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Oceanographic Investigations off West Greenland 2010

by

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Abstract

The regional hydrography in summer 2010 is presented and discussed based on data from standard sections along the west coast of Greenland and data retrieved during trawl surveys.

In winter 2009/10, the North Atlantic Oscillation (NAO) index was exceptionally negative describing weakening westerlies over the North Atlantic Ocean. Often this results in warmer conditions over the West Greenland region. The air temperature was much higher than normal during winter – especially over the southern Baffin Bay. The annual air temperatures was even more extreme with record high temperature anomaly at Nuuk almost exceeding the existing record twice.

The general settings in the region have traditionally been presented with offset in the hydrography observed over the Fylla Bank. Here, time series of mid-June temperatures on top of Fylla Bank show temperatures 0.5°C above average conditions in 2010 but with low salinities. At the southern sections on top of the shelf a thick low saline pool of Polar Water was observed from Cape Farewell to Maniitsoq and to a lesser degree on top of Fylla Bank suggesting above normal presence of Polar Water on the southern sections.

The presence of Irminger Water in the West Greenland waters was high in 2010. Pure Irminger Water (waters of Atlantic origin) could be traced north to the Sisimiut section. The mean (400–600 m) temperature west of Fylla Bank (st.4) was high and the salinity record high. For the same depth interval at Maniitsoq (st.5) and Sisimiut (st.5), the salinities were the second highest observed yet with very high temperature.

In the Disko Bay off Ilulissat (st.3), the bottom temperature and salinity has decreased since 2009 to only about average, but still generally above values before mid-1990. This was surprising as high salinities and temperatures were observed further south off West Greenland.

Introduction to the west Greenland oceanography

This report describe the hydrographic conditions in West Greenland Waters in 2010 from Cape Farewell in the southeastern Labrador Sea northward to Upernavik in the Western Baffin Bay (Figure 1). After describing data and methods, the atmospheric conditions are described and then the oceanographic conditions.

The ocean currents around Greenland are part of the cyclonic sub-polar gyre circulation of the North Atlantic and the Arctic region. The bottom topography plays an important role for guiding the circulation and for the distributing the water masses. Consequently, the strongest currents are found over the continental slope.

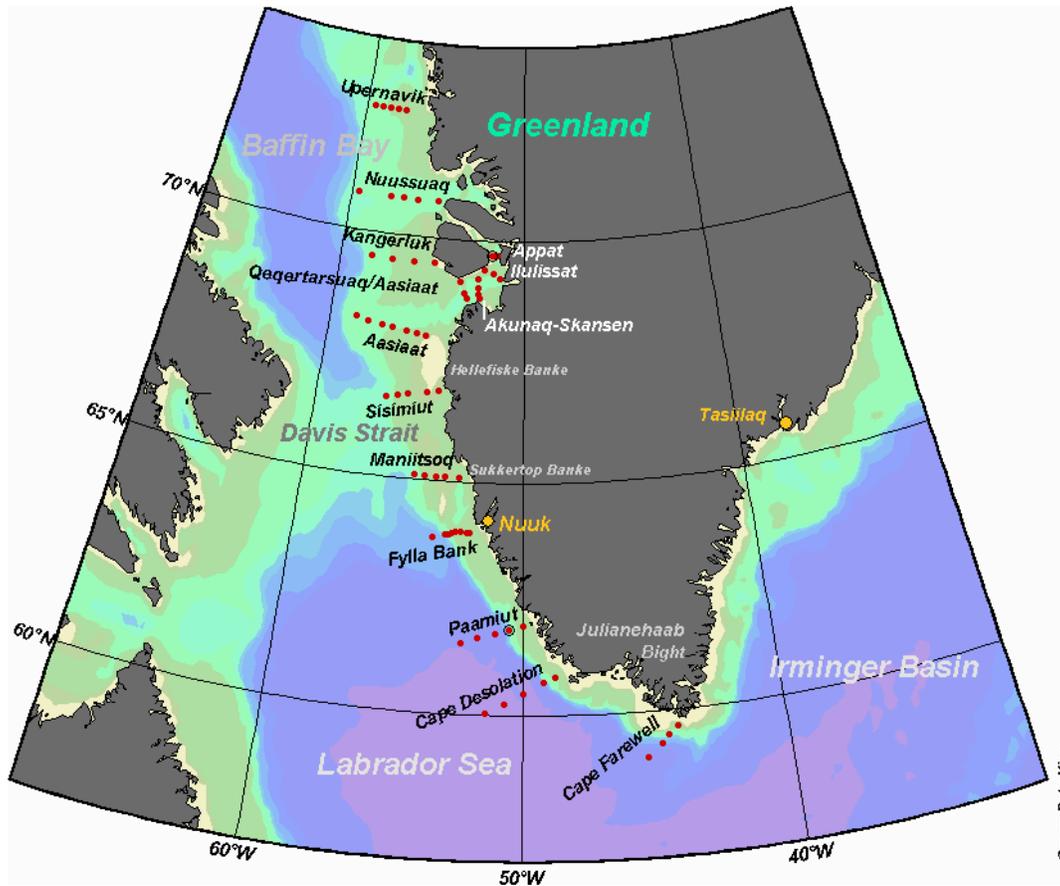


Figure 1. Position of the oceanographic sections off West Greenland where measurements were performed in 2010. Contours shown for water depths in colours. Map produced using Ocean Data View (Schlitzer, 2007).

The surface circulation off West Greenland is dominated by the north going West Greenland Current. It is primarily composed of cold low-saline Polar Water (PW) of the Arctic region and the temperate saline Irminger Water (IW) of the Atlantic Ocean. At intermediate depths Labrador Sea Water is found, and at the bottom overflow water from the Nordic Seas are found near the bottom. Only the circulation in the upper ~900m will be handled in this report.

The water mass characteristics in the West Greenland Current are formed in the western Irminger Basin where the East Greenland Current and the Irminger Current meets and flowing southward side by side. As they round Cape Farewell the IW subducts the PW (Figure 2b) forming the West Greenland Current (WGC). These water masses gradually mix along West Greenland, but IW can be traced all along the coast up to the northern parts of Baffin Bay (Buch, 1990). At Cape Farewell IW is found as a 500–800 m thick layer over the continental slope with a core at about 200–300 m depth. The depth of the core gradually decreases from east to west as seen in Figure 2b, whereas the depth gradually increases from south to north to below 400 m in the northern Davis Strait and Baffin Bay.

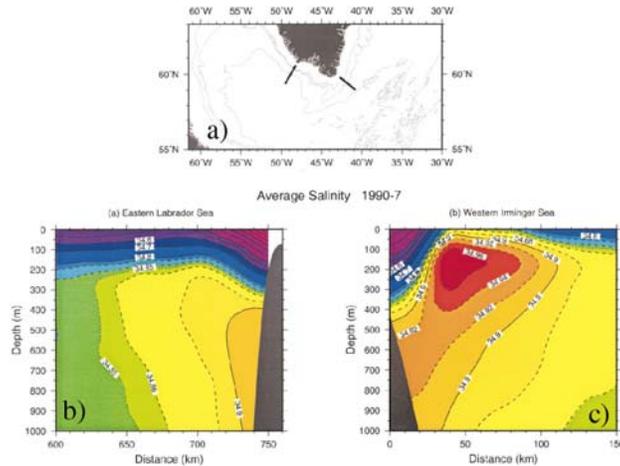


Figure 2. Mean upper-layer salinity sections for the period 1990–1997. Top: Location of the two sections. Isobaths shown: 1000, 2000 and 3000 m. Lower left: Eastern Labrador Basin. Lower right: Western Irminger Basin. From Pickart et al. (2002).

Over the fishing banks off West Greenland a mixture of IW and PW dominates, as sketched in Figure 3. PW is continuously diluted by freshwater run-off from the numerous fjord systems. As the WGC reaches the latitude of Fylla Bank it branches. The main component turns westward and joins the Labrador Current on the Canadian side, while the other component continues northward through Davis Strait.

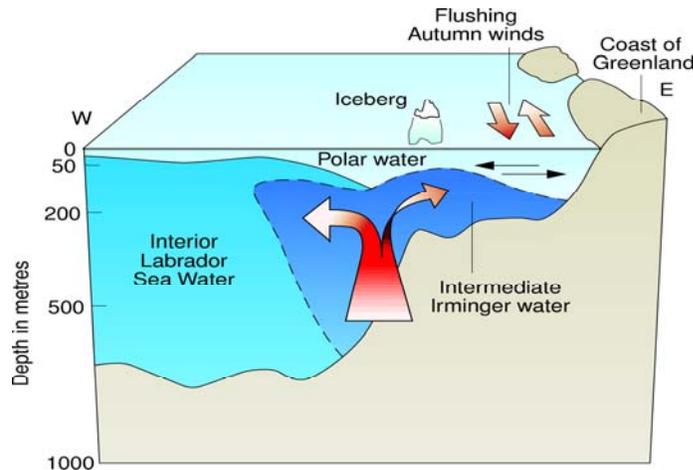


Figure 3. Sketch of the water masses off West Greenland in the Davis Strait region. From Valeur et al. (1997).

The tidal signal is significant. At West Greenland the strongest tidal signal is located close to Nuuk at 64°N. The tides are primarily semidiurnal with large difference between neap and spring (1.5 m versus 4.6 m at Nuuk, Buch, 2002). The interaction between the complicated topography and the strong tidal currents gives rise to a residual anticyclonic circulation around the banks in the Davis Strait area (Ribergaard et al., 2004).

Sea-ice is important in Greenlandic Waters. The West Greenland area is mainly dominated by 2 types of sea-ice. “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. “Vestice” is first-year ice formed in the Baffin Bay, Davis Strait, and western part of the Labrador Sea during winter.

1. Measurements

The 2010 cruise was carried out according to the agreement between the Greenland Institute of Natural Resources (GINR) and Danish Meteorological Institute (DMI) during the period June 04–24, 2010 onboard the Danish naval ship “I/K TULIGAQ”. Observations were carried out on the following standard stations (Figure 1):

Offshore Labrador Sea/Davis Strait:

- Cape Farewell St. 1–4
- Cape Desolation St. 1–5
- Paamiut (Frederikshaab) St. 1–5
- Fylla Bank St. 1–5
- Maniitsoq (Sukkertoppen) St. 1–5
- Sisimiut (Holsteinsborg) St. 1–5

Additional stations on the Fylla Bank section:

- Fylla Bank St. 1.5, 2.5, 3.5

On each station the vertical distributions of temperature and salinity was measured from surface to bottom, except on stations with depths greater than 900 m, where approximately 900 m was the maximum depth of observation.

Sea-ice was only present in small concentrations during the cruise at the southern sections (Figure 5). Unfortunately, due to the weather conditions in combination with limited time allocated, the Cape Farewell station 5 was skipped. In addition, planned fjord measurements in Godthaabfjord and fjords south of Sisimiut were cancelled due to ship-logistic reasons.

During the period June 13 – July 10, 2010 the Greenland Institute of Natural Resources carried out trawl survey from Sisimiut to the Disko Bay area and further North onboard “R/V PAAMIUT”. During this survey CTD measurements were carried out on the following standard stations (Figure 1):

Offshore Davis Strait/Baffin Bay:

- Sisimiut (Holsteinsborg) St. 1-5
- Aasiaat (Egedesminde) St. 1–7
- Kangerluk (Disko fjord) St. 1–4
- Nuussuaq St. 1–5
- Upernavik St. 1–5

Disko Bay:

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

2. Data handling

Measurements of the vertical distribution of temperature and salinity were carried out using a SEABIRD SBE 9-01 CTD. On the Paamiut cruise a SEABIRD SBE 25plus was used. All sensors were newly calibrated in 2010.

For the purpose of calibration of the salinity measurements 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 5.37d software provided by SEABIRD (www.seabird.com). Onboard the SBE 9-01 data was uploaded using term17 in SEASOFT version 4.249 (for DOS) provided by SEABIRD. For uploading SBE 25plus data, the SEABIRD program Seasave (for windows) was used.

All quality-controlled data are stored at the Danish Meteorological Institute from where copies have been sent to ICES. Data are also stored at Greenland Institute of Natural Resources who are the owner of the data.

Some of the CTD profiles taken by the SBE 9-01 showed oscillating behaviour forming spurious peaks (Figure 4a). The reason for the peaks are at present unknown, but the conductivity sensor might be unstable. Due to the tight time schedule, the cruise was continued using the instrument, as the profiles looks fairly ok disregarding the peaks and therefore there was hope that the errors could be corrected after the cruise. With this decision more stations were taken, however with a poorer result.

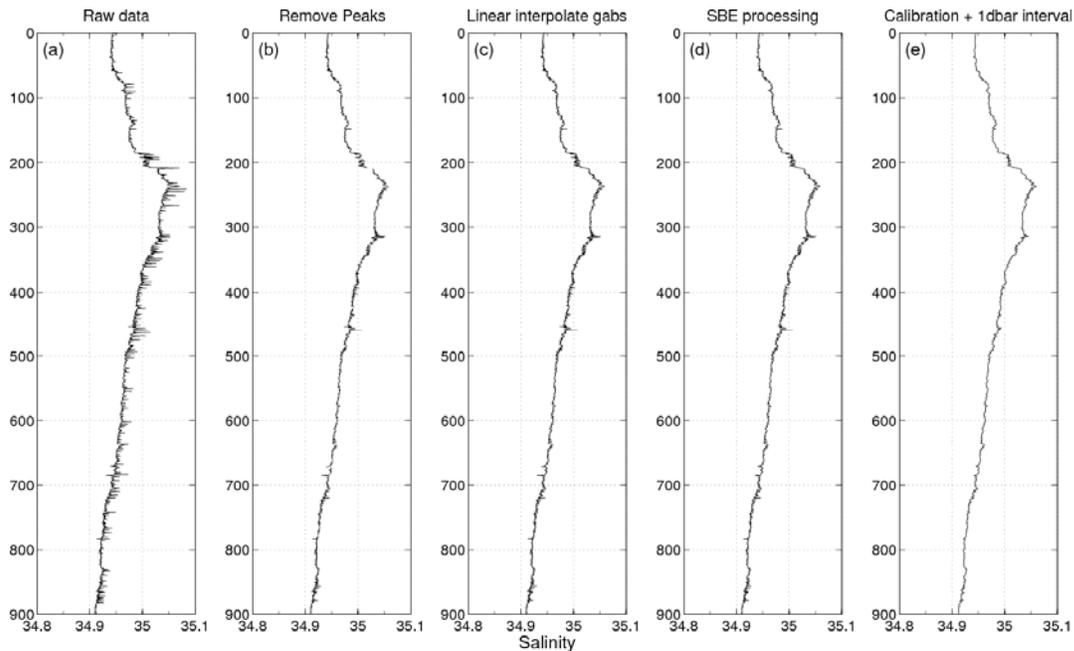


Figure 4. Example of the peak removing procedure on salinity measurements for Cape Farewell st. 3. a) Raw CTD downcast salinity as seen after extracting data from the CTD and removing measurements. b) Raw data after removing local peaks. c) A linear interpolation fills the gabs. d) Standard Seabird processing procedure using SBE Data processing software. e) Interpolate data to 1 dbar in the vertical using SBE Data processing software. Calibration are also done, but can't be seen on the scaling in this figure.

The peaks were after the cruise removed from the raw timeseries before the actual data processing and calibration was started. An example of the procedure is shown in Figure 4. Initial, the local peaks were found using a fixed time window for defining a local peak and data around the peaks are marked bad. Then a linear interpolation is done on the timeseries to replace these bad data. The interpolation turns out to be necessary in order not to remove too much information for successfully results by the following SBE data processing procedures. After the peak removal and interpolation, the profiles were quality-controlled and calibrated similar to the rest of the profiles.

The following 11 CTD profiles did undergo the “peak removal procedure” described above for salinity:

- Cape Farewell St. 1–4
- Maniitsoq (Sukkertoppen) St. 1, 5
- Sisimiut (Holsteinsborg) St. 1–5

The resulting profiles are obvious not as accurate as the rest of the profiles. Data interpolated to 1 dbar in the vertical still makes small oscillation fluctuations with a maximal amplitude of about 0.002–0.003. However if data is not needed in 1 dbar resolution a simple running mean filter can remove major part of the fluctuations.

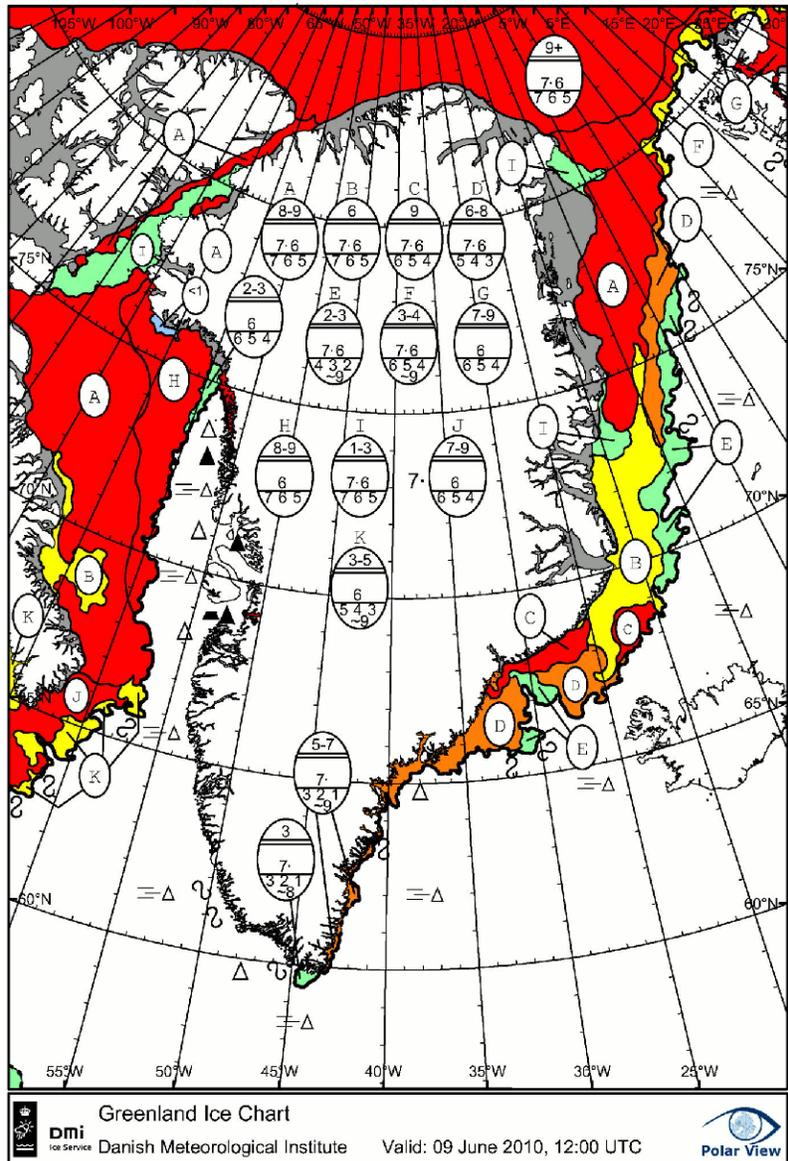


Figure 5. Distribution of sea ice in Greenland Waters valid for 09. June 2010. Note: The “S”-signs denotes bands of sea-ice within open water, which can be found up to about 62°N off West Greenland for this specific time. This indicates recent retreat of sea-ice within the area.

