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**Oceanographic Investigations off West Greenland 2012**

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**Abstract**

The regional hydrography in summer 2012 is presented and discussed based on data from standard sections along the west coast of Greenland and data retrieved during trawl surveys.

In winter 2011/12, the North Atlantic Oscillation (NAO) index was positive describing strengthened westerlies over the North Atlantic Ocean. Often this results in colder conditions over the West Greenland region which was also the case this winter with air temperature slightly below normal. This was followed by an exceptional atmospheric warming during summer resulting in higher than normal annual air temperatures.

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 0.2°C above average conditions in 2012 while low salinity was observed 0.2 below average.

The presence of Irminger Water in the West Greenland waters was high in 2012. Pure Irminger Water (waters of Atlantic origin) could be traced north to the Paamiut section and modified Irminger Water further north to the Sisimiut section. The mean (400–600 m) temperature and salinity was high over the Southwest Greenland shelf break.

The presence of Polar Water was slightly above normal in 2012. The normalized near-surface temperature and salinity indices were slightly below normal and the salinity in the upper ~50–100m of waters over the West Greenland shelf was in general lower than normal. The mean (50–150 m) temperature and salinity was lower than normal over the Southwest Greenland Shelf Break with the exception of Fylla Bank st.4.

## Introduction to the west Greenland oceanography

This report describes the hydrographic conditions in West Greenland Waters in 2012 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.

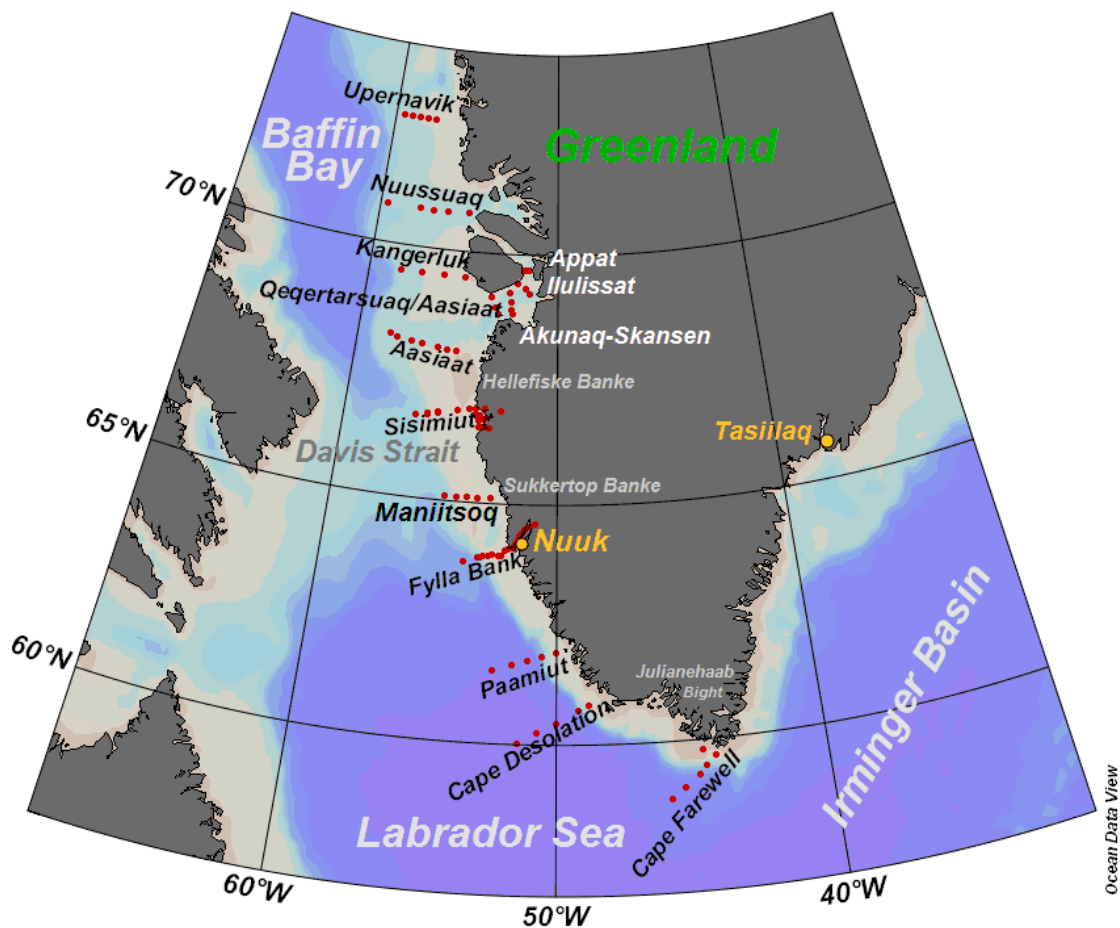


Figure 1. Position of the oceanographic sections off West Greenland where measurements were taken in 2012. Map produced using Ocean Data View (Schlitzer, 2007).

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. In southwest Greenland waters 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.

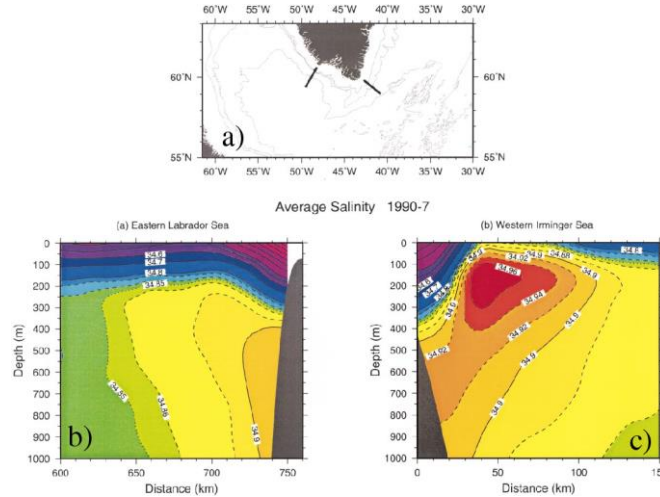


Figure 2. Mean upper-layer salinity sections for the period 1990–1997. Top: Location of the two sections. Isobaths shown: 1000, 2000 and 3000 m. Lower left: Eastern Labrador Basin. Lower right: Western Irminger Basin. From Pickart et al. (2002).

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.

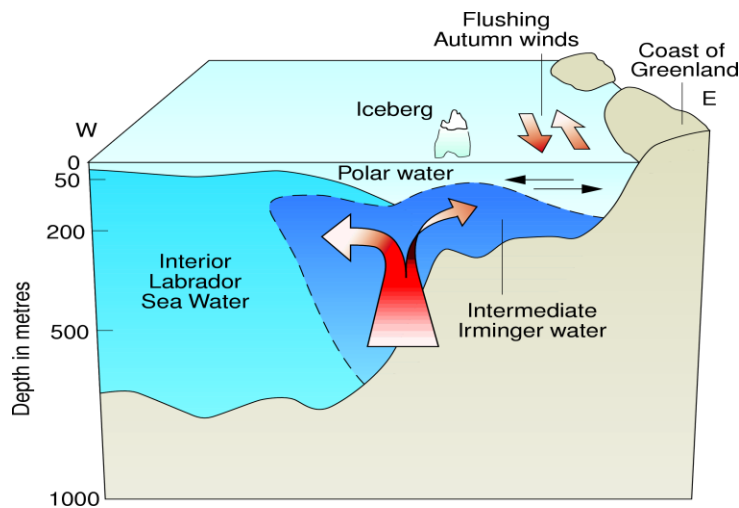


Figure 3. Sketch of the water masses off West Greenland in the Davis Strait region. From Valeur et al. (1997).

The tidal signal is significant. At West Greenland the strongest tidal signal is located close to Nuuk at  $64^{\circ}\text{N}$ . 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.

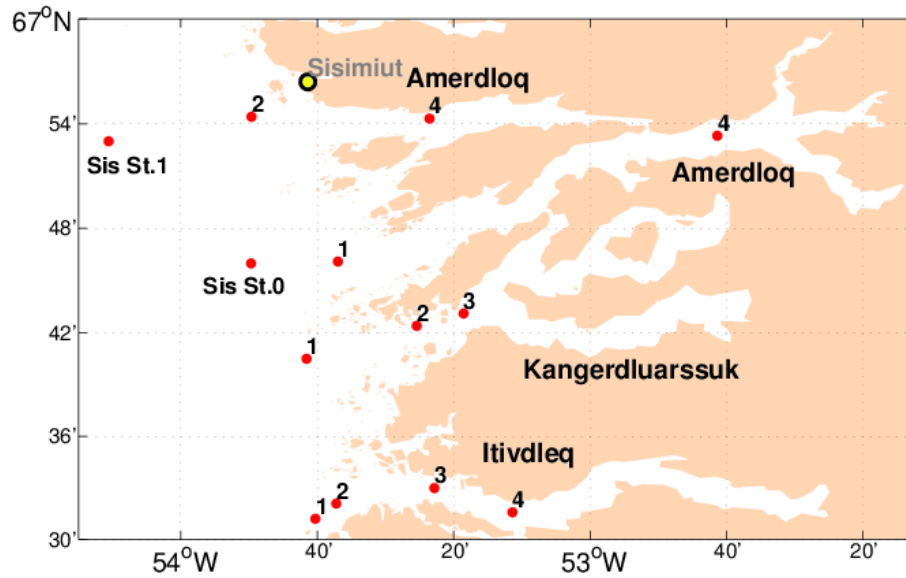


Figure 4. Position of the oceanographic stations around Sisimiut where measurements were performed in 2012. See Figure 1 for position of all sections measured in 2012.

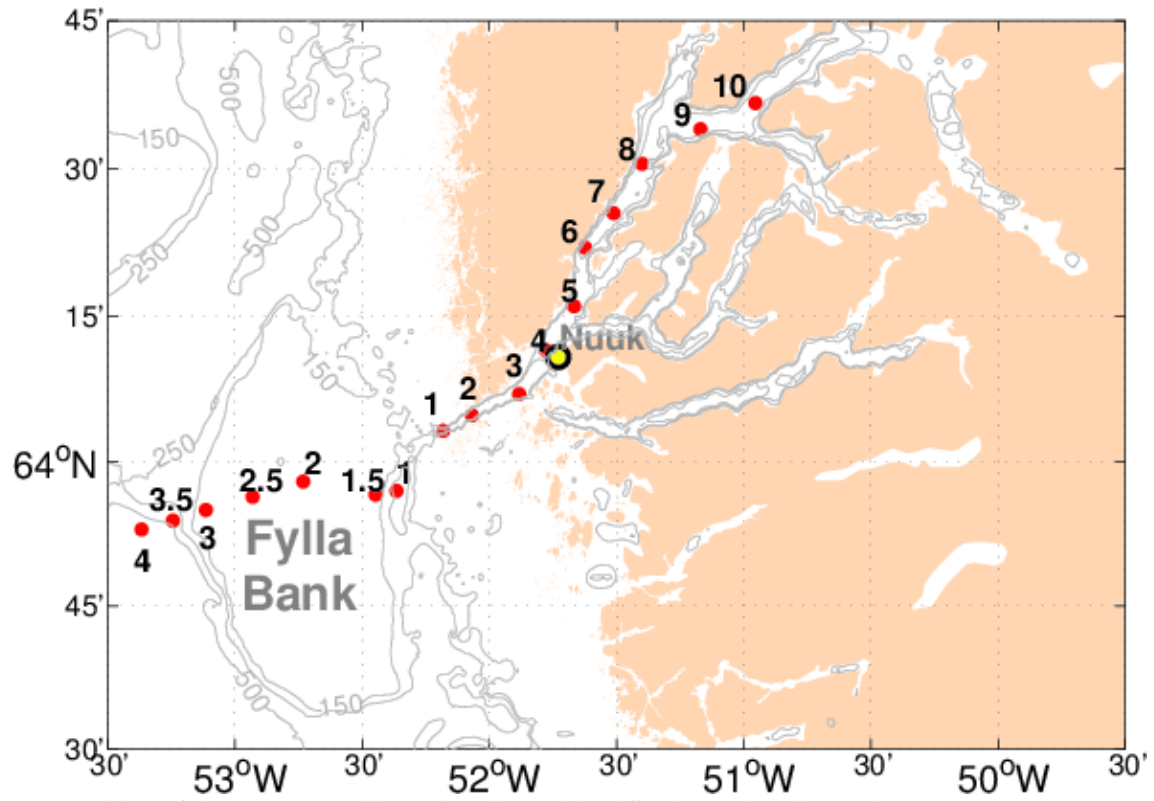


Figure 5. Position of the oceanographic stations in Godthaabfjorden and Fylla Bank. In 2012 measurements were performed over Fylla Bank and st. 1–10 in the “main arm” of the Godthaabfjorden. The numbers refer to standard station numbers as shown in Figure 43. See Figure 1 for position of all sections measured in 2012.

## 1. Measurements

The 2012 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 08 – 18, 2012 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. 1–5
- Cape Desolation St. 1–5
- Paamiut (Frederikshaab) St. 1–5
- Fylla Bank St. 1–5
- Maniitsoq (Sukkertoppen) St. 1–5
- Sisimiut (Holsteinsborg) St. 0–5

Additional stations on the Fylla Bank section:

- Fylla Bank St. 1.5, 2.5, 3.5

Additional stations inside Greenlandic fjords:

- Godthaabfjorden St. 1–10
- Amerdloq St. 2, 4
- Ikertoq St. 1, 4
- Kangerdlussuaq St. 1–3
- Itivdleq St. 1–4

A subset of the observations done will directly support ongoing projects within the Greenland Climate Research Centre (GCRC).

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 at the southern sections which did not have any influence on the ability to conduct the stations except for Cape Farewell st. 1., which was taken twice and the second time very close to the given coordinates.

During the period June 10 – July 01, 2012 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 19plus CTD. The instruments were lowered with a descent rate of approximately 45 m/min but slower in the upper ~100m. On the Paamiut cruise a Seabird SBE 25plus was used. All sensors were newly calibrated in 2012.

The CTD data were analysed using SBE Data Processing version 5.37d software provided by Seabird ([www.seabird.com](http://www.seabird.com)). For uploading SBE 19plus and 25plus data, the Seabird program Seasave Ver. 1.59 (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.

### 2.1. Calibration procedure

The SBE19plus was newly calibrated by Sea-Bird Electronics before the cruise and returned for post calibration after the cruise. Similar, the SBE25plus was also newly calibrated just prior to the cruise.

Until 2012 water samples were taken for the purpose of calibrating the salinity measurements obtained by the CTDs. This year water samples were taken as well, but they were not used this year, as they are also subject to uncertainties. A Niskin water sampler was mounted on the wire just above the CTD and it was closed close to the bottom using a drop messenger with an expected fall speed above 100 m/min. Due to the nature of the setup we do not know exactly at which time the drop messenger force the water sampler to close and additional the water sample is taken a few meters above the water intake of the CTD. However, the samples are taken in water masses which are to be expected to be very stable and weakly stratified with a CTD fluctuation of about  $\pm 0.002$ , which is similar to the precession of the conductivity sensor. Using water samples in this simple setup makes it possible to correct for an offset, but not for a slope with larger errors for larger conductivities, as the conductivity span is small.

In 2012 a calibration was performed using the pre- and post-calibration information performed at Sea-Bird Electronics. We follow the recommendation for calibration given by Sea-Bird Electronics. Usually the conductivity sensor has no offset at 0 S/m but a linear slope with larger error for larger conductivity. The temperature sensors usually drift by changing offset and only to a degree of changing slope. Sea-Bird Electronics recommend only correcting for an offset. For both sensors the error increases linear with time and usually in the same direction after a new calibration. For the oxygen sensor, any drift with time is primarily attributed to fouling of the membrane, either biological or waterborne contaminants (i.e., oil). The error is usually negligible for zero Oxygen concentration (instrument zero) and increases linear with Oxygen concentration. Thereby the sensor output can be calibrated by adjusting the slope dependence.

| SBE 19plus V2                 | 06 Apr-12 | 29 Jan-13  | islope / ioffset / iSoc |
|-------------------------------|-----------|------------|-------------------------|
| Conductivity slope correction | 0.9998605 | 1.0000000  | 1.0000318               |
| Temperature offset            | 3.2e-4 °C | -0.0e-4 °C | 0.73e-4 °C              |
| Oxygen slope correction (Soc) | 0.9862    | 1.0000     | 1.0032                  |

For conductivity we assume a linear drift in time and use the following formula to find the time interpolated slope, islope, as

$$islope = 1 + (b / n) [(1 / postslope) - 1]$$

where b is the number of days between pre-cruise calibration and the casts (63-73 days, 68 days used as a constant), n is the number of days between pre- and post-cruise calibrations (298 days), and postslope is the slope from calibration sheet as measured by Sea-Bird Electronics (0.9998605)

For temperature we assume a linear drift in time in offset and calculate the time interpolated offset, ioffset, as

$$islope = (b / n) postoffset$$

where postoffset is the offset temperature at 0°C from the calibration sheet as measured by Sea-Bird Electronics (3.2e-4 °C)

The Oxygen concentration [ml/l] is calculated using the formula given in Owens and Millard (1985). We make a similar slope correction for oxygen as for as for conductivity by correcting the Soc value as,

$$iSoc = 1 + (b / n) [(1 / postslope) - 1]$$

$$newSoc = iSoc * postSoc$$

where postSoc is the pre-cruise calibration Soc value.

In the configuration (.con or .xmlcon) file, we use the pre-cruise calibration coefficients and use the calculated islope (1.0000318) for the value of slope for conductivity and the calculated offset (7.3e-5 °C) for temperature. For Oxygen measurements we use the calculated slope factor iSoc (1.0032) to find the newSoc value (0.469725).

## 2.2. Data accuracy

For SBE 19plus, the nominal temperature sensor accuracy is +/- 0.005°C with an instrument resolution of about 0.0002°C. The real accuracy is likely better than the nominal temperature accuracy judging the weak drift of the sensor between calibrations. Nominal sensor (pressure) accuracy is 0.02% of full scale (3500 m) corresponding to about 0.7 meter for maximal depth with a similar annual drift. The accuracy is 0.0025% of full scale corresponding to less than 10 centimetres.

For SBE 25, the nominal temperature sensor accuracy is +/- 0.001°C with an instrument resolution of about 0.0003°C. Nominal sensor (pressure) accuracy is 0.1% of full scale (2000 m) corresponding to

about 20 meters on maximal depth. The accuracy is 0.015% of full scale corresponding to roughly 30 centimetres.

### 2.3. Data processing

The CTD data were analysed using SBE Data Processing version 7.22.4 software provided by Seabird ([www.seabird.com](http://www.seabird.com)). A chain of standard processing tools was used:

- *Data Conversion*: After calibration, raw data from the CTD (HEX format) are
- converted to engineering units including pressure, in situ temperature and salinity.
- *Filter*: Pressure readings are initially high pass filtered two ways in order to smooth high frequency data and to obtain a uniform descent history of the cast.

| Filter:<br>Instrument | Temperature<br>(seconds) | Conductivity/Salinity<br>(seconds) | Pressure<br>(seconds) |
|-----------------------|--------------------------|------------------------------------|-----------------------|
| SBE 19plus V2         | 0.5                      | 0.5                                | 1.0                   |
| SBE 25plus            |                          | 0.03                               | 0.5                   |

- *Align CTD*: Inherent misalignment time delay in sensor responses and transit time delay in the pumped plumbing line are corrected by advancing the measurements relative to pressure. By alignment, measurements refer to same parcel of water and the procedure eliminated artificial spikes in the calculated profiles especially in steep gradients.

| Align CTD:<br>Instrument | Temperature<br>relative to pressure<br>(seconds) | Conductivity/Salinity<br>relative to pressure<br>(seconds) | Oxygen<br>relative to pressure<br>(seconds) |
|--------------------------|--|--|---|
| SBE 19plus V2            | 0.5  |  | 7.0   |
| SBE 25plus               |  | 0.1  | 7.0   |

- *Cell thermal mass correction*: A correction of the conductivity measurements due to the effect of thermal variations on the conductivity cell. Most important in highly thermal stratified waters.

| Cell thermal mass:<br>Instrument | Thermal anomaly<br>amplitude (alpha) | Thermal anomaly time<br>constant (1/beta) |
|----------------------------------|--------------------------------------|---|
| SBE 19plus V2                    | 0.04                                 | 8.0                                       |
| SBE 25plus                       | 0.04                                 | 8.0                                       |

- *Loop Edit*: The tool removes scans with slow descent rate or reversals in pressure. Minimum descent rate is chosen between 0.1 and 0.2 m/s.
- *Derive and Bin Average*: A number of derived parameters is included (eg. potential temperature and density) and post processed data is averaged into 1 dbar bins

Finally each profile was visually inspected for obvious errors not cached by the above described SeaBird post-processing procedure.

