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Oceanographic Investigations West Greenland 2003

by

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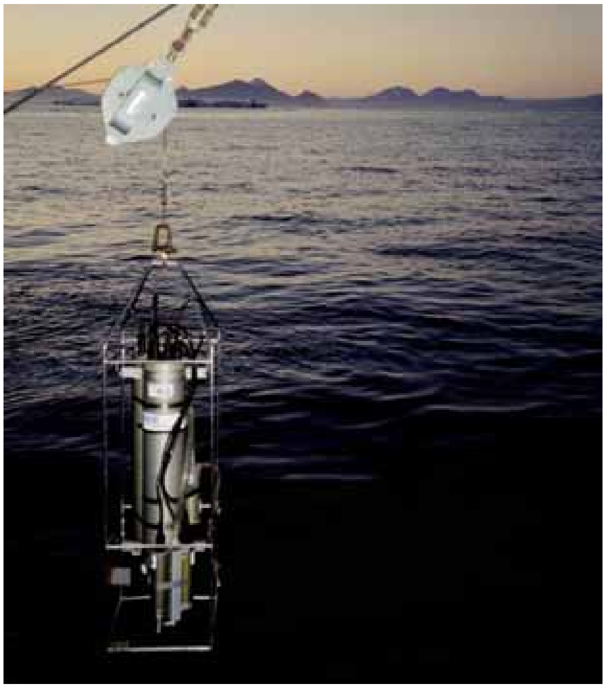
Abstract



Results of the summer 2003 standard section cruise along the west coast of Greenland are presented together with CTD data gathered during trawl surveys.

The NAO index was close to zero, but the Icelandic Low had moved towards southwest while the Azores high had moved north-eastward. As a consequence the wind anomaly in large part of the North Atlantic including the Denmark Strait was southwest-ward, reducing the strength of the East Greenland Current while strengthen the Irminger Current.

The time series of mid-June temperatures on top of Fylla Bank was about one degree above average conditions, while the salinity was slightly higher than normal.

The temperature of the Polar Water was high compared to normal years and the front between Polar Water and Irminger Water week indicating a reduced inflow of Polar Water to the West Greenland area in 2003. Pure Irminger Water was observed from Cape Farewell to the Fylla Bank section, and Modified Irminger Water could be traced as far north as the Maniitsoq (Sukkertoppen) section. The inflow of Irminger Water seems to be much higher than the last couple of years, which most likely can be a consequence of reduced inflow of Polar Water.

Two very different kinds of fjords systems were measured around Sisimiut. Two fjords have deep sills allowing relative warm and saline water of Atlantic origin to enter at the bottom. The density of this bottom water is higher than the surface Polar Water at its freezing point preventing winter convection to the bottom. The other type of fjord have a shallow sill preventing the warm Atlantic water to enter at the bottom. Therefore cold and fresh bottom water was measured below sill depth, which is surface water transformed by convection during winter, as the salinity of the whole fjord system was very homogeneous. At the surface of both fjord systems solar heated Polar Water was found.

1. **Introduction**

The North Atlantic marine climate is largely controlled by the so-called North Atlantic Oscillation (NAO), which is driven by the pressure difference between the Azores High and the Iceland Low pressure cells. We use wintertime (December–March) sea level pressure (SLP) difference between Ponta Delgada, Azores, and Reykjavik, Iceland, and subtract the mean SLP difference for the period 1961–1990 to construct the NAO anomaly. The winter NAO index during winter 2002/2003 was approximately zero (Fig. 1). However, the Icelandic low was during the winter months (December–Marts) displaced towards southwest and the Azores high was deflected towards central Europe (Fig. 2). The center of the low was just south of Cape Farewell. This has the effect that the wind anomaly (difference from normal conditions) over the eastern part of the Irminger Basin, the Iceland Basin and in the Denmark Strait was northwest-ward reducing the strength of the East Greenland Current through Denmark Strait and intensifying the Irminger Current as explained further in chapter 0

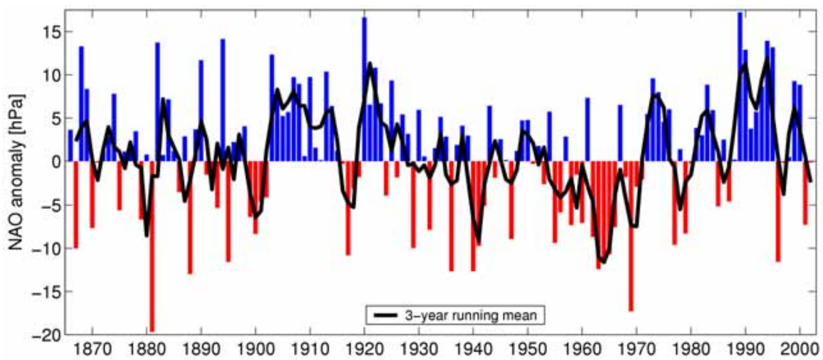


Fig. 1. Time series of winter (December–March) index of the NAO from 1865–2003. The heavy solid line represents the meridional pressure gradient smoothed with a 3-year running mean filter to remove fluctuations with periods less than 3 years. Note that values for both 2001/2002 and 2002/2003 were very close to zero. (Pressure data updated from http://www.cru.uea.ac.uk/cru/data/nao.htm, as described in Buch *et al*., 2003).

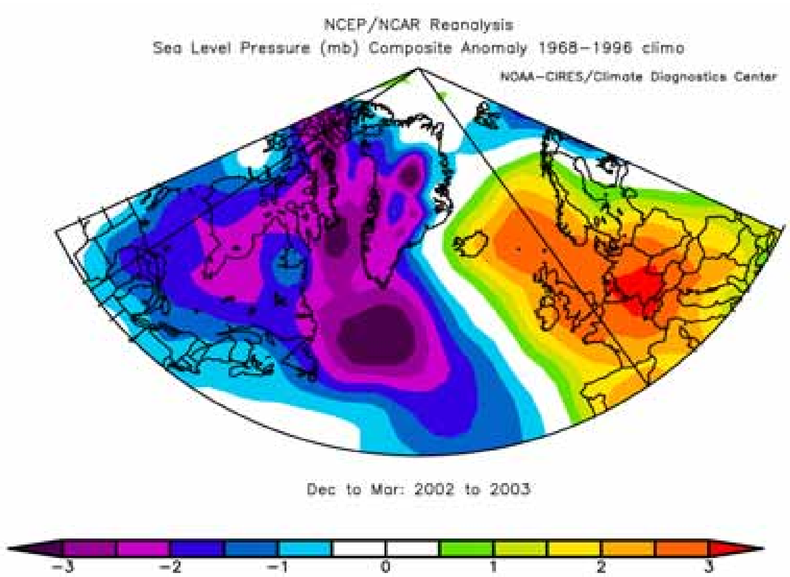


Fig. 2. Winter (DJFM) sea level pressure anomaly for 2002/2003 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

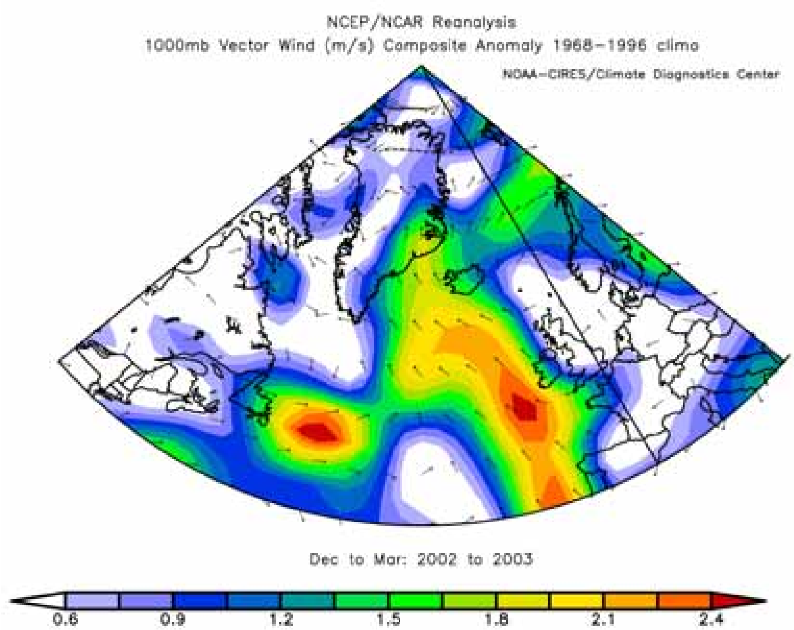


Fig. 3. Winter (DJFM) wind anomaly for 2002/2003 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

West Greenland lies within the area which normally experiences warm conditions when the NAO index is negative. As can be seen from Fig. 4 the annual mean air temperature for 2003[1] in Nuuk was minus 1.7°C which is close to the mean value, reflecting well the NAO value close to zero. The mean annual air temperature for November 2002–October 2003 was however above normal for most of the North Atlantic region, Fig. 5.

Changes in the ocean climate in the waters off West Greenland generally follow those of the air temperatures, exceptions are years with great salinity anomalies i.e. years with extraordinary inflow of Polar Water or water of Atlantic origin. In 2003 the mean temperature on top of Fylla Bank in the middle of June was 2.69°C which is about one degree above the average value of 1.67°C for the whole 53 year period and the forth highest value, whereas the mean salinity value, 33.57, was about equal to the average value for the entire period (Fig. 6). This does *not* correlate with the NAO, but can be explained by the displacement of the centers of the North Atlantic pressure system, see Chapter 0

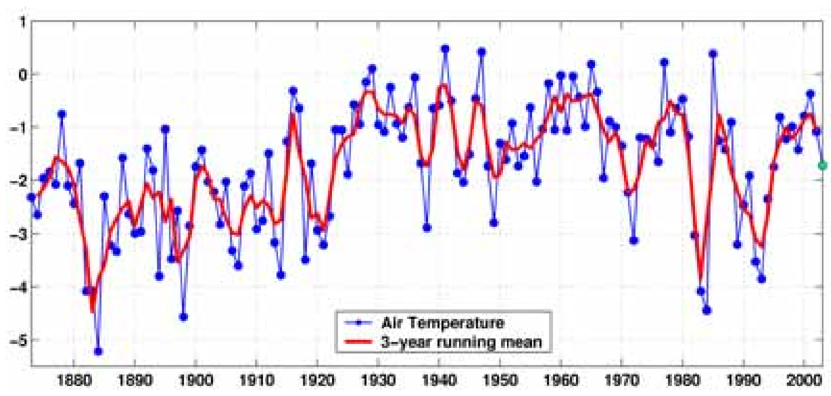


Fig. 4. Annual mean air temperature observed at Nuuk for the period 1873 to 2003. In 2003 (green) the values from November and December are taken as the mean value for these months for the rest of the period, as the plot was constructed in November 2003.

[1] As the mean temperature was made in November 2003, November and December values was taken as the mean values for the whole time series for these months.

