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Air-Sea-Ice Conditions off Southwest Greenland, 1981–97

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Abstract

The oceanography along the Southwest Greenland fishing banks is dominated by the inflow of water masses originating from various regions in the North Atlantic and Arctic Ocean carried to the area by the East Greenland Current, the Irminger Current and a side-branch of the North Atlantic Current. The existence of the latter transport has only recently been discovered and has led to the description of a new water mass in the Southwest Greenland area called the *Northwest Atlantic Mode Water*.

During the 1981–97 period Greenland experienced great fluctuations in climate. The North Atlantic Oscillation index has since the early-1980s been in a persistent and exceptionally strong positive phase, which results in cold and dry conditions over Greenland. Greenland has been characterized by very cold conditions since 1980 especially in the 1982–84 period, when record cold winters were experienced. Similarly the 1989–94 period was also extremely cold. These cold atmospheric conditions were reflected in the waters off Southwest Greenland by temperatures well below normal in the upper 400 m. Along with an increase in the formation of "Westice", the ice limit moved so far south that the situation seldom seen, of "Westice" and "Storis" joining each other in the Julianehaab Bight during the winter months, has been experienced several times during the recent 15 years.

Key words: currents, Greenland, ice, oceanography, temperature

Introduction

Knowledge of the oceanographic conditions in an ocean area, and in particular their variability, is extremely important to the assessment of: 1) climate variability, 2) environmental impact on living resources (primary production, fish stocks, marine mammals), 3) possibilities for exploitation of the living and non-living resources of the sea, and 4) possibilities for the establishment of an operational oceanographic service.

The oceanographic conditions of the Greenland waters are generally well known. The oceanography along the Southwest Greenland fishing banks is dominated by the inflow of water masses originating from various regions in the North Atlantic and Arctic Ocean carried to the area by the East Greenland Current, the Irminger Current and a side-branch of the North Atlantic Current. The existence of the latter transport has only recently been discovered (Buch, 1990) and has led to the description of a new water mass in the Southwest Greenland area called the *Northwest Atlantic Mode Water*. The Oceanographic conditions have been thoroughly discussed in Buch (1990). It is recognized that seasonal and interannual variability can be substantial. These can be reflected by climatic signals transferred to the Greenlandic area by the atmosphere and/or the ocean currents which influence the Greenland waters, i.e. the East Greenland Current, and a couple of side branches of the North Atlantic Current of which the Irminger Current is one.

The Greenland area has during the 1981–97 period been characterized by dramatic climatic variability. Especially remarkable were two extremely cold periods, 1982–84 and 1989–94. The winters of 1983 and 1984 were the coldest ever recorded at Greenland since regular meteorological observations started in 1873. These cold atmospheric conditions were reflected to the surface layer of the ocean having a severe impact on the living conditions of the economically important fish stocks, primarily the cod stock.

The objective of the present paper is to give an overview of the most important events in the oceanographic conditions in the Greenland waters in the 1981–97 period. The paper will especially focus on the waters off Southwest Greenland from Cape Farewell to the Disko Bay because of the economic importance of this area to the Greenland society.

Materials and Methods

The Greenland Fisheries Research Institute has since its inception in 1947 tried to operate oceanographic studies at all standard sections (Fig. 1) in the Convention areas of the International Commission for Northwest Atlantic Fisheries (ICNAF up to 1979) and Northwest Atlantic Fisheries Organization (NAFO, since 1980) along the west coast of Greenland. Sections were studied at least once a year, with especially the Fylla Bank section several times per year. In fact, all sections north of the Fylla Bank section were covered twice a year (June-July and November) while the southernmost sections were occupied only once (March–April). In 1990 the oceanographic activity was reduced due to reorganisation of the Institute, and the work on the standard sections was not conducted in 1991. From 1992 to 1997 one annual survey cruise to the NAFO standard sections has been performed by the Royal Danish Administration of Navigation and Hydrography on a contract with the Greenland Fisheries Research Institute, and since 1998 the Danish Meteorological Institute has undertaken this task.

The Greenland Fisheries Research Institute used Nansen Bottles equipped with reversing thermometers for their oceanographic observations until 1989 when a SEABIRD SBE 9-011 CTD was introduced in the work. The same type of CTD has been used by the Royal Danish Administration of Navigation and Hydrography. The maximum depth of observation has always been 1 000 m. Calibration of the CTD sensors were done *in vitro* at the manufacturer's calibration facilities and *in situ* by taking water samples at the deepest level of stations. The water samples collected for salinity analysis when using Nansen Bottles and those taken for CTD calibration purposes were analysed using a Guildline Autosal 8400 or a Guildline Portosal 8410.

Additionally temperature and salinity data from the Southwest Greenland area, as published in World Ocean Atlas 1994, have been used here for studies of inflow of water masses of Atlantic origin. World Ocean Atlas 1994 contains oceanographic data dating back to the beginning of the 1900s. These data were analysed using the Ocean Data View Software.

The Danish Meteorological Institute has carried out meteorological observations in Greenland since 1873, and the Institute kindly made observations from selected localities available for the present study. The Danish Meteorological Institute has also, for almost the same period, collected information on the distribution of sea ice in Greenland waters, and this work was optimised in 1959 when the Greenland Ice Service was formed and regular observation flights were carried out. These data are considered in this study.

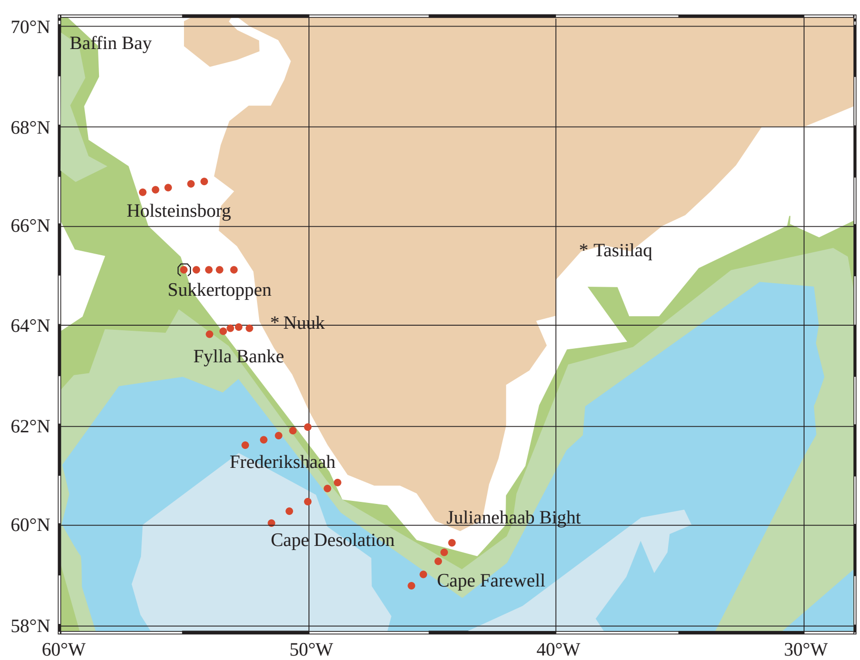

Fig. 1. Map showing area of investigation and standard sections established by ICNAF/ NAFO.

