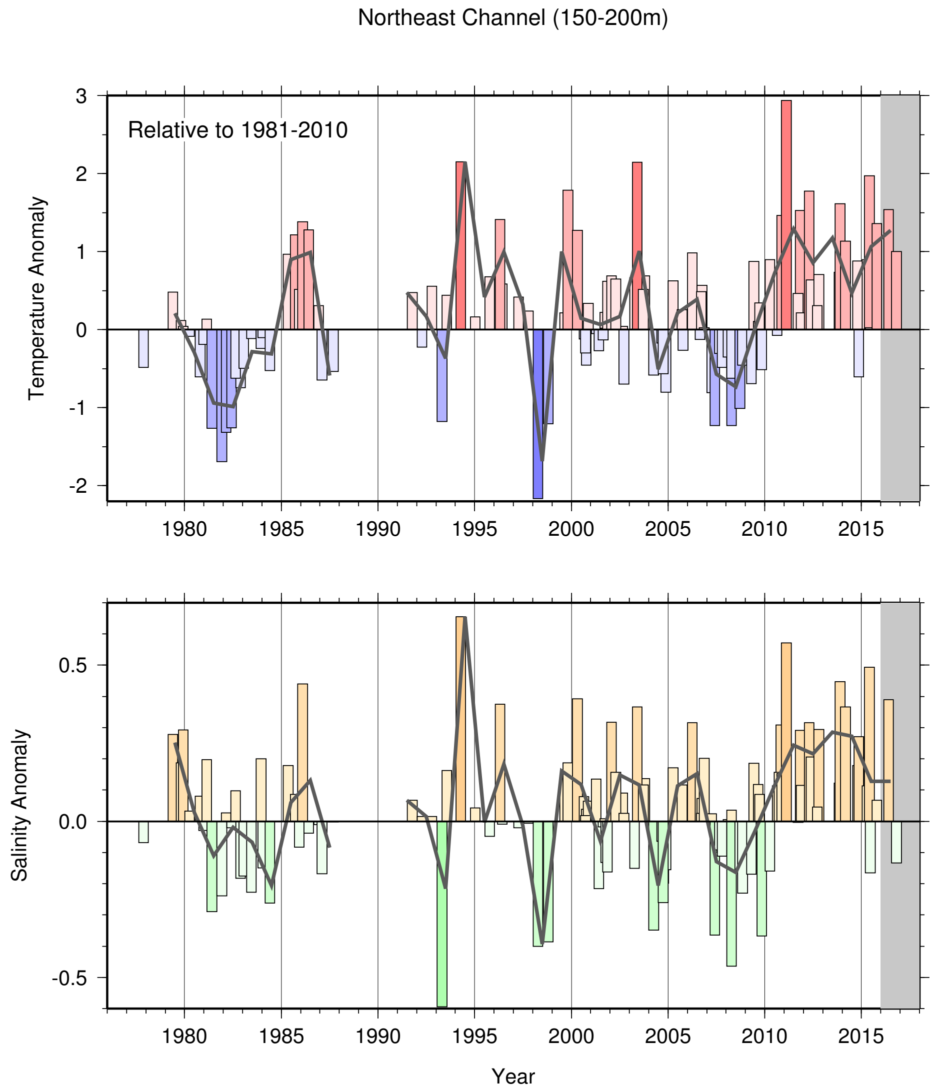

Figure 12: Time series of temperature and salinity anomaly in the deep Northeast Channel. Each bar represents a volume-weighted average of all observations from a single survey collected between 150-200 meters in the Northeast Channel. The grey curve shows the annual average anomaly time series. Positive values are warmer and saltier than the long-term mean calculated for 1981-2010. The gray shading highlights observations made in 2016.

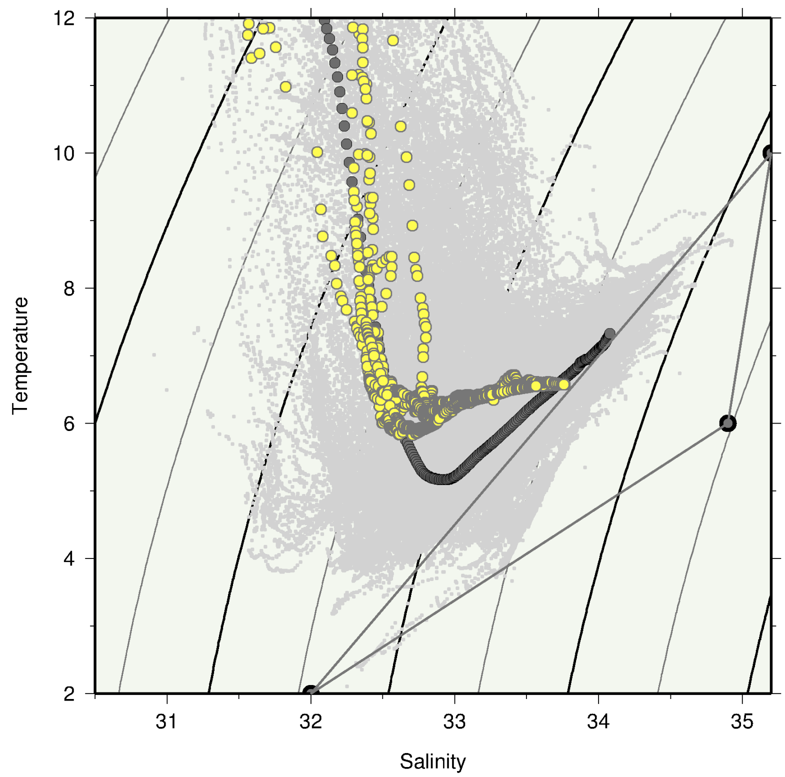

Figure 13: Temperature-salinity diagram showing water properties in Wilkinson Basin in the western Gulf of Maine. All observations from June (yellow) 2016 are shown along with the spring climatological average profile (1981-2010, dark gray). The lightest gray dots show the historical range encompassed by observations from the reference period, 1981-2010. Temperature and salinity properties representative of source waters entering the Gulf of Maine are shown by the mixing triangle.

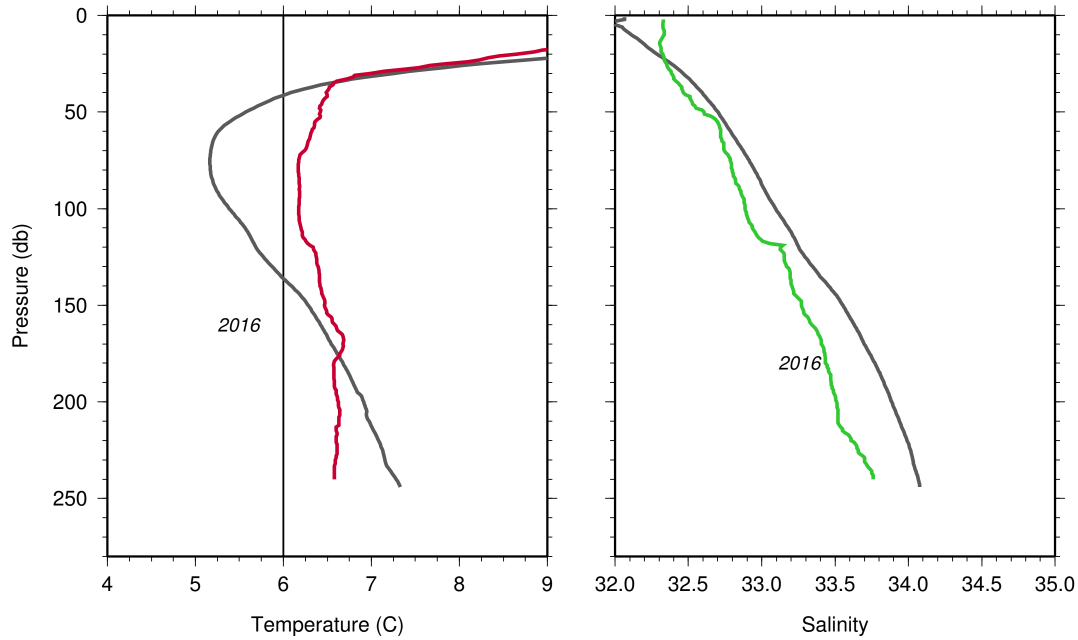

Figure 14: Average profiles of temperature (left) and salinity (right) from repeated observations collected during June in Wilkinson Basin in the western Gulf of Maine. All observations from June 2016 (red and green) are shown along with the climatological average profile for the same month (1981-2010, dark gray). Waters in the Cold Intermediate Layer in the western Gulf of Maine are typically colder than 6°C, denoted by the vertical line.

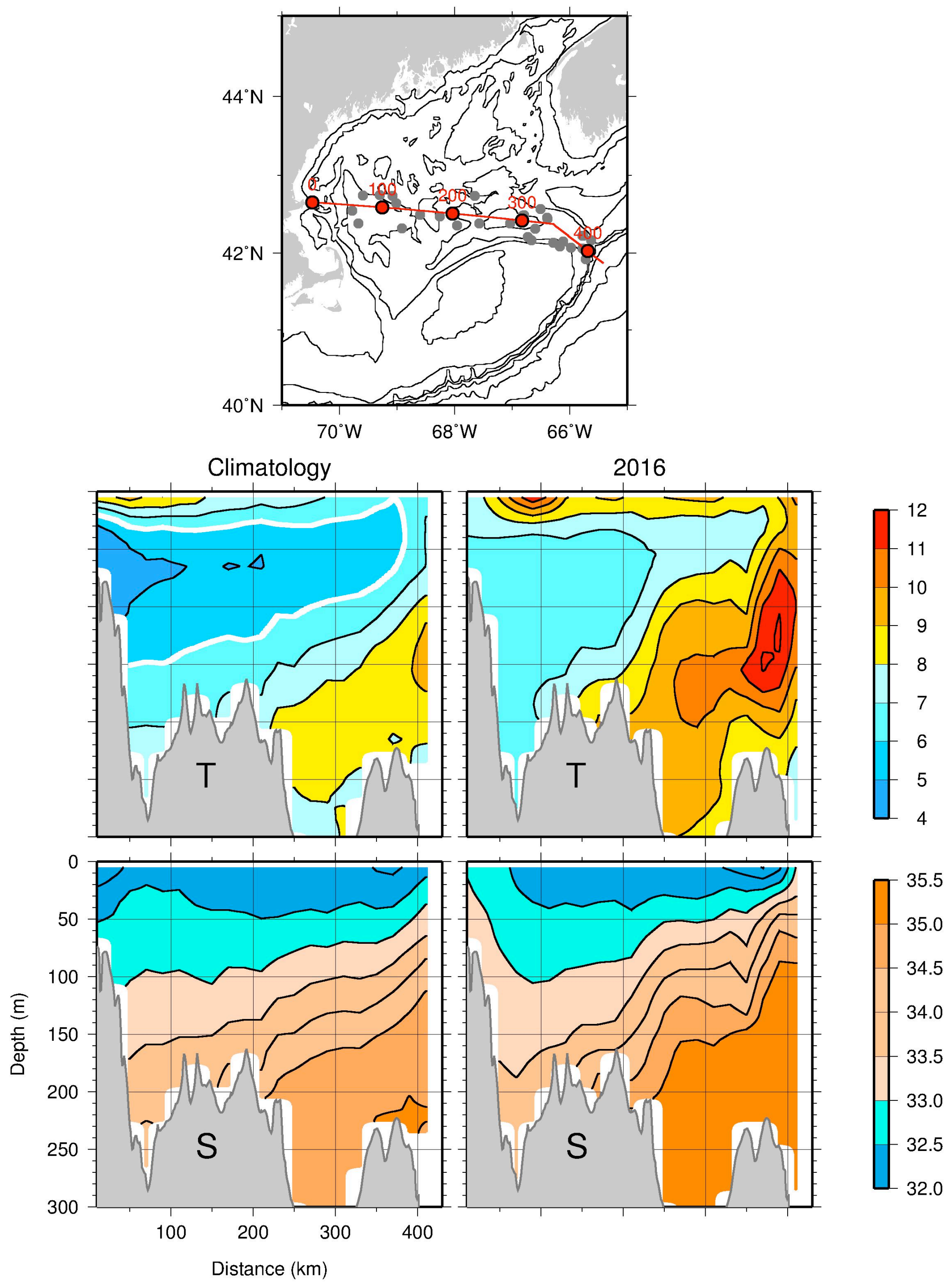

Figure 15: Vertical sections of temperature (top) and salinity (bottom) crossing the Gulf of Maine along a zonal transect shown in the map. The left panels show the climatological average for May spanning the years 1981-2010. The bottom panels show the synoptic mean section for May 2016. The heavy white contour highlights the 6°C isotherm as an indicator of the boundary of the cold intermediate layer. Along-transect distances and the May 2016 station distribution are shown on the map for reference.

Annex 8:

Regional report –
Contribution to the
ICES Working Group on Oceanic
Hydrography
National report: France, April 2017

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Contribution to the ICES Working Group on Oceanic Hydrography

National report: France, April 2017

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*Fabienne Gaillard, Ifremer Researcher at Labioratoire d'Océanography Physique et Spatial, Brest, France, has pasted away after a courageous battle against illness. For years, she has contributed consistently to produce and gather the French contributions to ICES-IROC annual report on the North Atlantic State of the Ocean. One of her major contribution is the production of the high quality in situ data product ISAS, from temperature and salinity in situ quality controlled profiles. For a decade, she has developed these tools and products, which is now acknowledged and wildly used in the oceanographer's scientific community. Fabienne was a scientist recognized for its scientific rigor and enthusiastic investment with its collaborators and in scientific community.

Rapport : LOPS-WGOH-2017-01

Summary

1 Argo gridded temperature and salinity field

The ARGO network of profiling floats has been set up to monitor the large-scale global ocean variability (http://www.argo.ucsd.edu/). Argo data are transmitted in real time and hastily made available by the two Global Data Assembly Centres (Argo-GDAC). Delayed mode data undergo expert calibration processes and are delivered later. In the North Atlantic, the temperature and salinity conditions of the upper 2000 m are adequately described since 2002. This dataset is thus suitable for an overview of the oceanographic conditions in this basin, giving the general context for the repeat stations and sections collected mostly at the periphery of the basin by the partners of the ICES Working Group on Ocean Hydrography (WGOH). Note that, in this Section, the temperature and salinity anomalies are compute using WOA-05 climatology (World Ocean Atlas-2005; https://www.nodc.noaa.gov/OC5/SELECT/woaselect/woaselect.html), that mainly reflects the mean oceanic conditions of the pre-Argo period, *i.e.* before 2000's. Thus, temperature and salinity anomalies reflect change in comparison to this period.

1.1 ISAS: gridded temperature and salinity fields

Temperature and salinity fields are estimated on a regular half degrees (Mercator scale) grid using the In Situ Analysis System (ISAS), (*Gaillard et al.*, 2016). The dataset is downloaded from the Coriolis Argo GDAC (http://www.coriolis.eu.org/). It should be noted that Coriolis assembles many types of data transmitted in real time, merging the ARGO data set with data collected by the GTS such as mooring data, marine animals, CTDs. However, the ARGO dataset remains the main contributor in the open ocean. The last years of the analyzed series uses the Near Real Time dataset prepared by Coriolis at the end of each month from real time data. Delayed mode data are progressively taken into account for the previous years, replacing the NRT data.

Data are pre-processed before entering the analysis. First we perform a climatological test to detect outliers then we vertically interpolate the profiles on 152 standard levels between the surface and 2000m. The analysis to produce gridded fields is performed at each standard level independently. The method is based on optimal estimation principles and includes a horizontal smoothing through specified covariance scales. The results presented here were produced with version 6 of ISAS (*Gaillard*, 2012). The reference state was computed as the mean of a 2004-2010 analysis (D2CA1S2) and the a priori variances were computed from the same dataset. The period 2002-2012 was fully reprocessed to take into account new delayed mode data and flags. Near-Real Time (NRT) temperature and salinity fields provided by Coriolis Center (Ifremer) are used to complete the time series from 2013 to 2016. Over this period, data are interpolated using ISAS v6 including only Real Time mode data (i.e. only from automatic QC processing).

1.2 Surface layers

During winter 2016, the near surface waters were anomalously cold and fresh in the middle of subpolare gyre and in the Labrador Sea (Fig. 1.1). Further South, waters were extremely warm and salty in the western basin south of 40°N, indicating a northward shift of the Gulf Stream. A warmer than normal subtropcial gyre is also observed.

This subpolar cold anomaly persists but decreases throughout the year 2016 (Fig. 1.1), and eventually re-increases during fall 2016. Summer 2016 has been anomalously warm in the northern subpolar basin, north of 55°N, including Labrador Sea and Irminger basin. South of 55°N, a slight cool anomaly is persistent over the northern subtropical gyre.