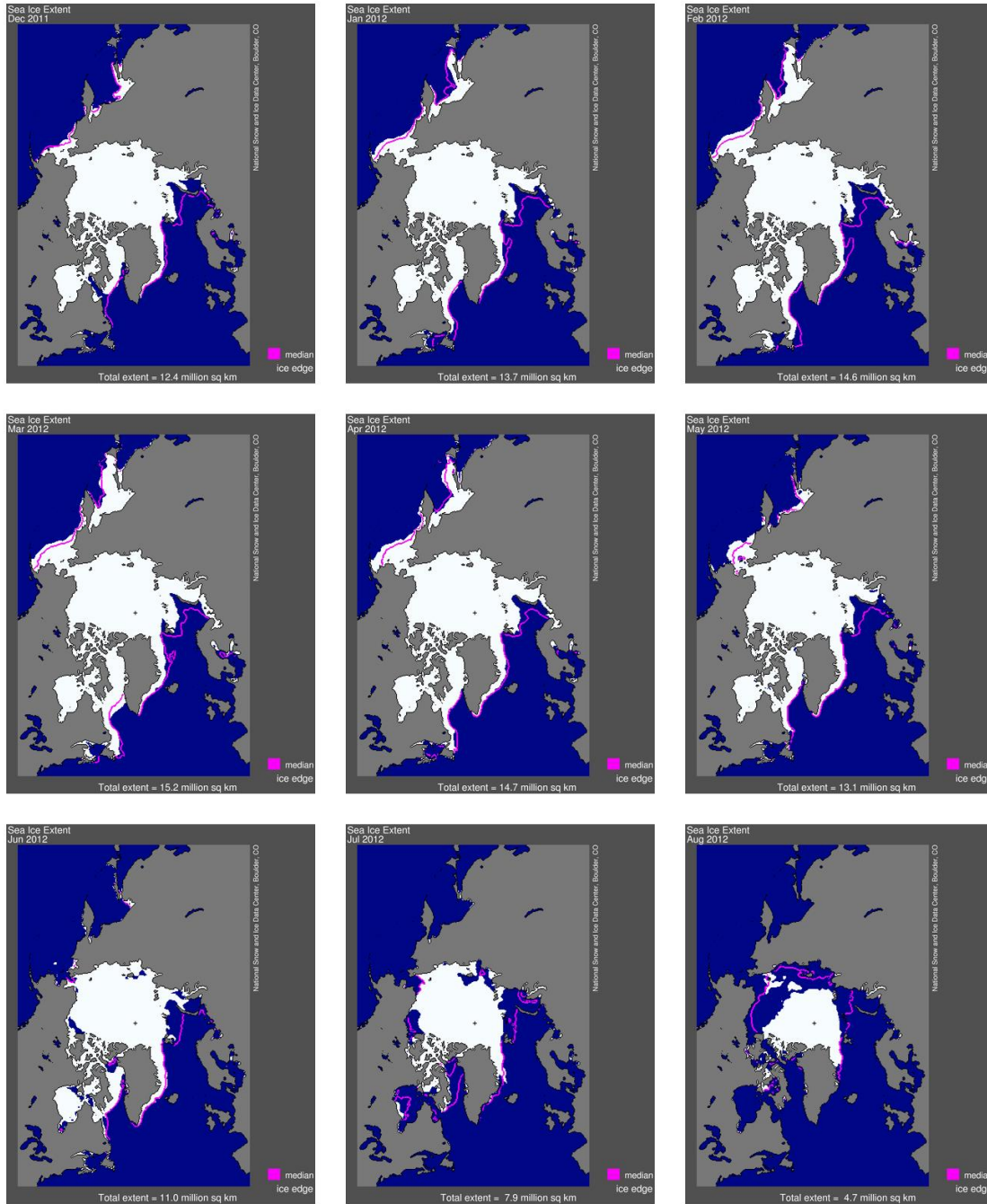


Figure 6. Sea ice extend (> 15%) for winter (DJF), spring (MAM), and summer (JJA) 2012. Pink line shows the median ice edge for 1979-2000. Figures from National Snow and Ice Center (<http://nsidc.org/>)

### 3. Atmospheric conditions in 2012

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 2011/12 was positive<sup>1</sup> (Figure 2).

The mean low pressure route during the winter months (December–March) was similar to normal from Labrador, across Iceland and further towards Northern Norway (Figure 8a). However, the Icelandic Low and Azores High was both strengthened (Figure 8b), resulting in stronger westerlies over the North Atlantic Ocean compared to normal conditions<sup>2</sup> (Figure 9).

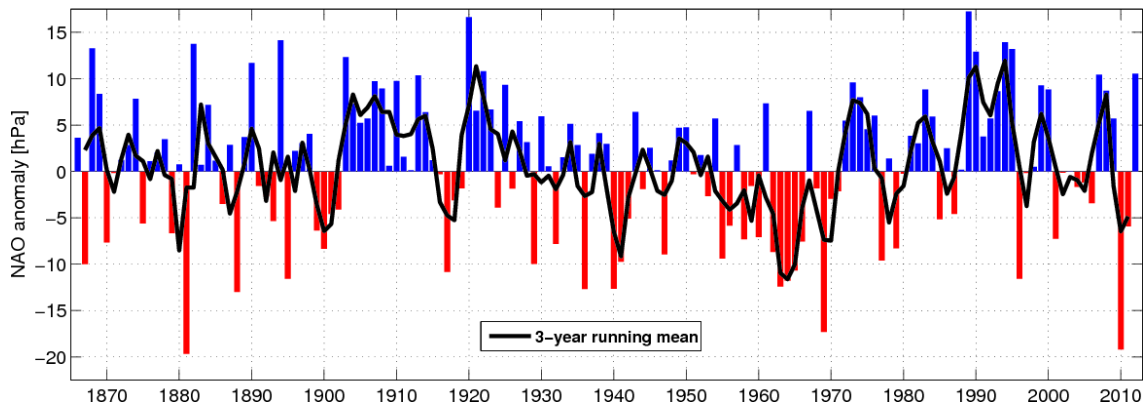


Figure 7. Time series of winter (December–March) index of the NAO from 1865/1866–2011/12. The heavy solid line represents the NAO index smoothed with a 3-year running mean filter to remove fluctuations with periods less than 3 years. In the figure the winter 1865/1866 is labelled 1866 etc.. The mean and standard deviation is  $0.78 \pm 7.5$  hPa. The 2011/12 value is 10.54 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 cold conditions when the NAO index is positive. During winter 2011/12, the mean temperature was slightly below normal over the West Greenland region and warmer than normal in northern Europe (Figure 11). In Nuuk the mean winter air temperature (DJFM) of  $-7.81$  °C was close to normal (Figure 12).

During summer West Greenland experienced an exceptional atmospheric heating (Hanna et al., 2013). As a result, the annual air temperature anomaly for 2012 was positive, especially over West Greenland waters (Figure 13). In Nuuk, the annual air temperature ( $0.01$  °C) was more than  $1\frac{1}{2}$  degrees above normal (Figure 14). The changes in atmospheric forcing can be seen in the sea-ice extent in Baffin Bay/Davis Strait (Figure 6). During wintertime the sea-ice extent was close to normal and even above for March. From June to July the sea-ice extent retreated rapidly at the same time as the exceptional air temperature rises.

<sup>1</sup> The NAO index using December – February was also positive.

<sup>2</sup> Normal conditions/anomaly defined as the difference from normal conditions relative to the period 1968–1996.

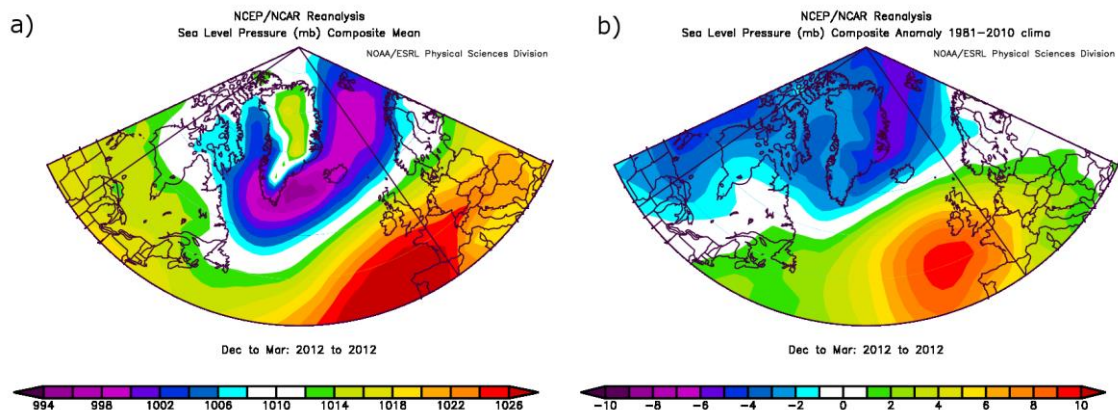


Figure 8. a) Winter (DJFM) sea level pressure for 2011/12 in the North Atlantic region. b) Sea level pressure anomaly. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>).

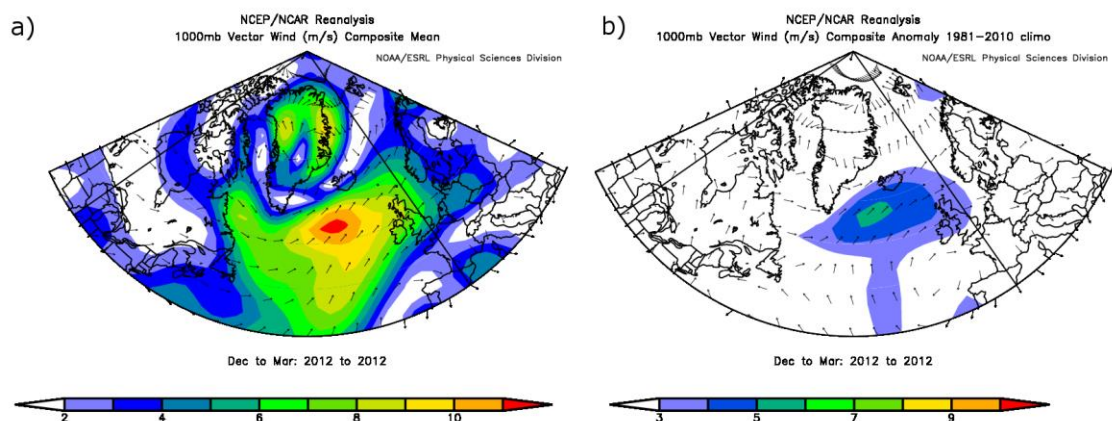


Figure 9. a) Winter (DJFM) wind (left) for 2011/12 in the North Atlantic region. b) Wind anomaly. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>).

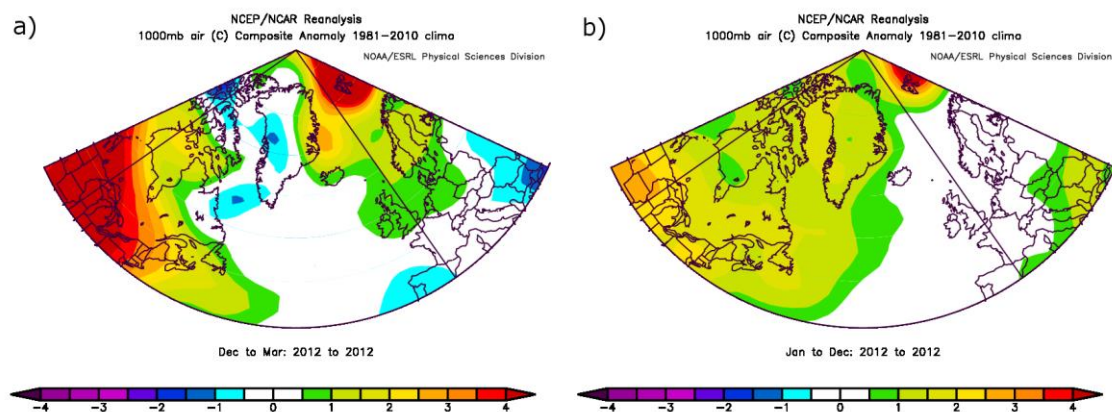


Figure 10. a) Winter (DJFM) mean air temperature anomaly for 2011/12 in the North Atlantic region. b) Annual mean air temperature anomaly for 2012. NCEP/NCAR re-analysis (from <http://www.esrl.noaa.gov/psd/>).

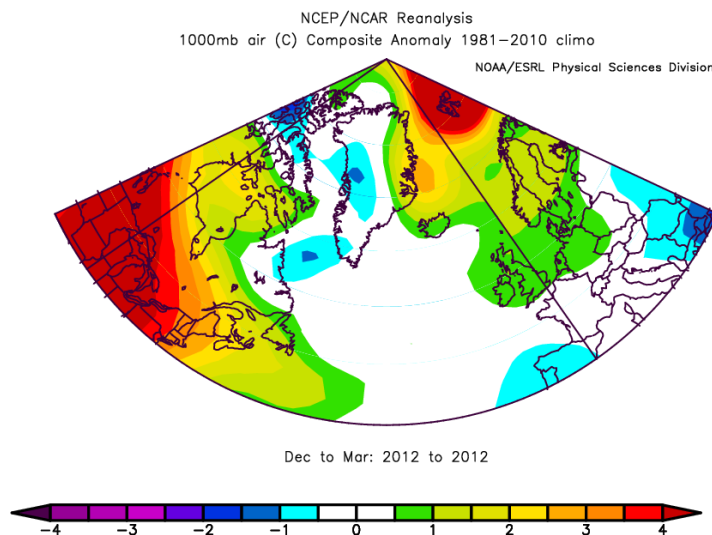


Figure 11. Winter (DJFM) mean air temperature anomaly for 2011/12 in the North Atlantic region. NCEP/NCAR reanalysis (from <http://www.esrl.noaa.gov/psd/>).

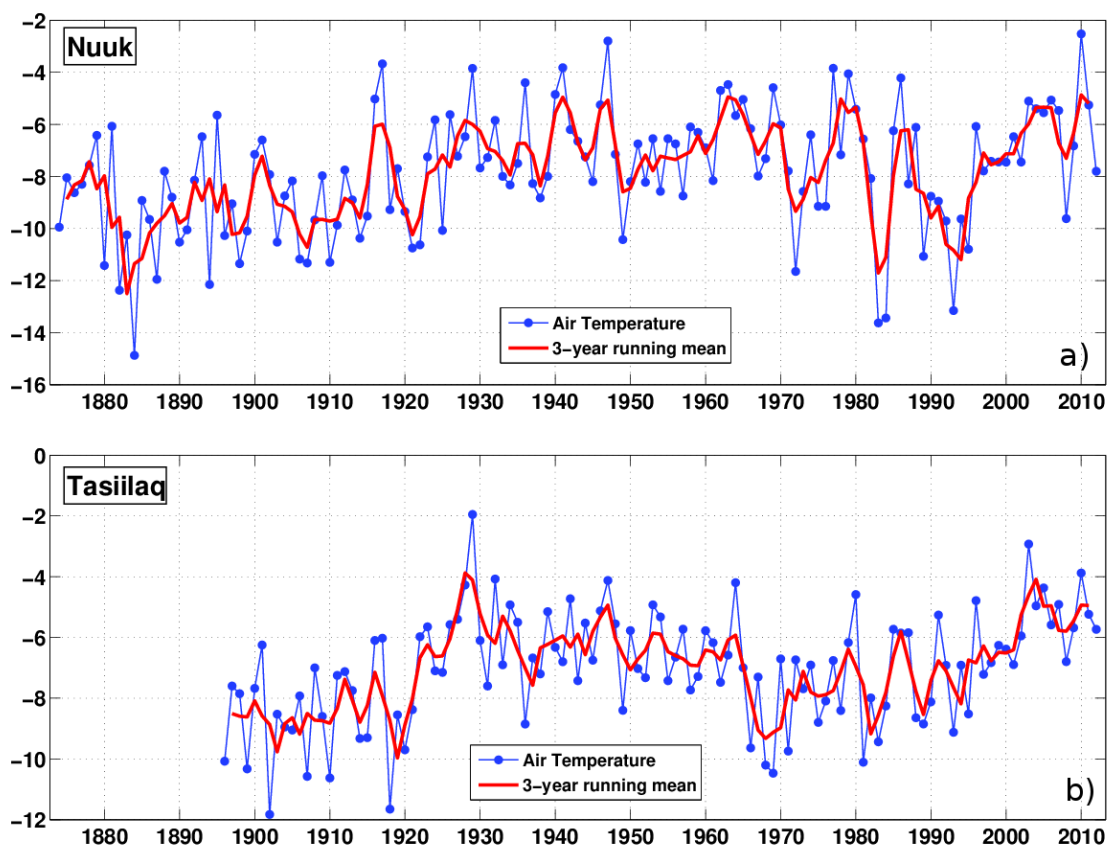


Figure 12. Winter (DJFM) mean air temperature observed at Nuuk and Tasiilaq for the period 1874–2012. The mean and standard deviation for the whole timeseries is  $-7.9 \pm 2.3$  °C for Nuuk and  $-7.0 \pm 1.8$  °C for Tasiilaq. Values for 2012 are respectively  $-7.81$  °C and  $-5.73$  °C. Nuuk temperature was taken from the Nuuk airport synop station 04254 due to a failure on the instrument (Nuuk synop 04250) for more than 65% of the following months (yyyymm): 200505, 200710, 200712, 200811, 201101, 201207.

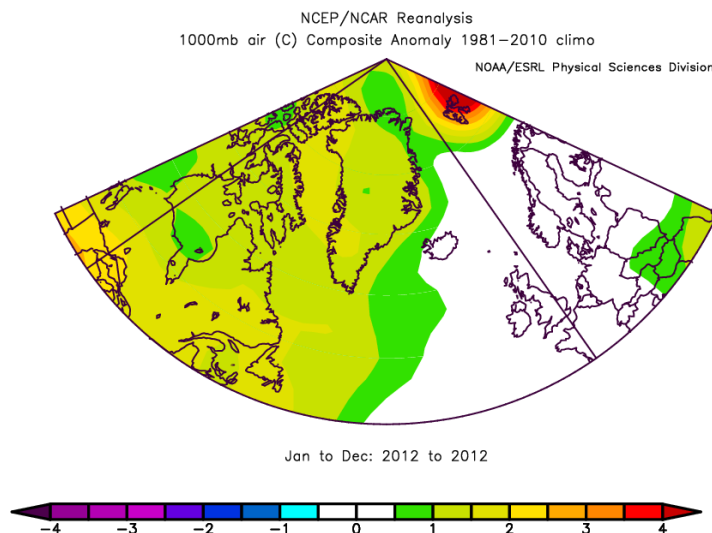


Figure 13. Anomalies of the annual mean air temperature for 2012 in the North Atlantic region. NCEP/NCAR reanalysis (from <http://www.esrl.noaa.gov/psd/>).

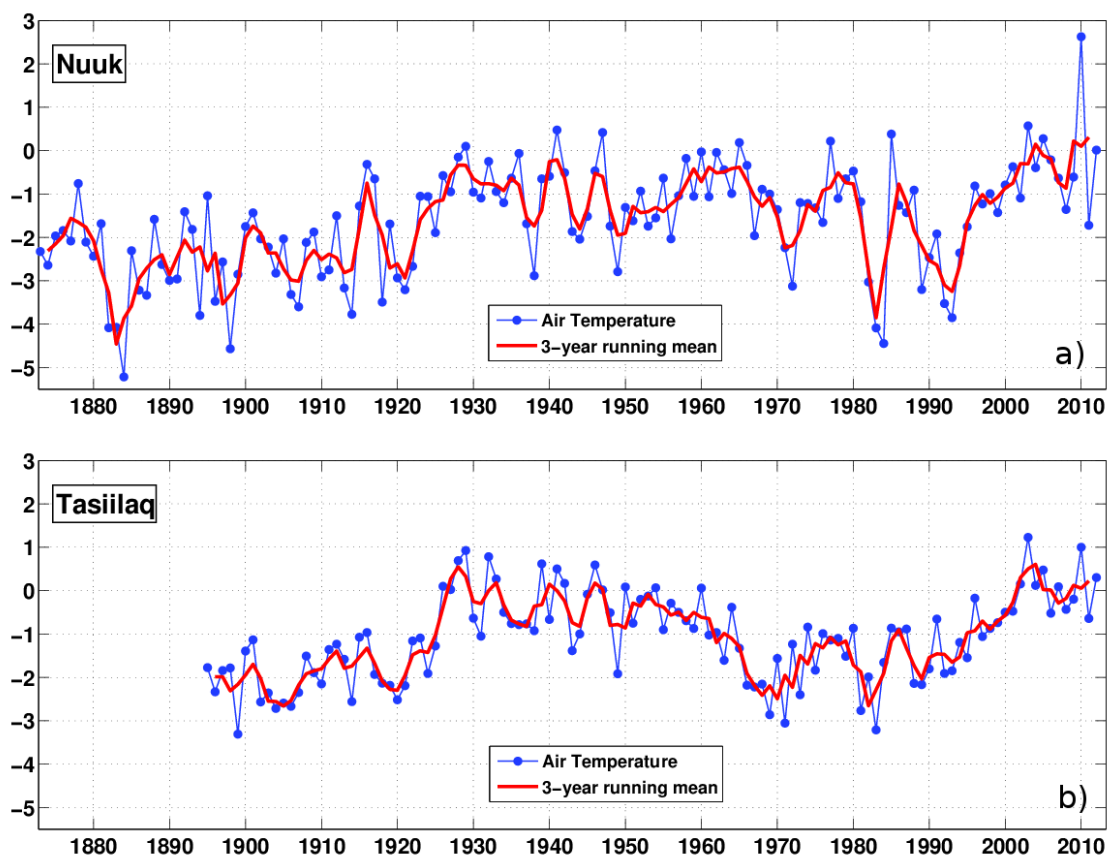


Figure 14. Annual mean air temperature observed at Nuuk and Tasiilaq for the period 1873–2012. The mean and standard deviation is  $-1.63 \pm 1.25$  °C for Nuuk and  $-1.09 \pm 1.00$  °C for Tasiilaq. Values for 2012 are respectively 0.01 °C and 0.30 °C. Nuuk temperature was taken from the Nuuk airport synop station 04254 due to a failure on the instrument (Nuuk synop 04250) for more than 65% of the following months (yyyymm): 200505, 200710, 200712, 200811, 201101, 201207.

#### 4. Oceanographic conditions off West Greenland in 2012

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 2012 the mean temperature ( $2.03^{\circ}\text{C}$ ) was slightly above average while the salinity (33.19) was low on top of Fylla Bank in the middle of June (Figure 15, Table 1). The positive temperature anomaly, despite of a negative salinity anomaly, is likely a result of the exceptional atmospheric heating during summer (Hanna et al., 2013), which resulted in exceptional heating of the surface waters.