Results and Discussion

Atmospheric conditions

General aspects. Recent climatic research has demonstrated that the North Atlantic Oscillation (NAO) and the El Niño-Southern Oscillation (ENSO) together are major components of interannual variability of weather and climate around the world (Hurrell and Van Loon, 1997). While there has been a major public interest and awareness of the El Niño event in 1997–98 and its many climatic consequences, the NAO has been a relatively unknown phenomenon outside the scientific community. But there are close correlations between NAO and the climate in the North Atlantic region, Greenland and Europe.

The NAO, which is associated with changes in the surface westerlies across the Atlantic onto Europe, refers to a meridional oscillation in the atmospheric mass with centres of action near the Iceland Low and the Azores High (van Loon and Rogers, 1978). Although it is evident throughout the year, it is most pronounced during winter and accounts for more than one-third of the total variance of the Sea Level Pressure (SLP) field over the North Atlantic. Because the signature of the NAO is strongly regional, a simple index of NAO was defined by Hurrell (1995) as the difference between the normalised mean winter (December–March) SLP anomalies at Lisbon, Portugal and Stykkisholmur, Iceland. The SLP anomalies at each station were normalised by dividing each seasonal pressure by the long-term mean (1964–95) standard deviation. The variability of the NAO index since 1864 is shown in Fig. 2, where the heavy solid line represents the low pass filtered meridional pressure gradient. Positive values of the index indicate stronger than average westerlies over the middle latitudes associated with low-pressure anomalies over the region of the Icelandic Low and anomalous high pressures across the subtropical Atlantic.

In addition to a large amount of interannual variability, there have been several periods when the NAO index persisted in one phase over many winters (van Loon and Rogers, 1978; Barnett, 1985; Hurrell and van Loon, 1997). Over the region of the Icelandic Low, seasonal pressures were anomalously low during winter from the turn of the century until about 1930 (with exception of the 1916–19 winters), while pressures were higher than average at lower latitudes. Consequently, the winds onto Europe had a strong westerly component and the moderating influence of the ocean contributed to higher than normal temperatures over much of Europe (Parker and Folland, 1988). From the early-1940s until the early-1970s, the NAO index exhibited a downward trend until the extreme low NAO of the 1970s, and this period was marked by European wintertime temperatures that were frequently lower than normal (van Loon and Williams, 1976; Moses *et al*., 1987). A sharp

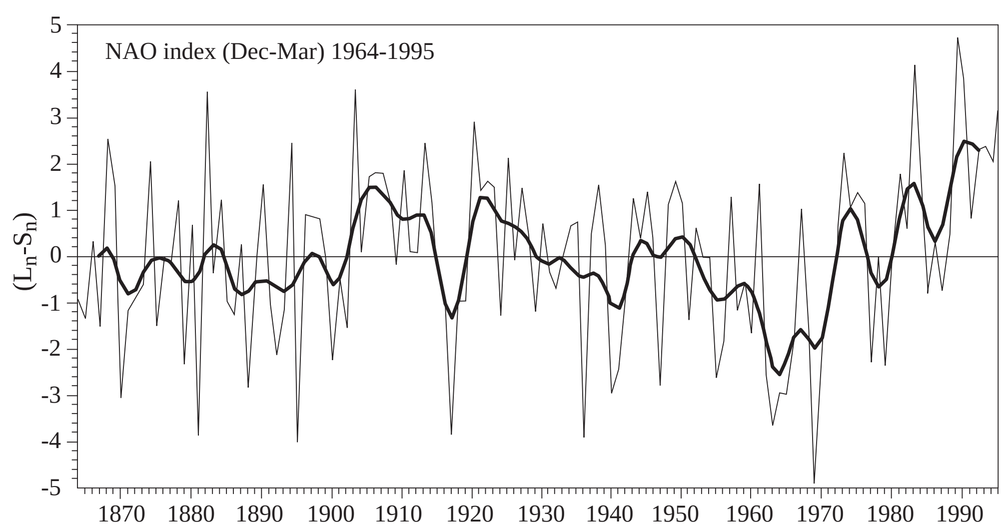

Fig. 2. Time series of the winter (December–March) index of the NAO (L_n-S_n) (as defined in the text) from 1864–95. The heavy solid line represents the meridional pressure gradient smoothed with low pass filter to remove fluctuations with periods less than 4 years. (After Hurrell and van Loon, 1997).

reversal has occurred over the past 25 years and, since 1980, the NAO has remained in a highly positive phase with SLP anomalies of more than 3 mb in magnitude over both the subpolar and the subtropical Atlantic. The 1983, 1989 and 1990 winters were marked by the highest positive values of the NAO index recorded since 1864 (Fig. 2).

The changes in local land- and sea-surface winter (December–March) temperatures based on linear regression with the NAO index 1864-1994 are shown in Fig. 3. Changes of more than 1°C associated with a one standard deviation change in the NAO index occurred over the Northwest Atlantic and extended from northern Europe across Eurasia. Changes in temperatures over northern Africa and Southeast United States were also noticeable.

The surface winter (December–March) temperature anomalies for the North Atlantic and surrounding landmasses for the 1980–94 period are shown in Fig. 4. The similarity between the departure pattern of temperature (Fig. 3) and the 1980–94 (Fig.4) conditions is striking and suggests that the recent temperature anomalies over these regions are strongly related to the persistent and exceptionally strong positive phase of the NAO index since the early-1980s.

These descriptions of the NAO index clearly illustrate the strong correlation between the strength of the westerlies across the North Atlantic, i.e. the NAO index, and the climate in Greenland and Europe. It also shows that the climate in Greenland and Europe are negatively correlated to each other, a phenomenon named "Seesaw" Van Loon and Rogers (1978).

Conditions over Greenland. Time series of annual mean air temperatures from Nuuk, West Greenland and Tasiilaq, East Greenland is shown in Fig. 5. In addition to the interannual variability, all stations reflect the general picture of variability outlined above in the description of the NAO index (Fig. 2).