During summer fresh salinity anomalies north of 40°N is however intensified throughout the year 2016. Waters were very fresh in the Greenland Sea/Norvegian Sea and along the East Greenland coast, while they are saltier in the Labrador Sea along the Canadian coasts; and in the Greenland Sea, north of Island.

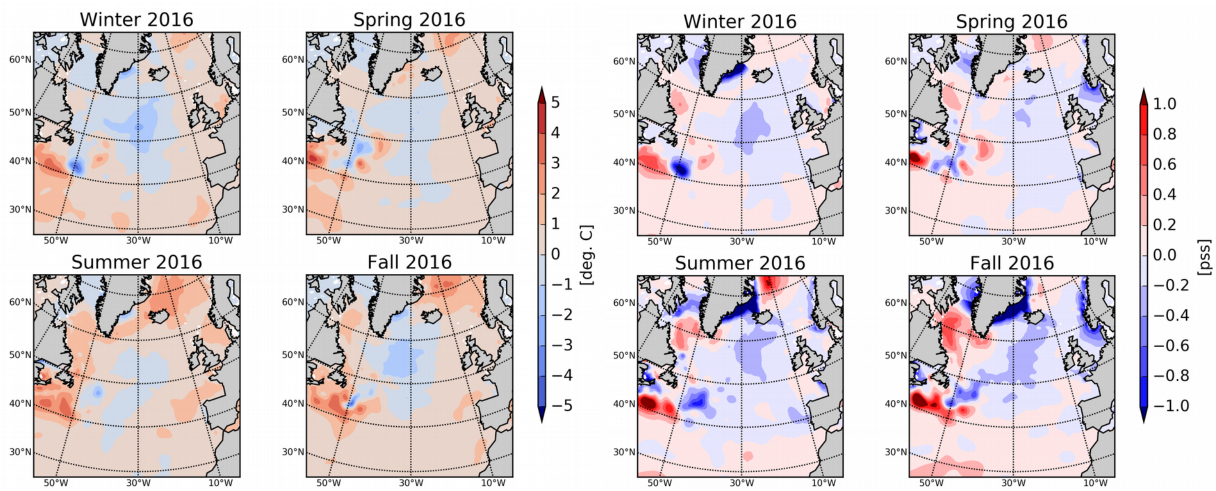


Figure 1.1: Near surface (10 meter) temperature (left) and salinity (right) averaged over Winter (JFM), Spring (AMJ), Summer (JAS) and Autumn (OND) 2016. The anomalies are shown relative to the World Ocean Atlas (WOA-05).

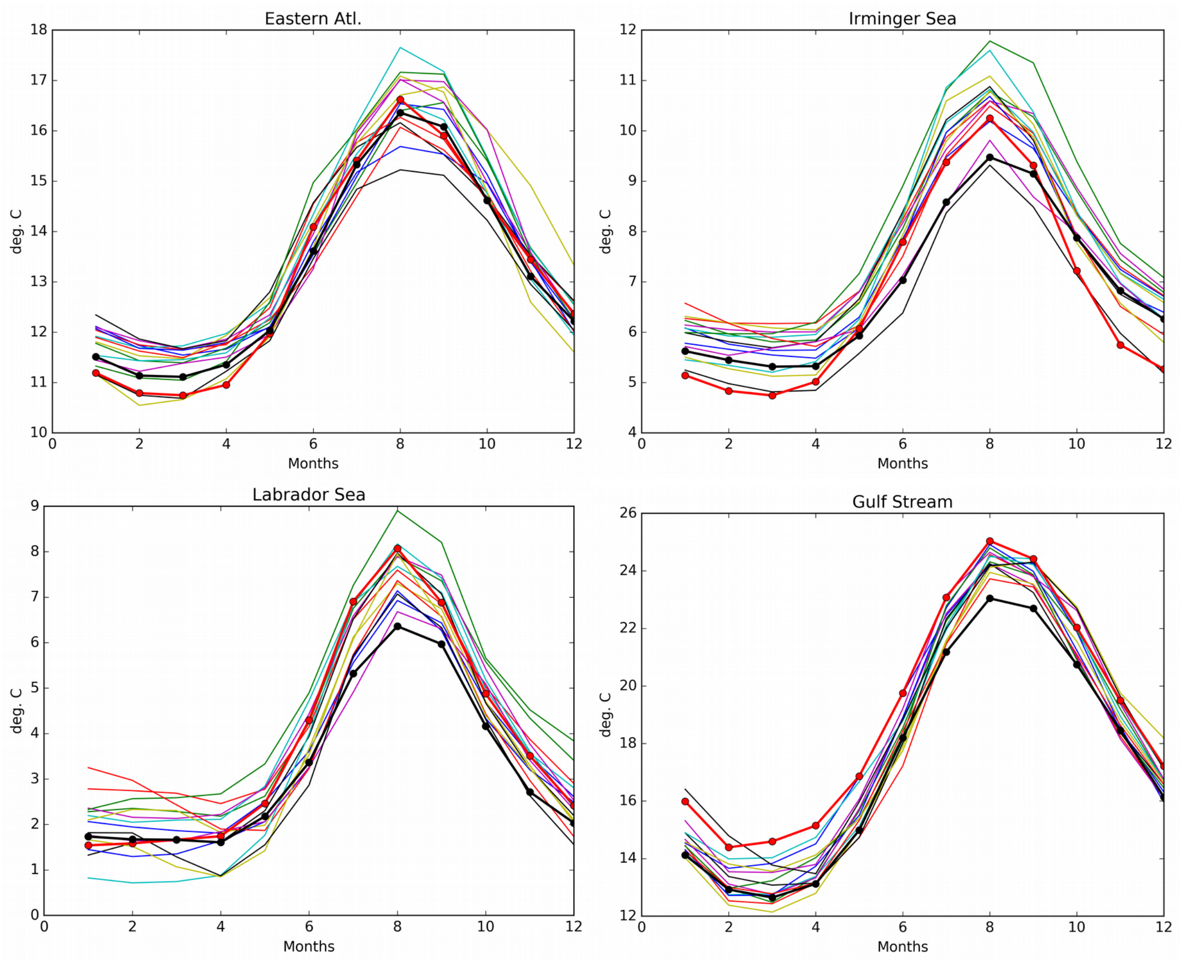
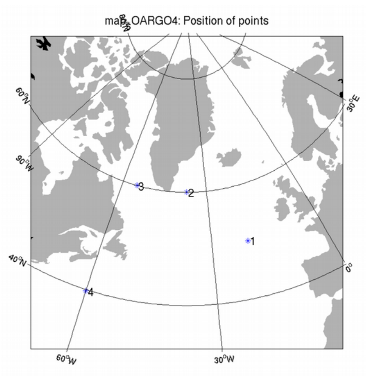


Figure 1.2: Seasonal cycle for near surface temperature at 4 points in the North Atlantic basin (see the map below), i.e. : a) Eastern Atlantic; b) Irminger Sea; c) Labrador Sea and d) Gulf Stream region. In heavy red the year 2016, in dashed black the WOA05 climatology, other curves show the years 2002-2015.



In the eastern North Atlantic, i.e. in the Irminger Sea and off the European coasts, the winter 2016 (as for winter 2015) appears to be one of the extreme cold winter over the 2002-2016 decade, (Fig. 1.2ab) where temperatures went well below the climatological mean (1° lower in the Irminger Sea). These conditions contrast with the general trend of warmers condition (than WOA05 climatology) observed over the 2002-2015 decade in winter and summer in the south-west part of the basin (Fig. 1.2d). One of the last decade warmest summer is observed in Labrador Sea (Fig. 1.2c).

Winter surface temperature and salinity determine the mixed layer properties (e.g. density, depth, ...). In order to compare all areas over the decade, we adopt a simple definition for the mixed layer depth, using the level at which density changes by more than 0.03 kg.m^{-3} with respect to the 10 meter depth. The criteria on density is more accurate because is sensitive to both temperature and salinity stratification. Nevertheless, it may slightly overestimate the mixed layer depth in region of temperature/salinity density compensation. The month of March is selected as the common period for maximum mixed layer depth. This is not perfectly true since the time of the deepest mixed layer may vary from year to year at a single location and does not occur at the same time over the whole basin (between February and March in North Atlantic).

In the North of the basin extending from the Labrador Sea to the Irminger Sea, in spite of the exceptional winter 2015, during late winter 2016 the area covered by a deep mixed layer (deeper than 1000 m) is the second most extended (Fig. 1.3). This deep mixed layer may reflect strong winter convection in both Labrador and Irminger basin. Unusual deep mixed layer is also observed in the eastern side of the basin off Scotland and Ireland coasts. In the South-East of the basin, the deep mixed layer extension stops around 48/50°N such that only moderate mixed layer depths are observed along the shelf in the Bay of Biscay contrary to the 2011, 2014 and 2015 winters.

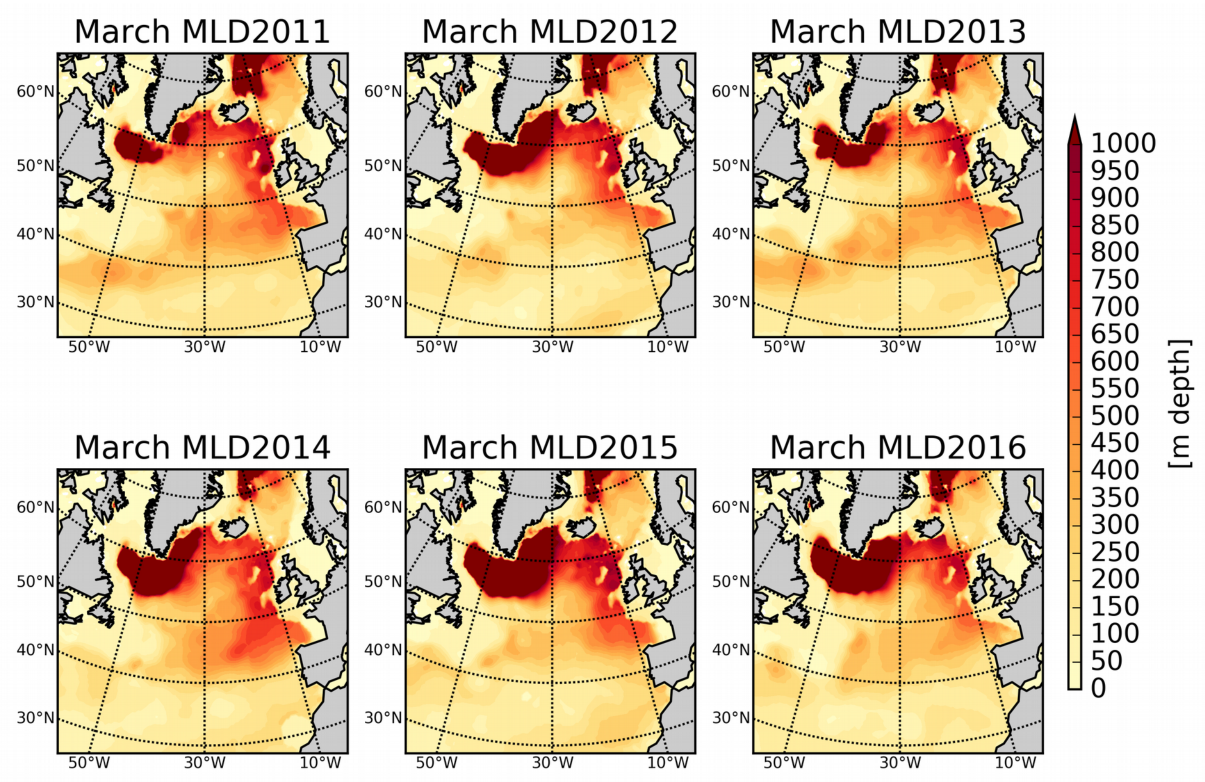


Figure 1.3: North Atlantic mixed layer depth in March from 2011 to 2016.

The most salient feature of the 2016 annual mean temperature anomaly (using WOA05 as reference climatology) is an intense cold anomaly, persistent and increasing since 2013) over the subpolar basin from the tip of Greenland to 40°N and the persistence and increase of a warm anomaly over the Greenland Sea and along the East Greenland coast (Fig. 1.4a).

In 2011, a salinity anomaly is observed in the western North Atlantic basin around 45°N, then the fresh near surface water anomaly translates toward the eastern North Atlantic entering the Irminger Sea in 2016 (Fig. 1.4b). In the Irminger Sea, fresher near surface water may explain the smaller than 2015 extend of deep mixed layer (Fig. 1.3), because of stratification effect of fresh water. Around the Greenland coast, strong fresh anomaly is also observed increasing since 2014. In Greenland Sea persistent warm/salty anomaly is observed since 2011. In contrast, in 2016 Labrador Sea is saltier than usual, likely favoring convection during winter.