3. Atmospheric conditions in 2010

The North Atlantic marine climate is to some extent controlled by the so-called North Atlantic Oscillation (NAO), which is a measure of the strength of the westerlies 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 2009/10 was significant negative¹ (Figure 2) with the second lowest pressure difference observed during the 146 year timeseries.

The Icelandic Low and Azores High was absent during the winter months (December–March, Figure 7). Instead the minimum pressures were observed south of Greenland centred off Nova Scotia about 1000 km south of Cape Farewell. This is on the lattice in the middle of Iceland and the Azores resulting in anomaly high pressure over

¹ The NAO index using December – February was also highly negative.

Iceland and anomaly low pressure over the Azores (Figure 8) Thereby the pressure difference between Iceland and the Azores were notable reduced to almost zero.

The pressure difference has the effect that the normal westerlies over the North Atlantic Ocean was absent (Figure 10) with anomalous² winds towards west across the North Atlantic Ocean (Figure 10) which is just the opposite of a year with “normal westerlies” .

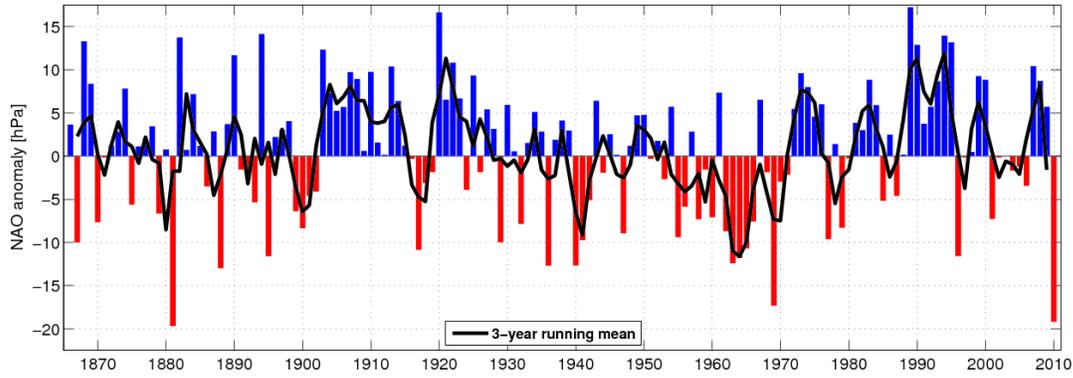


Figure 6. Time series of winter (December–March) index of the NAO from 1865/1866–2009/2010. The heavy solid line represents the NAO index smoothed with a 3-year running mean filter to remove fluctuations with periods less than 3 years. In the figure the winter 1865/1866 is labelled 1866 etc.. The mean and standard deviation is 0.76 ± 7.5 hPa. The 2009/2010 value is -19.2 hPa. Data updated, as described in Buch et al. (2004), from <http://ww.cru.uea.ac.uk/cru/data/nao.htm>.

West Greenland lies within the area which normally experiences warm conditions when the NAO index is negative. During winter 2009/10, the mean temperature was above normal for most of the western North Atlantic region including the waters surrounding Greenland and cold in northern Europe. Remarkable positive anomalies were found over the Baffin Bay and Davis Strait with anomalies above 8°C (Figure 11). In Nuuk the mean winter air temperature (DJFM) was the highest observed in the 136 year long timeserie (Figure 12). The remarkable warming over the western North Atlantic region centred over Davis Strait were even more pronounced on an annual basis. The mean annual air temperature in 2010 was more than 2°C above normal around Greenland and even more than 4°C above the Davis Strait and Baffin Bay with highest anomaly above 6°C (Figure 13). For Nuuk³, the annual air temperature in 2010 was 4.36°C above normal which is almost a doubling of the existing record on the 136 year long timeseries! (Figure 14).

² Anomaly defined as the difference from normal conditions relative to the period 1968–1996.

³ Nuuk temperature for October 2007 and November 2008 was taken from the Nuuk airport synop station 04254 due to failure on the instrument on synop station 04250 (Nuuk) for more than half of the months.

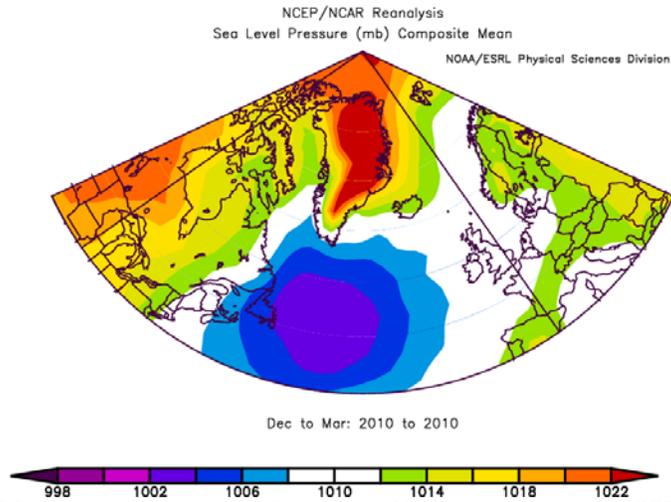


Figure 7. Winter (DJFM) sea level pressure for 2009/10 in the North Atlantic region. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>).

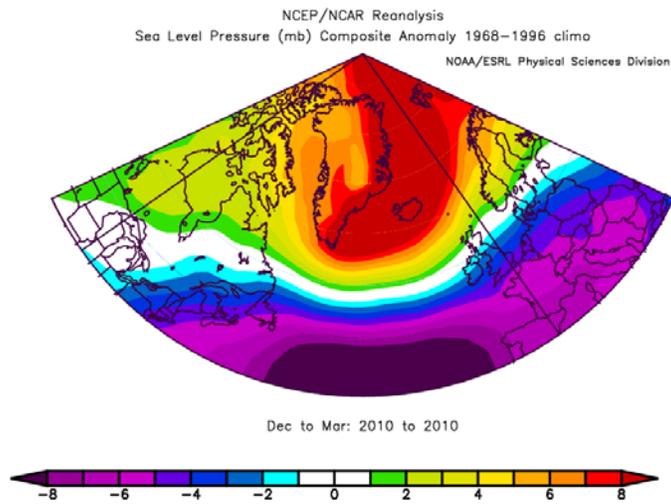


Figure 8. Winter (DJFM) sea level pressure anomaly for 2009/10 in the North Atlantic region. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>).

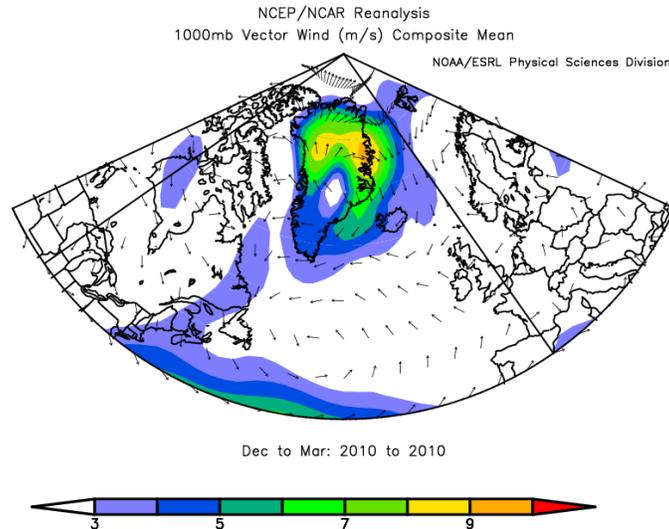


Figure 9. Winter (DJFM) wind for 2009/10 in the North Atlantic region. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>).

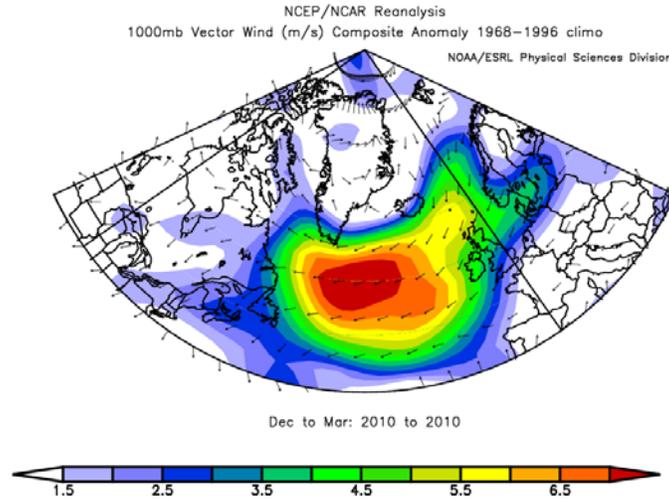


Figure 10. Winter (DJFM) wind anomaly for 2009/10 in the North Atlantic region. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>).

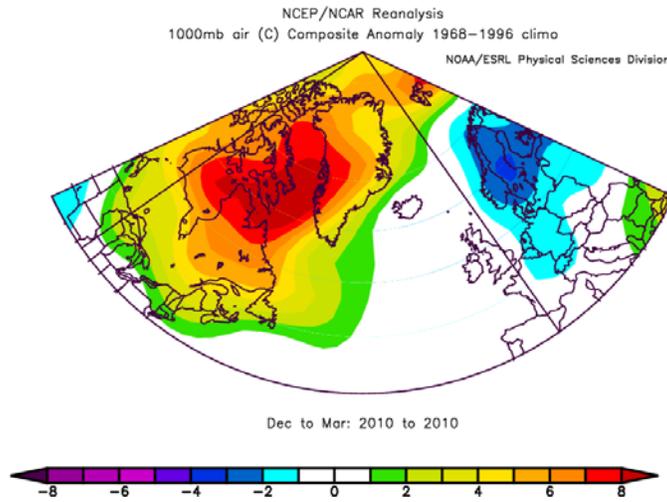


Figure 11. Winter (DJFM) mean air temperature anomaly for 2009/10 in the North Atlantic region. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>).

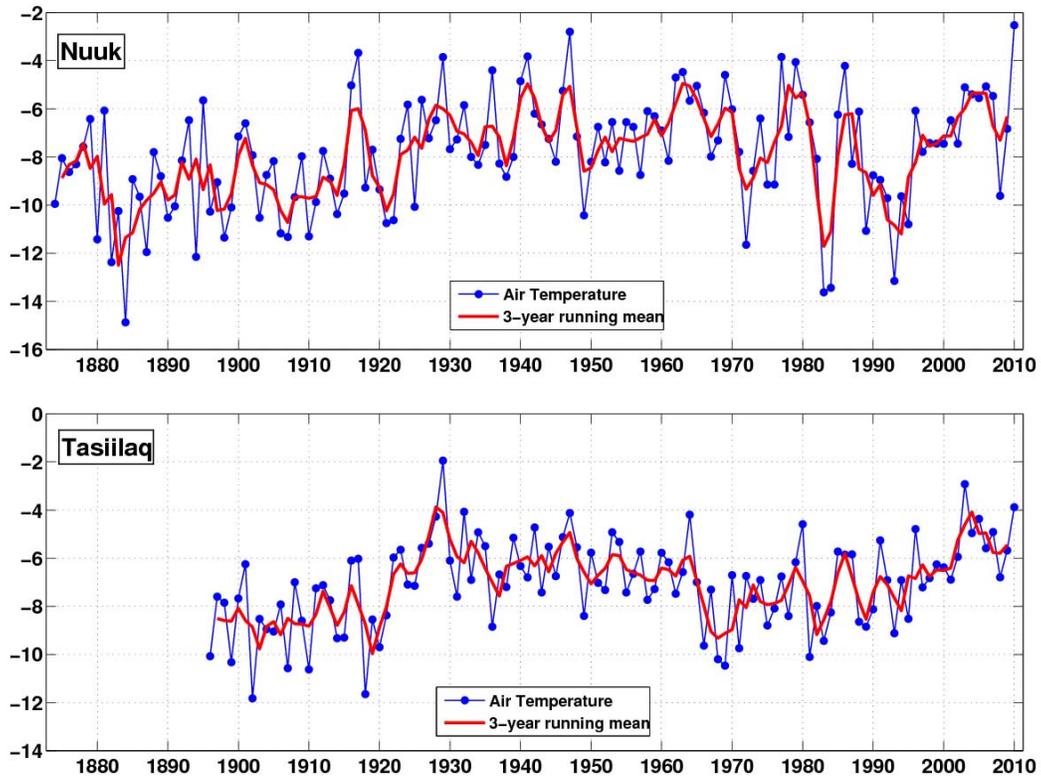


Figure 12. Winter (DJFM) mean air temperature observed at Nuuk and Tasiilaq for the period 1874–2010. The mean and standard deviation for the whole timeseries is -7.9 ± 2.3 °C for Nuuk and -7.0 ± 1.8 °C for Tasiilaq. Values for 2010 are respectively -2.52 °C and -3.88 °C.

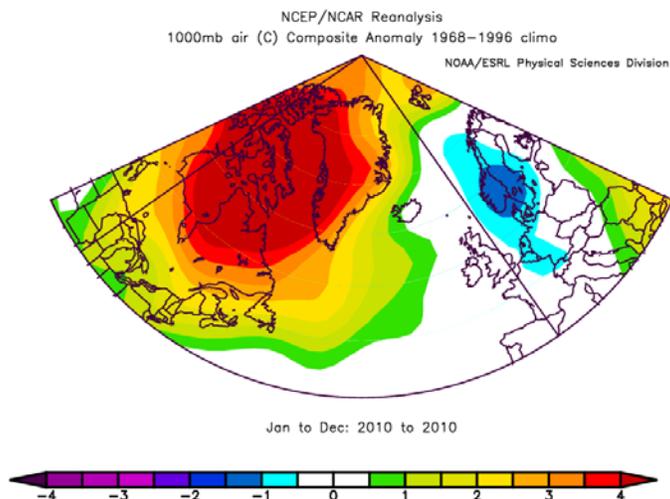


Figure 13. Anomalies of the annual mean air temperature for 2010 in the North Atlantic region. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>). Maximum temperature anomaly exceed 6°C over western Davis Strait / southeastern Baffin Island.

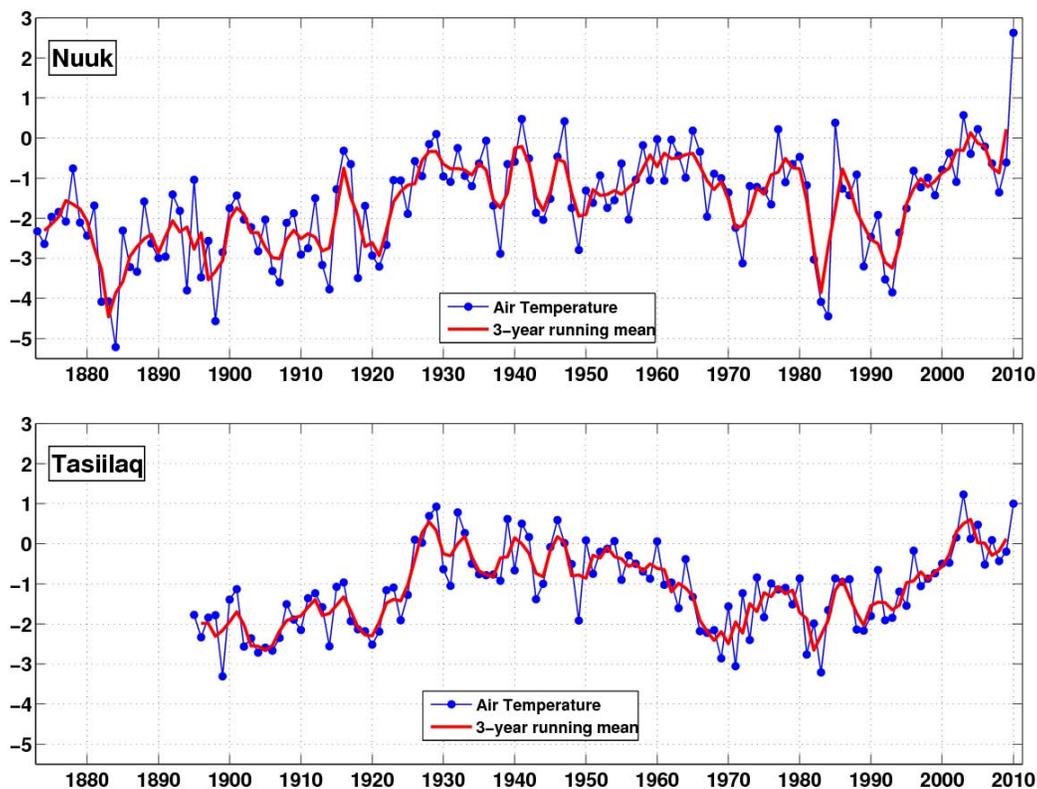


Figure 14. Annual mean air temperature observed at Nuuk and Tasiilaq for the period 1873–2010. The mean and standard deviation is -1.64 ± 1.25 °C for Nuuk and -1.11 ± 1.00 °C for Tasiilaq. Values for 2010 are respectively 2.63 °C and 1.00 °C. Nuuk temperature for October 2007 and November 2008 was taken from the Nuuk airport synop station 04254 due to a failure on the instrument (Nuuk synop 04250) for more than half of the respective months.