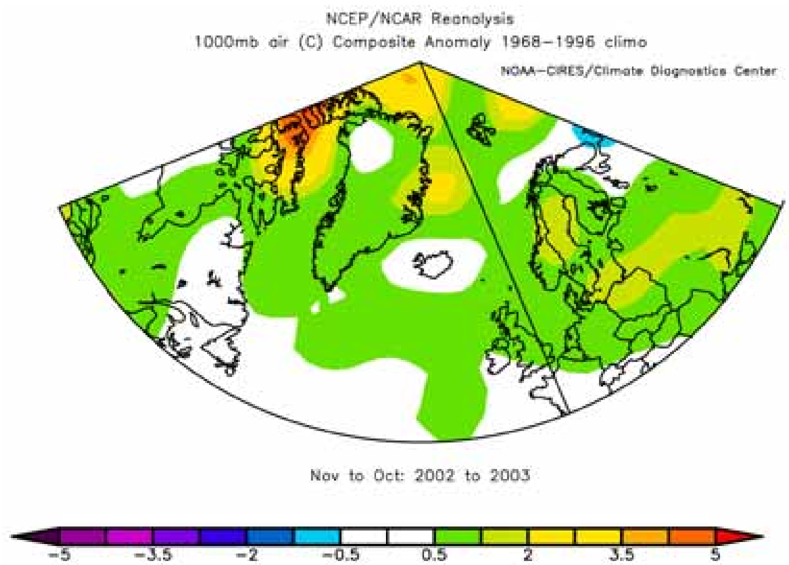


Fig. 5. Anomalies of the annual mean air temperature (taken as November–October) for 2002/2003 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

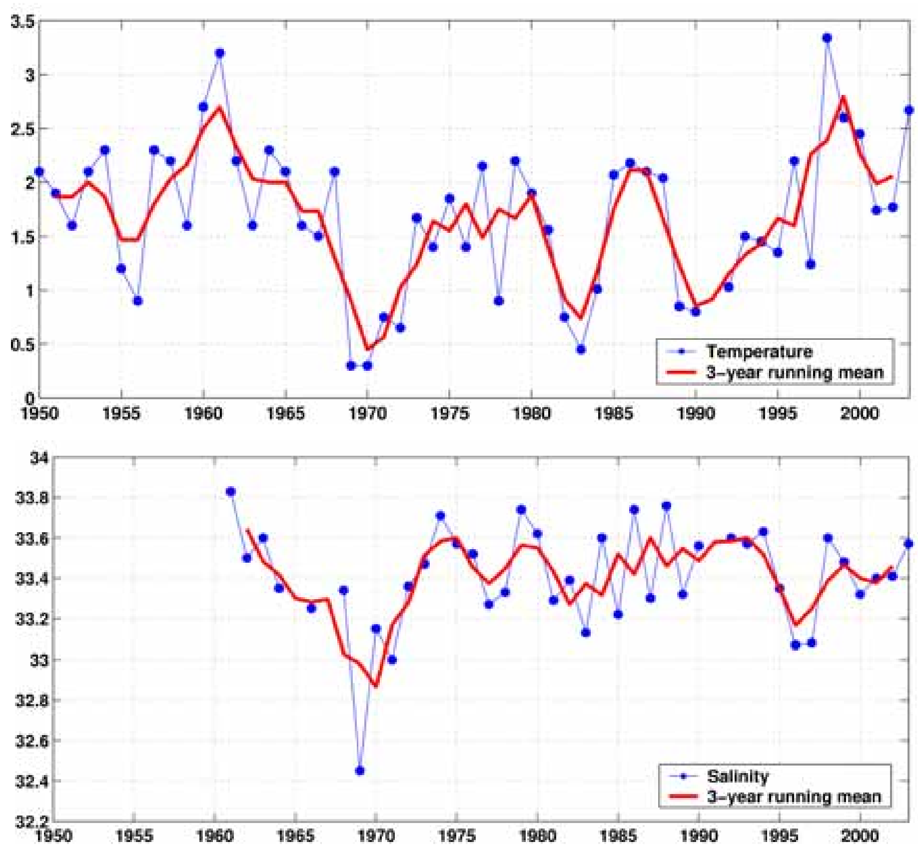


Fig. 6. Time series of mean temperature (top) and mean salinity (bottom) on top of Fylla Bank (0–40 m) in the middle of June for the period 1950 to 2003. The red curve is the 3 year running mean value.

2. Measurements

The 2003 cruise was carried out according to the agreement between the Greenland Institute for Natural Resources and Danish Meteorological Institute during the period June 29 to July 6, 2003 onboard the Danish naval ship **"AGPA".** Observations were performed on the following stations (Fig. 7 and Fig. 8):

Offshore Labrador Sea/Davis Strait:

- Cape Farewell St. 1–5
- Cape Desolation St. 1–5
- Paamiut St. 1–5
- Fylla Bank St. 1–5
- Maniitsoq St. 1–5
- Sisimiut St. 1–5

Fjords around Sisimiut:

- Amerdloq St. 1–5
- Ikertoq St. 1–5
- Kangerdluarssuk St. 1–6
- Qeqertalik St. 1

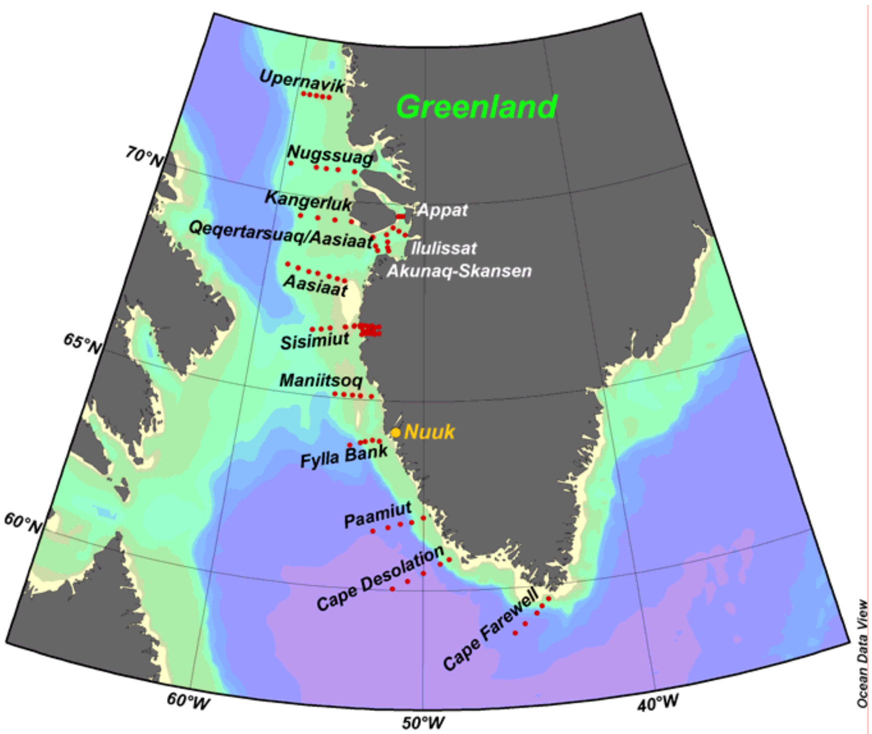


Fig. 7. Position of the oceanographic sections off West Greenland where measurements were preformed in 2003. See Fig. 8 for position of fjord measurements around Sisimiut measured in 2003. Map produced using Ocean Data View (Schlitzer, 2003).

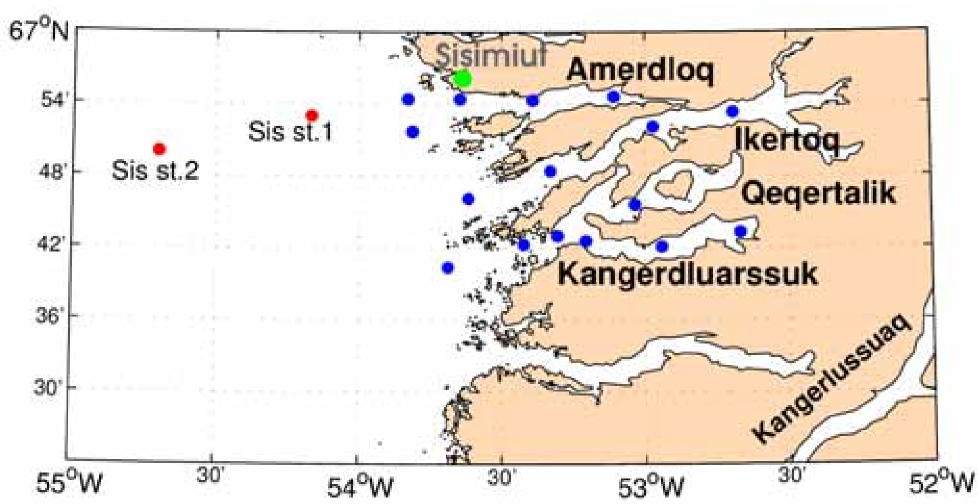


Fig. 8. Position of the oceanographic fjord sections around Sisimiut where measurements were preformed in 2003. See

Fig. 7 for position of all sections measured in 2003.