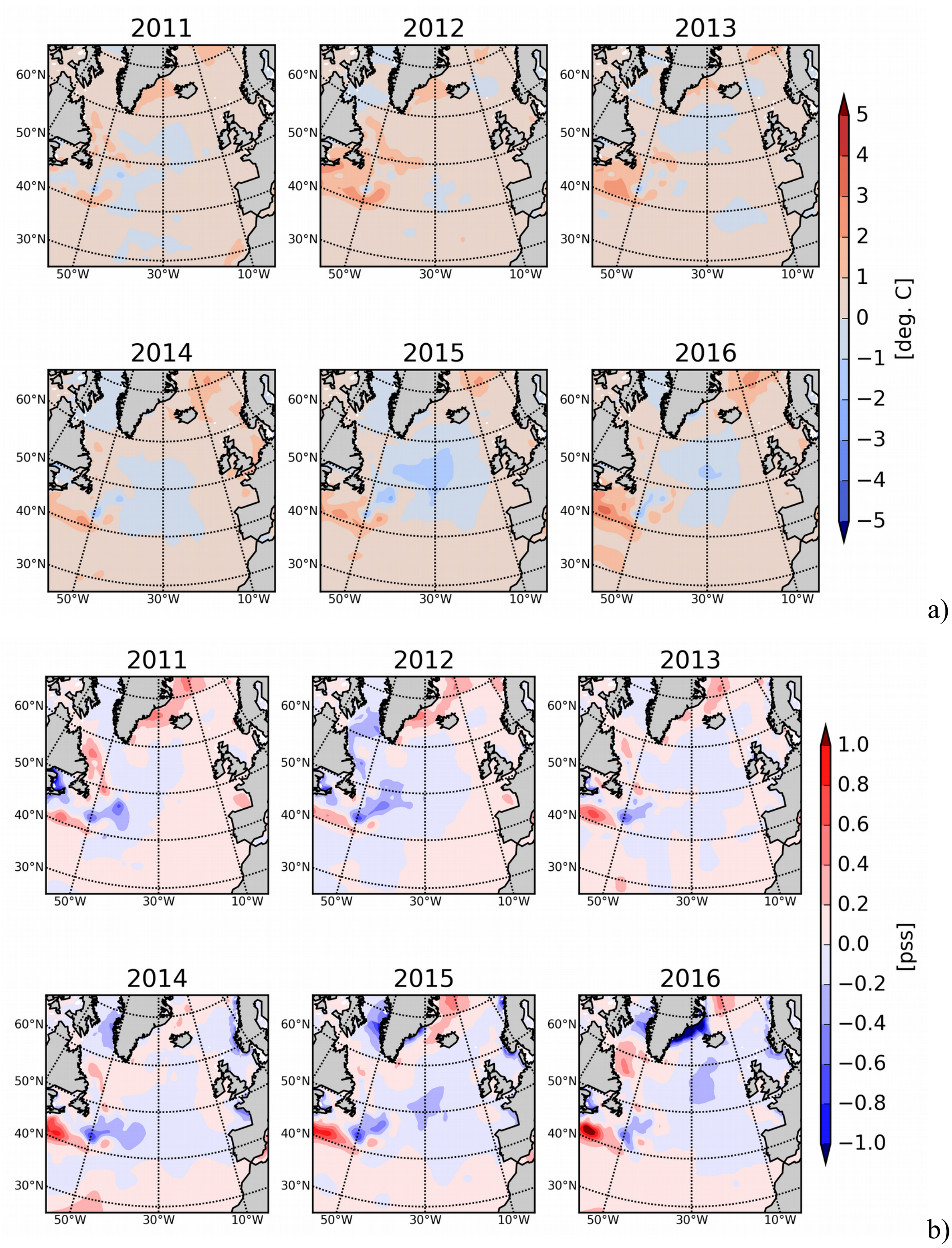
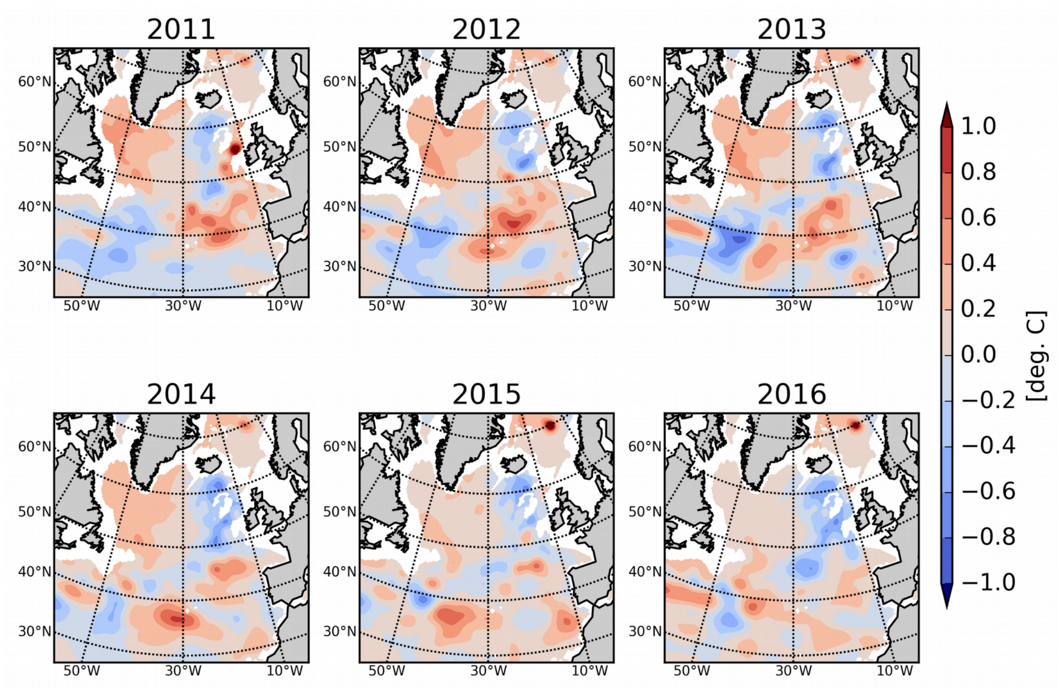
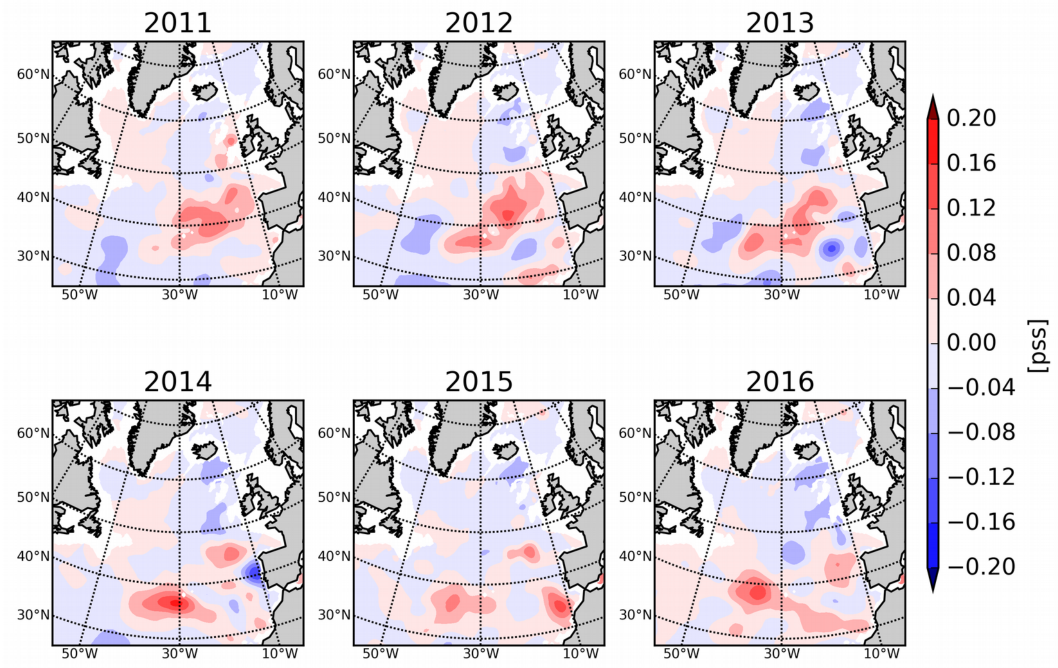


Figure 1.4: Annual average temperature (a) and salinity (b) anomalies at 10 m depth during 2011-2016



a)



b)

Figure 1.5: Annual average temperature (a) and salinity (b) anomalies at 1000 m depth during 2011-2016.

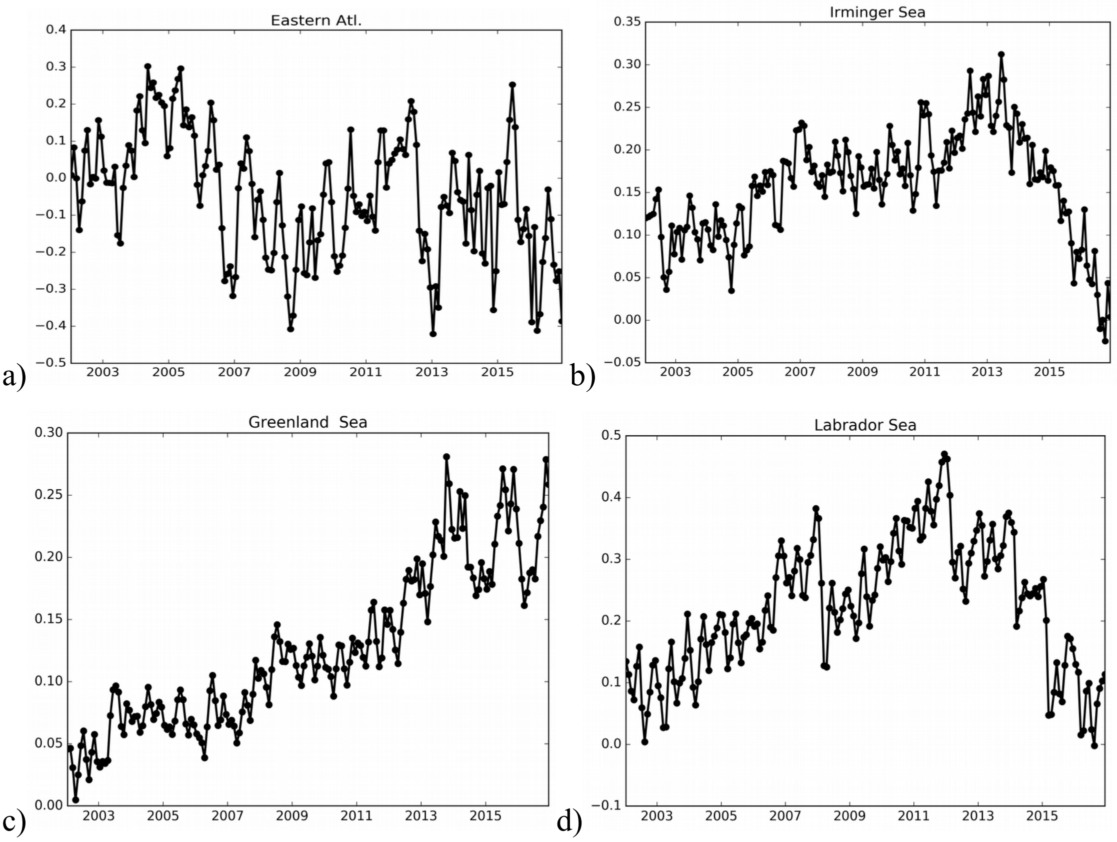


Figure 1.6: Time series of temperature anomalies (using WOA05 as reference) averaged over the 800-1200m layer over 2002-2016 period in a) Eastern Atlantic region; b) Irminger Sea; c) Greenland Sea and d) Labrador Sea.

1.3 Deep layers

At 1000 m (Fig. 1.5), the Labrador Sea and the Irminger Sea are warmer than normal, but the warming tendency observed since 2002 is interrupted since 2012 as seen in the time series (Fig. 1.6bd). This may likely reflect the return to deep winter convection in this both basin since 2012.

The Greenland sea warming reaches a maximum in 2014. Then, it remains stable during 2015-2016 (Fig. 1.6c).

The Mediterranean Outflow water is warmer and saltier south of 40°N and off Gibraltar straight. The salt increase seems to extend westward in the subtropical basin and northward off the Portuguese coasts (Fig. 1.5).A cold and fresh anomaly stands from the South of Iceland down to Rockall Trough, and is intensified in 2016 (Fig. 1.5). A warm and salty anomaly is observed south of the Gulf-Stream and Azores current (subtropical gyre; Fig. 1.5).

1.4 References

Gaillard, F., 2012. ISAS-Tool Version 6: Method and configuration. Rapport LPO-12-02, http://archimer.ifremer.fr/doc/00115/22583/

Gaillard, F., T. Reynaud, V. Thierry, N. Kolodziejczyk and K. von Schukmann , 2016 : In Situ–Based Reanalysis of the Global Ocean Temperature and Salinity with ISAS: Variability of the Heat Content and Steric Height, *J. Clim.,* 29, 1305-1323.

2 Surface sampling along AX1 and AX2 (North Atlantic subpolar gyre)

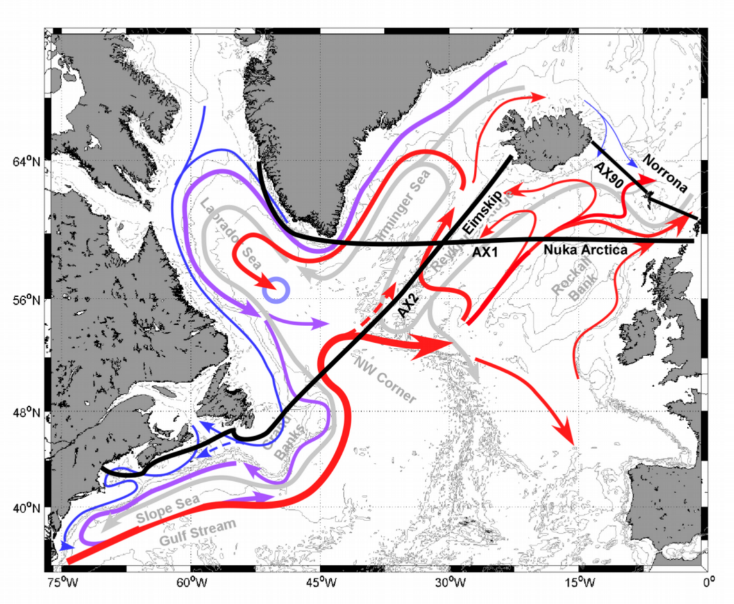


Figure 2.1 : AX1 and AX2 ship of opportunity lines equipped with Thermosalinograph and XBT launcher. Surface (red arrows) and deep (bleu and purple arrrow) main currents are indicated.

The two shipping routes along which surface sampling was continued were (Fig. 2.1) lines AX2 (since mid-1993; in 2015/mid-2016, MV Skogafoss) between southern Newfoundland and Reykjavik; and AX1 (since mid-1997; mostly from MV Nuka Arctica) between Denmark and west Greenland. Both ships were equipped with thermosalinograph and XBT launchers, and are part of a concerted multi-disciplinary effort, including the measurement of the current with a ship-ADCP on Nuka Arctica (Univ. Bergen) and pCO2 measurements on Skogafoss (NOAA/AOML) and Nuka Arctica (Univ. Bergen). Because of large sea ice extent in late winter and early spring, as well as numerous winter storms in the winter and early spring 2015 or 2016, the nominal AX2 route was not often followed during these seasons. Regular sampling on AX2 has stopped in mid-2016, and the update in 2016 will not be presented. For AX1 (Nuka Arctica), there were different issues with the instrumentation from August to November 2016, and the Hovmüller is only presented until early August 2016 for the part of the section between the shelf break off Cape Farewell and the approaches of Scotland is presented.

We will now comment the AX1 zonal section (Nunka Arctica. Most of the data originate along 59°N, the most sampled latitude band) (Fig. 2.2), but to fill gaps at times, we have also combined with data a little further south (near 58°N) or north (near 60°N). These three latitude bands indeed present rather coherent variability except at the eastern end, when combining data based on bathymetry (that is in a north-east to south-west direction, parallel to the Reykjanes Ridge). First, monthly anomalies are computed with respect to an average seasonal cycle, then a 1-2-1 running mean filter is applied over successive monthly anomalies. Isolated data gaps over more tan 3 months have also been interpolated linearly (mostly in 1993-1997). On this section, salinity anomalies can be rather different east of the Reykjanes Ridge in the Iceland Basin (15-30°W) than west of it. For example the low SSS anomaly in 1994-1996 was more pronounced in the Irminger Basin than to its east, whereas the low salinity anomaly in 2015-2016 was more pronounced in the Iceland

Basin between 15°W and 30°W. Also, it seems that anomalies close to the Scotian slope/eastern Faroe Channel end of the section follow by a little over 1 year the anomalies in the central Iceland Basin (although correlation is not very high). Also, it seems that anomalies are a little weaker near 10°W than to its east or west. The 2015-2016 negative SSS anomalies in the Iceland Basin are the largest anomalies recorded so far in this surface sampling program. Comparison with data compilation since 1896 indicate that they rival with the largest negative anomalies recorded in the late 1970s.

In comparison, SST anomalies that were also very large and negative in 2015 have returned to near normal (slightly negative) in early/mid 2016. The largest negative SST anomalies remain those found in the west (Irminger Basin) in 1993-1994. On a seasonal to interannual basis, SST anomalies tend to be much more zonally homogeneous than SST anomalies, and don't present much coherence with SSS anomalies (see also Reverdin, 2012). On multi-year to decadal time scales, there is more coherence between the SST and SSS anomalies, with a tendency for maximum SSS anomalies to lag the SST anomalies.

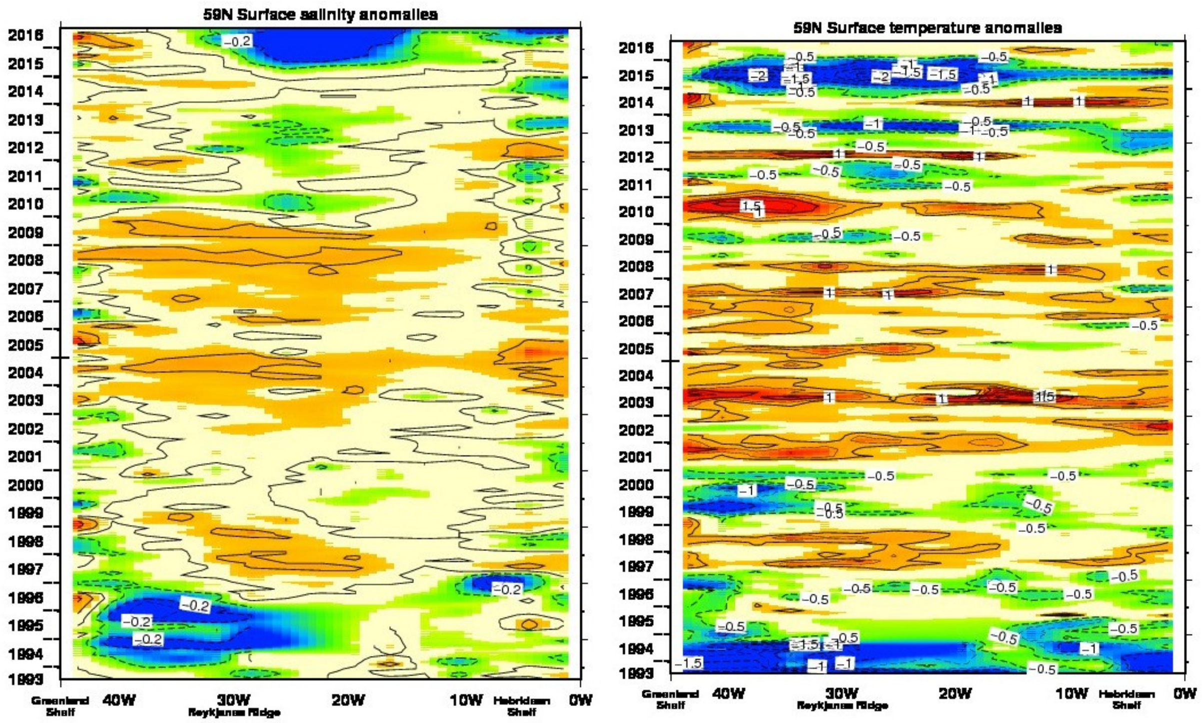


Figure 2.2: Monthly salinity (left panel) and temperature (right panel) anomalies from the Nuka Arctica along 59°N from the shelf break south-east of Cape Farewell to the north-west of Scotland between 1993 and August 2016.

