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Climatic Overview NAFO Subarea 1 – 1991-2000[1]

by

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Abstract

Based on climatological data on air temperatures, sea ice cover and sea surface temperatures, as well as on subsurface oceanographic time series data the paper analyses the climatic conditions off West Greenland during the decade of the 1990s, and compares the climatic conditions of this decade with previous decades climatology. Accordingly, the 1990s were a decade of extremes: The North Atlantic Oscillation (NAO) index flipped from one of its most positive values in winter 1995 to one of its most negative values in the winter thereafter and reached a high level again during the last winter of the decade. Air temperatures followed these extremes in the first part of the 1990s when a high NAO-index was paralleled by cold air temperatures at West Greenland. Northward extension of warm Irminger Water along the West Greenland banks and slopes showed extreme situations in 1992 when no Irminger mode water was found, and in 1999 when northernmost extension of this warm water was found. It would appear that polar water masses were mostly present around 1992 and 1993, and waters of southern origin like the Irminger component of the West Greenland Current system dominated the second half of the 1990s. Sea ice cover at the two southernmost sites off West Greenland, Nuuk and Prins Christian Sound, show concentrations of ice in the first half of the 1990s. From 1998 onwards there was no considerable sea ice cover observed in the vicinity of these stations. The northern two locations, Upernavik and Egedesminde, reveal sea ice presence throughout the decade, however there is a significant decrease of sea ice cover during the second half of the 1990s. Winter duration at West Greenland meteorological observation sites seems to differ from north to south: Whereas in the north winters extended into March during the decades, observations from southern sites show longer winters only from the 1960s onwards. Before that period, winters were shorter at Nuuk and the southern tip of Greenland. It is suggested here that the warmer than normal winter conditions during the first half of the 20th century favoured spawning of cod and hence led to increasing cod (*Gadus morhua*) populations off West Greenland.

Keywords: North Atlantic Oscillation (NAO) index, air temperatures, sea surface temperatures, Irminger Water, spawning of cod, cod (*Gadus morhua*) populations

Introduction

Quests for influences on climate are centuries-long in climatology science. Sunspot solar cycle influence on climate date to 1801, when astronomer Sir William Herschel suggested a possible correlation between the number of sunspots and the market price of wheat; his proposal has remained a controversial topic ever since (Currie *et al*., 1993; Meadows, 1975).

[1] Mini Symposium on "Environmental Conditions in the NAFO Water of the Northwest Atlantic during the Decade of the 1990s".

The climate system exhibits considerable natural variability on time scales of the order of decades Latif (1998).

Decadal climate variability is an important issue for three reasons:

- A better understanding of the mechanisms generating decadal climate variability might open the possibility to make predictions at decadal time scales.
- The detection of anthropogenic climate change requires information about natural variability to separate the anthropogenic signal from the natural background noise.
- Long-term changes in the climate state might influence short-term climate fluctuations. A better knowledge of the slowly evolving background state can improve the prediction of the faster climate variations substantially.

In review of the achievements of the Symposium "Hydrobiological Variability in the ICES Area, 1990-1999", held in Edinburgh, Scotland during 8-10 August 2001, NAFO Scientific Council felt during its September 2001 meeting in Varadero, Cuba, that although there was some information available for the Northwest Atlantic region, there were no papers contributed to the Symposium, which cover climatic variations off the US American Atlantic coast. It was therefore felt that it would be suitable to have a climatic overview on NAFO Subareas during the 1990s to be given during NAFO Scientific Council Meeting in June 2002 at the STACFEN Meeting (Anon., 2001, p. 216).

The present contribution deals with climatic changes during 1991-2000 in NAFO Subarea 1. After a chapter on Data and Methods, the West Greenland climatology of the 1990s is outlined and compared to the long-term climatic changes in the area. In a special chapter the duration of winters throughout the decades is considered. This is followed by chapters on ice conditions in the Northwest Atlantic, sea surface temperature anomalies, subsurface observations off West Greenland, and the North Atlantic Oscillation (NAO) index.

In the discussion the climatic conditions during the 1990s are considered in the context of the longer-term perspective of the climate off West Greenland.

Data and Methods

The long-term climatic conditions were taken from NASA Goddard Institute for Space Studies http://www.giss.nasa.gov/data/update/gistemp/station_data/ for the following sites around Greenland (Fig. 1, Table 1): Egedesminde, Godthaab/Nuuk, Prins Christian Sound. These data were referenced to the present climatic mean (1961-1990, see Table 1), and grouped into mean annual time-series (ANN), and seasonal time-series with DJF = winter, MAM = spring, JJA = summer, SON = autumn. The temperature reference level (1961-1990) is indicated by the zero-line in each figure.

Although not covering the recent two decades, climatic time-series of Upernavik was used to reveal climatic changes in the northern areas of West Greenland well back into the 19th century (c.f. Table 2).

The method of temperature sums was used to assess the characteristics of the individual seasons on a decadal background. This method was also used to evaluate the duration of winters during the past 130 years. The temperature sums prepared in this context do not contain a base temperature as used e.g. in models for predicting the date of harvest of vegetables (Cantliffe and Bryan, 1987).

Subsurface oceanographic observations off West Greenland were taken from the oceanographic database of the Institut für Seefischerei, Hamburg. The data set starts in autumn 1963 (Fyllas Bank) when the annual groundfish surveys off West Greenland were initiated. For climatic considerations temperature and salinity data from Fyllas Bank standard oceanographic station 4 were taken (Stein, 1988).

The NAO Index as given in Fig. xx refers to the mean December, January, February (DJF) Sea Level Pressure (SLP) from the Azores (Ponta Delgada) and from Iceland (Akureyri). The individual SLP's are standardized to 1961-90 base period, and calculated using

$$\mathrm{NAO_i} = \frac{p_i - \overline{p}}{s}\Big|PD - \frac{p_i - \overline{p}}{s}\Big|A.$$

DJF pressures for 1998/99 and 1999/2000 for Ponta Delgada were defined by regression (Stein, 2000).

To assess the annual variation of sea ice cover adjacent to the sites as given in Table 2, boxes were formed which cover 1x1° areas seawards off these sites (Upernavik 72N-73N, 56W-57W; Egedesminde 68N-69N, 53W-54W; Nuuk 63.5N-64.5N, 52W-53W; Prins Christian Sound 59.5N-60.5N, 43W-44W). Data on sea ice cover for these boxes around Greenland were extracted from the Climate Diagnostics Centre (CDC) of NOAA (http://sgi62.wwb.noaa.gov:8080/cgi-bin/disp_mf_cdas.sh). The sea ice cover of the 1x1° boxes is given in Fig. 9 to 12 (0 = no ice; 1 = full ice cover). A little insert map shows the location of the four boxes (c.f. Fig. 11 and 12). Sea surface temperature anomaly data for the region between Greenland and Labrador were taken from the IGOSS Data Base http://ingrid.ldgo.columbia.edu/SOURCES/.IGOSS . Water mass analysis was done using the "patch" option in Ocean Data View (Version 5.4) for Irminger Water (4°C < Theta < 6°C, 34.95 < S < 35.1) (Fig. 17).

Results

Climatology of West Greenland

Mean annual air temperatures at Egedesminde (Fig. 2) reveal a warming trend during the 1990s. This trend is apparent in all seasonal time-series as given in Fig. 3. Coldest conditions were encountered during 1993, mainly due to the extreme cold air temperatures in February (-22.1°C) and March (-25.3°C). Record cold temperatures were observed during February 1992 (-26.3°C) and March 1993 (-25.3°C). Mean annual air temperatures at Egedesminde are mainly influenced by climatic conditions during winter (84%) and spring (73%), e.g. Table 2. The seasonal decadal presentation of Egedesminde air temperatures indicates that the first two seasons (DJF, MAM), despite relative warming as compared to the 1980s, are still colder than the decades of the 1950s to 1970s.

The climatology of Nuuk (Fig. 4 and 5) yields similar conditions during the 1990s as encountered for Egedesminde: Coldest temperatures were found during 1993 which was mainly due to the extreme cold air temperatures in February (-22.1°C) and March (-25.3°C). Compared to previous decades, mean annual air temperatures during the 1990s were similar to the 1980s with 1983 and 1984 being the coldest years during the decade. The winter and spring conditions at Nuuk explain 75%, and 63% of the annual mean air temperature variation. Winter and spring conditions during the 1990s were among the coldest throughout the past 130 years (Fig. 5), summer and autumn revealed, however, mean conditions.

Further south, at Prins Christian Sound (Fig. 6 and 7), a similar warming trend is observed for the 1990s as seen at Egedesminde and Nuuk. In relation to previous decades, however, climatic conditions resembled the 1970s. Like at the two northern sites, 1993 was the coldest year on record with –8.1°C in January and –7.4°C in February. The decadal air temperature sums indicate most variation during the winter season (DJF, scaling one magnitude larger than during the other seasons), with the 1990s being the coldest decade.

