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Oceanographic Investigations off West Greenland, 2004

by

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Abstract

Results of the summer 2004 standard section cruise along the west coast of Greenland are presented together with CTD data gathered during trawl surveys.

The NAO index was slightly negative and the westerlies was weakened, i.e. anomaly easterlies.

The time series of mid-June temperatures on top of Fylla Bank was about 1.5°C above average conditions, while the salinity was slightly higher than normal. The mean (400-600 m) salinity west of Fylla Bank (st. 4) was record high and the temperature 0.9°C above normal. This indicates high inflow of Irminger Water.

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 2004. Pure Irminger Water was observed from Cape Desolation 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 to West Greenland waters seems to be high.

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 2003/2004 was slightly negative (Fig. 1). The Icelandic Low during the winter months (December–Marts) was weaker than normal - i.e. higher pressure - and the center of the Azores High was slightly deflected northeast towards Europe (Fig. 3). The center of the low was just southwest of Iceland, which is close to normal (Fig. 2). The pressure difference has the effect that the westerlies over the North Atlantic was weaker than normal resulting in an wind anomaly (difference from normal conditions) towards west across the North Atlantic (Fig. 4). Over the Denmark Strait area, the average wind conditions were close to normal.

West Greenland lies within the area which normally experiences warm conditions when the NAO index is negative. As can be seen from Fig. 5 the annual mean air temperature for 2004 in Nuuk was minus 0.4°C which is about one degree above average, reflecting well the negative NAO value. The mean annual air temperature for 2004 was above normal for most of the North Atlantic region with anomalies above 2°C over the Davis Strait region (Fig. 6).

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 2004 the mean temperature on top of Fylla Bank in the middle of June was 3.23^{o}C which is about 1.5°C above the average value of 1.73^{o}C for the whole 54 year period and the second highest value, whereas the mean salinity value, 33.51, was about equal to the average value for the entire period (Fig. 7).

2. **Measurements**

The 2004 cruise was carried out according to the agreement between the Greenland Institute for Natural Resources and Danish Meteorological Institute during the period June 21-June 29, 2004 onboard the Danish naval ships "AGPA" and "TULUGAQ"**.** Observations were performed on the following stations (Fig. 8):

Offshore Labrador Sea/Davis Strait:

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

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 conditions, "Storis"[1] (Fig. 9) was present in normal quantities and "Vestice"[2] was not present at all.

Unfortunately, caused by the limited ship time combined with "Storis" at Cape Farewell the Cape Farewell St. 1-5 was not carried out this year.

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. 8):

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. (St. 3 bad cast)

In late September/early October the Greenland Institute for Natural Resources carried out additional trawl surveys in the Baffin Bay. This included 24 CTD casts. However, these were not on sections, but we have tried to conduct three sections, which are *not* standard sections (see Fig. 8):

[1] "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.

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

- Baffin Bay sec. 1
- Baffin Bay sec. 2
- Baffin Bay sec. 3

3. Data Handling

Measurements of the vertical distribution of temperature and salinity were carried out using a SEABIRD SBE 9-11 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 SBE Data Processing version 5.33 software provided by SEABIRD (www.seabird.com).

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.

4. Oceanographic Conditions off West Greenland in 2004

The surface temperatures and salinities observed during the 2004 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 Desolation section and on the outermost station on the Paamiut section.

In the Baffin Bay the very low surface salinities generally below 33 is caused by melting of sea-ice during summer and fresh water runoff from land. The salinities around 34 reflect the core of the West Greenland Current, which is slightly modified by Atlantic Water. The warm-surface waters in the Disko Bay are caused by solar heating of the 20–30 m thin low-saline surface layer.

The vertical distribution of temperature, salinity and density at sections along the West Greenland coastline is given in Fig. 12-Fig. 24 and within the Disko Bay in Fig. 25-Fig. 28. In addition to data from the five standard sections obtained during the AGPA/TULUGAQ cruise in late June, standard sections further north from Sisimiut up to Upernavik, including section within the Disko Bay, is measured during the R/V PAAMIUT cruise in mid July/early August. Finally, three sections in the northern Baffin Bay are created using the scattered stations taken during the late September/early October R/V PAAMIUT cruise.

Temperature and salinity observations at intermediate depth showed that pure Irminger Water (T ~4.5^{o}C, S >34.95) was present at the Cape Desolation and Paamiut sections. At the Fylla Bank section, the maximum salinity is very close to 34.95 with temperature above 5, which can almost be classified as Pure Irminger Water. Modified Irminger Water (34.88 < S <34.95) was traced up to the Maniitsoq section. The northward extension of pure Irminger Water up to Fylla Bank indicates high inflow of water of Atlantic origin to the West Greenland area.

The average salinity and temperature at 400-600 m depth west of Fylla Bank (st. 4), which is where the core of the Irminger Water is normally found, supports, that the inflow of Irminger Water has been high in 2004 (red curves in Fig. 11). The temperature of this layer is above 5°C which is 0.9°C higher than normal and the average salinity of 34.93 is 0.12 higher than normal and is the highest observed in the 54 year time series.

Noticeably, the temperature seems to be relative warm and stable since the mid-1990s in all layers - and even increasing in the early 2000s. Likewise, the mean salinity in the 400-600 m layer have increased in the early 2000s indicating increased strength of the Irminger Current as pointed out by Ribergaard (2004). Since the early 2000s, not only the strength of the Irminger Current, but also the air temperatures has increased considerable and it is now comparable with the air temperatures for the period mid-1920s to the late 1960s (Fig. 5). It is interesting to observe, if the climate conditions will remain in this state or "regime" the coming years. According to Stein (2004), warming over time, not just interannual variations, seems to be important for the abundance of juvenile cod and haddock in Greenland waters.

The surface salinity seems in general to be close to normal. The "Storis" is occupying the Julianehaab Bight and this sea-ice is observed up to 61°N (Fig. 9), which is normal for this time of the year. 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. 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 2004 this core was hardly recognizable which is a sign of a reduced inflow of Polar Water in 2004. The core was even more absent than in 2002 (see Buch and Ribergaard, 2003), and comparable to the conditions in 2003 (see Ribergaard and Buch, 2004). This indicates a low intensity in the East Greenland Current component. One explanation could be that more than normal Polar Water is drifting eastward north of Iceland, caused by a small westerly wind anomaly just north of the Denmark Strait (Fig. 4).

The weak Polar Water core is also observed at the Sisimiut section from June (Fig. 16), and it has almost disappeared one month later in July (Fig. 17), whereas the water of Atlantic origin is found in larger quantities in July. This shows part of the annual cycle of the strength of the inflow of Polar Water and Irminger Water to the area, which is not in phase. The strength of the inflow of Irminger Water peaks during autumn and winter whereas the inflow of Polar Water peaks in spring and early summer.

As usual, parts of the Irminger Water re-circulates 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 seen as a slightly doming up of isolines. However, this cell was much more pronounced in 2003 than in 2004 (see Ribergaard and Buch, 2004).

From the Aasiaat section up to the Upernavik section and further north in the three Baffin Bay sections, a very cold subsurface layer is found with temperatures below -1°C with cores at depth of 75-200 m. This layer is most likely formed during winter by convection. Brine rejection increases the low surface (0-50 m) salinities, so it can overcome the strong surface gradients which are created during summer by melting of sea-ice and run-off of fresh water from land. Below the cold subsurface layer, a relative warm (>1°C) water mass is found with a core around 400-500 m. This water is the extension of the Irminger Water component of the West Greenland Current. It can be traced up to the northern Baffin Bay. Below this water mass, colder water with salinities slightly below 34.5 is found. This water is believed to be water from the Arctic Ocean that enters as "spill over" through the Canadian Archipelago.

Lifting of the density lines indicates an eddy close to the third station on the Nugssuaq section.

5. **Conclusions**

The oceanographic conditions off West Greenland during the summer 2004 was characterised by:

- NAO index was slightly negative.
- The westerlies over the North Atlantic is decreased, i.e. anomaly easterlies.
- Anomaly warm air to East Greenland.
- Weak East Greenland Current. The local wind stress north of Iceland forced higher than normal fraction of the Polar Water to turn eastward just north of Denmark Strait and further north of Iceland.
- Nuuk air temperature was about 1°C higher than normal.
- Medio June water temperature on top of Fylla Bank was about 1.5°C above average while the salinity were close to average. The water temperature was the second highest observed.
- Week inflow of Polar Water and high inflow of Irminger Water reflected by the facts that:
    - Cold core of Polar Water could hardly be distinguished at Fylla Bank.
    - 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 mean salinity west of Fylla Bank (st.4) in 400-600 m depth was record high and the temperature 0.9°C higher than normal.

6. Literature

Buch, E. and Ribergaard, M.H., 2003. Oceanographic Investigations off West Greenland 2002. *NAFO SCR* Doc., No. **03/003**.

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Ribergaard, M.H., 2004. On the coupling between hydrography and larval transport in the Southwest Greenland waters. *Ph.D. thesis. University of Copenhagen.*

Ribergaard, M.H., and Buch, E., 2004. Oceanographic Investigations off West Greenland 2003. *NAFO SCR* Doc., No. **04/001**.

