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On the Consistency of Thermal Events in the East Greenland/West Greenland Current System and off Labrador

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Abstract

Based on conductivity, temperature, depth (CTD) measurements with rosette mounted bottle performed along standard oceanographic sections off Greenland, the consistency of thermal events was analyzed. High consistency of events was found for the sections off Southeast Greenland and West Greenland, low consistency was revealed for the northernmost section off East Greenland and the West Greenland sections. Consistency of events was most expressed on the West Greenland side of the system, since the modification of the water masses was no longer under the regime of two concurrent components: Polar Water and Irminger Water. There was high correlation between the Cold Intermediate Layer extent of the Bonavista Section and the thermohaline changes off West Greenland (Fylla Bank). This signified an intense east/west coupling within the Labrador Sea system.

Key words: Advection, climatic changes, cold intermediate layer (CIL), Greenland, Labrador, water masses

Introduction

During the past decade the waters off West Greenland and eastern Canada off Labrador experienced a series of anomalously cold winters and ice conditions (1983, 1984, 1985, 1991), with 1991 being the worst year for ice build-up in 30 years in the Labrador region (Narayanan *et al.*, MS 1992). There is evidence that some of these anomalies are travelling along the North Atlantic Current system (Dickson *et al.*, 1988), while others are due to regional effects such as atmospheric cooling (Stein and Buch, 1985).

The composite of the West Greenland waters are a result of a large-scale circulation of the North Atlantic Ocean, where there is a meso-scale coexistence of warm and cold current components of the West Greenland Current system, and small-scale events like the shifting of water mass fronts and generation of meanders and eddies. The meso-scale variability in West Greenland waters is visible in the semi-annual signals of the two current components, the cold East Greenland component and the Irminger component. Buch (1982) and Stein and Buch (1985) note that the cold, near-coastal component attains its maximal influence on the West Greenland Current in early summer (June), whereas the warm component has its maximal influence in late autumn (November).

Since 1963, the Institut für Seefischerei, Hamburg has occupied a set of NAFO Oceanographic Standard Stations in West Greenland waters, and since 1981, a set of national Oceanographic Standard Stations in East Greenland waters (Fig. 1). Part of this standard station work has been compiled to form the database for the present paper. By means of these data, the hypothesis that thermal events which are observed in the East Greenland Current can be traced in the West Greenland Current system is tested.

Recent studies on filtered air temperature anomalies at Nuuk (Godthaab), West Greenland, and Canada at Iqualuit, Northwest Territories and at Cartwright, Labrador, show a downward trend which started in the late-1960s (Drinkwater *et al.*, MS 1992; Stein, MS 1992). Time-series at all three locations show large amplitude low-frequency variability, with the West Greenland data indicating record anomalies in the early-1980s (Buch and Stein, 1989). Characteristic high amplitude cold events occur in all three time-series during the early-1970s, early-1980s and around 1989/90. Taking into account the coupling of atmospheric conditions and the ocean as well as the advective model for the events, it is hypothesized that there should be east/west consistency between events in the hydrosphere which could be observed on both sides of the Labrador Sea.

Materials and Methods

During the annual groundfish surveys to the waters off East and West Greenland, the Institut für Seefischerei completed conductivity, temperature, depth (CTD) profiles with rosette mounted bottle at