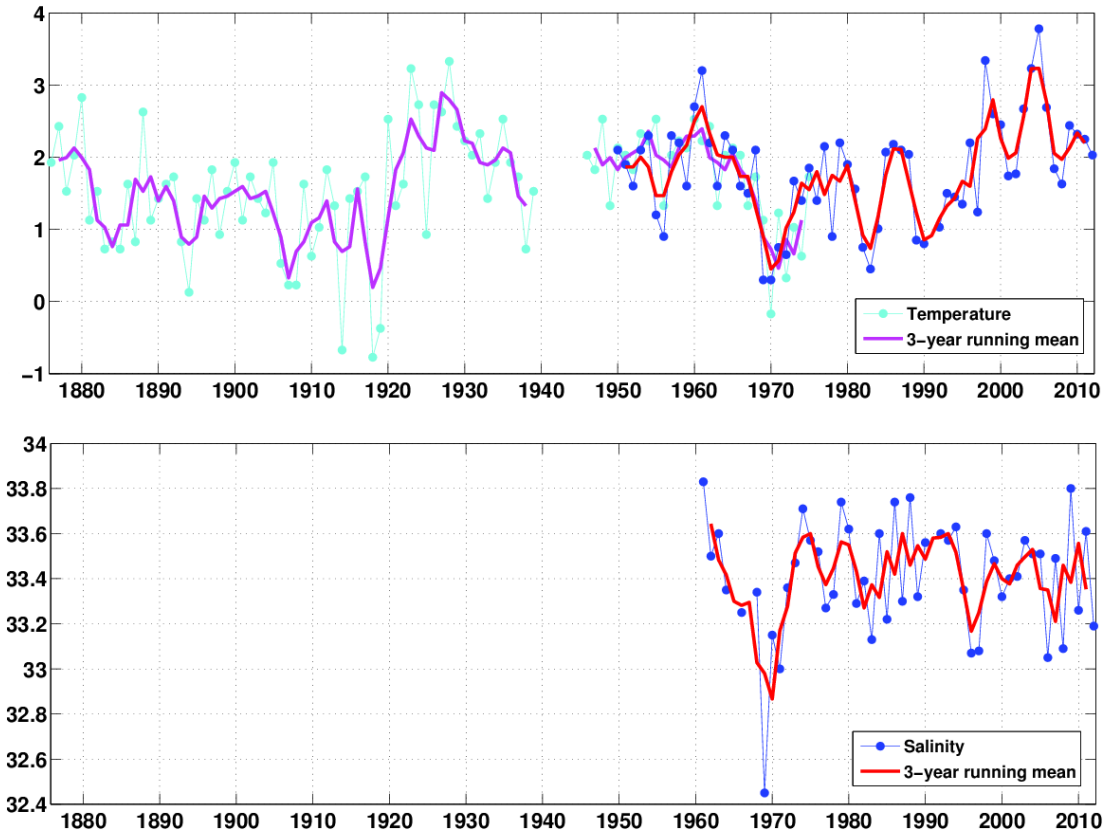


Figure 15. Timeseries of mean temperature (top) and salinity (bottom) on top of Fylla Bank (Station 2, 0–40 m) in the middle of June for the period 1950–2012. The red curve is the 3 year running mean value. Statistics is shown in Table 1. The timeseries for temperature (top, magenta/purple) is extended 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 calculated on the full timeseries using all years with measurements. Smed data are not included for the statistics.

| Fylla Bank<br>St. 2 | Temperature [ $^{\circ}\text{C}$ ] | Salinity         | 2012                   |       |
|---------------------|------------------------------------|------------------|------------------------|-------|
|                     | Mean $\pm$ std                     | Mean $\pm$ std   | Tpot                   | S     |
| 0–40 m              | $1.81 \pm 0.74^{\circ}\text{C}$    | $33.41 \pm 0.25$ | $2.03^{\circ}\text{C}$ | 33.19 |

The surface temperatures and salinities observed during the 2012 surveys are shown in Figure 21. The low salinity conditions observed close to the coast off Southwest Greenland reflect the Polar Water carried to the area by the East Greenland Current. It is less obvious seems from the temperature measurements likely due to surface heating from the atmosphere. During the present surveys it can be traced north to Sisimiut revealed by its low salinity.

Within the Disko Bay the lowest surface salinities is due to the runoff from the large outlet glaciers and partly 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 22). The coldest waters  $<-1^{\circ}\text{C}$  observed in the subsurface of the Baffin Bay are 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 22 and in its core in Figure 23.

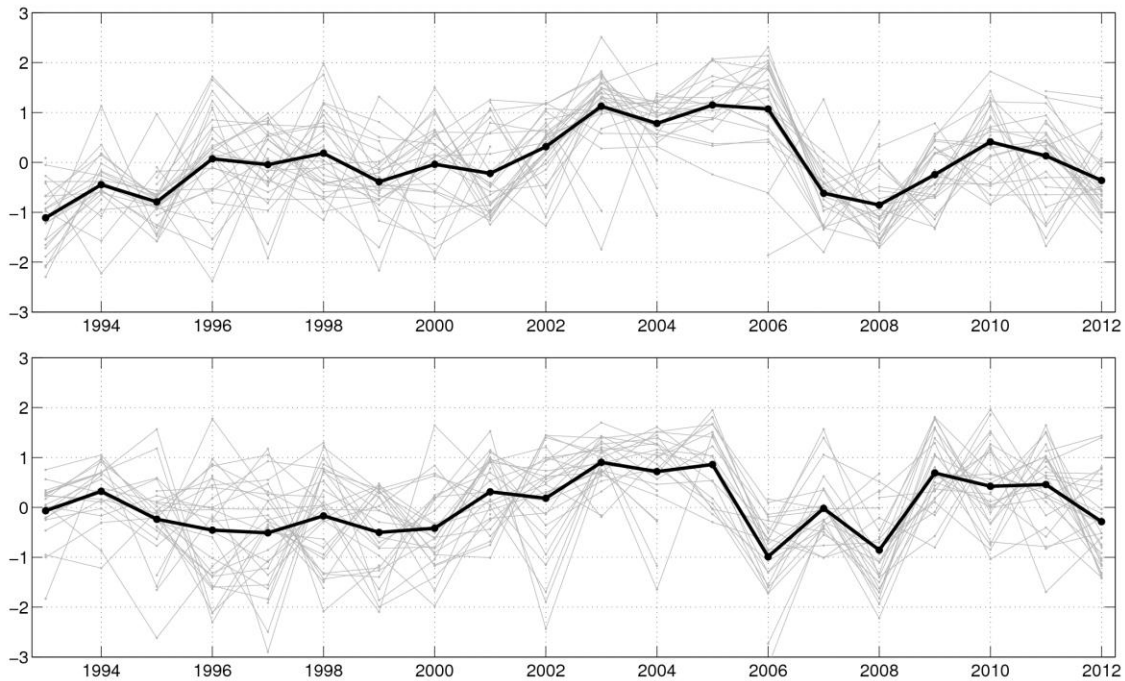


Figure 16. Near-surface (20–40m) temperature (upper) and salinity (lower) index for the West Greenland waters derived from CTD measurements from Cape Farewell to Sisimiut taken during the time period 1993–2012. Black thick line is the average of all the 5 individual stations on each of the 6 sections, and the thin grey lines are the 30 individual stations.

The normalized near-surface (20–40 m) temperature and salinity indices<sup>3</sup> for the Southwest Greenland Waters are shown in Figure 16. The near-surface temperature and salinity indices for 2012 were both slightly negative indicating slightly lower salinity and temperature conditions compared to the recent time period 1993–2012 (mainly a warm period). While the near-surface temperature index was slightly negative,

<sup>3</sup> These indices are formed by subtracting the long term mean and divide by the standard deviation for each of the 30 stations from the Cape Farewell to Sisimiut sections. Thereby we are able to combine all the stations in one single index for salinity and temperature. By using all the stations we reduce the influence of individual eddies and frontal movement over the continental shelf, which can alter the water property quite significant for individual stations. The upper 20 m are excluded to reduce the direct influence from atmospheric heating.

the temperature on top (0–40 m) of Fylla Bank in the middle of June was above average (Figure 15, Table 1). This is likely a result of the exceptional atmospheric heating during summer (Hanna et al., 2013), which resulted in exceptional heating of the surface waters.

A vertical section of salinity, temperature and density over the shelf from Cape Farewell to Upernavik is shown in Figure 27. Polar Water is found in the upper ~100 m up to Sisimiut with salinities mainly below 33.4 and cold ( $<1^{\circ}\text{C}$ ) sub-surface temperatures. At Fylla Bank the salinities has increased due to mixing but the salinity remains quite low below ~33.7. From Aasiaat section and further north to the Upernavik section a colder layer was found with temperatures below  $-1^{\circ}\text{C}$  in its core centred at about 75 m depth. This is likely Polar Water from the Baffin Current as described above.

West of Fylla Bank in the depth interval 50–150 m, where the core of Polar Water is found, the salinity and temperature was above average conditions (Figure 17 and Table 2). Contrary further north at Maniitsoq st.5 (Figure 18, Table 3) and Sisimiut st.5 (Figure 19, Table 4), the salinities and temperatures was below normal in the same depth interval.

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 are shown in Figure 24 and Figure 25. A vertical section of salinity, temperature and density over the shelf break from Cape Farewell to Upernavik is shown in Figure 26. The vertical distribution of temperature, salinity and density at sections along the West Greenland coastline is shown in Figure 28 – Figure 38 and within the Disko Bay in Figure 39 – Figure 42.

Pure Irminger Water ( $T \geq 4.5^{\circ}\text{C}$ ;  $S \geq 34.95$ ) was traced north to the Paamiut section and modified Irminger Water ( $T \geq 3.5^{\circ}\text{C}$ ;  $34.88 \leq S < 34.95$ ) was observed further north to Sisimiut section. The northward extension of Irminger Water may indicate intensified inflow of water of Atlantic origin to the West Greenland area. North of Sisimiut, a relative warm ( $> 3^{\circ}\text{C}$ ) water mass was found below 150–200 m. This water is the extension of the Irminger Water component of the West Greenland Current.

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 17 (red curves). The average salinity (34.91) and temperature ( $4.50^{\circ}\text{C}$ ) of this layer was above average (Table 2). This indicates, that the presence of Irminger Water in 2012 was still high compared to normal. Similar timeseries west of the banks further north at Maniitsoq st.5 (Figure 18, Table 3) and Sisimiut st.5 (Figure 19, 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 2012. Similar, the bottom temperature and salinity was well above average within the Disko Bay at Ilulissat st.3

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 2012 were characterised by:

- Positive NAO index resulting in strengthen westerlies over the North Atlantic during winter 2011/12.
- Winter air temperature over West Greenland waters was slightly below normal and warmer over the northern Europe consistent with positive NAO index.
- However the annual air temperature over West Greenland waters was higher than normal in 2012, due to an unusual warming summer.
- The air conditions is reflected in the sea-ice extend in Baffin Bay. In March the sea-ice extent was even higher (further south) than normal, but between June and July the sea-ice retreated rapidly.
- High presence of Irminger Water and slightly above normal presence of Polar Water indicated by:
  - Pure Irminger Water was observed on all section from Cape Farewell to Paamiut and modified Irminger Water at the Sisimiut section.
  - West of Fylla Bank, Maniitsoq and Sisimiut, the mean temperature and salinity in 400–600 m depth was high. Similar high values were found off Ilulissat at 300 m depth.
  - Water temperature on top of Fylla Bank was above average but salinity below average. The high temperature is likely due to an exceptional warming event during summer.
  - Low saline water on top of the shelf from Cape Farewell to Sisimiut was observed in the upper ~50–100 m.
  - Slightly negative near-surface (20–40 m) temperature and salinity indices for Southwest Greenland Waters.
  - Below normal temperatures and salinities observed at Maniitsoq st.5 and Sisimiut st.5 in the depth interval 50–150 m. Contrary, west of Fylla Bank (st.4) the temperature and salinity was above normal for the same depth interval.

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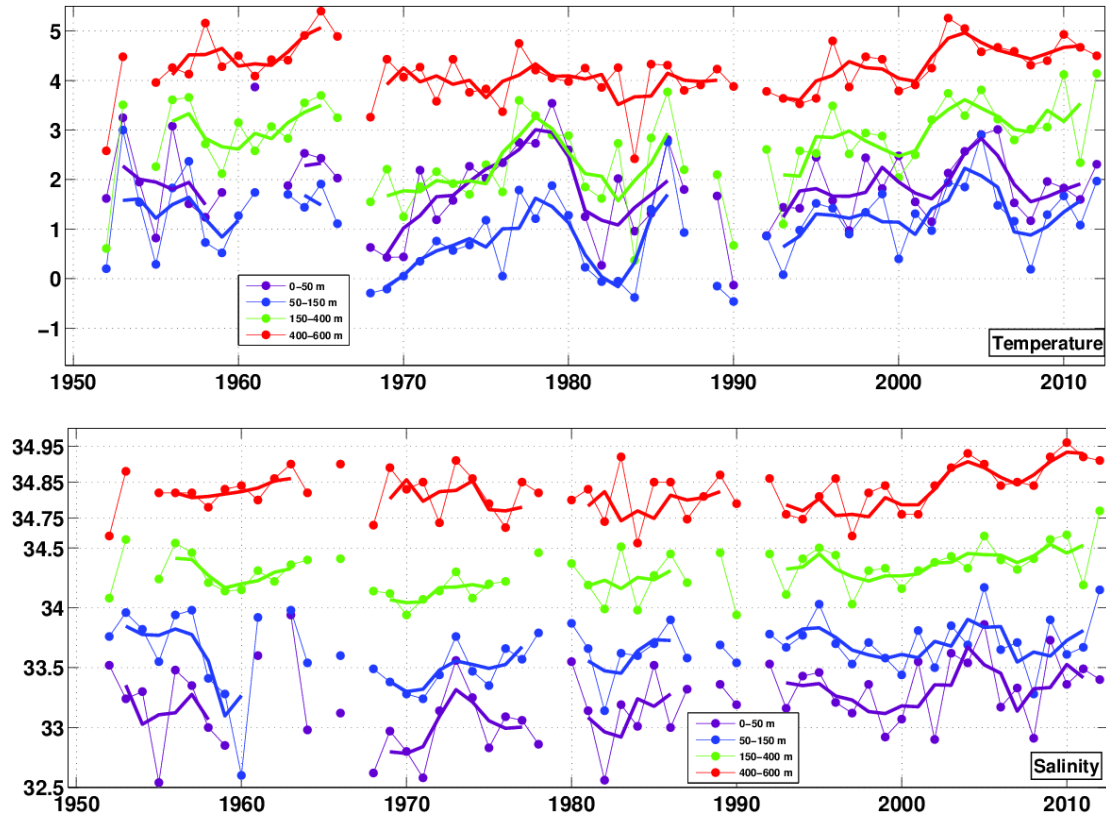


Figure 17. Timeseries of mean June-July temperature (top) and salinity (bottom) for the period 1950–2012 averaged in four different depth intervals west of Fylla Bank (st.4) over the continental slope. Thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics are shown in Table 2.

Table 2. Statistics for potential temperature and salinity at Fylla Bank st. 4. and values for 2012.

| Fylla Bank<br>St.4 | Temperature [°C]                | Salinity         | 2012                   |       |
|--------------------|---------------------------------|------------------|------------------------|-------|
|                    | Mean $\pm$ std                  | Mean $\pm$ std   | Tpot                   | S     |
| 0–50 m             | $1.85 \pm 0.83^{\circ}\text{C}$ | $33.22 \pm 0.32$ | $2.31^{\circ}\text{C}$ | 33.40 |
| 50–150 m           | $1.06 \pm 0.83^{\circ}\text{C}$ | $33.64 \pm 0.27$ | $1.97^{\circ}\text{C}$ | 34.15 |
| 150–400 m          | $2.63 \pm 0.87^{\circ}\text{C}$ | $34.30 \pm 0.19$ | $4.14^{\circ}\text{C}$ | 34.77 |
| 400–600 m          | $4.20 \pm 0.56^{\circ}\text{C}$ | $34.82 \pm 0.08$ | $4.50^{\circ}\text{C}$ | 34.91 |

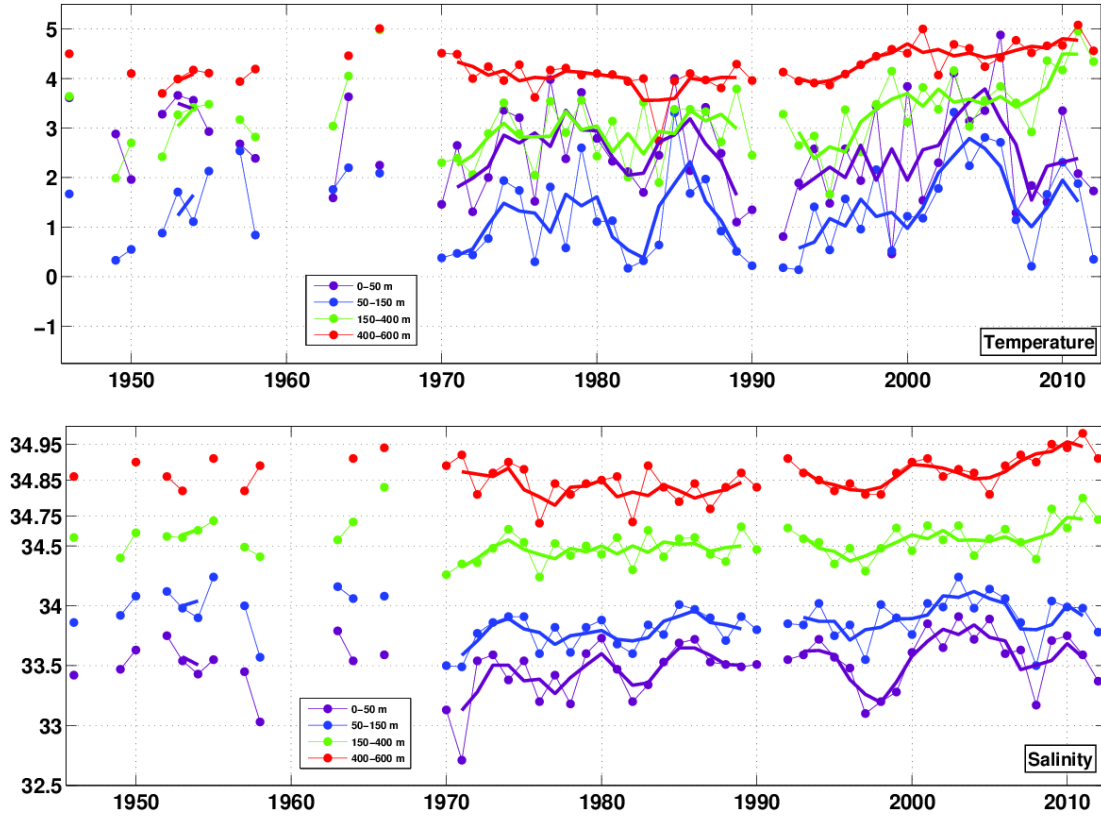


Figure 18. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1946–2012 in four different depth intervals west on Maniitsoq st.5 over the continental slope. The thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics is shown in Table 3.

Table 3. Statistics for potential temperature and salinity at Maniitsoq (Sukkertoppen) st. 5. and values for 2012.

| Maniitsoq<br>St.5 | Temperature [°C]                | Salinity         | 2012                   |       |
|-------------------|---------------------------------|------------------|------------------------|-------|
|                   | Mean $\pm$ std                  | Mean $\pm$ std   | Tpot                   | S     |
| 0–50 m            | $2.52 \pm 0.97^{\circ}\text{C}$ | $33.50 \pm 0.23$ | $1.69^{\circ}\text{C}$ | 33.38 |
| 50–150 m          | $1.32 \pm 0.87^{\circ}\text{C}$ | $33.88 \pm 0.19$ | $0.35^{\circ}\text{C}$ | 33.78 |
| 150–400 m         | $3.19 \pm 0.75^{\circ}\text{C}$ | $34.53 \pm 0.14$ | $4.34^{\circ}\text{C}$ | 34.72 |
| 400–600 m         | $4.23 \pm 0.39^{\circ}\text{C}$ | $34.86 \pm 0.06$ | $4.56^{\circ}\text{C}$ | 34.91 |

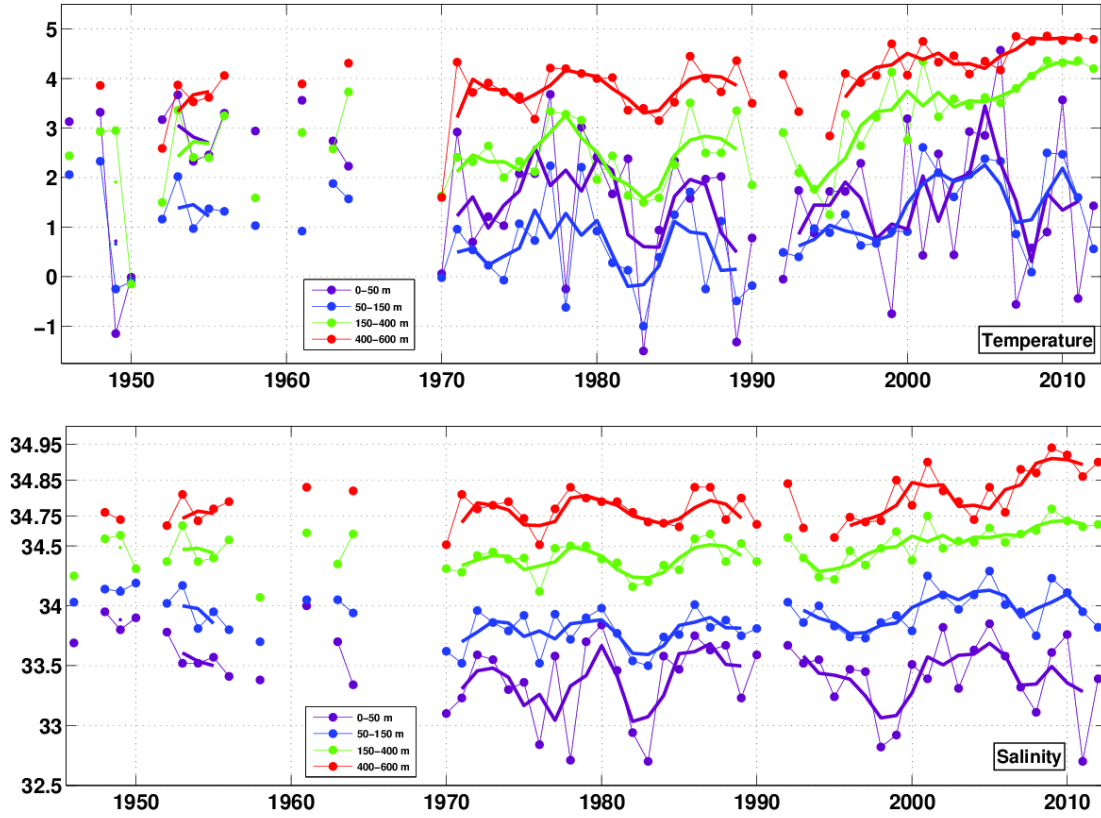


Figure 19. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1946–2012 in four different depth intervals at Sisimiut, st.5 over the continental slope. The thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics is shown in Table 4.