Winter duration

Figure 8 displays winter decadal air temperature sums for four locations as given in Table 2. The open rectangles denote the temperature sums of January, February and March (JFM). The two northern sites, Upernavik (Fig. 8a) and Egedesminde (Fig. 8b), show that JFM-temperature sums were generally less than DJF-temperature sums. Winters of the 1980s and 1990s were considerably colder than those in the 1950s to 1970 at Egedesminde.

The Nuuk winter conditions changed throughout the past 130 years: Long winters, extending into March, prevailed during the 1990s, 1980s, 1970s and 1960s. Prior to these decades, winters were shorter (1890s to 1950s, except for 1900s), and the 1870s and 1880s were characterized by winters extending well into March (Fig. 8c).

Ice Conditions off West Greenland

Off Upernavik the climatology indicates sea-ice being present at all times during the 1990s. There is variation between 60% and 100% cover (Fig. 9). Off Egedesminde there is an all-time presence of 20% sea-ice, and peak cover reaches about 70%. There is indication that the last four years of the 1990s have less ice cover than the first six years of the decade (Fig. 10). Further south, off Nuuk, only the winter of 1993 reveals major ice cover, and there was no ice – as concerns climatology – during the last three years of the 1990s (Fig. 11). The site of Prins Christian Sound is influenced by sea-ice coming from the East Greenland current. Major ice cover was encountered during the first months of 1993 through 1997. The last three years of the 1990s indicated no ice at this site (Fig. 12).

Sea-Surface Temperature Anomalies

Sea-surface temperature (SST) anomalies between 50°N-70°N, 60°W-40°W for the month of August 1991-2000 are displayed in Fig. 13 and 14. Coldest conditions were observed during 1992. From 1996 onwards there was considerable warming which affected mostly the region off Labrador and Newfoundland (lower right panel of Fig. 13). Warmer than normal SSTs were encountered during August 1998 and 2000 (Fig. 14) when SSTs rose by +2.5K. While this warming was seen mostly at the Canadian side of the Labrador Sea in August 2000, off South and West Greenland cooling took place (lower right panel of Fig. 14).

Sub-surface Observations off West Greenland

Oceanographic observations from Fyllas Bank are given in Fig. 15 and 16, climatic means of temperatures and salinities are displayed in Table 3. The near-surface thermal conditions reveal extreme cooling during 1992 (Fig. 15, 0-50 m), and warming thereafter. This cooling feature was also observed during the early-1970s and early-1980s. This phenomenon is coherent with atmospheric cooling at West Greenland sites Egedesminde (Fig. 2), Nuuk (Fig. 4) and Prins Christian Sound (Fig. 6) during the same periods. Present thermal conditions of the upper 50 m water layer are record high.

The top 200 m of the water column at station 4 of Fyllas Bank were also considerably warmer during the 1990s than in the previous decades. Peak warming was encountered during 1996 (Fig. 15, 0-200 m), and temperatures have remained warmer than normal since then.

The so-called Irminger Water mass layer (Fig. 15, 200-300 m) indicates colder than normal temperatures during 1993 and 1995, and warming thereafter. Major heat import to Fyllas Bank by this water mass was observed in 1998 when record high temperatures were measured (6.43°C) in this layer.

Salinities at station 4 of Fyllas Bank were mostly above normal during the 1990s (Fig. 16 and Table 3). Major deviations from mean conditions were found during 1993 in the Irminger Water layer (Fig. 16, 200-300 m).

The most recent salinity observations (2001) show unusually high anomalies for the 0-50 m layer and the 0-200 m layer.

Irminger Water Mass

The distribution of Irminger Water Mass along the West Greenland slope area is given in Fig. 17 for a swath of 60km in width. Data presentation is done with standard depth data (0, 10, 20, 30, 50 m, ….). If the observed temperature and salinity data meet the T,S-characteristics of the Irminger Water Mass (4°C < Theta < 6°C, 34.95 < S < 35.1) a green dot marks the position in depth and geographic latitude. The position of NAFO Standard Oceanographic Sections (Stein, 1988) is indicated by section name. At Cape Desolation section there was each year Irminger Water except for 1992, which was the coldest year as shown above. Northernmost location of this water mass was found during 1999 when T, S-properties at Hellefiske Bank Section indicated the presence of Irminger Water (Fig. 17, lower left panel).

The North Atlantic Oscillation (NAO) Index

The NAO index as given for the decade of the 1990s shows mostly positive values (Fig. 18). The 1990s were high index years. There was a major exception to this pattern occurring between the winter preceding 1995 and the winter preceding 1996, when the index flipped from being one of its most positive values to its most negative value during last century. As can be seen from Fig. 18 Nuuk annual mean air temperature anomalies indicate negative correlation with the NAO.

Discussion

Analysis of mean annual climatic conditions in NAFO Subarea 1 reveals that the 1990s experienced warming during the second half of the decade. In the north, at Egedesminde (Fig. 2), mean annual air temperatures increased to warmer-than-normal conditions ressembling those seen during the 1960s and mid-1970s. Record high (2000) and record low (1993) temperatures were observed during the 1990s. Similar conditions were encountered at the southern tip of Greenland at Prins Christian Sound (Fig. 6) with the same years as concerns the extremes. At Nuuk climatic conditions showed also warming during the second half of the 1990s (Fig. 4). Mean annual conditions were, however, not as warm as during the 1960s, nor did the 1990s reach the very warm conditions prior to the 1960s. Seasonal analysis of the climatic time-series reveals that the winter season (December-February) and the spring season (March-May) are the most variable seasons throughout the decades (Fig. 3, 5, 7). They contribute 56% to 84% to the annual variation of the mean annual climatic time-series (Table 2).

Comparison of decadal air temperature sums of four sites at West Greenland shows that at the northern sites Upernavik (Fig. 8a) and Egedesminde (Fig. 8b), January to March temperatures were consistently lower than December to February temperatures. It would appear that at these sites winters extended into March throughout the entire time-series. The two southern sites, Nuuk (Fig. 8c) and Prins Christian Sound (Fig. 8d), indicate that there was variation in winter duration during the decades. In recent times winters became longer from the 1960s onwards, and the 1980s and 1990s showed extremely cold and long winters. Similar conditions were encountered at Nuuk near the end of the 19th century, during the 1870s and 1880s. Warmer winters were observed during the first part of the 20th century with January to March decadal air temperature sums being less than those sums of December to February.

The warmer than normal winter conditions during the first half of the 20th century could have led to favourable environmental conditions during spawning of cod and hence to increasing cod (*Gadus morhua*) populations off West Greenland.

Sea-ice cover showed high variability in the southern parts off West Greenland. There was no ice observed during 1998 to 2000 in the 1x1° boxes off Nuuk and Prins Christian Sound (Fig. 11, 12). The record cold years of the early 1990s, 1992 and 1993, indicate largest ice cover off Nuuk. The southern tip of Greenland was covered with sea-ice during most of the first half of 1993 (Fig. 12).

The two northern 1x1° boxes off Upernavik (Fig. 9) and off Egedesminde (Fig. 10) show an all year presence of ice which amounts to about 60% and about 20%, respectively. From 1997 onwards, the amount and duration of sea-ice cover is diminishing at both sites.

Upper ocean climatology for the 1990s between Greenland and Labrador as taken from IGOSS (Fig. 13, 14) reveals considerable warming from 1996 onwards. Warming is, however, mostly confined to the Labrador side of the area. Off West Greenland these data show mostly cooling which is contradictory to the atmospheric and sub-surface conditions (see below). Referring to Fyllas Bank Station 4 autumn temperature data (Fig. 15), only the 1992 SST anomalies (Fig. 13, upper right panel) indicate consistent anomalous cold conditions off West Greenland.

Sub-surface oceanographic observations (Fig. 15) reveal warmer-than-normal conditions during most of the 1990s. The Irminger layer (200-300 m) shows record warming for 1998 (Fig. 15, lower panel). Salinities were mainly above- or around-normal with a major negative deviation occurring in 1993 (Fig. 16, lower panel). The above-normal salinities of the Irminger layer are consistent with the northward extension of the sub-surface expression of the Irminger component in the West Greenland Current, the Irminger water mass which was found well north off West Greenland during the four recent years of the 1990s (Fig. 17).