Some geographical differences can be recognized, of which one of the most significant is the relatively long cold period experienced in Tasiilaq, East Greenland in the late-1960s and early-1970s, Fig. 5b. These cold conditions can also be traced at the southernmost West Greenland stations around 1970. The cause for the cold conditions at East and Southwest Greenland around 1970 has been thoroughly discussed in literature. This well known "Mid-seventies anomaly" or the "Great salinity anomaly", which was traced all over the North Atlantic

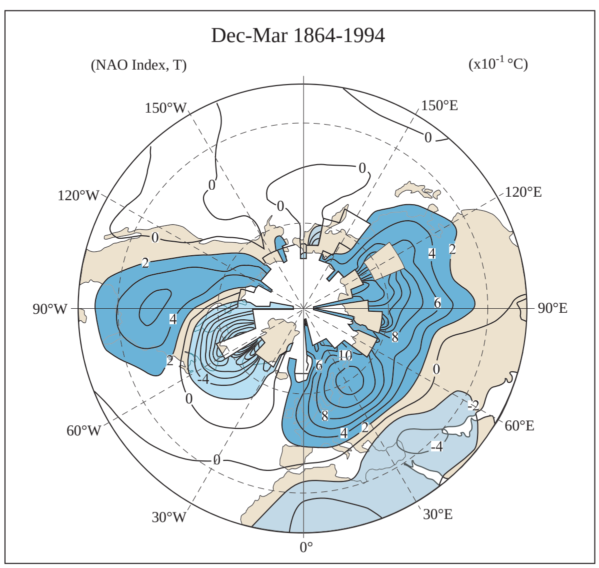

Fig. 3. Land- and sea-surface temperature changes (0.1°C) corresponding to one standard deviation of the NAO index computed over the winters (December–March) from 1864 through 1994. The contour increments are 0.2°C, and regions of insufficient data are not contoured. (After Hurrell and van Loon, 1997).

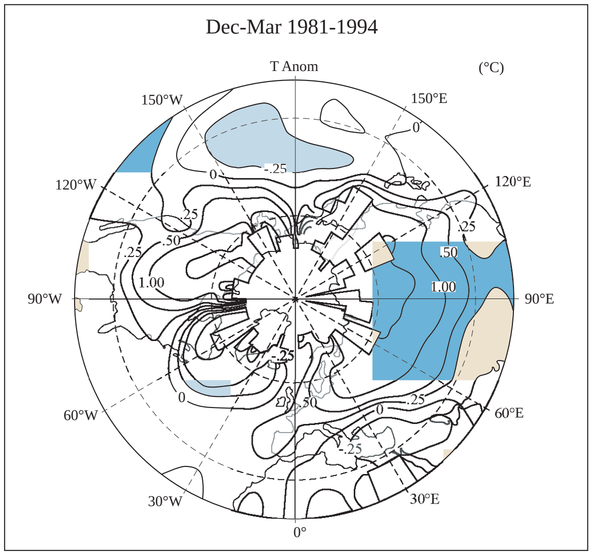

Fig. 4. Average surface temperature (°C) and SST anomalies over fourteen years (December–March) 1981–94. Temperature anomalies >0.25°C are indicated by dark shading and those <-0.25°C are indicated by light shading. Regions of insufficient data coverage are not contoured. (After Hurrell and van Loon, 1997).

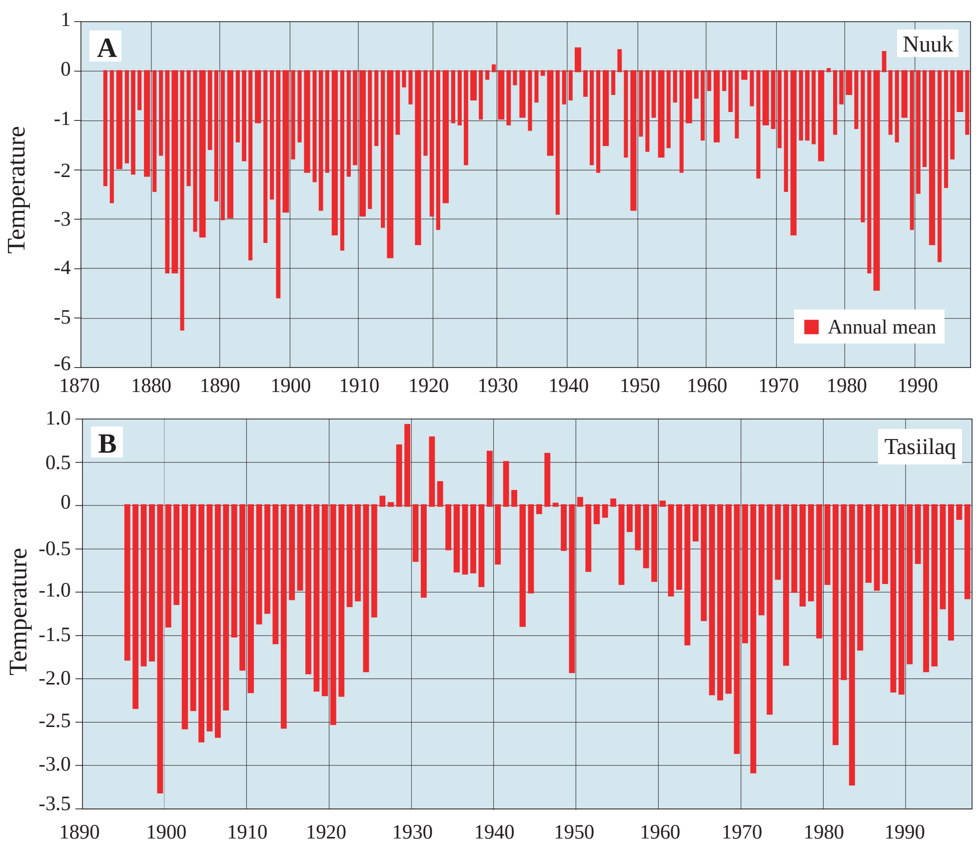

Fig. 5. Annual mean air temperatures from (**A**) Nuuk and (**B**) Tasiilaq, obtained from the Danish Metrological Institute records.

area during the 1970s and early-1980s, was a result of a period of extremely high frequency of northerly winds over the Arctic Ocean and northern North Atlantic in the 1960s (Dickson *et al.*, 1988). The northerly winds caused a greater than normal outflow of cold and relatively fresh polar water from the Arctic Ocean. This water, together with large amounts of polar ice, was carried along the east coast of Greenland to the West Greenland area by the East Greenland Current. It is therefore logical that the most extreme air temperature conditions was experienced at Tasiilaq.

Focusing on the 1981–97 period attention must be paid to two remarkably cold periods: 1982–84 and 1989–94, Fig 5a,b. These two cold periods in time coincided well with the occurrence of the highest positive values of NAO index (1983, 1989 and 1990) as shown in Fig. 2.

The 1982–84 period has been discussed by Rosenørn *et al*. (1985), who showed that the cold conditions were due to the inflow of an extremely cold air mass from Arctic Canada to the Davis Strait region with the centre in the vicinity of Aasiat. Judging from the annual mean temperatures given in Fig. 5a, it is seen that the 1982–84 period is one of the coldest ever recorded at Greenland although not the coldest. Rosenørn *et al*. (MS 1985) showed that negative temperature anomalies were observed every month from February 1982 to November 1984, but especially the winter months were extremely cold. The mean temperatures for the winter months (December, 1983, January and February, 1984) were the coldest ever recorded (-15.2^{o}C in Nuuk). It is needed to go 99 years back in time to find similar cold winter conditions (-15.1^{o}C in 1885).