3 South western Channel: Astan and Estacade time series

3.1 The year 2016 vs Climatology

Here, we present measurements collected twice a month at two stations located on the north coast of Brittany in France. The Estacade site is located at the end of a pier (3°58'58°W and 48°43'56°N) (Figure 3.1) in the city of Roscoff (France) where the bottom depth varies from 3 to 12 m depending on the tides. Measurements began in 1985 and are collected at 1 m depth. The Astan site (3°56'15°W; 48°46'40°N) is located 3.5 kilometers offshore from the Estacade site (Figure 3.1) and measurements began in 2000. Seawater biogeochemical properties at this site are typical of the Western Channel waters. Bottom depth is about 60 m depth and the water column is well mixed for most of the year. More details can be found at http://somlit.epoc.u-bordeaux1.fr/fr/ and http://www.sb-roscoff.fr/en/coastal-observatory/marine-system-hydrological-parameters-offshore-roscoff. The Western Channel is connected to the eastern boundary current and linked to the North Atlantic drift. The climatic conditions are impacted by the westerlies blowing over the Atlantic basin which transport heat and moisture towards the Western Europe. These conditions explain the typical weather conditions observed in the Roscoff area: Winter precipitations generate intensive weathering of the soils loaded with important nutrients amounts from intensive agriculture. River discharges contribute to influence the salinity cycles and to feed the stocks of nutrients in coastal waters. Salinity of this coastal waters remained close to 35.5, a typical value of the waters adjacent to the North Atlantic Ocean. This system can be considered as a coastal system.

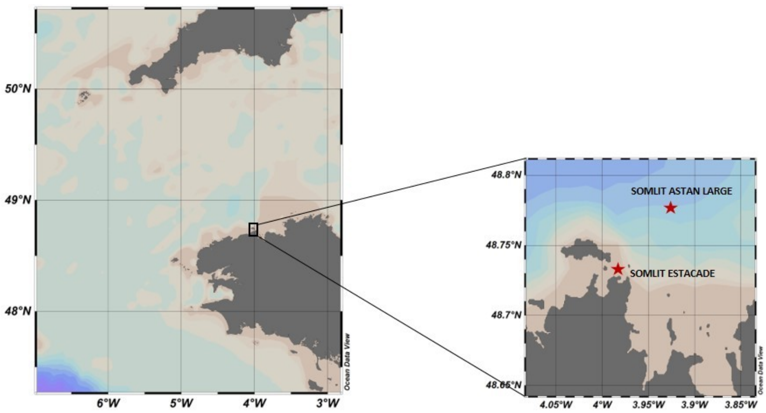


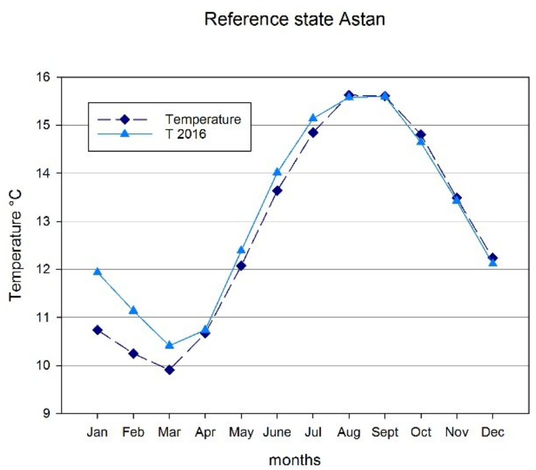
Figure 3.1: Localisation of Estacade and Astan large sites.

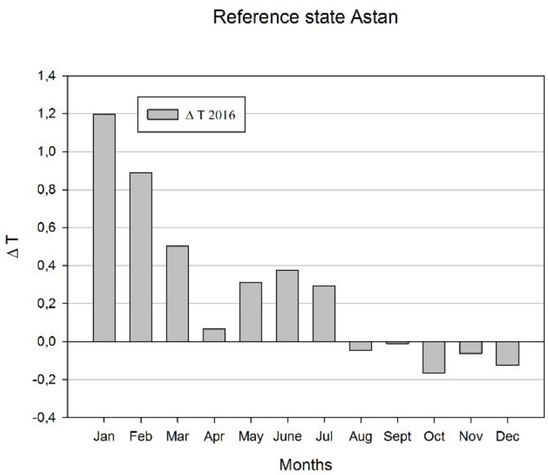
Figures 3.2 and 3.3 display the 2016 cycles of temperature, salinity and nitrate in relation to the mean annual cycle at the Astan and Estacade stations. The temperature cycles show similar dynamics between the 2 studied stations: At Astan station, for the year 2016, temperatures are higher than the climatology values for the winter, spring, summer (from 1.20°C to 0.07°C) and lower from august to december (from -0.17 °C and -0.01°C). At Estacade station, temperatures are higher than climatology values for the winter and at the beginning of spring (from +1.38°C to

+0.20°C) but become lower in summer and the beginning of fall with a maximum deviation equal to -0.44°C in october. In the two stations, except in winter, we can observe that the temperature values are close to the climatology The annual average and global values are given in tables 3.1 and 3.2.

The mean Salinity cycles at the two stations are characterized by an important seasonality with minimum values in spring and maximum in fall. The salinity seasonal cycle is starts one month earlier at the Astan station compared to the Estacade station. In 2016, the salinity cycle is atypical in comparison with the global average cycle. Indeed, there are no low values in winter and spring except in February and march at Estacade station and we can observe a constant increase all along the year (we observed a maximum deviation in salinity equal to +0.166 at Estacade and +0.122 at Astan, in December). Salinity values are just lower than the average for summer. Minimum salinity values weren't observed in 2016, especially at Astan station, because of a dry winter with low water precipitations reducing the river inputs in the Western Channel. We 've observed the same kind of cycle with no spring salinity low values in 2005, 2007, 2012 and 2015. At Estacade, we can observe a minimum salinity value. This event is just located in the shore station and didn't affect the deep sea station. We can link this low salinity value at Estacade with the very high nitrate (11.4 μM) value observed in March. This value corroborates an episodic discharge of fresh water from soil weathering.

During 2016, at Astan station, nitrate concentrations were significantly lower than the averaged values excepted from August to september where they are above the mean values. At the Estacade station, we observed a different evolution than in the Astan station. Nitrate concentrations were almost totally exhausted at Estacade contrary to Astan where the nutrients stock is spread over the well-mixed water column and not totally consumed by the phytoplankton development. The low levels of nitrate concentrations are linked to the high levels of salinity for 2016, especially at Astan station in winter and spring as in 2015. The weaker river inputs contributed less to the nutrients supplies.





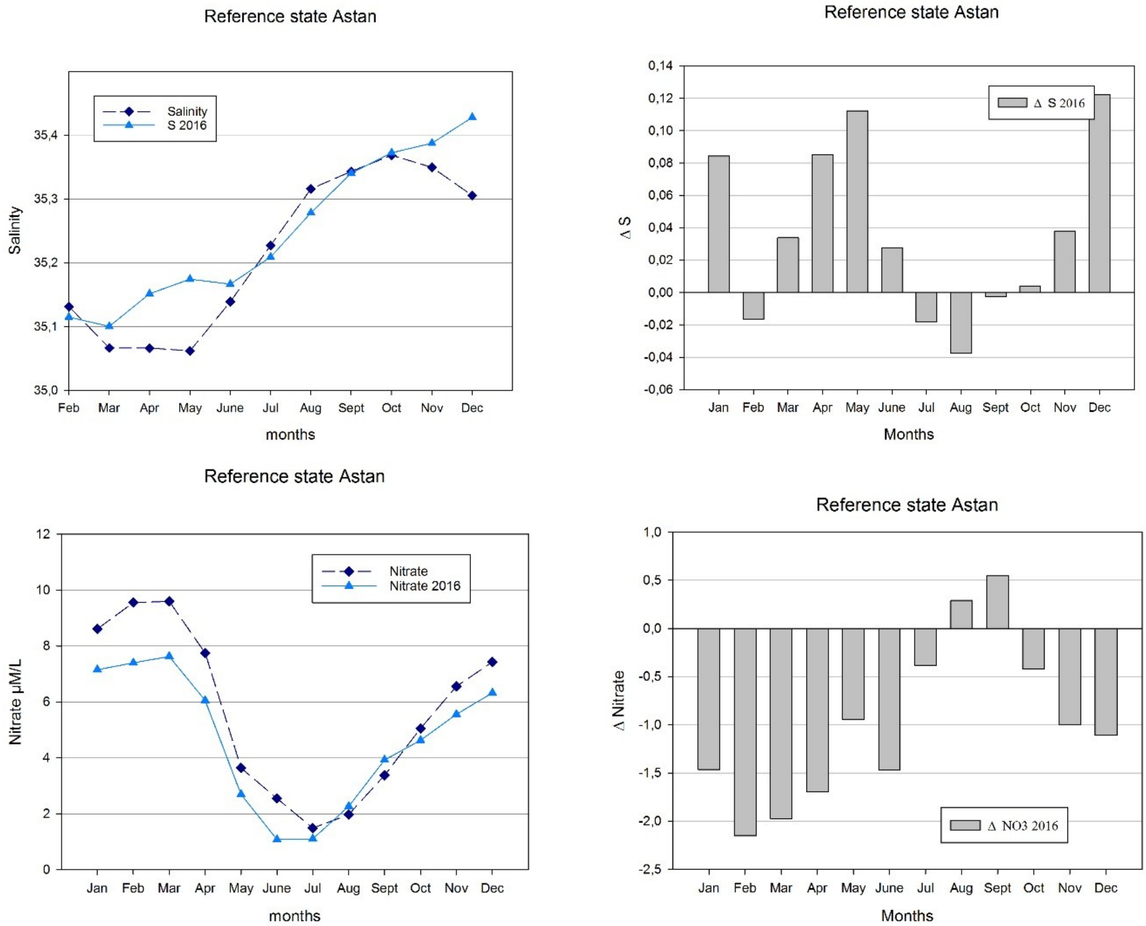
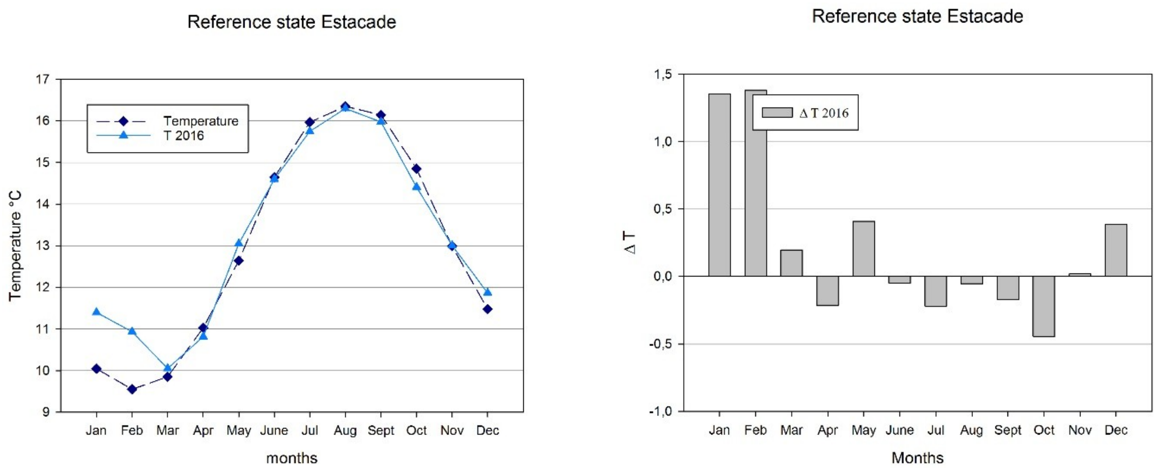


Figure 3.2: comparison between time series of temperature (upper), salinity (middle) and nitrate (lower) at Astan site in 2016 with the climatological cycle (average over the 2000-2016 period). (Left panels) Dark blue line represents the mean annual cycle and the light blue line represent 2016 data. (Right panels) 2016 deviation to mean values.



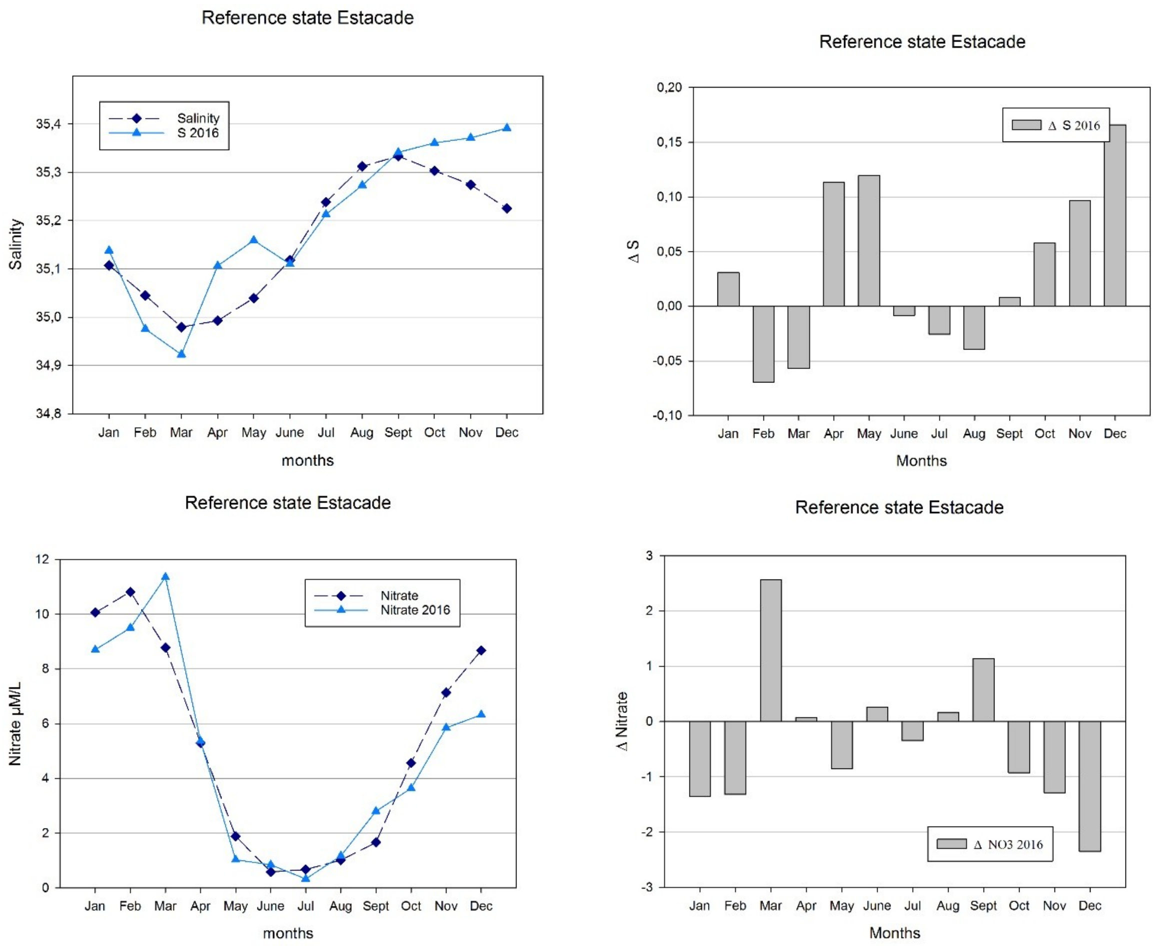


Figure 3.1: comparison between time series of temperature (upper), salinity (middle) and nitrate (lower) at Estacade site in 2016 with the climatological cycle (average over the 2000-2016 period). (Left panels) Dark blue line represents the mean annual cycle and the light blue line represent 2016 data. (Right panels) 2016 deviation to mean values.

Estacade	Temperature (°C)	Salinity	Nitrate (µmole/l)
Global average	12.94	35.172	5.1
2016	12.95	35.190	4.9

Table 3.1: Global mean for the period 1985-2015 and 2015 values at Estacade station.

Astan	Temperature (°C)	Salinity	Nitrate (µmole/l)
Global average	12.84	35.213	5.5
2016	13.00	35.246	4.7

Table 3.2: Global mean for the period 2000-2016 and 2016 values at Astan station.

3.2 Water column properties

As usually observed in this area, the Western Channel waters were well-mixed over the entire water column during the whole year with no significant gradient observed between the surface and the bottom (Figure 3.4). The low vertical temperature gradient observed episodically in late summer (late august- early September) during low wind-neap tides period was not observed in 2016. As for temperature Western Channel waters were generally well-mixed over the entire water column since no salinity differences between surface and bottom waters were observed even during the late summer surface heating.