Table 4. Statistics for potential temperature and salinity at Sisimiut (Holsteinsborg) st. 5. and values for 2012.

| Sisimiut<br>St.5 | Temperature [°C]                | Salinity         | 2012                   |       |
|------------------|---------------------------------|------------------|------------------------|-------|
|                  | Mean $\pm$ std                  | Mean $\pm$ std   | Tpot                   | S     |
| 0–50 m           | $1.68 \pm 1.45^{\circ}\text{C}$ | $33.45 \pm 0.32$ | $1.43^{\circ}\text{C}$ | 32.39 |
| 50–150 m         | $1.01 \pm 0.90^{\circ}\text{C}$ | $33.90 \pm 0.19$ | $0.56^{\circ}\text{C}$ | 33.82 |
| 150–400 m        | $2.78 \pm 0.94^{\circ}\text{C}$ | $34.45 \pm 0.16$ | $4.20^{\circ}\text{C}$ | 34.68 |
| 400–600 m        | $3.96 \pm 0.63^{\circ}\text{C}$ | $34.77 \pm 0.09$ | $4.79^{\circ}\text{C}$ | 34.90 |

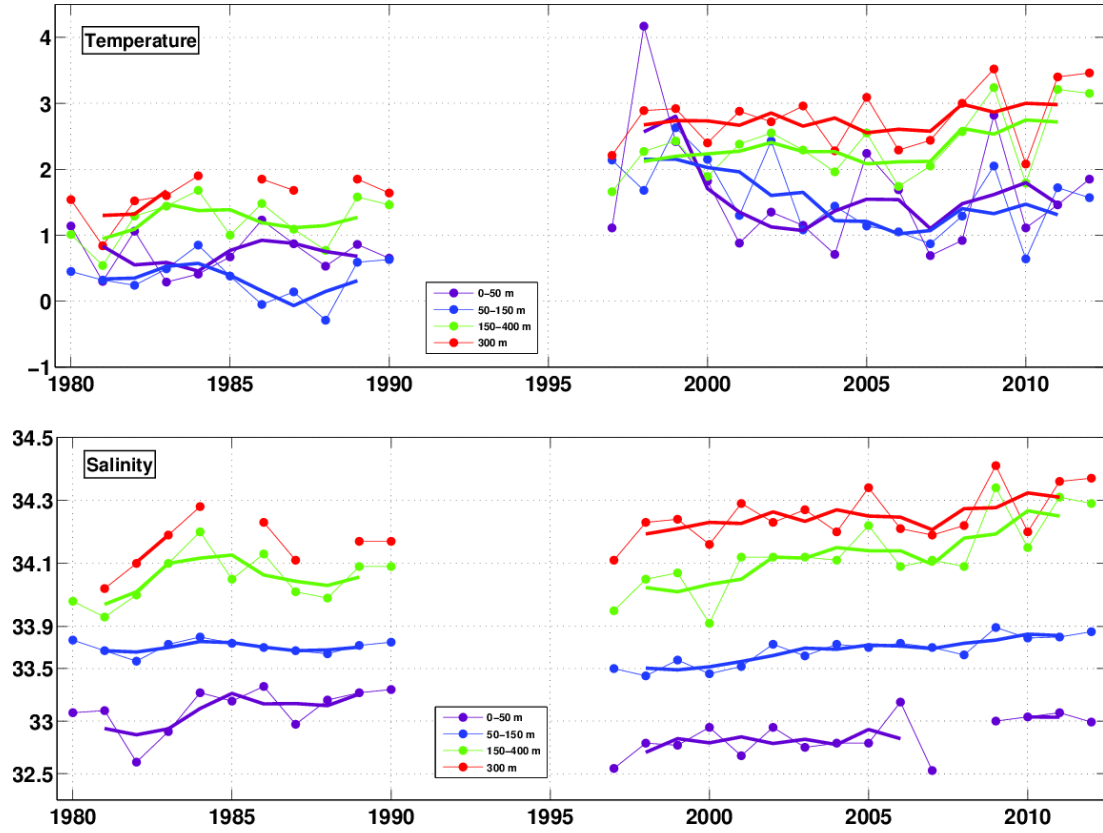


Figure 20. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1980–2012 in four different depth intervals on Ilulissat st.3 in the Disko Bay close to Jakobshavn Isbrae. The thick curves are the 3 year running mean values. Note the change in scales at 33.9 for salinity. Statistics is shown in Table 4.

Table 5. Statistics for potential temperature and salinity at Ilulissat-Skansen (Jakobshavn-Skansen) st. 3. and values for 2012.

| Ilulissat<br>St.3 | Temperature [°C]                | Salinity         | 2012                   |       |
|-------------------|---------------------------------|------------------|------------------------|-------|
|                   | Mean $\pm$ std                  | Mean $\pm$ std   | Tpot                   | S     |
| 0–50 m            | $1.33 \pm 0.90^{\circ}\text{C}$ | $32.98 \pm 0.26$ | $1.85^{\circ}\text{C}$ | 32.99 |
| 50–150 m          | $1.07 \pm 0.77^{\circ}\text{C}$ | $33.69 \pm 0.12$ | $1.57^{\circ}\text{C}$ | 33.85 |
| 150–400 m         | $1.87 \pm 0.72^{\circ}\text{C}$ | $34.10 \pm 0.11$ | $3.15^{\circ}\text{C}$ | 34.29 |
| 300 m             | $2.34 \pm 0.70^{\circ}\text{C}$ | $34.22 \pm 0.09$ | $3.46^{\circ}\text{C}$ | 34.37 |

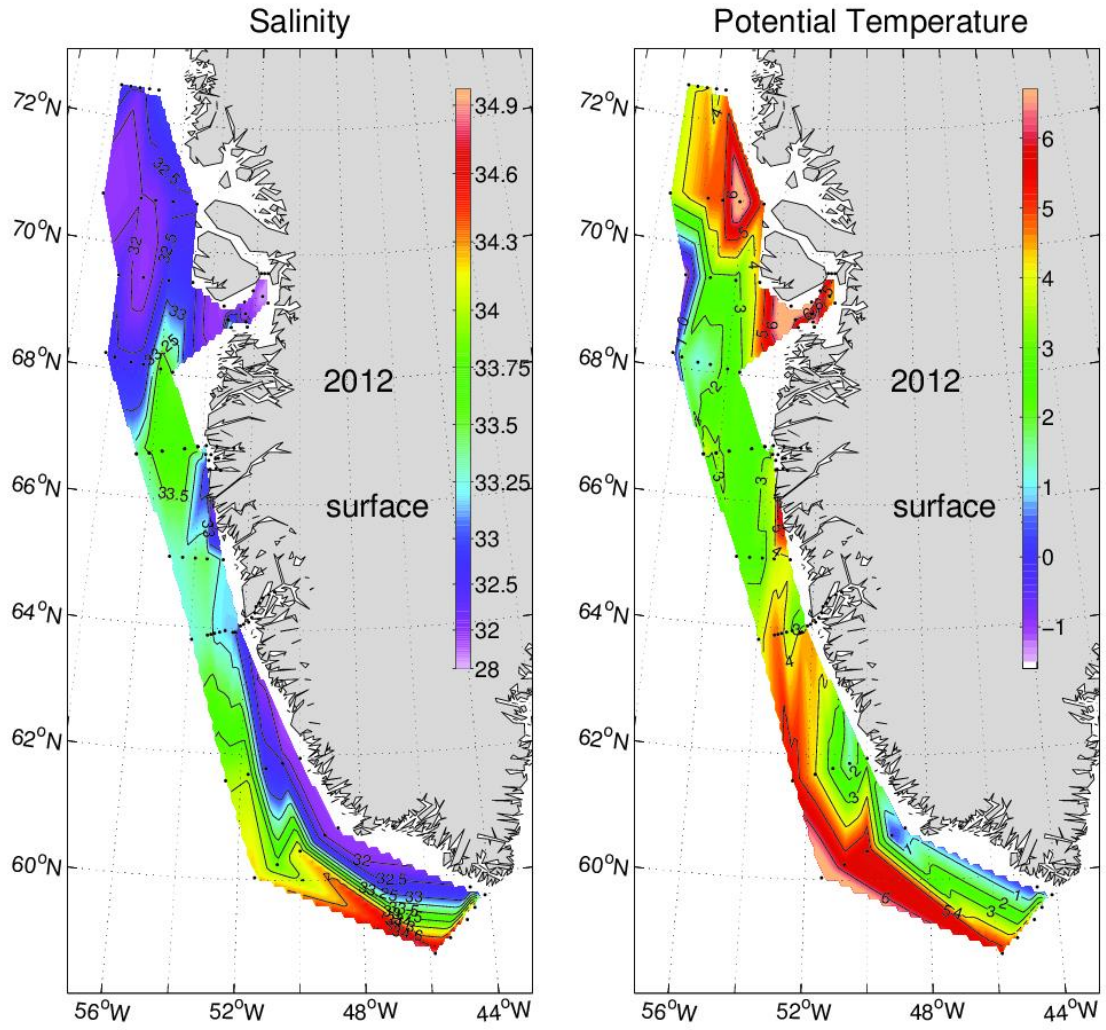


Figure 21. Surface salinity (left) and temperature (right) observed in 2012 taken June 08 – July 01.

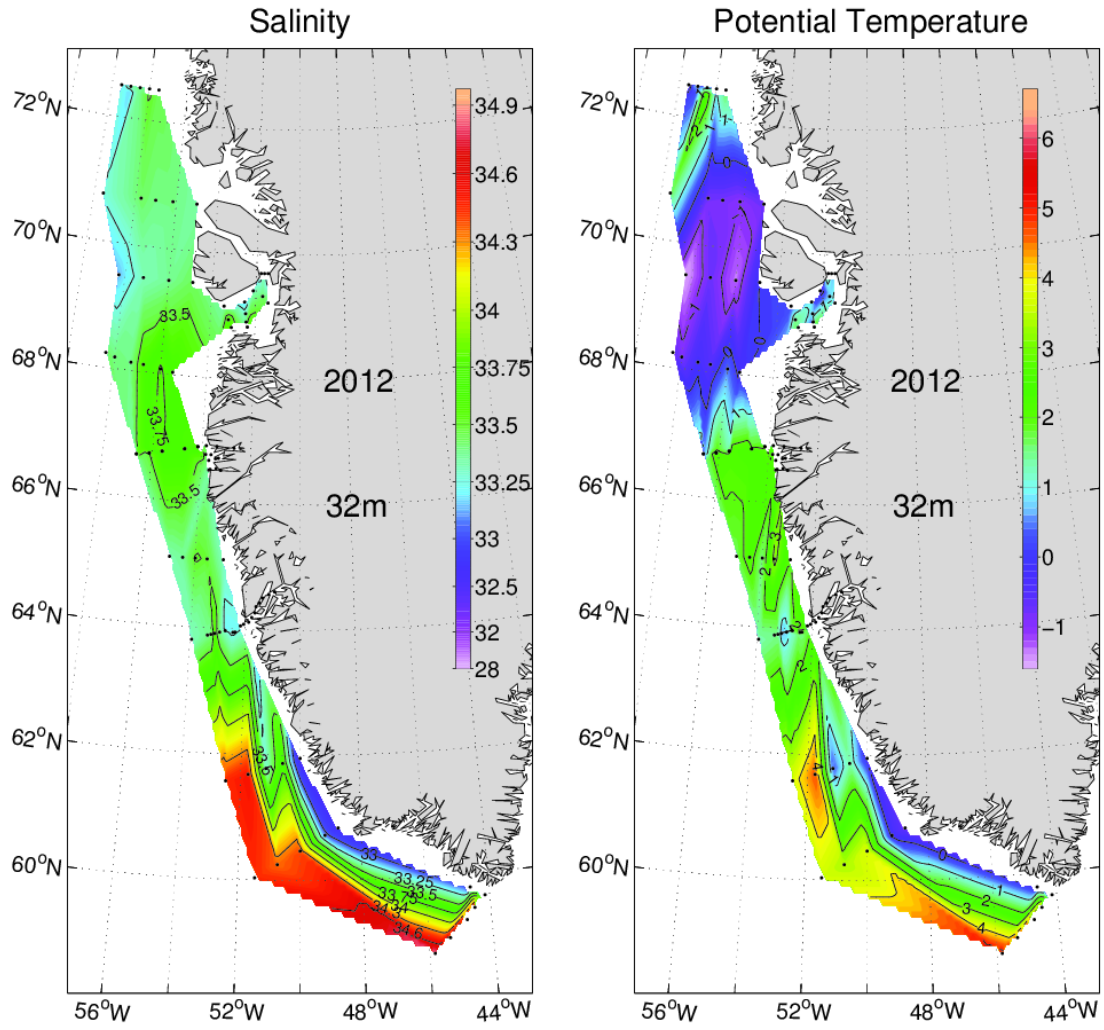


Figure 22. As Figure 21, but for 32 m depth.

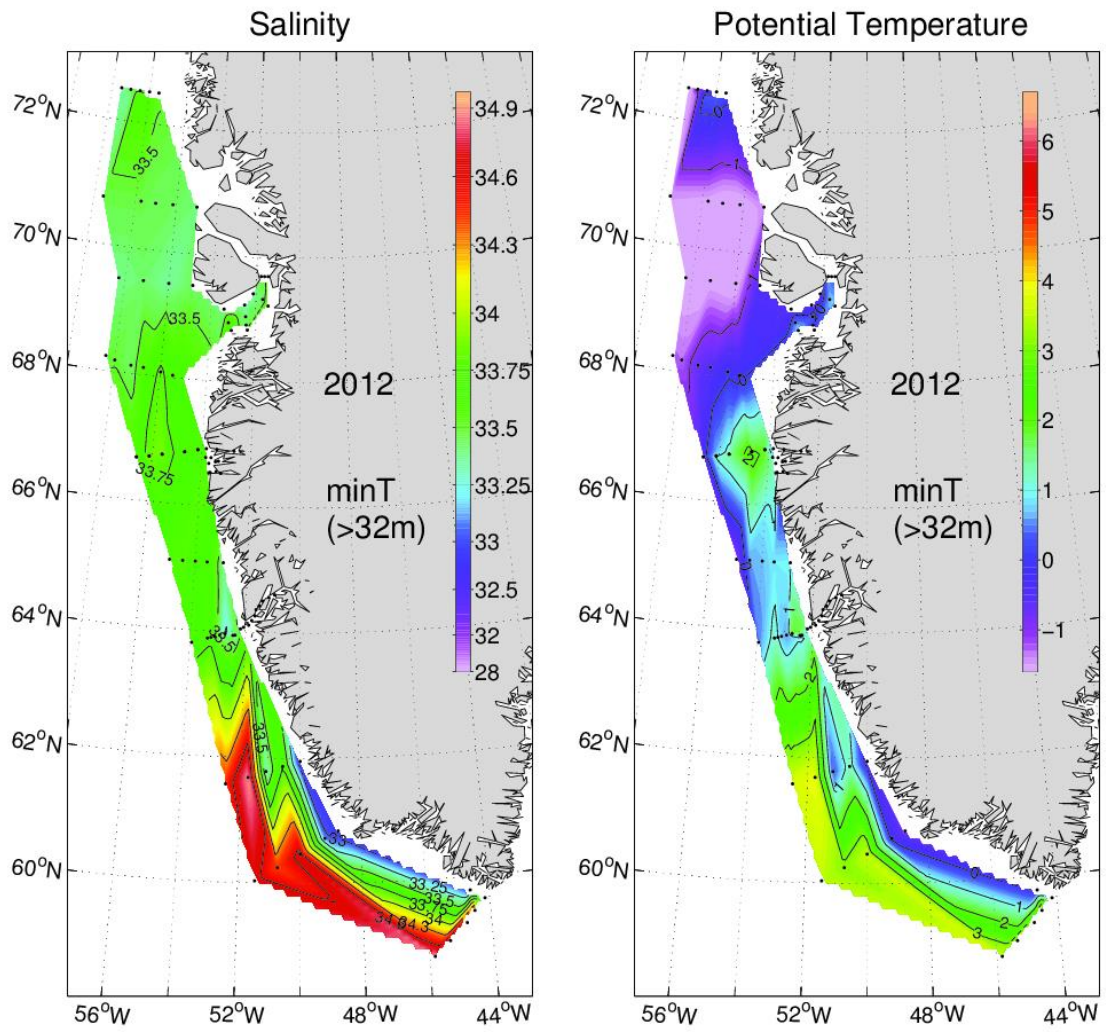


Figure 23. Salinity (left) and temperature (right) observed in 2012 (June 08 – July 01) at the depth of minimum temperature disregarding the upper 32 meters.

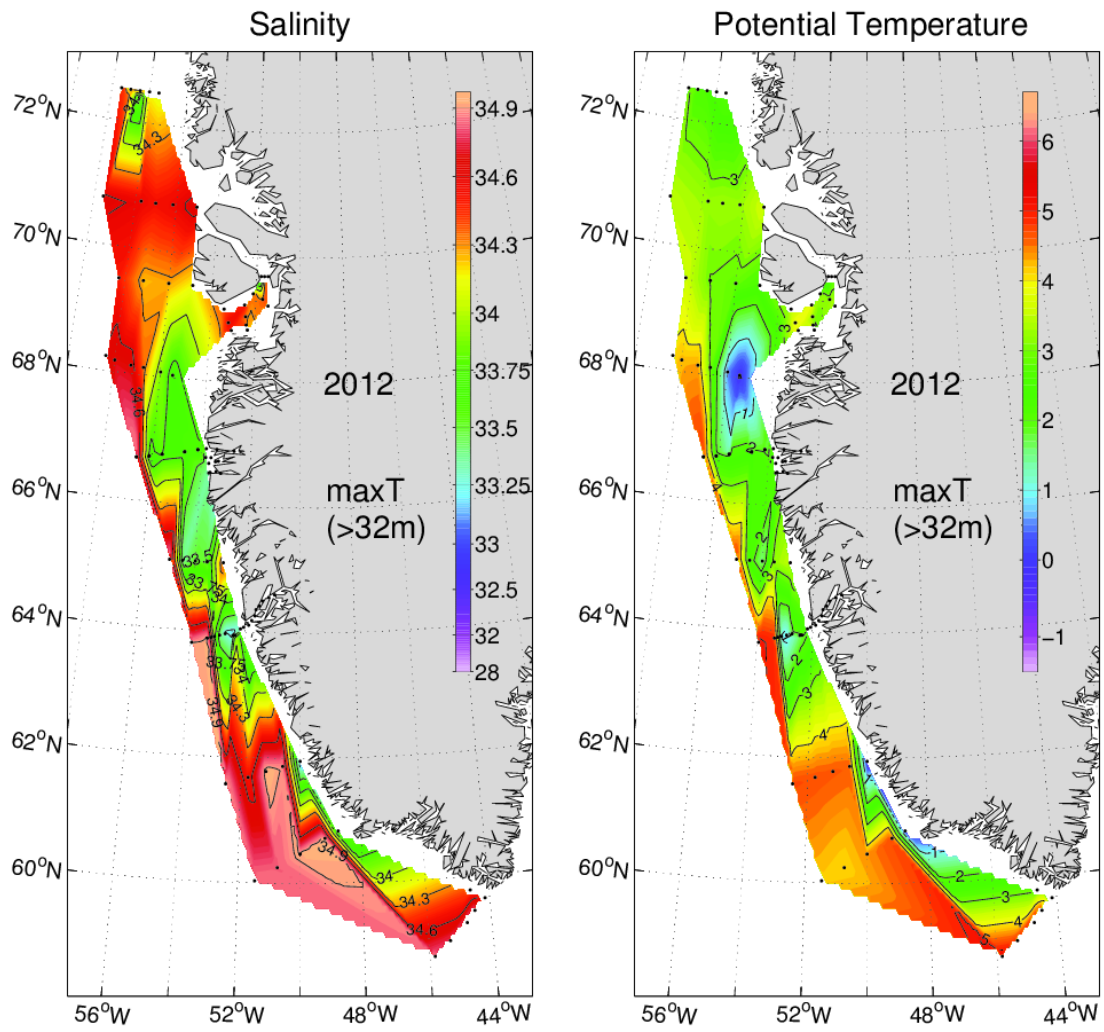


Figure 24. Salinity (left) and temperature (right) observed in 2012 (June 08 – July 01) at the depth of maximum temperature disregarding the upper 32 meters.