Sea ice

Sea ice is an important parameter in Greenland waters and the Southwest Greenland area is mainly dominated by two types of sea ice:

1) "Storis", multi-year ice of polar origin carried to Southwest Greenland by the East Greenland Current.
2) "Westice", first-year ice formed in the Baffin Bay and Davis Strait.

The Southwest Greenland waters, primarily the Julianehaab Bight, are covered with "Storis" 8–9 months of the year. The leading edge of the "Storis" normally passes Cape Farewell in December or January, but can vary by several months from year to year. The amount of "Storis" entering Southwest Greenland waters show great interannual variability and is governed by several factors such as the outflow of sea ice from the Arctic Ocean, the formation of sea ice in the Greenland Sea, wind conditions in the Greenland Sea, Iceland Sea and the Irminger Sea. In the 1981–97 period, extremely great amounts of "Storis" entered Southwest Greenland water in 1982, 1984, 1989, 1990 and 1993 (Hans Valeur, Greenland Ice Service, pers. comm.).

The formation of "Westice" starts in the northern Baffin Bay in September and in the succeeding months it continues to block larger areas along the Northwest Greenland coast. In most years the ice limit reaches Aasiat in December–January. The water of Southwest Greenland is normally not affected by "Westice" because the inflow of warm water of Atlantic origin has its maximum during autumn and early winter (Buch, 1990).

The presence of extremely cold air masses over the Davis Strait in 1983–84 and 1989–94 naturally resulted in the formation of extraordinary large amounts of "Westice". Thereby the ice limit was moved so far south that the seldom situation of the "Westice" and the "Storis" joining each other in the Julianehaab Bight has been experienced several times during the recent 15 years.

Oceanographic conditions

Water masses. The waters off Southwest Greenland are dominated by four water masses formed outside the Davis Strait (Buch, 1990) (see map of surface currents in Fig. 6:

- In the surface layer close to the coast, cold and low saline Polar Water is found. The Polar Water is carried to Southwest Greenland by the East Greenland Current.
- Below and west of the Polar Water, water originating from the North Atlantic Current is found.

At great depths Northeast Atlantic Deep Water and Northwest Atlantic Bottom Water are found.

The two deepwater masses are not discussed in the present paper since they are found at depths greater than the 1 000 m maximum depth of observation used by the Greenland Fisheries Research Institute in their observation program.

The T/S characteristics of Polar Water as it is found in the East Greenland Current are temperatures generally below 0°C and salinities below 34.4 PSU (Lee, 1968). During the summer the temperatures may rise to 3–5°C in the surface layer. Buch (1990), however, showed that the T/S characteristics of Polar Water are altered on its way to Southwest Greenland due to mixing with surrounding water masses. Along the Southwest Greenland fishing banks the Polar Water therefore is characterized by temperatures below 1°C, which may rise to 3–5°C during summer, with salinities below 33.75–34.0 PSU. This classification is quite similar to the one given by Kiilerich (1943).

The Atlantic water component has until recently been referred to as Irminger Water, but a more detailed analysis questions this statement. Lee (1968) and Clarke (1984) have defined Irminger Water as a mixture of Irminger Sea Water formed in the Irminger Sea during winter and North Atlantic Water, and they characterized Irminger Water to have temperatures between 4 and 6°C and salinities between 34.95 and 35.1 PSU.

In order to study the water masses of Atlantic origin in more detail, a T/S analysis was performed using observations from all available data from the Southwest Greenland area as published in World Ocean Atlas 1994. Due to the seasonal variability of the inflow of Atlantic water, T/S diagrams were prepared using the Ocean Data View Software for each of the four seasons (Fig. 7. a–d, S <34.0 PSU have been disregarded). These T/S diagrams clearly indicated the presence of Irminger Water (T ~4.5°C, S >34.95 PSU) during all seasons. A more detailed analysis producing seasonal T/S plots for each decade showed great decadal variability in the inflow of Irminger Water to the Southwest Greenland area, with high inflows during the 1960s and less in the following decades. However, further discussion of this aspect is beyond the scope of the present paper.

Figure 7 additionally shows that throughout the year there is a body of water in the Southwest Greenland area with temperatures around 4°C and salinities above 34.85 PSU. This body of water would most likely have been formed by the Irminger Water mixing with the surrounding water as it flows towards Southwest Greenland and resulting in a decrease in temperature and salinity. Water off Southwest Greenland with temperatures above 4°C and salinities between 34.85 and 34.95 PSU may therefore be named *Irminger Mode Water*. This water mass can always be observed off Southwest Greenland, while pure Irminger Water (temperatures around 4.5°C and salinities >34.95 PSU) is only occasionally observed in the area and then primarily in the southernmost part.

The T/S plots in Fig. 7 and the example of a vertical temperature and salinity distribution plot in Fig. 8 show that there exists a huge volume of water with temperatures above 2.5°C and salinities between 34.50 and 34.85 PSU. Additionally it is seen in Fig. 7 that the temperature increases during autumn. Water with salinities above 34.5 PSU is found at greater depths excluding the possibility of a temperature rise due to atmospheric heating (see Fig. 7 where the colour coding indicates the observation depth). The high temperatures, especially during autumn, support the assumption that water with salinities in the 34.5–34.85 PSU intervals originates from the North Atlantic Current. These results supports the findings by Buch (1990) based only on Fylla Bank data from 1950–88.

Along the Cape Farewell section of the NORWESTLANT surveys (Lee, 1968), a rather thick water layer (200 to 250 m) with salinities between 34.6 and 34.85 PSU was observed at a distance of around 100 naut. m south of Cape Farewell. The temperatures were around 2.5°C during the first two NORWESTLANT surveys, and increased to above 4.5°C during the third survey. Clarke (1984) reported observations from a section between Cape Farewell and Flemish Cap taken in early-1978. North of the North Atlantic Current to about 100 naut. m south of Cape Farewell a 200–300 thick layer with temperatures above 2.5°C and salinities below 34.85 PSU was observed (Fig. 9).

There is therefore reason to believe, as suggested by Buch (1990), that the water mass observed off Southwest Greenland characterized by temperatures above 2°C and salinities between 34.5 and 34.85 PSU (late in the year often with temperatures above 5°C) has its origin in the northern part of the North Atlantic Current. It is most likely the relatively low salinities are due to the influence from the Labrador Current. It was proposed by Buch (1990) that this water mass be called "Northwest Atlantic Mode Water". A possible path towards Southwest Greenland can be seen in Fig. 6, where water from the northern rim of North Atlantic Current turns north at around 40°W flowing towards the area off Southeast Greenland. Here it turns southward flowing towards the Cape Farewell area, where it turns northward again. In the Davis Strait at around 63–65°N the water flows towards west until it reaches the Labrador Current.

