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Oceanographic Investigations off West Greenland 2013

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Abstract

The regional hydrography in summer 2013 is presented and discussed based on data from standard sections along the west coast of Greenland and data retrieved during trawl surveys.

In winter 2012/13, the North Atlantic Oscillation (NAO) index was negative describing weakening westerlies over the North Atlantic Ocean. Often this results in warmer conditions over the West Greenland region which was also the case this winter with air temperature above normal.

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 2013 and average salinities. The normalized near-surface salinity index and the presence of Polar Water were normal in 2013.

The presence of Irminger Water in the West Greenland waters was high in 2013. 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. However, at the three southernmost sections, the pure Irminger Water does not occupy as large a volume as in recent years. It has to a large extent been replaced by modified Irminger Water. In contrast, mean (400–600 m) temperature and salinity were still very high over the Southwest Greenland shelf break north of Fylla Bank and into the Disko Bay region.

Introduction to the west Greenland oceanography

This report describes the hydrographic conditions in West Greenland Waters in 2013 from Cape Farewell in the southeastern Labrador Sea northward to Upernavik in the 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.

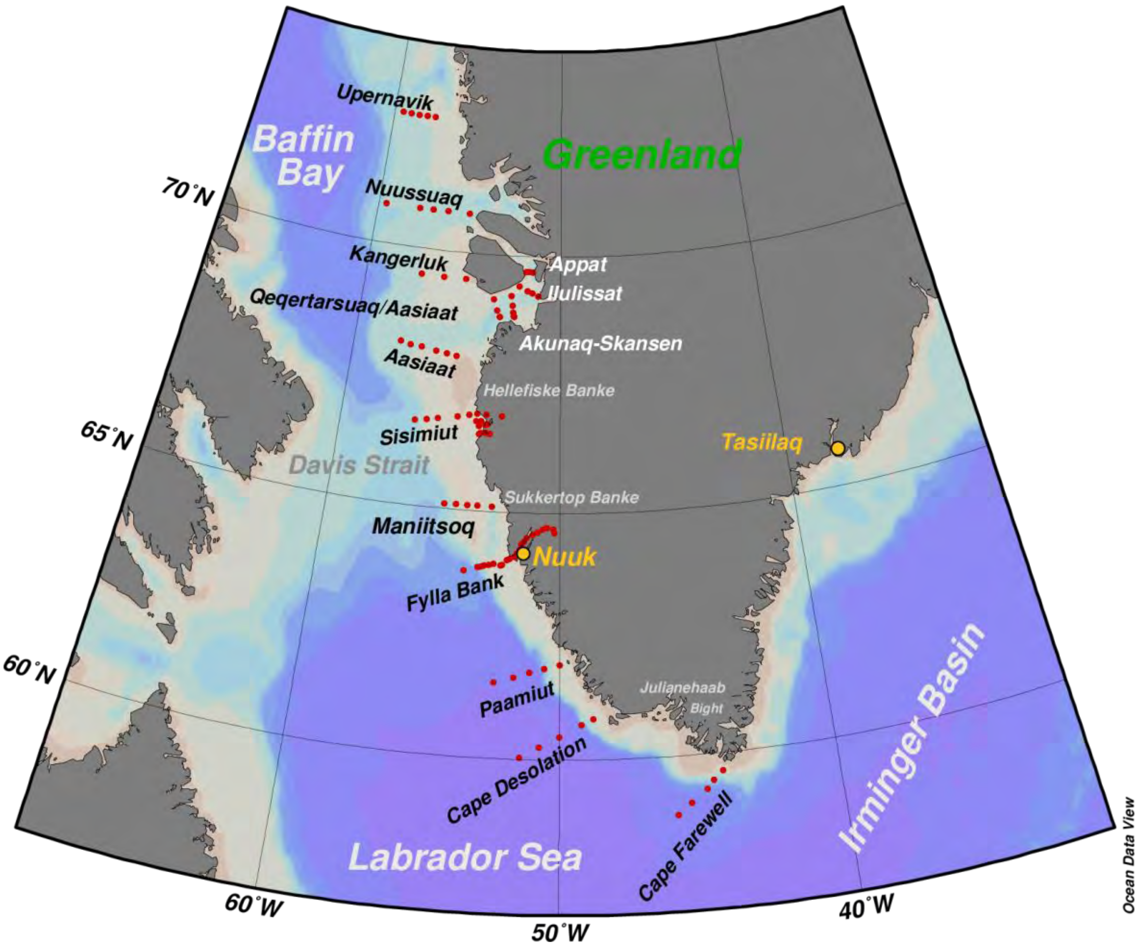

Figure 1. Position of the oceanographic sections off West Greenland where measurements were taken in 2013. Map produced using Ocean Data View (Schlitzer, 2007).

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, limited by the winch.