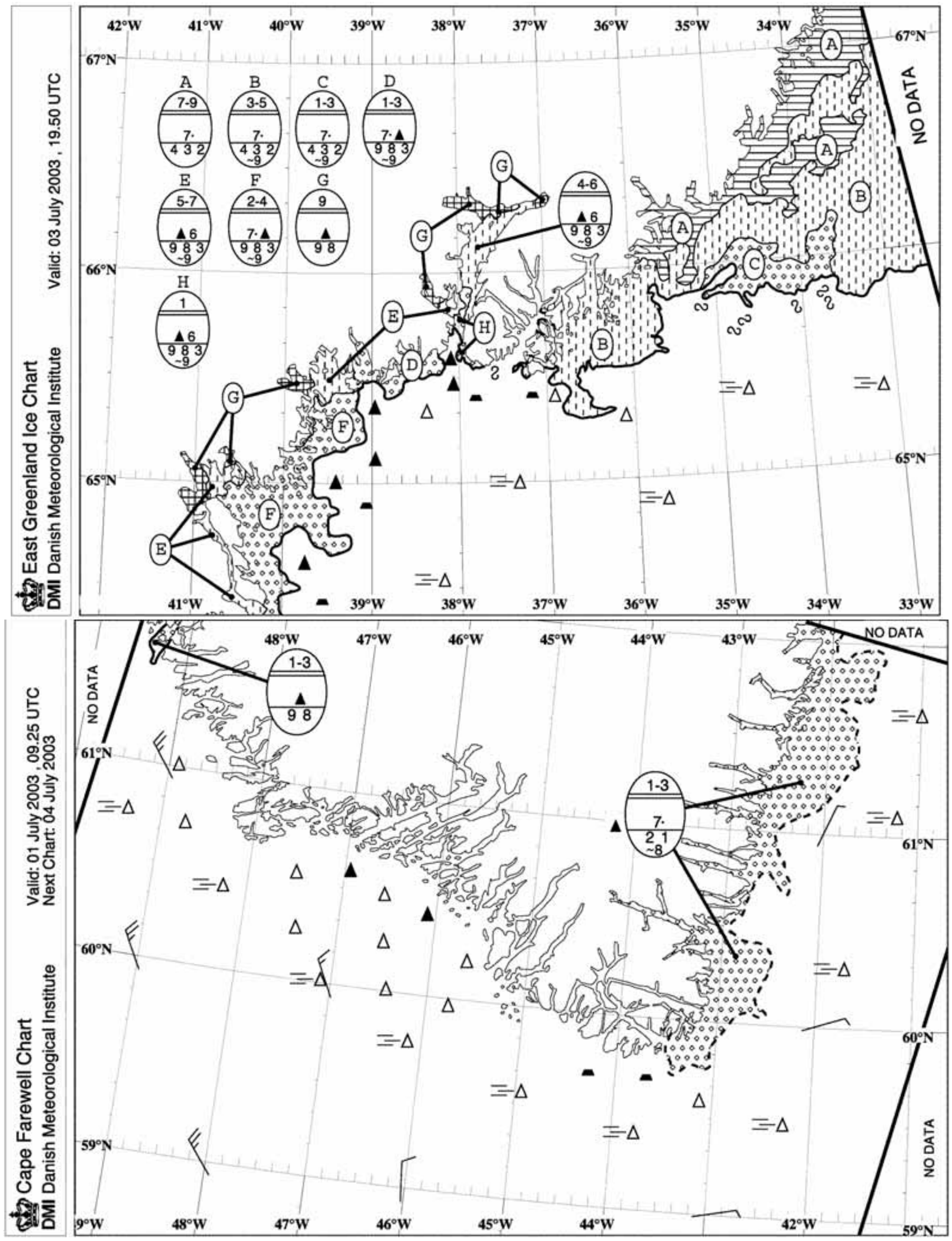


Fig. 9. Distribution of sea ice in the Amerssalik region valid at 3. July 2003 (top) and in the Cape Farewell region valid at 1. July 2003 (bottom).

On each station the vertical distributions of temperature and salinity was measured from surface to bottom, except on stations with depths greater than 750 m, where approximately 750 m was the maximum depth of observation.

The cruise was blessed with favourable weather and ice conditions. Both "Storis"[2] (Fig. 9) and "Vestice"[3] was not present at all. The absent of "Storis" is very seldom for the area at that time of the year.

2 "Storis" is multi year ice transported from the Arctic Ocean through Fram Strait by the East Greenland Current to Cape Farewell, where it continues northward by the West Greenland Current.

3 "Vestice" is one year ice formed in the Baffin Bay, Davis Strait, and western part of the Labrador Sea during winter.

In mid July/early August the Greenland Institute for Natural Resources carried out trawl surveys in the Disko Bay area and further North onboard R/V PAAMIUT. During these surveys CTD measurements were carried out on national oceanographic standard stations (Fig. 7):

Offshore Davis Strait/Baffin Bay:

- Aasiaat (Egdesminde) St. 1–7
- Kangerluk (Disko fjord) St. 1–4
- Nugssuag St. 1–5
- Upernavik St. 1–5

Disko Bay:

- Qeqertarsuaq–Aasiaat (Godhavn–Egdesminde) St. 1–3
- Akunaq–Skansen St. 1–4
- Ilulissat (Skansen–Jakobshavn) St. 1–4
- Appat (Arveprinsens Ejlande) St. 1–3

3. **Data handling**

Measurements of the vertical distribution of temperature and salinity were carried out using a SEABIRD SBE 9-01 CTD. For the purpose of calibration of the conductivity sensor of the CTD, water samples were taken at great depth on stations with depths greater than 500 m. The water samples were after the cruise analysed on a Guildline Portosal 8410 salinometer.

The CTD data were analysed using SEASOFT 4.249 software provided by SEABIRD.

CTD data collected by the Greenland Institute of Natural Resources during cruises with R/V Paamiut using the same instrumentation have gone through the same calibration and quality check.

All quality-controlled data are stored in the Marine Database at the Danish Meteorological Institute from where copies have been sent to ICES and MEDS.

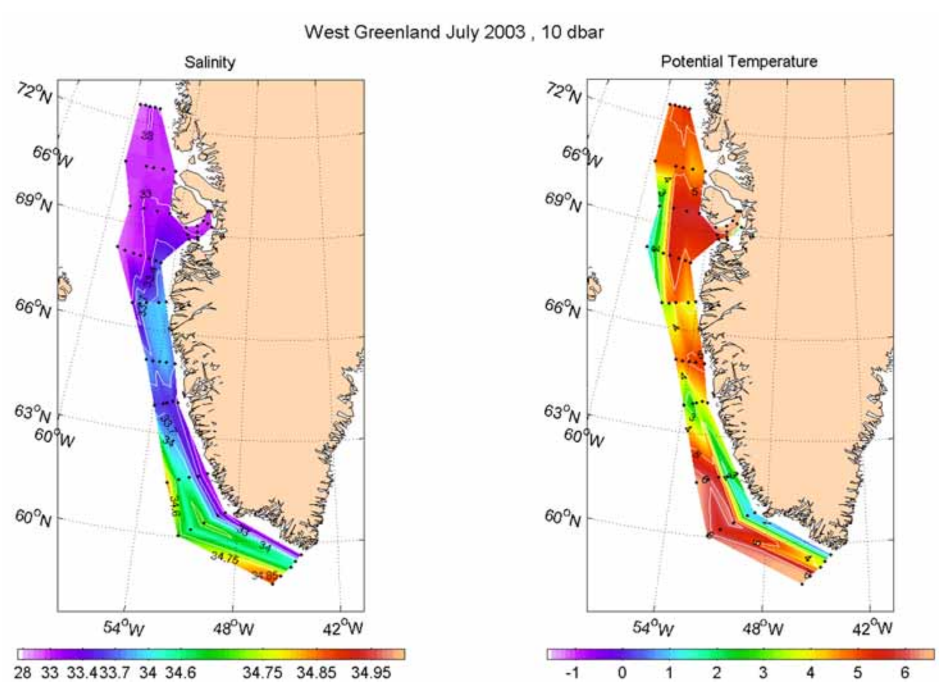


Fig. 10. Salinity and temperature at 10m from late June/early July 2003 south of Sisimiut and from mid July/early August north of Sisimiut (section near 67°N).

4. Oceanographic conditions off West Greenland in 2003

The surface temperatures and salinities observed during the 2003 cruise are shown in Fig. 10. The cold and low salinity conditions observed close to the coast off Southwest Greenland reflect the inflow of Polar Water carried to the area by the East Greenland Current. Water of Atlantic origin (T> 3^{o}C; S> 34.5) is found at the surface at the two outermost stations on the Cape Farewell Section, at the mid and outermost station on the Cape Desolation section and on the outermost station on the Paamiut section.

The surface salinity seems in general to be close to normal, except for the innermost stations on the southern sections where the surface salinities are higher than normal. This indicate low inflow of Polar Water, which additionally is seen by the lack of "Storis" west of Greenland at this time of the year (Fig. 9). In general the concentration of "Storis" measured in 2003 was extreme low.

The vertical distribution of temperature, salinity and density at sections along the West Greenland coastline is given in Fig. 12–Fig. 26. In addition to data from the six standard sections obtained during the AGPA cruise in early July, data further north from Sisimiut up to Upernavik obtained during the R/V PAAMIUT cruise in mid July/early August are shown.

Temperature and salinity observations at greater depth showed that pure Irminger Water (T ~ 4.5^{o}C, S > 34.95) was present at the Cape Farewell section up to the Fylla Bank section, where it was seen as a small blob at the outer section. Modified Irminger Water (34.88 < S < 34.95) was traced up to the Sisimiut section.

In the surface layer (0–100 m) week gradients between the cold, low-saline Polar Water and the warm, high-saline water of Atlantic origin was observed. This indicates a low intensity in the East Greenland Current component but a normal or high inflow of water of Atlantic origin, as pure Irminger Water are seen up to the Fylla Bank section.

Normally there is a very pronounced core of Polar Water, revealed by its low temperatures, just west of Fylla Bank at depth of 50–100 m, but in 2003 this core was hardly recognizable i.e. another sign of reduced inflow of Polar Water in 2003. The core was even more absent than in 2002 (for 2002 condition, see Buch and Ribergaard, 2003).

From the Sisimiut section up to the Upernavik section Polar Water originating from the Baffin Current are seen in the upper 100 m as a very cold watermass with extreme cold temperatures around 75 m. This watermass enters the Baffin Bay from the Arctic ocean through the Canadian Archipelago flowing southward at the Canadian side. At the Davis Strait part of this water crosses the strait moving northward at the Greenland side of the Baffin Bay. As this watermass is only located on the outer stations, and the salinity is slightly lower than at the stations closer to the coast (see also Fig. 10), this water is not just entirely winter cooled surface water. The low saline surface water north of Disko Bay close to the coast is fresh water from the Disko Bay (Fig. 10).

As usual parts of the Irminger Water recirculate in a cell from just north of Paamiut to the south of Cape Farewell (see e.g. Jakobsen *et at*., 2003). At Paamiut this recirculation is easily seen as a doming up of isolines for density with Pure Irminger Water both at station 3 (northward) and 5 (southward). The same overall pattern is seen at the Cape Farewell section. This cell was much more pronounced in 2003 than in 2002 as the inflow of Irminger Water was higher in 2003 compared to 2002.

The week inflow of Polar Water can be explained by the wind field. As mention in Chapter 0the wind anomaly over Denmark Strait was towards northwest and north of the strait towards north. This most likely caused a reduction of the strength of the East Greenland Current and thereby reducing the inflow of cold and fresh water towards south Greenland. At the same time the displacement of the low caused the windstress anomaly over large parts of the North Atlantic to be toward northwest and thereby strengthen the Irminger Current component, by enhancing the barotropic flow following the isobaths around Reykjanes Ridge into the Irminger Basin.

Finally, the direct heating of the surface waters east of Greenland by the atmosphere was most likely higher than normal in 2003, as the wind anomaly along East Greenland is generally from southwest into the Irminger Sea, i.e. from warmer environments dominated by the relative warm Atlantic Water. North of Denmark Strait the wind anomaly continues from south towards north. This could have altered the amount of sea ice seen at Cape Farewell.

5. Fjords around Sisimiut

The hydrography in fjords is to a large extent determinated by the land runoff of fresh water in the surface and at the inflow near the bottom at the mouth of the fjord (see Fig. 11). Often fjords have a sill at the opening to the open ocean and it is the depth of this sill that determinate which watermass is allowed to enter near the bottom. Above sill depth water can freely flow either in or out of the fjord. At the surface the current are often directed out of the fjord caused by the runoff of fresh water, which will increase the sea level in the fjord. Thereby a pressure gradient is established and surface water will flow out of the fjord. Normally this surface water will entrain water from below. To compensate for this entrainment, inflow is taking place at the bottom as sketched in Fig. 11.