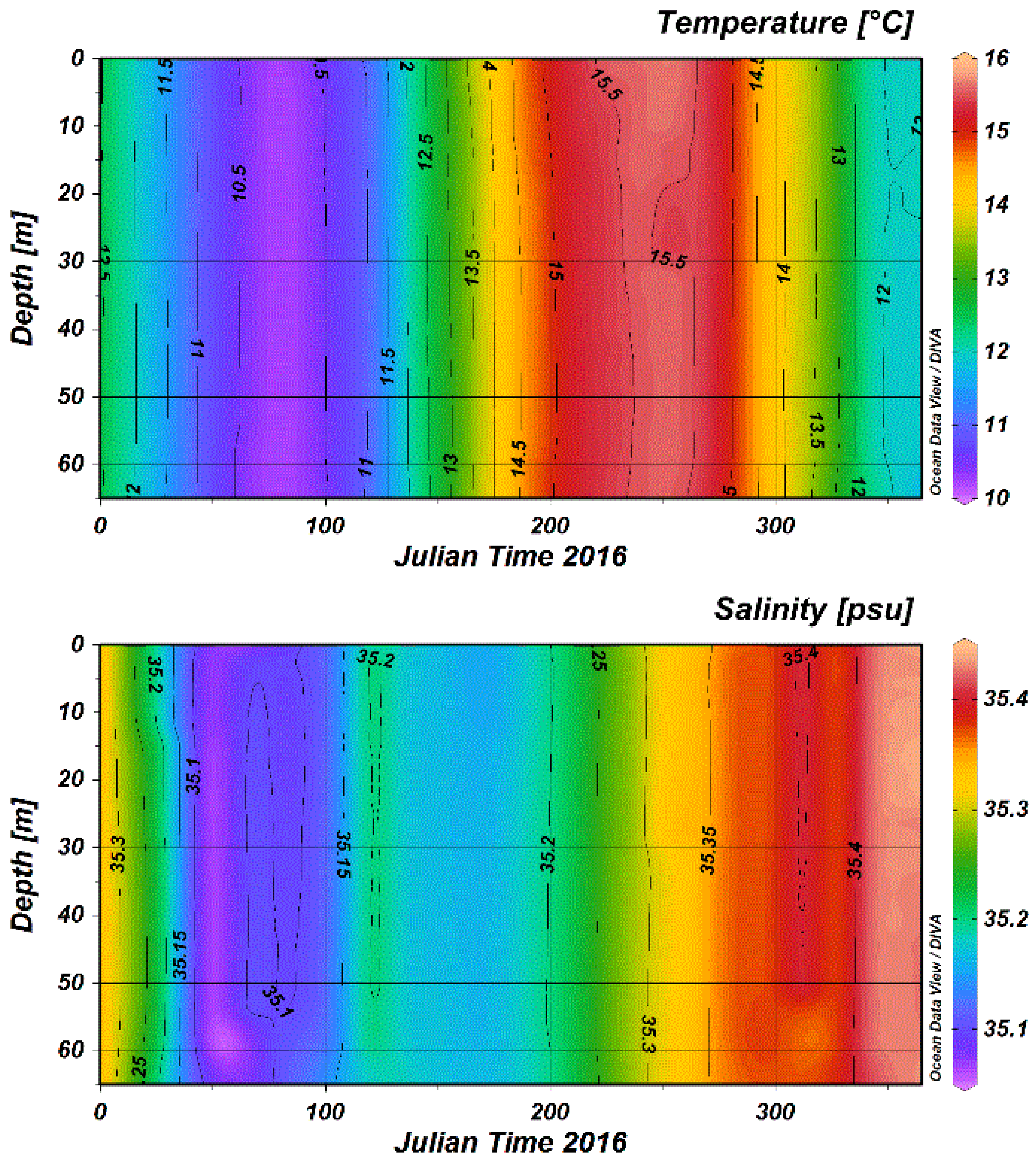


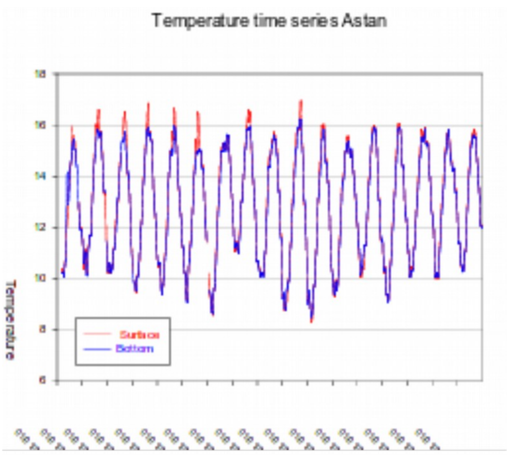
Figure 3.4: vertical distributions of temperature (top) and salinity (bottom) at Astan site during 2016 (bimonthly CTD profiles). Well-mixed waters were observed during the whole year due to an enhanced vertical mixing by tidal currents.

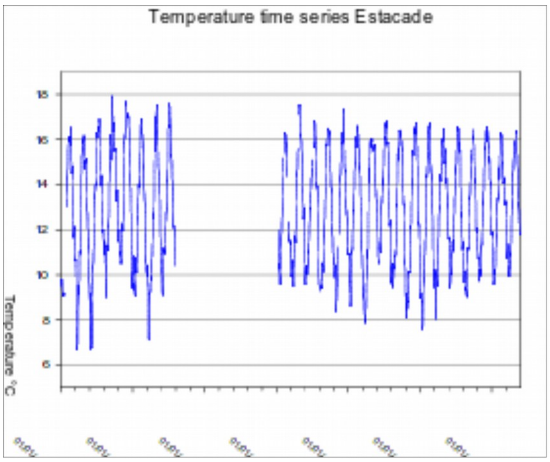
3.3 Long-term trends

Figure 3.5 shows the time series of temperature, salinity and nitrate at Astan over the period 2000-2016 and at Estacade over the period 1985-2016 with a large gap from 1992 through 2000 for temperature, salinity and nitrate measurements. At the Astan and Estacade sites, winter 2016 minimum temperature were significantly higher than the global mean calculated over the time series.

In 2016, salinity cycle is characterized, as mentioned above, by higher values than those usually observed in this area, especially in winter. Annual salinity Means at Astan and Estacade are slightly higher than the global average values. The differences are more important during winter explaining the low values of nitrate in the first part of the year, except for March at Estacade. Usually, nitrate concentrations, as salinity and temperature, present a large interannual variability particularly in the winter maximum values which is linked to the interannual variability in the oceanic influence in the Channel waters. Maximum nitrate winter concentration (7.6 µM/l at Astan) was significantly lower than average winter values due to the reduced influence of the low salinity waters in the Western Channel. At Estacade, the hydrological cycle shows a different evolution, particularly in winter with a 2016 nitrate maximum above the average values (11.4 µM in 2016 vs 10.8 µM for the maximum average value).

The winter (January to March) mean nitrate concentrations was the third minimum concentrations observed between January and April since 2000 at Astan. Nitrate winter and early spring stock for the spring phytoplankton development was reduced in 2016 when compared to the previous years but not in the lowest values measured since 2000 at the two stations.





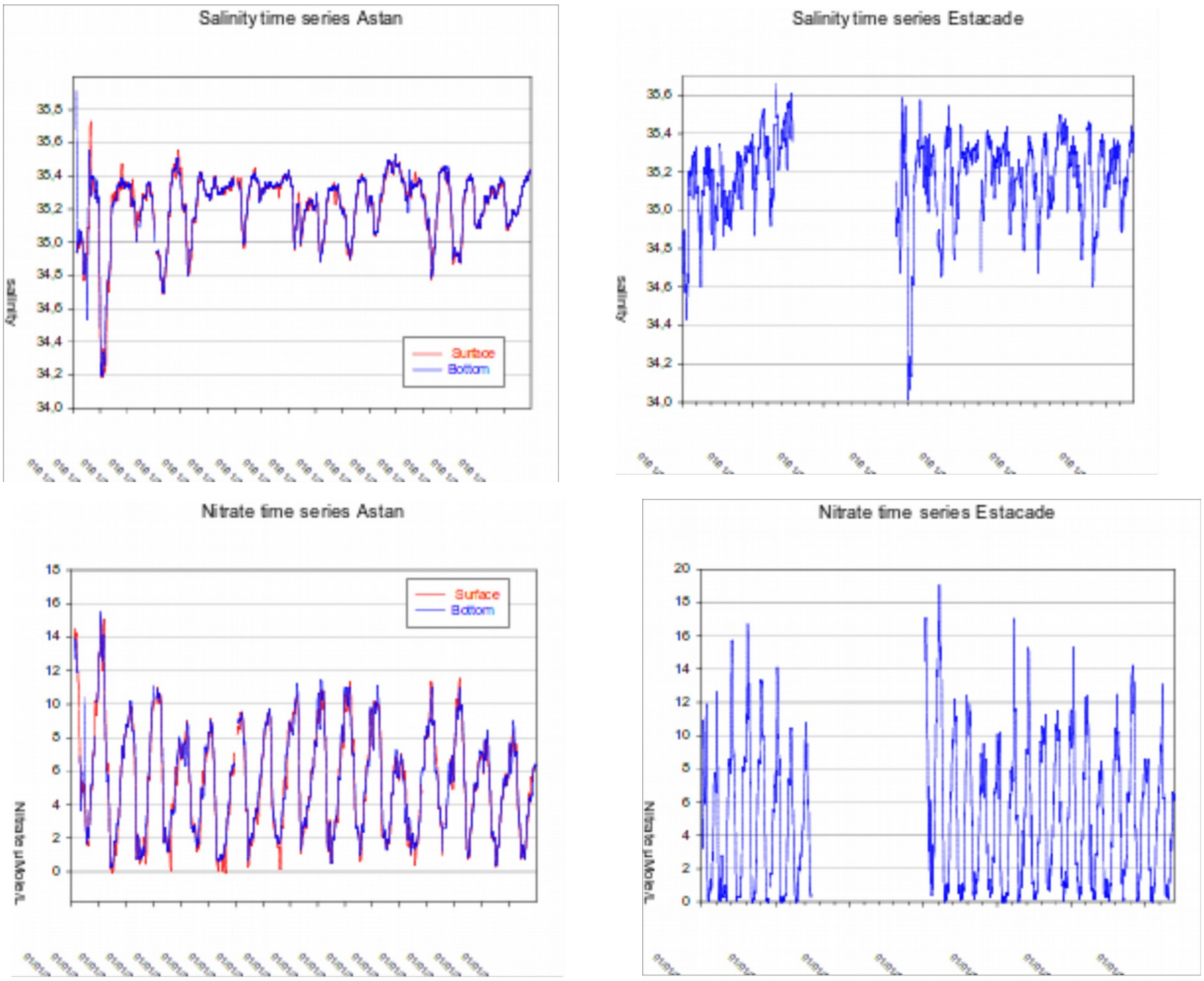


Figure 3.5: Interannual variability of the temperature, salinity and nitrate at Astan site over 2000-2016 (left panels) and at Estacade site over 1985-2016 (right panels).

We calculated the trends over the time series for the 2 periods mentioned above: At Astan station, we observed a decrease of SST (-0.002°C/year), an increase of the SSS (+0.007 pss/year) associated to a decrease of the nutrient concentrations (-0.06 µmole/year).

At Estacade station, on the same period (from 2000 to 2016), we observed an increase of SST (+0.002°C/year), an increase of the SSS (+0.007 pss/year) and a decrease of the nutrient concentrations (-0.07 µmole/year). There is a slight difference between the two sites in the temperature trend with a decrease in the open sea station (Astan) and an increase at the coastal point (Estacade).

Annex 9:

Regional report –
Hydrographic conditions in the Barents Sea in 2016

Hydrographic conditions in the Barents Sea in 2016

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The Barents Sea is a shelf sea of the Arctic Ocean. Being a transition area between the North Atlantic and the Arctic Basin, it plays a key role in water exchange between them. Atlantic waters enter the Arctic Basin through the Barents Sea and the Fram Strait (Fig. 1). Variations in volume flux, temperature and salinity of Atlantic waters affect hydrographic conditions in both the Barents Sea and the Arctic Ocean and are related to large-scale atmospheric pressure systems.

The analysis of hydrographic conditions in the Barents Sea is based on the available observations along standard sections and the data from fish stock assessment surveys. The total number of hydrographic stations made by PINRO in 2016 was 525 including 71 stations at the standard sections.

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

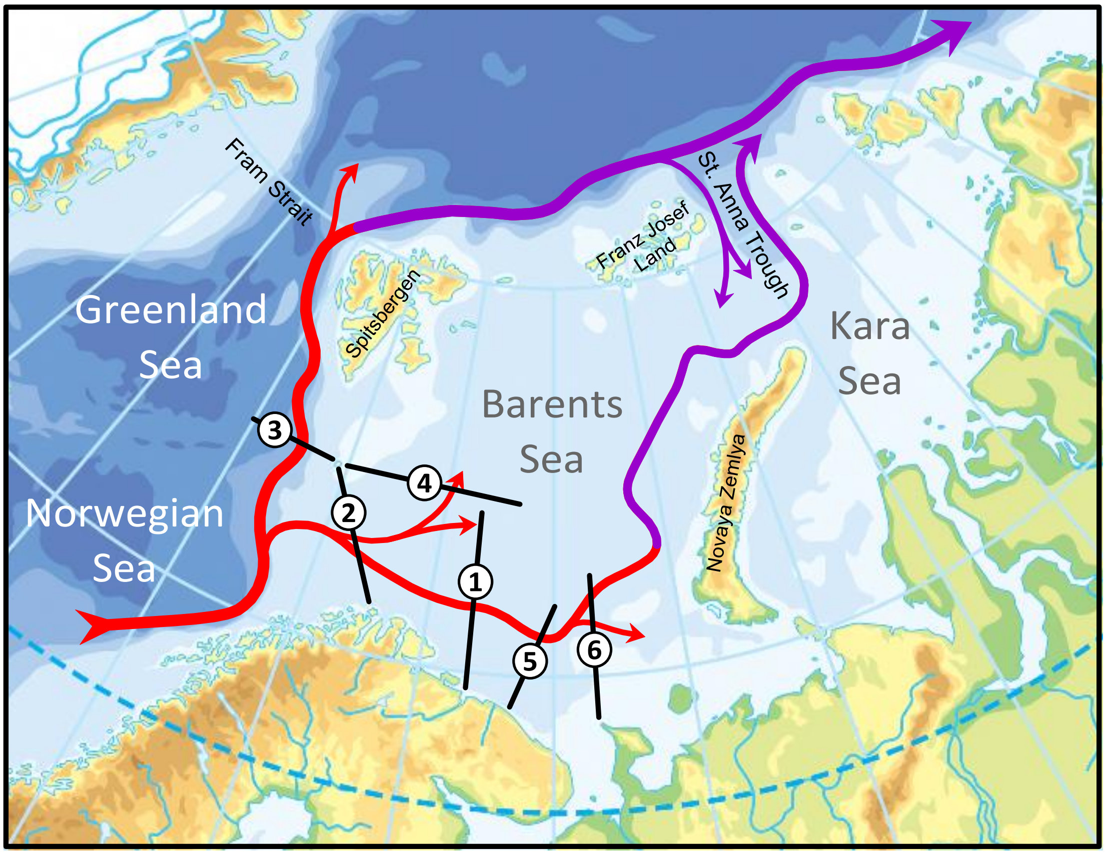

Figure 1. *The main paths of Atlantic waters and the main Russian standard sections in the Barents Sea: Kola (1), North Cape – Bear Island (2), Bear Island – West (3), Bear Island – East (4), Kharlov (5), Kanin (6).*

The observations along these hydrographic sections have been made since the first half of the last century (the Kola Section – since 1900, the North Cape – Bear Island Section – since 1929, the Bear Island – West Section – since 1935, the Bear Island – East Section and the Kanin Section – since 1936). The Kola Section has been occupied more than 1 200 times by now.

Published time series from the main standard sections (Bochkov, 1982; Tereshchenko, 1997, 1999; Karsakov, 2009) were also used in the analysis. Anomalies were calculated using the long-term means for the periods 1951–2010 (Kola Section), 1954–1990 (Kanin Section), 1951–1990 (other standard sections).

Meteorological conditions

In 2016, the winter (December–March) NAO index dropped to 1.01 after the third highest (since 1899) positive value of 1.87 observed in 2015. Over the Barents Sea, easterly winds prevailed in the first half of the year and southwesterly winds – in the second half. In 2016, the number of days with winds more than 15 m/s was larger than usual most of the year. It was less or close to normal only in January (western and central parts of the sea) and April (eastern part). In summer 2016, the storm activity in the Barents Sea was record high since 1981.

Air temperature (http://nomad2.ncep.noaa.gov) averaged over the western (70–76°N, 15–35°E) and eastern (69–77°N, 35–55°E) Barents Sea showed that positive air temperature anomalies prevailed over the sea during 2016 (Fig. 2). Higher positive anomalies (up to 7.5°C in February) were found in the east. The positive anomalies in the western part of the sea in May and in the eastern part in February, July and September were the highest since 1948. As a result, the 2016 annual mean air temperature anomalies in the western and eastern Barents Sea were also the highest since 1948.

