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Hydrographic and Atmospheric Conditions Off East Greenland – Their Potential Effect on the Distribution of Shrimp (*Pandalus borealis*)

by

M. Stein

Institut für Seefischerei, Bundesforschungsanstalt für Fischerei
Palmaille 9, D-22767 Hamburg, Germany
e-mail: stein.ish@bfa-fisch.de

Abstract

As recommended during the Shrimp (*Pandalus borealis*) assessment of NAFO during 1997 (**Anon. 1997**) Chairman of the Standing Committee on Fisheries Environment (STAFEN) undertook the task to evaluate the hydrographic conditions in the major Shrimp catching areas north of 65°N off East Greenland, and to evaluate possible changes in the physical environment which might explain the southward shift of Shrimp aggregations as observed from 1993 onwards. Based on the historic mean summer (JAS) hydrographic conditions in the area of the Denmark Strait, the paper outlines the regional distribution of Polar and Atlantic water masses on the Greenland-Iceland Ridge. It is shown that topographic features have a steering influence on the flow of these waters, and that they might be responsible for the entrainment of major Shrimp aggregations. A salient topographic feature is the deep Kangerdlugsuak Fjord which carves in the East Greenland Shelf, just south-west of the Dohrn Bank (**Stein, 1988**). Until 1992, the northern Shrimp aggregations were confined to this fjord region. Recent hydrographic data as sampled during the German bottom trawl surveys off East Greenland, give a potential explanation for the observed southward shift of Shrimp (*Pandalus borealis*) distribution from 1992 onwards. It is hypothesised that an increased advection of warm Atlantic water masses as observed during September 1993 and thereafter, led to a southward displacement of the Shrimp concentrations, and hence to a southward shift of the catching areas. These "warm water conditions" are maintained through to present. By means of Sea Surface Anomaly data as derived from the TOPEX/POSEIDON Satellite, it is shown that the variability of sea surface elevation – which is mostly due to changes in the density of the upper water column of the area under investigation – is in the order of about ten to twenty days.

Variability of the atmospheric environment is shown by using air temperature anomalies at Angmagssalik/East Greenland, as well as air temperature and air pressure anomalies over the Northwest Atlantic Ocean. It would appear that the recent development of the atmospheric environment points at a regime shift from cold conditions as observed during the 1970s, the 1980s, and during the first half of the 1990s, to warm conditions in the Northwest Atlantic Ocean which were observed from winter 1995 onwards.

Introduction

The East Greenland shelf region is, from a topographic point of view, a rugged area. Fishing activities in this area are very often hampered by this topography, and the amount of complete gear losses reported from the East Greenland shelf region is high. Nevertheless, there is a large quantity of oceanographic information sampled during this century in the area, and a considerable amount of these temperature and salinity profiles is available through the oceanographic archives (e.g. World Data Center A, Oceanography, Washington, D.C.). To evaluate the mean hydrographic conditions in the major Shrimp (*Pandalus borealis*) catching areas north of 65°N off East Greenland, historic data were taken from (**Anon., 1994**). Fig. 1 shows the positions of part of the extracted oceanographic information (18569 profiles). Note that the accumulation of dots at 62°N, 33°W denotes the position of the former weather ship ALPHA in the Irminger Sea. To reveal possible changes in the physical environment which might explain the southward shift of Shrimp aggregations as observed from 1993 onwards, recent CTD data from the East Greenland shelf and slope area, as sampled by the German FRV "Walther Herwig III" during the annual autumn bottom trawl surveys were used (Fig. 2). The general oceanography of the Denmark Strait region has been widely discussed in literature (e.g. references as listed in: **Stein, 1988**): Accordingly, two major water masses one of polar origin, the other of subtropical origin meet and mix in the area. The East Greenland Current as an extension of the outflow of cold low saline waters from the North Polar Sea, is confined to the East Greenland shelf area. Steered by the submarine extension of the Middle Atlantic Ridge system, the Reykjanes Ridge, a branch of the Gulf Stream system flows northwards towards the west of Iceland, and a major part of this flow is deflected to the west when meeting the sill of the Greenland-Iceland Ridge. On its way to the west this current, called the Irminger Current in honour to the Danish captain and marine explorer Irminger, meets the polar East Greenland Current in the Dohrn Bank region. Both currents flow towards the south-west forming large meandering features at the interface between the cold and the warm water masses. The Irminger Current has a vertical extension of several hundreds of metres whereas the East Greenland Current water mass is confined to the upper 100m (Fig. 5). Shrimp are caught mostly at depths between 200m and 300m off East Greenland (**Sigstad and Skuladottir, pers. comm.**). It seems therefore suitable to perform an analysis of the upper 300m of the water column. This maximum depth of analysis seems to be adequate since the data as obtained during the German bottom trawl surveys are confined to the shelf , the shelf edge and to the adjacent shelf slope area.

Material and Methods

Information on the mean hydrographic situation in the Denmark Strait area is based on the World Ocean Atlas 1994 which is available on CD-ROM (**NOAA, 1994**). 6408 station data sets, obtained during summer (JAS) were downloaded for the WMO squares 7603 and 7602. These data form the background for the mean climatic conditions as displayed in Figs. 3 to 4. The data consist of Nansen bottle profiles and CTD profiles. The data set sampled recently during the German bottom trawl surveys off East Greenland consists of temperature and salinity calibrated CTD profiles which were reduced to standard depths. Data analysis for both data sets was achieved with the Ocean Data View software (ODV 4.0, Version 4.0.5) which is provided by R. Schlitzer from the Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven, Germany. This software is available through the Internet (http://www.awi-bremerhaven.de/GPH/ODV). From the NOAA TOPEX/Poseidon ftp-server 10-day means of sea surface anomaly maps were downloaded and assembled as a slide show (ftp://podaac.jpl.nasa.gov/pub/sea_surface_height/topex_poseidon/images/cycle_images). This slide show gives information of the variability of sea surface elevation anomalies of the Global Ocean, and on the thermal anomalies of the ocean surface layer during August 1, 1996 and February 9, 1999. Two examples of cycle 164 and 165 are included in the paper as Figs. 9 and 10. Information on sea surface temperature anomalies, air temperature and air pressure anomalies were taken from the internet:
http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS

http://www.cdc.noaa.gov/Correlation/

http://www.cdc.noaa.gov/Composites/

Air temperature data from Angmagssalik/East Greenland (65°36'N, 37°40'W) were supplied by the Seewetteramt, Hamburg.

Results

Historic-Data Analysis

6408 station profile data were extracted from the WMO squares 7603 and 7602 to represent the summer (JAS) conditions in the vicinity of Denmark Strait (Figs. 3, 4). Potential temperature and salinity are given at 50m, 100m, 200m and 300m depth. The Oceanic Polar Front clearly emerges from the pictures. Meandering features are dominating the frontal zone at depths of 50m and 100m, but also the 200m T and S plot indicates a tongue of cold low saline water of polar origin which heads to the Dohrn Bank area (Figs. 3, 4).