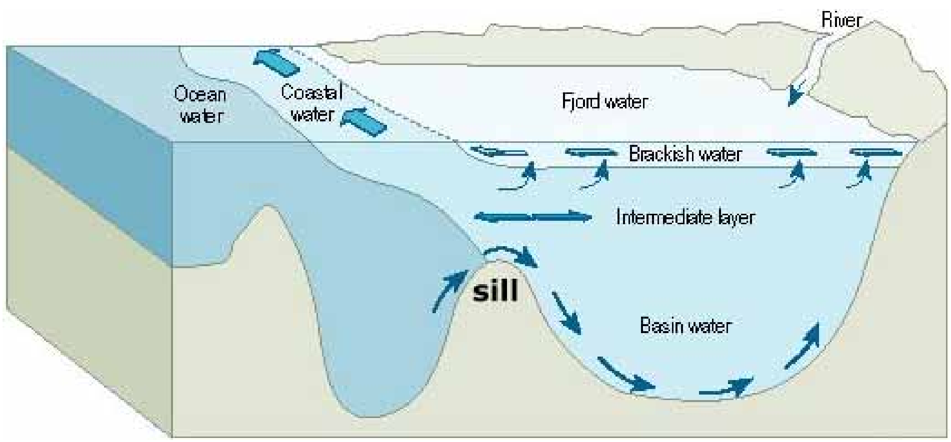


Fig. 11. Sketch of the circulation in a fjord (modified from http://www.amap.no/maps-gra/show.cfm?figureId=58).

In the West Greenlandic fjord basically three different kinds of waters exists:

- Relative warm and saline waters of Atlantic origin (mixed Irminger Water).
- Cold and relative fresh water of polar origin (mixed Polar Water).
- Fresh surface water from land, either as melting of the Greenland Ice Sheet or from precipitation (surface water). The amount of this water is highly variable depending on the time of the year. The water is mixed with the surrounding surface waters, which is Polar Water. This mixing is continues going on along the coast, and the watermass stays close to the coast. In the following it is named Coastal Polar Water.

Four fjords around Sisimiut were investigated (Fig. 8). They represent two very different types of fjords: two with deep sills (Amerdloq and Ikertoq) and two with shallow sills (Kangerdluarssuk and Qeqertalik). Section plot of the two fjords with deep sills are shown in Fig. 27 and Fig. 28. As both Qeqertalik fjord and Kangerdluarssuk fjord have a common sill, they should be regarded as one single fjord system Kangerdluarssuk (Fig. 29). None of the fjords are directly connected to the Greenland ice sheet, and so the fresh water supply added are limited to runoff from land. The fresh water added is of minor importance as can be seen directly from a topographic map, but also by the fact, that almost no fresh water measured at the surface.

In the two deep sill fjords, Amerdloq and Ikertoq fjord, the conditions are different (Fig. 27 and Fig. 28). The sill depth of Amerdloq fjord is about 180m and about 150m in the Ikertoq fjord. These sill depths allow relative warm and saline waters of Atlantic origin to enter the fjords close to the bottom. The density is higher than the Coastal Polar Water above, even at the freezing point of the Coastal Polar Water. Thereby winter convection to the bottom is prevented. The bottom water up to about 150m from the surface remain saline and “warm” (2-3°C). In the upper 150m the salinities are almost homogenous whereas the temperature was coldest just above the interface between the diluted Irminger Water and the Coastal Polar Water. This cold water are likely a result of winter convection of Coastal Polar Water, as this cold water is not seen outside the fjord or in the Sisimiut section (Fig. 17). It could also be some Coastal Polar Water entered from outside earlier of the year. Close to the surface a thin warm layer is found caused by the sun heating.

In the Kangerdluarssuk fjord with a shallow sill (sill depth about 50 m, Fig. 29) the whole bottom layer below sill depth are filled with Coastal Polar Water and the salinity are very homogeneous. During winter the Coastal Polar Water are cooled and undergoes convection. As the water inside the fjord have homogenous salinities the whole water column are gradually cooled by winter convection and the water become totally homogenous (neutral stability). Therefore cold temperatures are measured below sill depth. At the surface relative warm water is found caused by the solar radiation during spring and summer.

6. **Conclusions**

The oceanographic conditions off West Greenland during the summer 2003 was characterised by:

- NAO index was for the second year very close to zero, but the center of the low and high was displaced towards southwest and central Europe (northeast) respectably.
- Northwest-ward anomaly in the wind component over the Iceland Basin, the eastern Irminger Basin and in the Denmark Strait.
- Anomaly warm air to East Greenland.
- Weakening East Greenland Current through Denmark Strait caused by the local wind stress.
- Nuuk air temperature was lower than in 2002 but still close to average.
- Medio June water Temperature on top of Fylla Bank about 1°C above average, while the salinity were close to average.
- Week inflow of Polar Water and normal inflow of Irminger Water reflected by the facts that:
  - the concentration of “Storis” was very small.
  - Cold core of Polar Water could hardly be distinguished at Fylla Bank.
  - the gradient between the two water masses observed was week.
  - Relative high salinities and temperatures of the surface Polar Water close to south west Greenland.
  - pure Irminger Water could be traced up to the Fylla Bank section and Modified Irminger Water could be traced up to the Maniitsoq section.
  - The temperature on top of Fylla Bank was high even though the mean air temperature was normal and the salinity was close normal.

Literature

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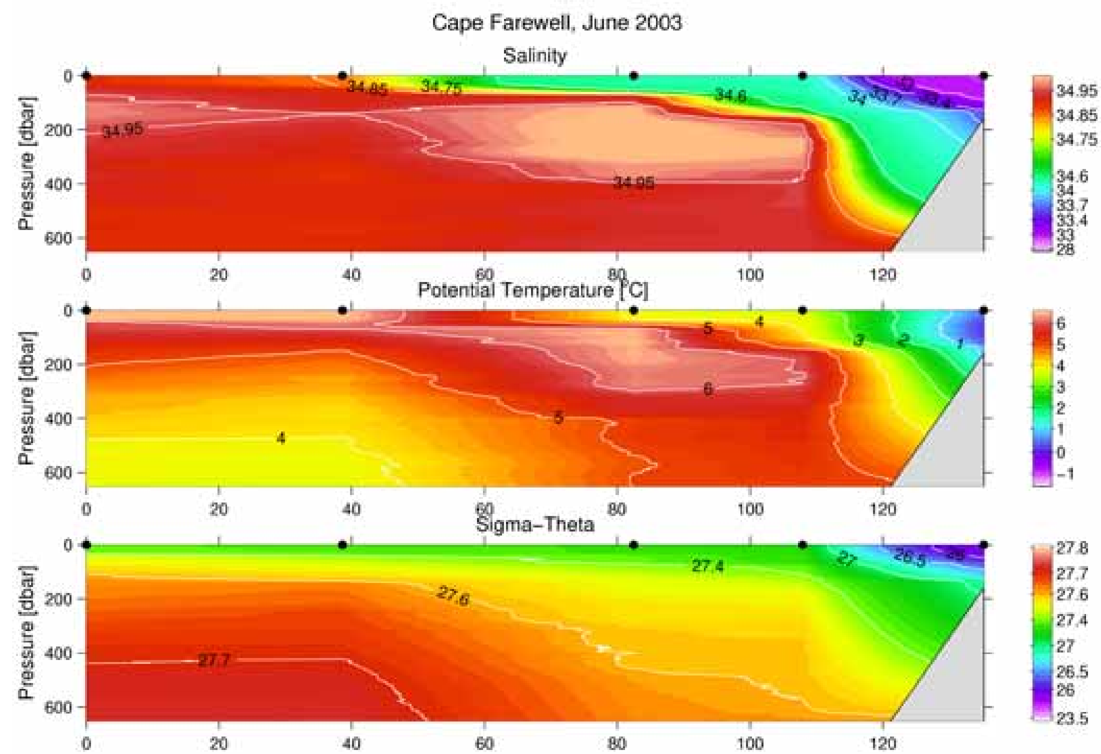

Fig. 12. Vertical distribution of temperature, salinity and density at the Cape Farewell section, June 29, 2003.

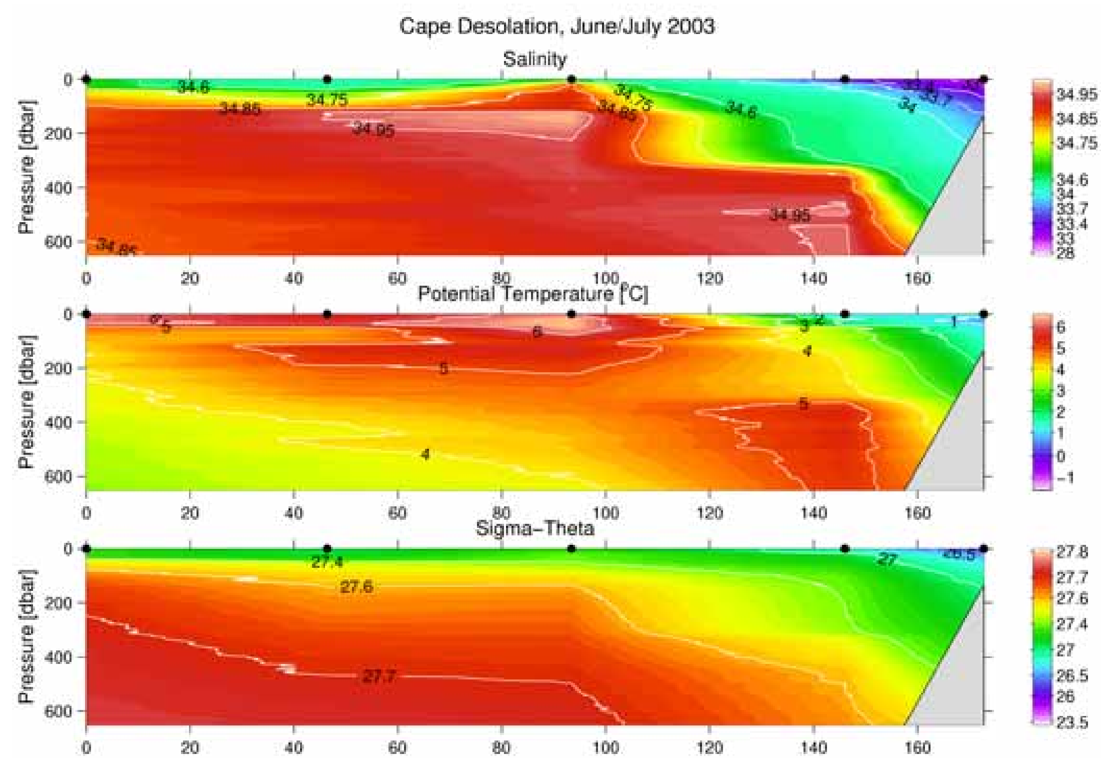

Fig. 13. Vertical distribution of temperature, salinity and density at the Cape Desolation section, June 30–July 1, 2003.