Conclusion

The 1990s were a decade of extremes: The North Atlantic Oscillation (NAO) index flipped from one of its most positive values in winter 1995 to its most negative values in the winter thereafter (1995: +3.96; 1996: -3.78) and reached a high level again during the winter of 2000 (2.8). Nuuk air temperatures followed these extremes in the first part of the 1990s when a high NAO-index was paralleled by cold air temperatures at Nuuk (Fig. 18). Northward extension of Irminger Water along the West Greenland banks and slopes showed extreme situations in 1992 (no Irminger mode water found), and in 1999 (northernmost extension of Irminger mode water found). Sub-surface water mass properties indicated record low salinities in the Irminger water layer during 1993 and warmest conditions in this layer during 1998. It would appear that polar water masses were mostly present around 1992 and 1993 as far as the surface layer (Fig. 15) and the deep Irminger mode water layer are concerned, and waters of southern origin like the Irminger component of the West Greenland Current system dominated the second half of the 1990s (e.g. record warm conditions in Irminger mode water layer during 1998, Fig. 15). Sea ice cover at the two southernmost sites off West Greenland, Nuuk and Prins Christian Sound, show concentrations of ice in the first half of the 1990s. From 1998 onwards there was no considerable sea ice cover observed in the vicinity of these stations. The northern two locations, Upernavik and Egedesminde, reveal significant decrease of sea ice cover during the second half of the 1990s. Winter duration at West Greenland meteorological observation sites seems to differ from north to south: Whereas winters at Upernavik and Egedesminde extend into March during previous decades, Nuuk and Prins Christian Sound observations show longer winters (extending into March) from the 1960s onwards. Before that period, winters were shorter at Nuuk and the southern tip of Greenland. It is suggested here that the warmer than normal winter conditions during the first half of the 20th century could have led to favourable environmental conditions during spawning of cod and hence to increasing cod (*Gadus morhua*) populations off West Greenland.

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Table 1: Climatic Means [°C] (1961-1990) for sites given in Fig. 1

Site	**Lat/Lon**	**DJF**	**MAM**	**JJA**	**SON**	**ANN**	**Data**
Egedesminde	68.7N, 52.8W	-12,95	-9,25	4,58	-1,90	-4,88	1949-2001
Godthaab/Nuuk	64.2N, 51.8W	-7,14	-3,76	5,51	-0,23	-1,41	1866-2001
Prins Chr.Sound	60.0N, 43.2W	-3,71	-0,98	5,75	1,49	0,63	1949-2001

Table 2: Seasonal contribution (R^2) to annual variation for sites given in Fig. 1. (**bold:** significant at .950 level)

Site	**Lat/Lon**	**DJF**	**MAM**	**JJA**	**SON**	**Data**
Upernavik	72.8N, 56.2W	**0,73**	**0,56**	**0,30**	**0,24**	1873-1981
Egedesminde	68.7N, 52.8W	**0,84**	**0,73**	**0,25**	**0,12**	1949-2001
Godthaab/Nuuk	64.2N, 51.8W	**0,75**	**0,63**	**0,51**	**0,36**	1866-2001
Prins Chr.Sound	60.0N, 43.2W	**0,56**	**0,64**	**0,48**	**0,43**	1949-2001

Table 3: Climatic Means [°C/ psu] (1963-1990) Fyllas Bank Station 4

Site	**Lat/Lon**	**0-50m**	**0-200m**	**200-300m**	**Data**
Fyllas Bank Temperature	63°53’N,53° 22’W	1.73	2.68	4.78	1963-2001
Fyllas Bank Salinity	63°53’N,53° 22’W	33.01	33.48	34.56	1963-2001

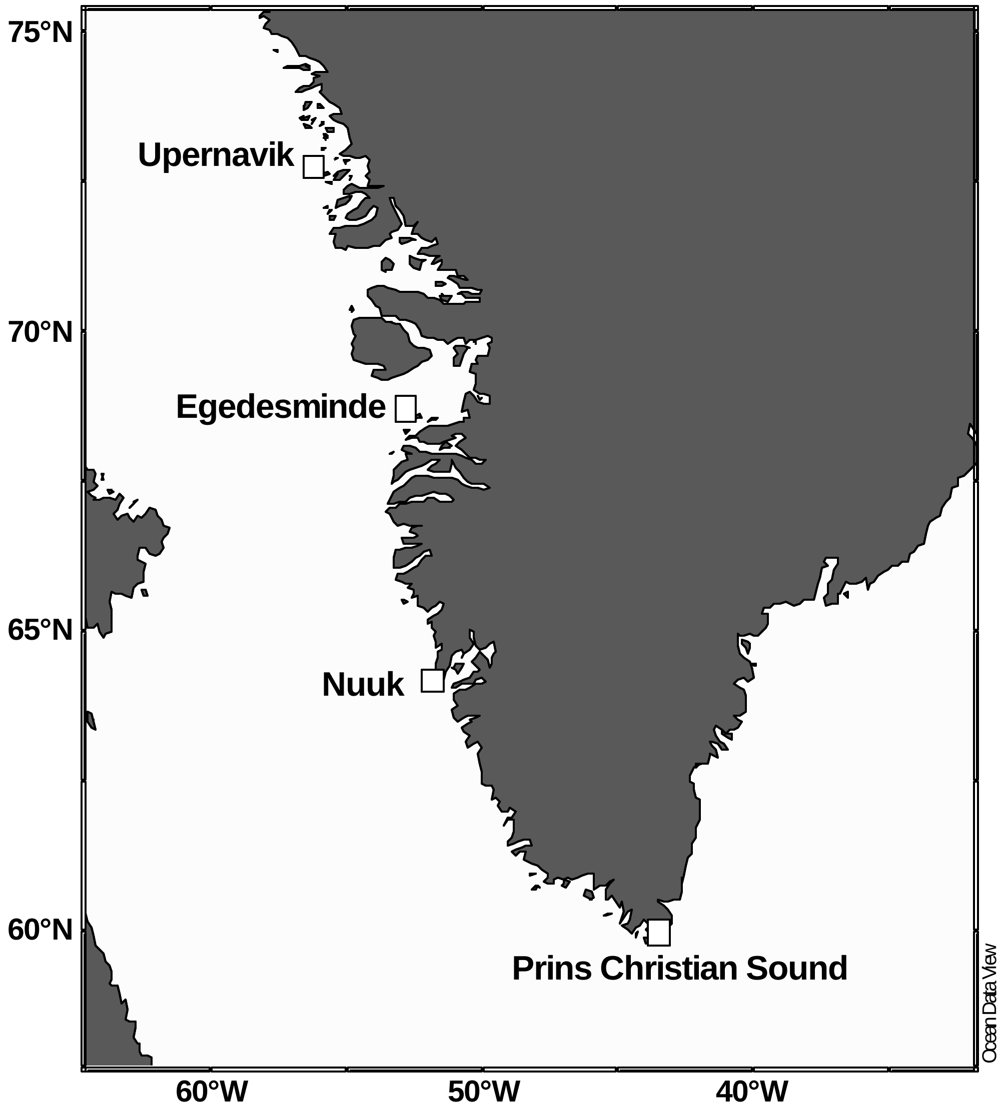

Fig. 1. Locations of sites for climatic background time-series as given in Table 1.

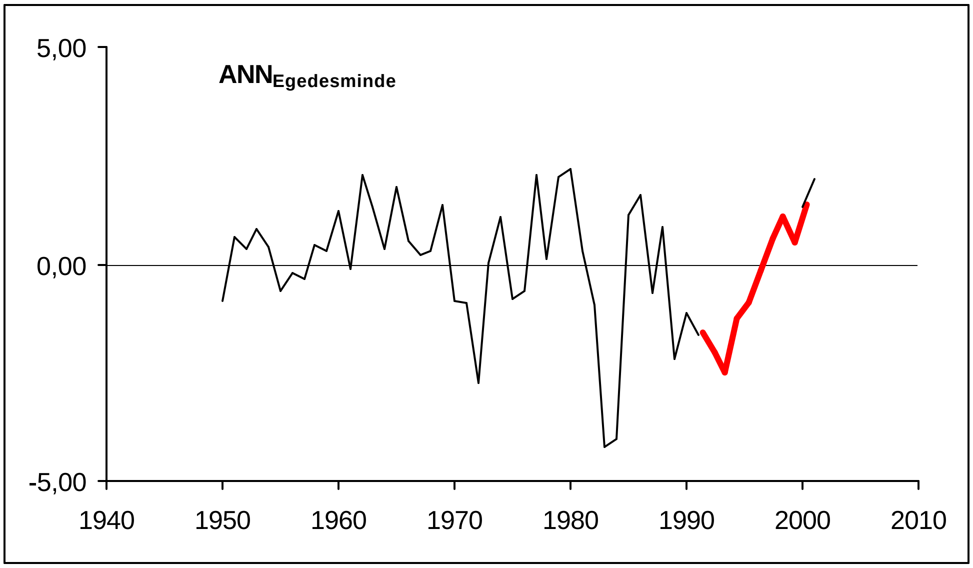

Fig. 2. Mean annual air temperature anomaly [K] Egedesminde (ref. to climatic mean as given in Table 1); **bold:** 1991-2000.