Vertical fields of temperature and salinity are given along a section which crosses the Denmark Strait in the Dohrn Bank area, and cuts across the deep Kangerdlugsuak fjord (Fig. 5). The lower panel of Fig. 5 reveals the low salinity properties of the polar current, the East Greenland Current. The 34 psu isohaline might give a good estimate of the vertical magnitude of this surface current. Below 200m on the East Greenland shelf, salinities range between 34.5 psu and less than 35 psu. In this type of water shrimp are normally found.

The eastern portion of the section is dominated by Irminger mode water (T > 6°C, S > 34.95 psu). At depths around 400m and beyond, bottom waters are found which may be consisting of Arctic Intermediate Mode water (e.g. **Stein, 1988**). Strong thermohaline gradients lead to strong baroclinic activities. Hence, geostrophic calculations as performed with the Ocean Data View software, reveal geostrophic currents which peak at 150 cm/sec, a value which has been proven by direct current meter measurements in the Denmark Strait area (**Stein, 1974, 1988**).

Recent-Data Analysis

The hydrographic situation in the East Greenland shelf area north of 65°N during autumn 1992 is given in Fig. 6. The vertical sections of potential temperature and salinity reveal a mixture of cold, low saline water masses, and warm, saline waters. The surface expression of the polar water mass of the East Greenland current clearly emerges from the upper (Potential temperature) and the lower panel (Salinity) of Fig. 6. During autumn 1993 considerable warming, and an increase of salinity was observed (Fig. 7). The northern area was dominated by thermohaline conditions of the Irminger Current. The warming and the increased haline conditions maintained through to the end of the observation period (Fig. 8, 1993 to 1997)

Statistical analysis of recently collected hydrographic data reveals for the shelf edge area north of 65°N mean temperature, salinity and density indices as follows in Table 1:

Table 1: Indices of temperature, salinity and σ_O north of 65°N

	Temperature	Salinity	σ_O
1992	4.11	34.262	27.155
1993	6.58	34.952	27.425
1994	5.19	34.737	27.422
1995	5.19	34.533	27.272
1996	5.28	34.568	27.273
1997	5.44	34.812	27.459

There is a considerable change in water properties taking place between September 1992, and September 1993. It indicates a shift from cold, low saline intermediate water regime to a warm and saline water regime as derived from the Irminger Current.

Thermohaline conditions south of 65°N are given in Table 2:

Table 2: Indices of temperature, salinity and σ_O south of 65°N

	Temperature	Salinity	σ_O
1989-91	4.60	34.615	27.399
1992	no data	no data	no data
1993	5.59	34.736	27.376
1994	no data	no data	no data
1995	4.71	34.599	27.374
1996	5.85	34.549	27.197
1997	5.46	34.747	27.409

Prior to 1992 thermohaline conditions south of 65°N were colder than during the following years. In contrast to the data as given in Table 1, no warm, saline water of Irminger Current mode water has been observed.

Figs. 9 and 10 give some information on the temporal scales of ocean variability with respect to the heat content of the water column. Being only 10 to 20 days apart from each other, the sea surface anomalies show density changes during the end of February/beginning of March 1997 in the Greenland/Iceland area. This example indicates that the changes in heat and/or salt content in the East Greenland shelf region north of 65°N may have taken place at any time between the two observations made in autumn 1992 and 1993.

Atmospheric conditions

Air temperature anomalies for the East Greenland region around 65°N are given in Fig. 11. The data are referenced to the present climatic mean which is 1961-1990, and they show the late summer warming (August, September) as observed from 1993 onwards.

Air temperatures in the region off East Greenland, and between Greenland and Atlantic Canada, are largely affected by a large scale phenomenon, called the North Atlantic Oscillation (NAO). This oscillation which is basically the result of hemispherical air pressure changes observed at the centres of the Icelandic Low and the Azores High, significantly influences the air temperatures in the region. In Fig. 12 the 0.60 / - 0.60 contour lines mark the boundaries of those areas where the NAO significantly (95% level) influences the air temperatures.

Shrimp stocks in the Northwest Atlantic area are located in those areas encompassed by the –0.6 contour line in Fig. 12. This suggests that when the NAO Index is negative mild air temperatures dominate the Northwest Atlantic region.

On an annual scale the NAO Index reveals high frequency variability, on a decadal scale it shows periods of positive and negative signs (Fig. 13), with the 1960s being strongly negative (mild conditions in the Northwest Atlantic region), the 1970s being a transition period from a negative NAO regime to a positive NAO regime in the 1980s and the first half of the 1990s (cold conditions in the Northwest Atlantic region). Winter (February) sea surface temperature anomalies indicate considerable warming in the Northwest Atlantic region since 1995 (Fig. 14).

Discussion

There is strong indication that in the northern region of Shrimp *(Pandalus borealis*) distribution (north of 65°N) hydrographic conditions changed for warmer and more saline conditions in 1993, and thereafter if compared to the 1989-92 period. Shrimp habitats which were concentrated in an area of topographic peculiarity, the Kangerdlugsuak fjord, used to be influenced by a mixed water mass (TSσ_O -indices: 4.11°C, 34.262 psu, σ_O 27.155) which originates from intense mixing of the polar and subtropical water masses, the East Greenland Current mode water and the Irminger Current mode water. Since then, the northern area is dominated by warm saline water masses of Irminger Current origin which peaked at the TSσ_O -indices (6.58°C, 34.952 psu, σ_O 27.425).

Whether Shrimp actively can leave an area with unfavourable environmental conditions, or whether they might be entrained by strong currents associated with the renewal of water masses, can only be hypothesised here. The shift of Shrimp distribution to the East Greenland shelf south of 65°N is based on catch information. This must not necessarily represent a shift from northern to southern distribution, since non-availability of Shrimp in northern areas could have directed the fishing effort to the southern areas of the rugged shelf, facilitated by new fishing gear.

Scientific information on by-catch as recently presented from the German Bottom Trawl surveys off East and West Greenland (**Rätz, 1997**) indicates that Shrimp (*Pandalus borealis*) were present in both shelf regions throughout the period of observation (1982 to 1996).

As can be seen from satellite information, the density of the water column may change on time scales of 10 to 20 days (Figs. 9, 10). This indicates that tremendous density changes are not outstanding events in the ocean around Greenland and Iceland – the same is valid for air temperature variability around Greenland which is characterised by high variability (**Stein, 1996**), and that the living resources in the ocean must be adapted to this regular change which might comprise more of the water column than just the sea surface. As shown by **Stein (1988)** the variability in the geographical extension of the warm water mass of Irminger mode amounts to several tens of nautical miles horizontally, and several hundreds of meters vertically.

Atmospheric conditions seem to point at a regime shift, maybe back to the mild conditions as encountered during the 1960s in the region of the Northwest Atlantic Ocean.

Shrimp (*Pandalus borealis*) populations developed to large stock sizes during times of cooling in the East Greenland and Greenland/Atlantic Canada region. Whether the warming as observed in the area since the mid 1990s will lead to a reduction in stock size can only be speculated here.