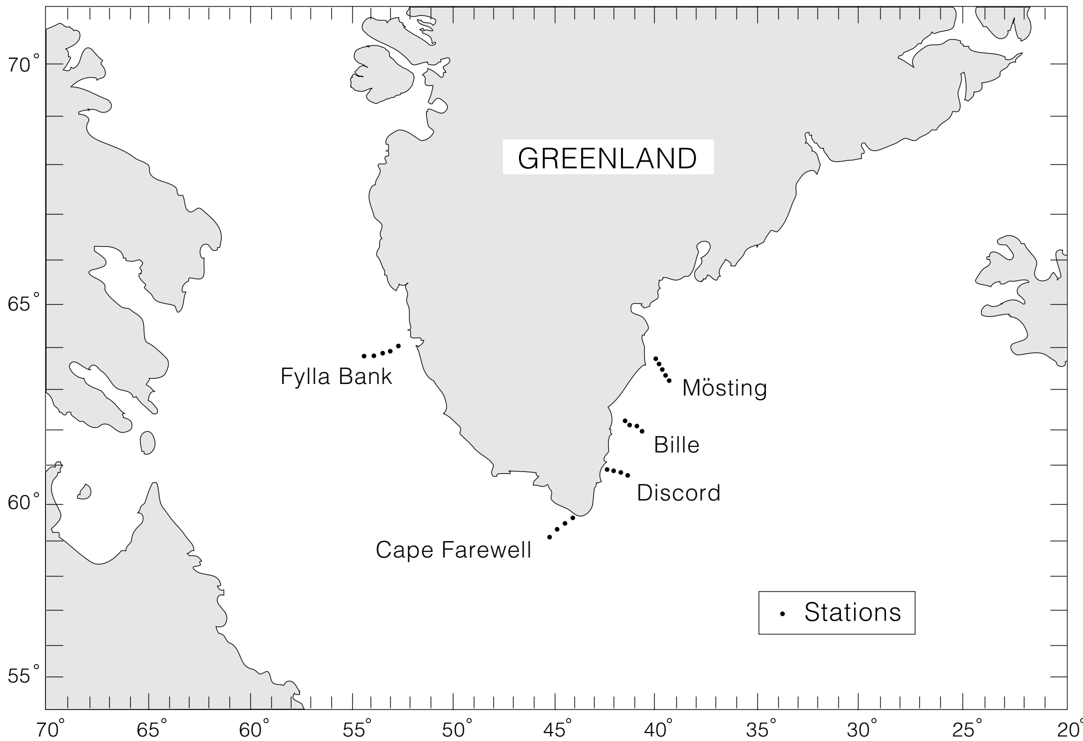

Fig. 1. Locations of sections and stations.

national oceanographic standard stations (East Greenland) and at NAFO standard stations off West Greenland (Stein, MS 1982; MS 1988). From the database, standard depth data were extracted and temperature anomalies were calculated for individual depth ranges. The base periods for the mean value were 1982–1989/90 for East Greenland waters, 1963–91 or 1981–90 for the Fylla Bank data, and 1983–91 for the Cape Farewell Station 4. The data represented the autumn conditions, i.e. September/October conditions for the East Greenland sections, and October/November conditions for the West Greenland sections. The 1981 anomaly value in the East Greenland sections Mösting, Bille and Discord (Fig. 2–4, respectively) was added to show early December conditions.

For the Labrador/West Greenland correlation, four data sets were taken and statistically treated. These were the Nuuk (Godthaab) monthly and annual mean air temperature, the Fylla Bank temperature and salinity time-series, and the cold intermediate layer (CIL) time-series of the Bonavista section (Drinkwater *et al.*, MS 1992; Stein, MS 1988). The location of the three sites of observation is given in Fig. 1. The CIL data of the Bonavista section represent a measure for the amount of water colder than 0°C crossing the vertical plane. The Fylla Bank data represent October/November conditions, while the CIL data at the Bonavista section were obtained in July.

Results

East Greenland/West Greenland Current system

Off East Greenland the thermal conditions along the Mösting, Bille and Discord section indicated cold events during 1983 and 1984 (Fig.5A, B, C). The 1983 event was documented at Stations 2, 3 and 5 of the Mösting section (Fig. 5A), Stations 2 and 3 of the Bille section (Fig. 5B), and Stations 1 and 2 of the Discord section (Fig. 5C). Off Cape Mösting, anomalous cold conditions were found at Stations 1 and 4 during 1984. Off Cape Bille, Stations 1 and 4 revealed a cold event during 1984 with a clear signal at the inner Station 1. The Discord section data enabled a clear discrimination between the 1983 and 1984 events along the section, with the inner stations being anomalously cold during 1983, and the outer stations during 1984. Off Cape Farewell, at Station 4 of the section, the years 1983 and 1984 emerged as anomalous cold years in relation to the depth layers 0-50 m, 0–200 m and 200–300 m (Fig. 6). The Fylla Bank section data clearly indicated anomalous low temperatures for the years 1982 to 1984 and 1989 (Fig. 7).