Schlitzer, R., 2005. Ocean Data View, http://www.awi-bremerhaven.de/GEO/ODV.

Stein, M., 2004. Transport of Juvenile Cod (*Gadus morhua*) and Haddock (*Melanogrammus aeglefinus*) from Iceland to Greenland – Is there environmental forcing? *NAFO SCR* Doc., No. **04/004**.

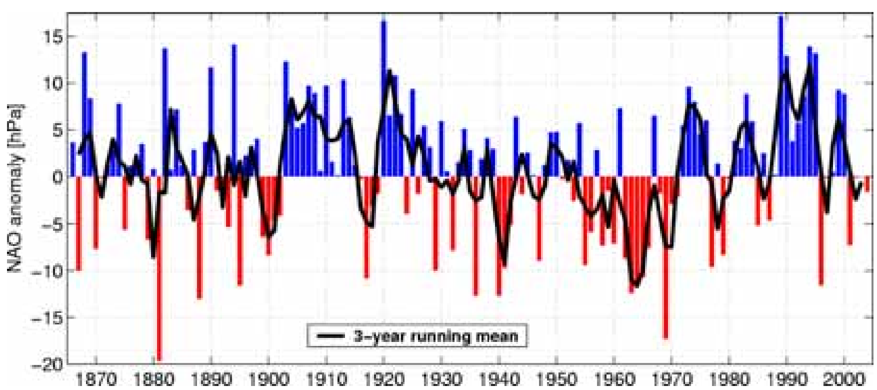

Fig. 1. Time series of winter (December–March) index of the NAO from 1865–2004. The heavy solid line represents the meridional pressure gradient smoothed with a 3-year running mean filter to remove fluctuations with periods less than 3 years. (Data updated, as described in Buch *et al*., 2003, from http://www.cru.uea.ac.uk/cru/data/nao.htm).

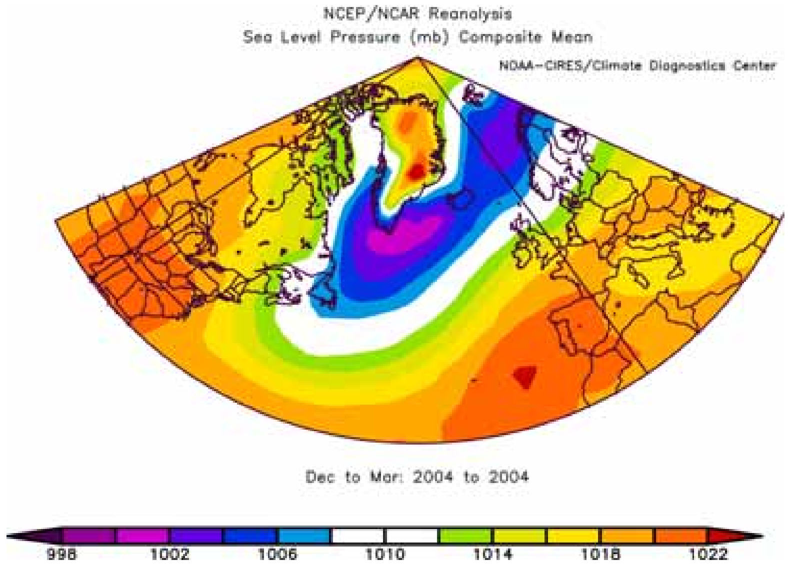

Fig. 2. Winter (DJFM) sea level pressure for 2003/2004 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

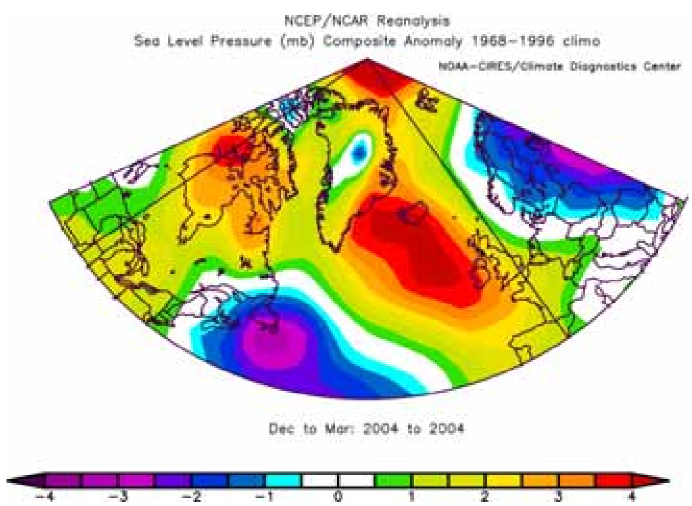

Fig. 3. Winter (DJFM) sea level pressure anomaly for 2003/2004 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

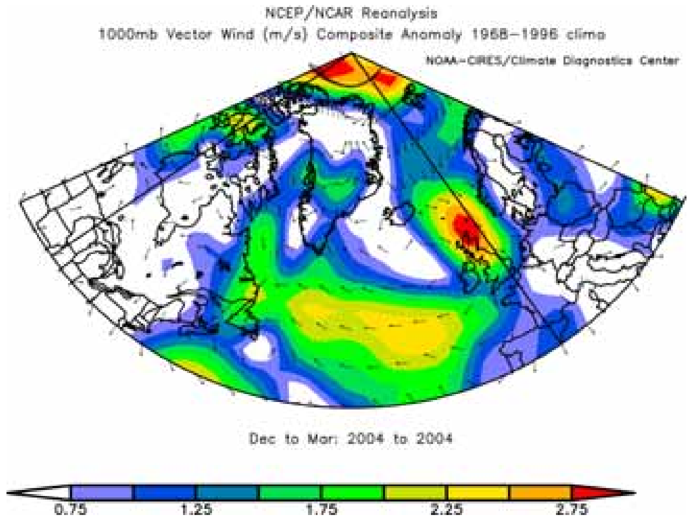

Fig. 4. Winter (DJFM) wind anomaly for 2003/2004 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

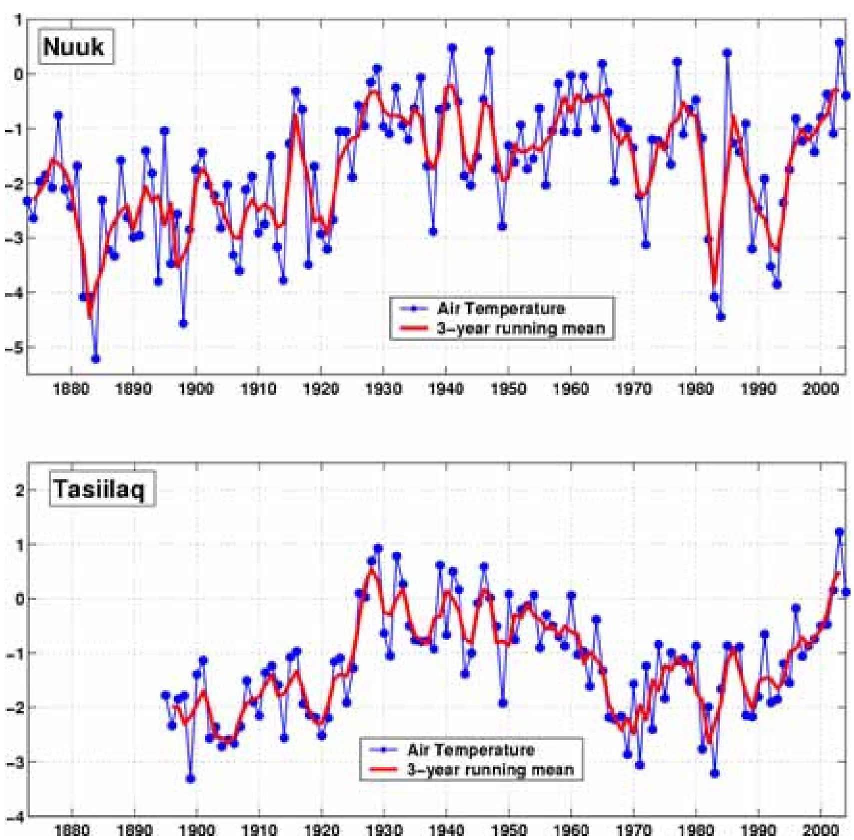

Fig. 5. Annual mean air temperature observed at Nuuk and Tasiilaq for the period 1873–2004.

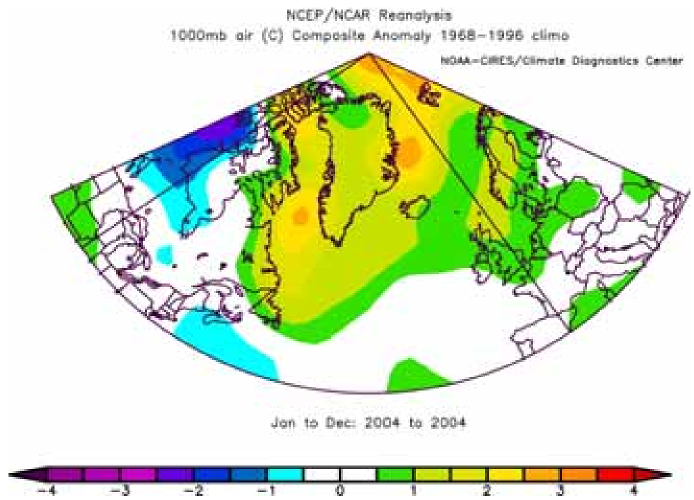

Fig. 6. Anomalies of the mean air temperature for 2004 in the North Atlantic region. NCEP/NCAR re-analysis (taken from http://www.cdc.noaa.gov).