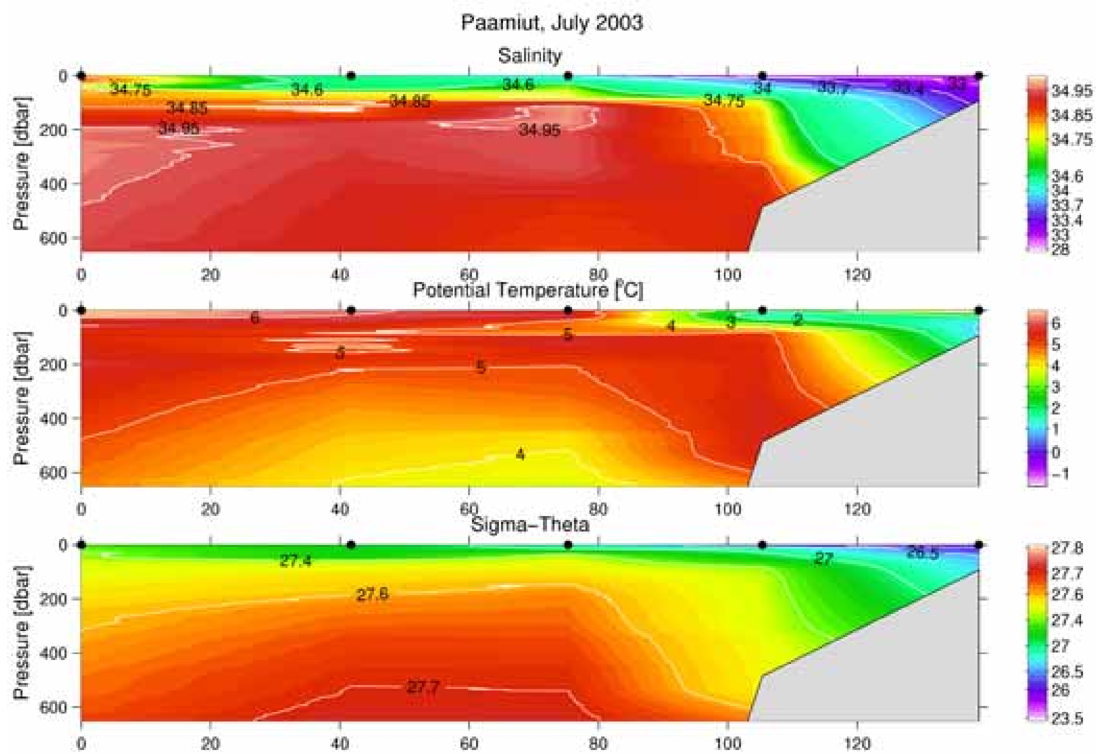

Fig. 14. Vertical distribution of temperature, salinity and density at the Paamiut (Frederikshaab) section, July 1, 2003.

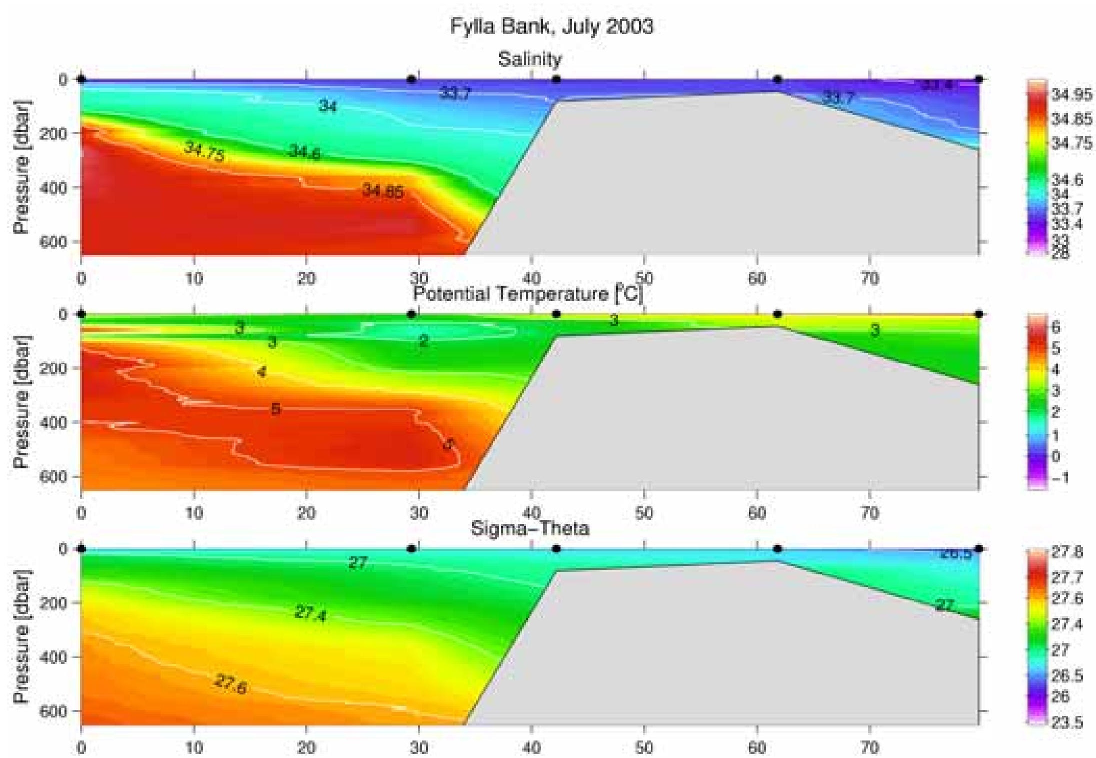

Fig. 15. Vertical distribution of temperature, salinity and density at the Fylla Bank section, July 2, 2003.

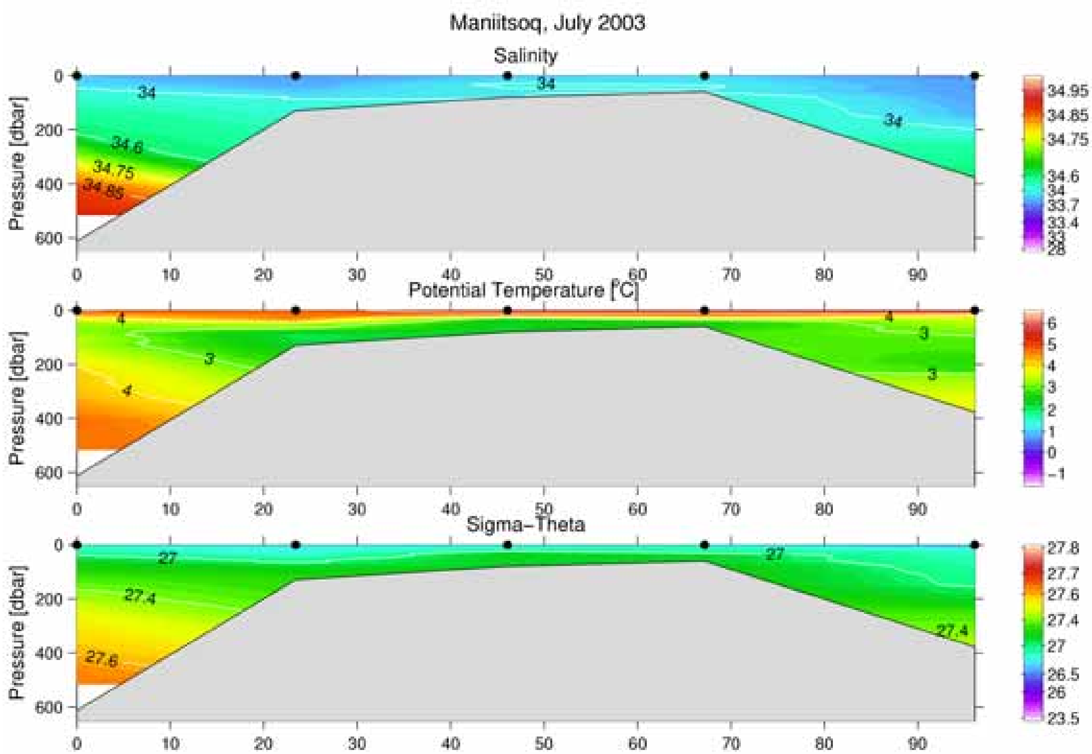

Fig. 16. Vertical distribution of temperature, salinity and density at the Maniitsoq (Lille Hellefiske Banke, Sukkertoppen) section, July 4, 2003.

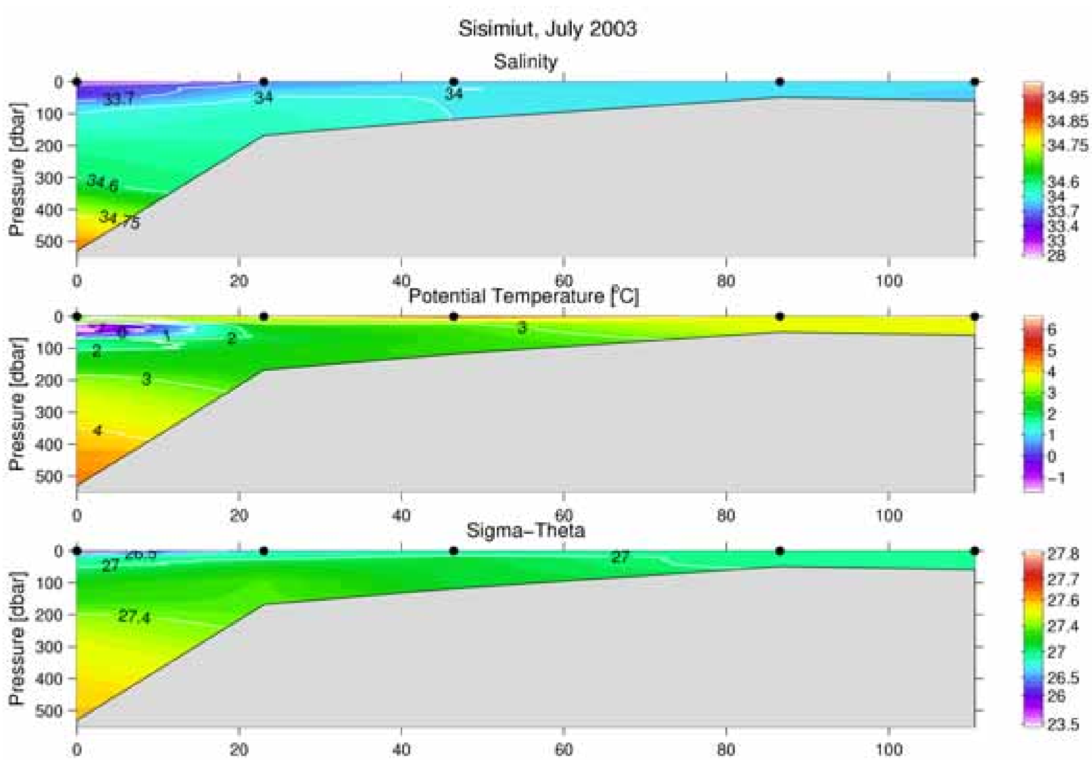

Fig. 17. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, July 4–5, 2003.