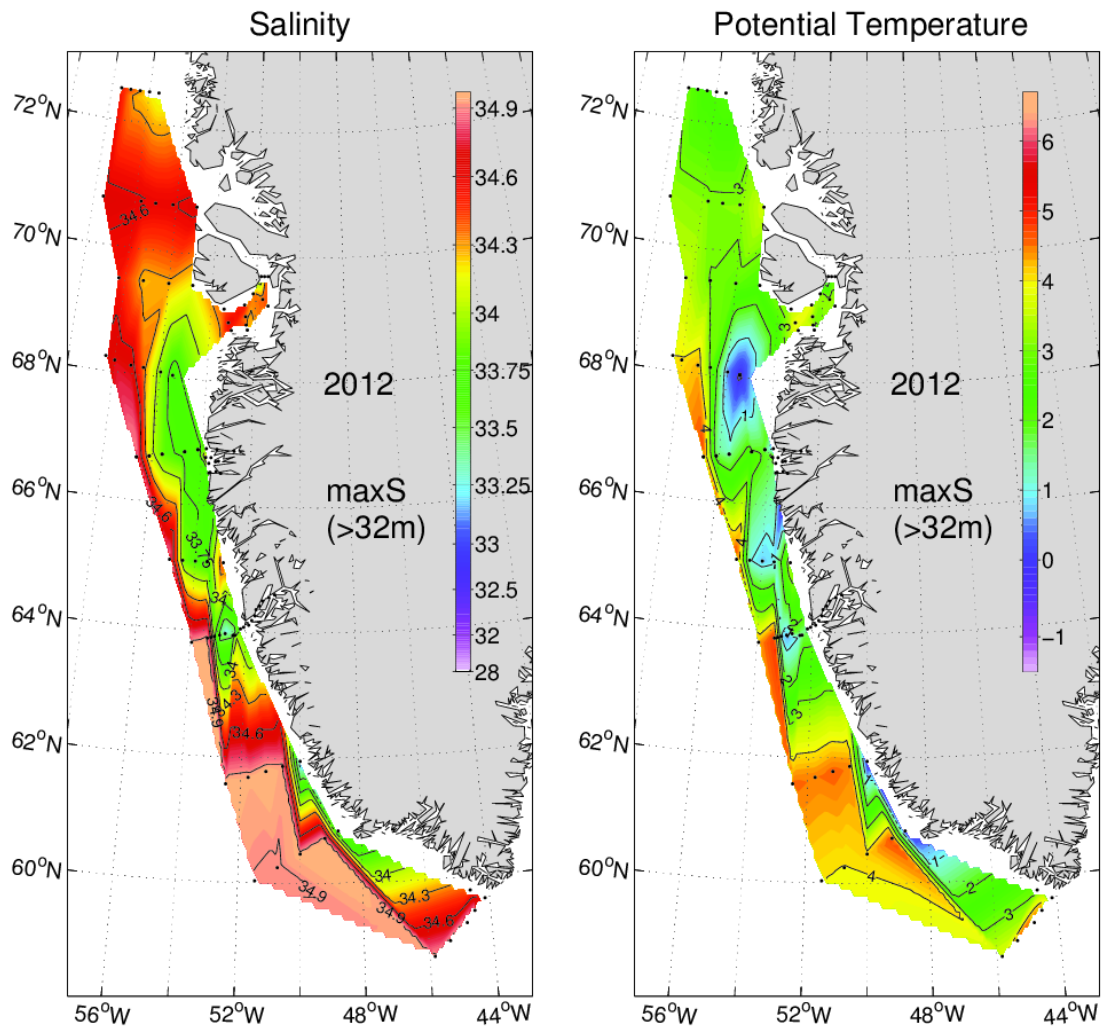


Figure 25. Salinity (left) and temperature (right) observed in 2012 (June 08 – July 01) at the depth of maximum salinity disregarding the upper 32 meters.

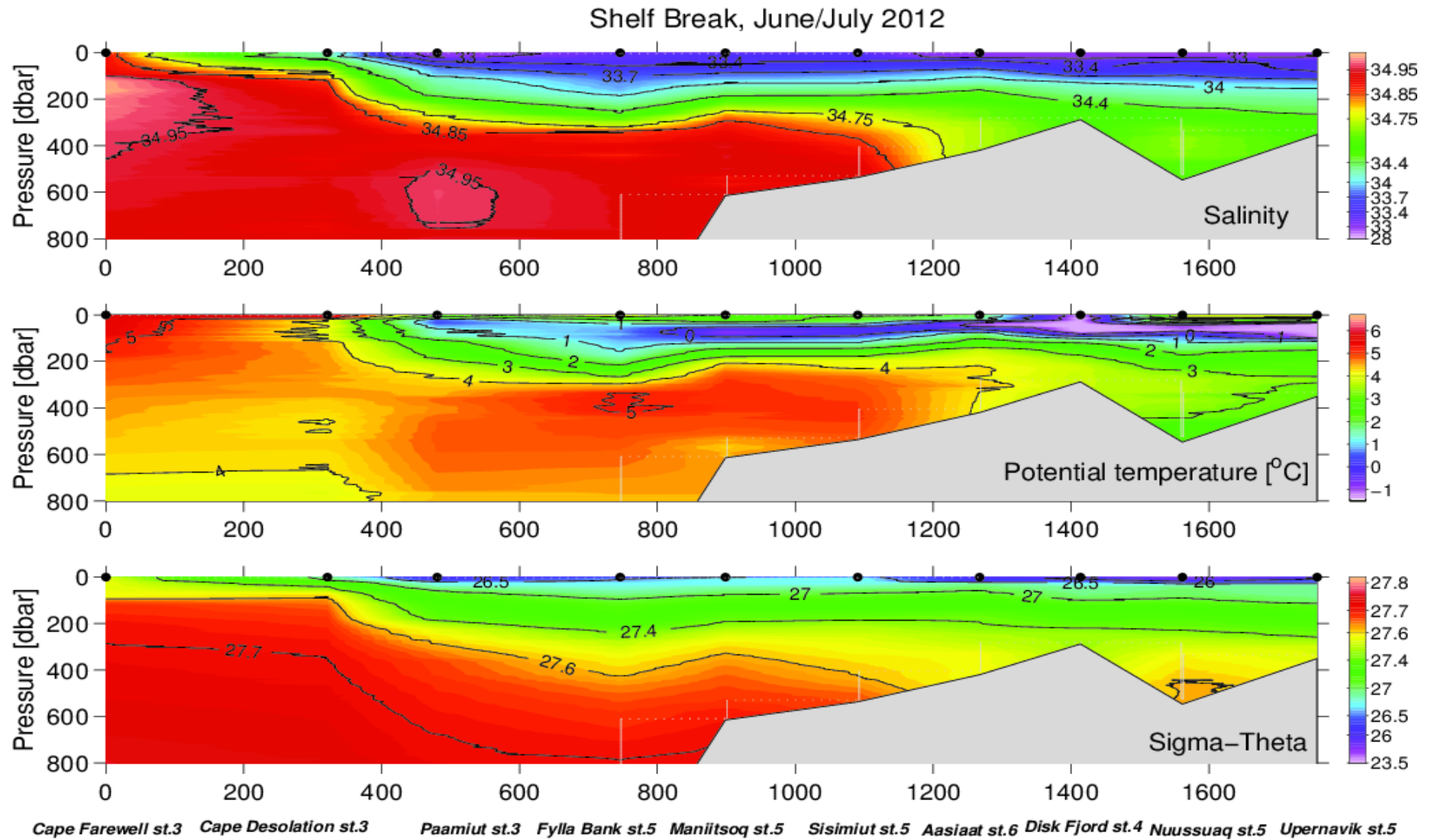
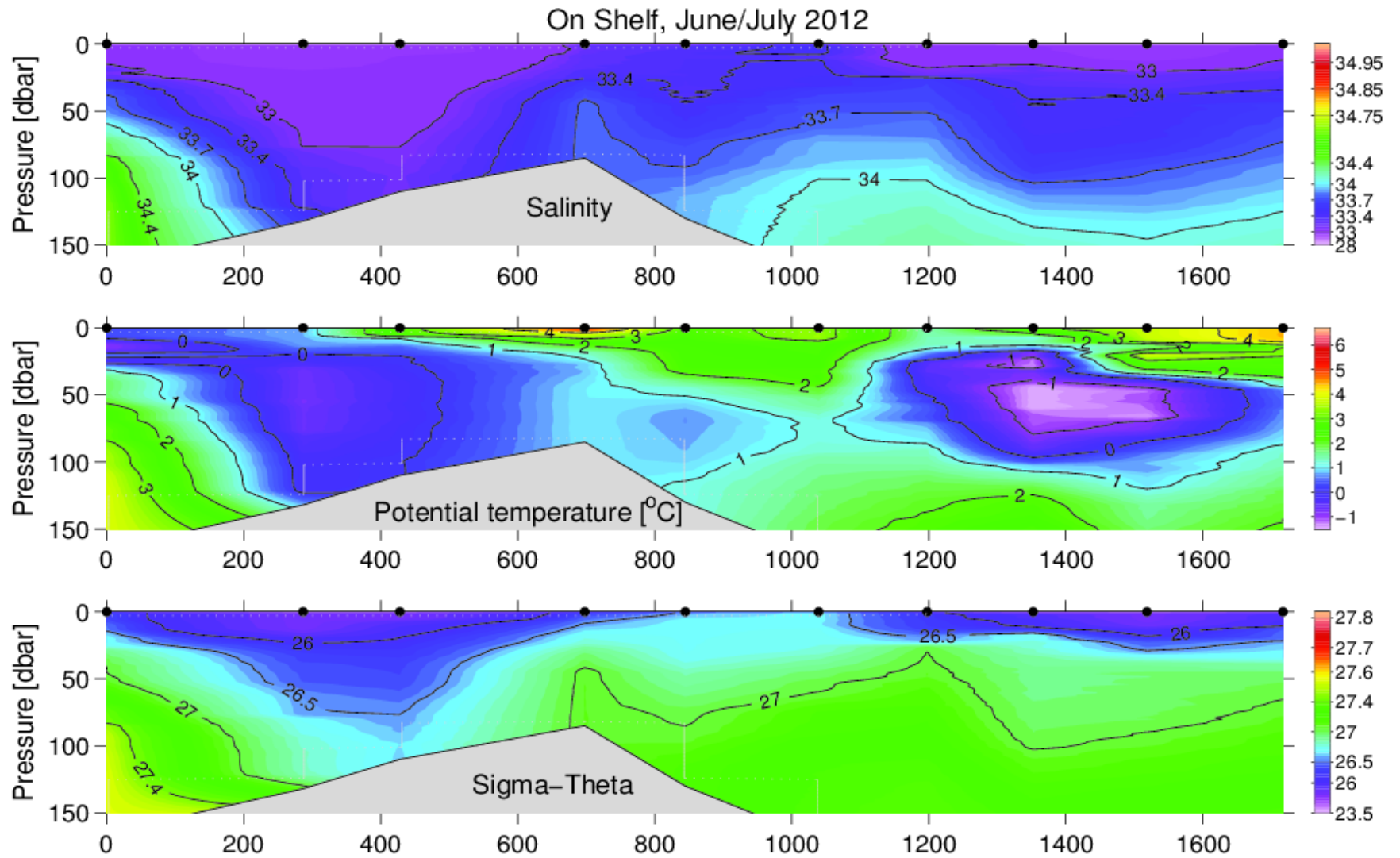


Figure 26. Vertical distribution of temperature, salinity and density over the continental shelf break from Cape Farewell to Upernavik, June 09–July 01, 2012.



Cape Farewell st.1 Cape Desolation st.1 Paamiut st.1 Fylla Bank st.3 Maniitsoq st.4 Sisimiut st.4 Aasiaat st.4 Disko Fjord st.3 Nuussuaq st.5 Upernavik st.3

Figure 27. Vertical distribution of temperature, salinity and density over the shelf banks from Cape Farewell to Upernavik, June 09–July 01, 2012.

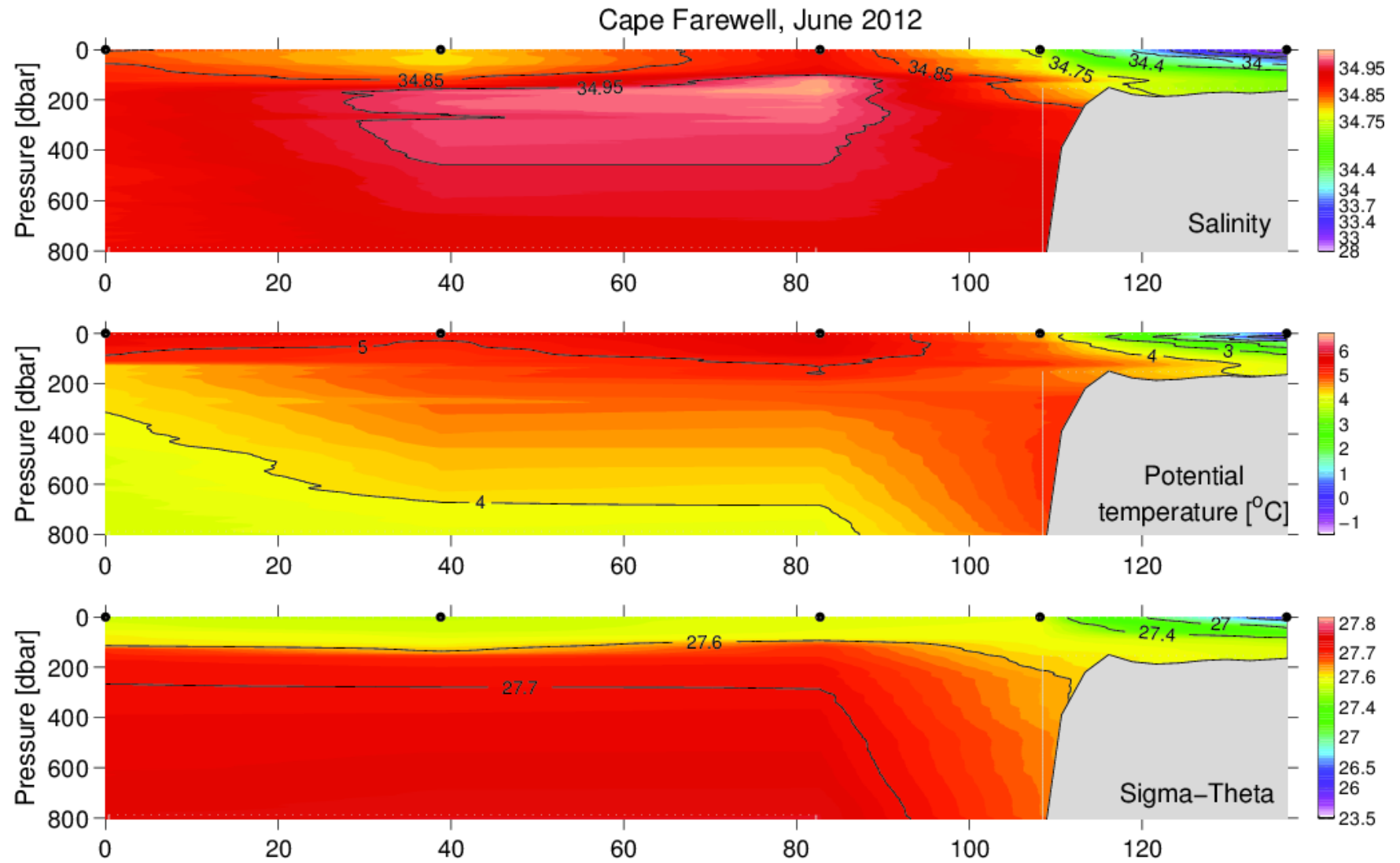


Figure 28. Vertical distribution of temperature, salinity and density at the Cape Farewell section, June 08–09, 2012.

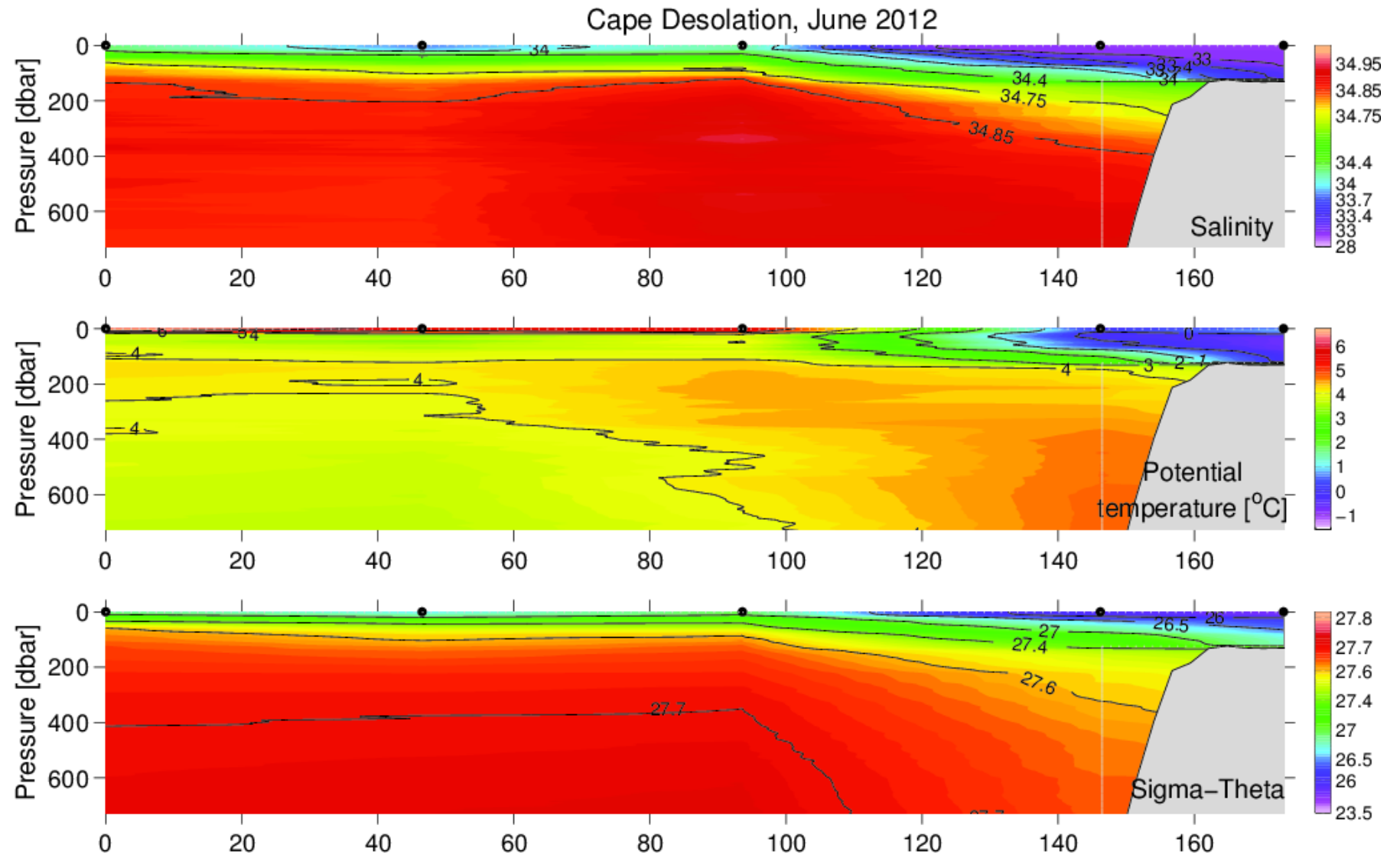


Figure 29. Vertical distribution of temperature, salinity and density at the Cape Desolation section, June 10, 2012.

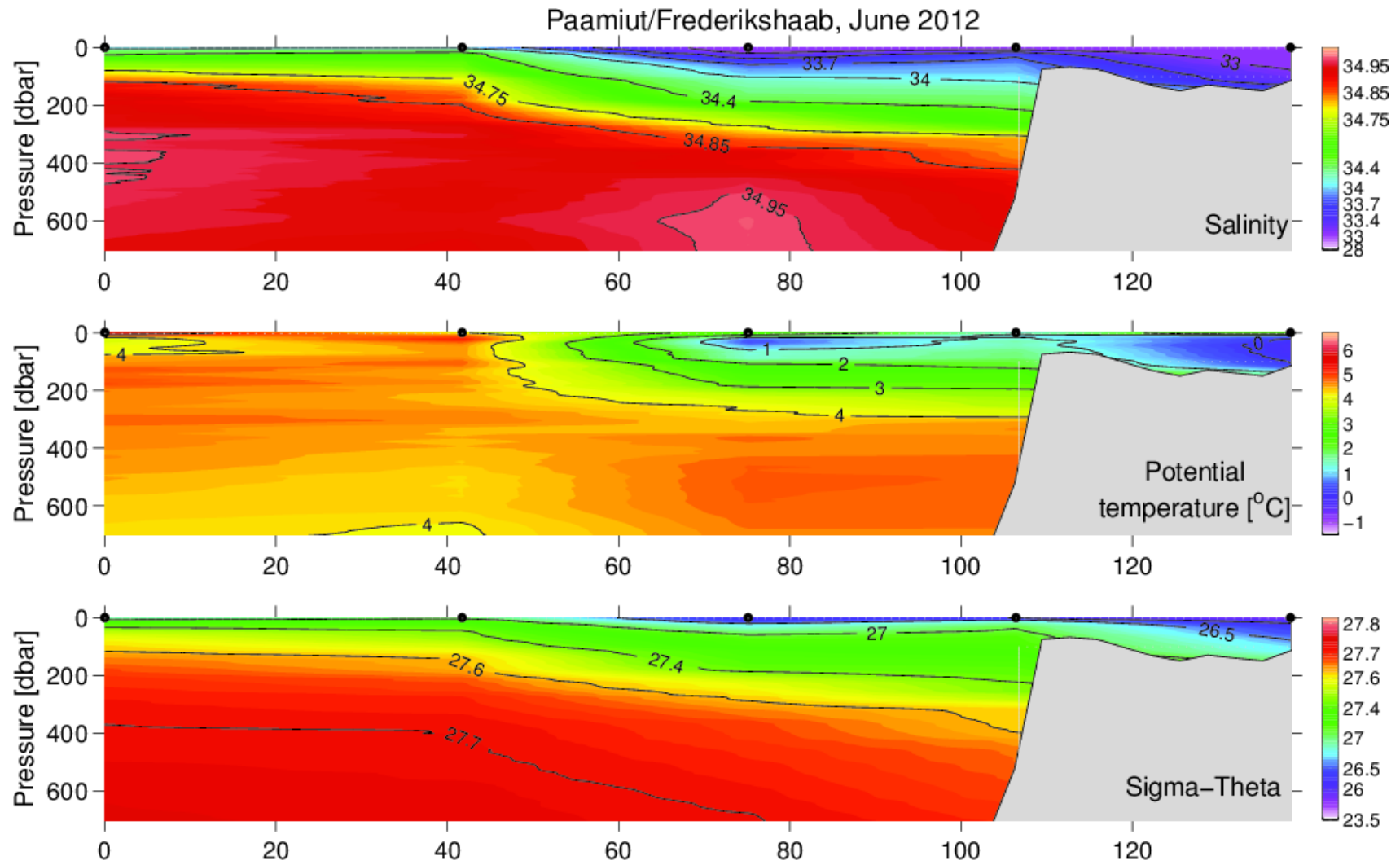


Figure 30. Vertical distribution of temperature, salinity and density at the Paamiut (Frederikshaab) section, June 11, 2012.