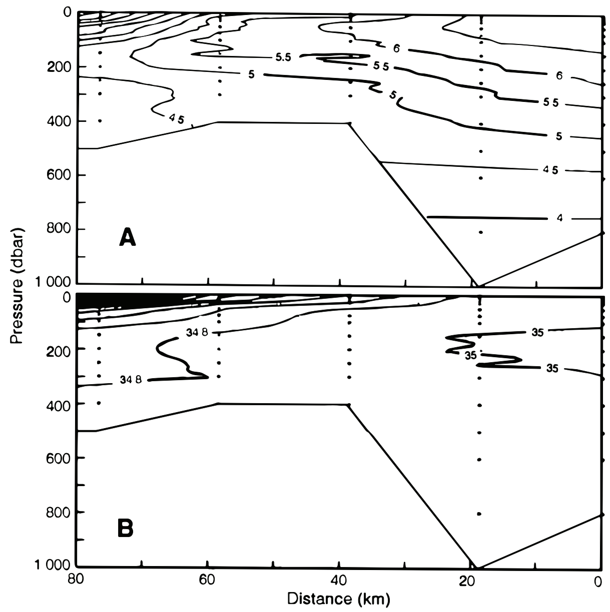

Fig. 2. Mean vertical distribution of (**A**) temperature (°C) and (**B**) salinity along the Mösting section.

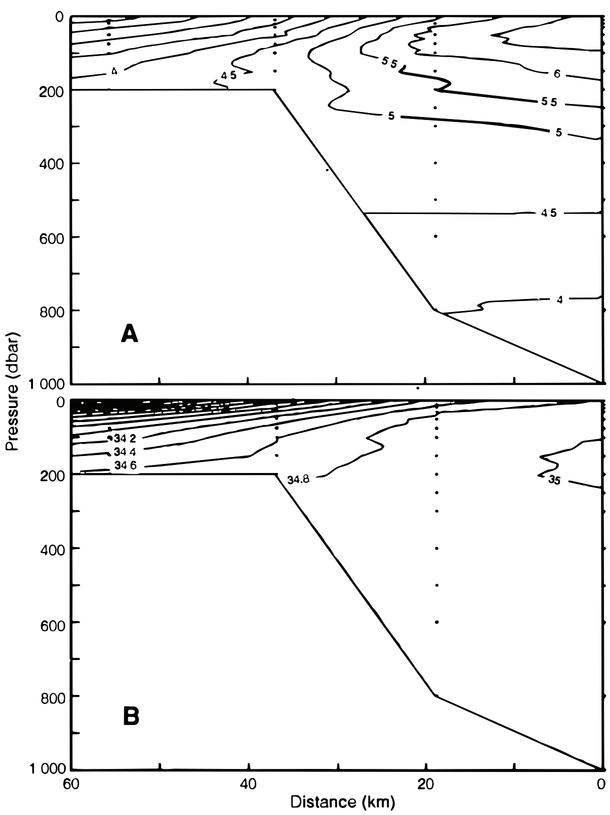

Fig. 3. Mean vertical distribution of (**A**) temperature and (**B**) salinity along the Bille section.