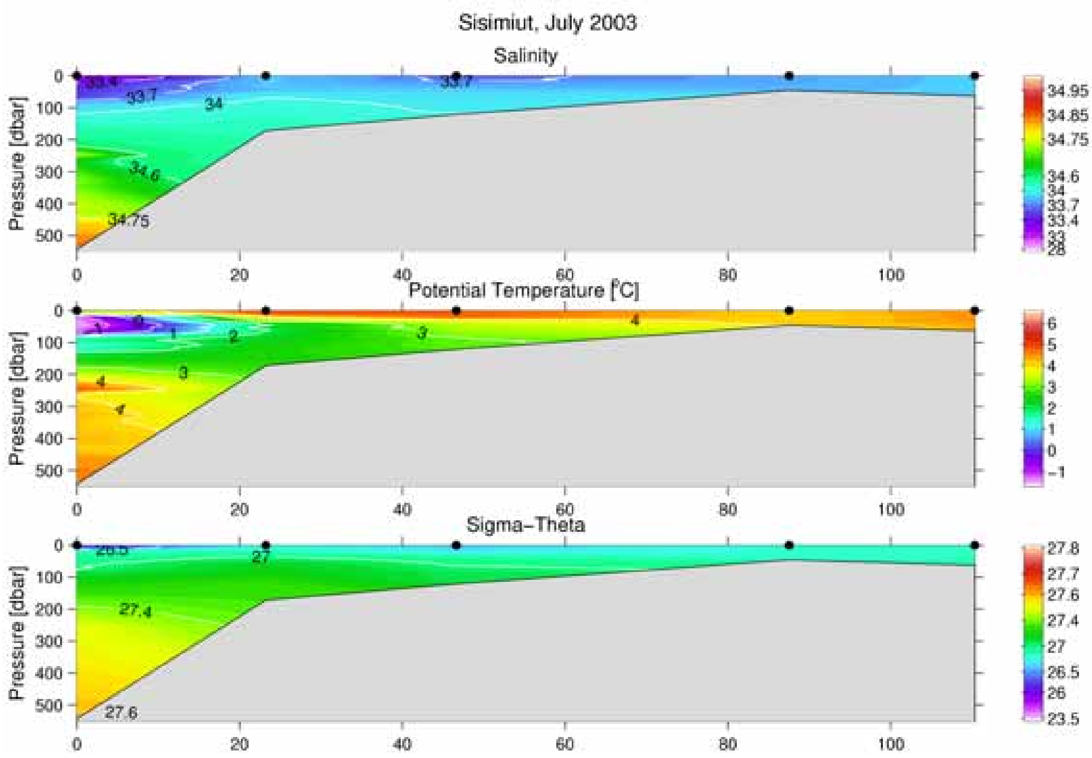

Fig. 18. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, July 11–12, 2003.

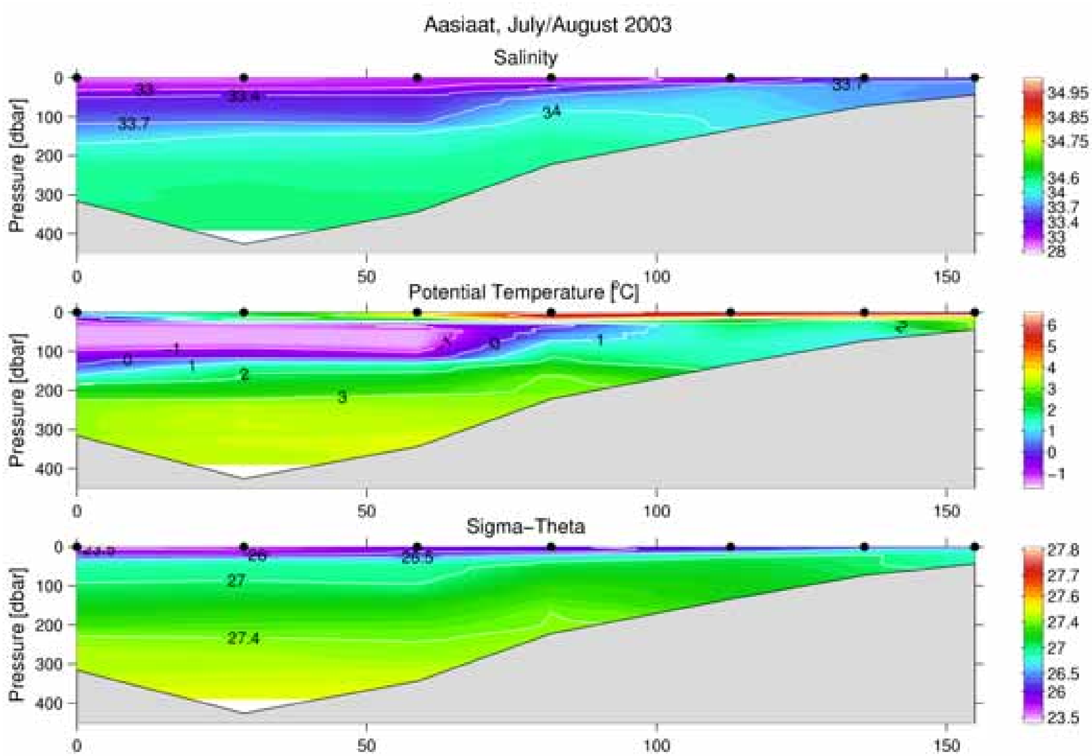

Fig. 19. Vertical distribution of temperature, salinity and density at the Aasiaat section, July 14–16, 2003 and August 6–8, 2003 (3 deepest).

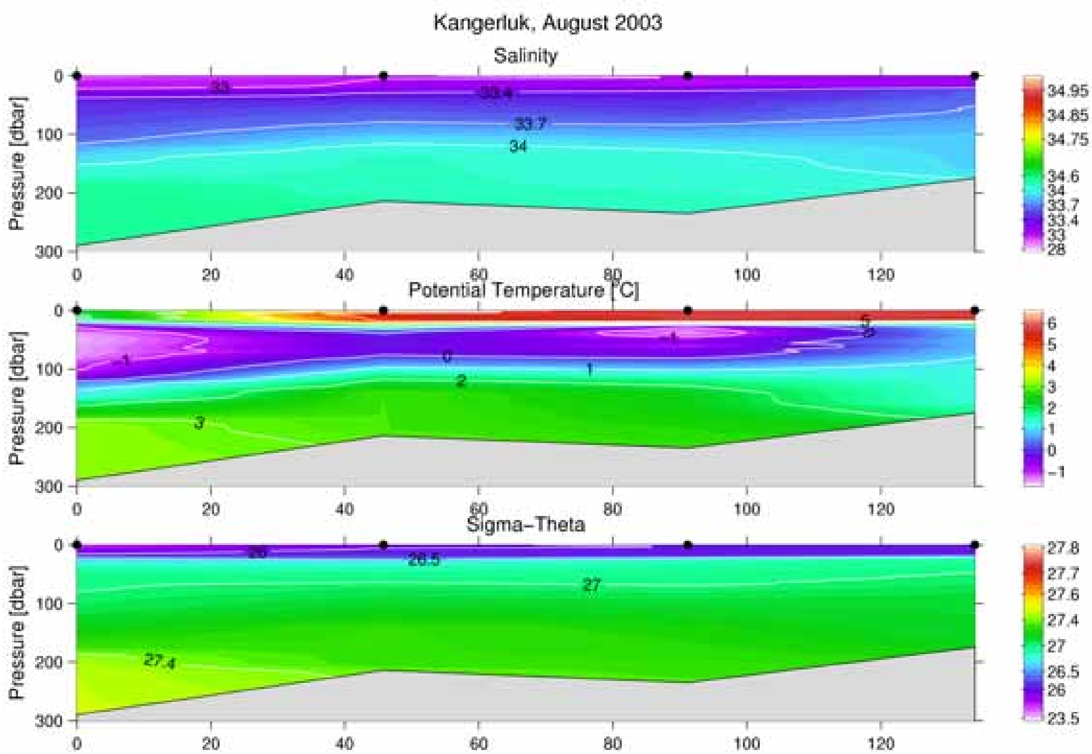

Fig. 20. Vertical distribution of temperature, salinity and density at the Kangerluk (Disko Fjord) section, August 1–2, 2003.

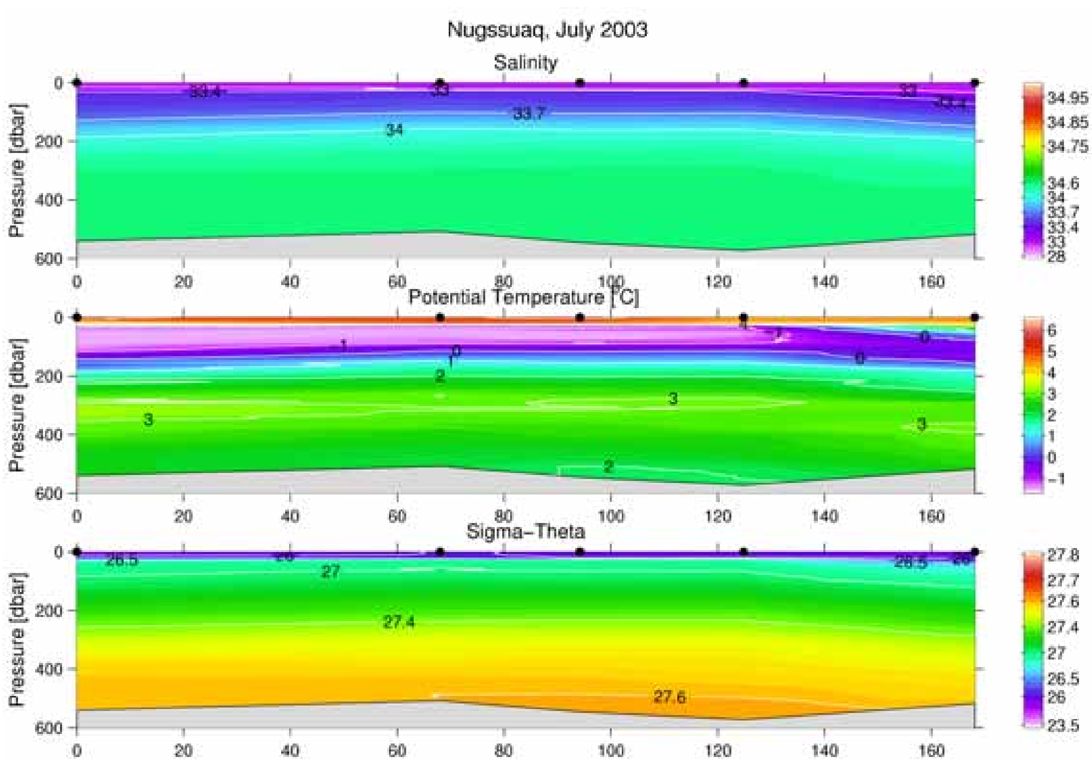

Fig. 21. Vertical distribution of temperature, salinity and density at the Nugssuaq section, July 27–31, 2003.