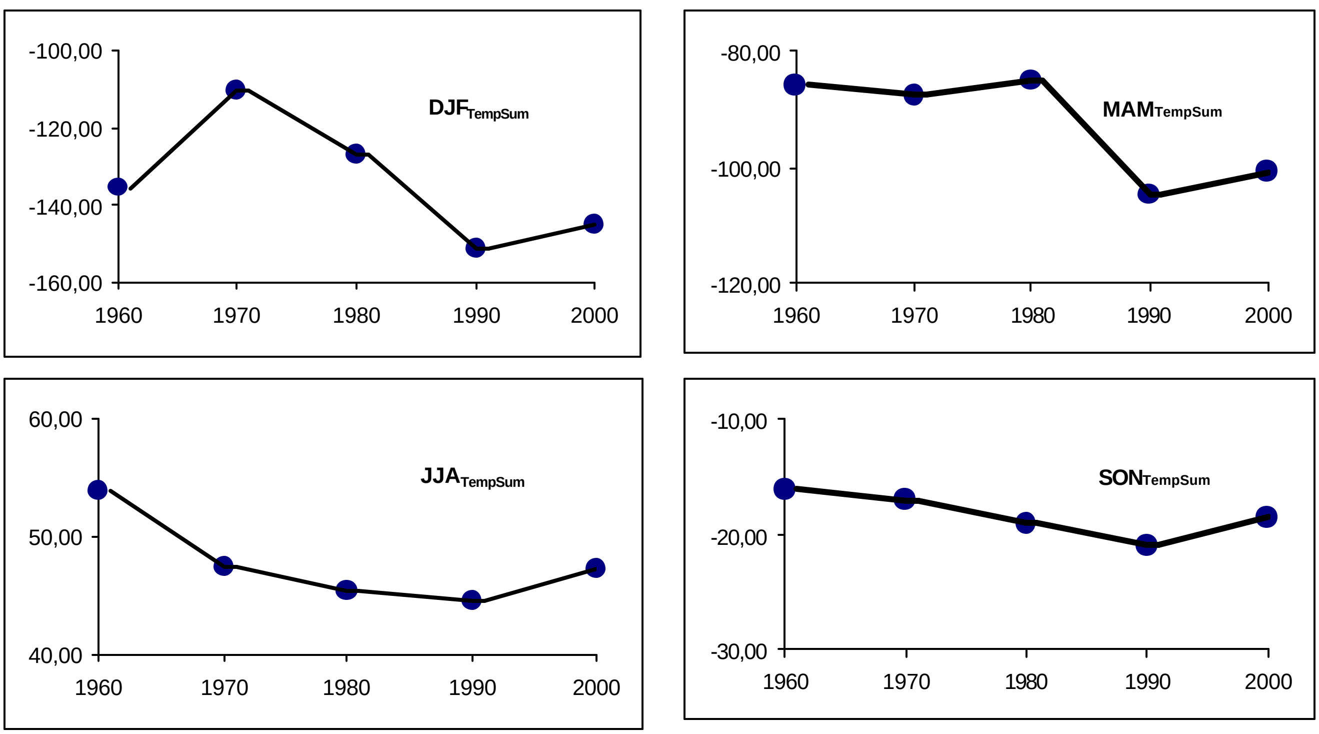

Fig. 3. Seasonal decadal air temperature sums [K] Egedesminde (last year of decade shown: e.g. 2000 denotes 1991-2000) DJF=December, January, February; MAM=March, April, May; JJA=June, July, August; SON=September, October, November.

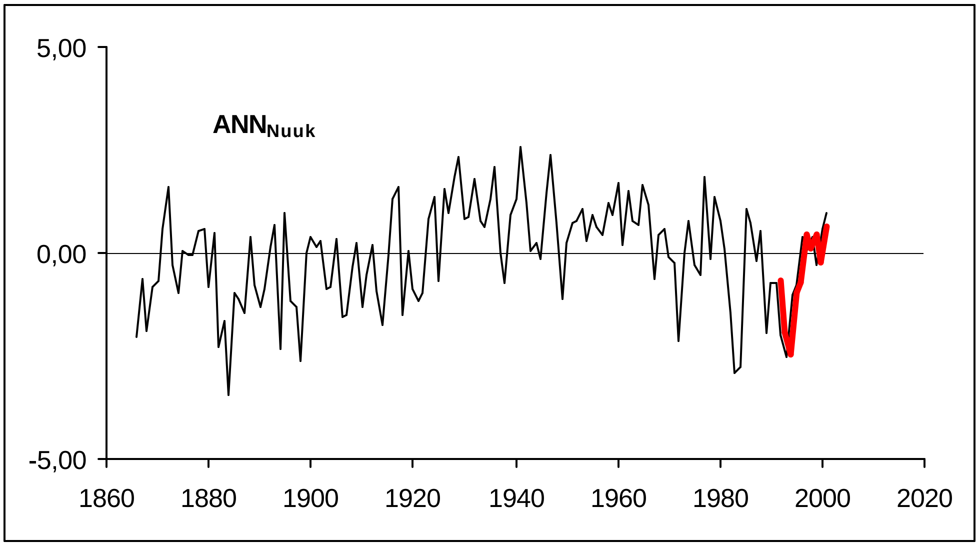

Fig. 4. Mean annual air temperature anomaly [K] Nuuk (ref. to climatic mean as given in Table 1); **bold:** 1991-2000.

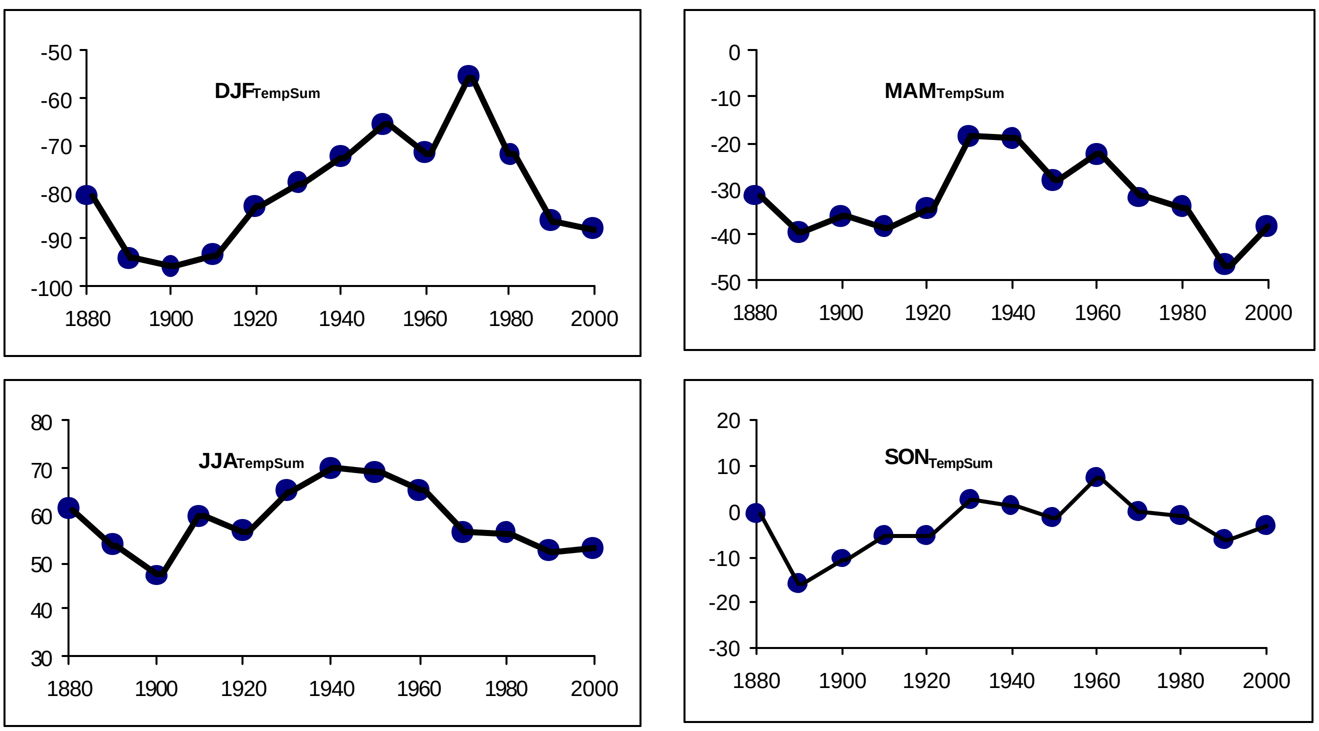

Fig. 5. Seasonal decadal air temperature sums [K] Nuuk (last year of decade shown: e.g. 2000 denotes 1991-2000) DJF=December, January, February; MAM=March, April, May; JJA=June, July, August; SON=September, October, November.