In conclusion it must be emphasised here that although dramatic environmental changes have taken place in the Dohrn Bank area after 1992, and a regime shift from polar to subtropical water masses was observed in 1993, it *remains questionable whether the changed hydrographic conditions off East Greenland had an effect on the distribution* of Shrimp **(***Pandalus borealis***)**

There is obviously a basic need for additional studies on the interaction between Shrimp (*Pandalus borealis*) and the environment to better understand possible interactions between this biotic component and changing atmospheric and oceanographic conditions in the Shrimp habitat area.

References

Anon., 1997. Northwest Atlantic Fisheries Organisation, Scientific Council Reports 1997. p 238, p274.

NOAA, 1994. World Ocean Atlas 1994, CD-ROM Data Set Documentation. National Oceanographic Data Center, Ocean Climate Laboratory, Washington, D.C., November 1994.

Rätz, H.-J. 1997. Biomass Indices and Geographical Distribution Patterns of Survey Catches for Shrimp (*Pandalus borealis*) off West and East Greenland, 1982-96. NAFO SCR Doc. 97/96, 8p.

Stein, M. 1974. Observations on the variability of the outflow of the Greenland Sea through the Denmark Strait. Ber. Dtsch. Wiss. Komm. Meeresforsch., **23**: 337-351.

Stein, M. 1988. Variability of Water Masses, Currents and Ice in Denmark Strait. NAFO Sci. Coun. Studies, **12**: 71-84.

Stein, M. 1996. Environmental Overview of the Northern Atlantic Area – With Focus on Greenland. NAFO Sci. Coun. Studies, **24**: 29-39.

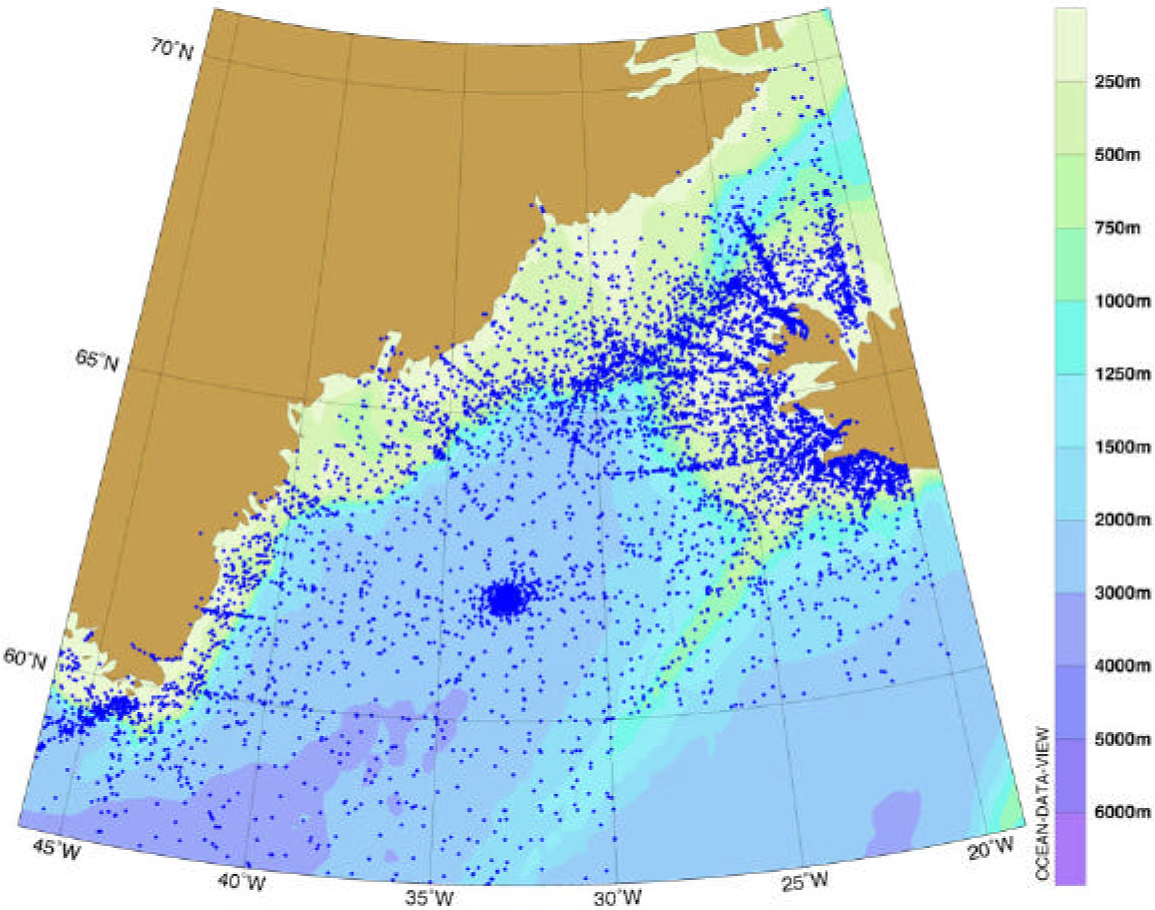

Fig. 1. Oceanographic Stations derived from the World Ocean Atlas 1994 for the analysis of thermohaline properties in the Denmark Strait area.