4. Oceanographic conditions off West Greenland in 2010

Sea surface temperatures in West Greenland often follow those of the air temperatures, major exceptions are years with great salinity anomalies i.e. years with extraordinary presence of Polar Water. In 2010 the mean temperature (2.32°C) on top of Fylla Bank in the middle of June was 0.5°C above normal conditions but not as extreme as for the air temperature (Figure 15 and Table 1). However, the mean salinity (33.26) was below normal suggesting higher than normal presence of Polar Water which might explain why sea surface temperatures on top of Fylla Bank was not among the highest in 2010.

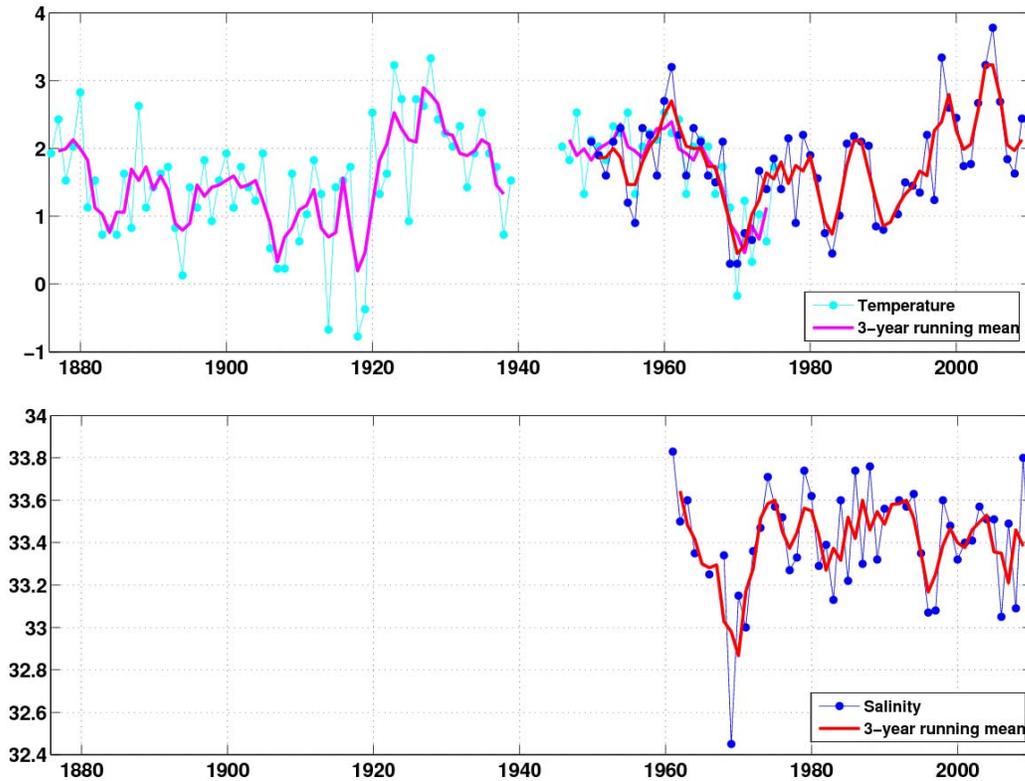


Figure 15. Timeseries of mean temperature (top) and salinity (bottom) on top of Fylla Bank (Station 2, 0–40 m) in the middle of June for the period 1950–2010. The red curve is the 3 year running mean value. Statistics is shown in Table 1. The timeseries for temperature (top, magenta/purple) is extended back to 1876 using Smed-data for area A1 (Smed, 1978). See Ribergaard et al. (2008) for details.

Table 1. Statistics for potential temperature and salinity Fylla Bank st. 2. The timeseries are corrected for annual variations in order to get the temperature in mid-June. Means are defined as mean of the years with data, i.e. can change slightly from year to year. Smed data are not included for the statistics.

Fylla Bank St. 2	Temperature [°C]	Salinity	2010	
	Mean ± std	Mean ± std	Tpot	S
0–40 m	1.80 ± 0.75°C	33.41 ± 0.26	2.32°C	33.26

A vertical section of salinity, temperature and density over the shelf from Cape Farewell to Sisimiut is shown in Figure 26. Polar Water is found in the upper ~100 m up to Paamiut with salinities below 33.4 and cold (<1°C) sub-surface temperatures. At Fylla Bank the salinities has increased due to mixing but the salinity remains quite low. This quite thick and low saline layer of Polar Water indicating above normal presence of Polar Water on the southern sections despite below normal sea-ice conditions during the cruise and only a narrow band of sea-ice off the southeast coast of Greenland (Figure 5).

However, west of Fylla Bank (st. 4, Figure 18 and Table 2) in the depth interval 50–150 m where the core of Polar Water is found, the salinity was about average but with higher than normal temperature. Further north at Maniitsoq st.5 (Figure 19, Table 3) and Sisimiut st.5 (Figure 20, Table 4), both the salinities and temperatures was above normal in 50–150 m depth, indicating that above normal presence of Polar Water was limited to the southern sections south of Maniitsoq.

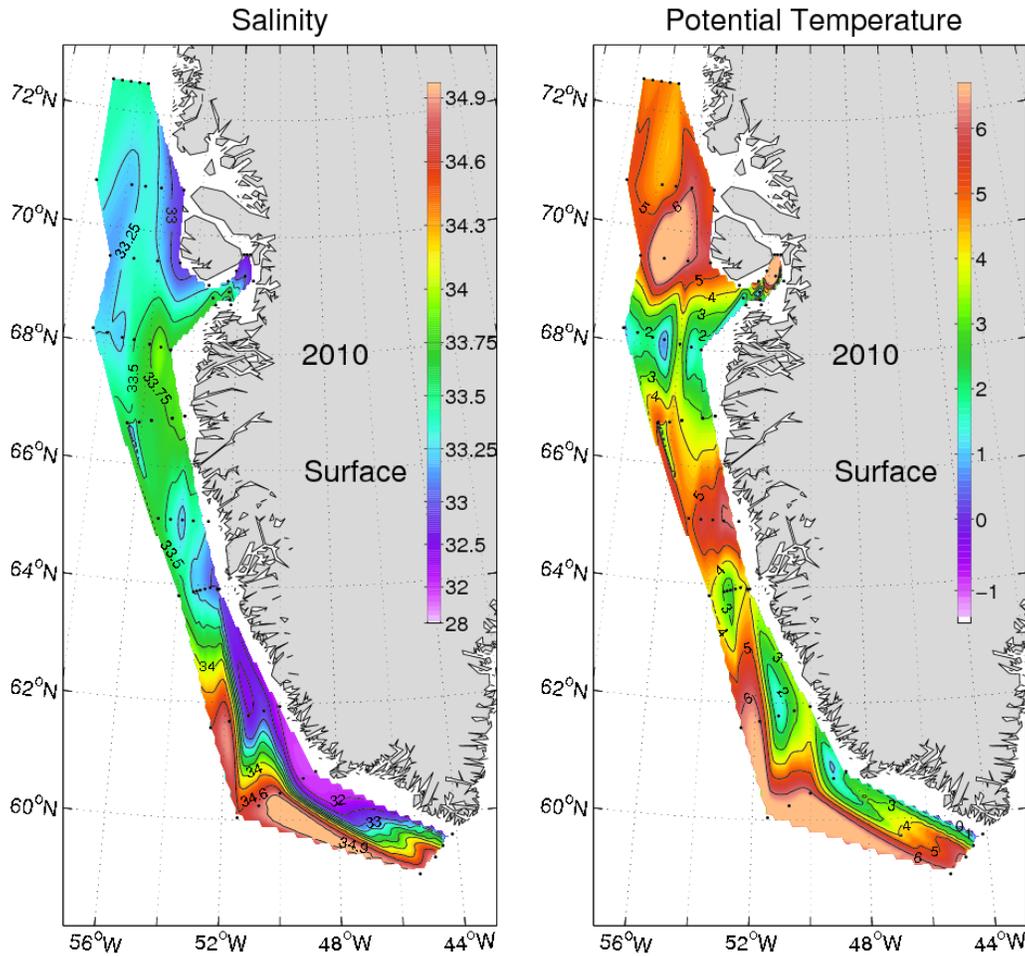


Figure 16. Surface salinity (left) and temperature (right) observed in 2010. The data are all from June except the three northern offshore sections (Disko Fjord/Kangerluk, Nuussuaq, and Upernavik) which are taken in early July.

The surface temperatures and salinities observed during the 2010 cruise are shown in Figure 16. The cold and low salinity conditions observed close to the coast off Southwest Greenland reflect the Polar Water carried to the area by the East Greenland Current. During the present cruise it can easily be traced up to Fylla Bank on its low salinity whereas water of Atlantic origin ($T > 3^{\circ}\text{C}$; $S > 34.5$) is found from Cape Farewell to Paamiut section at the surface.

In the Baffin Bay the highest salinities reflect the core of the West Greenland Current, which is slightly modified by Atlantic Water. In the Disko Bay the low surface salinities, generally below 33, originate from the large outlet glaciers but also from melting of sea-ice during summer forming a 20–30 m thin surface layer. A thin low-saline surface layer is also observed in the Baffin Bay outside Disko Bay properly formed by melting of sea-ice. Due to solar heating these thin surface layers are relatively warm. The strong halocline acts as an effective isolator and thereby the subsurface waters remain considerable colder (Figure 17). The coldest waters $< 0^{\circ}\text{C}$ observed in the subsurface of the Baffin Bay are likely the remains of past winters cooling, where formation of sea-ice ejects enough salt to overcome the shallow surface halocline formed during summer by melting of sea-ice and run-off of fresh water from land. A major part of this subsurface water is likely cold Polar

Water from the Baffin Current originating from the Arctic Ocean through the Canadian Archipelago as suggested by Tang et al (2004). The upper part of this water is easily recognized in Figure 17 and in its core in Figure 22.

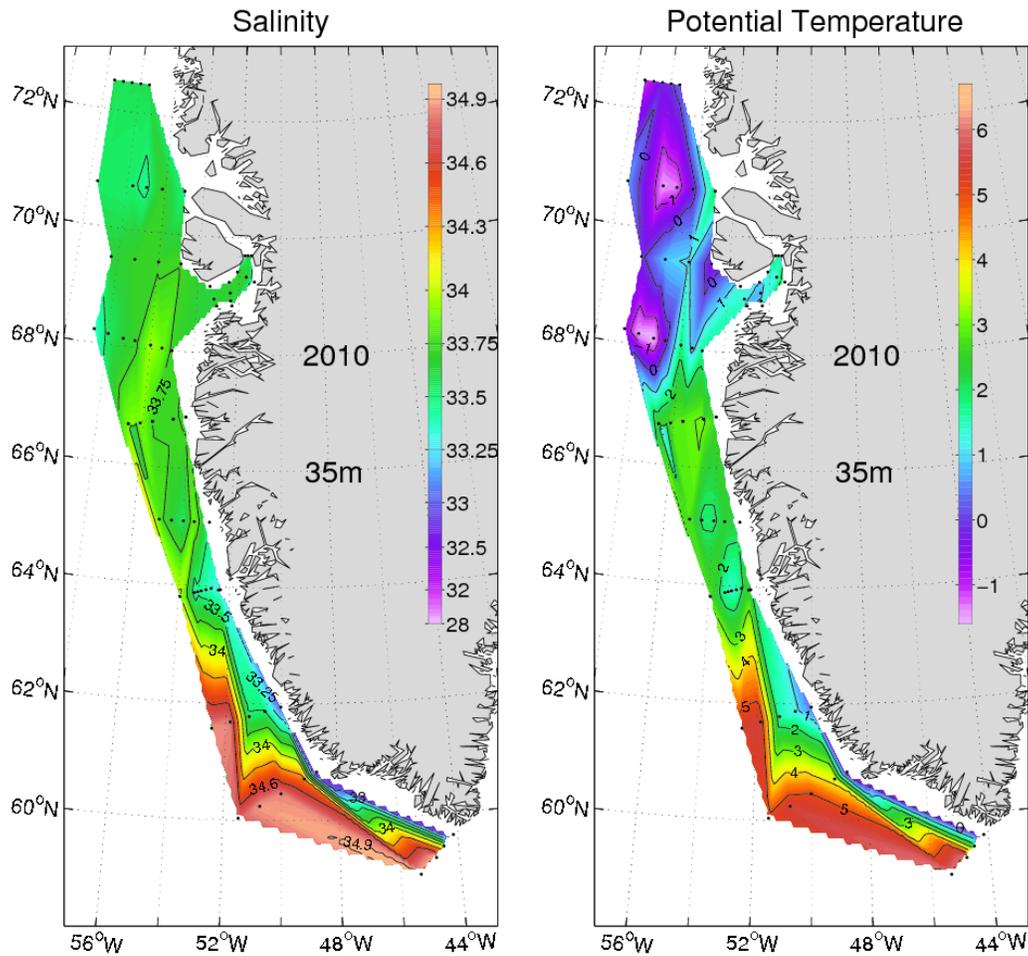


Figure 17. As Figure 16, but for 35 m depth.

At intermediate depths water of Atlantic origin forms a layer with maximum salinity and temperature. Horizontal maps of salinity and temperature at depth of maximal salinity and maximal temperature is shown in Figure 23 and Figure 24. A vertical section of salinity, temperature and density over the shelf break from Cape Farewell to Sisimiut is shown in Figure 25. The vertical distribution of temperature, salinity and density at sections along the West Greenland coastline is shown in Figure 27 – Figure 37 and within the Disko Bay in Figure 38 – Figure 41.

Pure Irminger Water ($T \geq 4.5^{\circ}\text{C}$; $S \geq 34.95$) was traced north to the Sisimiut section. Modified Irminger Water ($T \geq 3.5^{\circ}\text{C}$; $34.88 \leq S < 34.95$) was observed all the way north to Sisimiut section. The northward extension of Irminger Water may indicate intensified inflow of water of Atlantic origin to the West Greenland area.

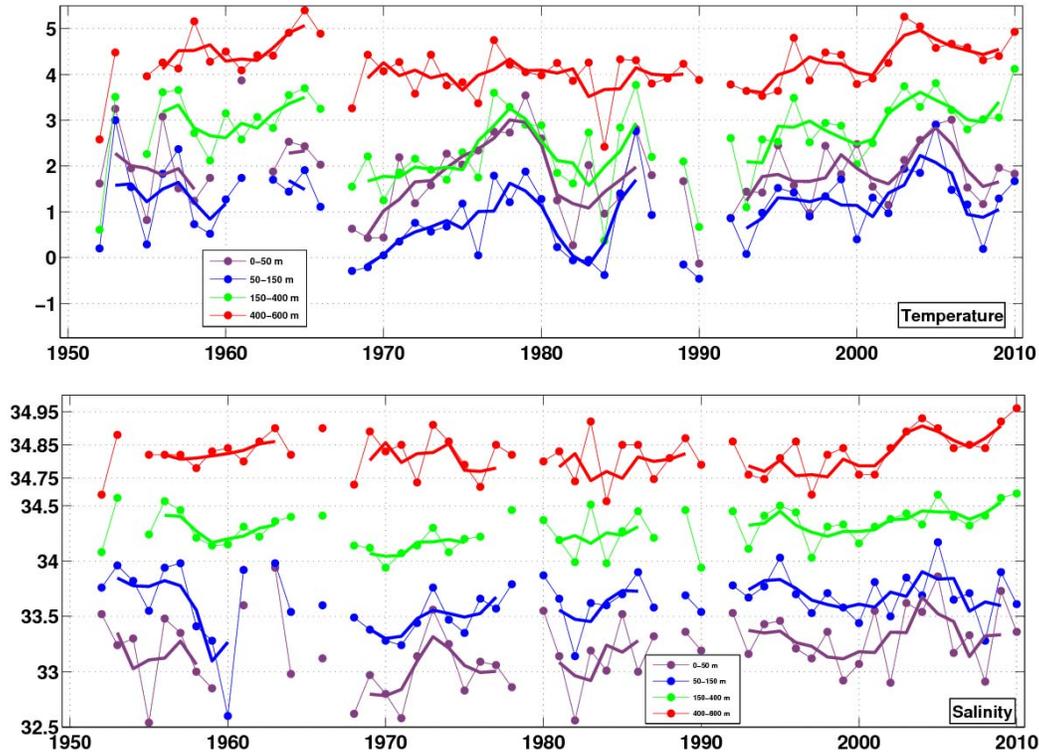


Figure 18. Timeseries of mean June-July temperature (top) and salinity (bottom) for the period 1950–2010 averaged in four different depth intervals west of Fylla Bank (st.4) over the continental slope. Thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics are shown in Table 2.

Table 2. Statistics for potential temperature and salinity at Fylla Bank st. 4. and values for 2010.

Fylla Bank St.4	Temperature [°C]	Salinity	2010	
	Mean \pm std	Mean \pm std	Tpot	S
0–50 m	1.85 \pm 0.85°C	33.21 \pm 0.33	1.83°C	33.36
50–150 m	1.04 \pm 0.84°C	33.63 \pm 0.26	1.67°C	33.61
150–400 m	2.61 \pm 0.86°C	34.29 \pm 0.18	4.12°C	34.61
400–600 m	4.19 \pm 0.57°C	34.82 \pm 0.08	4.93°C	34.96

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 normally is found, is shown in Figure 18 (red curves). The average salinity (34.96) of this layer was the highest observed yet and the temperature (4.93°C) was the fifth highest observed (Table 2). This indicates that the presence of Irminger Water in 2010 was high compared to normal.

Similar timeseries west of the banks further north at Maniitsoq st.5 (Figure 19, Table 3) and Sisimiut st.5 (Figure 20, Table 4) confirms, that the Irminger Water component of the West Greenland Current still brings considerable amount of heat and salt to the area in 2010. Temperatures and salinities measured in 400–600 m was high at both Sisimiut and Maniitsoq. Indeed the salinities were the second highest observed yet on these stations and the temperatures among the five highest. However, contrary to the Fylla Bank st.4 (Figure 18), Maniitsoq st.5 and Sisimiut st.5 are only regularly measured since 1970, while the former “warm period” in the 1950s–1960s was only sporadically measured. Consequently the statistical means are less certain.