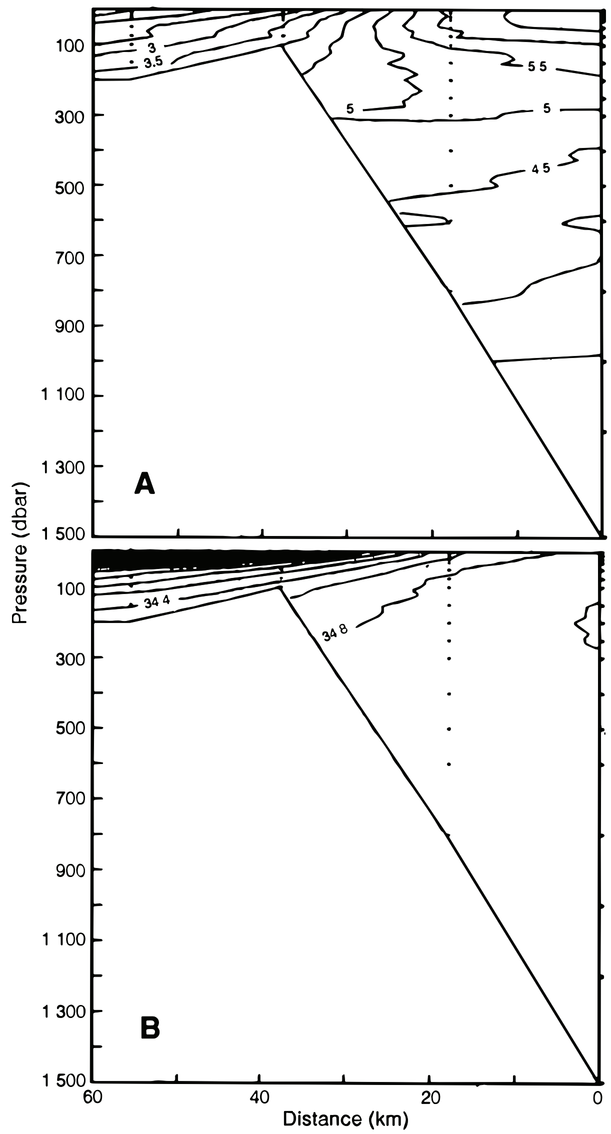

Fig. 4. Mean vertical distribution of (**A**) temperature (°C) and (**B**) salinity along the Discord section.

West Greenland/Labrador

Correlation between Nuuk monthly mean air temperature and the areal extent of the CIL indicated that only 24% (38%) of the variance of the CIL can be explained by the air temperatures of the previous winter months, January (February), in Nuuk. Considering the year previous to the CIL observations, January (February) conditions at Nuuk explained 53% (63%) of the variance.

The correlation was, however, based on a short time-series of 14 years. This can imply that the consistency was relevant only for this specific pe-