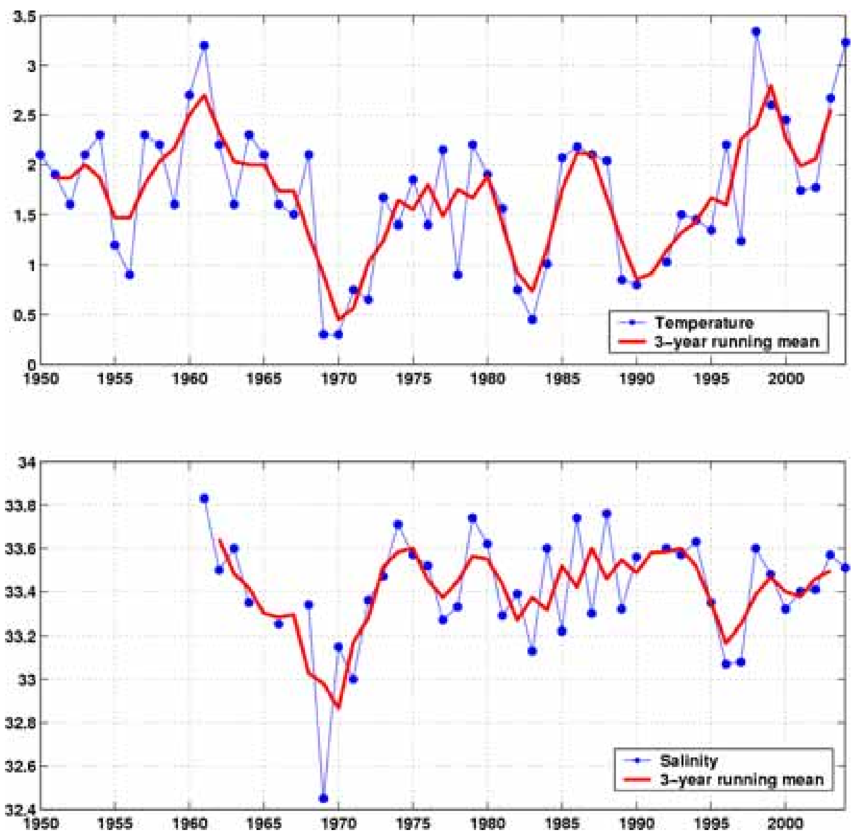

Fig. 7. Time-series of mean temperature (top) and mean salinity (bottom) on top of Fylla Bank (0–40 m) in the middle of June for the period 1950 to 2004. The red curve is the 3 year running mean value.

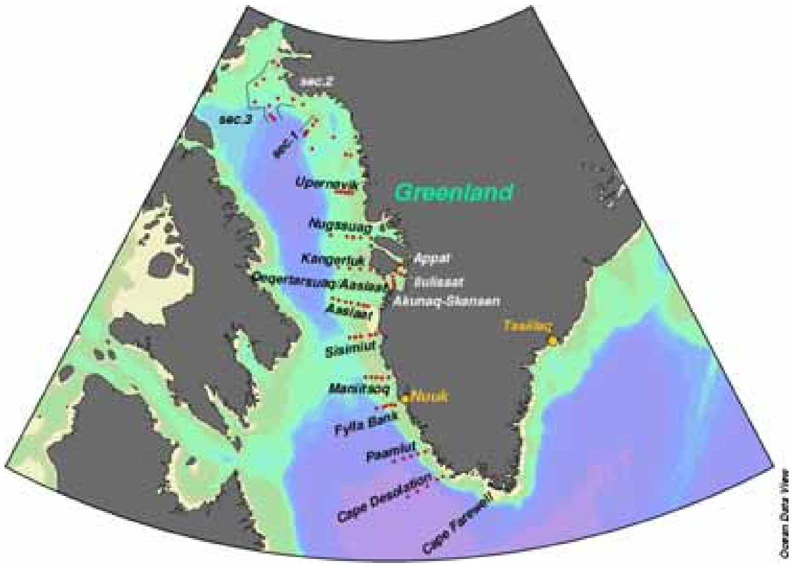

Fig. 8. Position of the oceanographic sections off West Greenland where measurements were preformed in 2004. The three northern section in the Baffin Bay is *not* standard sections, but sections are extracted for this report. Map produced using Ocean Data View (Schlitzer, 2005).

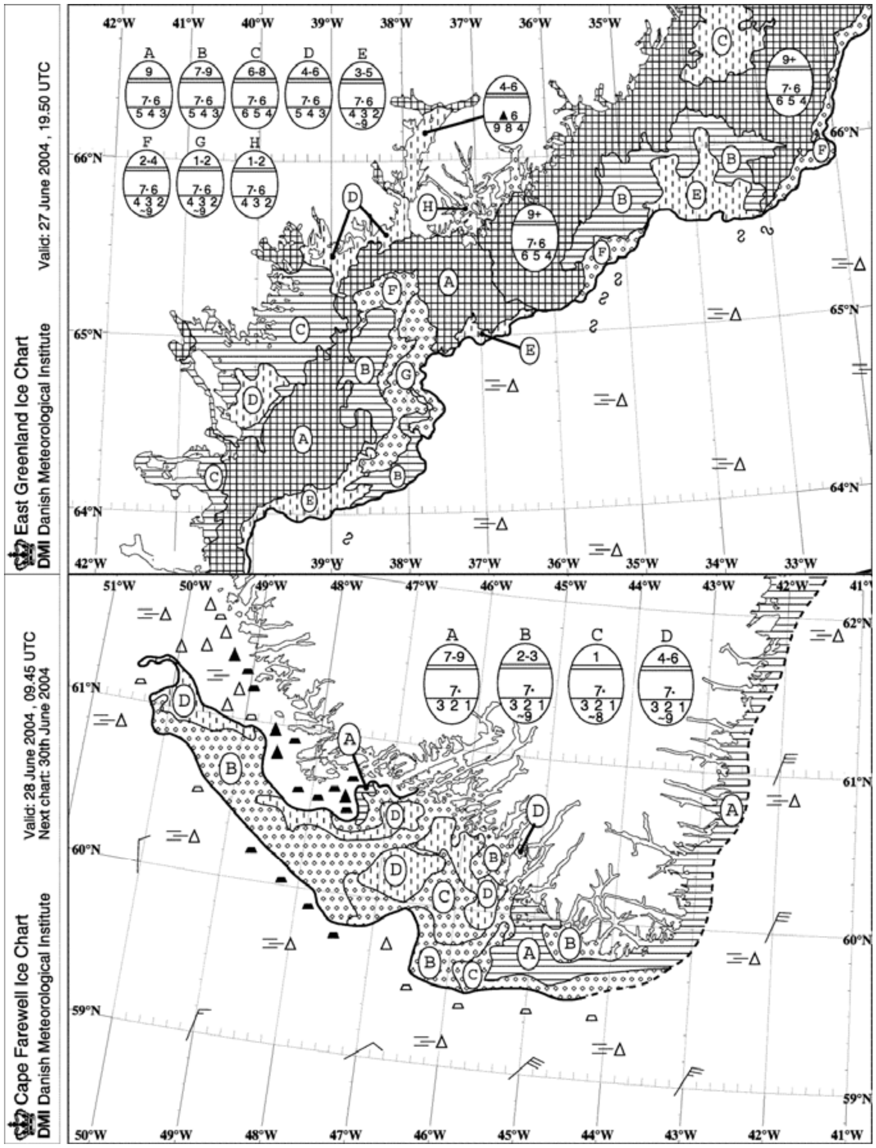

Fig. 9. Distribution of sea ice in the Amerssalik region valid at 27 June 2004 (top) and in the Cape Farewell region valid at 28 June 2003 (bottom).

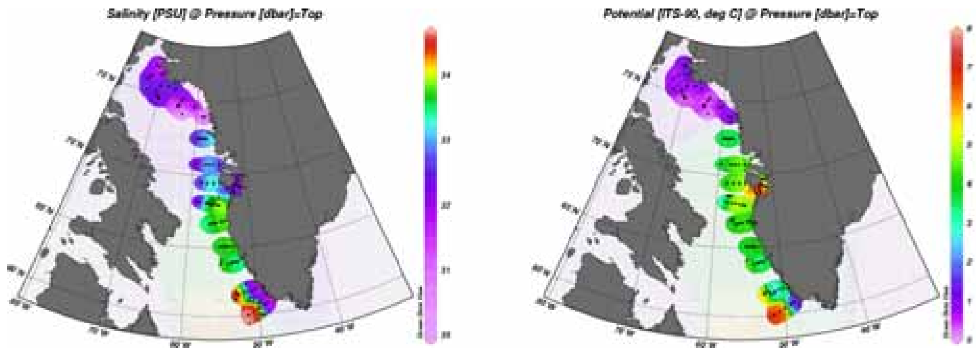

Fig. 10. Salinity (left) and temperature (right) observed in 2004 at the surface. The data are from late June south of Sisimiut, mid July/early August north of Sisimiut (section about 67°N) to Upernavik section (about 72°30'N) and late September/early October in the northern Baffin Bay north of Upernavik section. Contour lines shown for 33.0, 33.4, 33.7, 34.0, 34.4, 34.75, 34.85, 34.95 for salinity and from -2°C to 7°C for temperature with an interval of one degree.