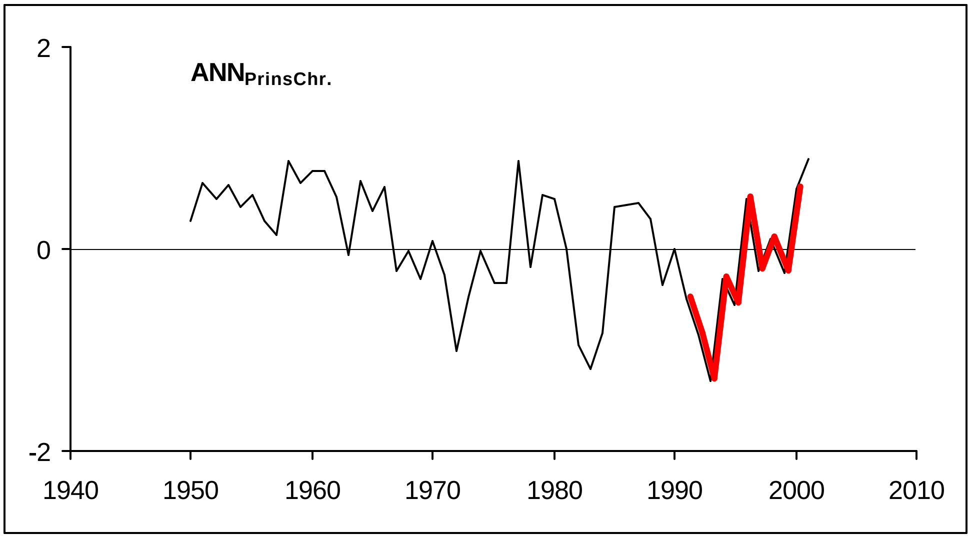

Fig. 6. Mean annual air temperature anomaly [K] Prins Christian Sound (ref. to climatic mean as given in Table 1); **bold:** 1991-2000.

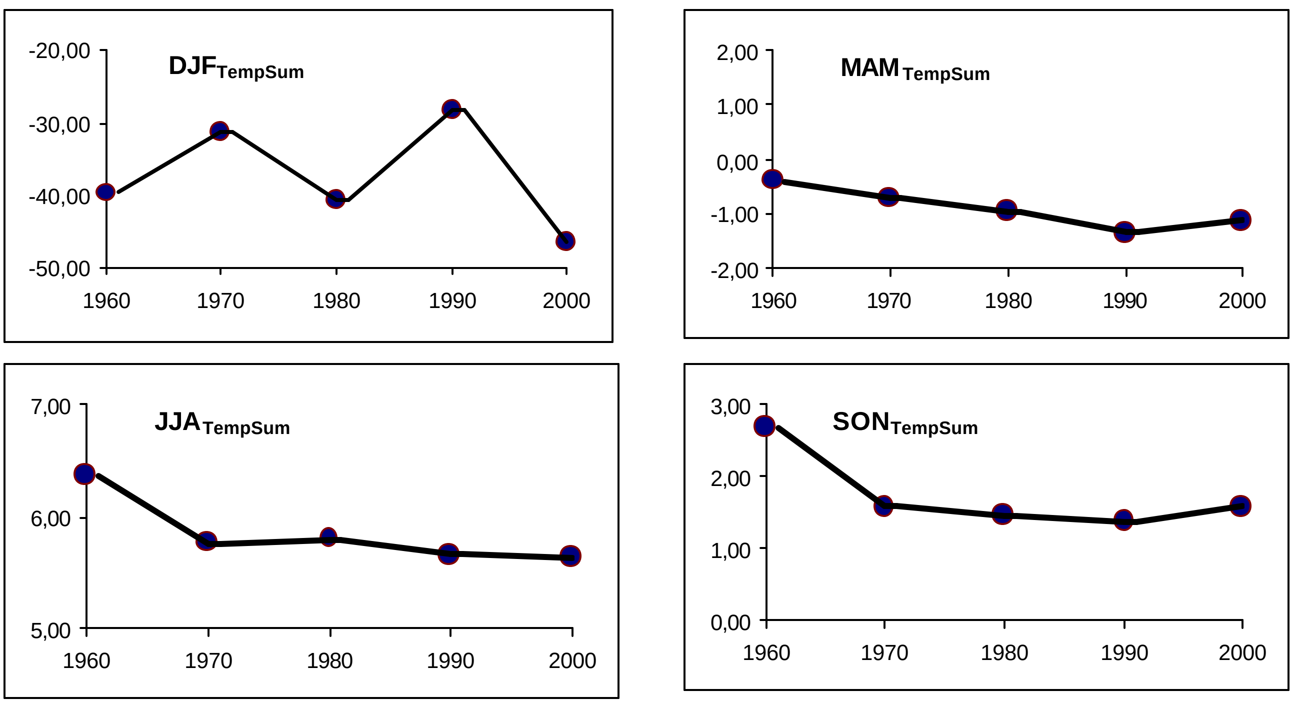

Fig. 7. Seasonal decadal air temperature sums [K] Prins Christian Sound (last year of decade shown: e.g. 2000 denotes 1991-2000); DJF=December, January, February; MAM=March, April, May; JJA=June, July, August; SON=September, October, November.

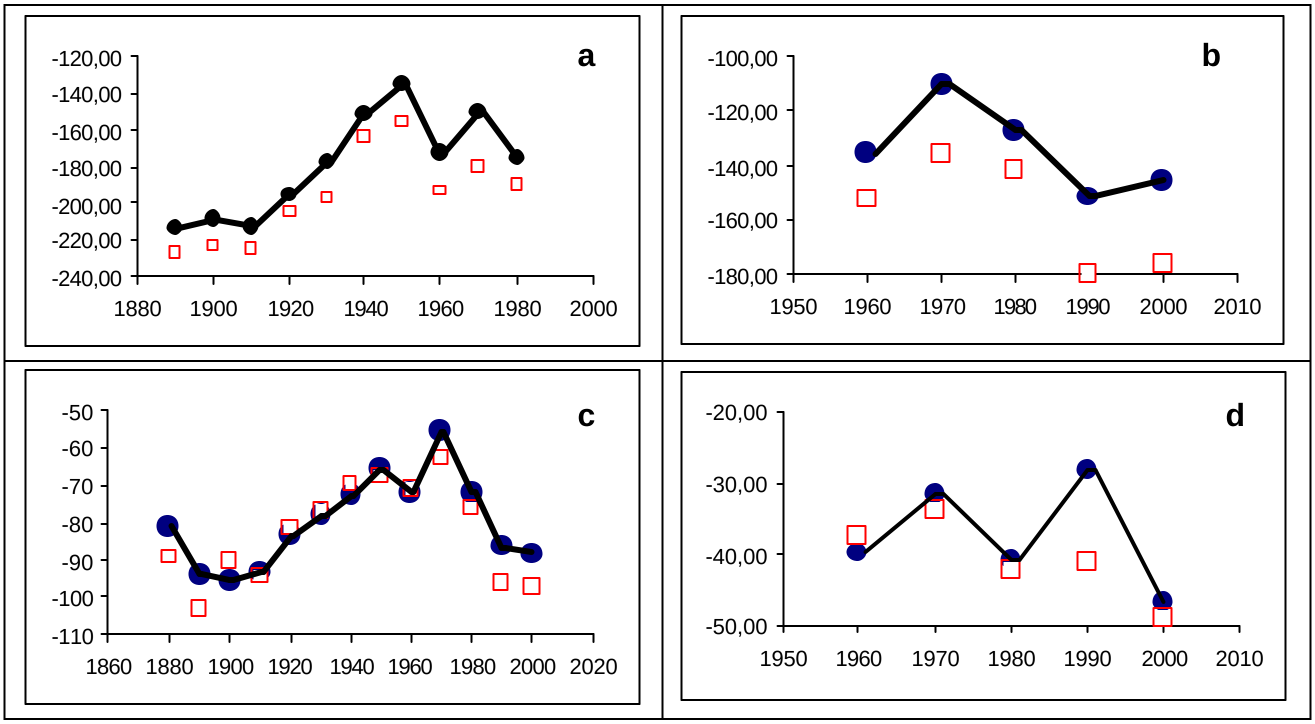

Fig. 8. Winter decadal air temperature sums [K]: (a) Upernavik, (b) Egedesminde, (c) Nuuk, (d) Prins Christian Sound (last year of decade shown: e.g. 2000 denotes 1991-2000); dots and lines: December, January, February; open rectangles: January, February, March.

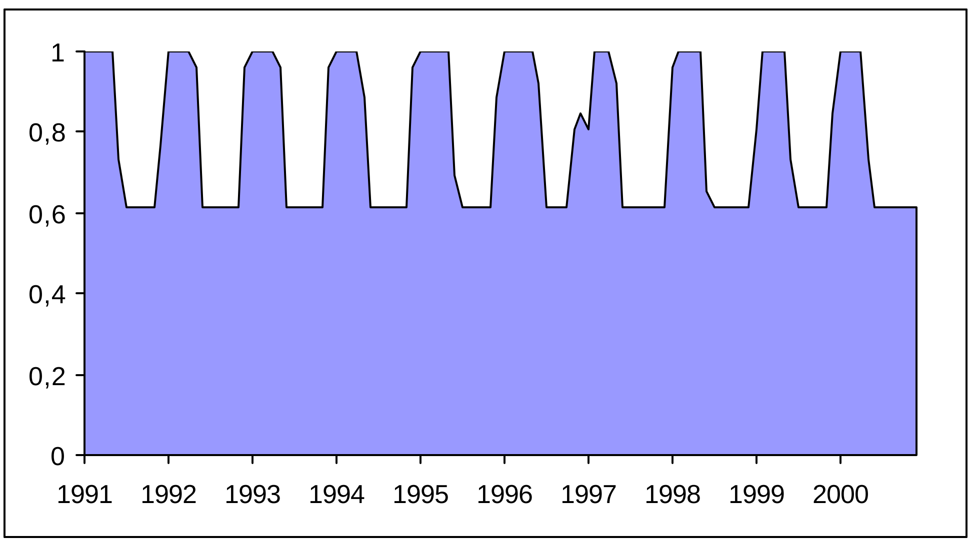

Fig. 9. Sea-ice cover of the 1x1° box Upernavik 72N-73N, 56W-57W: 0 = no ice; 1 = full ice cover. Insert map in Fig. 11 and 12 shows the location of the box.