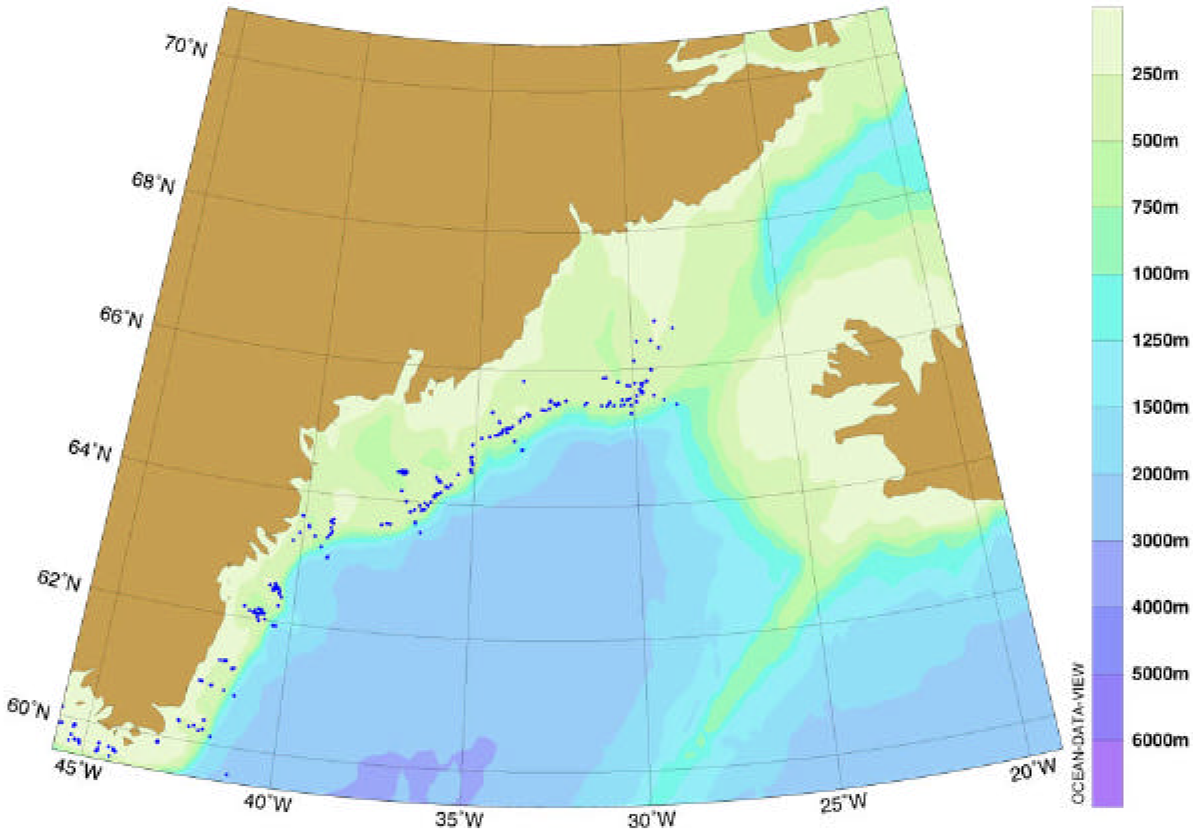

Fig. 2. Oceanographic Stations derived from German Bottom Trawl surveys off East Greenland and in the Denmark Strait area, 1989-1997.

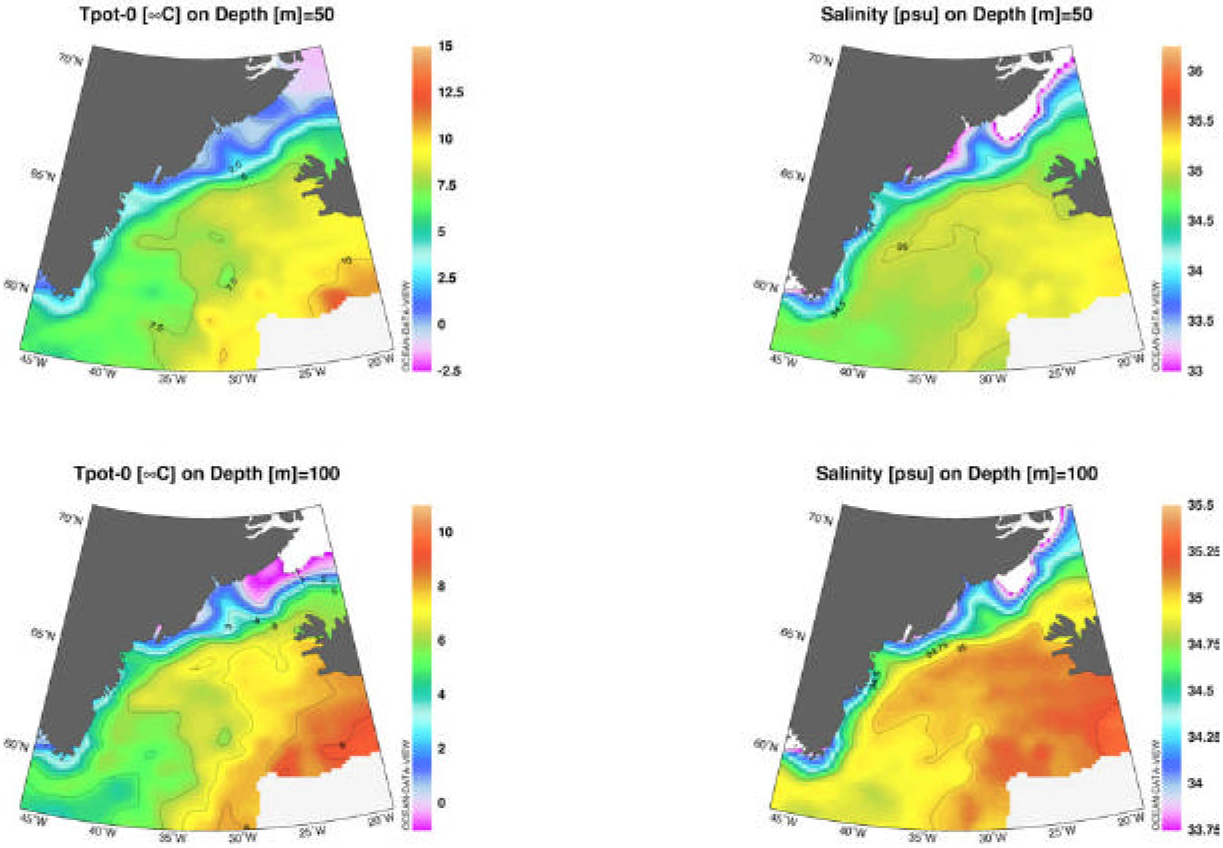

Fig. 3. Horizontal distribution of Potential Temperature and Salinity off East Greenland and in the Denmark Strait area; Upper panel: 50m depth, lower panel: 100m.