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 flow southward side by side (Figure 2c). 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.

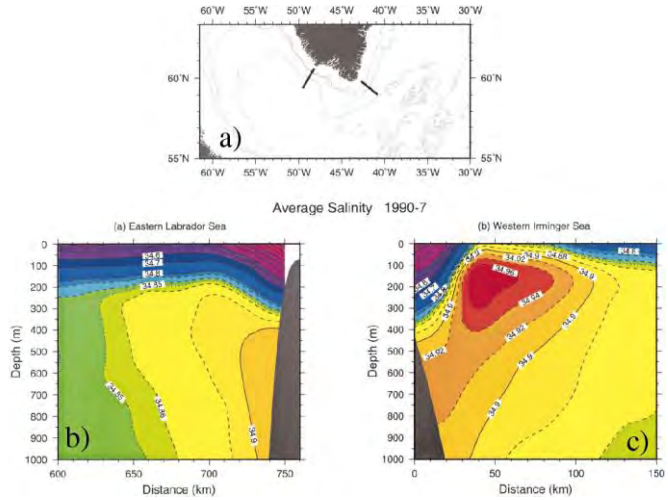

Figure 2. Mean upper-layer salinity sections for the period 1990–1997. Top: Location of the two sections. Lower left: Eastern Labrador Basin. Lower right: Western Irminger Basin. From Pickart et al. (2002).

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.

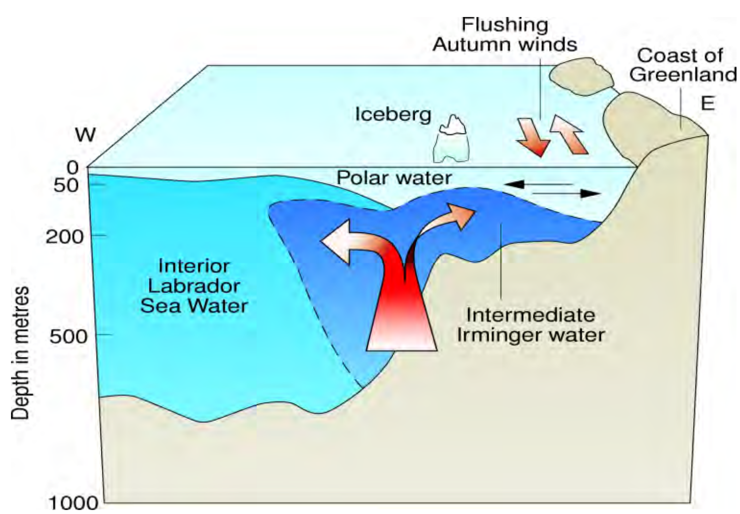

Figure 3. Sketch of the water masses off West Greenland in the Davis Strait region. From Valeur et al. (1997).

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.

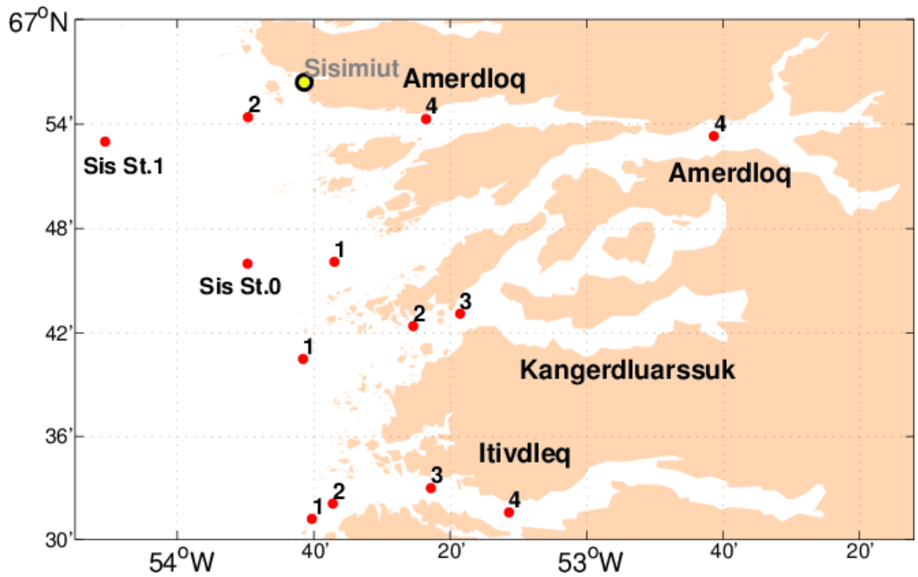

Figure 4. Position of the oceanographic stations around Sisimiut where measurements were performed in 2013. See Figure 1 for position of all sections measured in 2013.