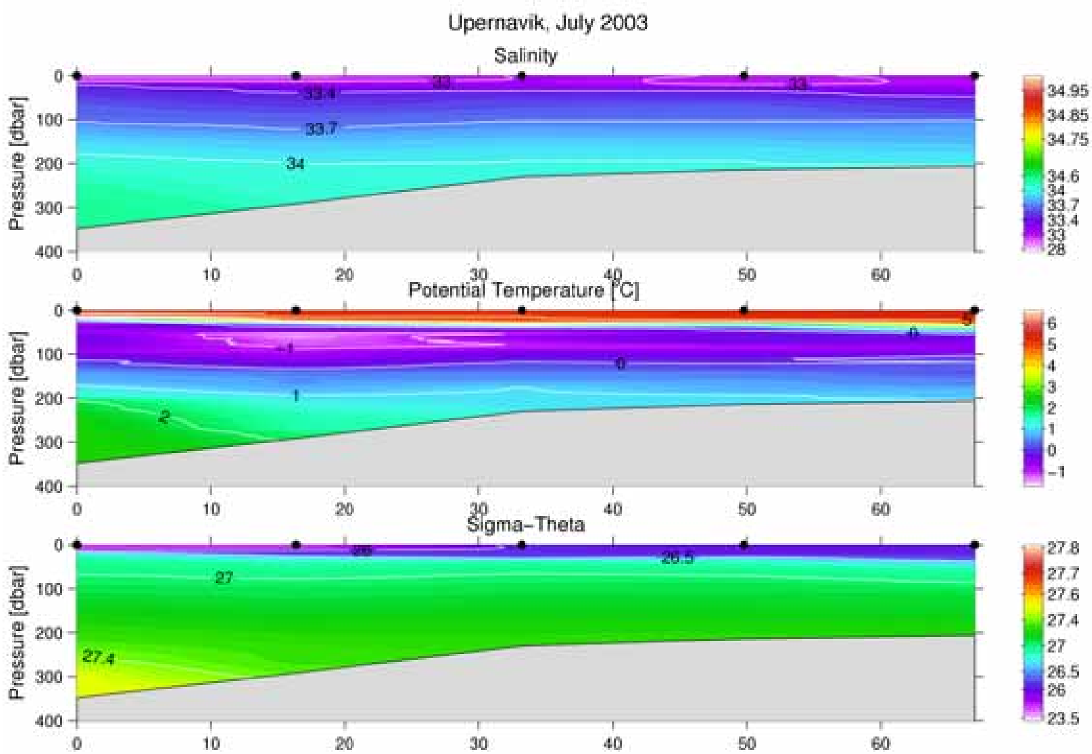

Fig. 22. Vertical distribution of temperature, salinity and density at the Upernavik section, July 30–31, 2003.

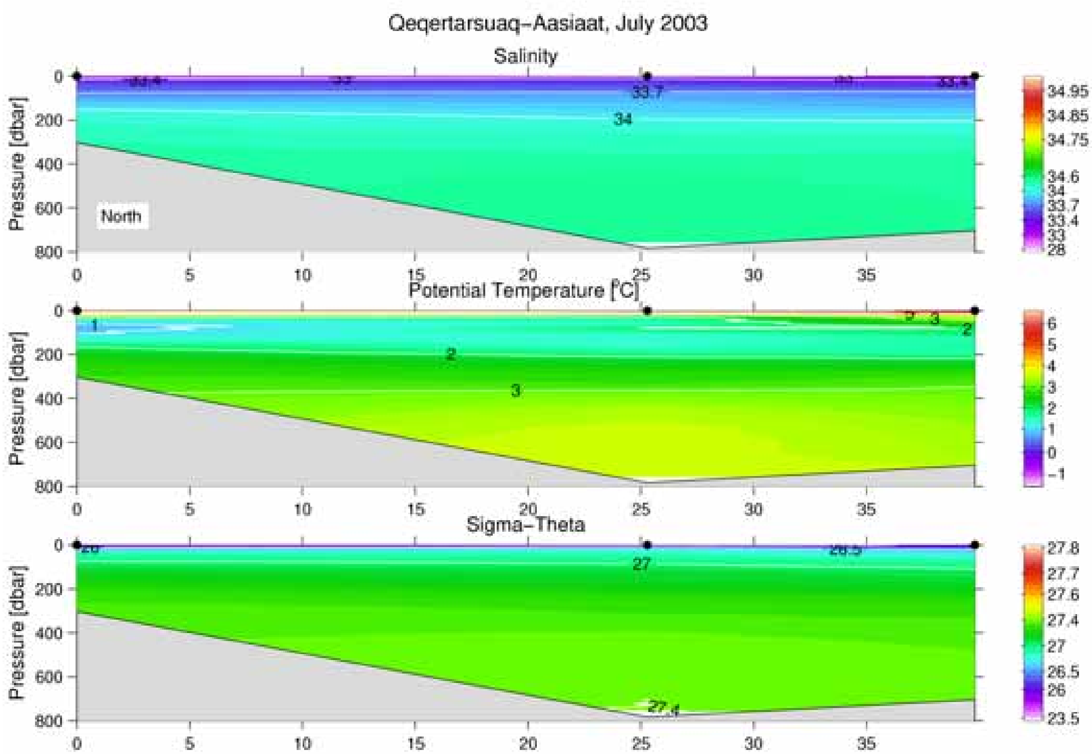

Fig. 23. Vertical distribution of temperature, salinity and density at the Qeqertarsuaq–Aasiaat (Godhavn–Egedesminde) section, July 24, 2003.

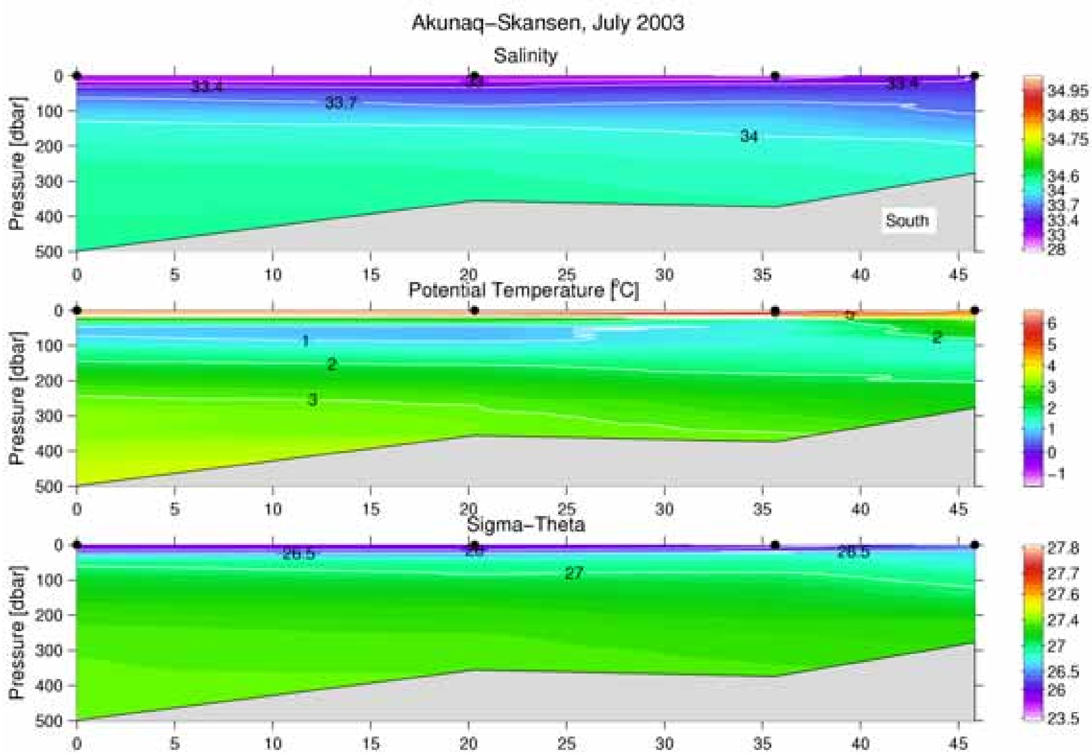

Fig. 24. Vertical distribution of temperature, salinity and density at the Akunaq–Skansen section, July 22–23, 2003.

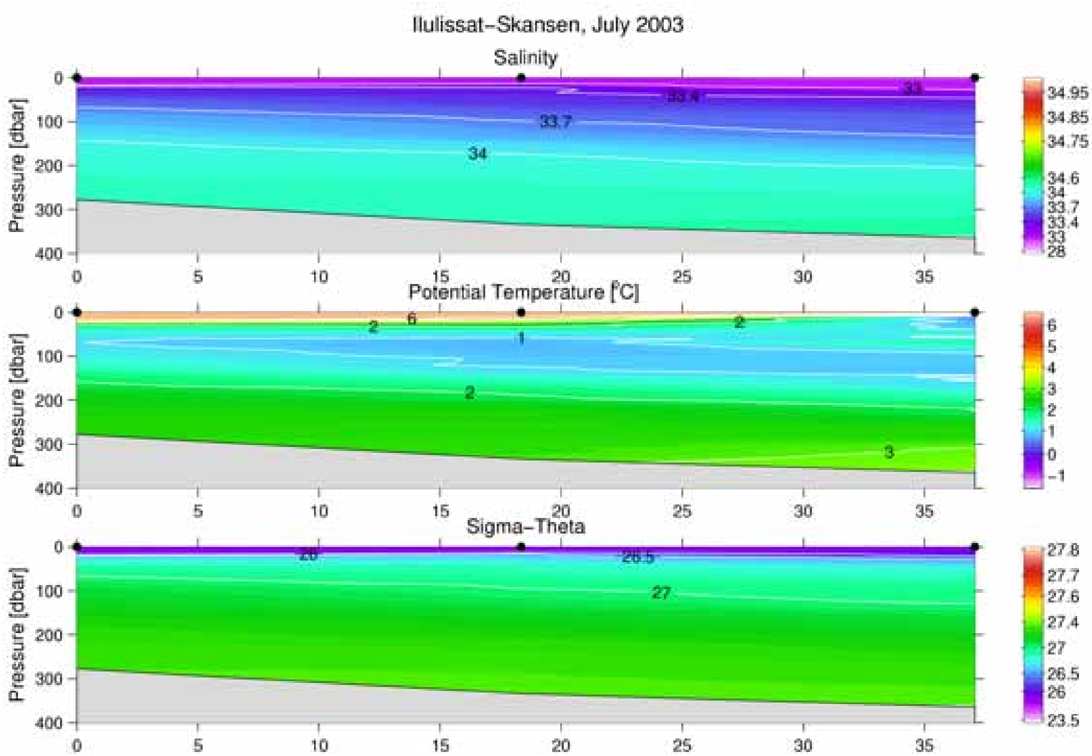

Fig. 25. Vertical distribution of temperature, salinity and density at the Ilulissat–Skansen (Jakobshavn-Skansen) section, July 23–24, 2003.