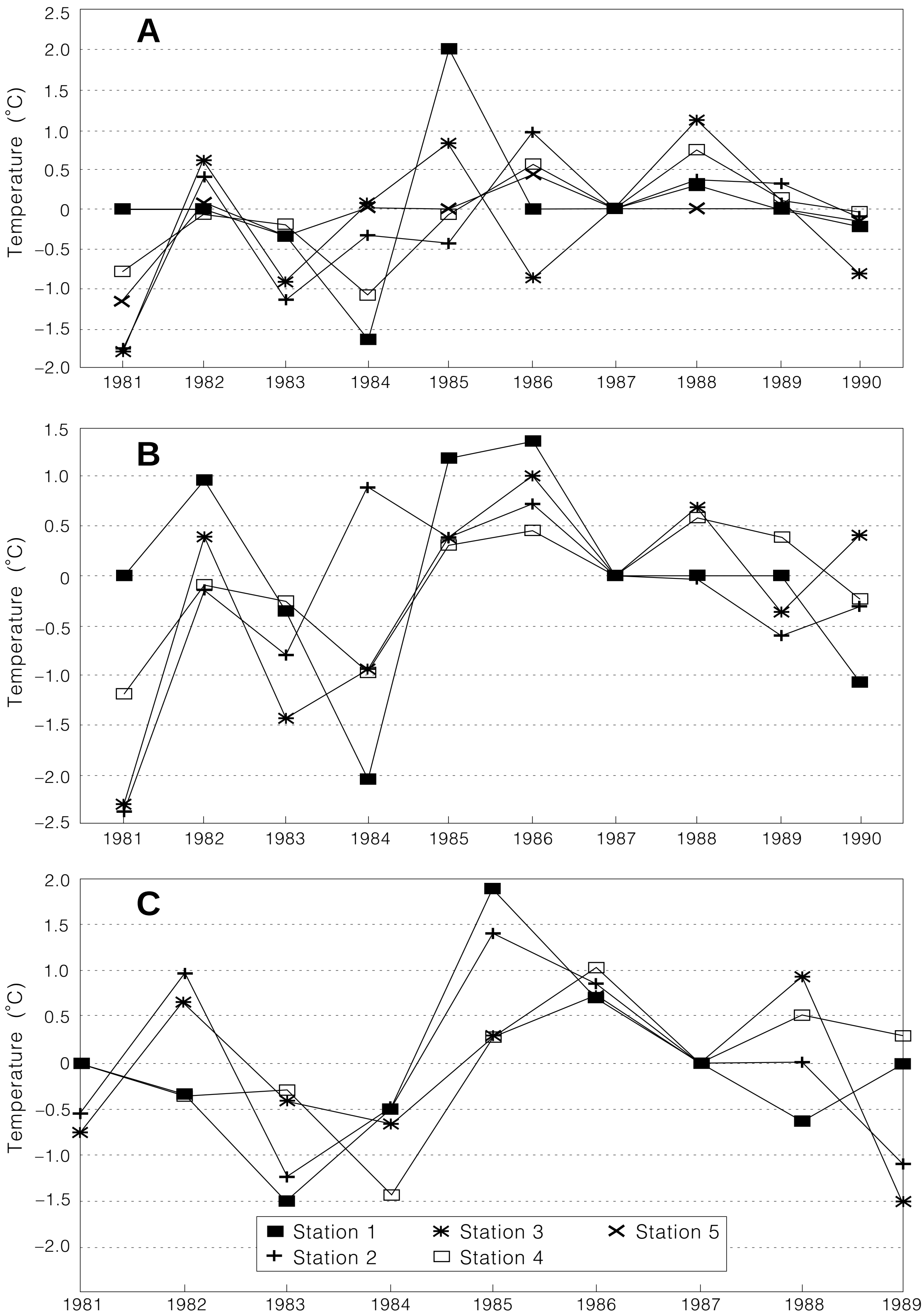

Fig. 5. Annual variation of temperature (0–200 m) along the (**A**) Mösting section, (**B**) Bille section and (**C**) Discord section.

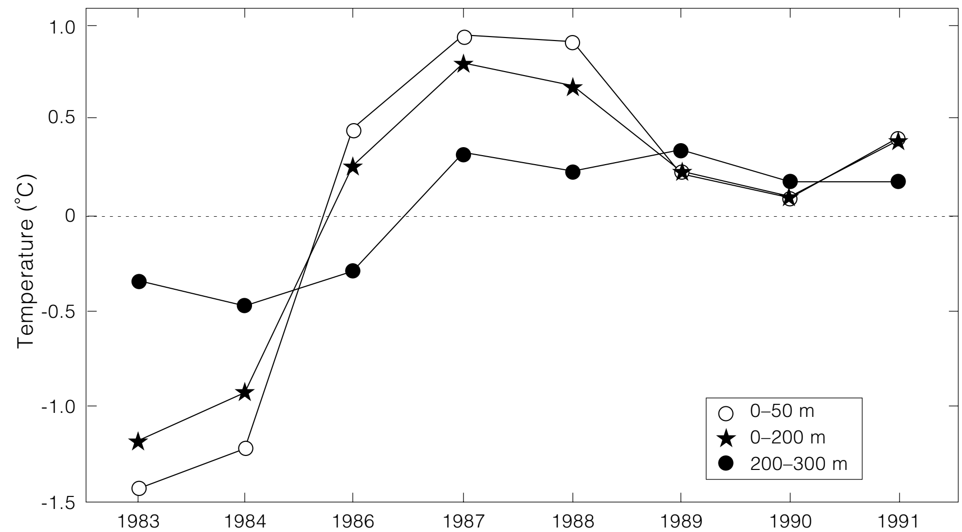

Fig. 6. Annual variation of temperature at the Cape Farewell section Station 4.