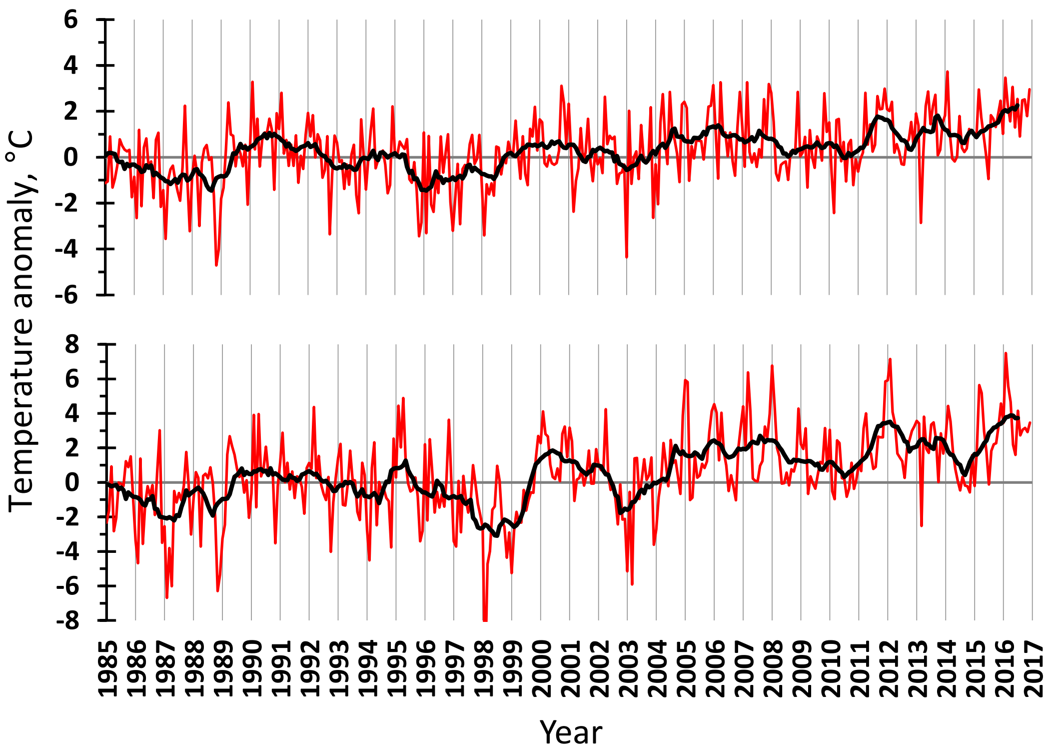

Figure 2. *Air temperature anomalies in the western (upper) and eastern (lower) Barents Sea in 1985–2016. The red line shows monthly values, the black one – 11-month running means.*

Ice conditions

At the end of 2015 and beginning of 2016, meteorological conditions over the Barents Sea resulted in decreasing the sea ice coverage. Ice formation was going very slowly at the beginning of the year; the ice coverage (expressed as a percentage of the sea area) was 17–25% lower than normal (Fig. 3). In March–April, the seasonal maximum of ice coverage, there was almost no increase in the ice coverage compared to that early in the year: in January and February, the ice coverage was 32 and 30% respectively, whereas, in March and April, it was 32 and 31% that was 26–30% lower than normal. From March to July, the ice coverage of the Barents Sea was the lowest since 1951. From July to September, there was no ice in the Barents Sea. In July, it happened for the first time since 1951. In autumn, freezing started in the northern Barents Sea in October, when ice appeared near the Franz Josef Land Archipelago; the ice coverage was 2% that was 13% less than normal. In November and December, the ice coverage was 25–26% less than average and it was record low since 1951. Overall, the 2016 annual mean ice coverage of the Barents Sea was the lowest since 1951 being 22% lower than normal and 7% lower than in 2015.

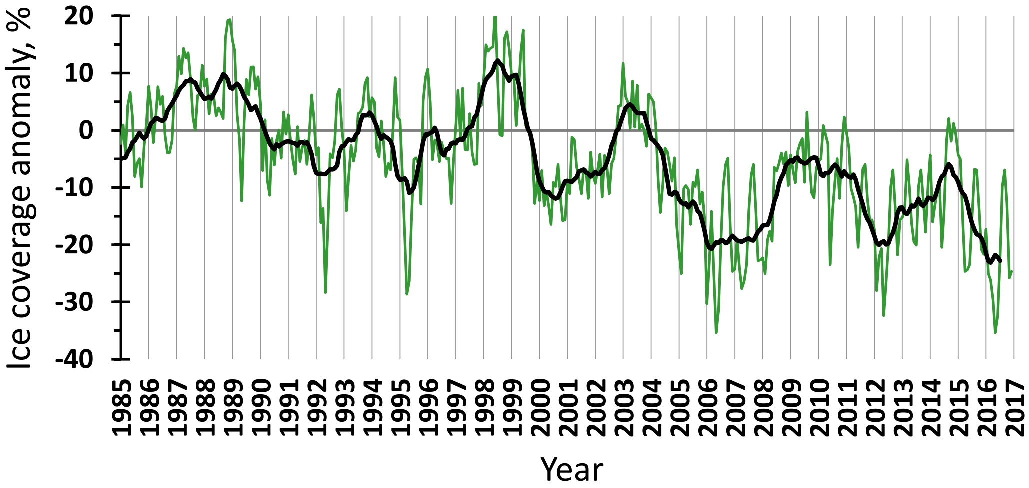

Figure 3. *Ice coverage anomalies in the Barents Sea in 1985–2016. The green line shows monthly values, the black one – 11-month running means (Anon., 2017).*

Hydrographic conditions (standard sections)

In 2016, the Kola Section was only occupied 5 times that was the bare minimum for the last 70 years and made it impossible to calculate annual mean temperatures and salinities in the section. According to the available observations along this section, from January to May, coastal and Atlantic waters in the 0–200 m layer had large positive temperature anomalies exceeding 1°C (Fig. 4). The temperature anomalies in the coastal waters (March–May, November), the Murman Current (January, March, April) and the Central branch of the North Cape Current (January) were the highest since 1951. As a result, January–May averaged temperature was the highest in the coastal waters and as large as the 2012 record-high value in the Atlantic waters of the central part of the section. Compared to 2015, the coastal and Atlantic waters were warmer (by up to 0.8°C) during all the observation period in 2016.

In 2016, the salinity of the coastal and Atlantic waters (the Murman Current) in the Kola Section was lower than normal and compared to 2015 (see Fig. 4). The coastal waters were much fresher than normal with negative salinity anomalies achieving –0.3 in the first half of the year. The salinity of the Atlantic waters in the outer part of the section (the Central branch of the North Cape Current) was close to both the average and that in the previous year.

Besides the Kola Section, some other sections were occupied in the Barents Sea in 2016.

The North Cape – Bear Island Section was sampled in May. The temperature in the North Cape Current (0–200 m) was 1.4°C higher than normal.

There were no observations along the Bear Island – West Section (along 74°30'N) in 2016.

The Bear Island – East Section (along 74°30'N) was sampled in May. The temperature in the 0–200 m layer in the Northern branch of the North Cape Current (74°30'N, 26°50'–31°20'E) was 1.7°C higher than normal.

The Kharlov Section was also occupied in May. The temperature in the 0–200 m layer in the Murman Current was 2.1°C higher than normal.

The Kanin Section (along 43°15'E) located in the eastern Barents Sea was sampled in February and September. Positive temperature anomalies in the 0–200 m layer in the Novaya Zemlya Current (71°00'–71°40'N, 43°15'E) increased from 1.5°C in February to 2.2°C in September.

Overall, the temperature of the main currents in the Barents Sea in 2016 was higher than normal and typical of anomalously warm years.

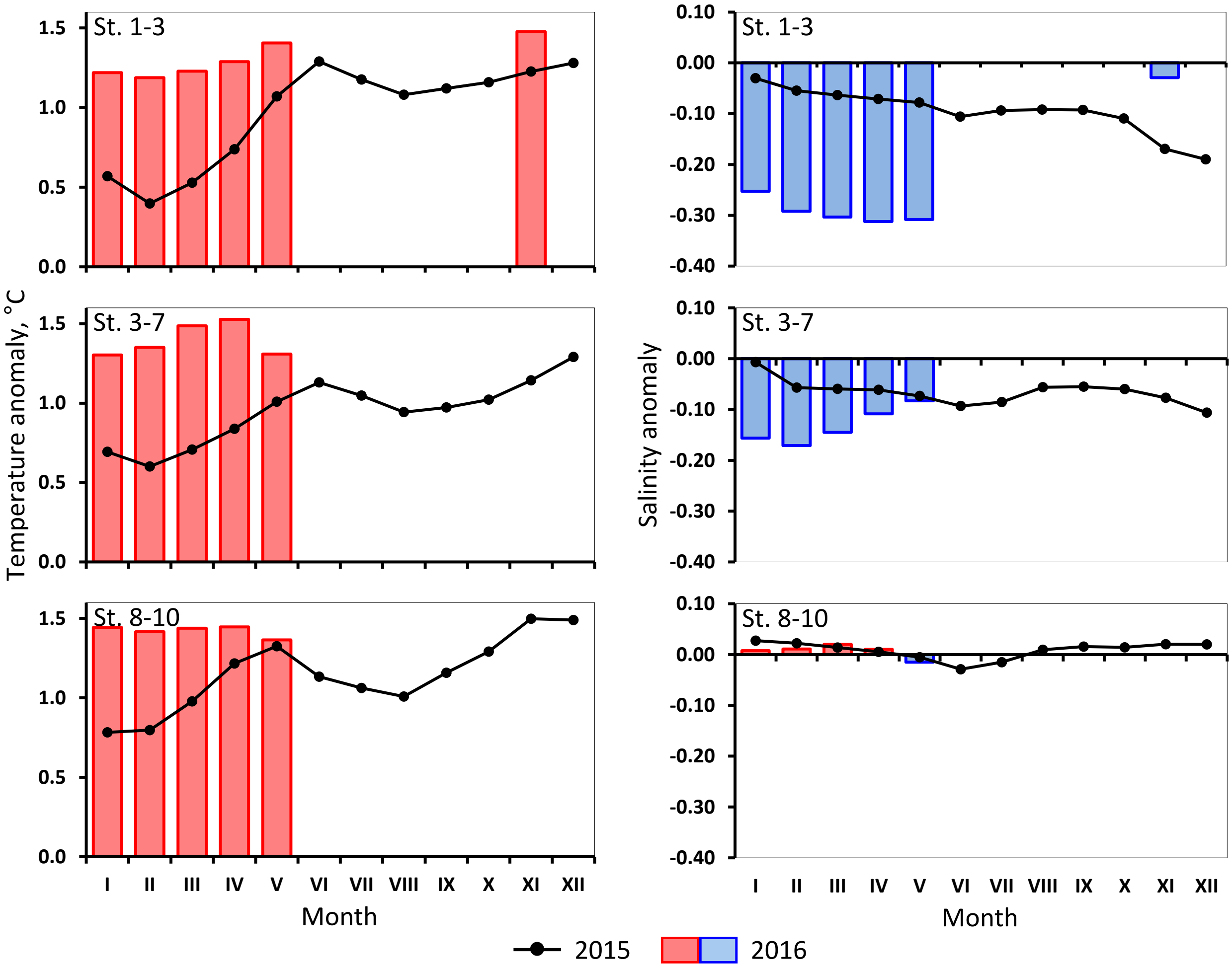

Figure 4. *Monthly mean temperature (left) and salinity (right) anomalies in the 0–200 m layer in the Kola Section in 2015 and 2016. St. 1–3 – Coastal waters, St. 3–7 – Murman Current, St. 8–10 – Central branch of the North Cape Current (Anon., 2017).*

Hydrographic conditions (surface, 100 m and bottom)

Sea surface temperature (SST) (http://iridl.ldeo.columbia.edu) averaged over the southwestern (71–74°N, 20–40°E) and southeastern (69–73°N, 42–55°E) Barents Sea showed that positive SST anomalies prevailed in both areas during 2016 (Fig. 5). The positive anomalies in the east were much higher than in the west (by up to 3.7–4.0°C in July–August). The SST anomalies in the southwestern part of the sea in October–December, as well as in the southeastern part in

February–May and July–December were the highest since 1982. As a result, the 2016 annual mean SST anomalies in the southwestern and southeastern parts of the Barents Sea were also the highest since 1982.

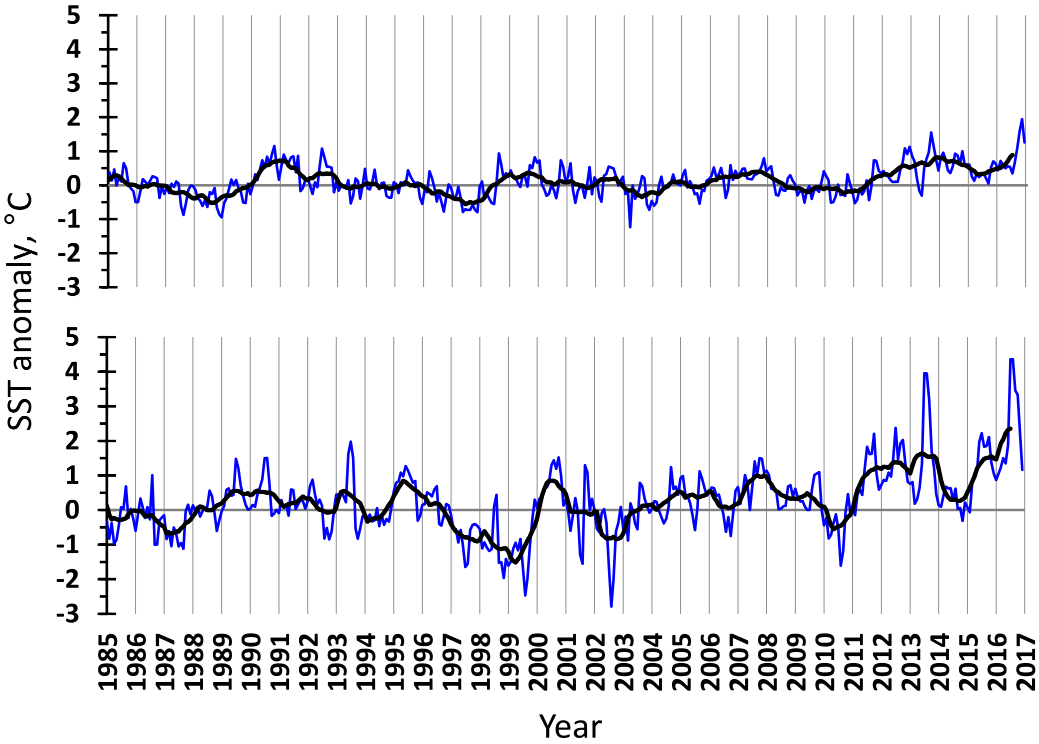

Figure 5. *Sea surface temperature anomalies in the western (upper) and eastern (lower) Barents Sea in 1985–2016. The blue line shows monthly values, the black one – 11-month running means.*

In August–September 2016, the joint Norwegian-Russian ecosystem survey was carried out in the Barents Sea. The surface temperature was on average 1.8°C higher than the long-term means (1931–2010) all over the Barents Sea (Fig. 6). The largest temperature anomalies (>2.5°C) were mainly observed in the eastern and southeastern parts of the sea and resulted from anomalously warm air masses over those areas. The smallest positive anomalies (<0.5°C) took place in the southwestern Barents Sea. Compared to 2015, the surface temperature was higher (by 1.1°C on average) in most of the sea (two thirds of the surveyed area), especially in the northwestern and southeastern parts. The surface waters were on average 0.4°C colder than in 2015 mostly in the southwestern and central Barents Sea.

Arctic waters were mainly found, as usual, in the 50–100 m layer north of 77°N. The 100 m temperature was higher than the long-term means (on average, by 1.5°C) all over the Barents Sea (Fig. 7). Compared to 2015, the 100 m temperature was higher (on average, by 0.5°C) in most of the sea (five sixths of the surveyed area). Negative differences in temperature between 2016 and 2015 (–0.3°C on average) took place only in some local areas.

The bottom temperature was in general 1.6°C above average throughout the Barents Sea (Fig. 8). The largest temperature anomalies (>2.5°C) were mainly observed over the Spitsbergen Bank and in the Pechora Sea. Compared to 2015, the bottom temperature was on average 0.8°C higher almost all over the Barents Sea. Small negative differences in temperature between 2016 and 2015 were on average –0.2°C and occupied only about 6% of the surveyed area (mainly in the southwestern part of the sea).