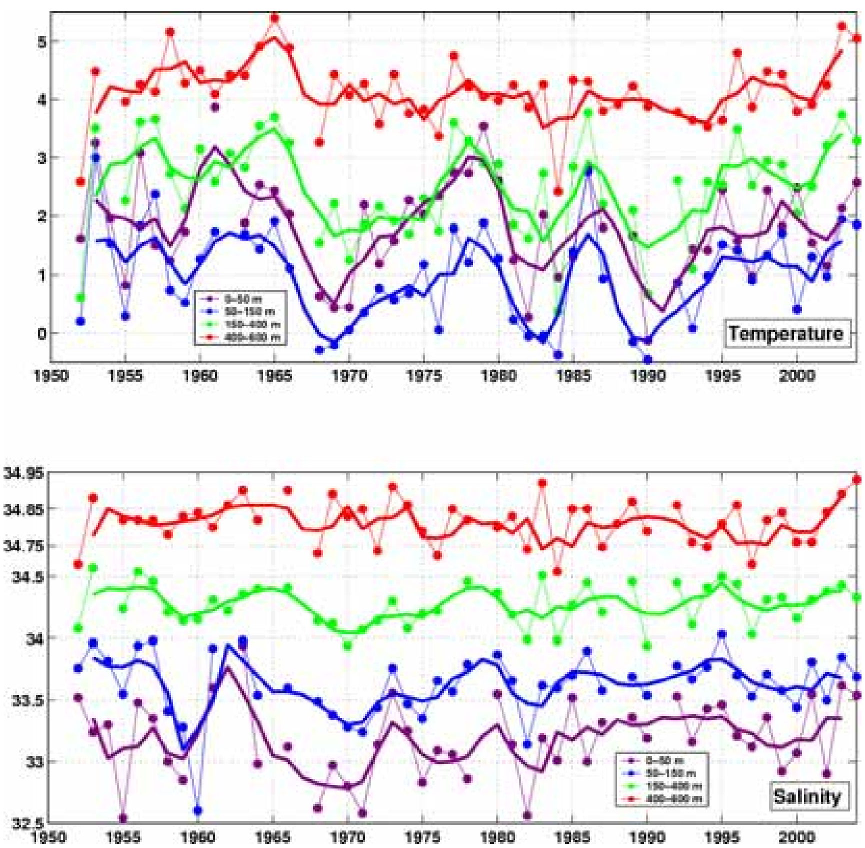

Fig. 11. Time series of mean temperature (top) and mean salinity (bottom) for the period 1950–2004 in four different depth intervals west of Fylla Bank (st.4) over the continental slope. The thick curves is the 3 year running mean values. Note the change in scales at 34.75 for salinity.

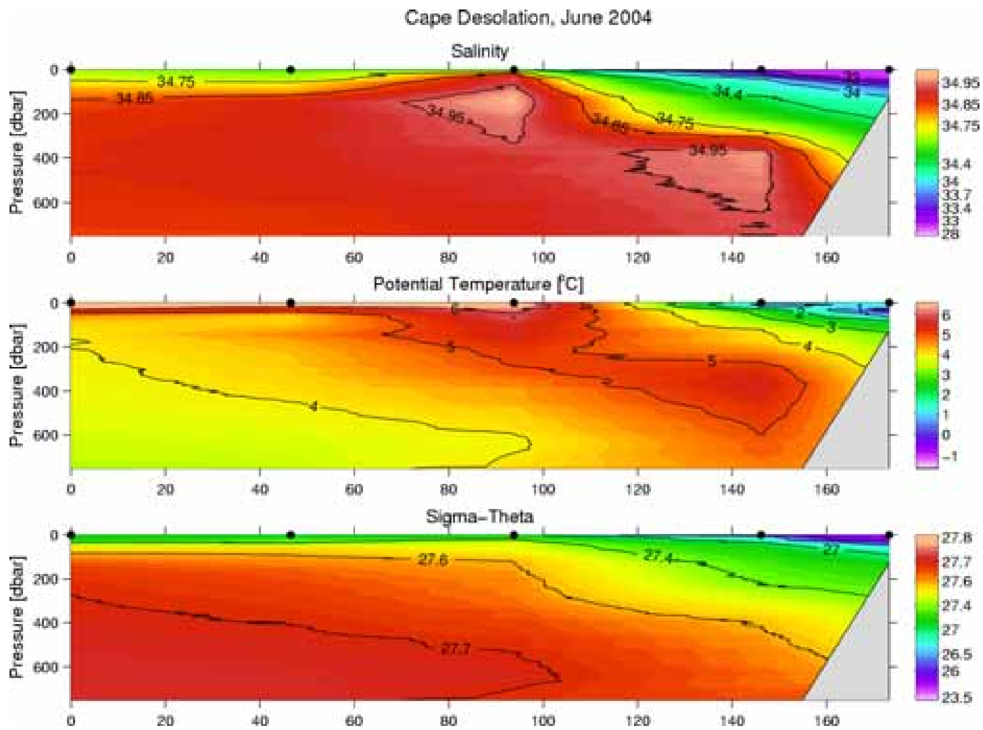

Fig. 12. Vertical distribution of temperature, salinity and density at the Cape Desolation section, June 29, 2004.

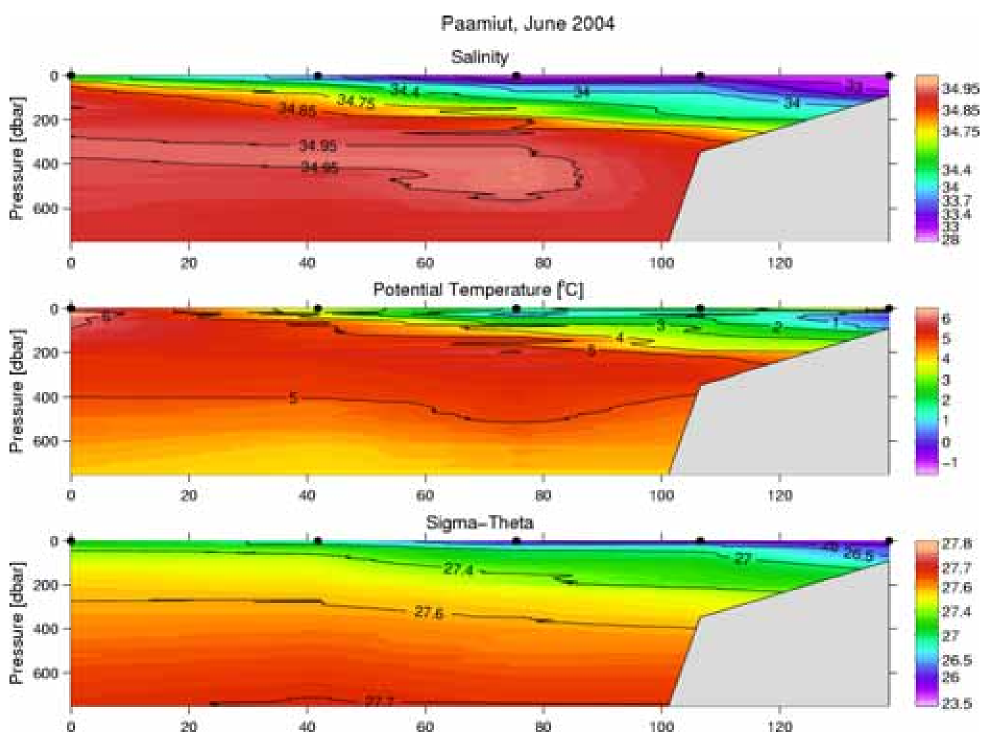

Fig. 13. Vertical distribution of temperature, salinity and density at the Paamiut (Frederikshaab) section, June 30, 2004.