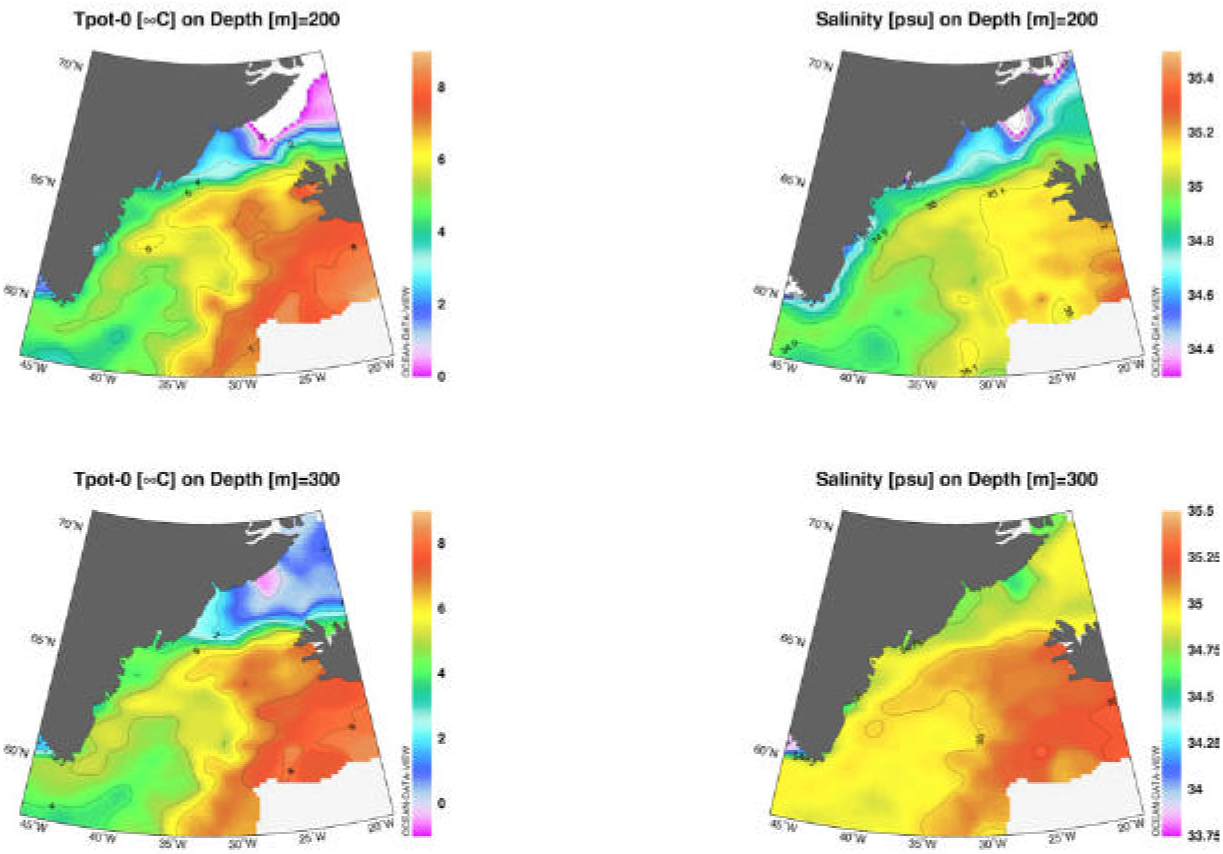

Fig. 4. Horizontal distribution of Potential Temperature and Salinity off East Greenland and in the Denmark Strait area; Upper panel: 200m depth, lower panel: 300m.

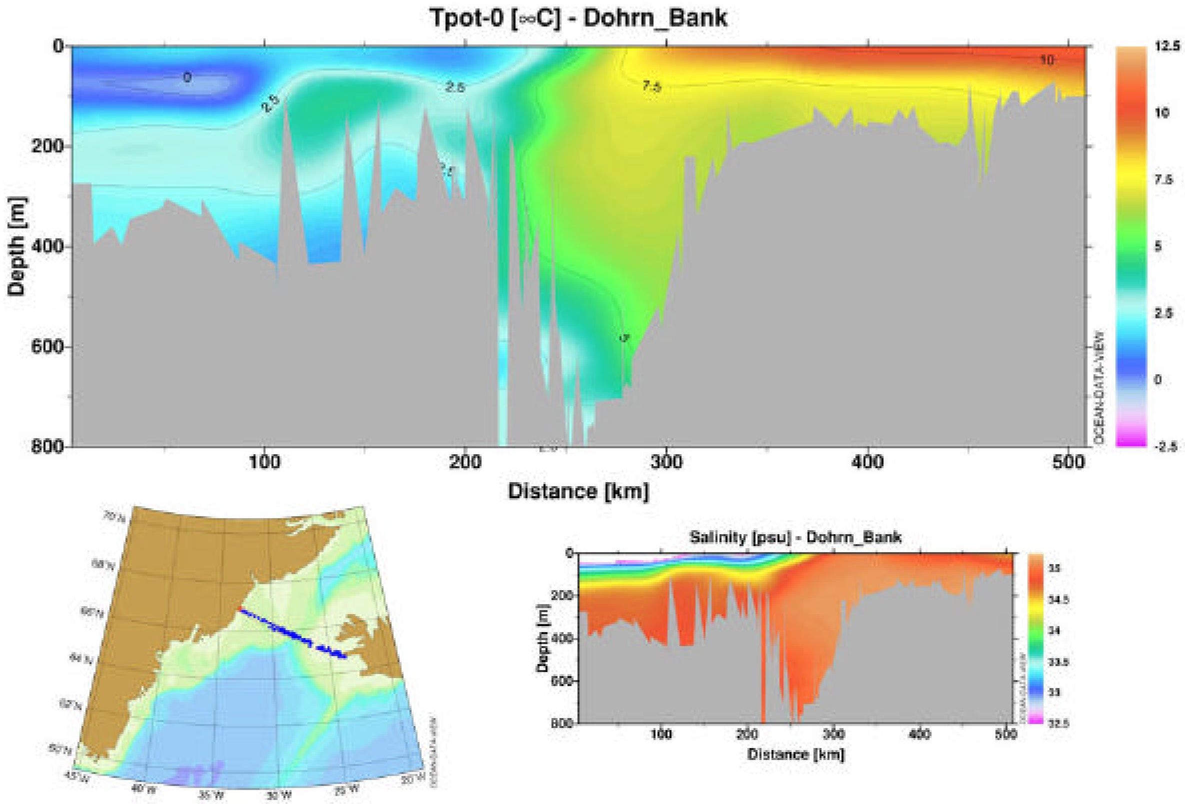

Fig. 5. Vertical distribution of Potential Temperature and Salinity between East Greenland and Iceland in the Dohrn Bank region, based on historic data.

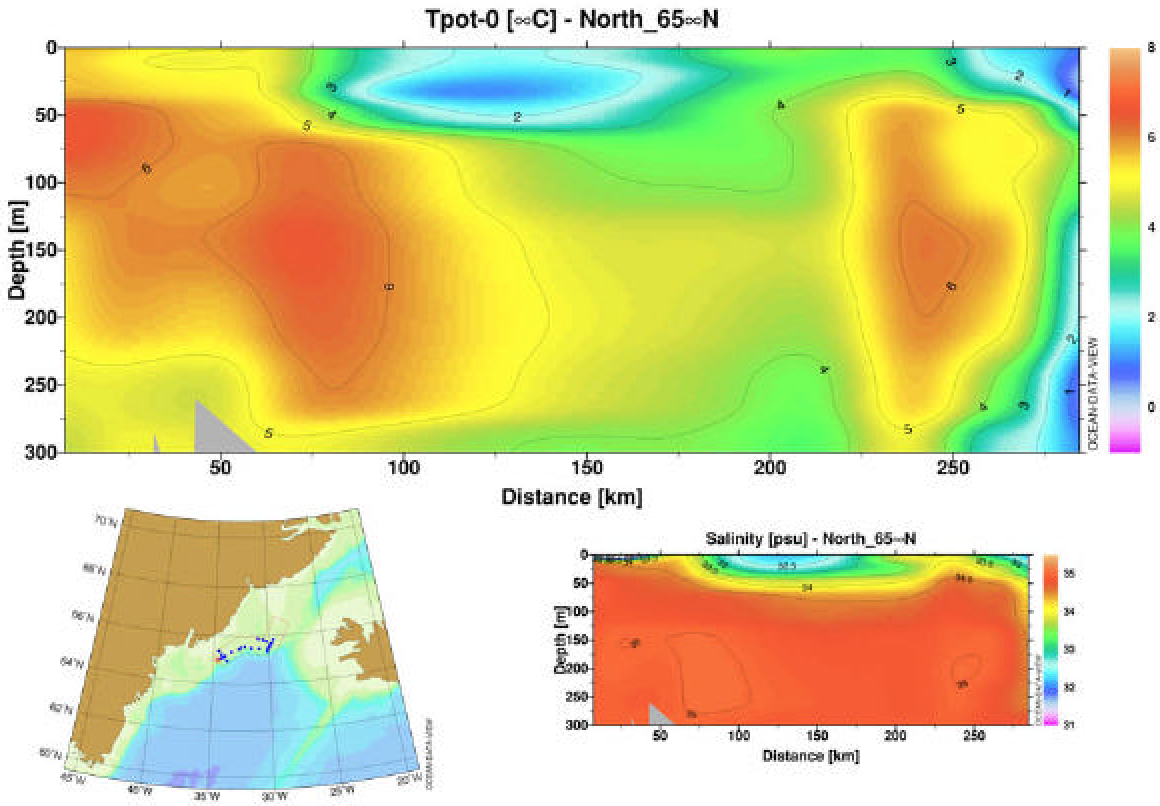

Fig. 6. Vertical distribution of Potential Temperature and Salinity north of 65°N on the East Greenland shelf, based on German Bottom trawl station CTD data during autumn 1992.