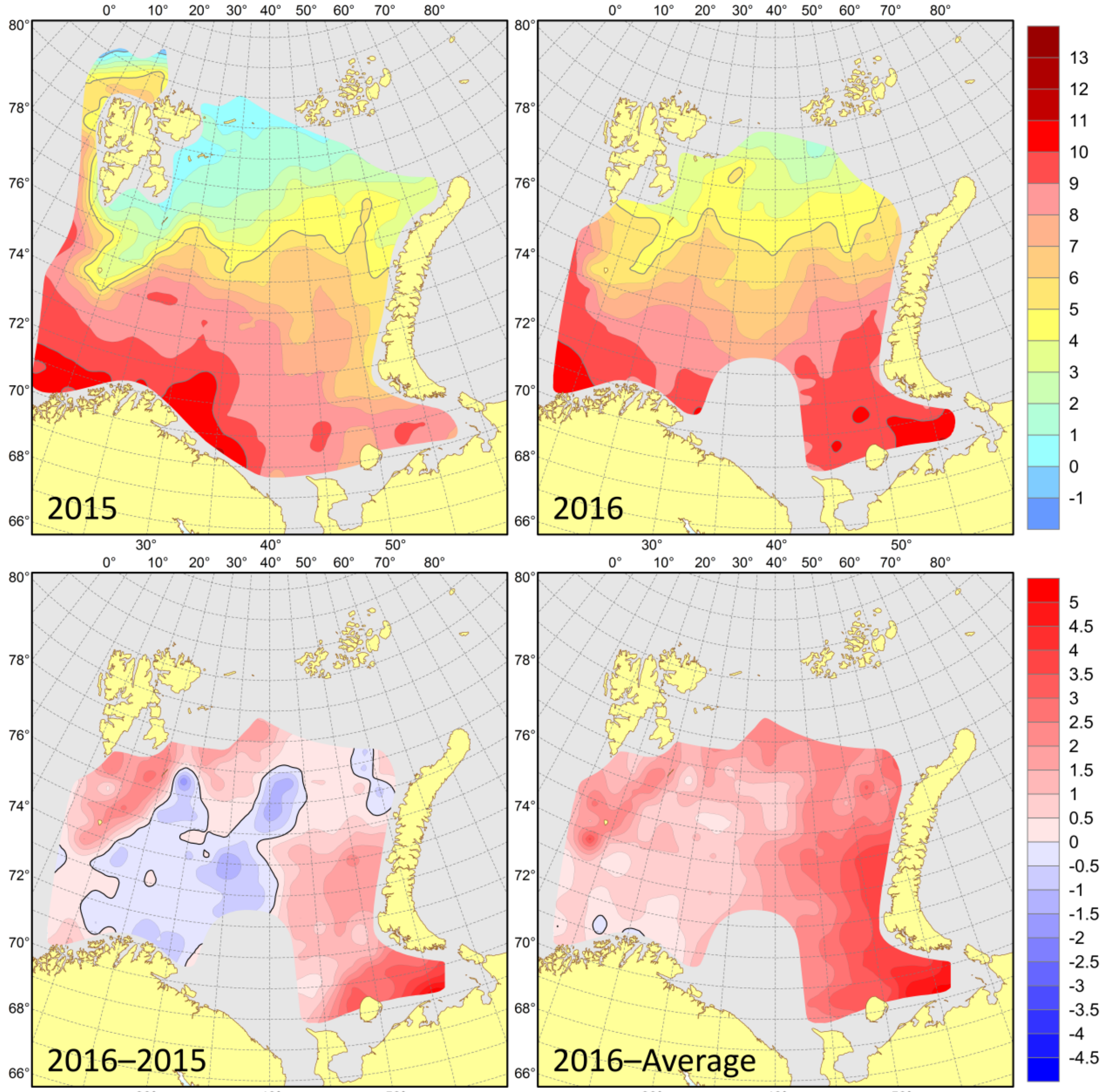

Figure 6. *Surface temperatures (°C) in August–September 2015 (upper left) and 2016 (upper right), their differences between 2016 and 2015 (lower left, °C) and anomalies in August–September 2016 (lower right, °C).*

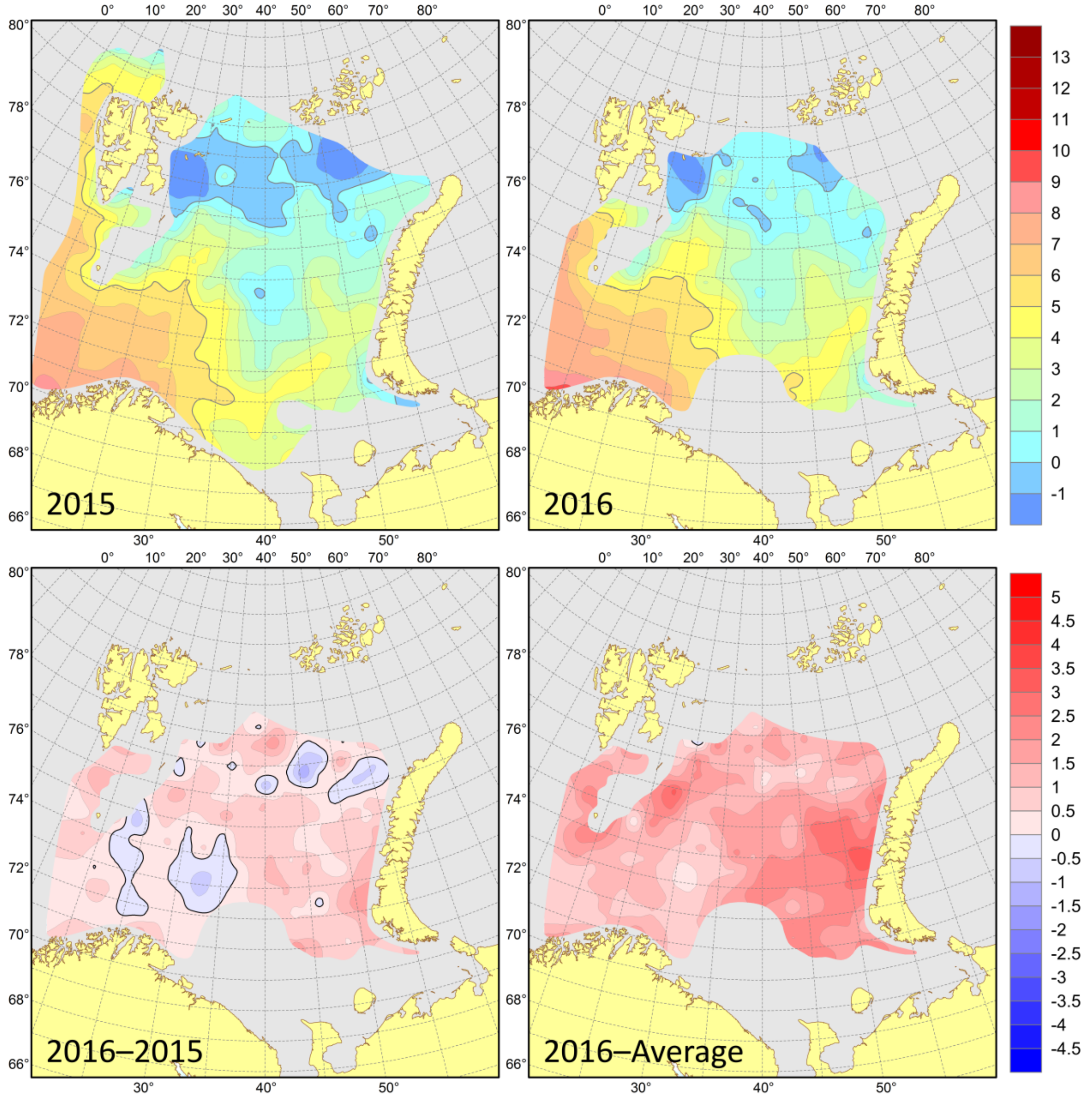

Figure 7. *100 m temperatures (°C) in August–September 2015 (upper left) and 2016 (upper right), their differences between 2016 and 2015 (lower left, °C) and anomalies in August–September 2016 (lower right, °C).*

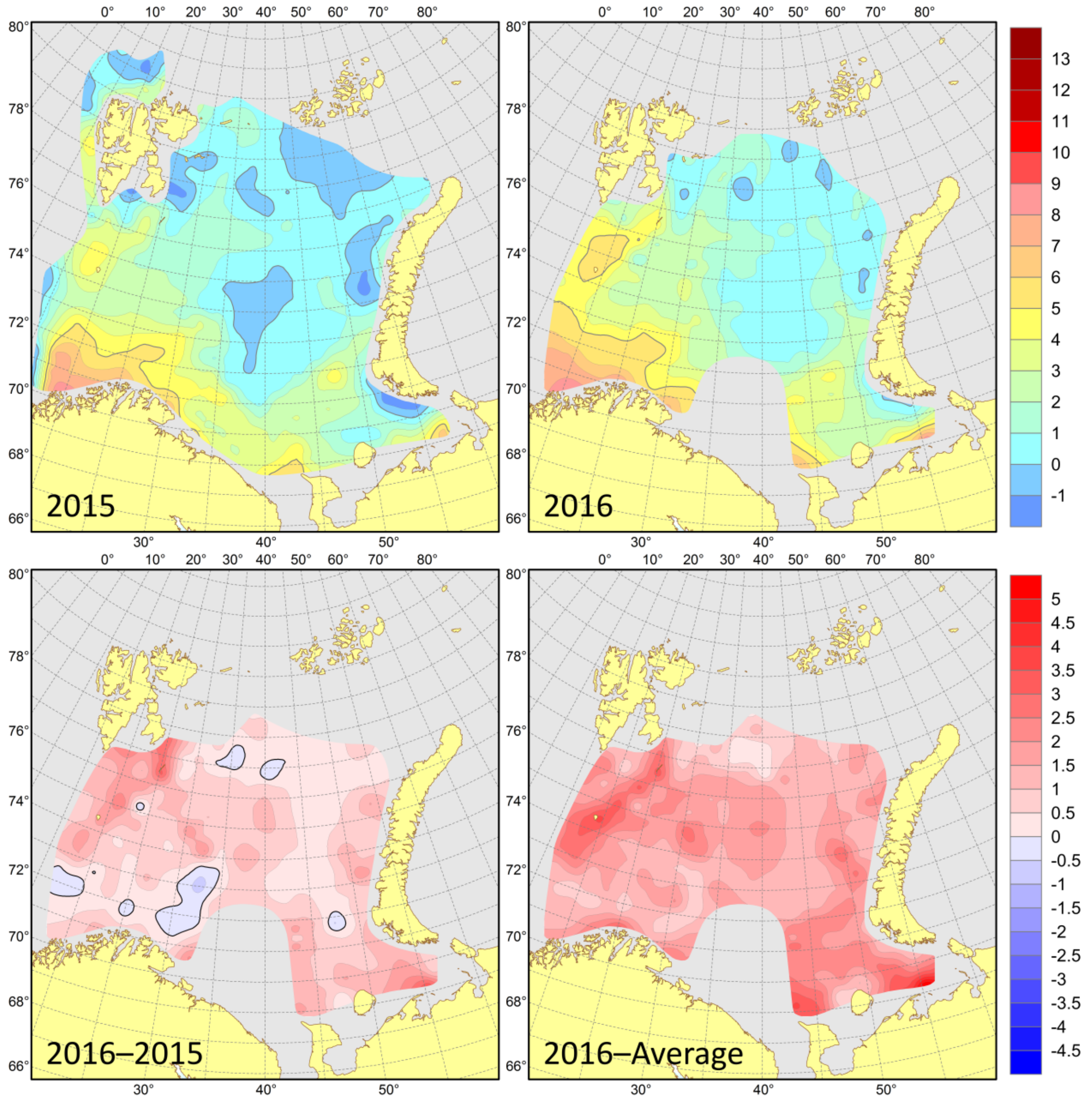

Figure 8. *Bottom temperatures (°C) in August–September 2015 (upper left) and 2016 (upper right), their differences between 2016 and 2015 (lower left, °C) and anomalies in August–September 2016 (lower right, °C).*

In August–September 2016, at 50, 100 m and near the bottom, the area covered by warm water (above 3°C) was the largest whereas the area covered by cold water (below 0°C) was the smallest since 2000 (Fig. 9). Since 2000, the area covered by cold bottom water was the largest in 2003 and rather small in 2007, 2008, 2012 and 2016; in 2016, it reached a record low value since 1965 – the year when the joint autumn surveys started.

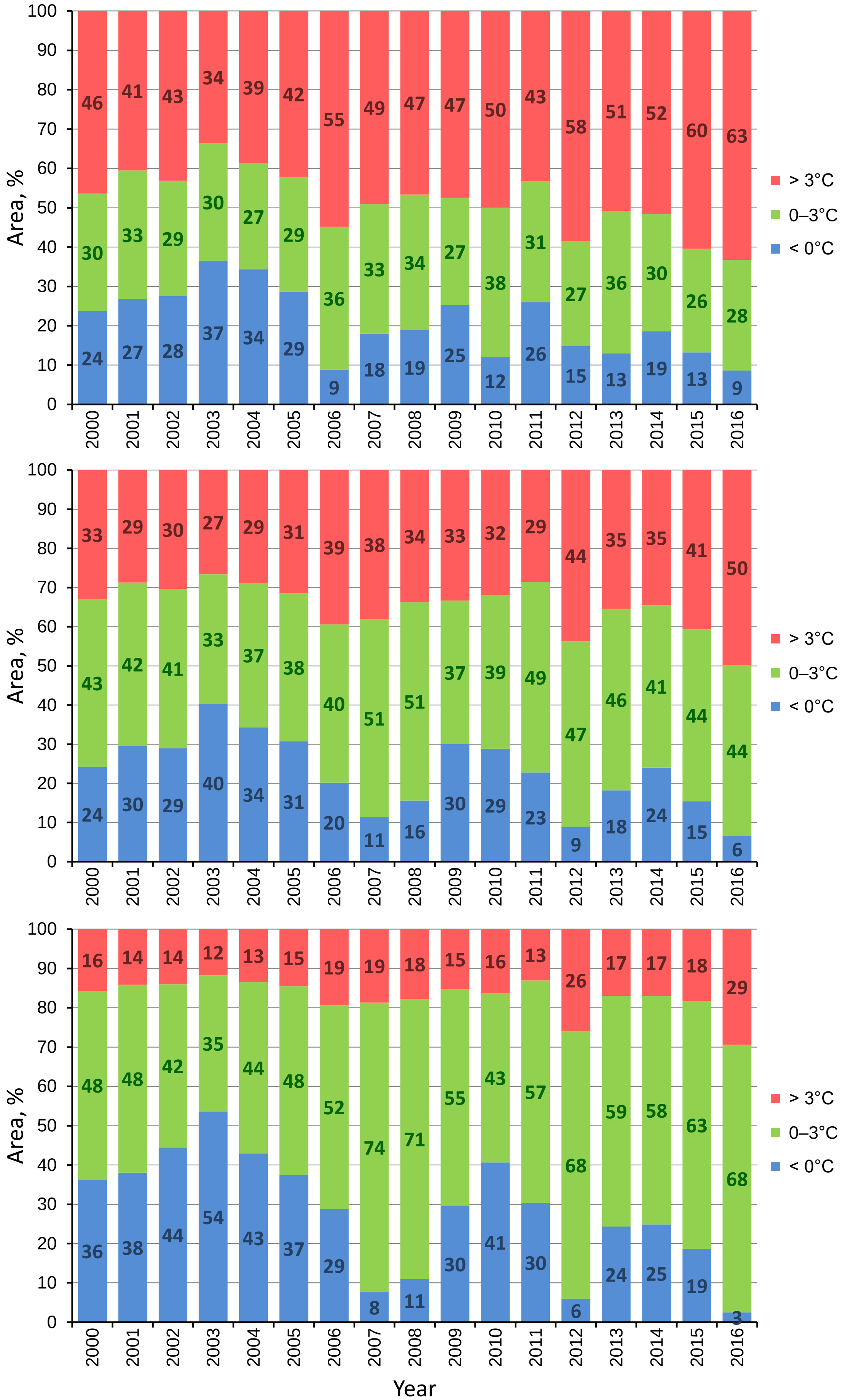

Figure 9. *Areas covered by water with different temperatures at 50 (upper panel), 100 m (middle panel) and near the bottom (lower panel) in the Barents Sea (70–79°N, 20–60°E) in August–September 2000–2016.*

In the past decades, the area of Atlantic and mixed waters has increased, whereas that of Arctic waters has decreased (Fig. 10). In August–September 2016, the area covered by Atlantic waters was the largest, whereas the area covered by Arctic waters was the smallest since 1965.