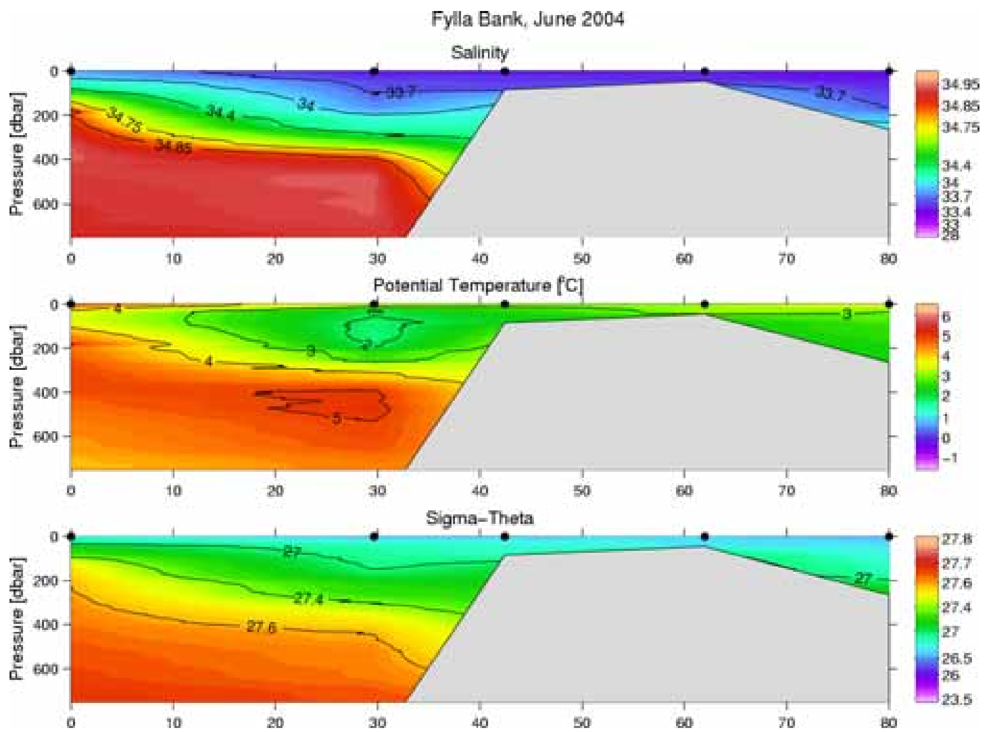

Fig. 14. Vertical distribution of temperature, salinity and density at the Fylla Bank section, June 23, 2004.

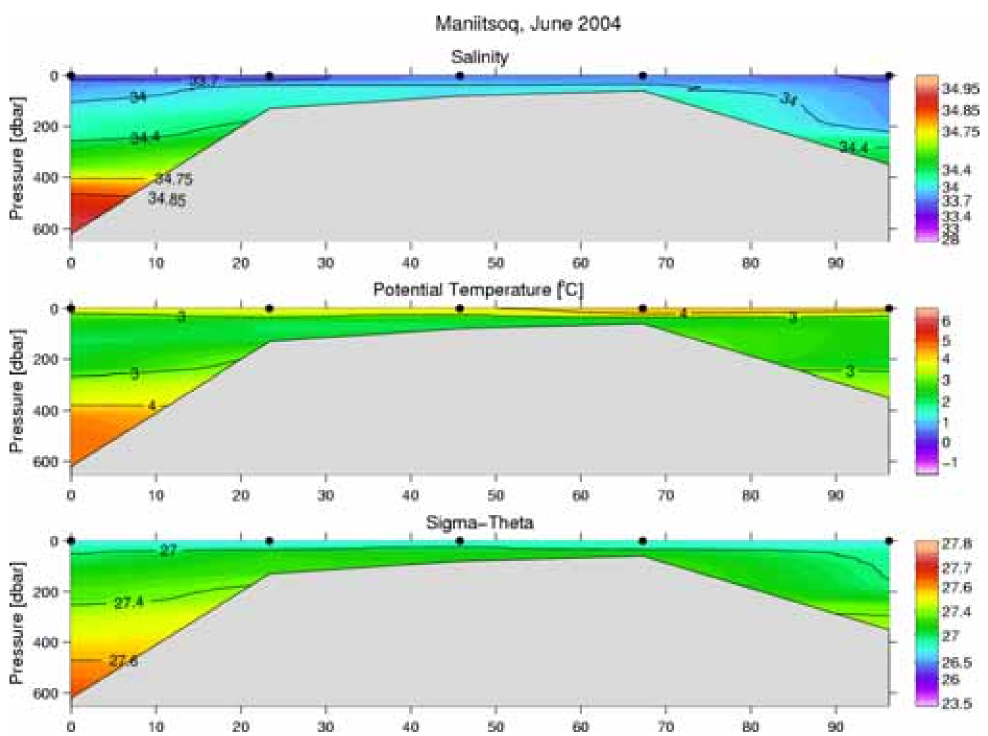

Fig. 15. Vertical distribution of temperature, salinity and density at the Maniitsoq (Lille Hellefiske Banke, Sukkertoppen) section, June 22, 2004.

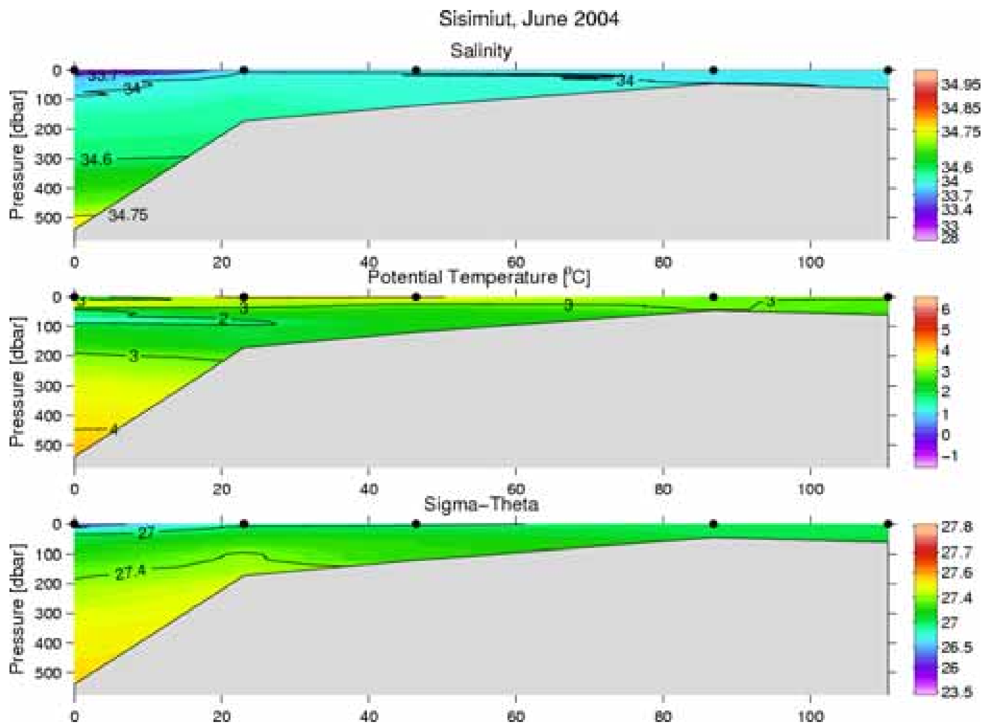

Fig. 16. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, June 21–22, 2004.

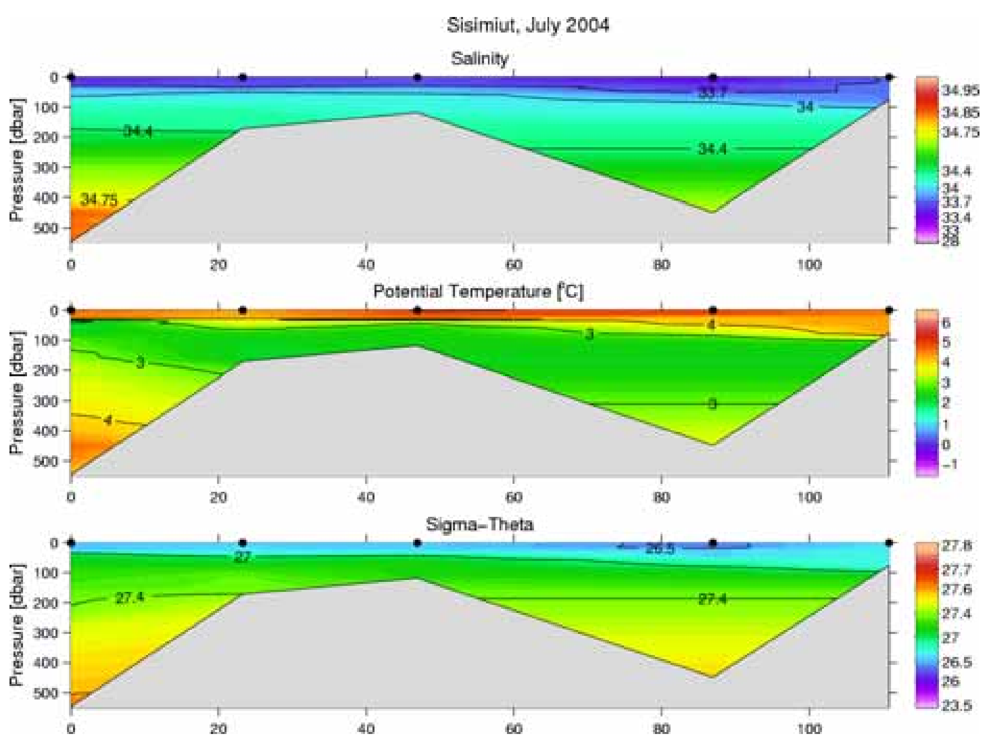

Fig. 17. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, July 17, 2004.