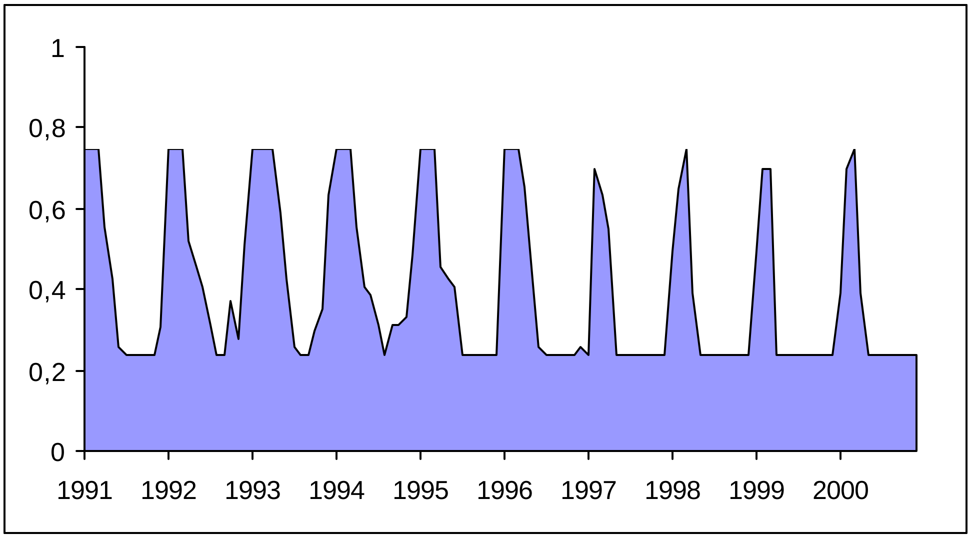

Fig. 10. Sea-ice cover of the 1x1° box Egedesminde 68N-69N, 53W-54W: 0 = no ice; 1 = full ice cover. Insert map in Fig. 11 and 12 shows the location of the box.

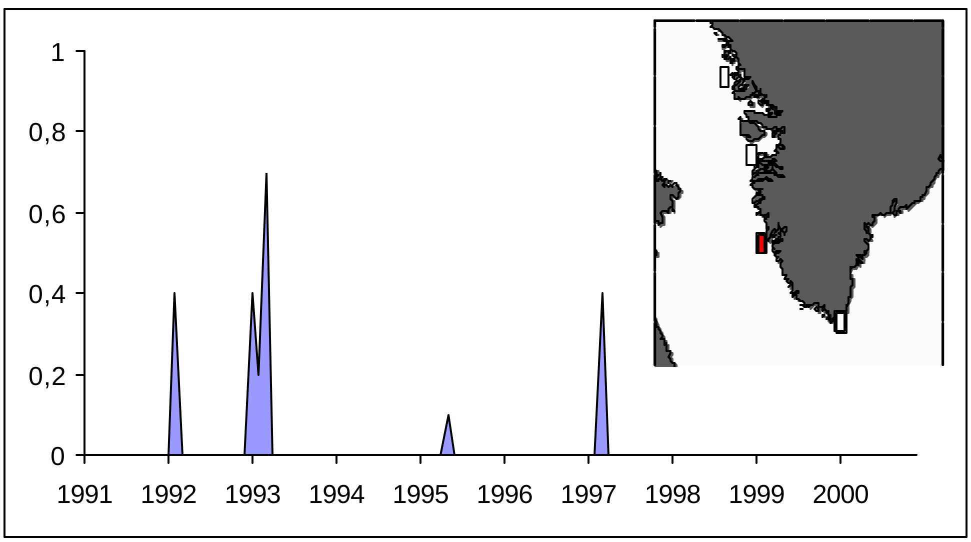

Fig. 11. Sea-ice cover of the 1x1° box Nuuk 63.5N-64.5N, 52W-53W: 0 = no ice; 1 = full ice cover. Insert map shows the location of the box.

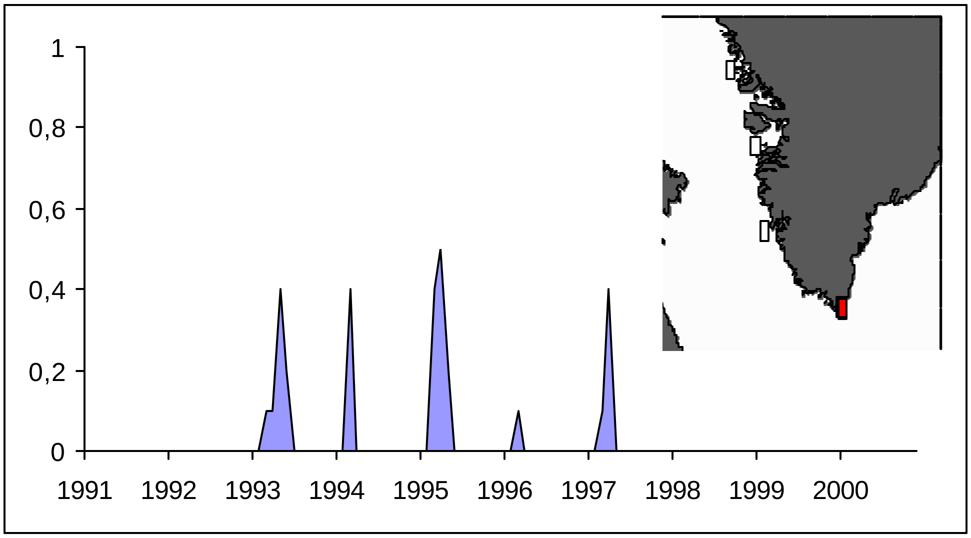

Fig. 12. Sea-ice cover of the 1x1° box Prins Christian Sound 59.5N-60.5N, 43W-44W: 0 = no ice; 1 = full ice cover. Insert map shows the location of the box.