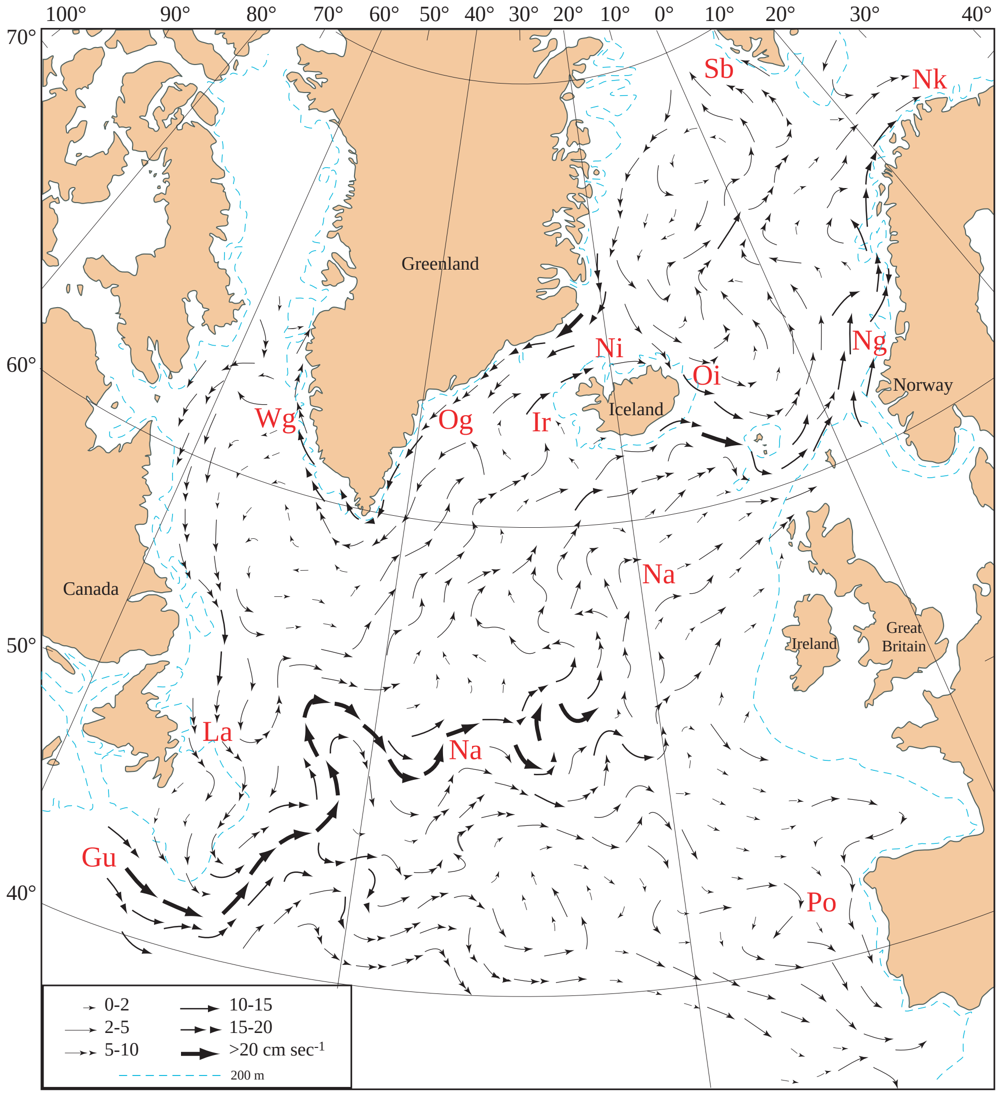

Fig. 6. Surface currents in the northern part of the Atlantic Ocean (After Dietrich *et al.*, 1975).

This analysis of T/S data from Southwest Greenland therefore indicates the presence of three water masses of Atlantic origin:

- *Irminger Water* – temperature around 4.5°C and salinity above 34.95 PSU.
  Irminger Mode Water – Irminger Water mixed with surrounding water masses on its way to Southwest Greenland, with temperatures around 4°C and salinities between 34.85 and 34.95 PSU.
- *Northwest Atlantic Mode Water* – Temperatures above 2°C and salinities between 34.5 and 34.85 PSU. In late autumn the temperatures rise to above 5°C.

Interannual variability. The most well known oceanographic time series from Southwest Greenland is the mid-June mean temperature on top of Fylla Bank (Fylla Bank station 2, 0–40 m) (Fig. 10), which the Greenland Fisheries Research Institute has carefully maintained because of its importance to the cod stock assessment. Here the temperature may vary quite drastically from one year to the next, often more than 1°C, reflecting the variability of both the atmospheric influence and the inflow of Polar Water. The curve showing the 3-year running mean values naturally smoothens out the variations and therefore better reflects the large-scale climatic variability.