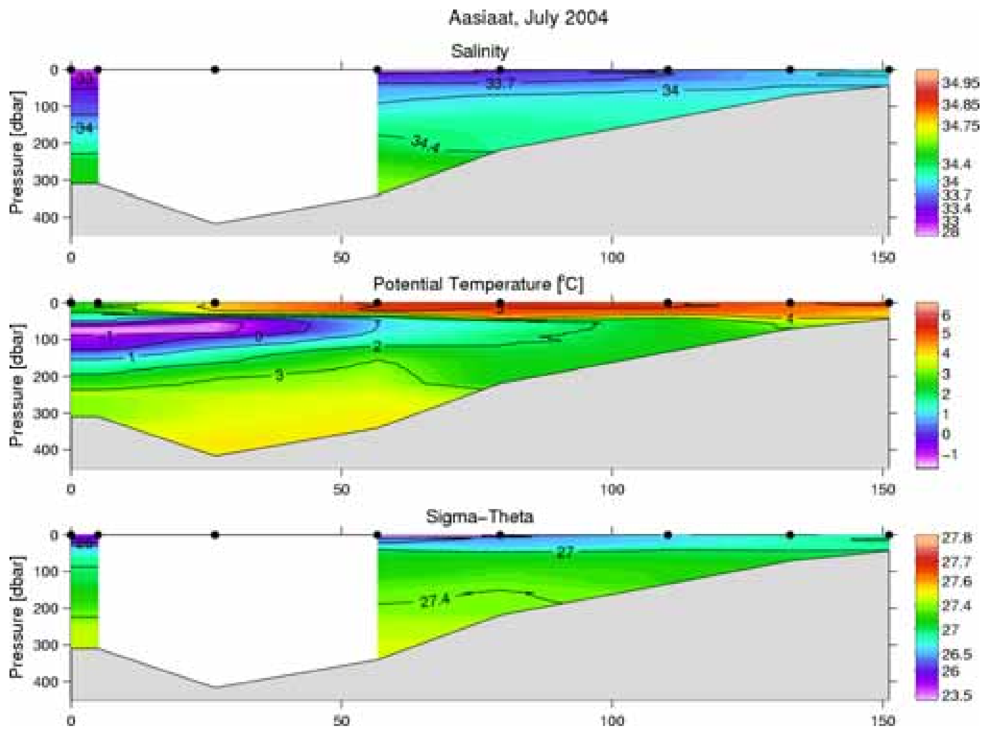

Fig. 18. Vertical distribution of temperature, salinity and density at the Aasiaat section, July 21, 2004. Note, the most offshore station has been repeated in the plot in order to plot salinity and density.

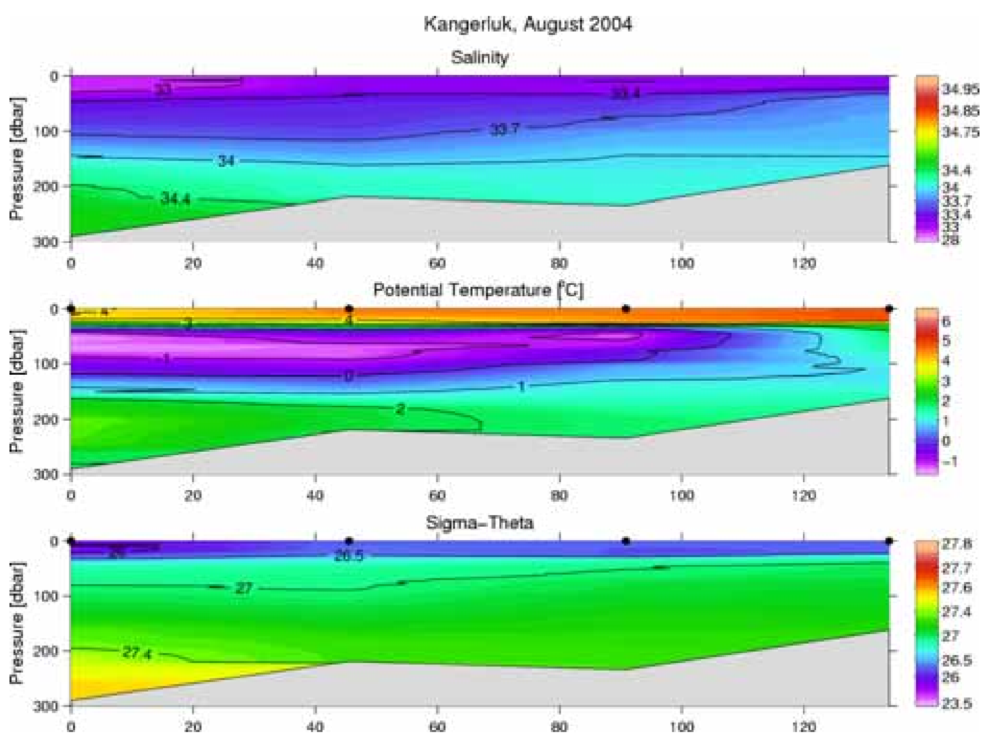

Fig. 19. Vertical distribution of temperature, salinity and density at the Kangerluk (Disko Fjord) section, August 3–8, 2004.

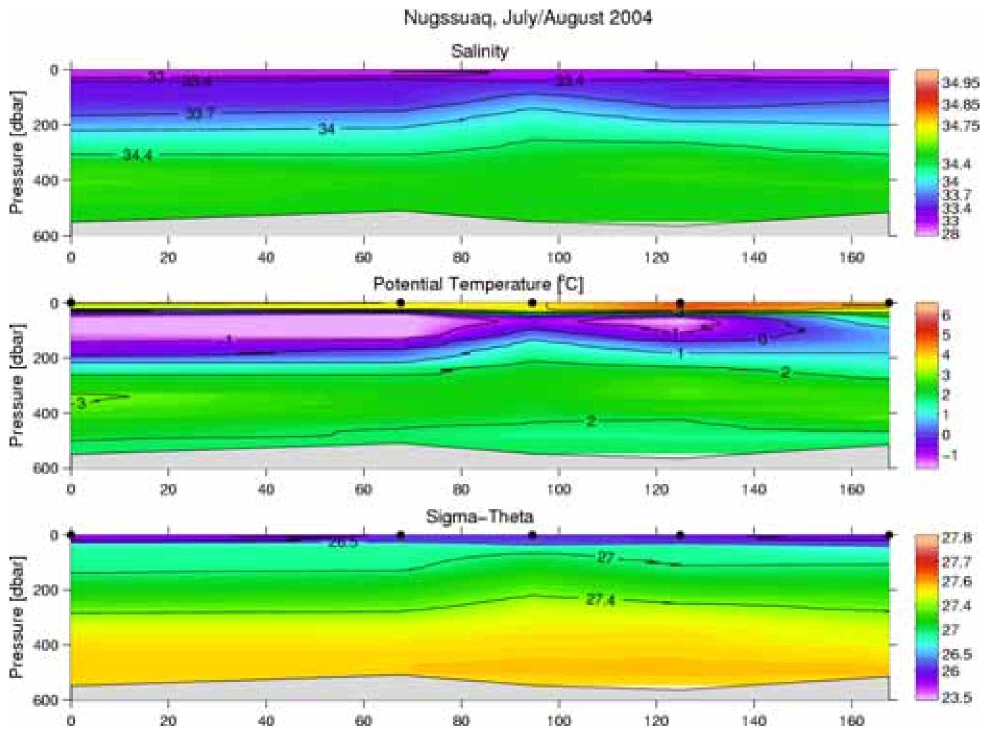

Fig. 20. Vertical distribution of temperature, salinity and density at the Nugssuaq section, July 29–August 2, 2004.

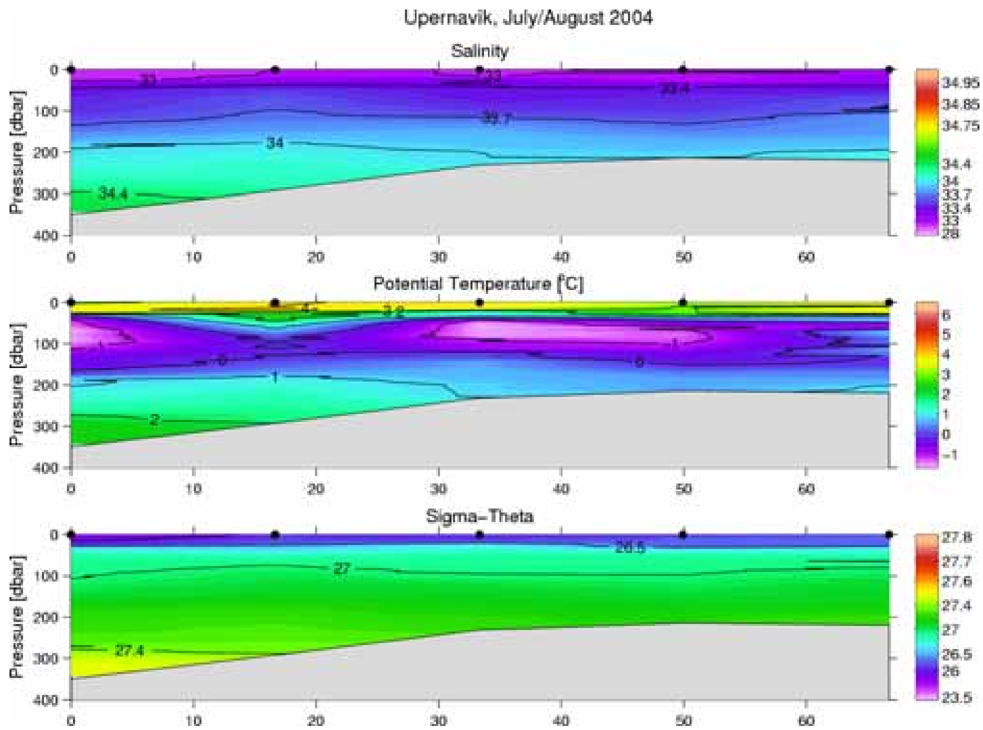

Fig. 21. Vertical distribution of temperature, salinity and density at the Upernavik section, July 31–August 1, 2004.