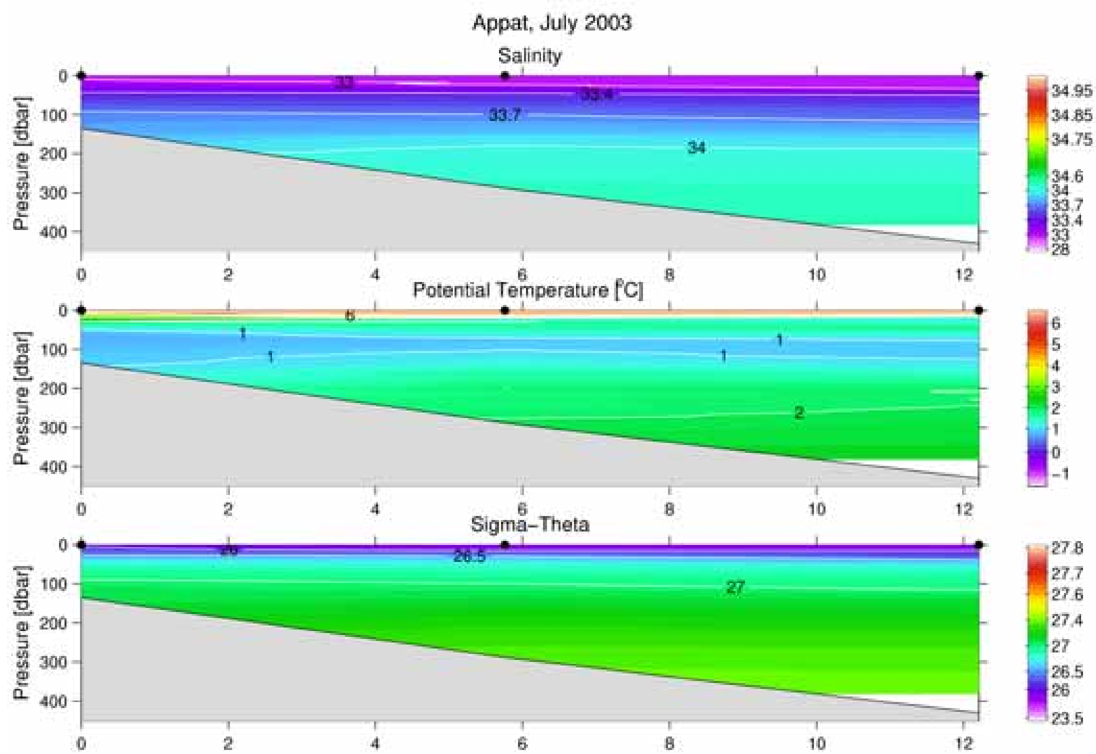

Fig. 26**.** Vertical distribution of temperature, salinity and density at the Appat (Arveprins Ejlande) section, July 23–24, 2003.

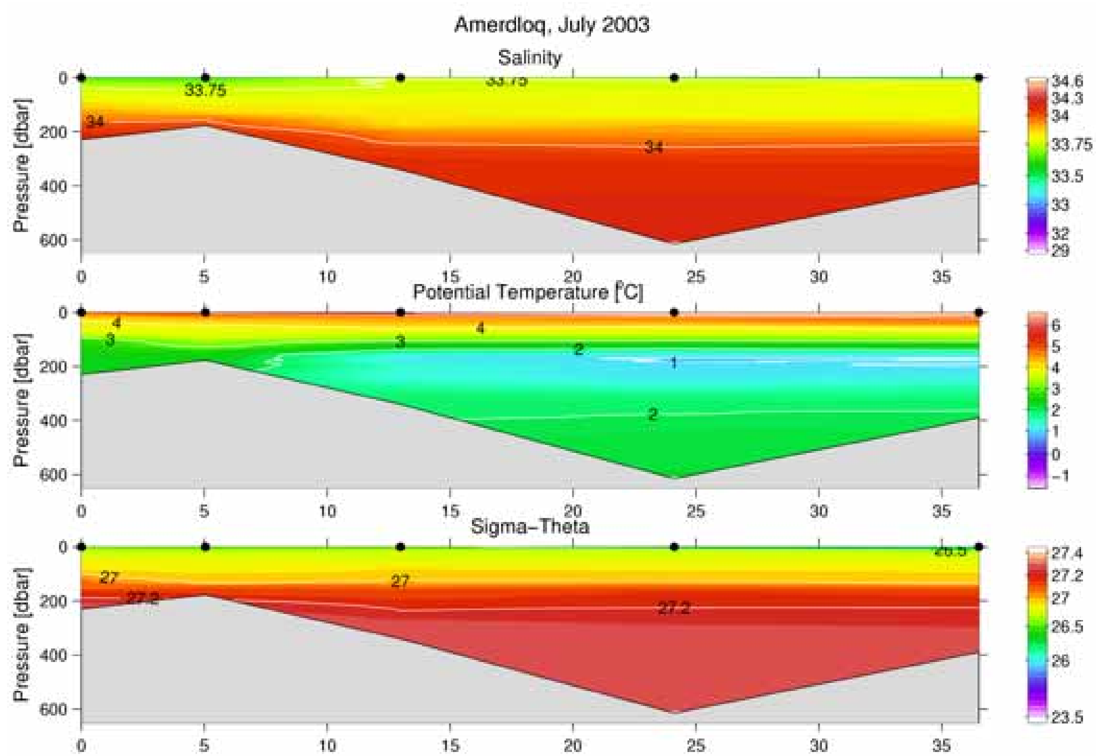

Fig. 27**.** Vertical distribution of temperature, salinity and density at the Amerdloq fjord, July 6, 2003. St.1 (left) south of the fjord.

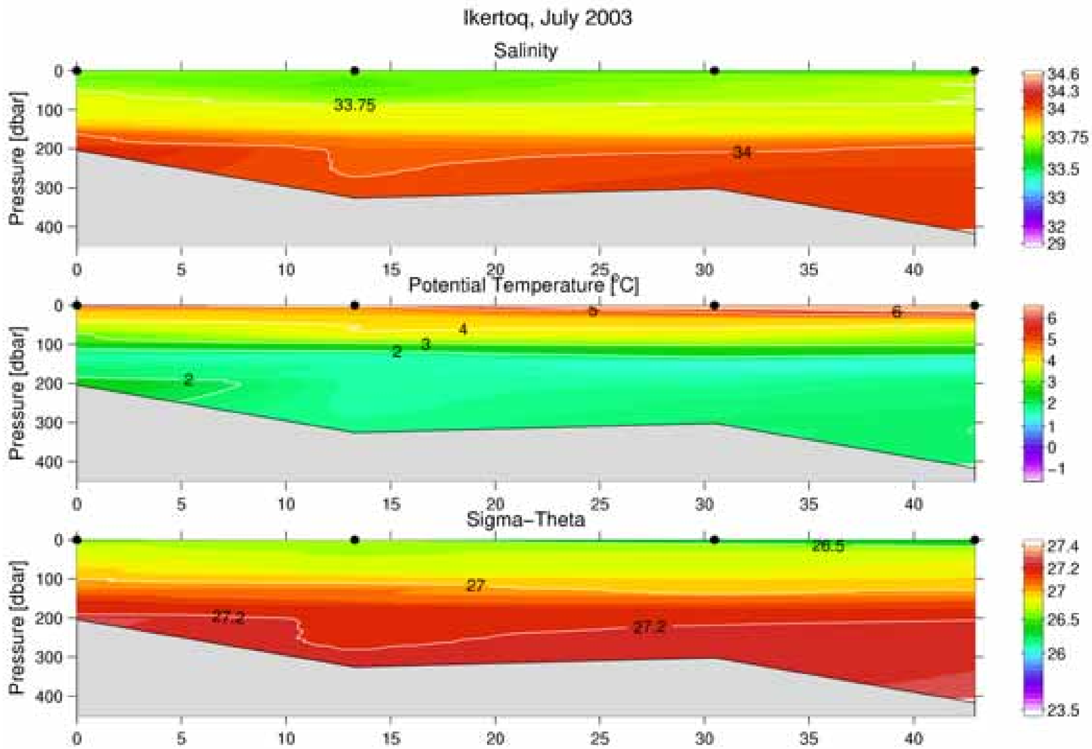

Fig. 28**.** Vertical distribution of temperature, salinity and density at the Ikertoq fjord, July 5, 2003.

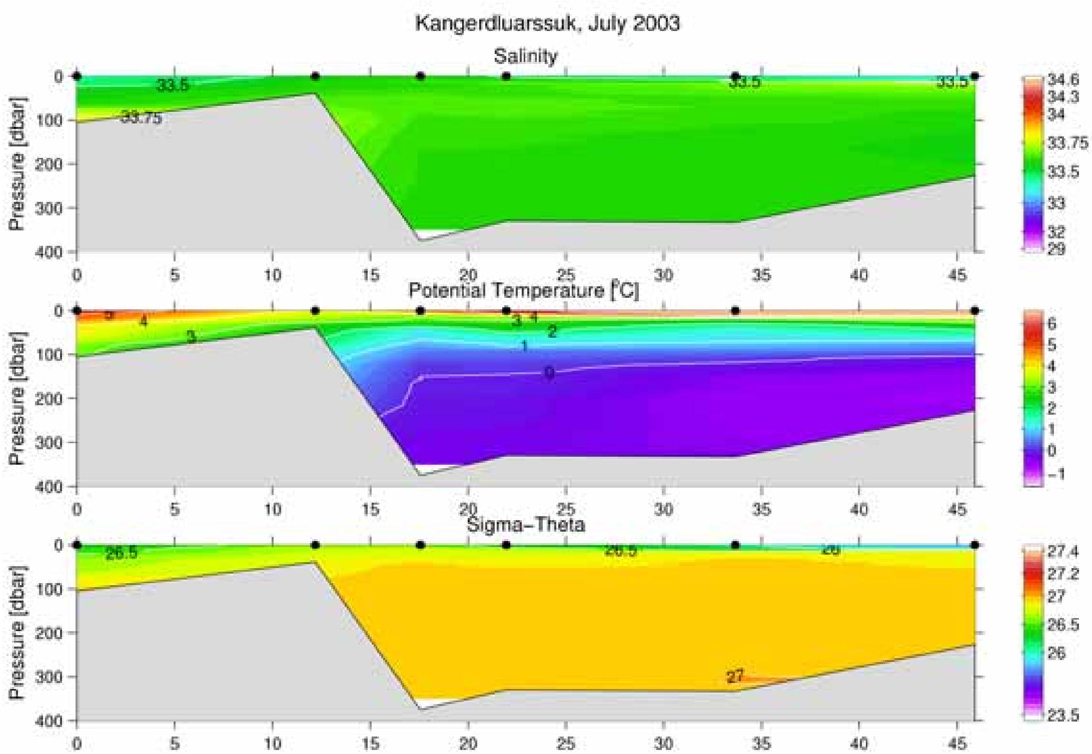

Fig. 29**.** Vertical distribution of temperature, salinity and density at the Kangerdluarssuk fjord, July 5, 2003. Properties of Qeqertalik are very similar to the inner Kangerdluarssuk as they have common sill.