In 2007–2009 the bottom salinities and temperatures in 400–600 m at Maniitsoq st.5 and Sisimiut st.5 was higher than observed further south at Fylla Bank st.4 (Ribergaard et al., 2008 and Ribergaard, 2009, 2010). This was not the case in 2010 confirming the high presence of Irminger Water in June 2010.

Surprisingly, the bottom temperature and salinity within the Disko Bay just outside Ilulissat ("Jakobshavn") at Skansen-Ilulissat st.3 has decreased and are now at about the mean values for the relatively short timeseries, however still generally higher than before mid-1990. This was not expected as the salinities and temperatures further south were high.

At the Aasiaat (Egedesminde) section and further north to the Upernavik section a distinct Polar Water core was absent. Instead a colder layer was found with temperatures below 1°C (below -1°C in its core) with its center at about 75 m depth which is likely winter cooled Polar Water from the Baffin Current as described above. Below this cold subsurface layer, a relative warm (> 3°C) water mass was found below 150–200 m. This water is the extension of the Irminger Water component of the West Greenland Current.

Noticeably, since the early 2000s, the mean salinity and temperature of the Irminger Water at 400–600 m depth west of Fylla Bank (Figure 18) "Sukkertopbanke" (Figure 19) and "Store Hellefiskebanke" (Figure 20) has increased which may indicate increased strength of the Irminger Current as suggested by Ribergaard (2004). Similar findings was reported by Myers et al. (2007, 2009) and Stein (2005) which they linked to the North Atlantic subpolar gyre circulation (Hátún et al., 2005). Not surprisingly, similar increase in salinity and temperature are observed in the Atlantic Water in the eastern North Atlantic and the Nordic Seas (Holliday et al., 2008), suggesting that the recent changes in the Irminger Water property is an outcome of changes in the circulation in the North Atlantic subpolar gyre circulation.

For a more comprehensive study of the hydrographic conditions off West Greenland, the reader is recommended to the work done by Myers et al. (2009, 2007). Here calculations of volume, heat and fresh water transport for the 6 southern sections are given for the time period up to 2008.

Conclusions

Atmospheric and oceanographic conditions off West Greenland during the summer 2010 were characterised by:

- Negative NAO index resulting in weakening westerlies over the North Atlantic. Indeed the westerlies were absent in average during winter 2009/10.
- Winter air temperatures over Greenland waters was warmer than normal – especially over the Baffin Bay / Davis Strait where temperature anomalies exceed 8°C. Similar extreme anomalies are seen on an annual basis exceeding 4°C over the Baffin Bay / Davis Strait with extremes above 6°C.
- Mean annual and mean winter air temperature in Nuuk was the highest observed yet. The annual anomaly record (4.3°C) almost double the existing record.
- Winter air temperatures over the Northern Europe was colder than normal consistent with low NAO.
- Water temperature on top of Fylla Bank was 0.5°C above average in June whereas the salinity was lower than normal.
- Above normal presence of Polar Water on the southern sections and high presence of Irminger Water indicated by:
 - Thick layer (~100m) of low saline water on top of the shelf from Cape Farewell to Paamiut and low salinities on top of Fylla Bank.
 - Despite of record high air temperatures, water temperature on top of Fylla Bank in June was only above average but far from record. Instead the salinity observed was low.
 - Above average temperature and salinities in the 50-150 m depth west of Hellefiske Banke (Maniitsoq and Sisimiut st.5) indicating the above presence of Polar Water was limited to the southern sections.
 - Pure Irminger Water was observed on all section from Cape Farewell to Sisimiut.
 - West of Fyllas Bank (st.4) the mean temperature in 400–600 m depth was high and the salinity record high.
 - West of "Sukkertop Banke" and "Store Hellefiskebanke", the observed temperatures were among the highest observed in 400–600 m depth and the salinities the second highest observed.
 - However: Though still generally higher than before mid-1990s, only about average bottom temperature and salinity observed within the Disko Bay off Ilulissat after years with high values. This was surprising as high temperatures and salinities was observed further south.

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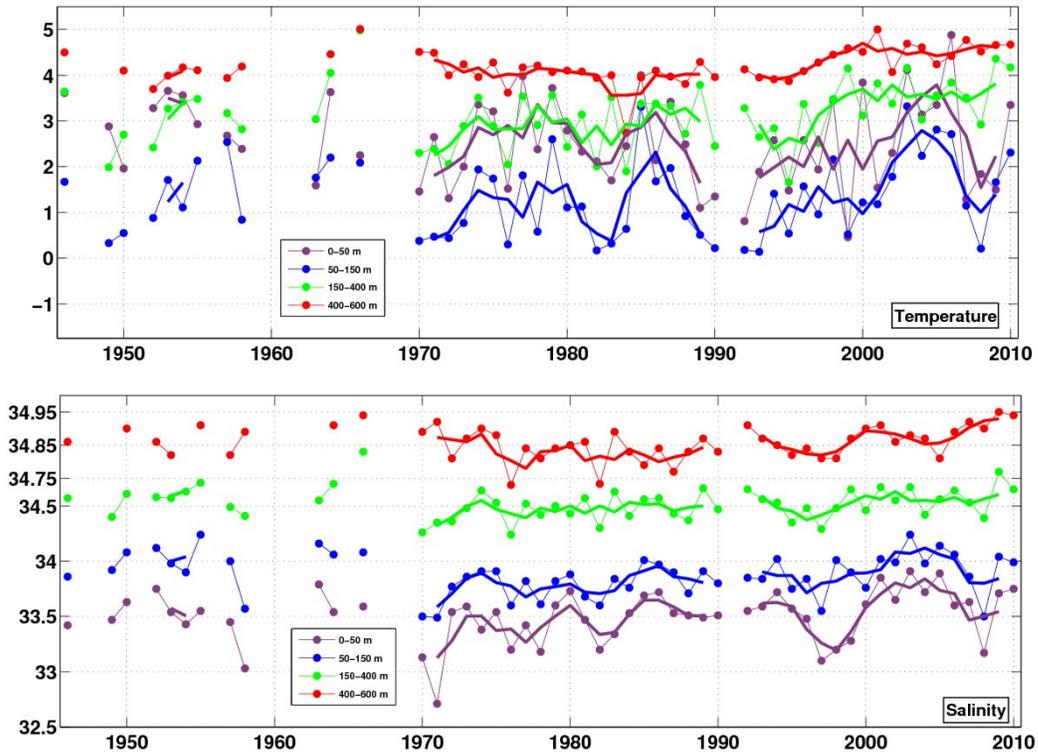


Figure 19. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1946–2010 in four different depth intervals west of “Sukkertop Banke” (Maniitsoq, st.5) over the continental slope. The thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics is shown in Table 3.

Table 3. Statistics for potential temperature and salinity at Maniitsoq (Sukkertoppen) st. 5. and values for 2010.

Maniitsoq St.5	Temperature [°C]	Salinity	2010	
	Mean ± std	Mean ± std	Tpot	S
0–50 m	2.54 ± 0.98°C	33.50 ± 0.23	3.35°C	33.75
50–150 m	1.32 ± 0.87°C	33.88 ± 0.19	2.32°C	33.99
150–400 m	3.13 ± 0.70°C	34.52 ± 0.13	4.17°C	34.65
400–600 m	4.20 ± 0.38°C	34.86 ± 0.05	4.67°C	34.94

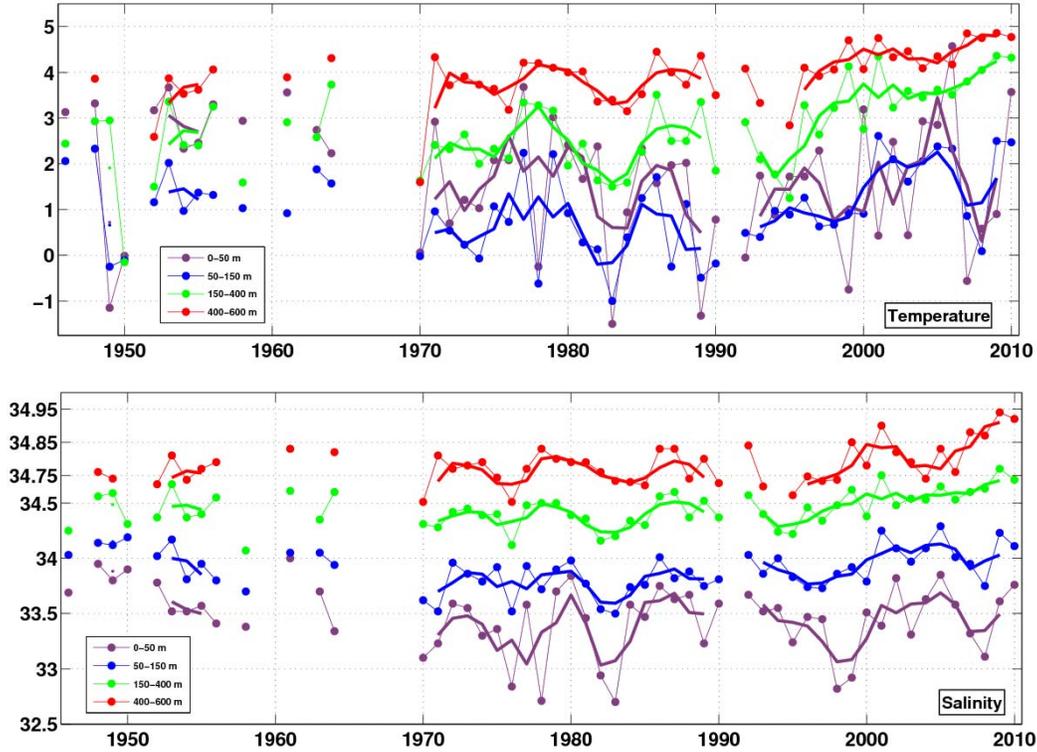


Figure 20. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1946–2010 in four different depth intervals west of “Store Hellefiskebanke” (Sisimiut, st.5) over the continental slope. The thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics is shown in Table 4.

Table 4. Statistics for potential temperature and salinity at Sisimiut (Holsteinsborg) st. 5. and values for 2010.

Sisimiut St.5	Temperature [°C]	Salinity	2010	
	Mean \pm std	Mean \pm std	Tpot	S
0–50 m	1.72 \pm 1.44°C	33.47 \pm 0.31	3.57°C	33.76
50–150 m	1.01 \pm 0.91°C	33.90 \pm 0.19	2.47°C	34.11
150–400 m	2.73 \pm 0.91°C	34.45 \pm 0.16	4.32°C	34.71
400–600 m	3.92 \pm 0.62°C	34.76 \pm 0.09	4.77°C	34.92

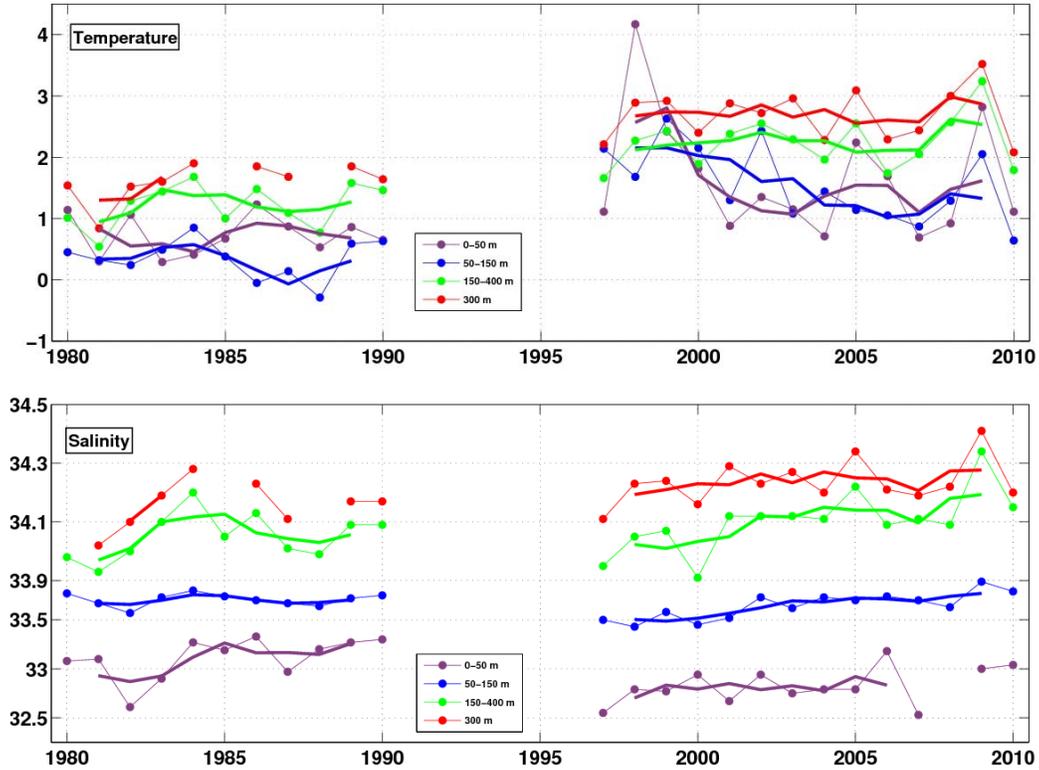


Figure 21. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1980–2010 in four different depth intervals west of “Jakobshavn-Skansen” (Ilulissat-Skansen) st.3 in the Disko Bay close to Jakobshavn Isbræ. The thick curves are the 3 year running mean values. Note the change in scales at 33.9 for salinity. Statistics is shown in Table 4.

Table 5. Statistics for potential temperature and salinity at Ilulissat-Skansen (Jakobshavn-Skansen) st. 3. and values for 2010.

Ilulissat St.3	Temperature [°C]	Salinity	2010	
	Mean ± std		Mean ± std	Tpot
0–50 m	1.31 ± 0.93°C	32.98 ± 0.27	1.11°C	33.04
50–150 m	1.02 ± 0.78°C	33.68 ± 0.11	0.64°C	33.79
150–400 m	1.77 ± 0.65°C	34.08 ± 0.09	1.79°C	34.15
300 m	2.25 ± 0.65°C	34.21 ± 0.08	2.08°C	34.20

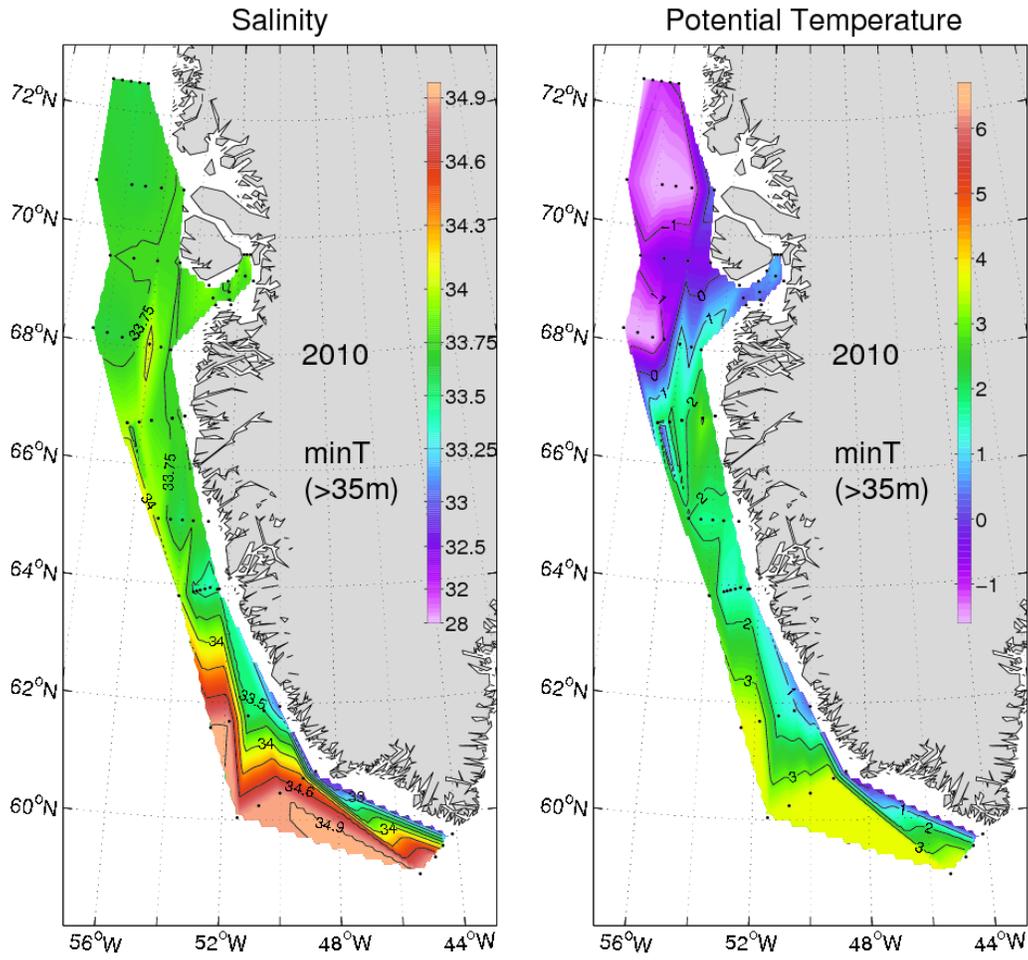


Figure 22. Salinity (left) and temperature (right) observed in 2010 at the depth of minimum temperature (disregarding the upper 35 meters). The data are all from June except the three northern offshore sections (Disko Fjord/Kangerluk, Nuussuaq, and Upernavik) which are taken in early July.