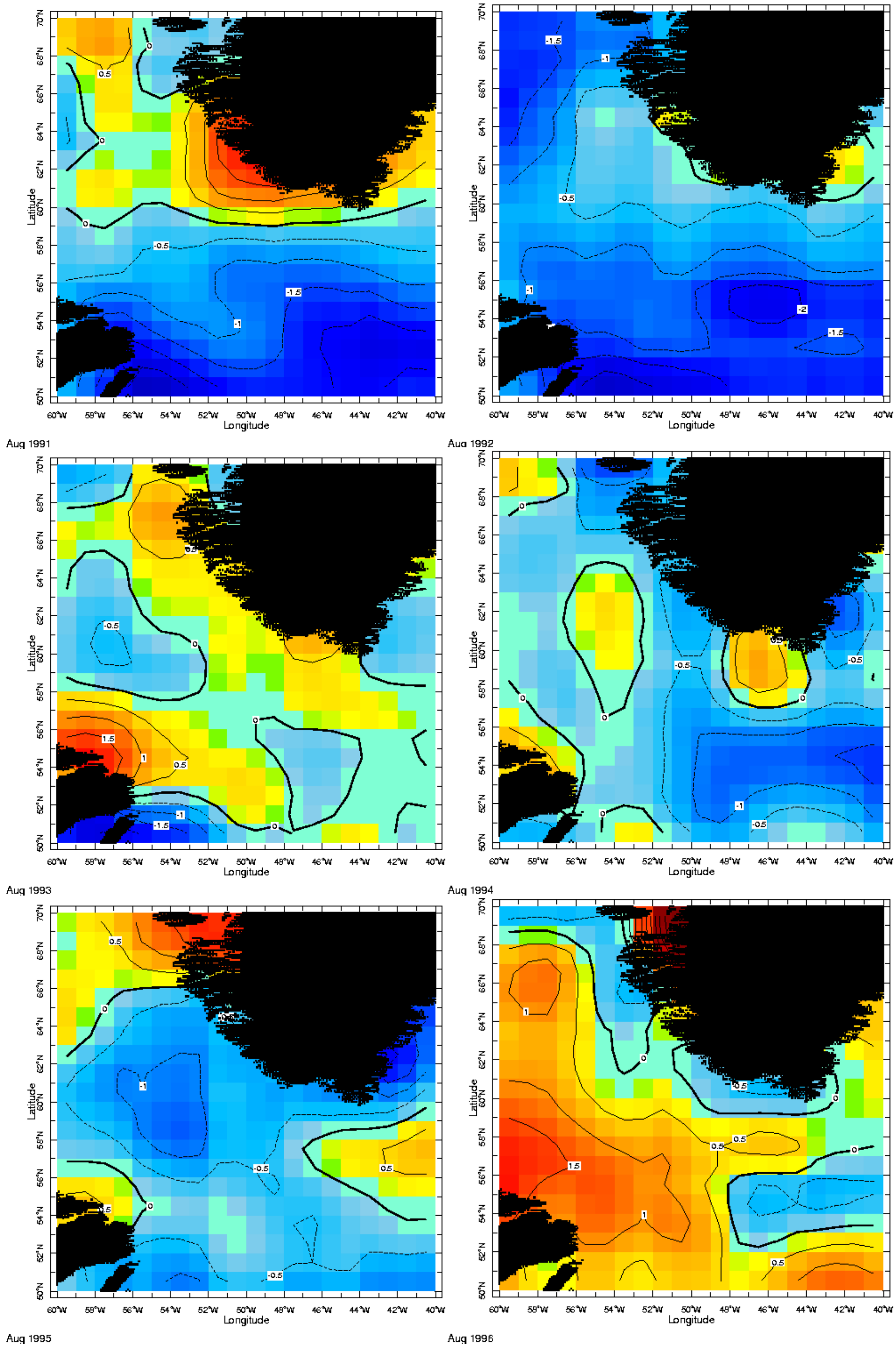

Fig. 13. Sea-Surface Temperature Anomalies during August 1991-1996.

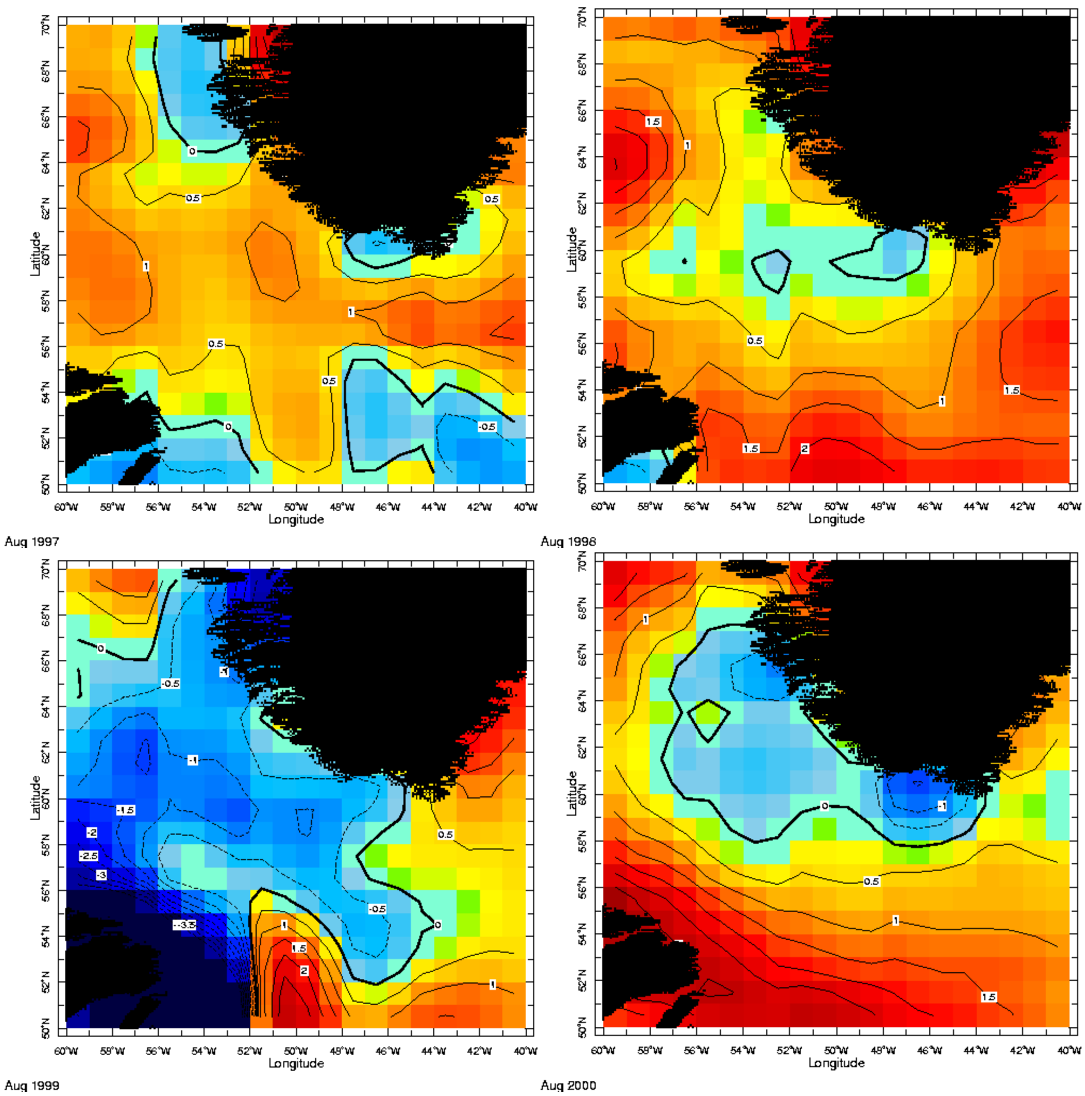

Fig. 14. Sea-Surface Temperature Anomalies during August 1997-2000.

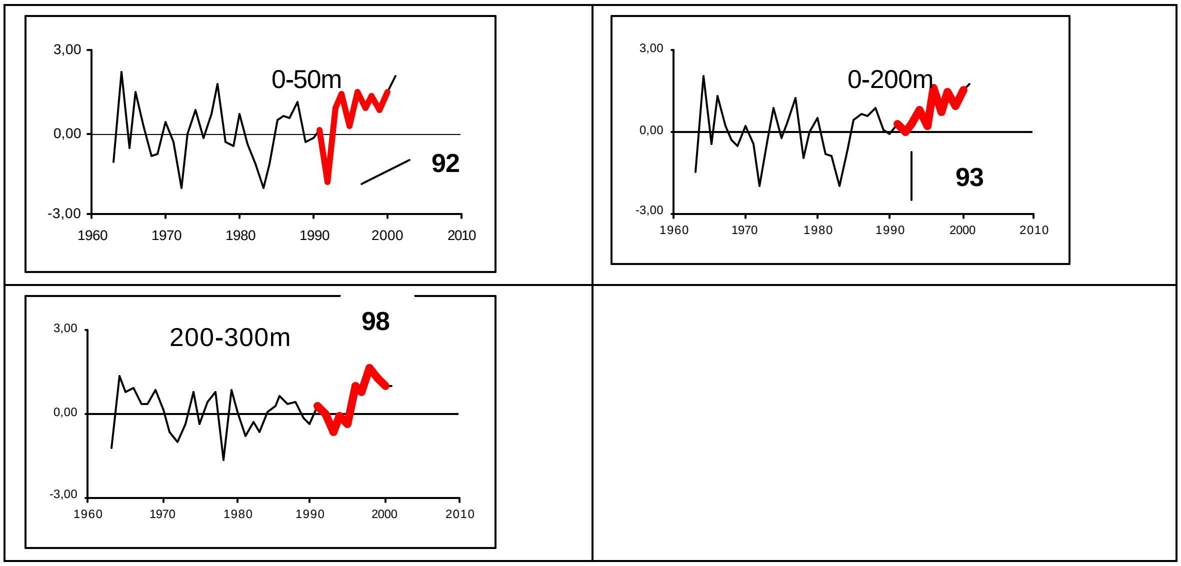

Fig. 15. Fyllas Bank Station 4 temperature anomaly autumn, 0-50 m, 0-200 m and 200-300 m; **bold:** 1991-2000.