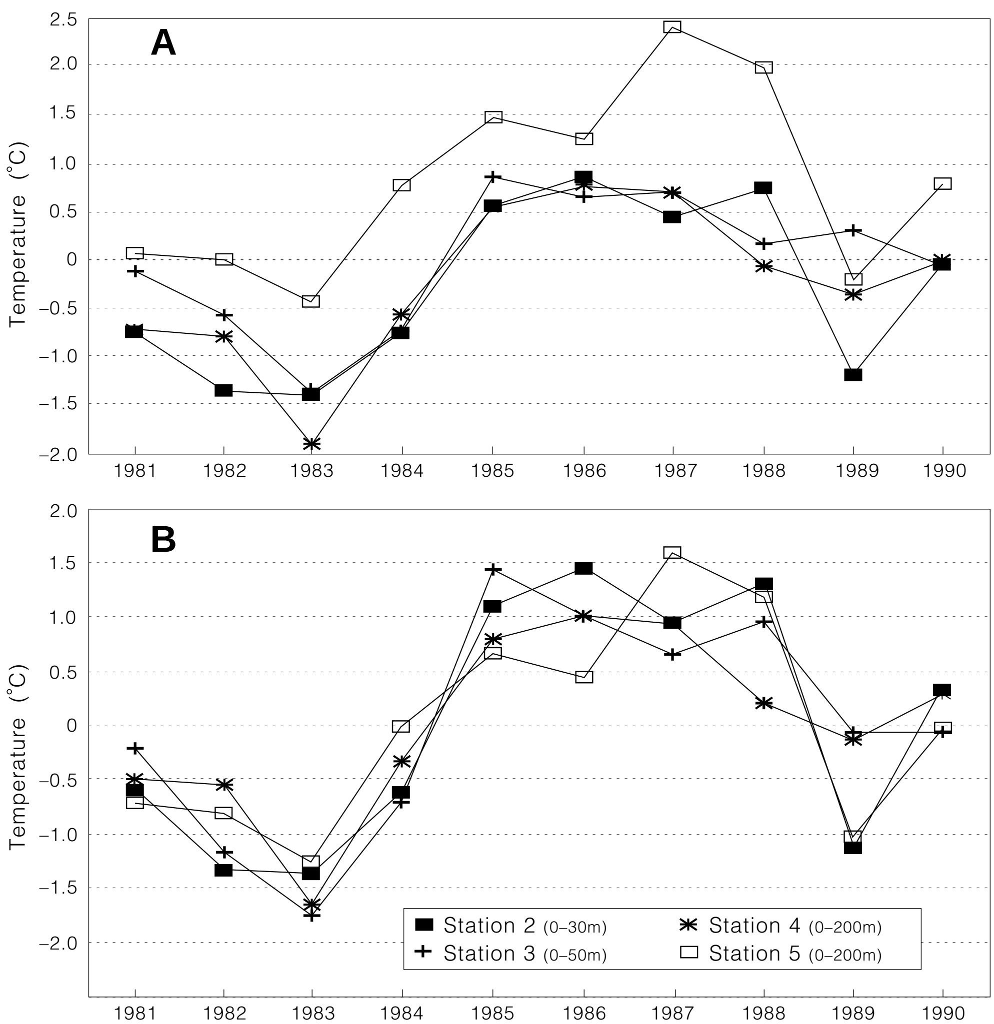

Fig. 7. Annual variation of temperature along the Fylla Bank section (**A**) based on mean 1963–91, (**B**) based on mean 1981–90 (0–30 m – Station 2; 0–50 m – Station 3; 0–200 m – Station 4, 5).

riod from 1978 to 1991. In contrast to the entire time series from Nuuk (Godthaab) which started in 1876 and shows low frequency changes of warmer and colder than normal conditions, with 1923 to 1969 being warmer than normal (Stein, MS 1992), the time span from 1978 to 1991 represented parts of a decreasing temperature trend in the Greenland/ Labrador region.

Correlation based on the 116 years time-series revealed that February conditions explain 57% of the variance of the mean annual air temperature, whereas for the short period January (February) conditions explain 74% (66%) of the variance of the mean annual air temperature.

Taking the ocean conditions off Nuuk into account, the temperature/salinity anomaly time series revealed similar correlation results. The results of this calculation are as follows:

Correlation Matrix for time series Fylla Bank/CIL (FYLS = Fylla Bank salinity; FYLT = Fylla Bank temperature; CIL = cold intermediate layer along the Bonavista section)

	Correlation coefficient	1.0	.77	–.87
FYLS	Sample size	(11)	(11)	(11)
	Significance level	.000	.006	.001
	Correlation coefficient	.77	1.0	–.82
FYLT	Sample size	(11)	(11)	(11)
	Significance level	.006	.000	.002
	Correlation coefficient	–.87	–.82	1.0
CIL	Sample size	(11)	(11)	(11)
	Significance level	.001	.002	.000

Discussion

The drift of ice-floats off East Greenland might be a measure for the surface current speeds in the East Greenland Current, although the influence of the surface winds on the ice-float's drift might play a role. Figure 8 displays the track of pack ice, which was monitored with a radio beacon. The ice-float passed from 65°N to 60°N in 10 days, which represented a mean speed of 64 cm/sec. After passing Cape Farewell, it began to move northwestward, but it subsequently made an anticlockwise loop south of Cape Farewell and then disappeared. The surface waters may also travel from East to West Greenland along similar paths. Some current bands may also find their way to the waters off West Greenland and transport "thermal information", such as cold events. On the other hand, there was quite a dramatic change in the horizontal, as well as in the vertical, distribution of cold and warm water masses. As emphasized by Stein (1988), there is variability on the small-scale (less than 10 nautical miles). This elucidates the width of polar and subtropical current bands which meet and mix in the area off East Greenland. The oceanographic time-series is thus unfortunately infected by meandering water mass boundaries, or even by the entrainment of water boluses (Stein, MS 1990). This might influence the consistency of events along an individual section. Mean temperatures for the individual stations off East Greenland are given in Table 1.

TABLE 1. Mean temperature (°C) of the 0–200 m layer for the East Greenland sections Mösting, Bille, Discord.