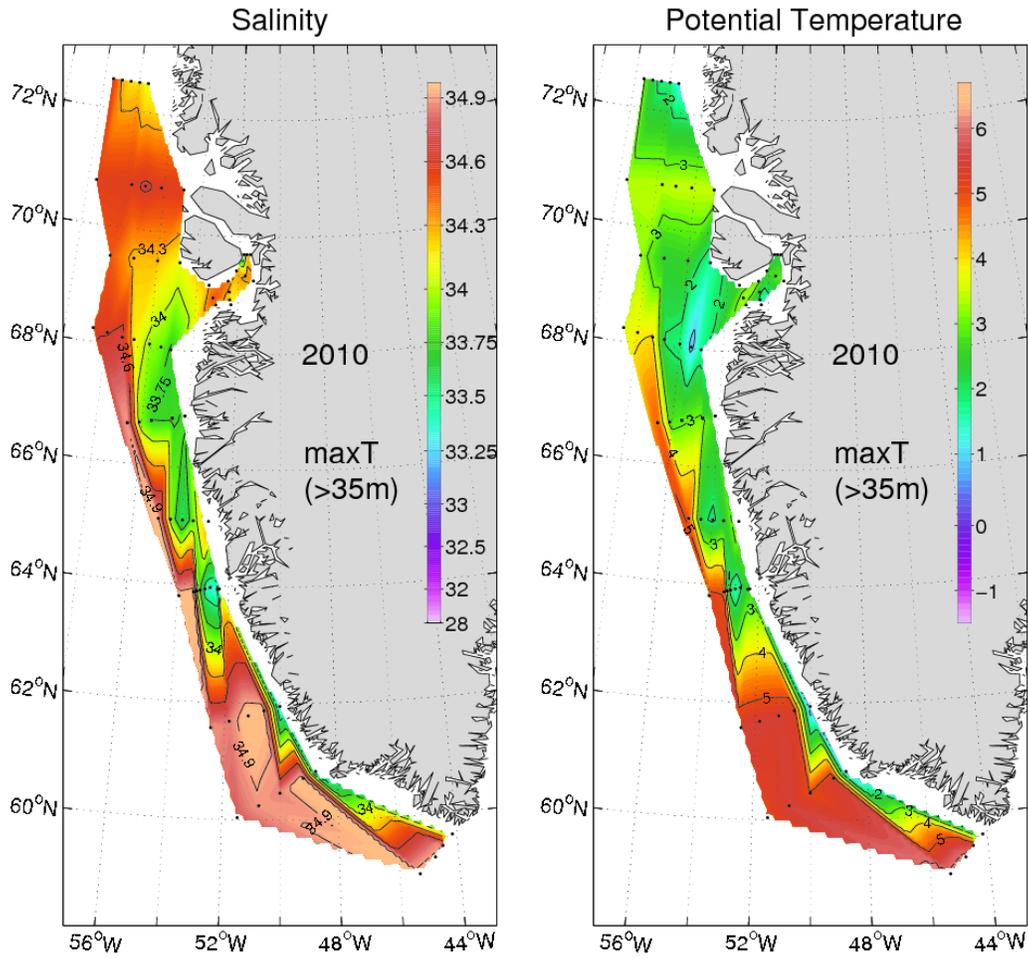


Figure 23. Salinity (left) and temperature (right) observed in 2010 at the depth of maximum temperature (disregarding the upper 35 meters). The data are all from June except the three northern offshore sections (Disko Fjord/Kangerluk, Nuussuaq, and Upernavik) which are taken in early July.

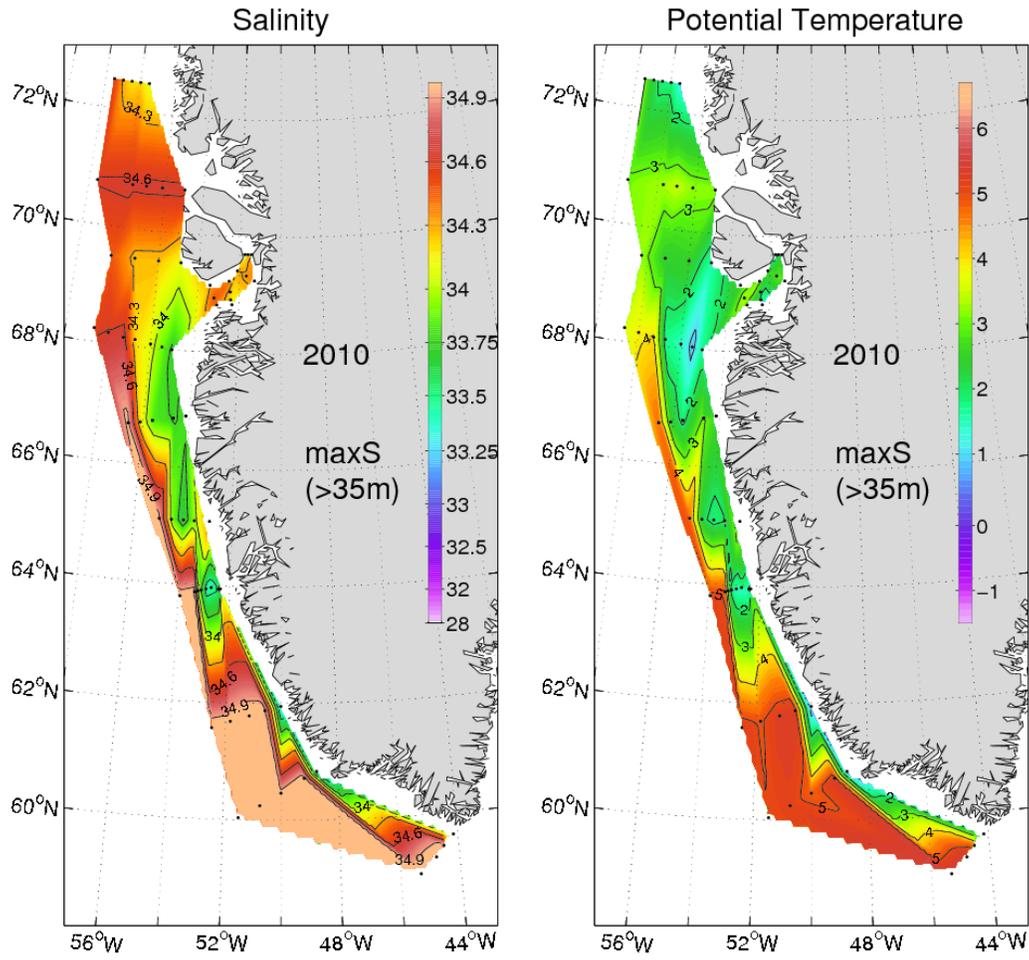


Figure 24. Salinity (left) and temperature (right) observed in 2010 at the depth of maximum salinity (disregarding the upper 35 meters). The data are all from June except the three northern offshore sections (Disko Fjord/Kangerluk, Nuussuaq, and Upernavik) which are taken in early July.

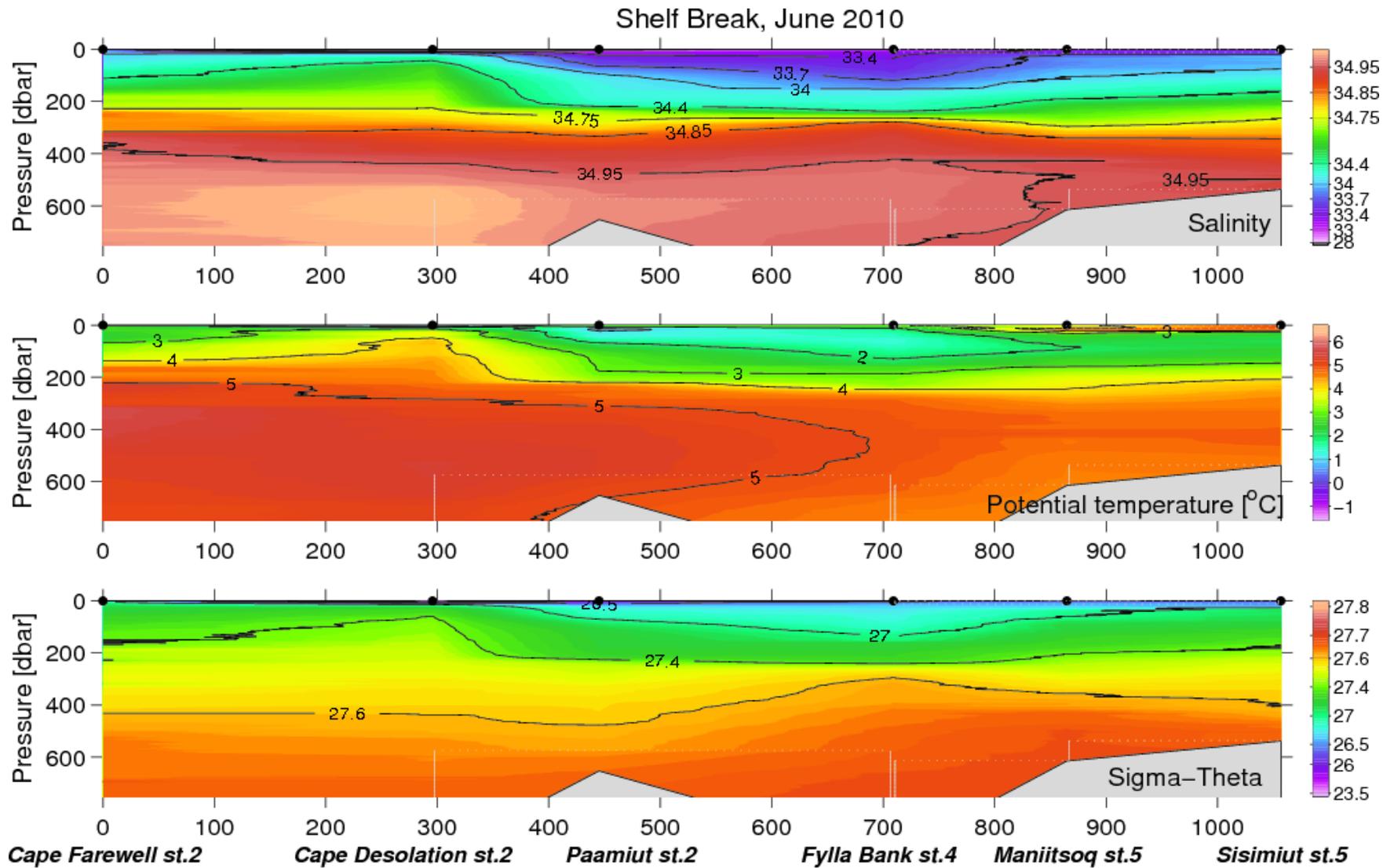


Figure 25. Vertical distribution of temperature, salinity and density over the continental shelf break from Cape Farewell to Sisimiut, June 04–23, 2010.

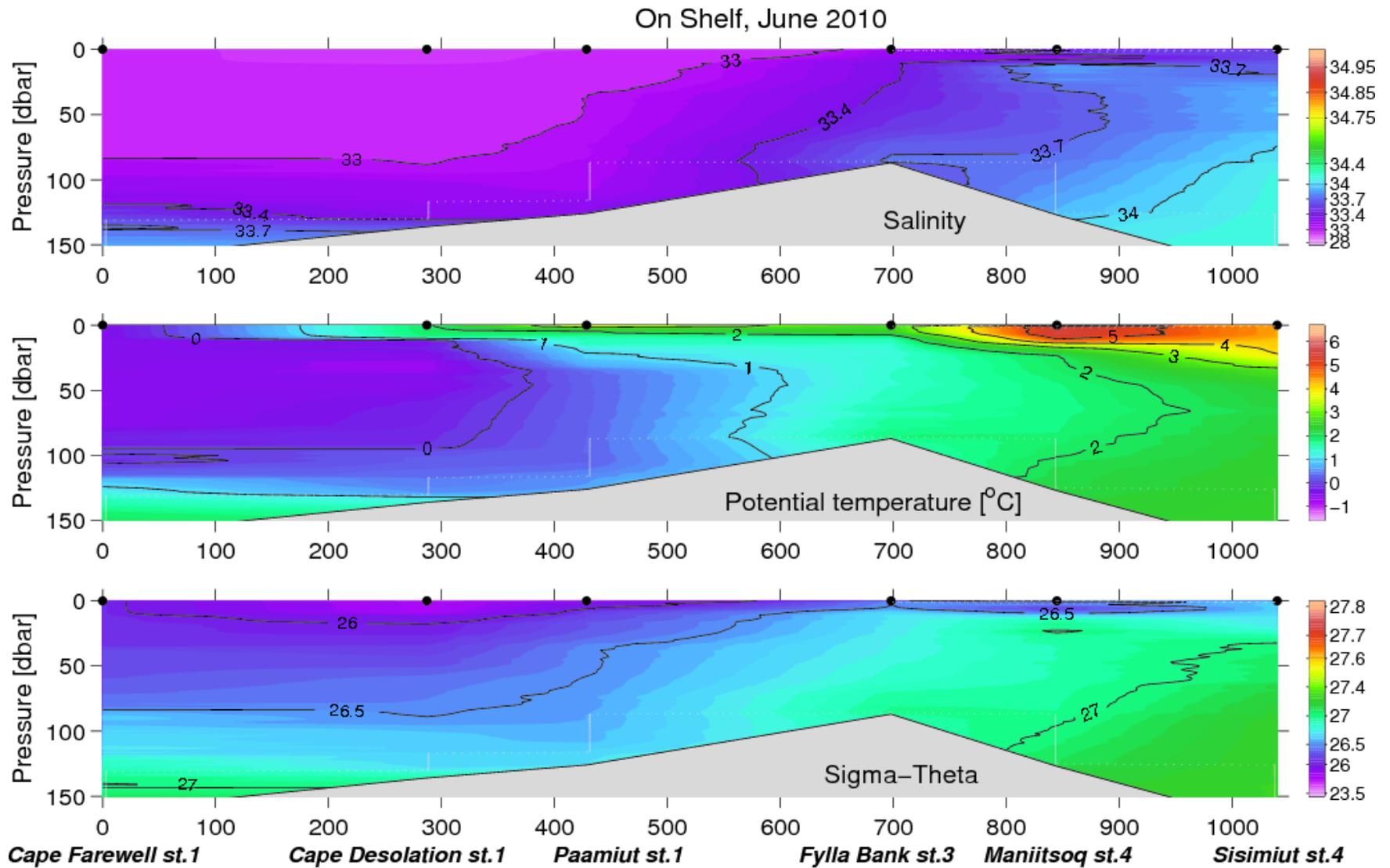


Figure 26. Vertical distribution of temperature, salinity and density over the shelf banks from Cape Farewell to Sisimiut, June 04–24, 2010.

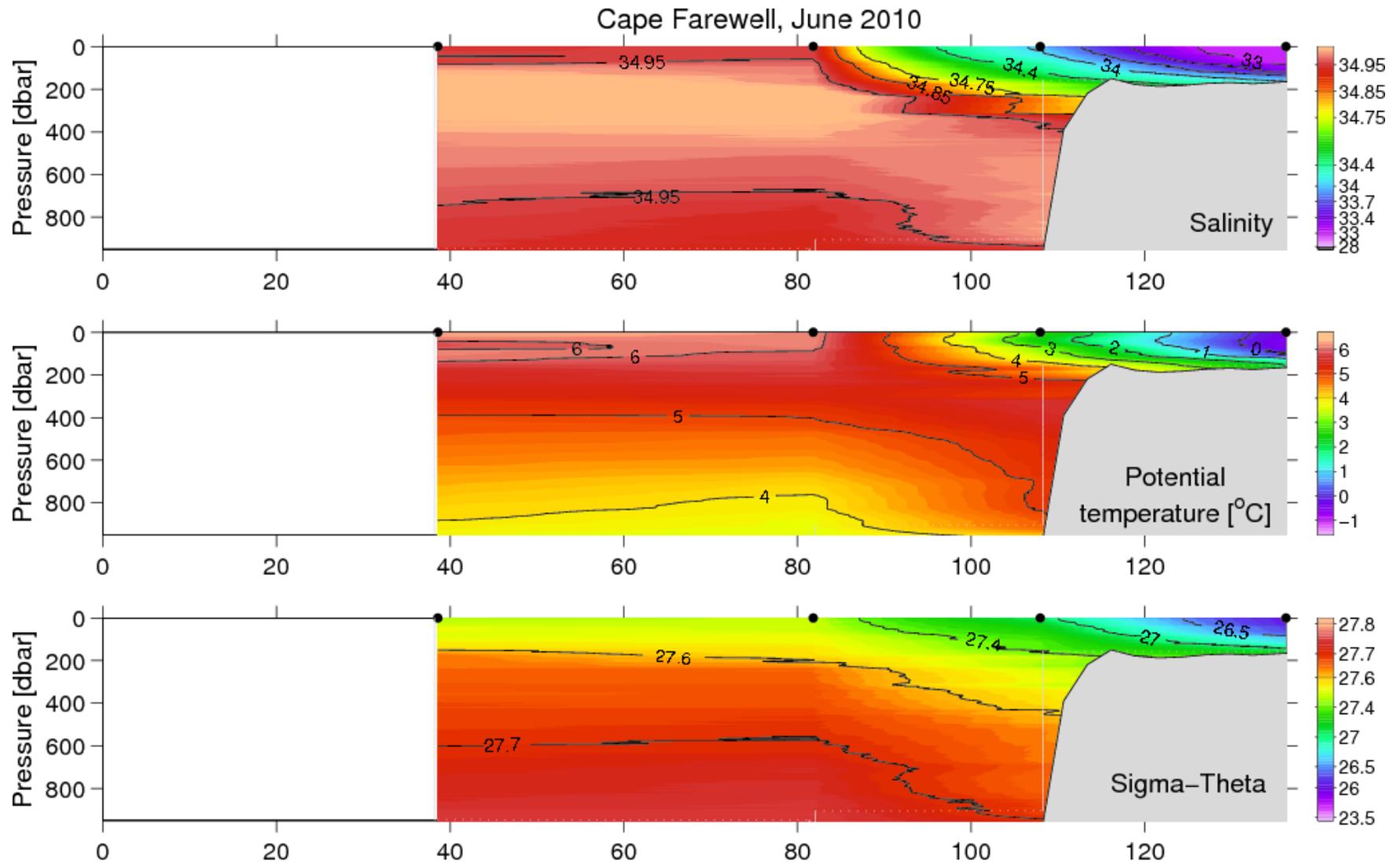


Figure 27. Vertical distribution of temperature, salinity and density at the Cape Farewell section, June 07–08, 2010.