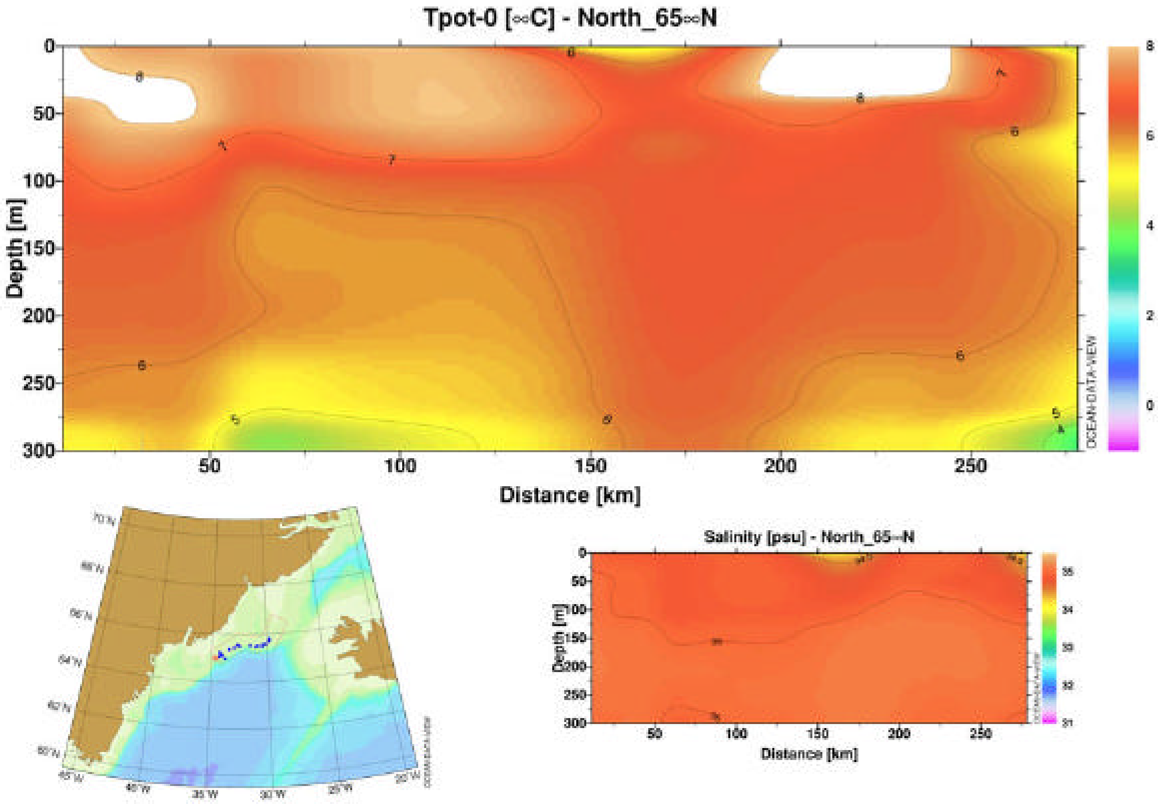

Fig. 7. Vertical distribution of Potential Temperature and Salinity north of 65°N on the East Greenland shelf, based on German Bottom trawl station CTD data during autumn 1993 (note: the surface expressions of potential temperature >8°C are intentionally left white due to maintaining same temperature scale and colouring as in Figs. 6 and 7).

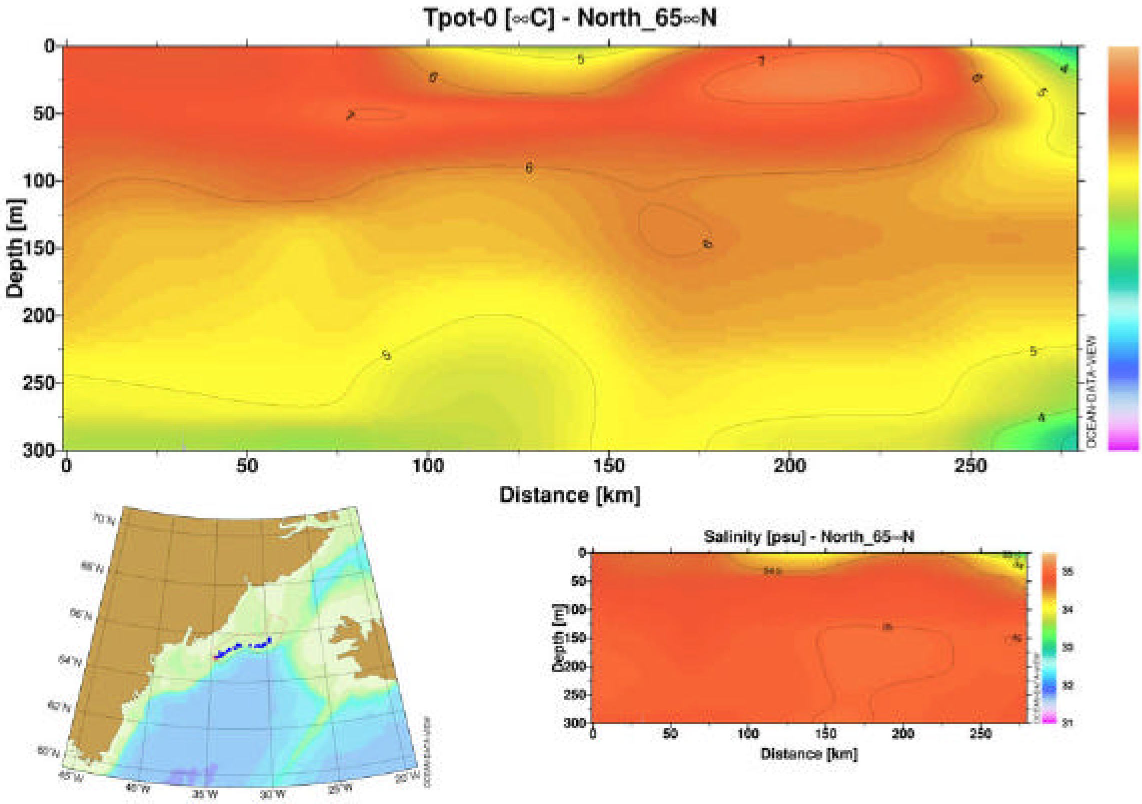

Fig. 8. Vertical distribution of Potential Temperature and Salinity north of 65°N on the East Greenland shelf, based on German Bottom trawl station CTD data during autumn 1993-97.