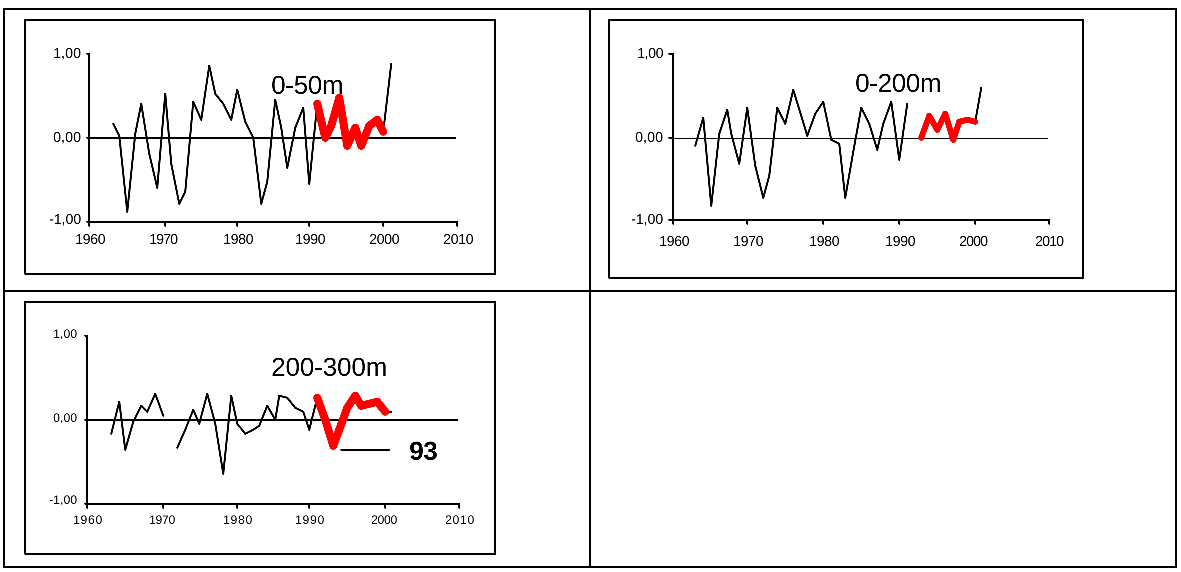

Fig. 16. Fyllas Bank Station 4 salinity anomaly autumn, 0-50 m, 0-200 m and 200-300 m; **bold:** 1991-2000.

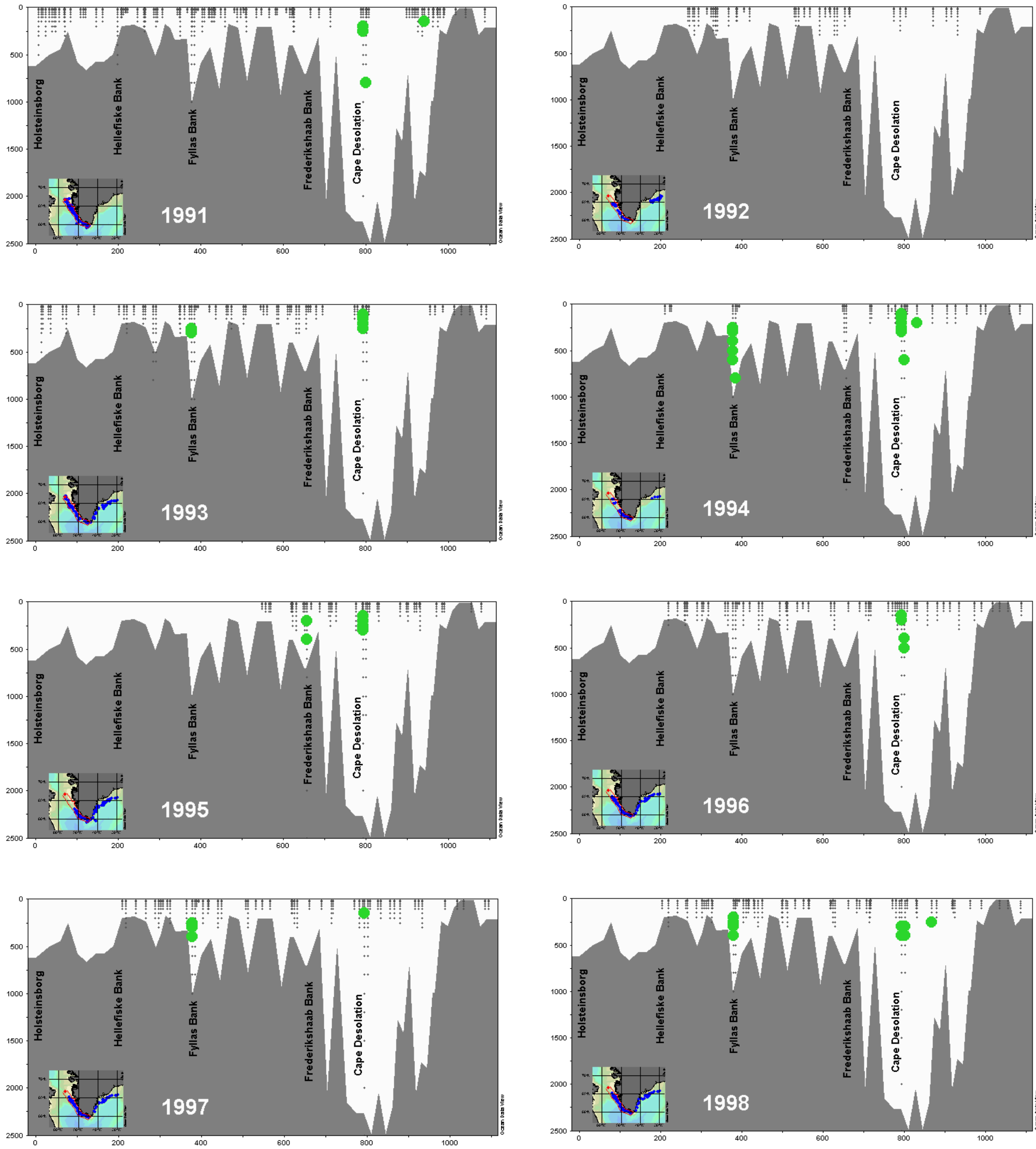

Fig. 17. Presence of Irminger Water mass along West Greenland shelf and slope region during 1991-2000.

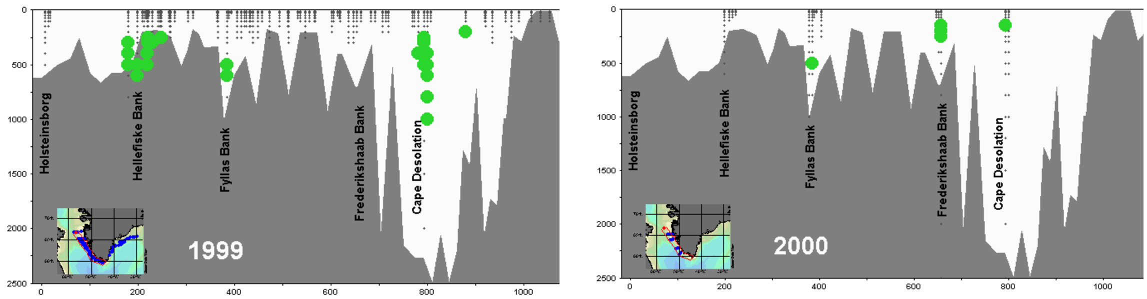

Fig. 17. Continued.

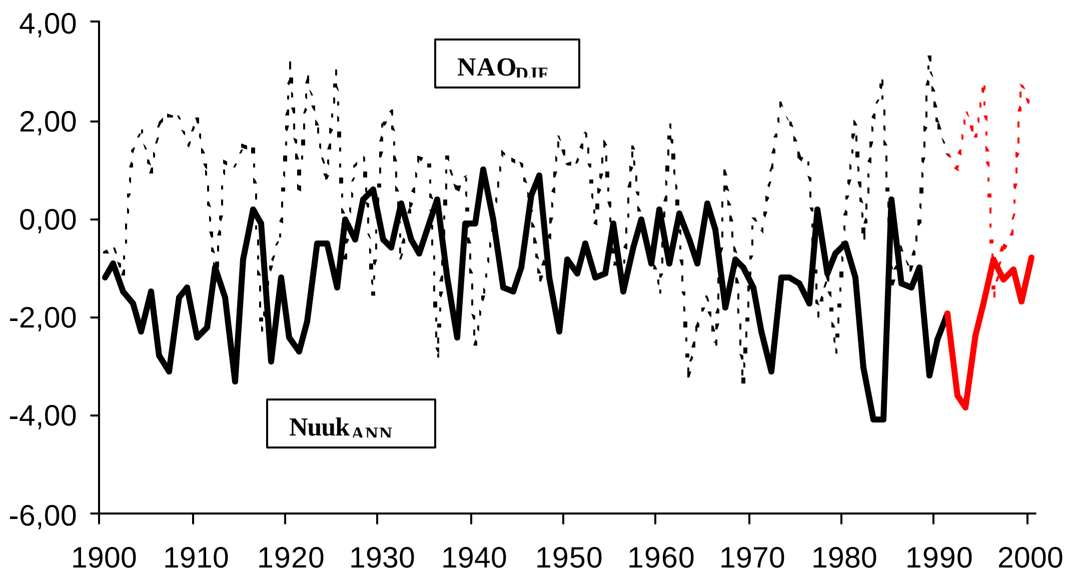

Fig. 18. NAO index (dotted) and annual mean temperature Nuuk (**red:** 1991-2000).