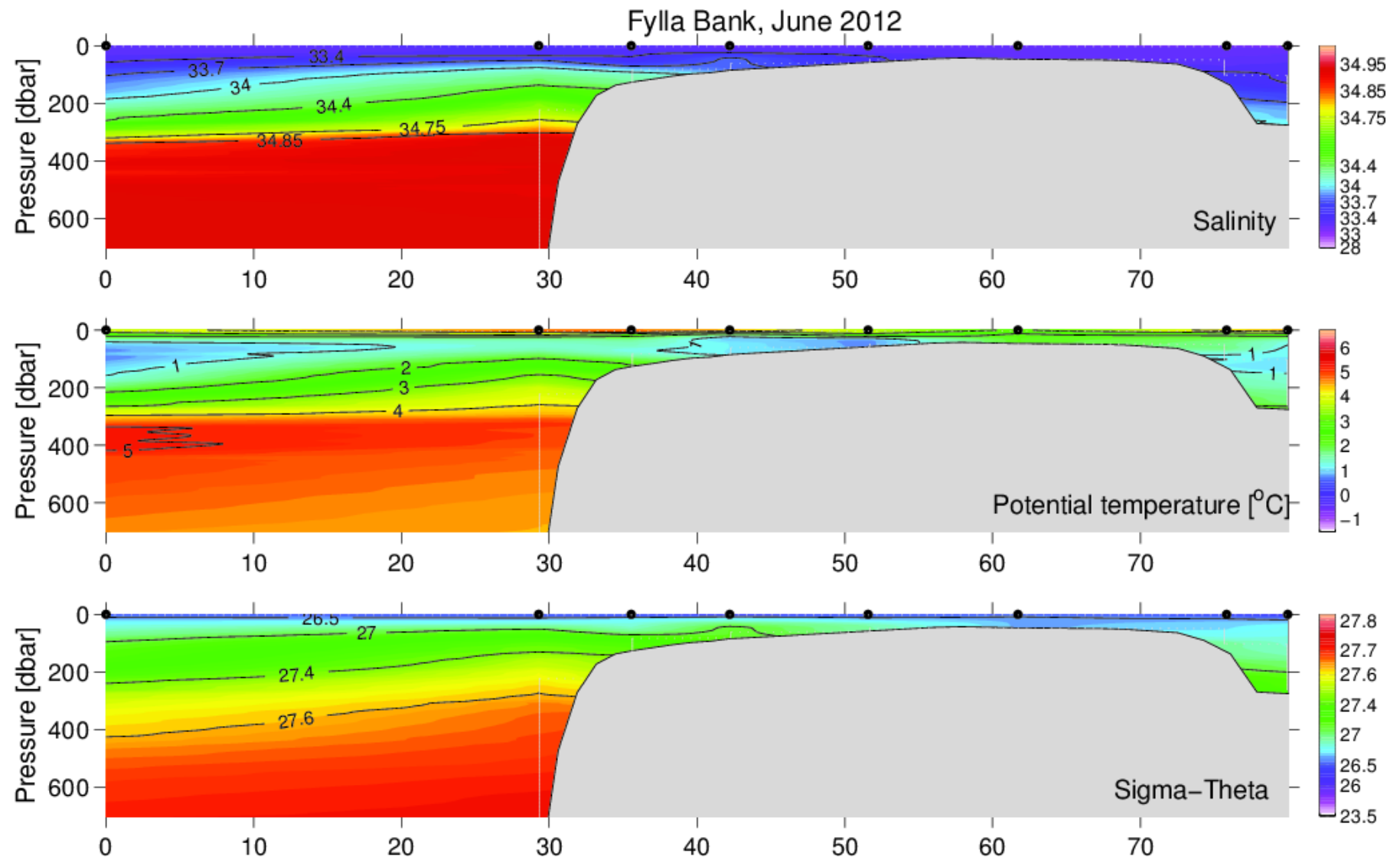


Figure 31. Vertical distribution of temperature, salinity and density at the Fylla Bank section, June 12, 2012. Three intermediate stations were taken too.

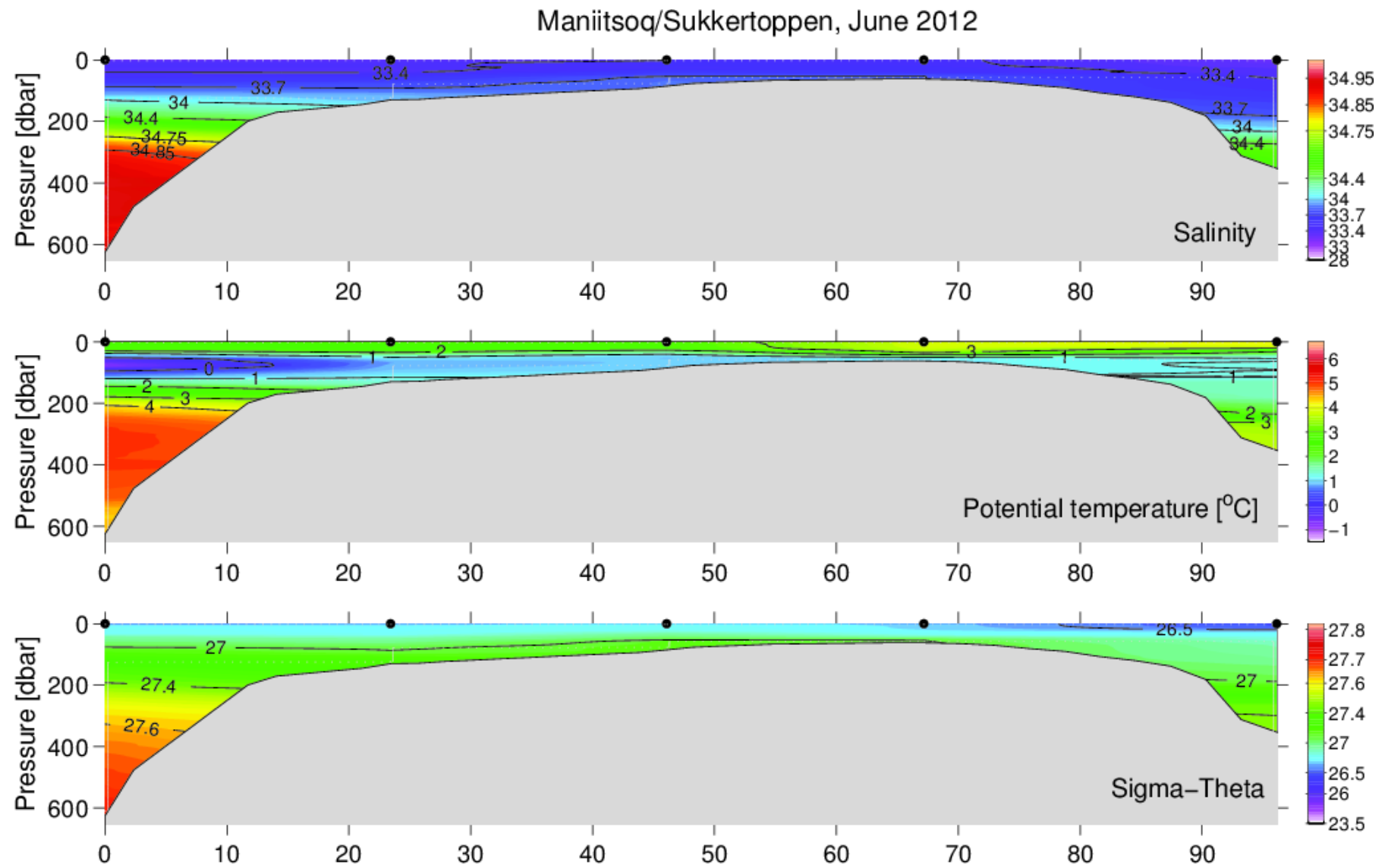


Figure 32. Vertical distribution of temperature, salinity and density at the Maniitsoq (Sukkertoppen) section, June 16, 2012.

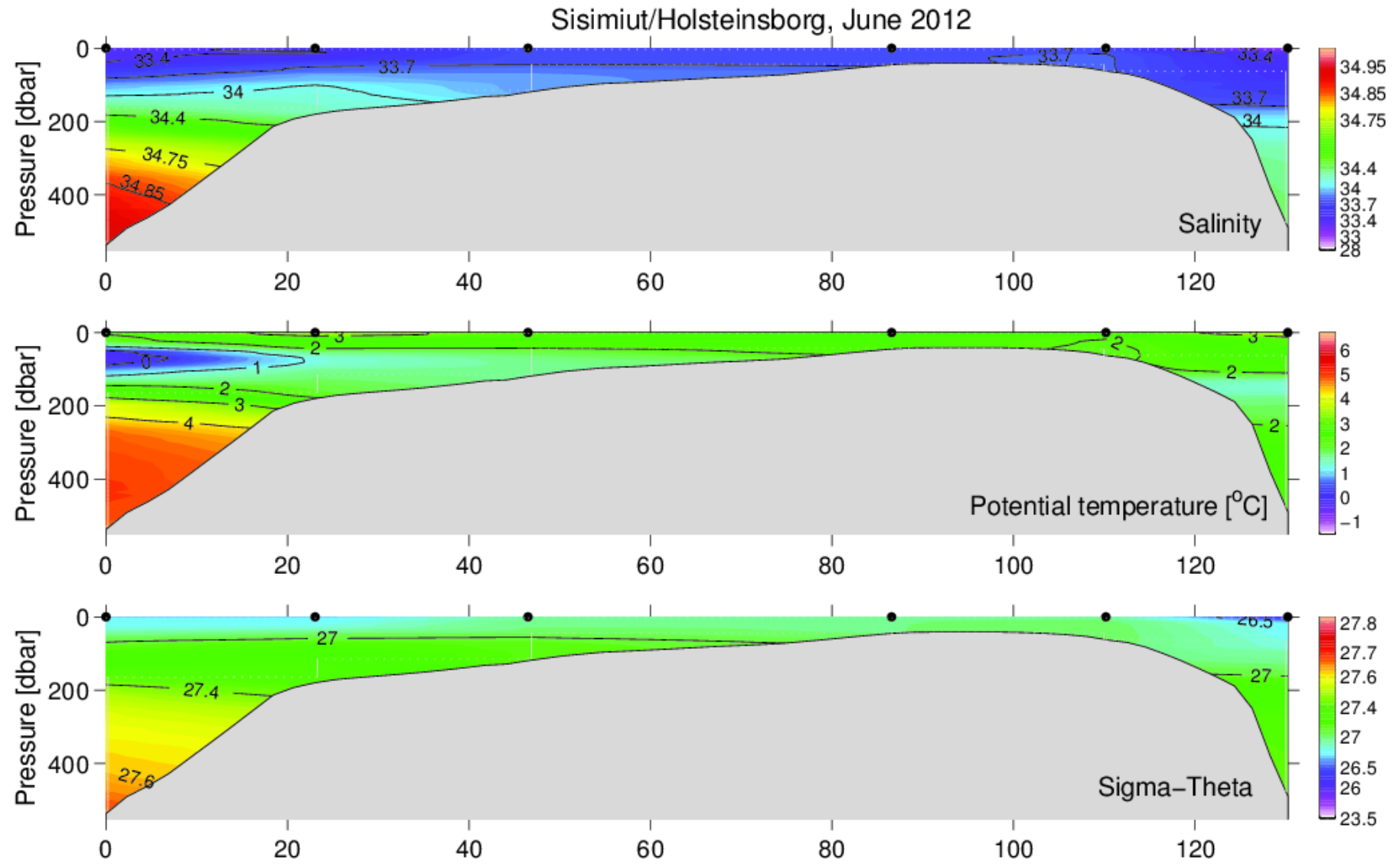


Figure 33. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, June 17, 2012.

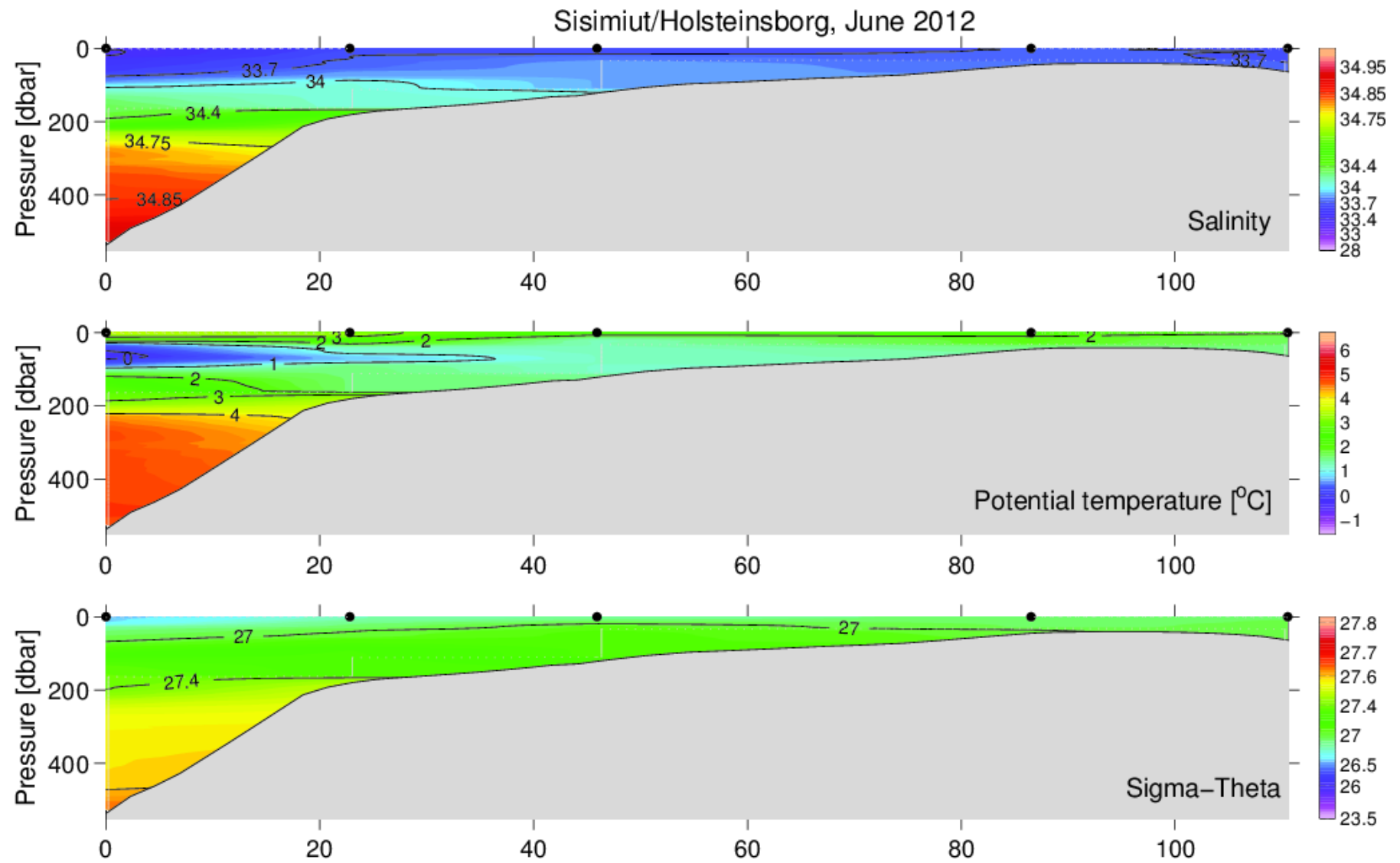


Figure 34. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, June 10–11, 2012.

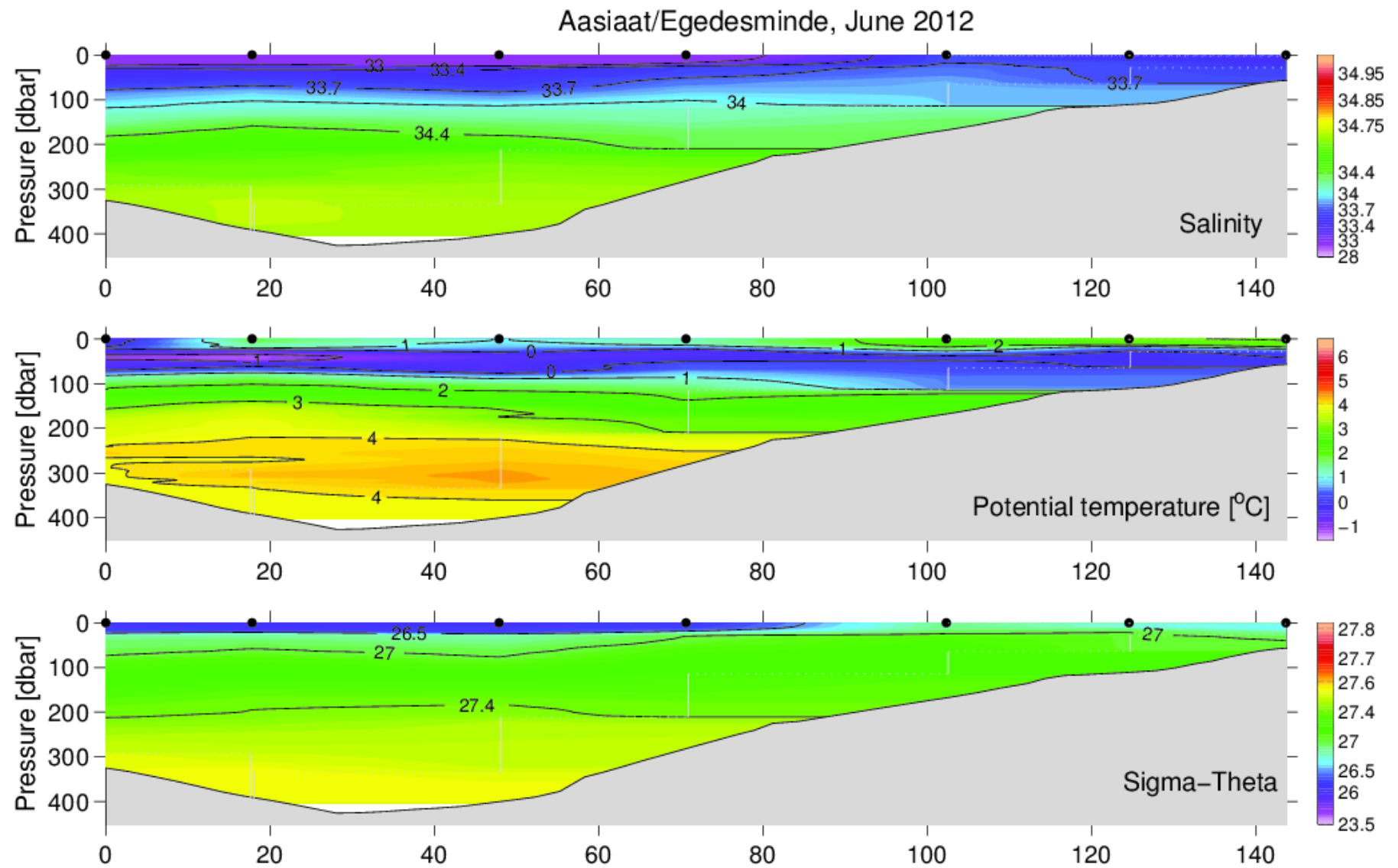


Figure 35. Vertical distribution of temperature, salinity and density at the Aasiaat (Egedesminde) section, June 14–15, 2012.

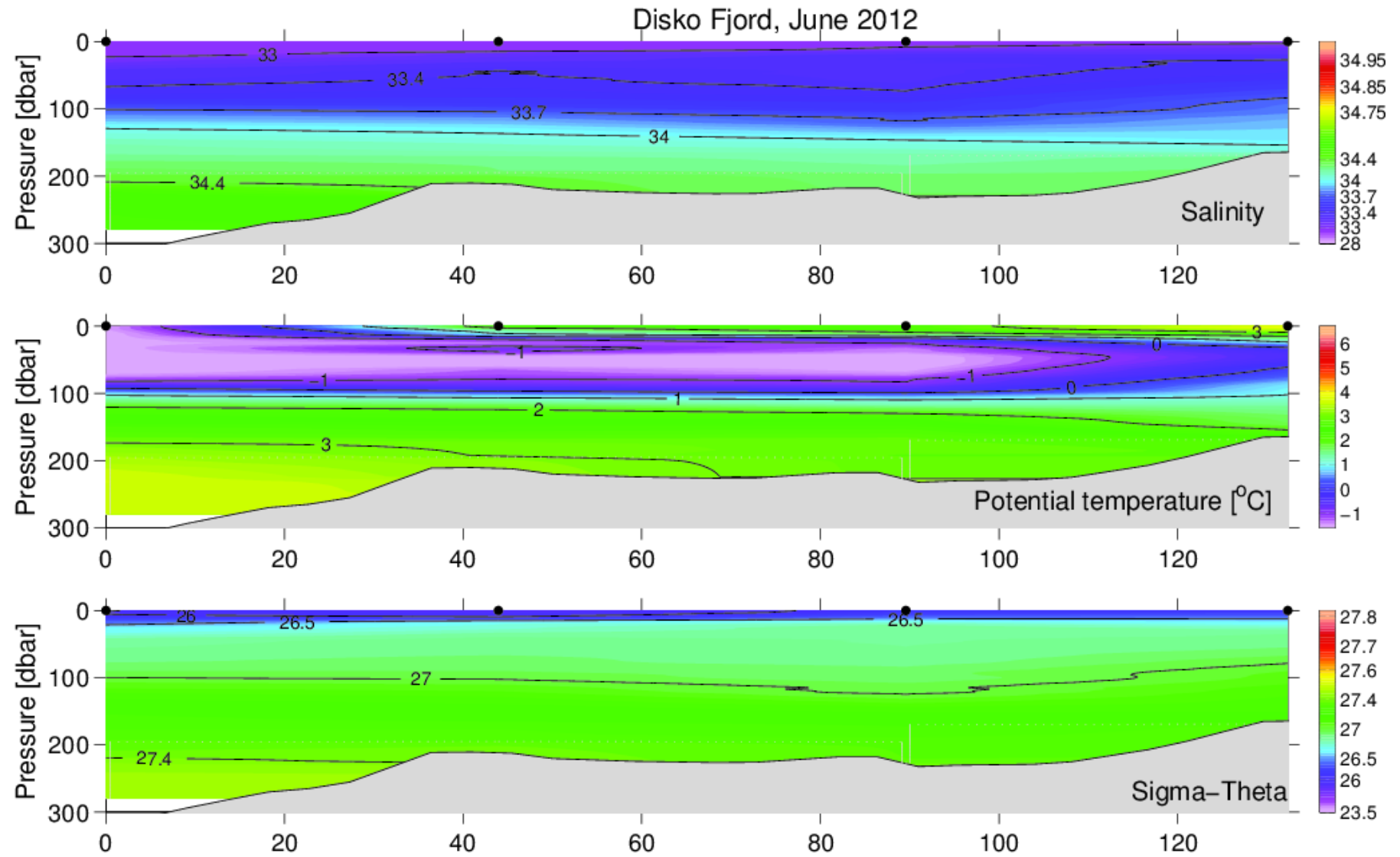


Figure 36. Vertical distribution of temperature, salinity and density at the Kangerluk (Disko Fjord) section, July 17–18, 2012.