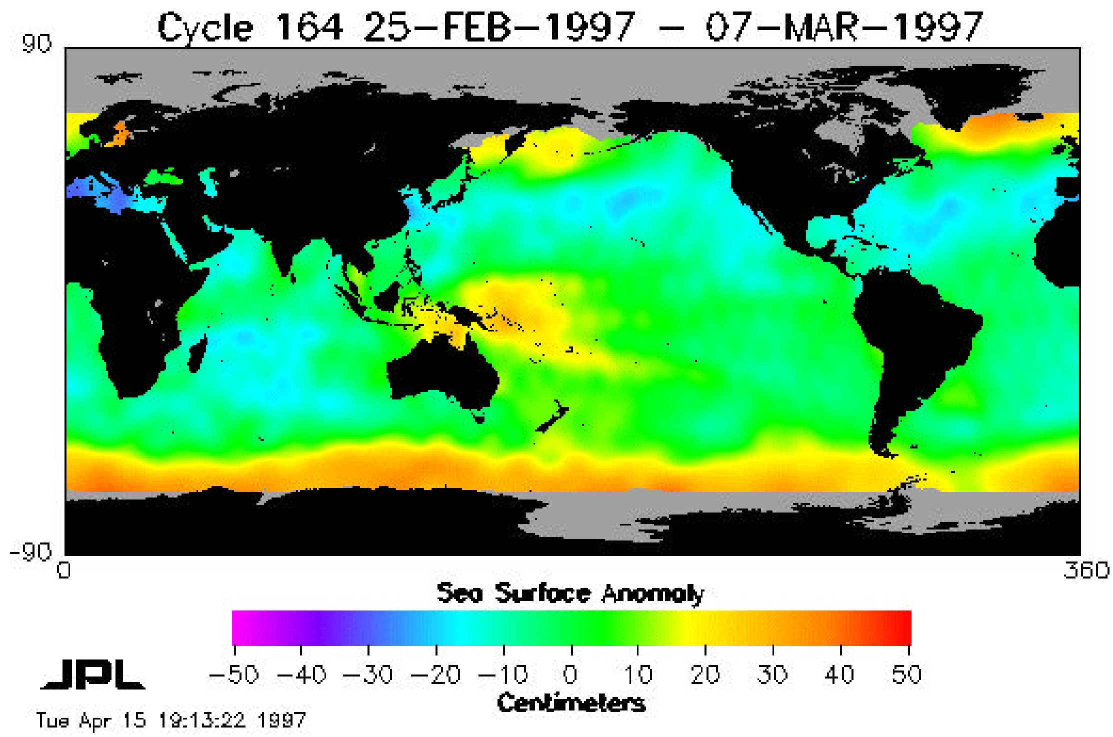

Fig. 9. Cycle 164 (25 February 1997 – 07 March 1997) Sea Surface Anomaly as observed by the satellite TOPEX/Poseidon.

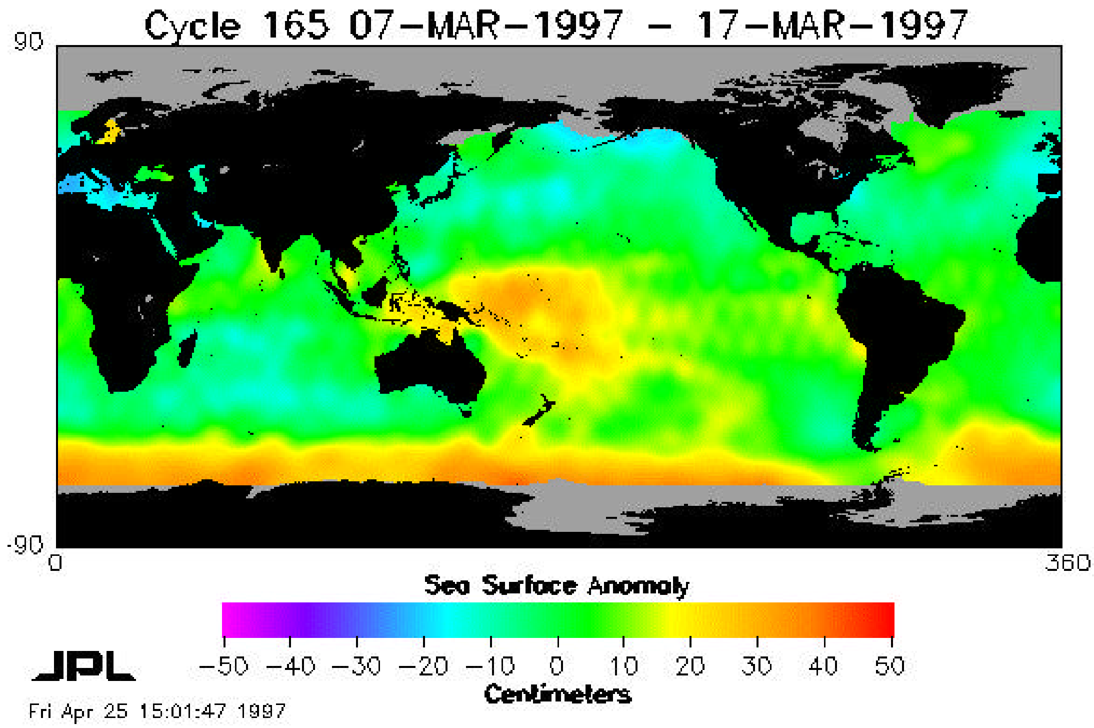

Fig. 10. Cycle 165 (07 March 1997 – 17 March 1997) Sea Surface Anomaly as observed by the satellite TOPEX/Poseidon.

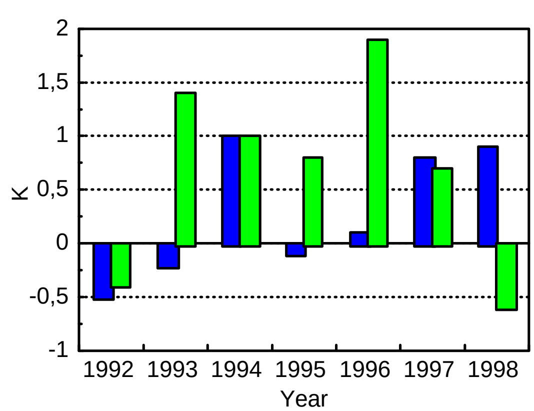

Fig. 11 Air temperature anomalies Angmagssalik (August, September) 1992-1998; mean values: August 3.1°C, September –0.8°C.