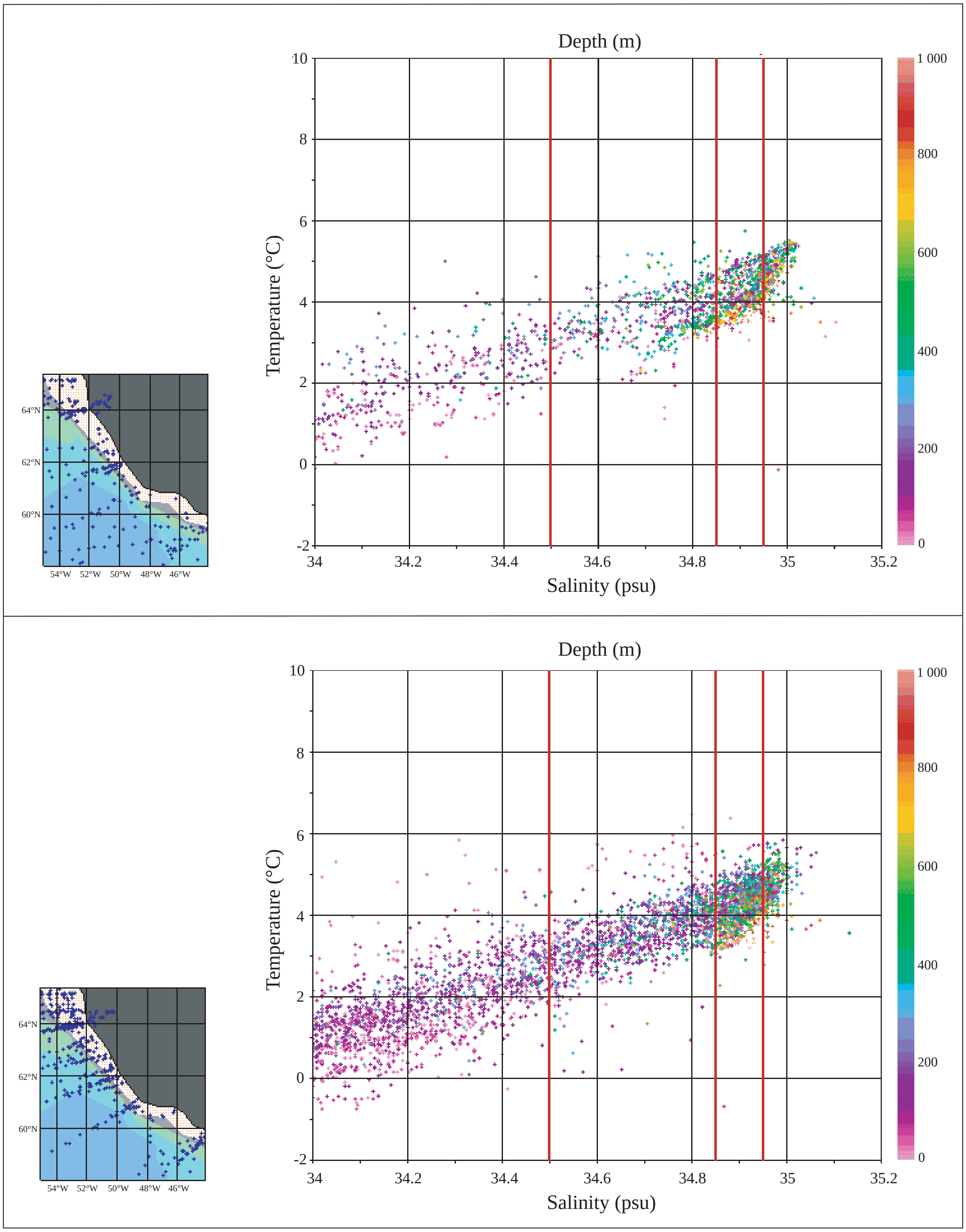

Fig. 7. Seasonal T–S plots from the Southwest Greenland area using all available data in the World Ocean Atlas 1994. The colour indicates the observation depth (upper = winter; lower = spring).

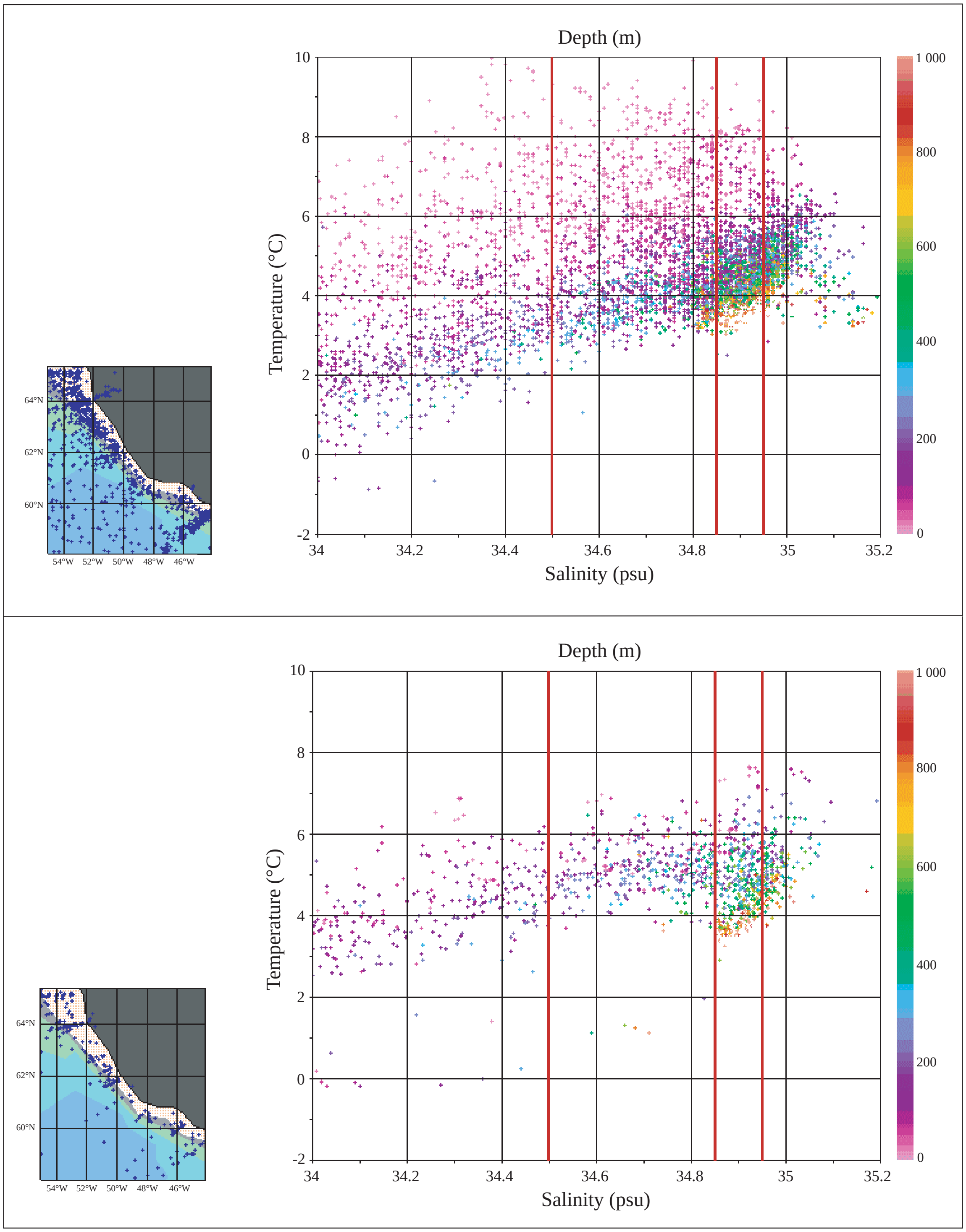

Fig. 7. (Continued). Seasonal T–S plots from the Southwest Greenland area using all available data in the World Ocean Atlas 1994. The colour indicates the observation depth (upper = summer; lower = autumn).