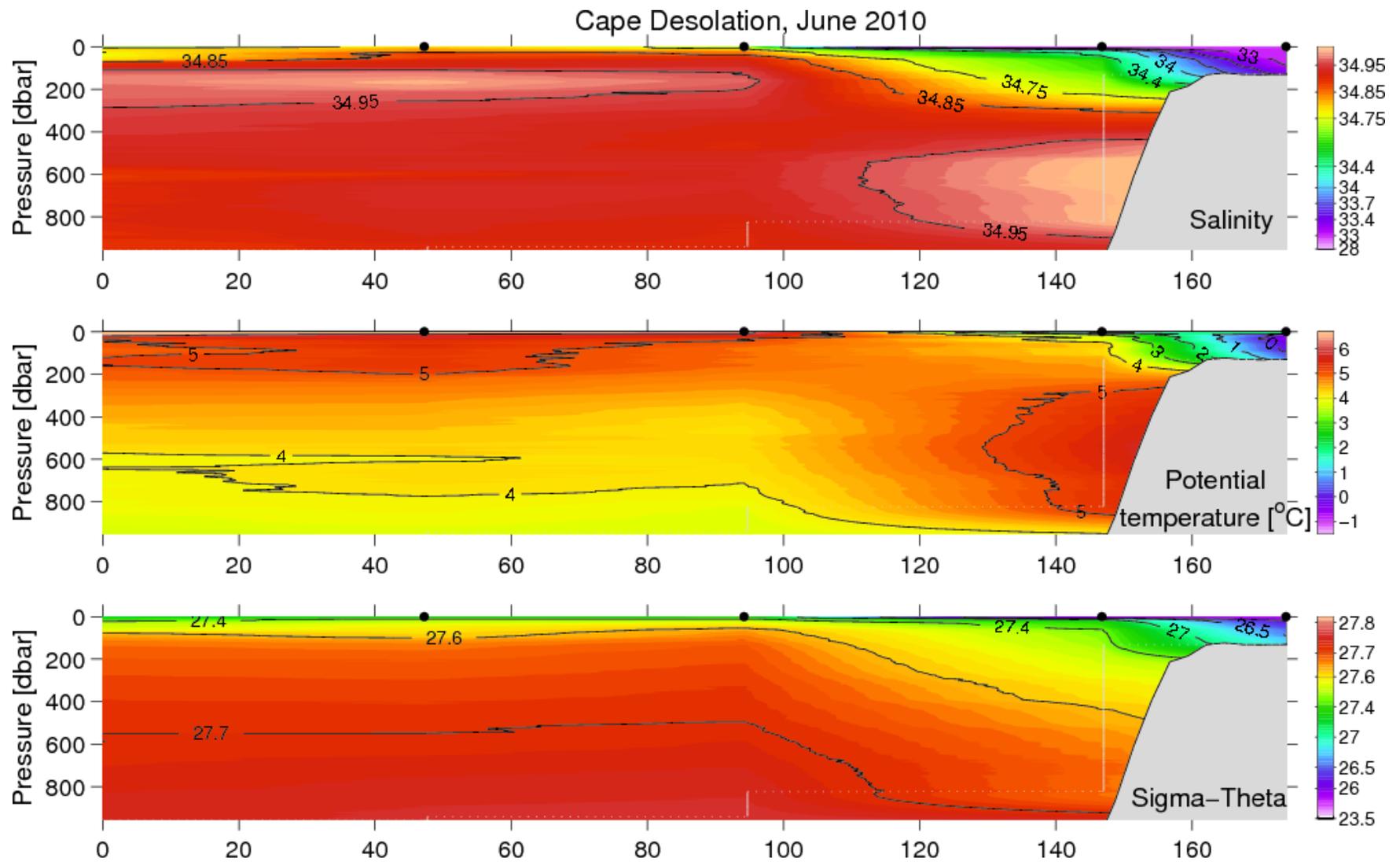


Figure 28. Vertical distribution of temperature, salinity and density at the Cape Desolation section, June 05–06, 2010

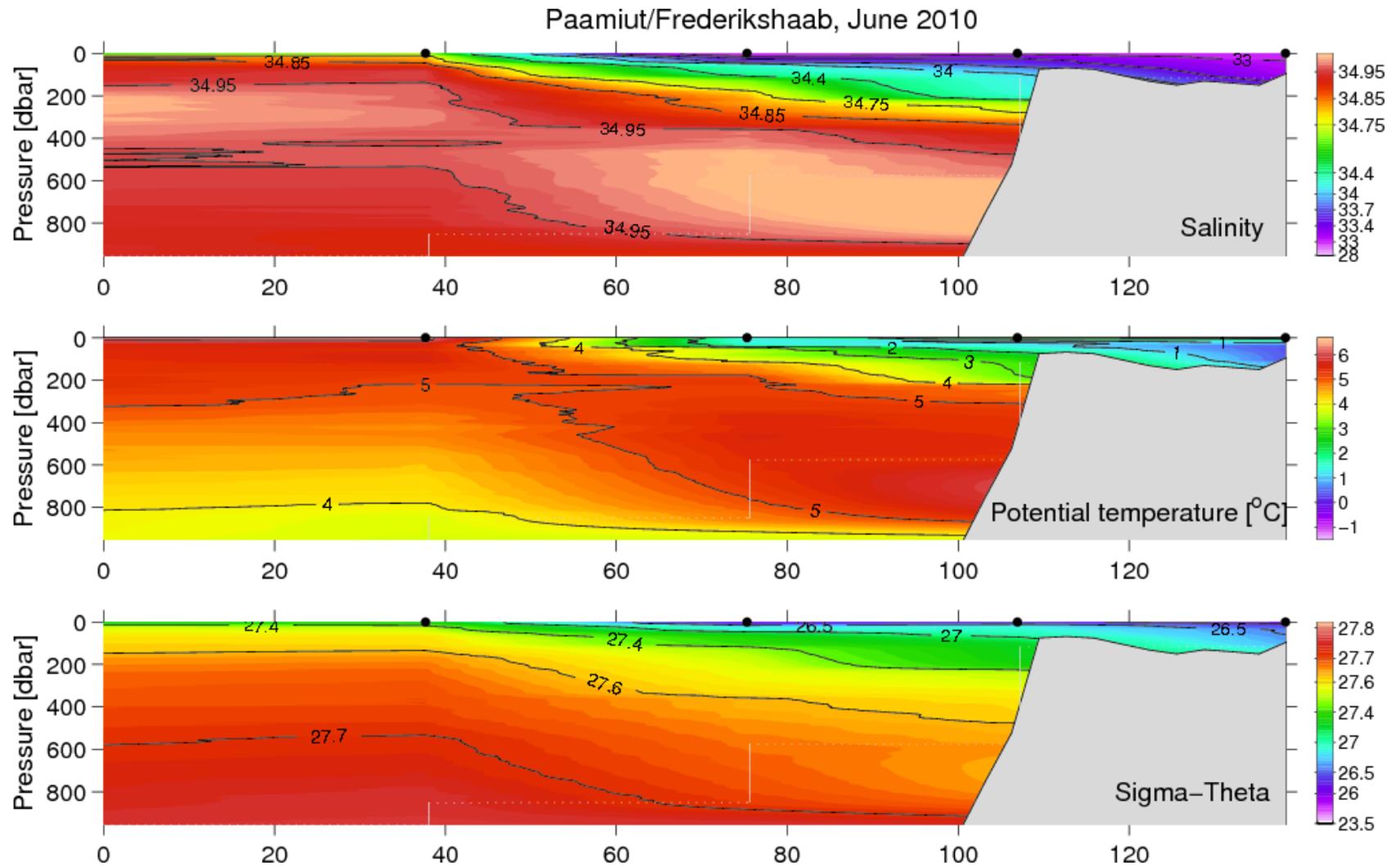


Figure 29. Vertical distribution of temperature, salinity and density at the Paamiut (Frederikshaab) section, June 05, 2010.

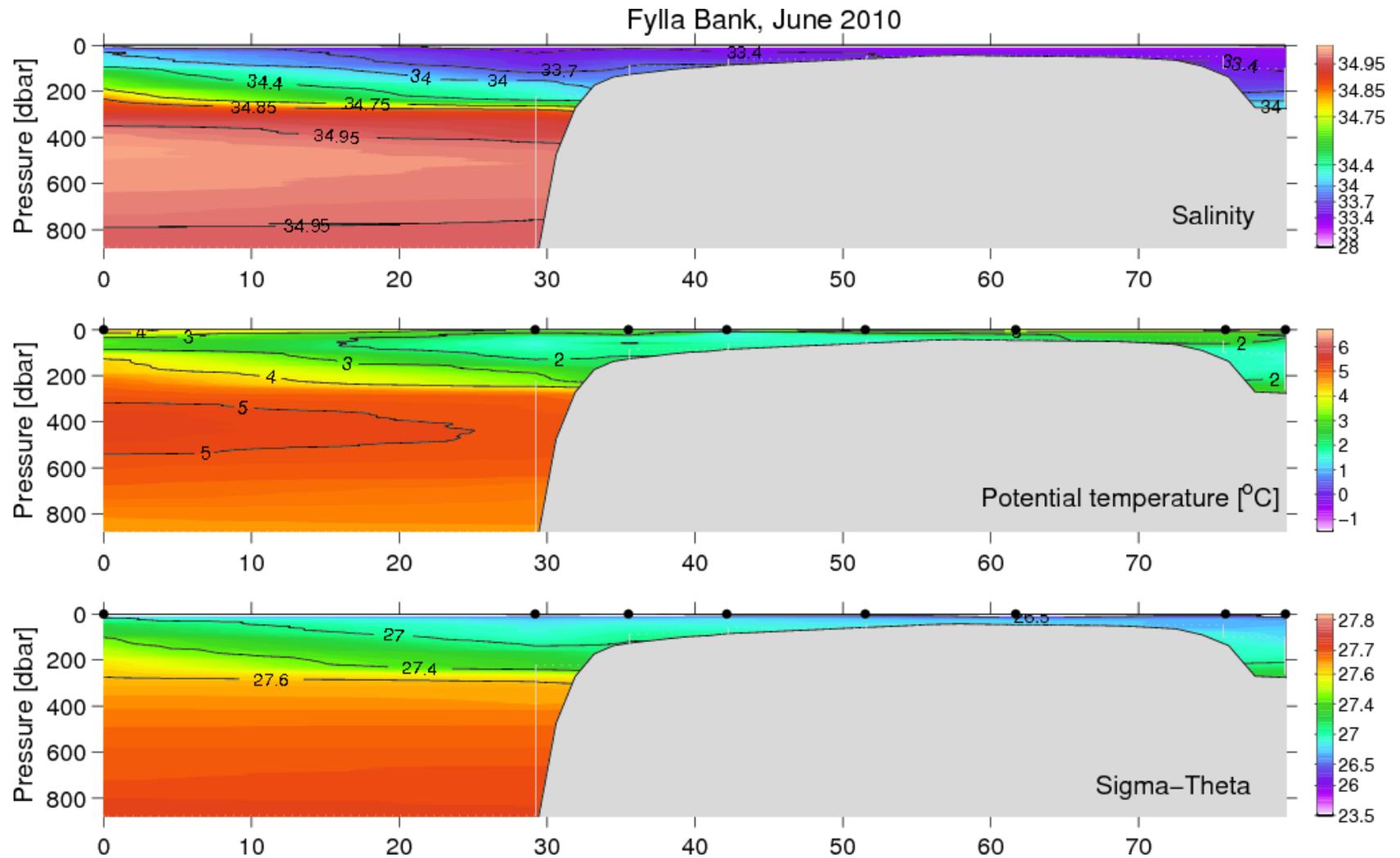


Figure 30. Vertical distribution of temperature, salinity and density at the Fylla Bank section, June 04, 2010. Three intermediate stations were taken too.

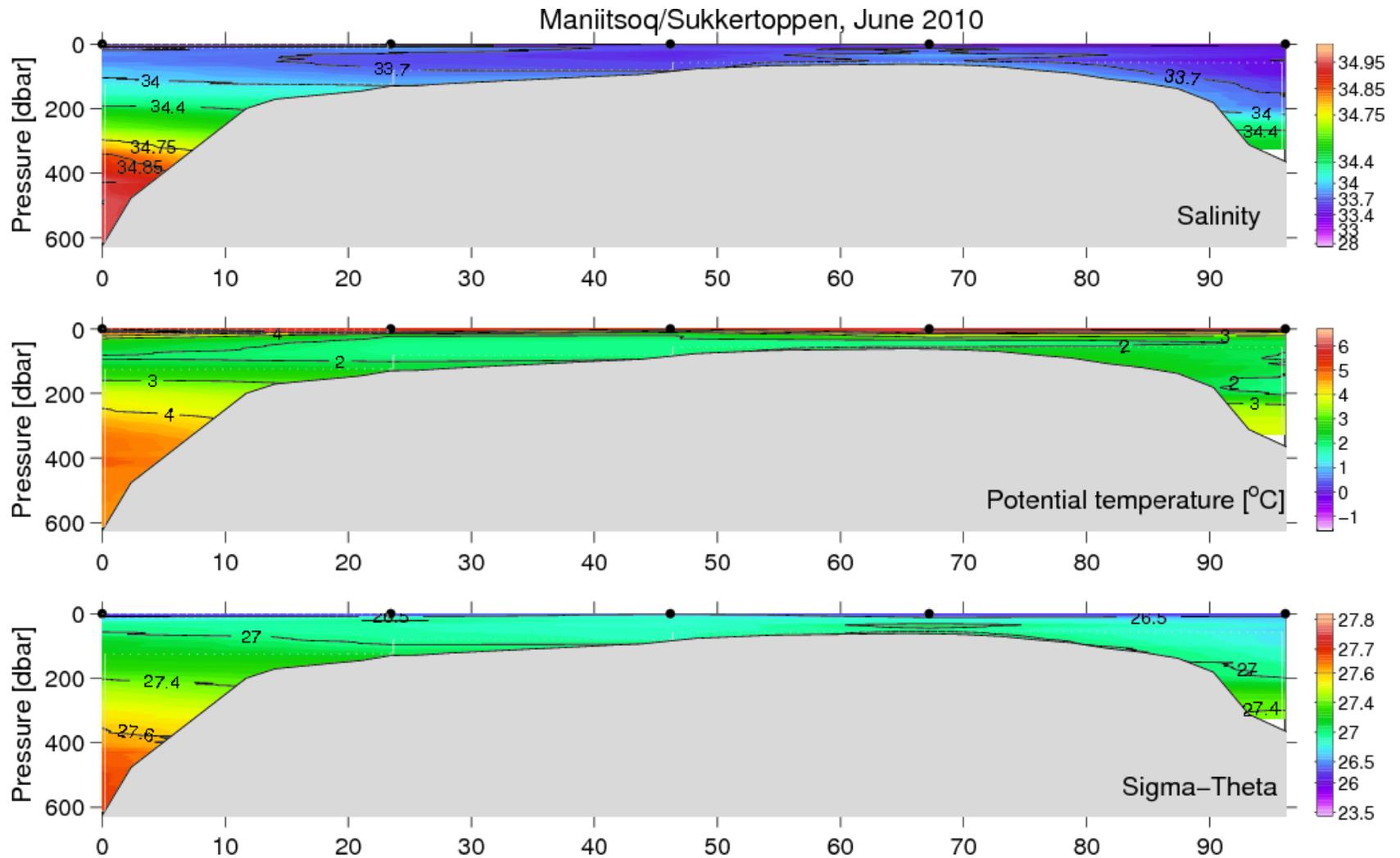


Figure 31. Vertical distribution of temperature, salinity and density at the Maniitsoq (Sukkertoppen) section, June 23–24, 2010.

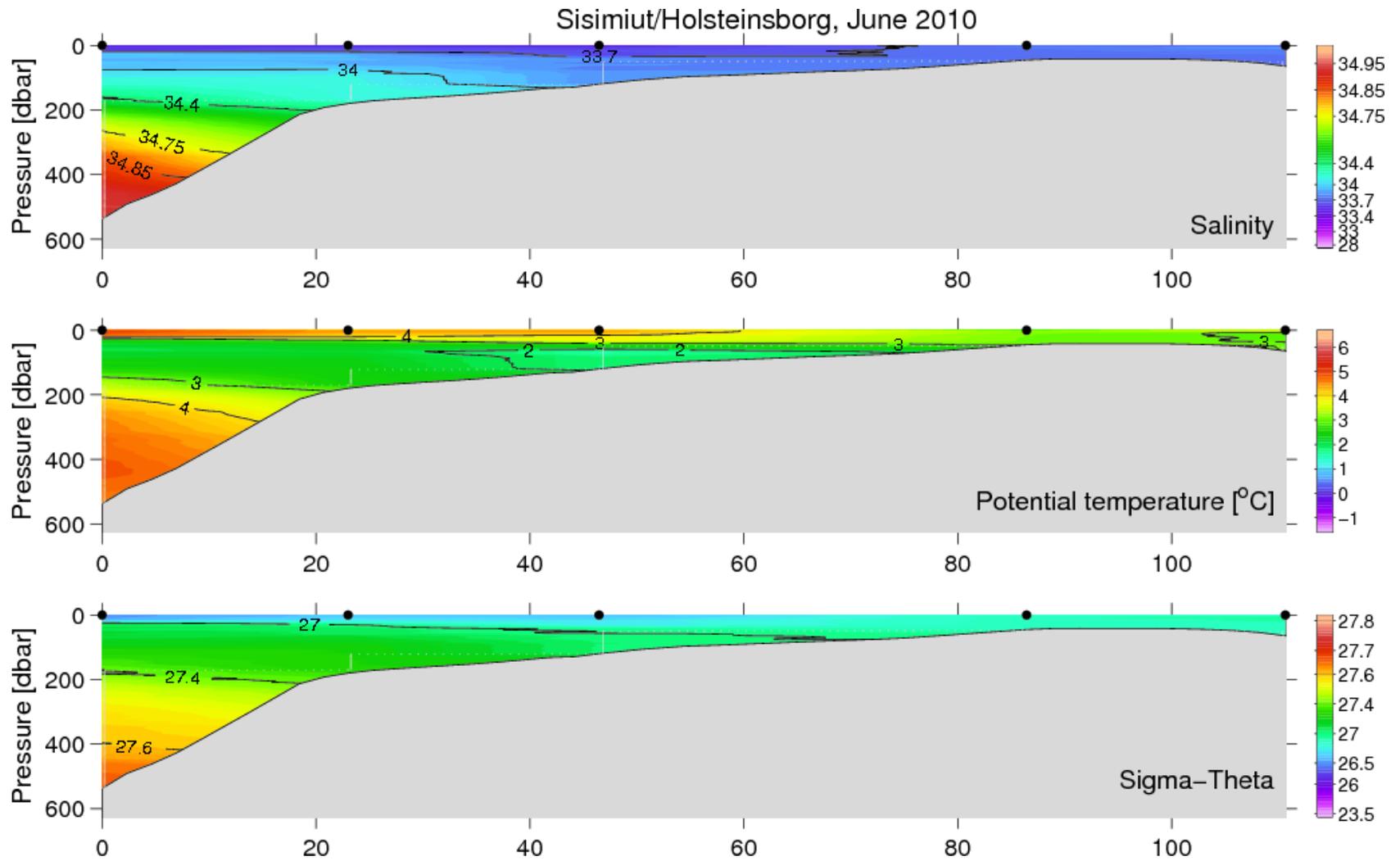


Figure 32. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, June 23, 2010.