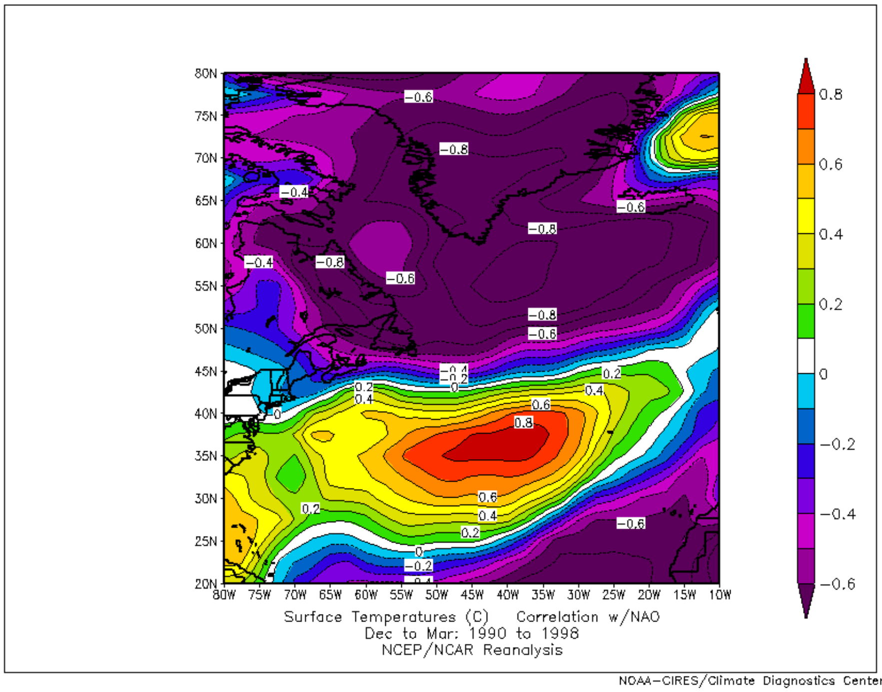

Fig. 12 Correlation air temperature / NAO Index (1990-1998)

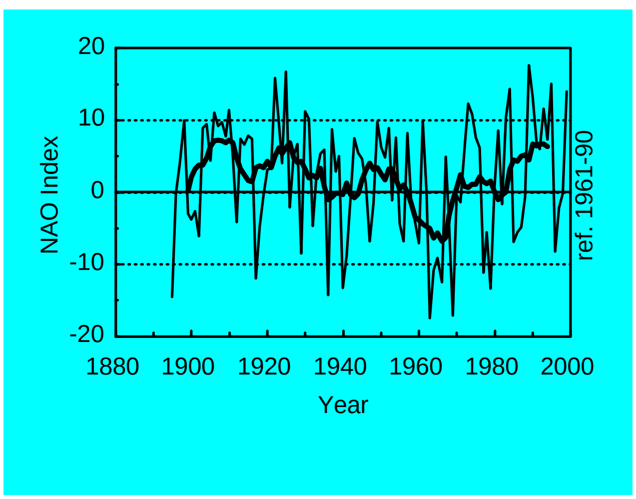

Fig. 13 NAO Index; annual index: thin line, 10 year r. mean: bold line.

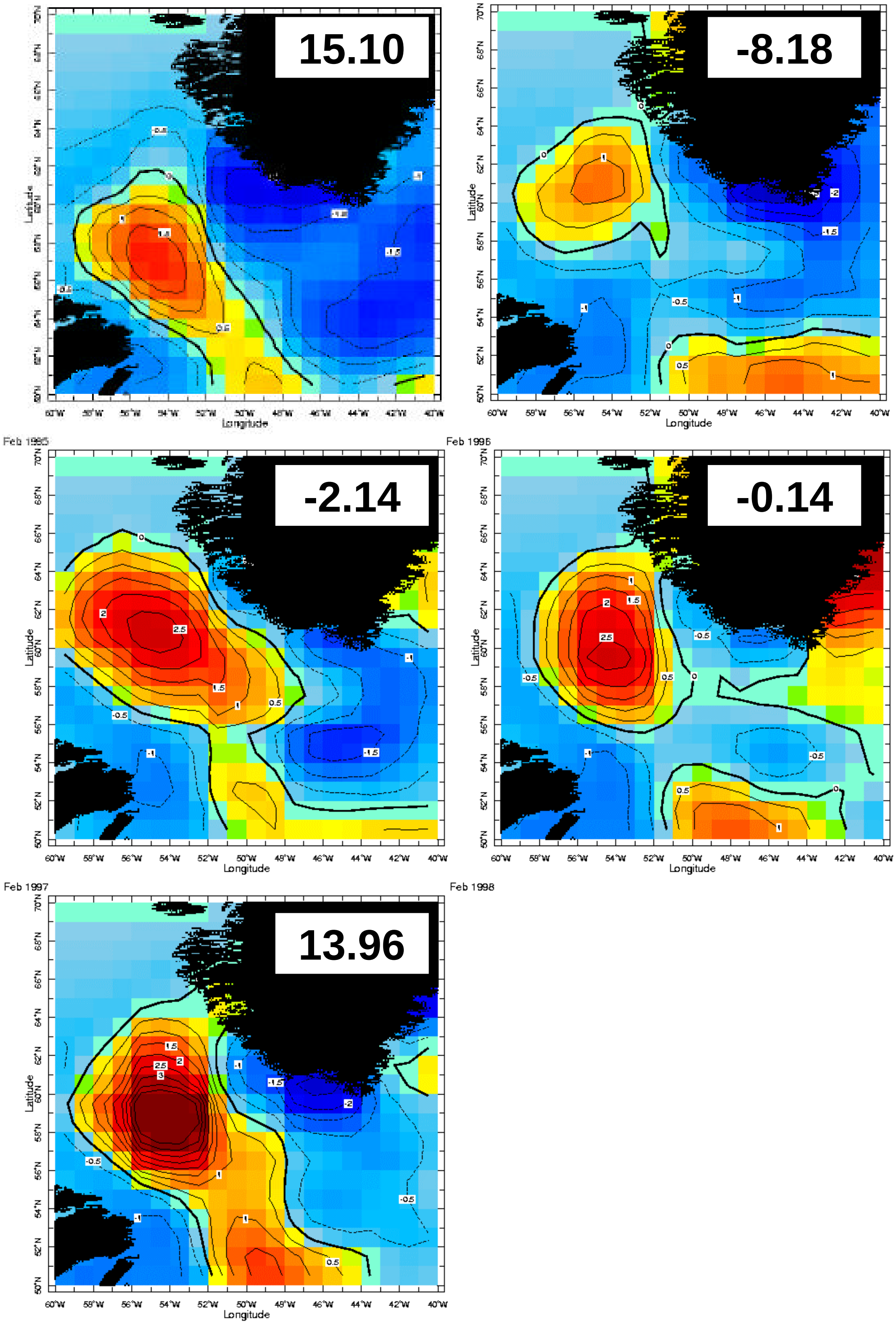

Fig. 14 Composite of SST Anomalies for the months of February (1995 to 1999), and NAO Index of the corresponding winter season (DJF) given as insert.