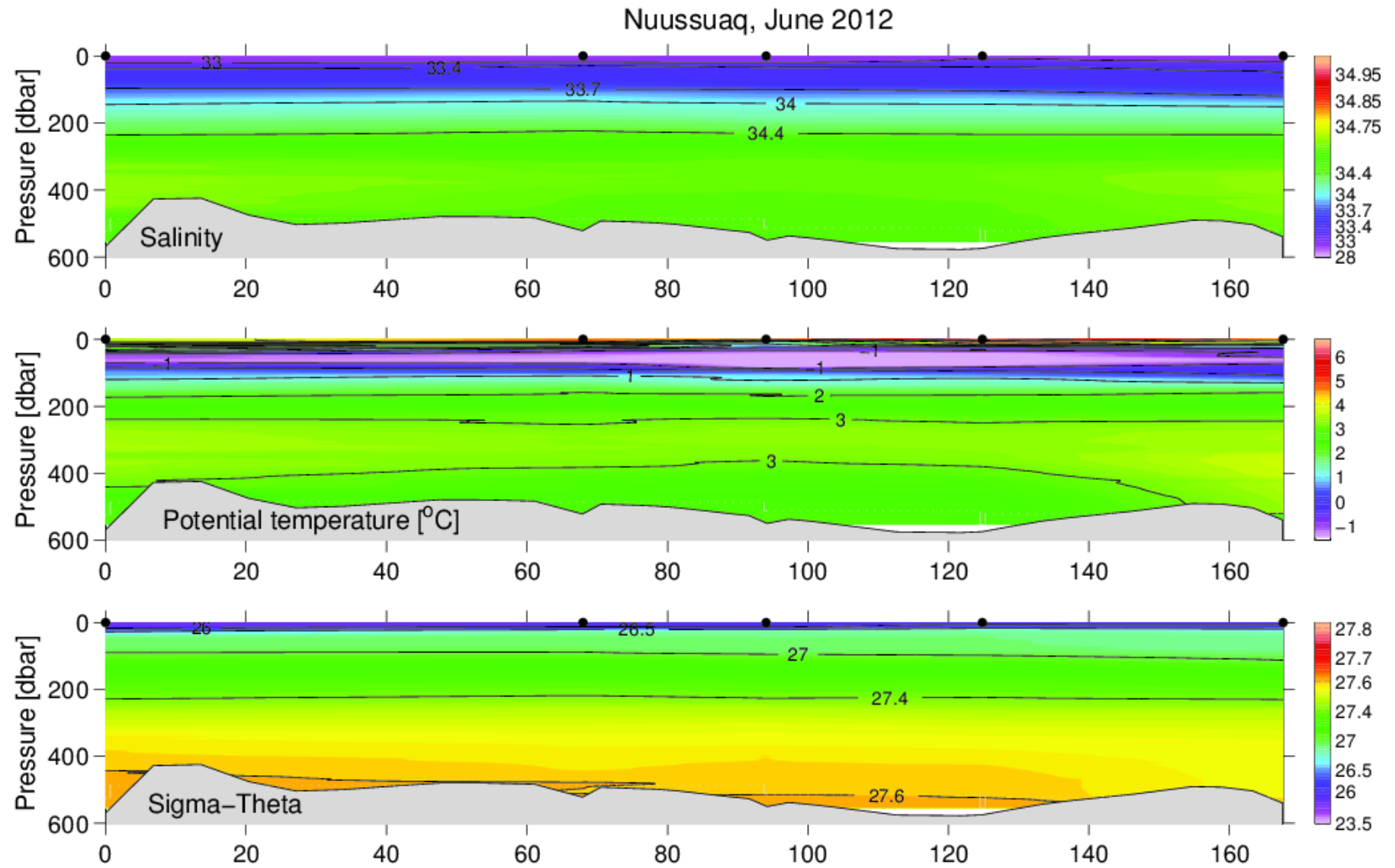


Figure 37. Vertical distribution of temperature, salinity and density at the Nuussuaq section, June 28-30, 2012.

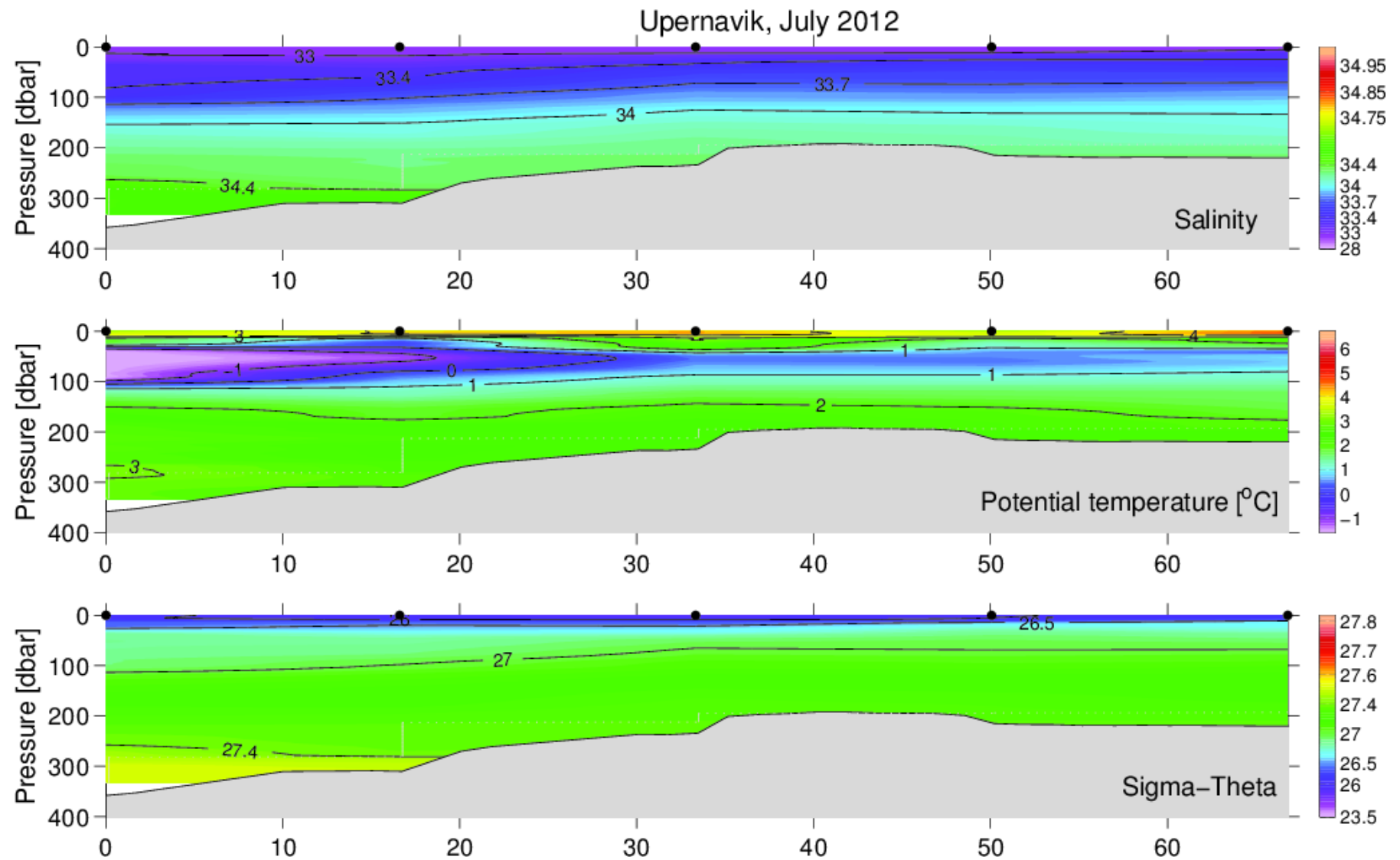


Figure 38. Vertical distribution of temperature, salinity and density at the Upernavik section, July 01, 2012.

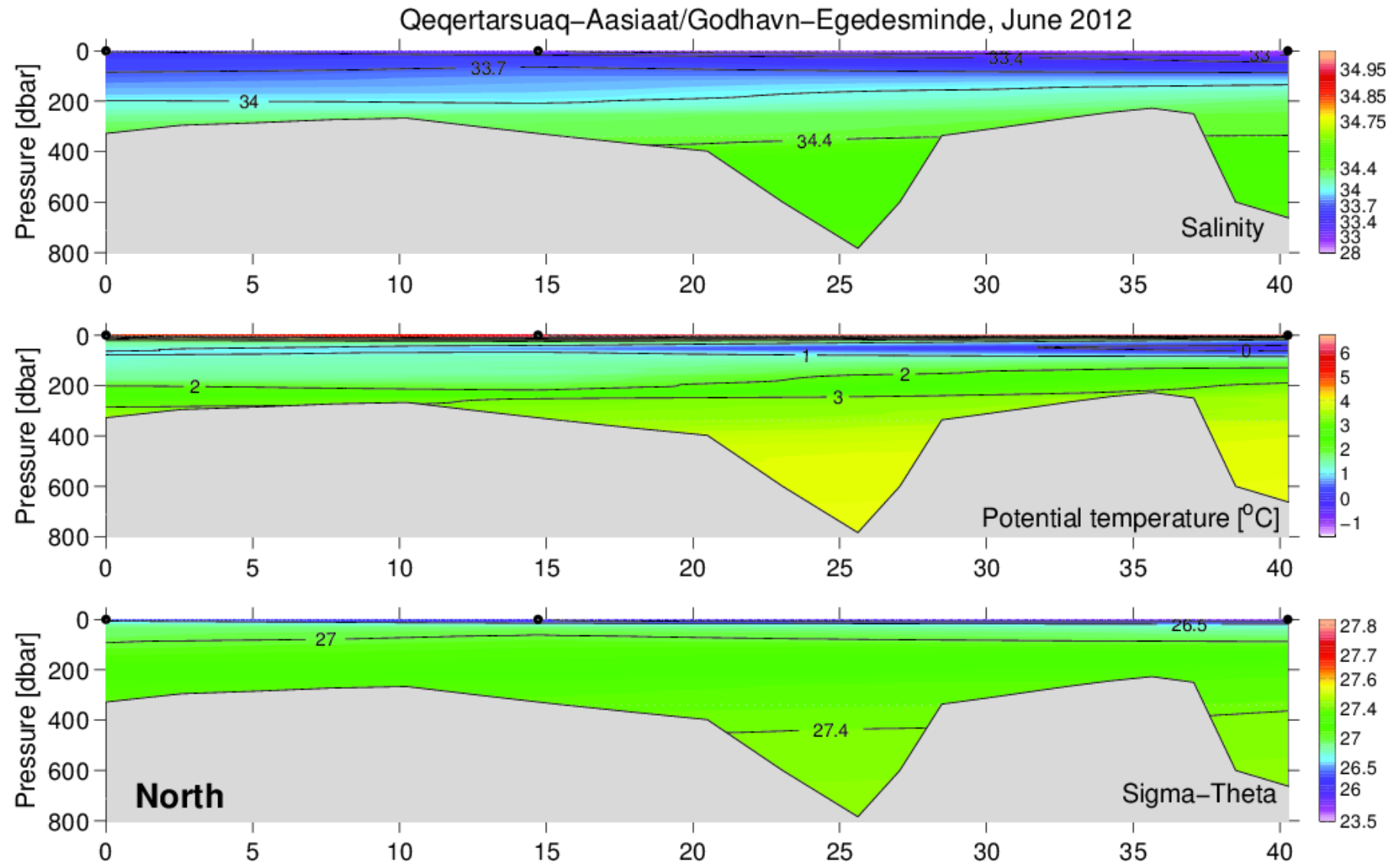


Figure 39. Vertical distribution of temperature, salinity and density at the Aasiaat–Qeqertarsuaq (Egedesminde–Godhavn) section, June 21, 2012.

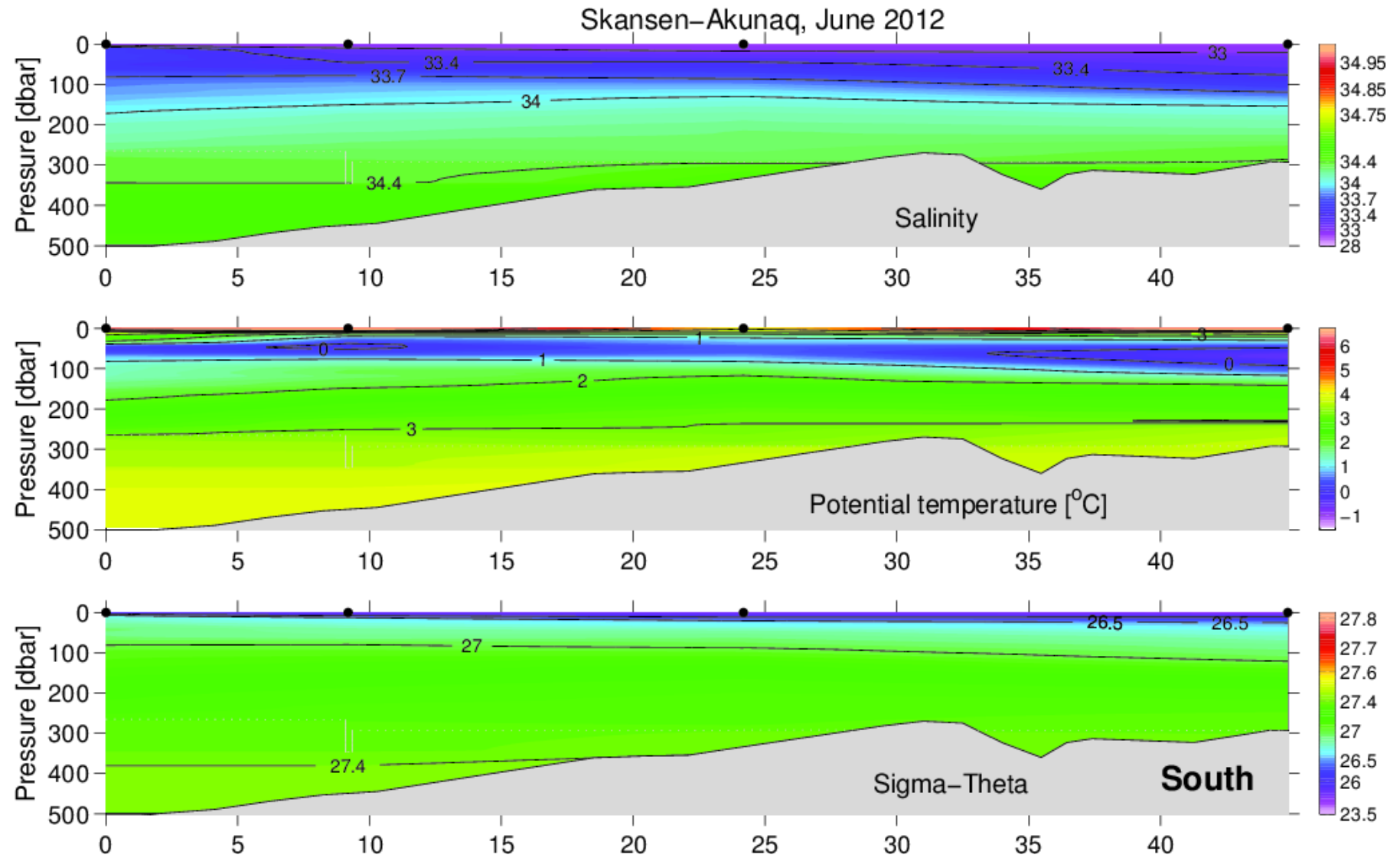


Figure 40. Vertical distribution of temperature, salinity and density at the Skansen–Akunaq section, June 21–22, 2012.

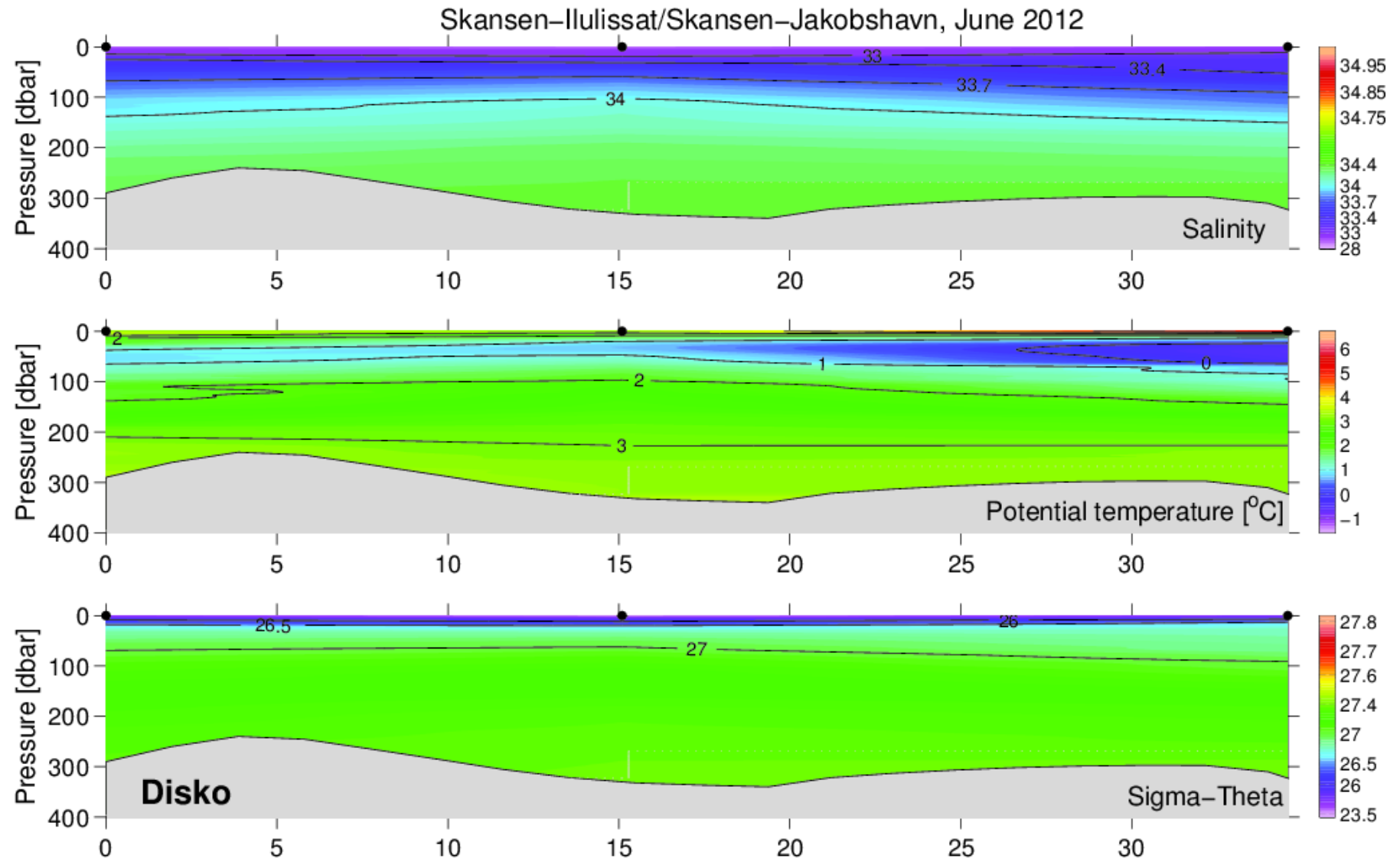


Figure 41. Vertical distribution of temperature, salinity and density at the Skansen–Ilulissat (Skansen–Jakobshavn) section, June 22–23, 2012.