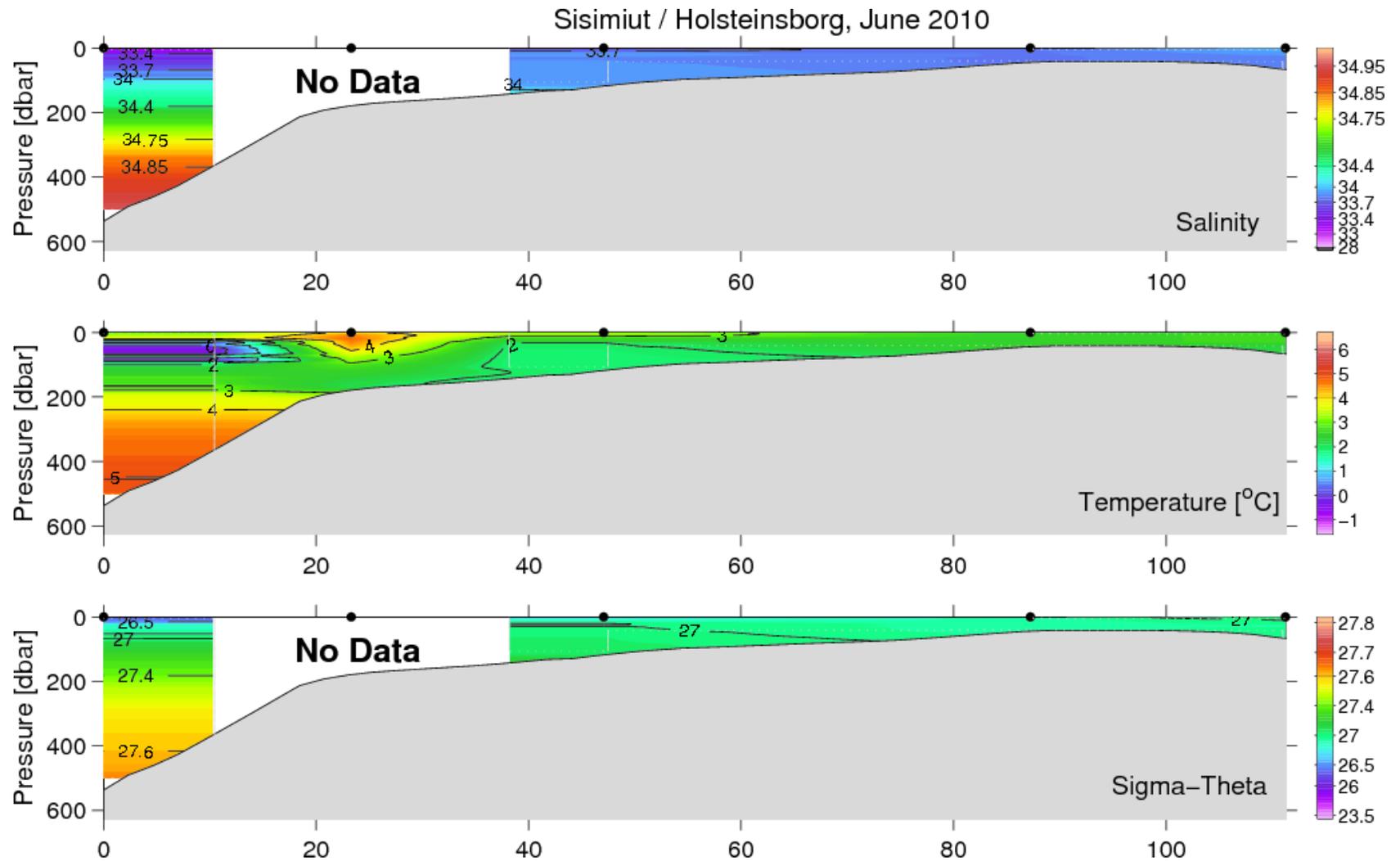


Figure 33. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, June 13–14, 2010.

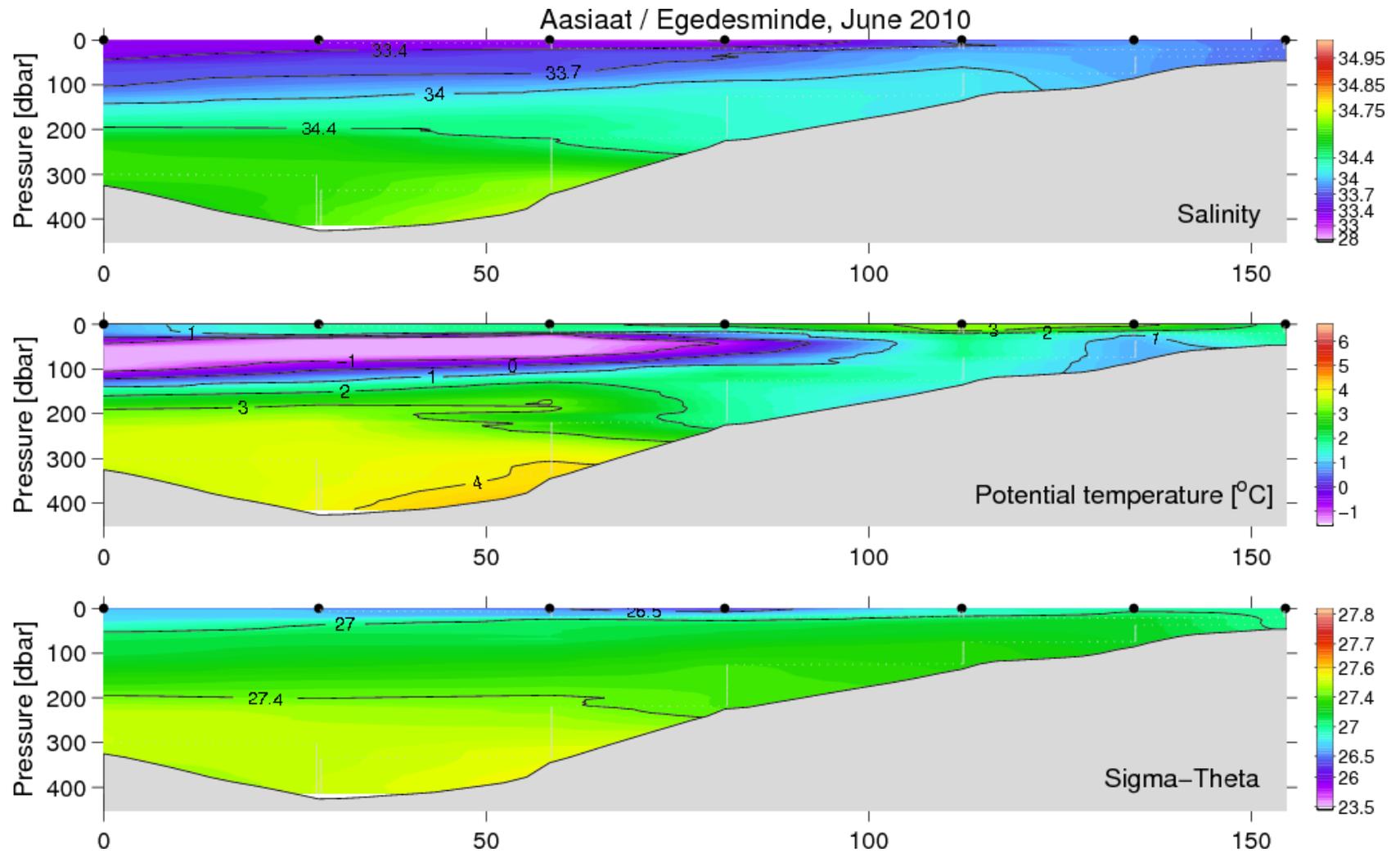


Figure 34. Vertical distribution of temperature, salinity and density at the Aasiaat (Egedesminde) section, June 18, 2010.

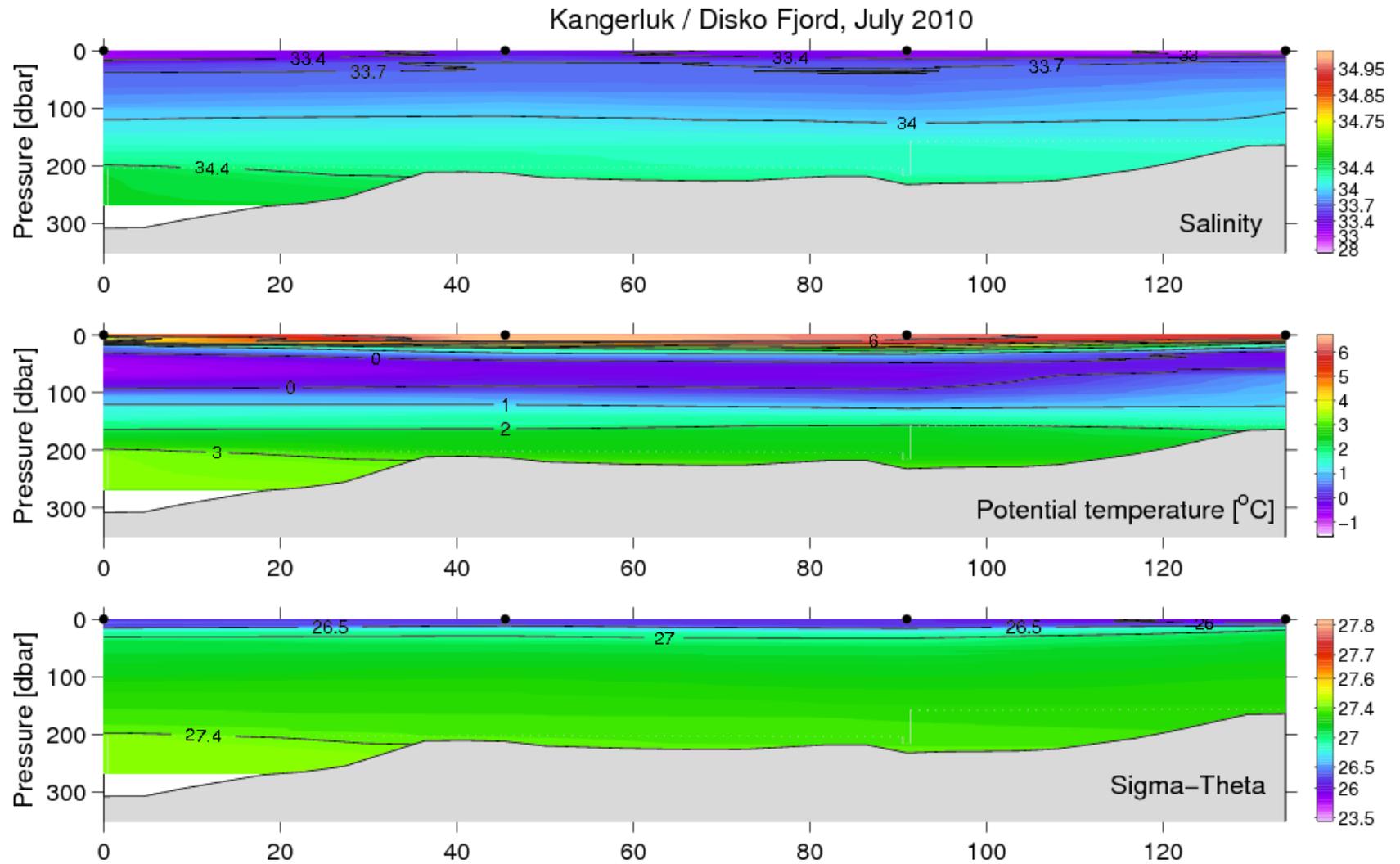


Figure 35. Vertical distribution of temperature, salinity and density at the Kangerluk (Disko Fjord) section, July 08–10, 2010.

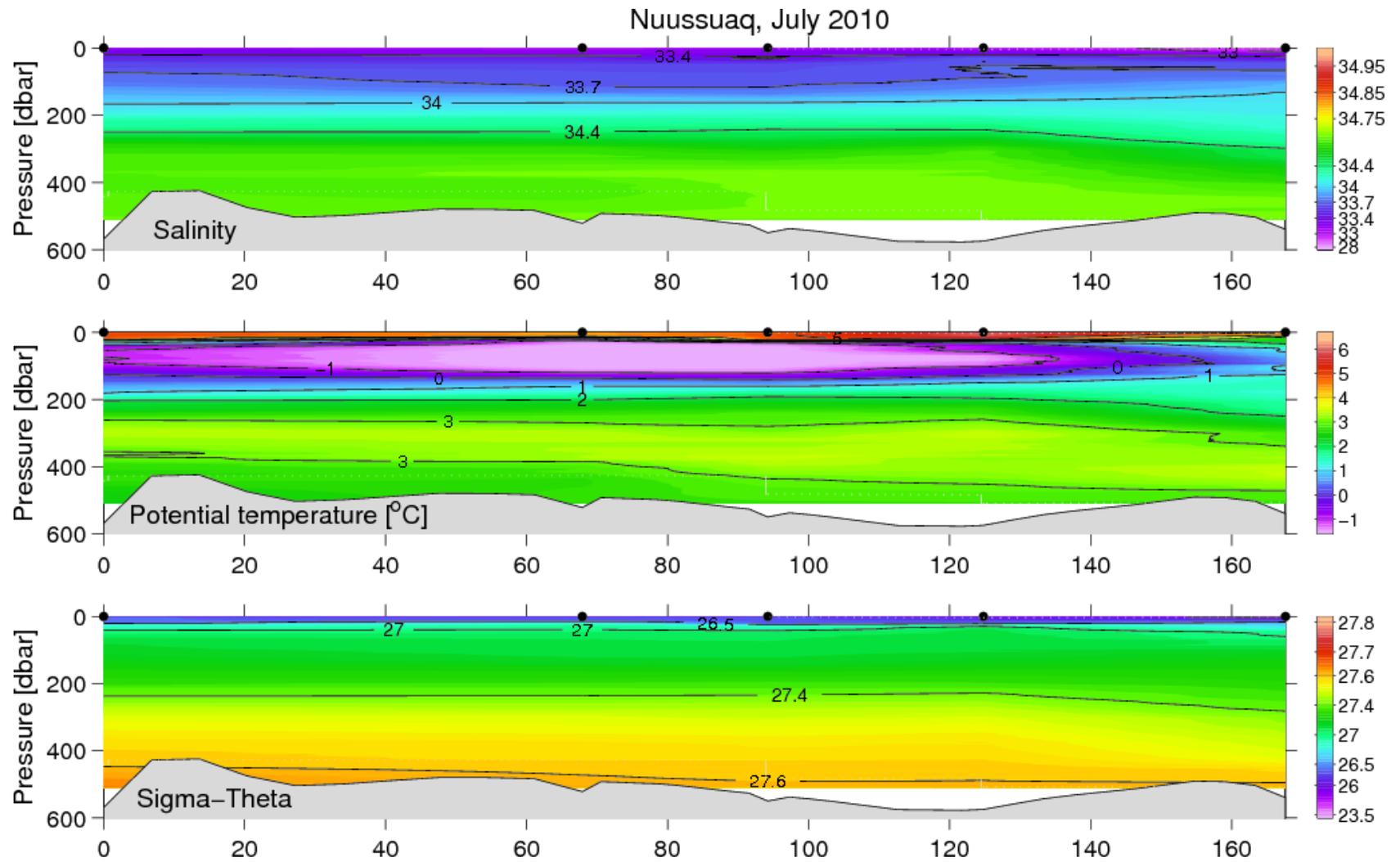


Figure 36. Vertical distribution of temperature, salinity and density at the Nuussuaq section, July 03-04, 2010.