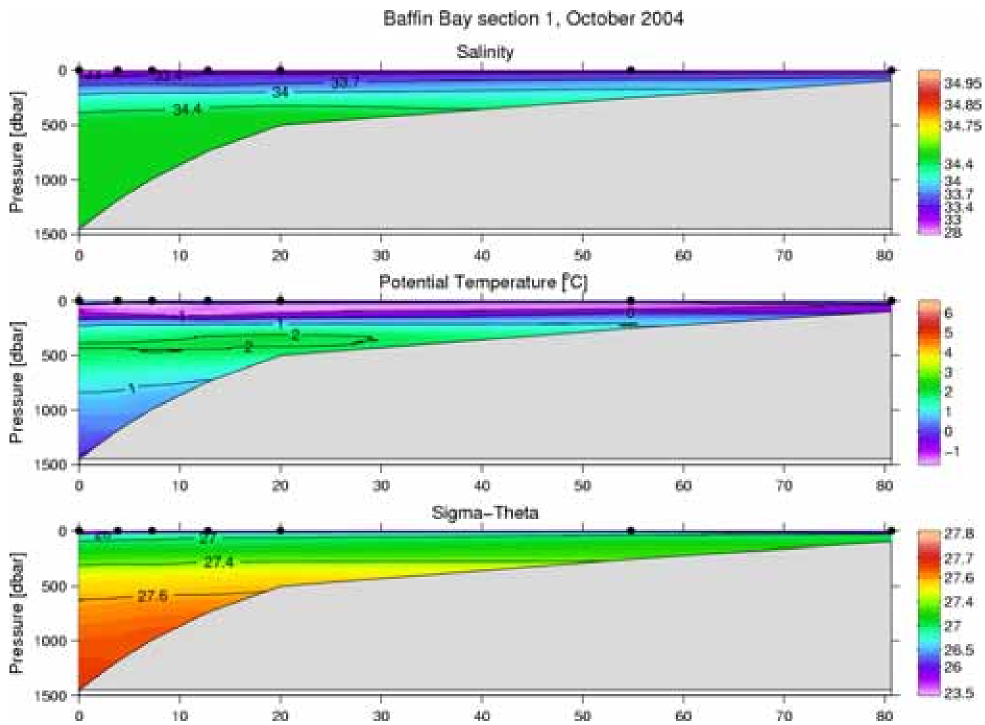

Fig. 22. Vertical distribution of temperature, salinity and density at the Baffin Bay section 1, October 1–2, 2004.

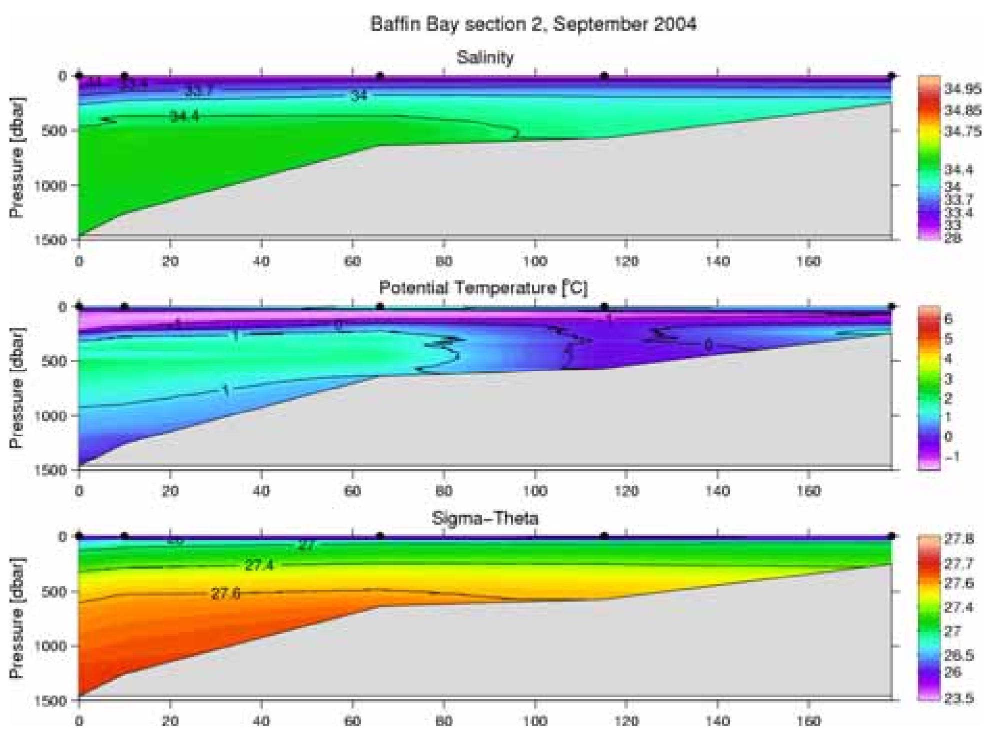

Fig. 23. Vertical distribution of temperature, salinity and density at the Baffin Bay section 2, September 24–29, 2004.

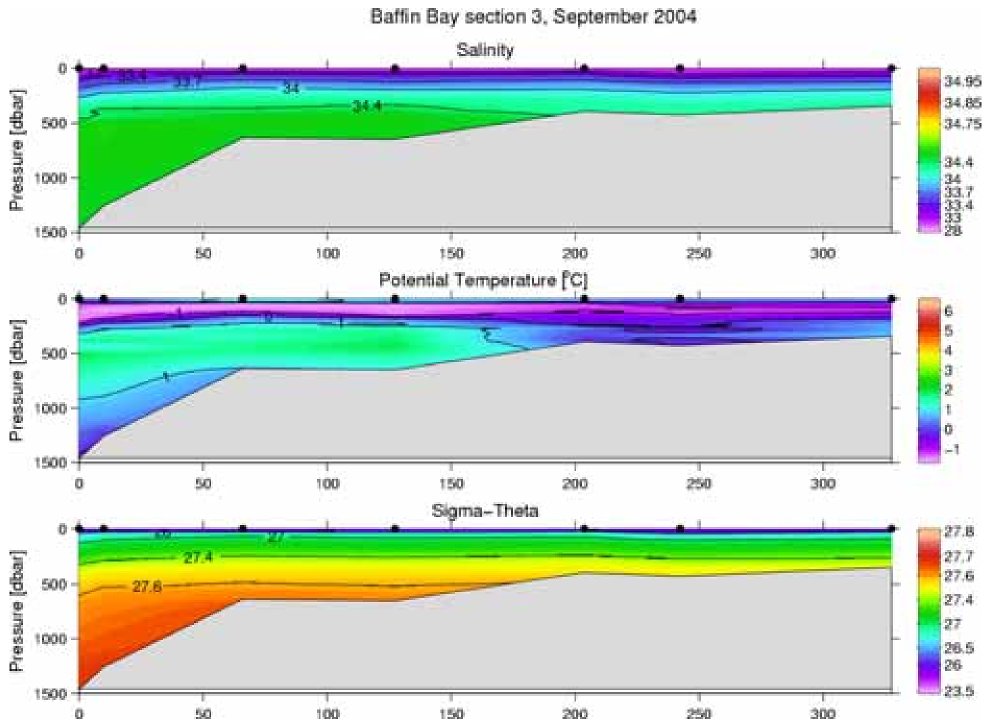

Fig. 24. Vertical distribution of temperature, salinity and density at the Baffin Bay section 3, September 25–29, 2004.