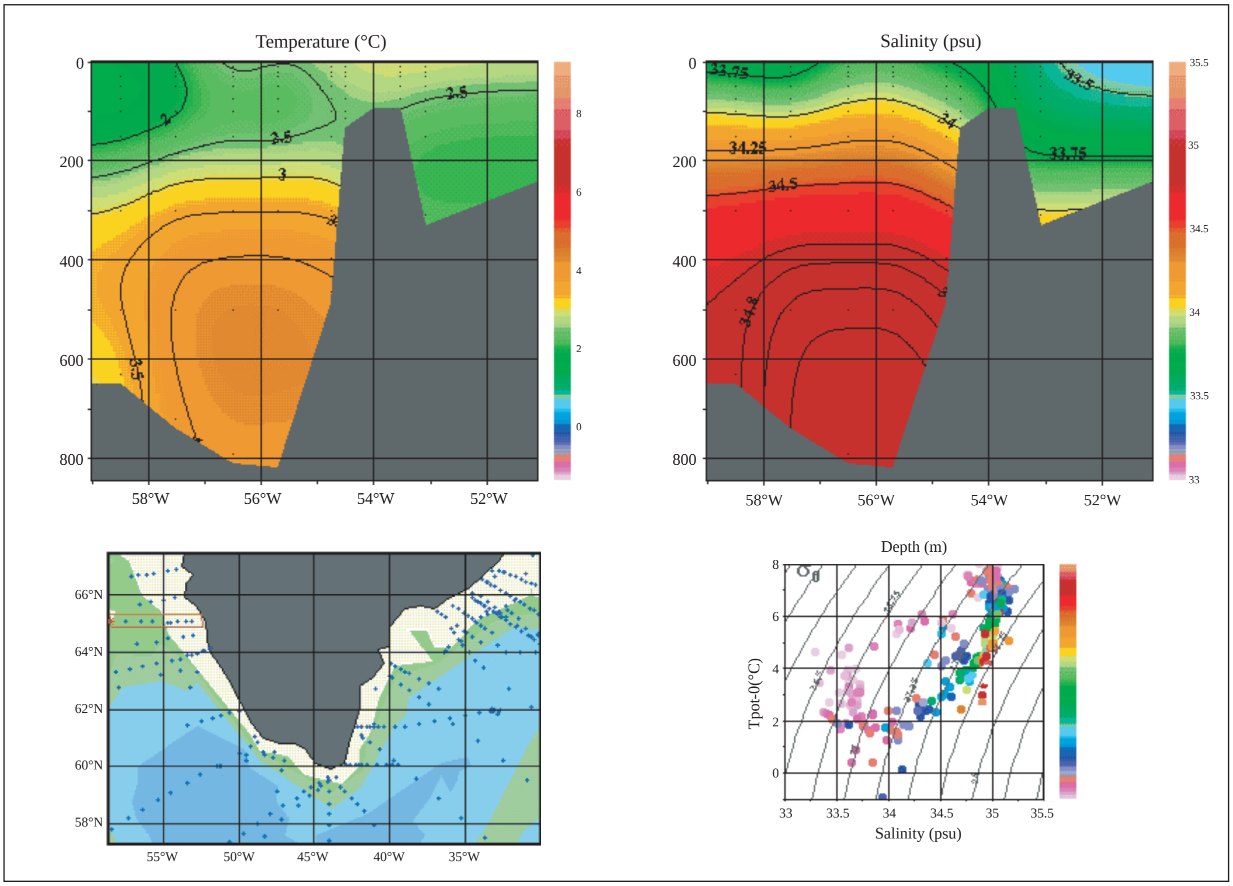

Fig. 8. Vertical temperature and salinity distribution at NORWESTLANT 3, section 13 (close to the Sukkertoppen).

The almost 50 year temperature time-series reveal some very distinct climatic events:

- The 1950–68 period generally showed high temperatures around 2°C.
- Around 1970 a cold period, the coldest recorded, was experienced. The cold climate of this period was due to an anomalous high inflow of Polar Water, which was closely linked to the "Great Salinity Anomaly" (Dickson *et al.*, 1988). This again is reflected with the NAO negative index changing to positive indices.
- In the early-1980s and early-1990s two extremely cold periods were observed reflecting the cold atmospheric conditions in the Davis Strait area (as discussed above) due to the high NAO indices during these years.
- A remarkably low temperature was observed in 1997 although the atmospheric conditions were quite warm (Fig. 5), which indicates a high inflow of Polar Water.

Figure 11 shows the time-series of the Mid-June salinity on top of Fylla Bank (actual observations as well as a 3 years running mean). The "Great Salinity Anomaly" around 1970 is clearly reflected in this data set, while the climatic anomalies in the early-1980s and 1990s do not expose themselves in any significant way in the surface salinities at Fylla Bank. This of course was not to be expected because these cold periods were due to atmospheric cooling.

Relatively low salinities were observed in 1996 and 1997 indicating that the inflow of Polar Water have been above normal in these years. This could be a sign of a new "Salinity Anomaly" although not yet of the same dimension as the one experienced around 1970. Analysis of data from the other Southwest Greenland sections show extremely low salinity values at the sections north of Fylla Bank in 1996, comparable to the low values observed in the late-1960s. At the southernmost sections, Cape Farewell to Frederikshaab, no real time series exists, but based on the observations made in June–July since 1992 abnormally low salinities were observed only at the Cape Farewell section in 1996.

Further offshore, just west of the fishing banks, relatively long time series of July temperatures and salinities exists. In Fig. 12 is shown a time series of

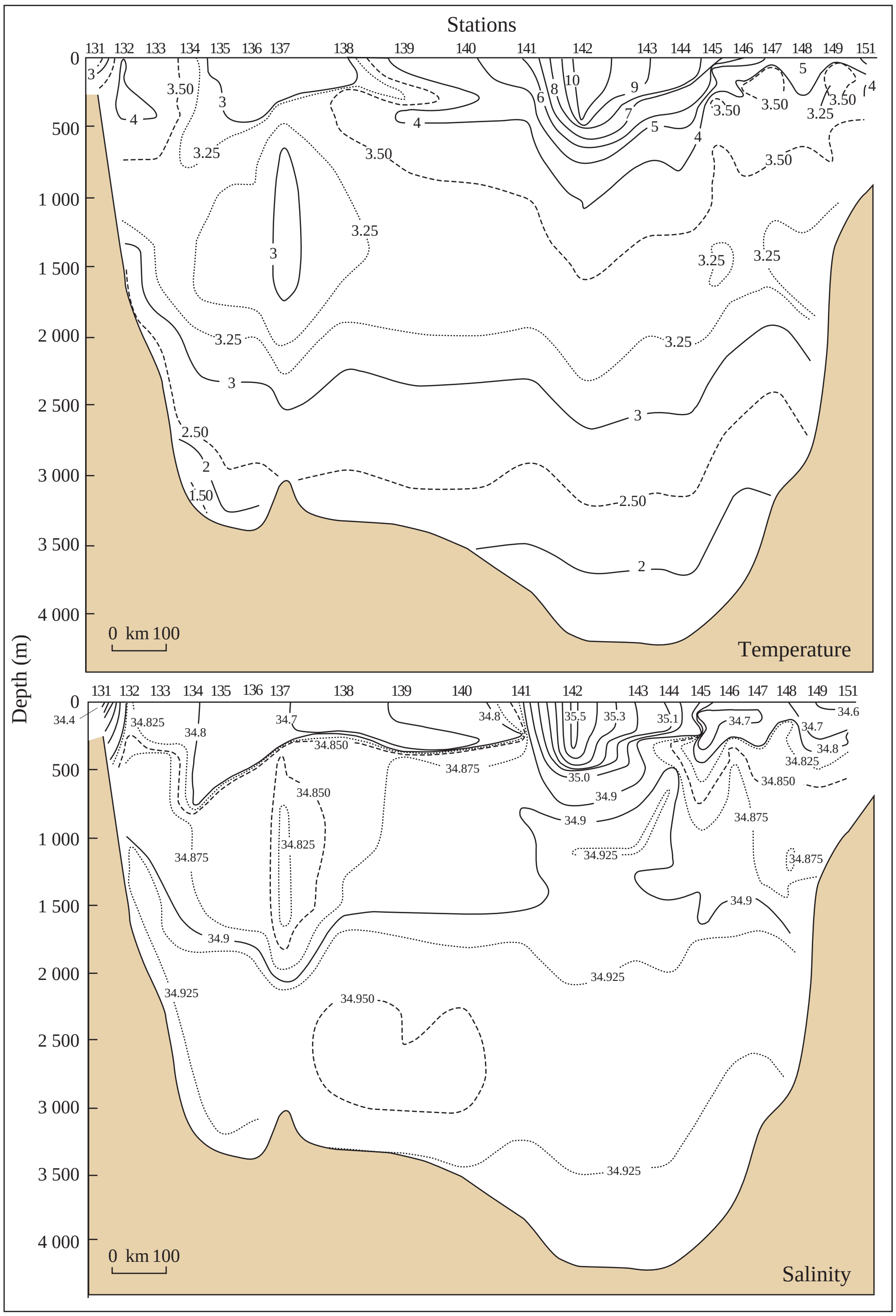

Fig. 9. Potential temperature and salinity fields along the Cape Farewell to Flemish Cap Section, 1978 (after Clarke, 1984).