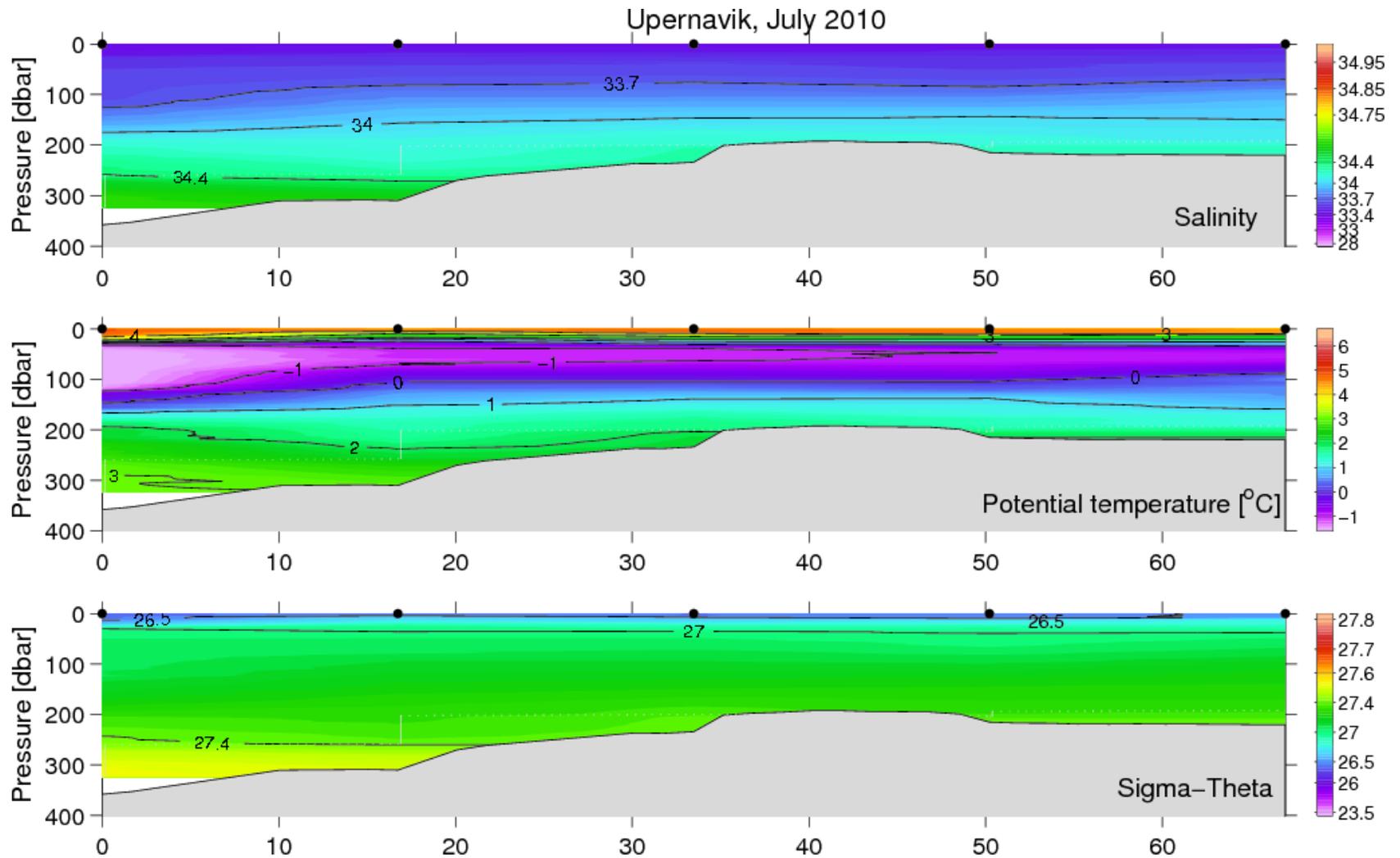


Figure 37. Vertical distribution of temperature, salinity and density at the Upernavik section, July 01–02, 2010.

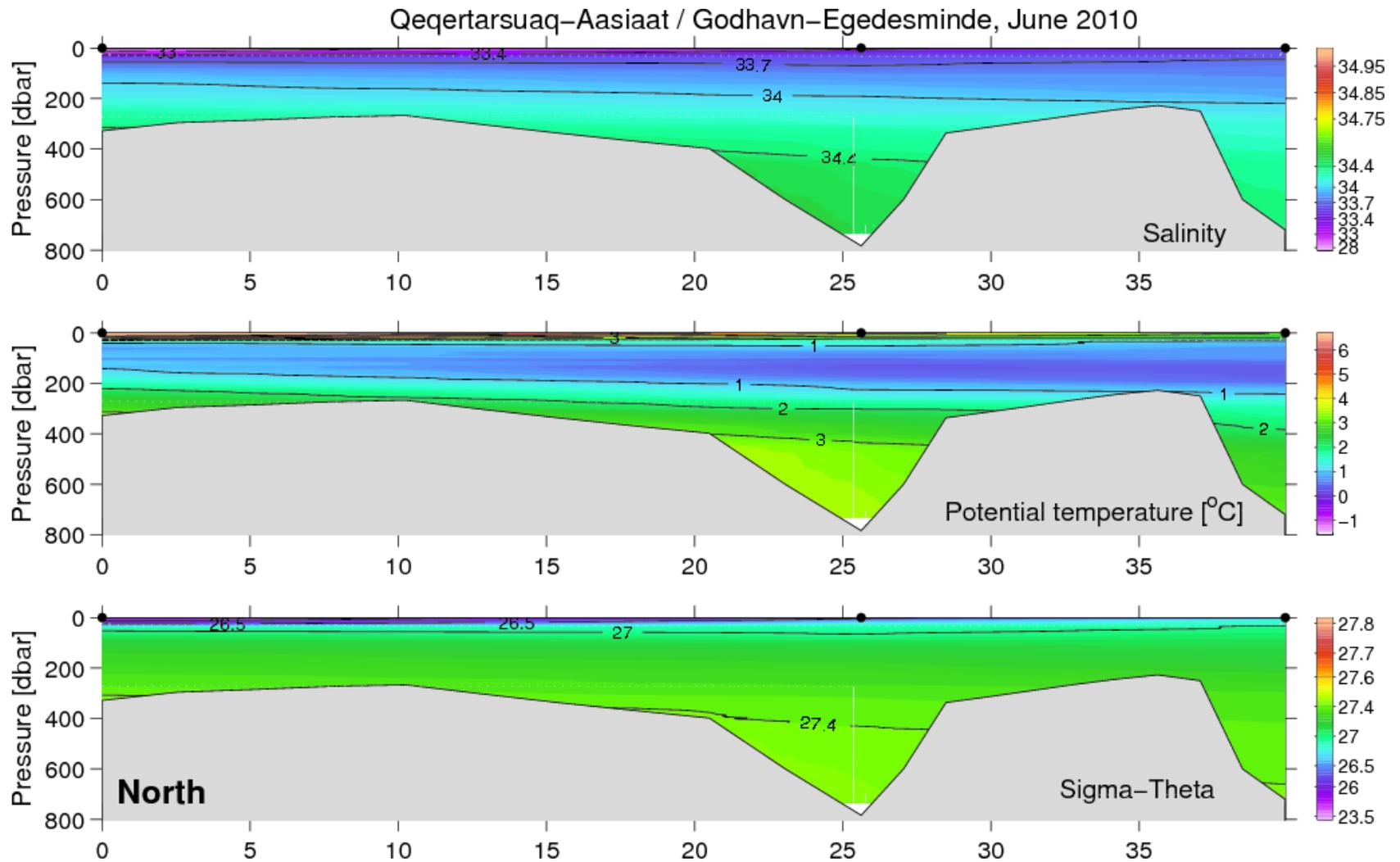


Figure 38. Vertical distribution of temperature, salinity and density at the Aasiaat–Qeqertarsuaq (Egedesminde–Godhavn) section, June 21–22, 2010.

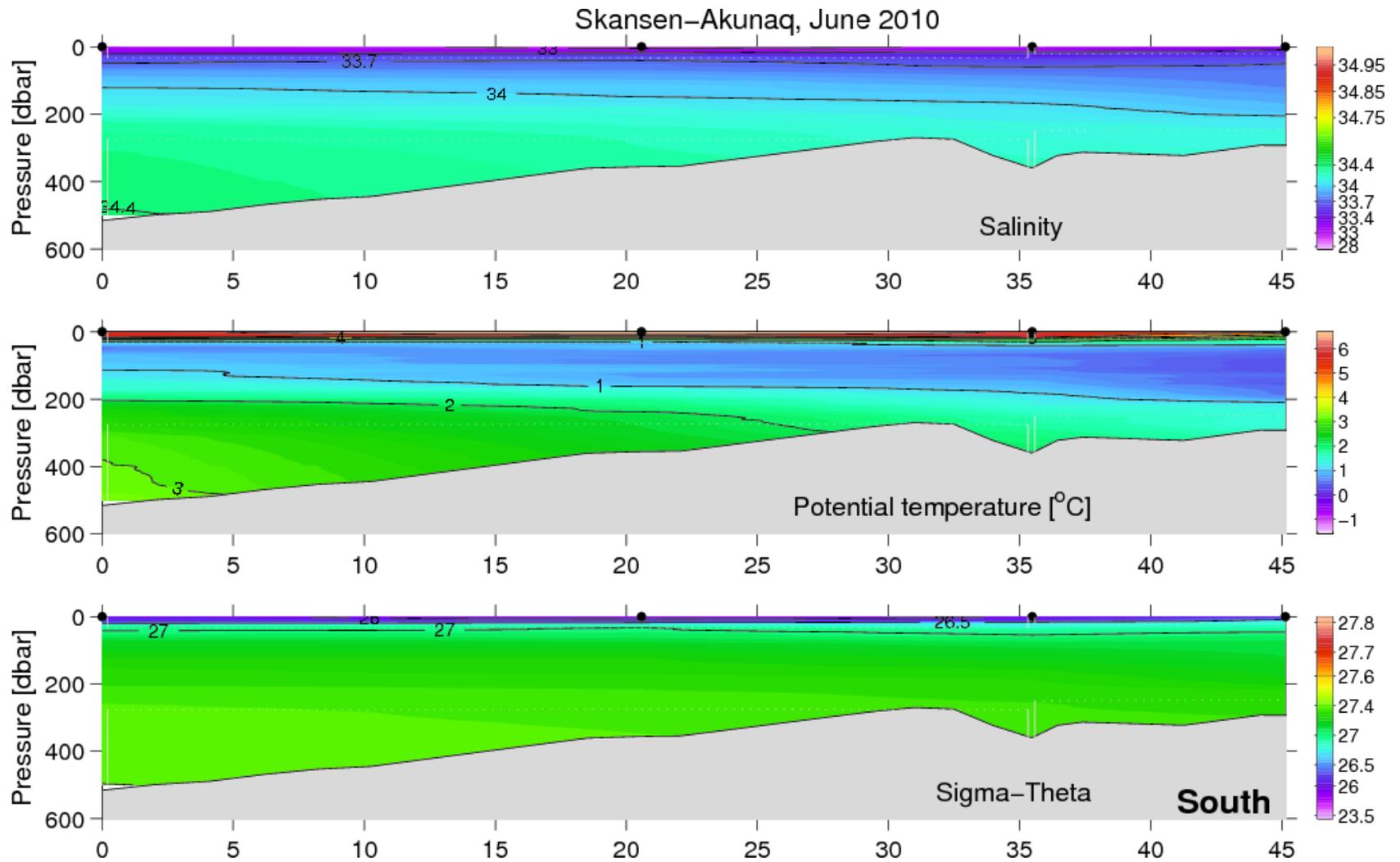


Figure 39. Vertical distribution of temperature, salinity and density at the Skansen–Akunaq section, June 22–23, 2010.

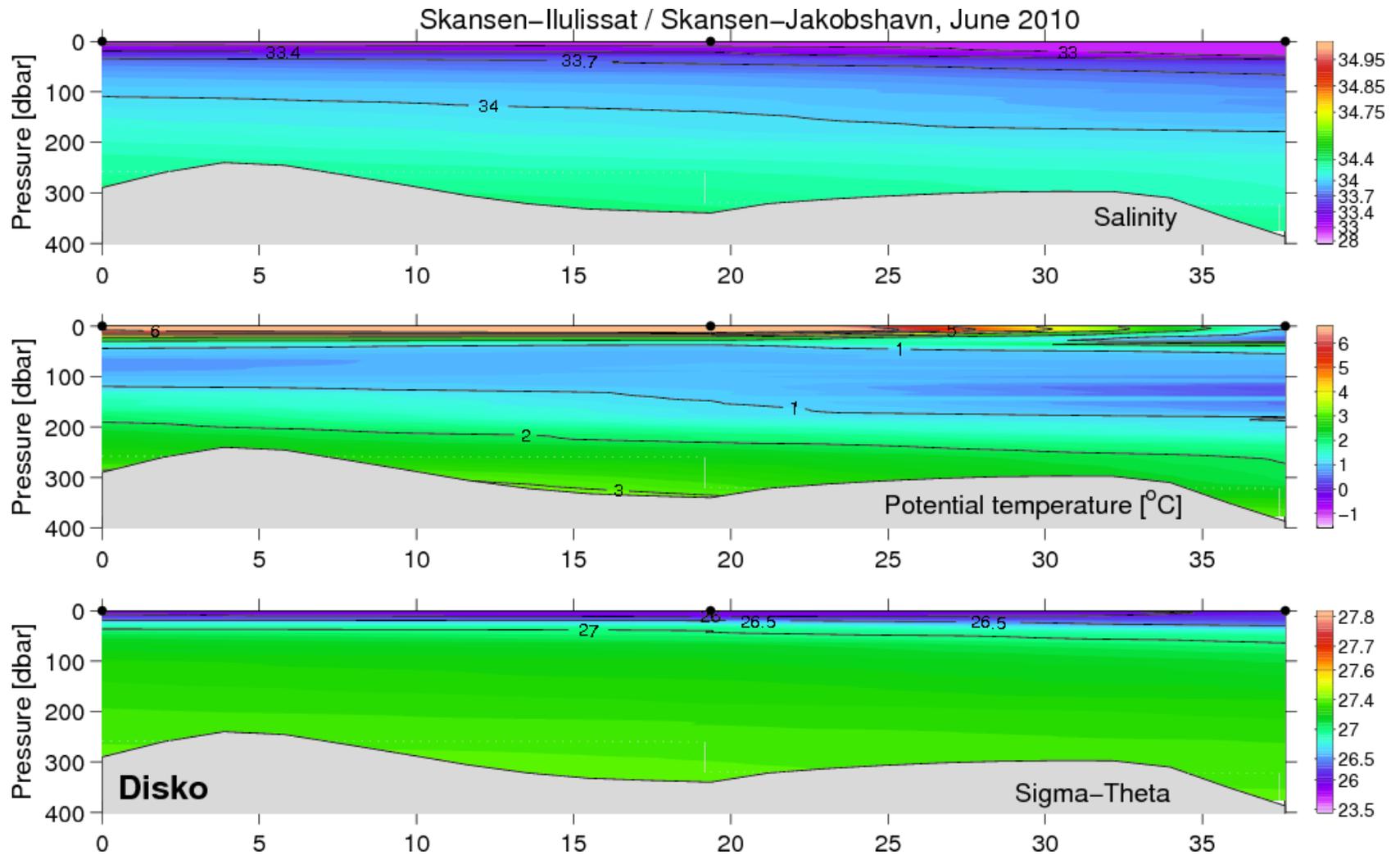


Figure 40. Vertical distribution of temperature, salinity and density at the Skansen–Ilulissat (Skansen–Jakobshavn) section, June 26–27, 2010.

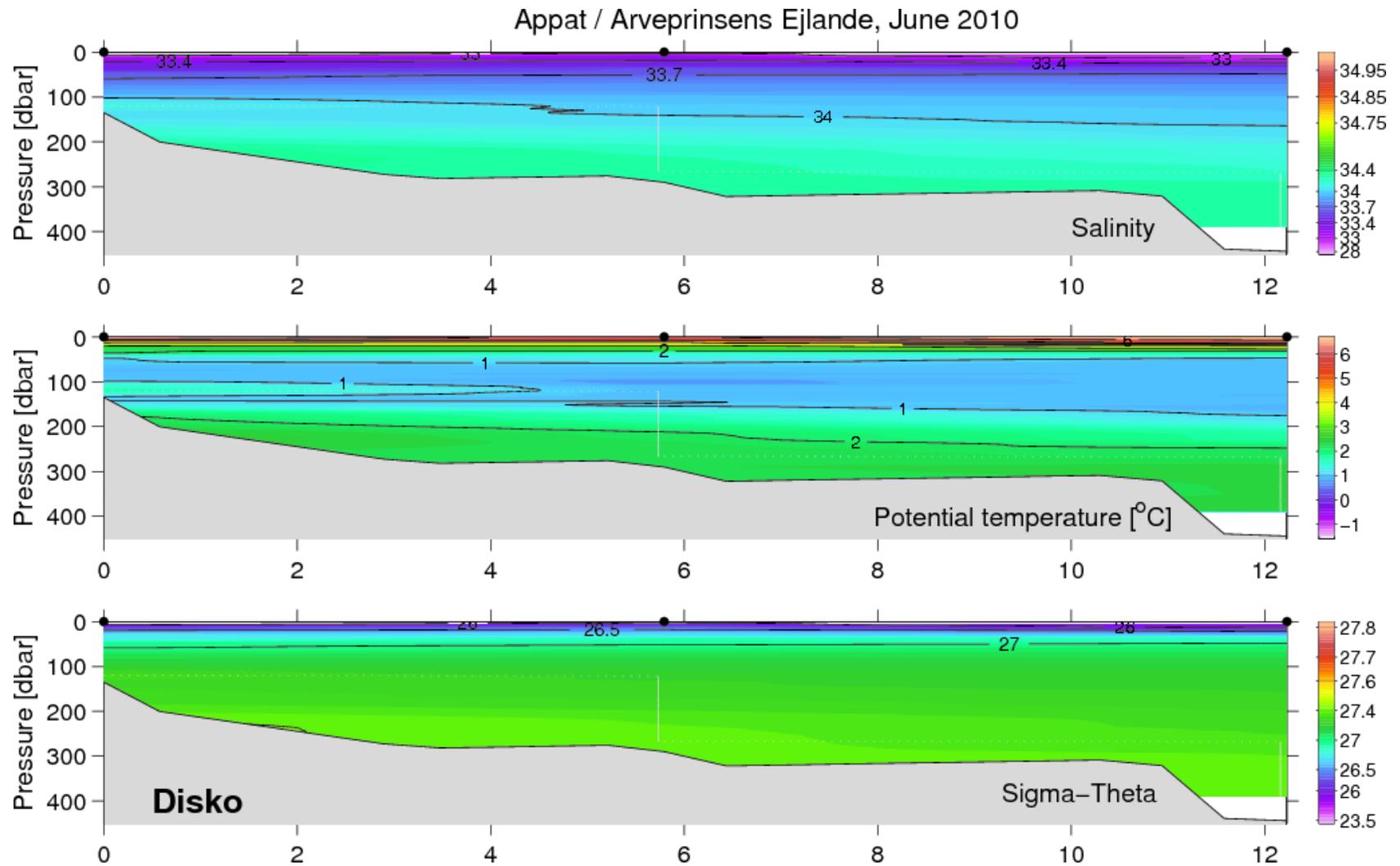


Figure 41. Vertical distribution of temperature, salinity and density at the Appat (Arveprinsens Ejlande) section, June 27, 2010.