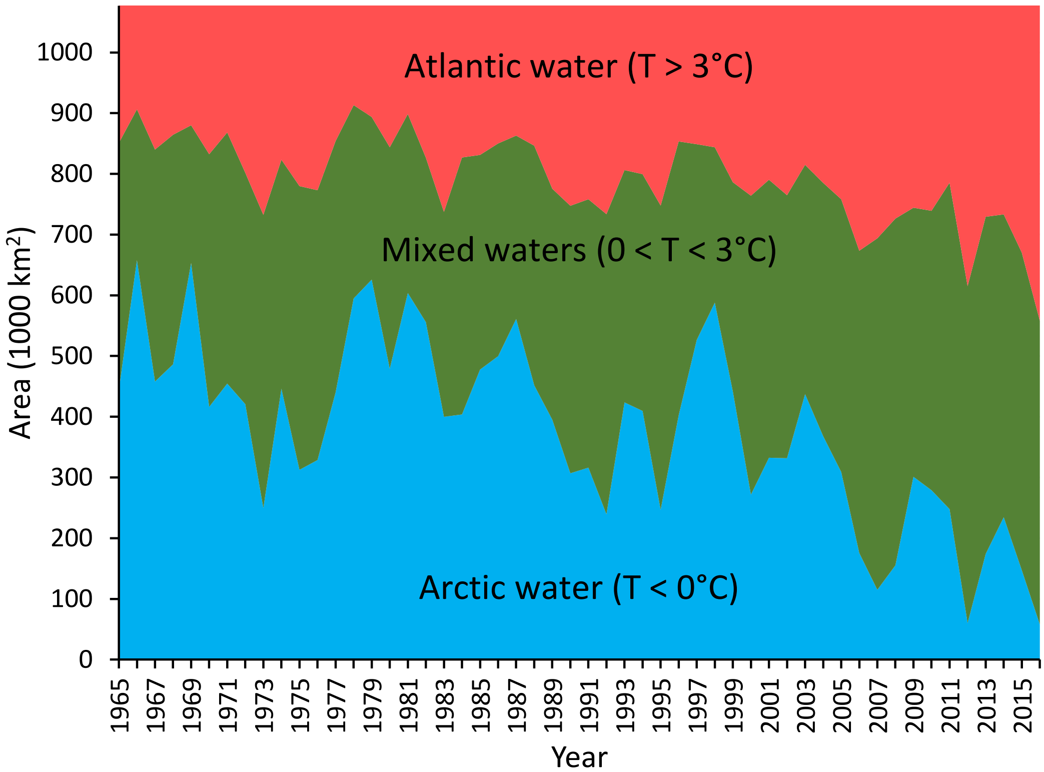

Figure 10. *Area of water masses in the Barents Sea (70–79°N, 20–60°E) in August–September 1965–2016 (based on 50–200 m averaged temperature).*

The surface salinity was on average 0.5 higher than the long-term means (1931–2010) almost all over the Barents Sea with the largest positive anomalies (>0.5) mainly north of 75°30'N (especially in the area of the Great Bank) and east of 48°E (especially west and south of Southern Island of the Novaya Zemlya Archipelago) (Fig. 11). The large negative anomalies were only observed north of Kolguev Island. In August–September 2016, the surface waters were saltier than in 2015 in about 60% of the surveyed area with the largest positive differences in the Pechora Sea, along the Novaya Zemlya Archipelago and south of the Spitsbergen Archipelago. Negative differences in salinity between 2016 and 2015 were mainly found in the central and northeastern Barents Sea as well as north of Kolguev Island.

The 100 m salinity was higher than the long-term means (on average, by 0.1) in about 80% of the surveyed area (Fig. 12). Small negative anomalies were only observed in some areas, especially in the southwestern and southeastern Barents Sea. Compared to 2015, negative differences in salinity between 2016 and 2015 prevailed in the Barents Sea and occupied almost two thirds of the surveyed area. The positive differences were mainly found in the southwestern part of the sea.

The bottom salinity was slightly higher than the long-term means (by up to 0.1) in about four fifths of the surveyed area and it was close to that in 2015 (Fig. 13). Negative anomalies were mainly found in the southeastern Barents Sea, especially in the Pechora Sea. The largest differences in salinity between 2016 and 2015 were observed in shallow waters between Bear and Hopen Islands (positive values) and in the southeastern Barents Sea (negative values).

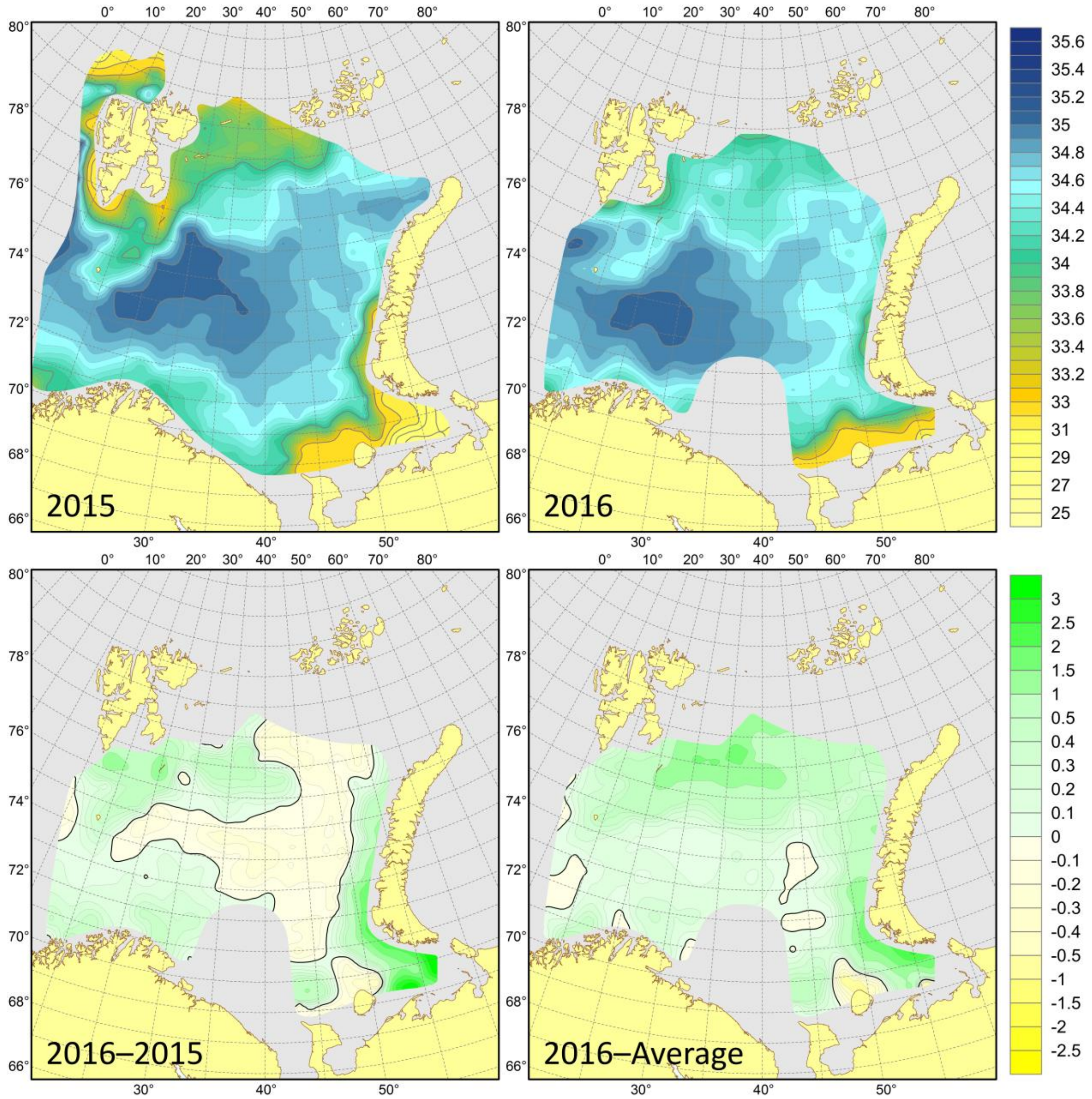

Figure 11. *Surface salinities in August–September 2015 (upper left) and 2016 (upper right), their differences between 2016 and 2015 (lower left) and anomalies in August–September 2016 (lower right).*

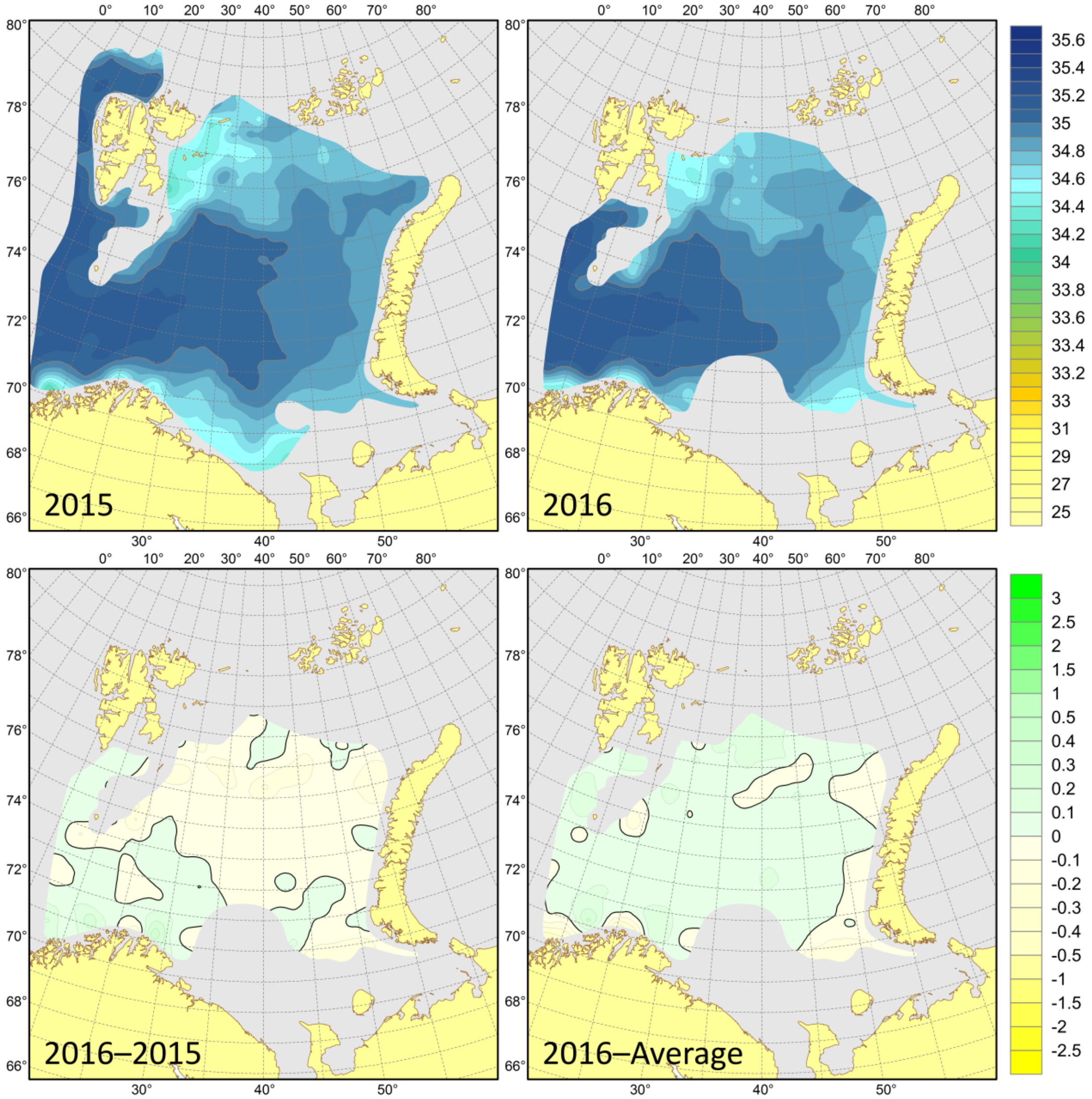

Figure 12. *100 m salinities in August–September 2015 (upper left) and 2016 (upper right), their differences between 2016 and 2015 (lower left) and anomalies in August–September 2016 (lower right).*

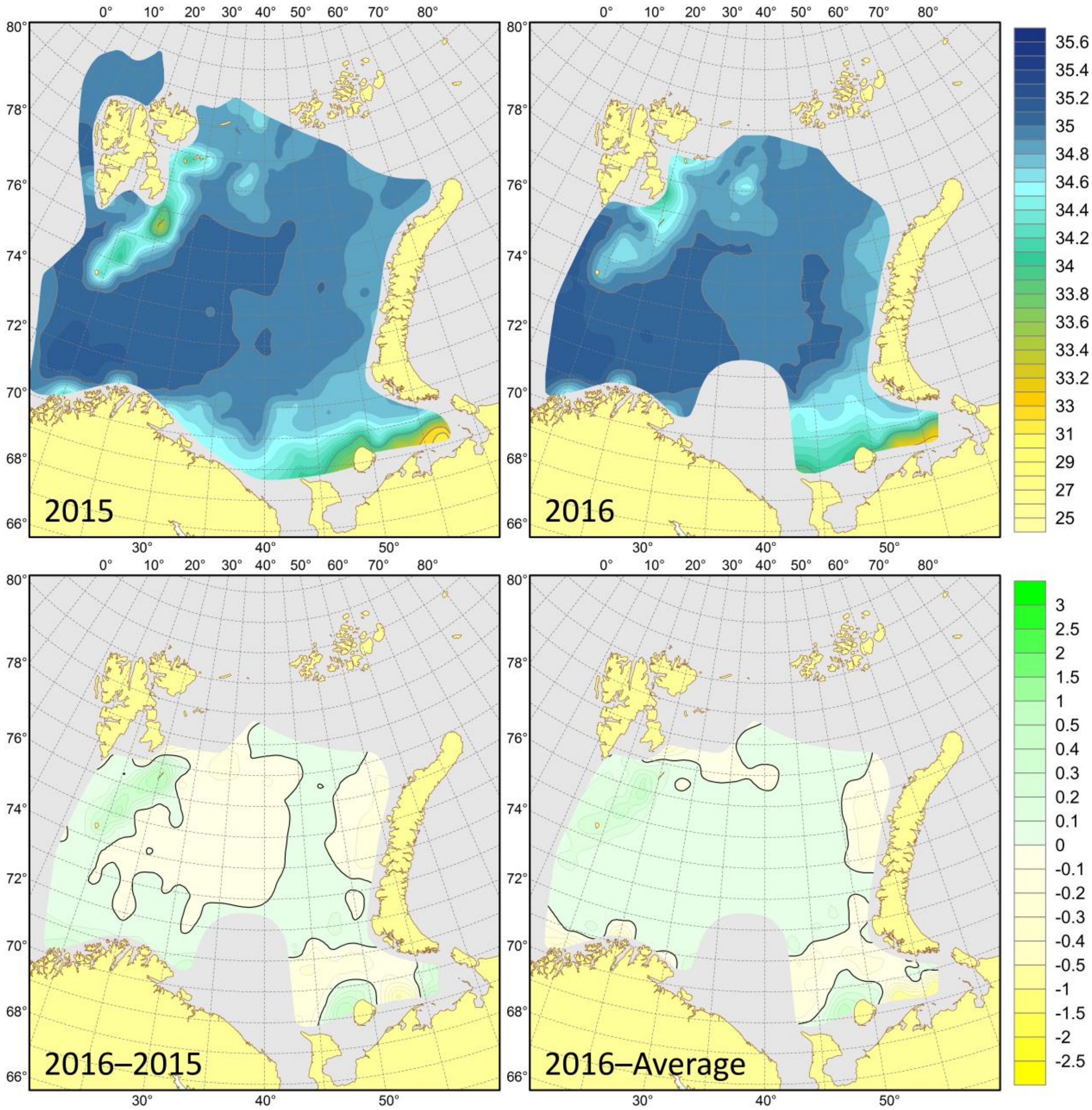

Figure 13. *Bottom salinities in August–September 2015 (upper left) and 2016 (upper right), their differences between 2016 and 2015 (lower left) and anomalies in August–September 2016 (lower right).*

Summary

The air and water temperatures in the Barents Sea in 2016 were well higher than average and compared to 2015 that was typical of anomalously warm years; the temperature anomalies in the eastern sea were well larger than in the western one. In some months, the Atlantic and coastal waters as well as air masses had the highest temperature anomalies since 1951.

The coastal waters in the Kola Section were much fresher than average and compared to 2015; the Atlantic water salinity in the central part of the section was also below normal but with smaller anomalies; the Atlantic water salinity in the outer part of the section was close to both the average and that in 2015.

In autumn 2016, the area covered by Atlantic waters (>3°C) was the largest, whereas the areas covered by Arctic and cold bottom waters (<0°C) were the smallest since 1965.

The 2016 annual mean ice coverage of the Barents Sea and its monthly mean values in March–July and November–December were the lowest since 1951; there was no ice in the Barents Sea from July to September (in July, it happened for the first time since 1951).

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