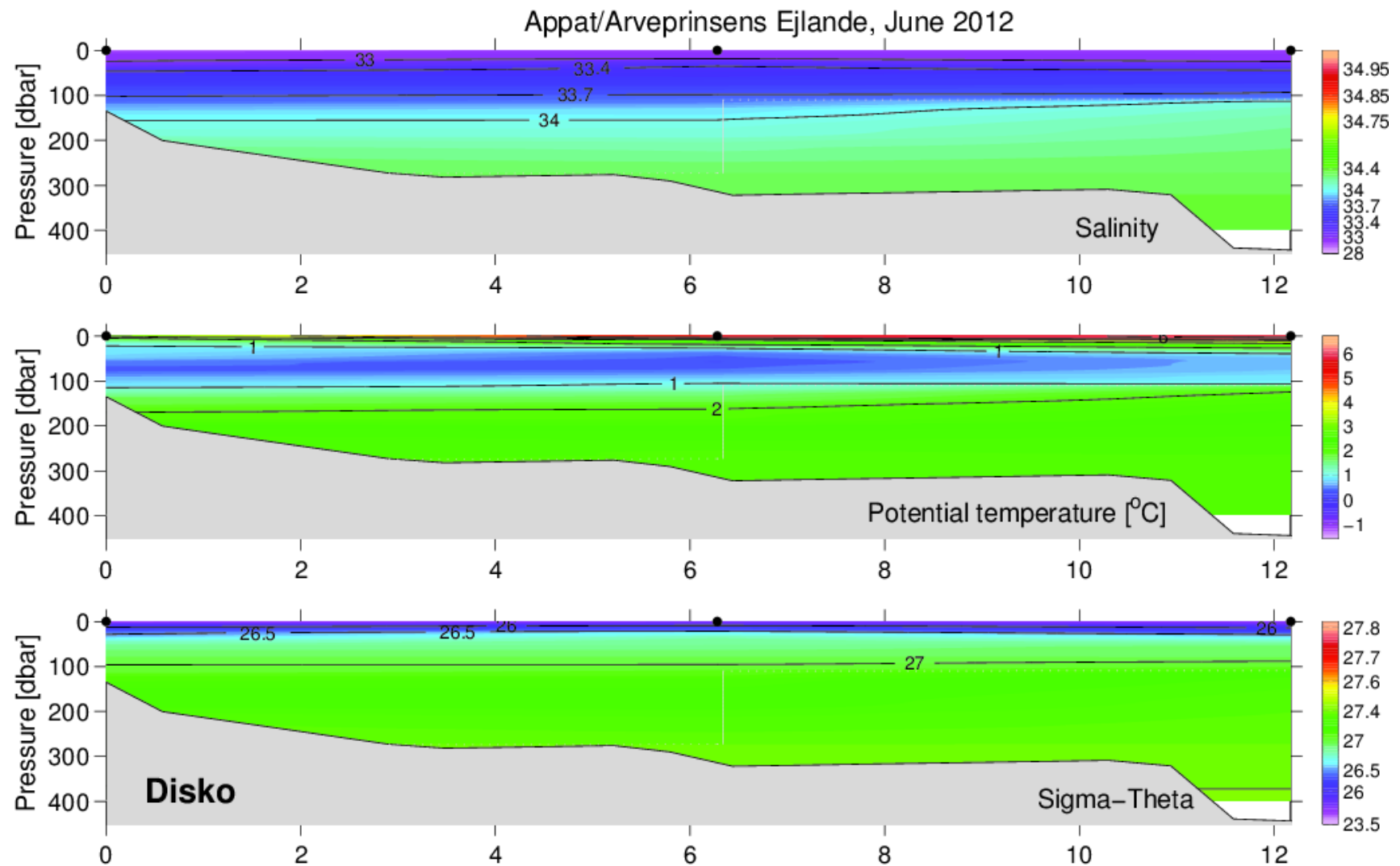


Figure 42. Vertical distribution of temperature, salinity and density at the Appat (Arveprinsens Ejlande) section, June 27, 2012.

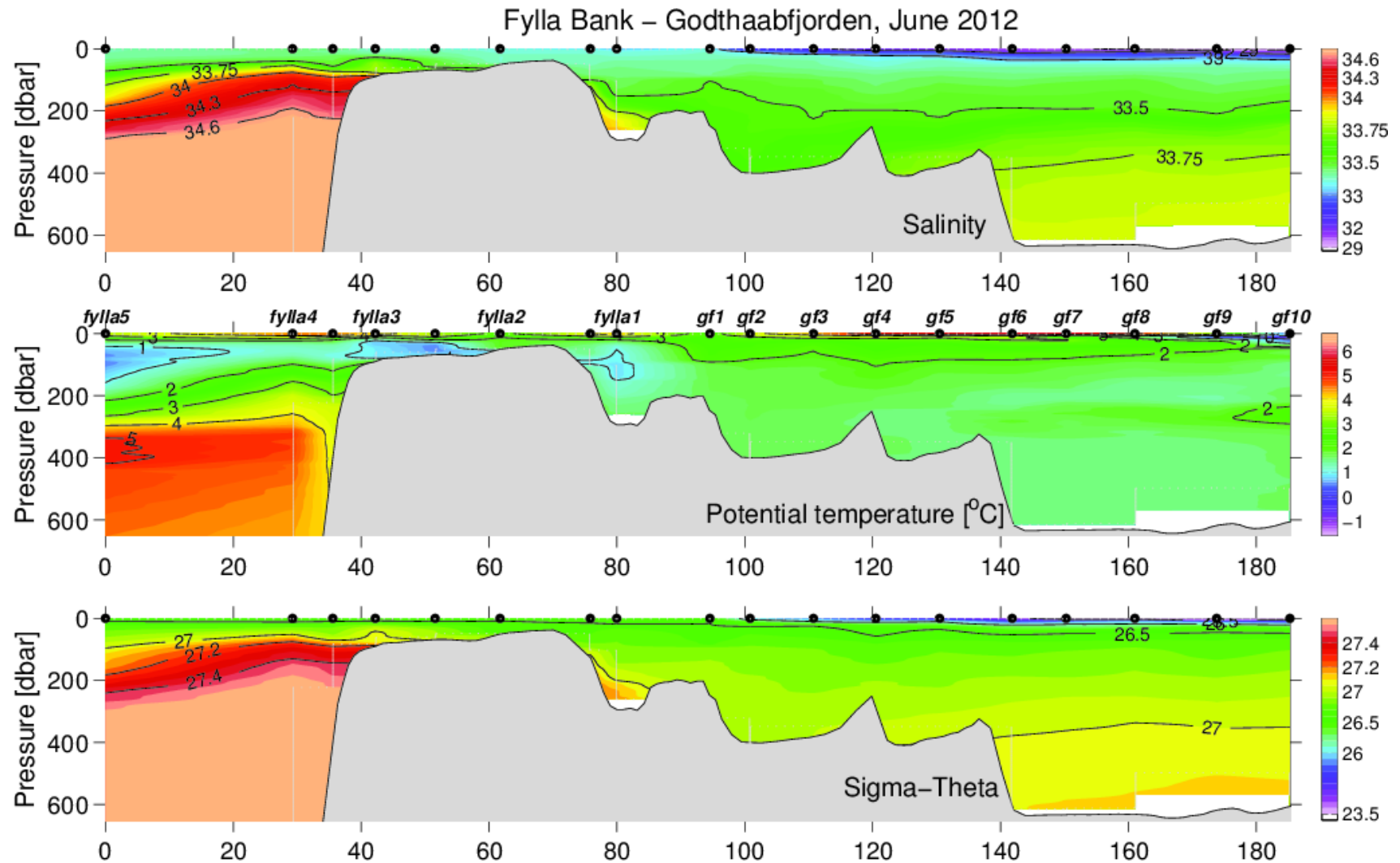


Figure 43. Vertical distribution of temperature, salinity and density at the Godthaab fjord section, June 12–13, 2012. Fylla Bank section left (as in Figure 31).

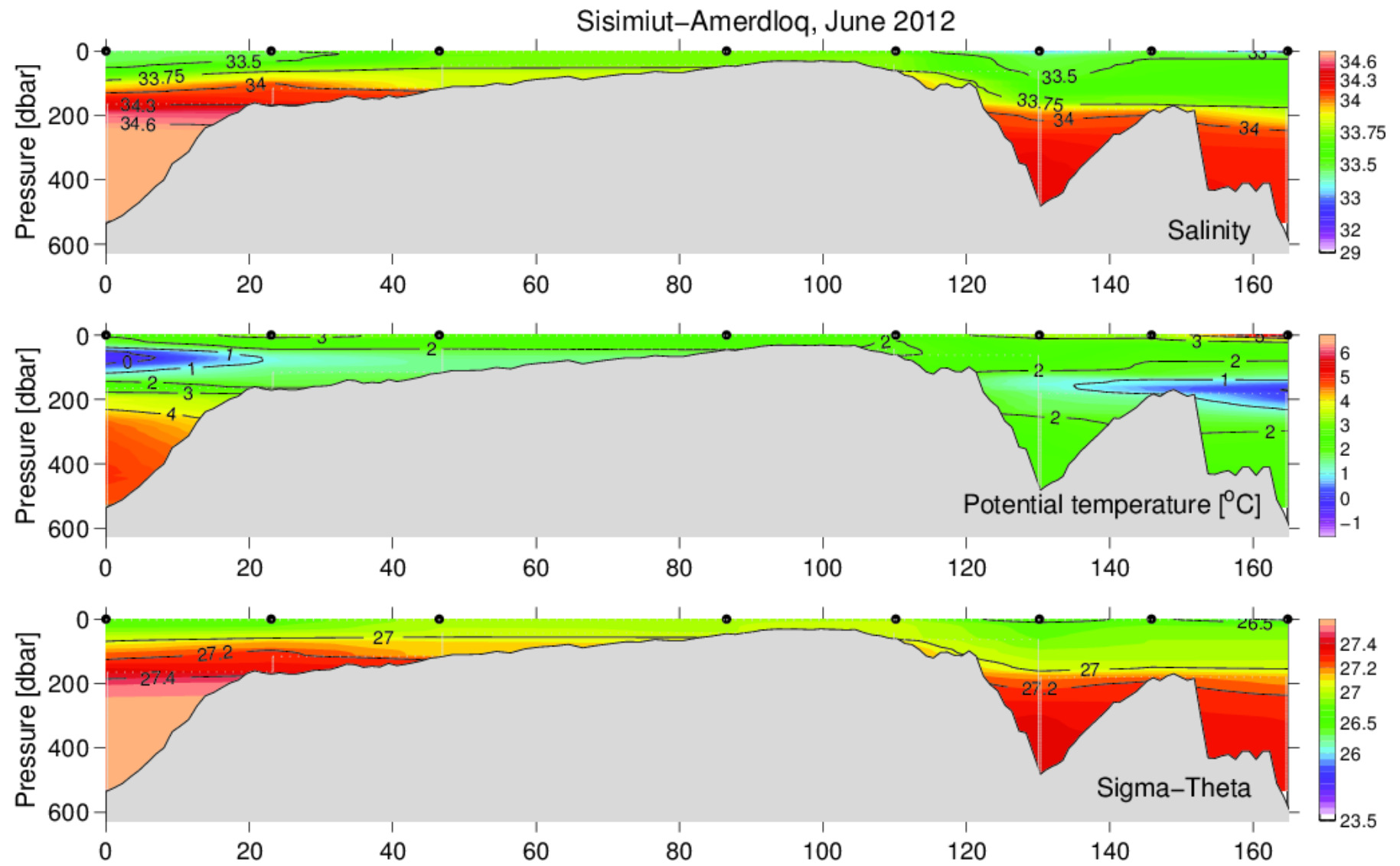


Figure 44. Vertical distribution of temperature, salinity and density at the Amerdloq fjord, June 17, 2012. Sisimiut section left.

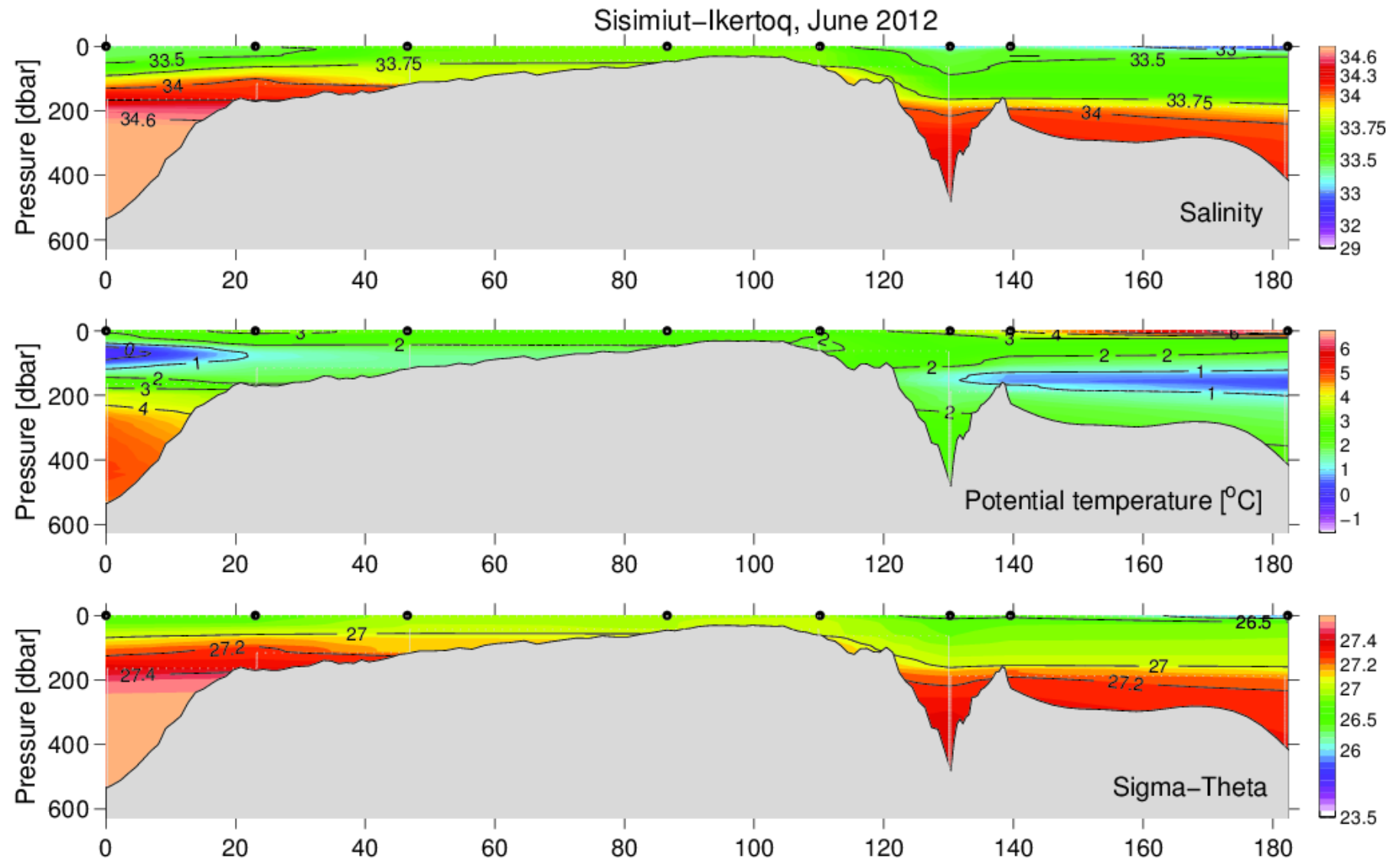


Figure 45. Vertical distribution of temperature, salinity and density at the Ikertoq fjord, June 17–18, 2012. Sisimiut section left

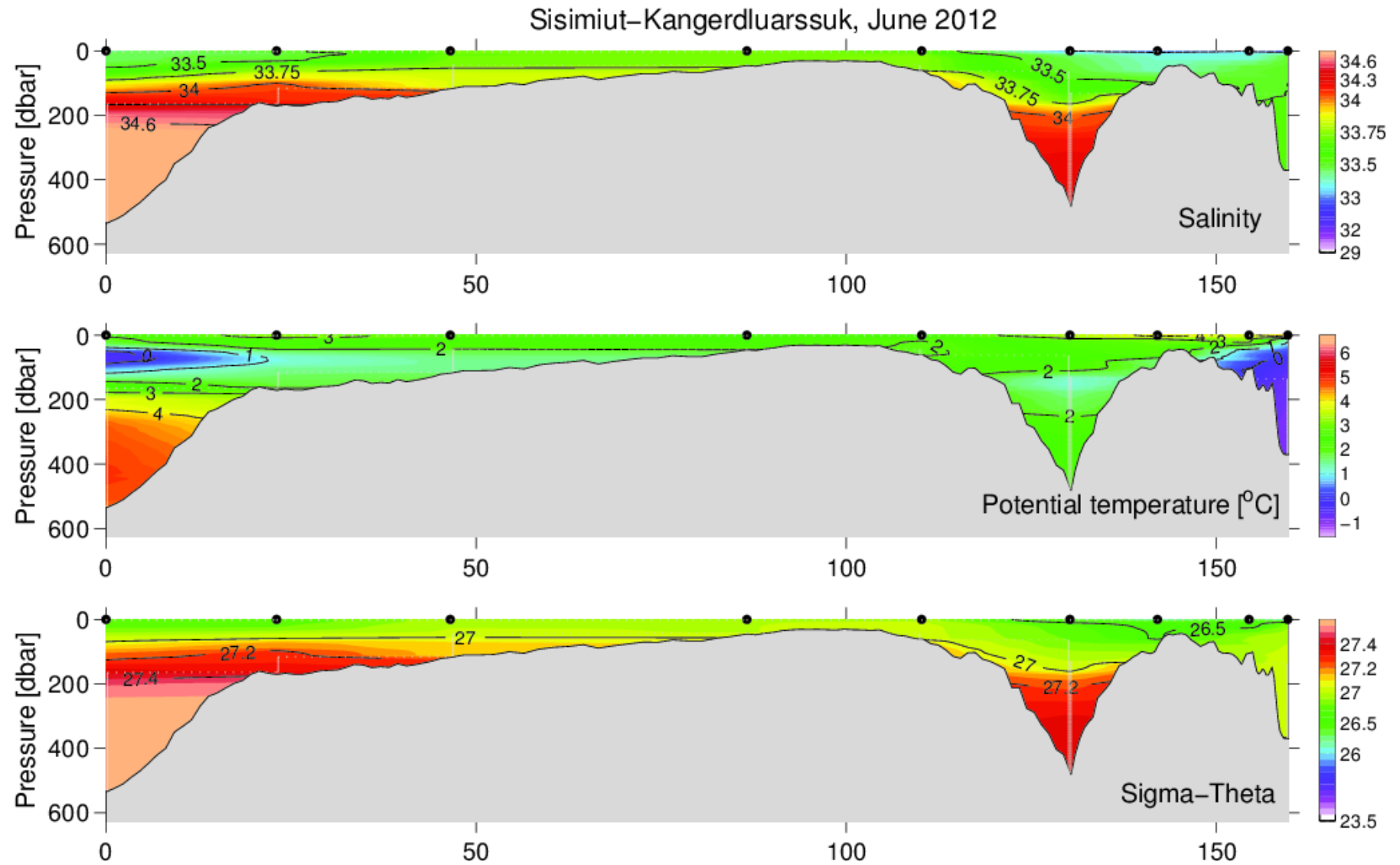


Figure 46. Vertical distribution of temperature, salinity and density at the Kangerdluarssuk fjord, June 17–18, 2012. Sisimiut section left.

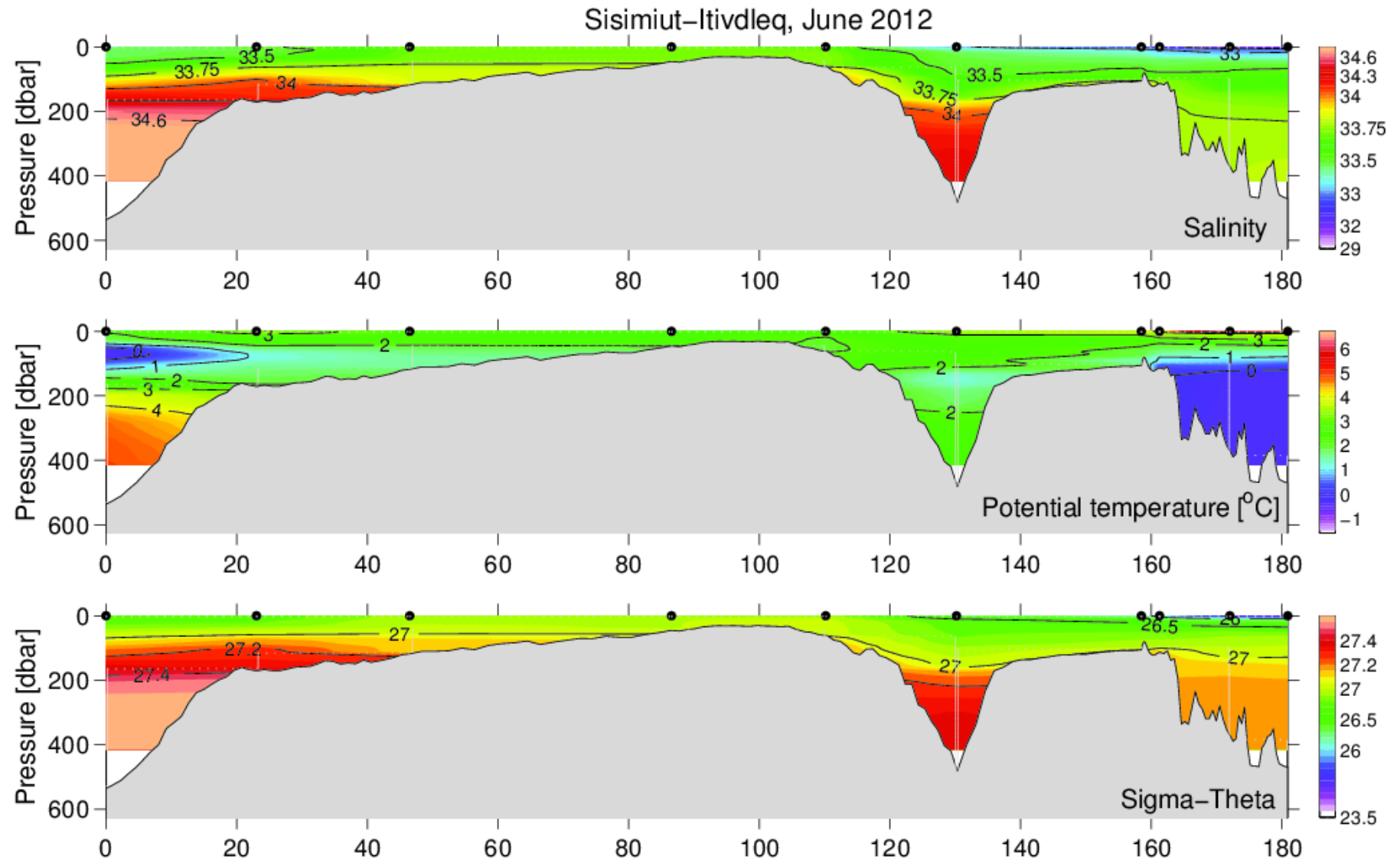


Figure 47. Vertical distribution of temperature, salinity and density at the Itivdleq fjord, June 17, 2012. Sisimiut section left.