	Stations				
Section	1	2	3	4	5
Mösting	3.05	5.34	5.68	6.47	6.65
Bille	2.89	3.94	5.87	6.50	
Discord	2.35	3.25	5.88	6.43	

The inner stations of the sections are influenced by the polar component of the East Greenland Current, whereas the outer stations are under the regime of the Irminger Current. Off Cape Mösting, Station 5, which is under the regime of the Irminger Current (6.65°C mean temperature for the 0-200 m layer) revealed little change in the temperature field throughout the years 1982–90 (Fig. 2). The standard deviation ranged from 0.34 to 0.1 in the 0–200 m layer, indicating stable thermal conditions in the

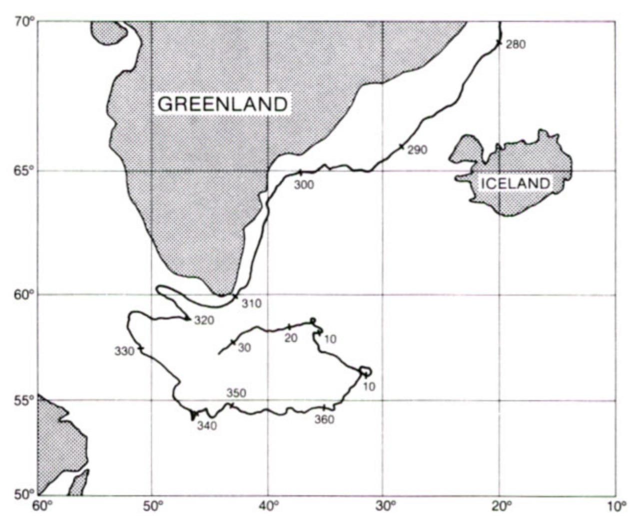

Fig. 8. Monitored track of an ice float from October 1984 (day 280) to February 1985 (day 35). (Courtesy of A. Clarke, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada).

Irminger component at this site during autumn. Largest interannual variability occurred at Station 1 of the Mösting section, with the standard deviation being 1.55 at the surface and 0.67 at a depth of 200 m.

The largest variability was observed at Station 1 of the Bille section (Fig. 3). The temperature anomalies along this section, as well as along the Cape Discord section (Fig. 4) yielded similar trends as off Cape Farewell (Fig. 6): cold conditions during 1983, 1984 (Stations 1 and 2 of the Discord section), and warm conditions from 1985 to 1988 at the outer stations (Stations 3 and 4). The years 1989 and 1990 indicated a downward trend off Southeast Greenland, as was the case at the Cape Farewell Station 4. On the West Greenland side, however, the temperature was still above normal.

Station 4 of the Cape Farewell section lies in the core of the Irminger component of the West Greenland Current (Stein and Wegner, 1990; Stein, MS 1992). The variability of temperature from 1983 onwards (no observation during 1985) very clearly indicated the cold events in 1983 and 1984, and warm years from 1986 to 1988 in the surface layer 0–50 m and the 0–200 m layer. Figure 9 also reveals that warmer than normal conditions prevailed in the Irminger layer (200–300 m) from 1986 onward. The warming of this layer was postponed by 1 year as compared to the 0–50 m and 0–200 m layers.

At Fylla Bank thermal conditions indicated the cold early–1980s, and a warmer than normal period from 1985 to 1988. The downward trend, as observed versus the end of the 1980s, is also apparent in the middle off West Greenland. In contrast to the Cape Farewell section, however, this trend implies colder than normal years, especially 1989.

There was evidence that salinity and temperature changes at the Fylla Bank was significantly correlated with the extent of the CIL area at the Bonavista section. 75% (67%) of the variance in the CIL-extent may be explained by the changes in salinity (temperature). This high correlation would suggest an intense east/west coupling within the Labrador Sea system. If the coupling was the effect of the advective event model, the CIL events would be lagged by about 7 months with the Fylla Bank events.

Low salinities recorded at the Fylla Bank section Station 4 during autumn reflected a decrease in salinity of the Irminger branch of the West Greenland Current. Time-series analysis based on standard oceanographic sections around Greenland and off South Iceland, clearly reveal the travel of salinity and thermal events (Malmberg and Kristmannsson, 1991; Stein, MS 1992) in the northwestern North Atlantic.