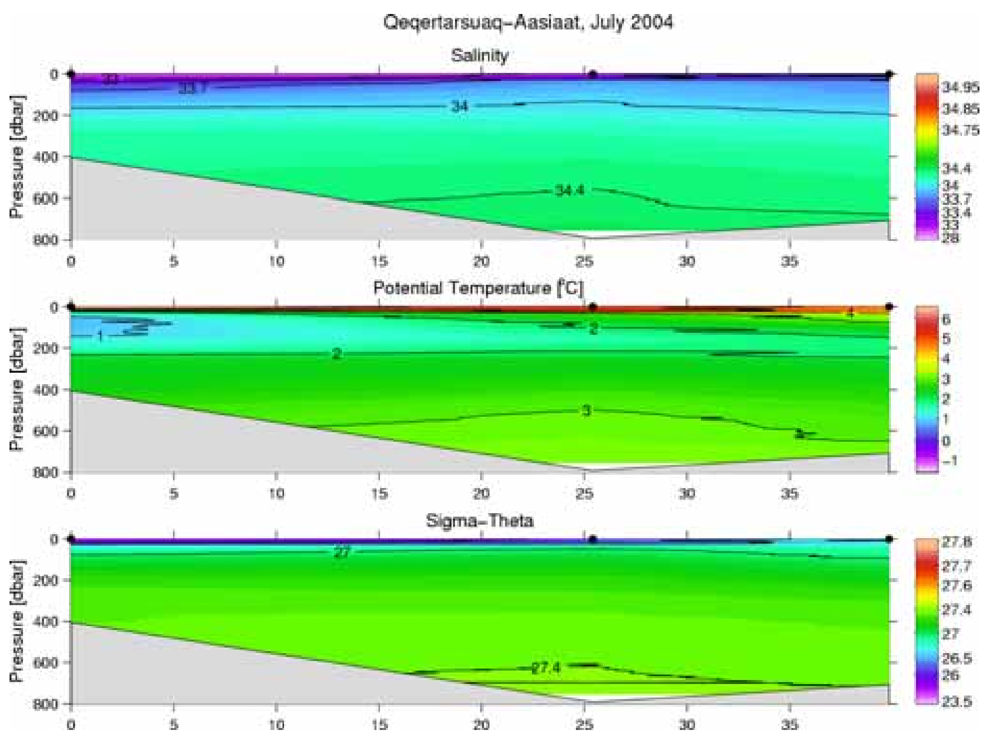

Fig. 25. Vertical distribution of temperature, salinity and density at the Qeqertarsuaq–Aasiaat (Godhavn–Egedesminde) section, July 22, 2004.

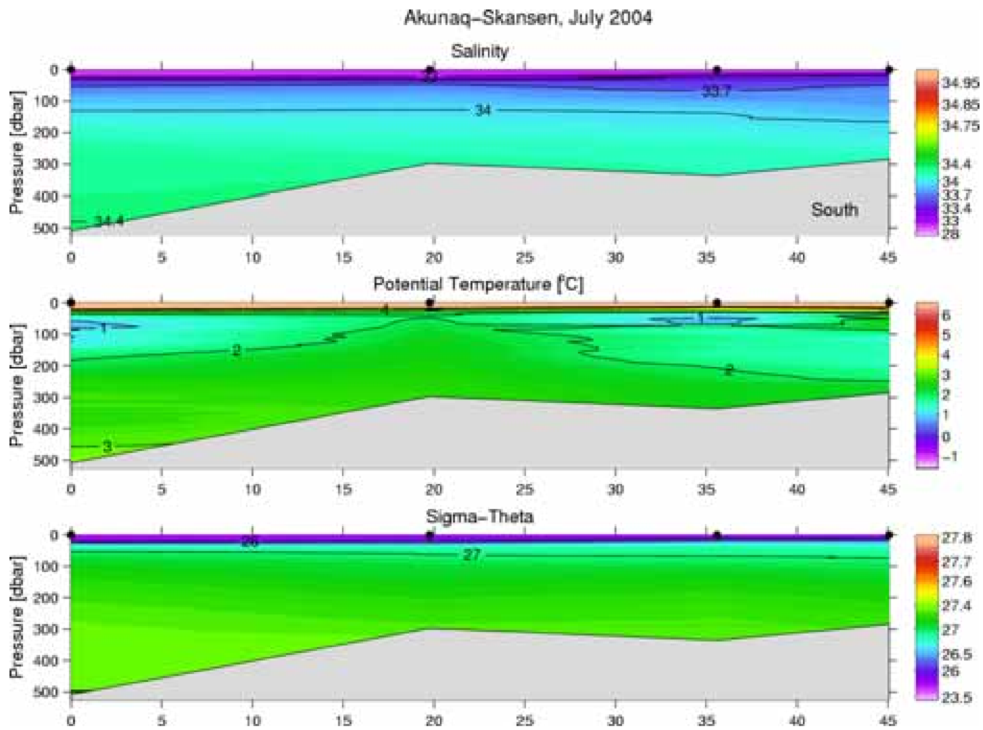

Fig. 26. Vertical distribution of temperature, salinity and density at the Akunaq–Skansen section, July 22, 2004.

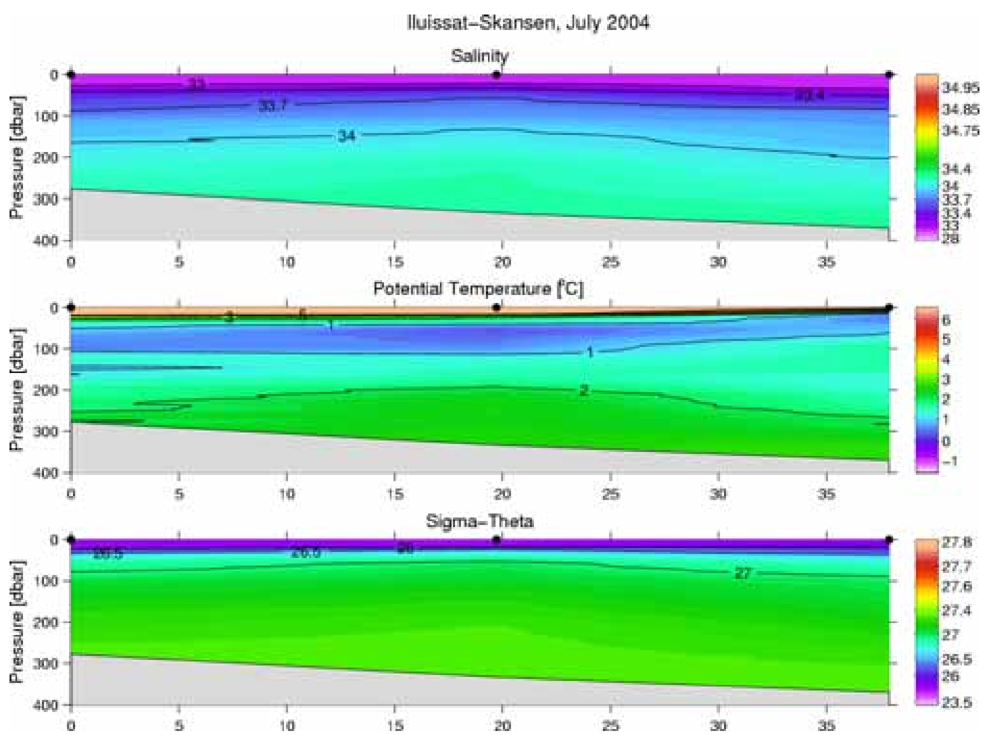

Fig. 27. Vertical distribution of temperature, salinity and density at the Iluissat–Skansen (Jakobshavn–Skansen) section, July 22, 2004.

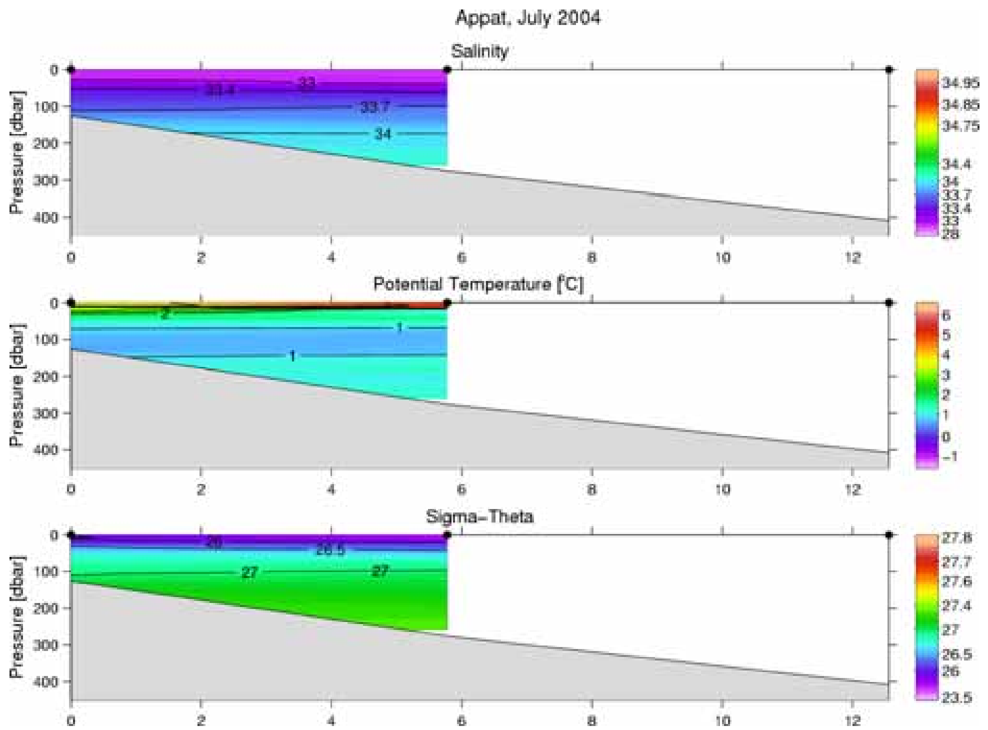

Fig. 28. Vertical distribution of temperature, salinity and density at the Appat (Arveprins Ejlande) section, July 25, 2004.