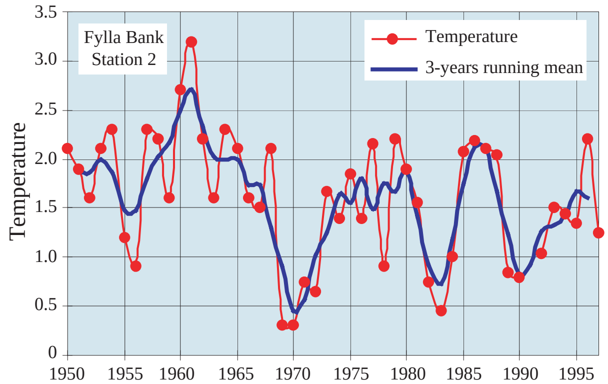

Fig. 10. Mean sea temperatures (°C) of the upper 40 m on Fylla Bank Station 2, mid-June 1950–97.

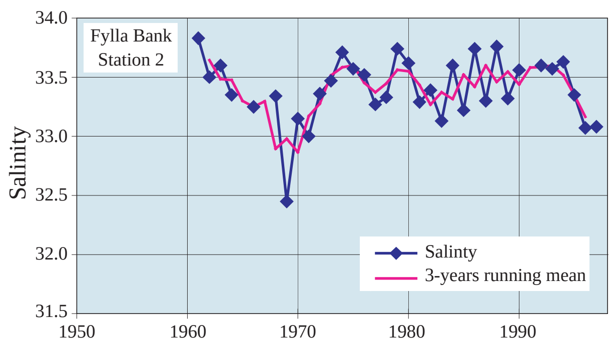

Fig. 11. Mean salinity (PSU) of the upper 40 m on Fylla Bank Station 2, mid-June 1961–97.

the mean salinity of the upper 50 m at Fylla Bank Station 4 from 1970 to 1997. A tendency analysis showed that there is a general increase in the salinity during this period, which according to Blindheim *et al.* (2000) might be a result of changes in the ocean circulation of the North Atlantic that can be related to the rise in the NAO index since 1970.

Summary and Conclusions

The overview of the oceanographic conditions in the ICNAF/NAFO areas along the Southwest Greenland fishing banks during the 1981–97 period shows this area is highly dominated by the inflow of water masses originating from various regions in the North Atlantic and Arctic Ocean.

An analysis of T/S data from Southwest Greenland indicates the presence of three water masses of Atlantic origin:

- *Irminger Water* – temperature around 4.5°C and salinity above 34.95 PSU.
- *Irminger Mode Water* – Irminger Water mixed with surrounding water masses on it way to Southwest Greenland with temperatures around 4°C and salinities between 34.85 and 34.95 PSU.
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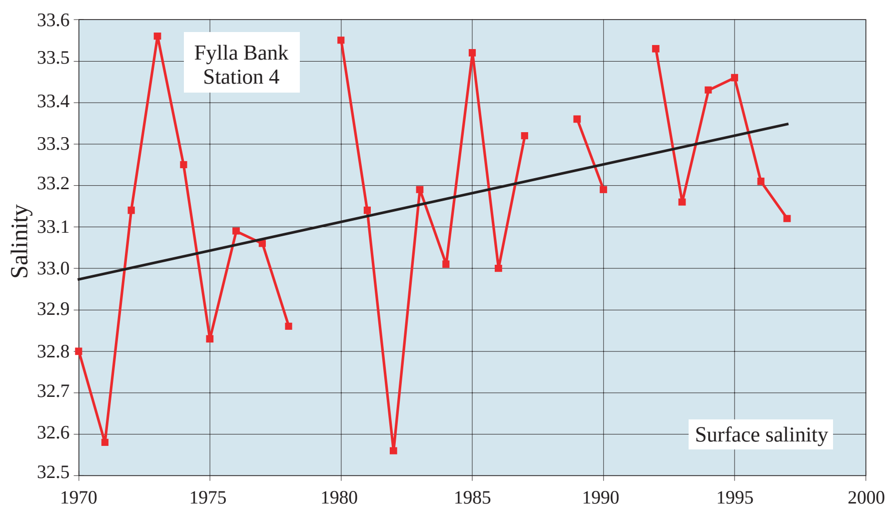

Fig. 12. Mean salinity (PSU) of the upper 50 m on Fylla Bank Station 4, July 1970–97.

In addition to the transport of ocean water masses there is intense air-sea interaction in the areas influencing primarily the temperature conditions. These subsequently influence the extent of sea ice, which again has an impact on the salinity of the surface water and by vertical convection also on deeper layers.

The atmospheric conditions over the North Atlantic area is highly dominated by the NAO index, which since the early-1980s has been in a persistent and exceptionally strong positive phase. A high NAO index means cold and dry conditions over Greenland, and Greenland has been characterized by very cold conditions since 1980 especially in the 1982–84 period when record cold winters were experienced. The 1989-94 period was also extremely cold. These cold atmospheric conditions were reflected in the waters off Southwest Greenland by temperatures well below normal in the upper 400 m. This increased the formation of "Westice" moving the ice limit so far south that the seldom situation of "Westice" and "Storis" joining each other in the Julianehaab Bight during the winter months was experienced several times during the recent 15 years.

The interannual variability of the oceanographic conditions, analysed using time series of June temperatures and salinities from the Fylla Bank, showed the most significant oceanographic events observed in the Southwest Greenland area since 1980 were closely related to the two periods (1982–84 and 1989–94) of very cold atmospheric conditions.

The great variability in the oceanographic conditions off Southwest Greenland reported in this paper do have a strong impact on the living conditions for a number of fish stocks living close to the limit of their distribution in this area. The cold conditions experienced in this area during the recent two to three decades appear to have caused a dramatic change in the ecological balance. Cod was found in great quantities from the 1920s up until 1970. Since then only in small numbers have been found and in recent years after the latest cold period, cod has virtually been absent along the Southwest Greenland fishing banks (Buch *et al.*, 1994). To Greenland, being almost totally economically dependent on fishery, the disappearance of the most important fish stock is a disaster.

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