Conclusions

Bearing in mind that anomaly calculations are based on a given time window (Stein, MS 1992), the analysis is focused on this selected period. In areas like Greenland this can imply that warmer than normal conditions take place in a colder than nor-

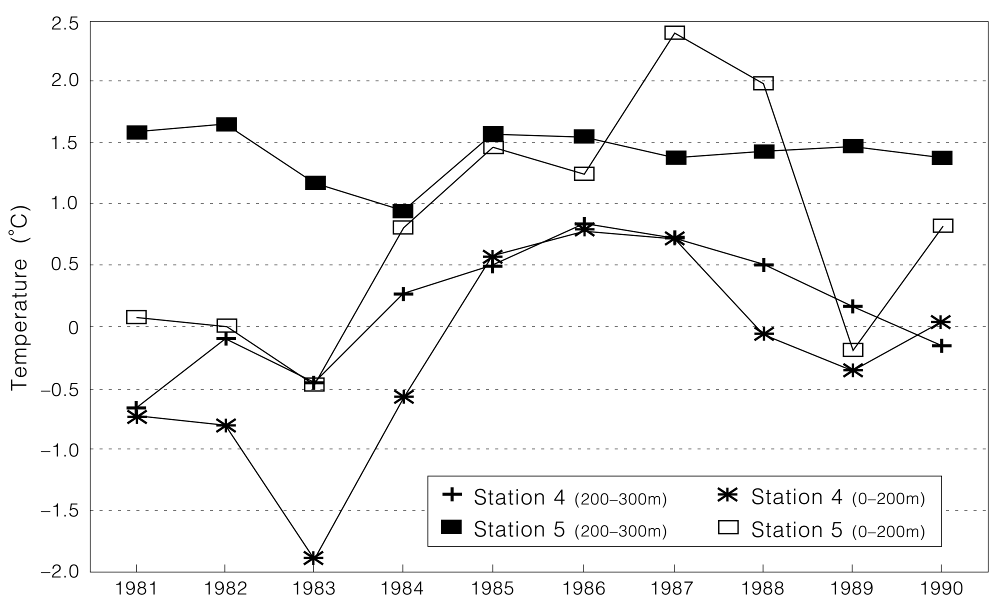

Fig. 9. Annual variability of temperature at Stations 4 and 5 of the Fylla Bank section with reference to the Irminger layer (200–300 m).

mal period if the time window is opened wide enough. The data suggest that there is east-west consistency in the cold and warm signals as observed under East and West Greenland. The inter section consistency of events was high for the Bille, Discord and Cape Farewell sections, and for the Cape Farewell and Fylla Bank section, while consistency was low in the Mösting, Cape Farewell and Fylla Bank sections.

Consistency of events is most expressed on the West Greenland side of the system, since the modification of the water masses is no longer under the regime of two concurrent components, the polar and subtropic parts (Polar Water and Irminger Water) which is the oceanic environment on the East Greenland shelf. The co-existence of polar and subtropic water masses on the East Greenland shelf leads to inconsistencies of events along the sections, especially documented along the Cape Mösting section.

Not covered by this paper, but emphasized in a recent paper by Buch and Stein (1989), are regional meteorological events which may lead to negative heat flux from ocean to atmosphere, resulting in tremendous cooling and ice formation. The early-1980s anomaly was induced by this process. Since the core of cold air masses was placed over the town of Egedesminde (Northwest Greenland), the cooling was more intense on the West Greenland side than on the East Greenland side. This might be one reason for the inconsistency of the 1983 event between the Cape Mösting temperature anomalies and the West Greenland section anomalies.

Bearing in mind the limited power of statistical analysis, it would appear that there is coupling of thermohaline events which are observed on both sides of the Labrador Sea. However, as shown above, consistency of events might be a question of time-windows. For the time being we have at hand only limited information of 14 years of CIL observations. Other CIL data from the Labrador/Newfoundland region are even shorter (Drinkwater *et al.*, MS 1992).

This lack of long-term time series requires continuation of field work along the same sampling grids. A dense cover of monitoring sections on both sides of the Labrador Sea, and extended to the East Greenland area would be necessary to answer in more detail the travel of events from east to west. Based on the framework of the NAFO Standard Oceanographic Sections and Stations (Stein, MS 1988), as well as along national standard sections, there is predictive power in data sets collected along these lines.

Of potential value for fishery management, these data and their interrelations could serve as statistically significant indicators for environmental changes in the northwestern North Atlantic.

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