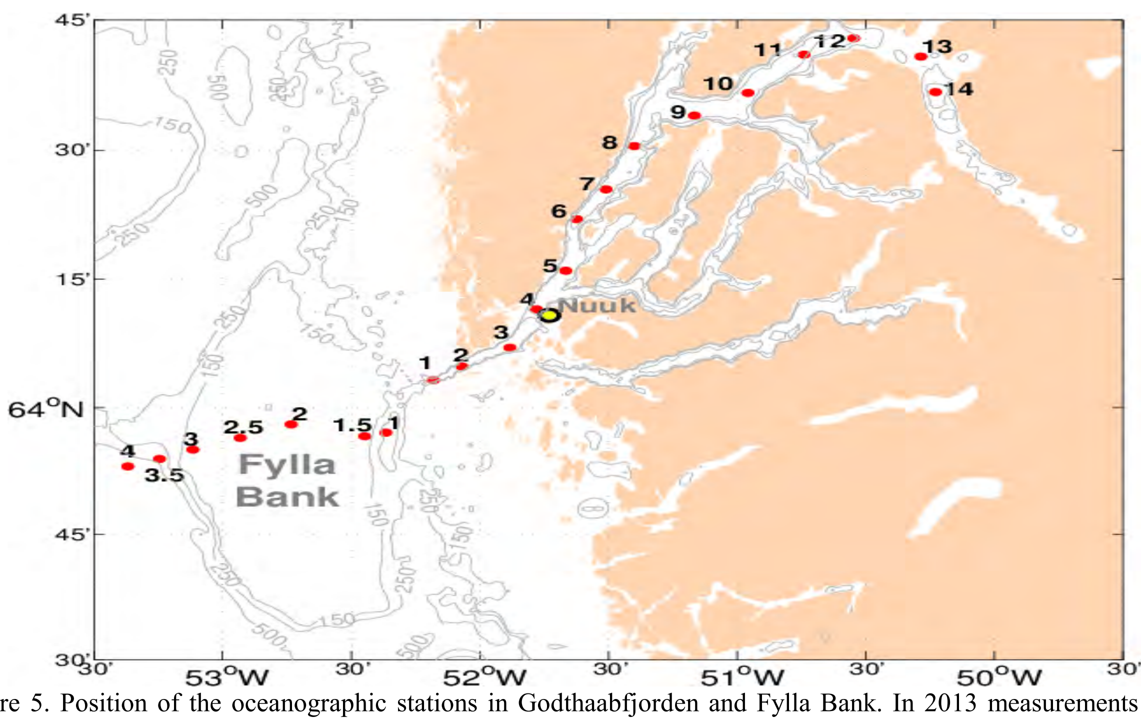

Figure 5. Position of the oceanographic stations in Godthaabfjorden and Fylla Bank. In 2013 measurements were performed over Fylla Bank and st. 1–14 in the "main arm" of the Godthaabfjorden. The numbers reefer to standard station numbers as shown in Figure 42. See Figure 1 for position of all sections measured in 2013.

1. Measurements

The 2013 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 11 – 21, 2013 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. 1–14
- Amerdloq St. 2, 4
- Ikertoq St. 1, 4
- Kangerdluarssuq St. 1–3
- Itivdleq St. 1–4

Part of the observations do directly support work done within the Greenland Climate Research Centre (GCRC).

On each station the vertical distributions of temperature and salinity were 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 low concentrations and did not have any influence on the ability to conduct the stations.

During the period June 13 – July 01, 2013 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:
- Aasiaat (Egedesminde) St. 1–6
- Kangerluk (Disko fjord) St. 1–3
- 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

Aasiaat St. 6 was taken approximately 5 nautical miles east of position, and St. 7 was not taken due to the presence of Vestice. Similar Kangerluk st.4 was skipped.

2. Data handling

Measurements of the vertical distribution of temperature and salinity were carried out using a Seabird SBE 19plus CTD. The instrument was 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 calibrated in winter/spring 2013.

The CTD data were analysed using SBE Data Processing version 5.37d software provided by Seabird (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

2.1.1. SBE19plus calibration

The SBE19plus was newly checked and calibrated by Sea-Bird Electronics before the cruise and returned for post calibration after the cruise.

In 2013 a calibration was performed using the pre- and post-calibration information performed at Sea-Bird Electronics for SBE19plus. 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	29 Jan-13	19 Dec-13	islope / ioffset / iSoc
Conductivity slope correction	0.9999832	1.0000000	1.00000716
Temperature offset	-5.5e-4 ºC	-0.0e-4 ºC	-2.34e-4 ºC
Oxygen slope correction (iSoc)	1.0024	1.0000	0.99898

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 (133-143 days, 138 days used as a constant), n is the number of days between pre- and post-cruise calibrations (324 days), and postslope is the slope from calibration sheet as measured by Sea-Bird Electronics (0.9999832)

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 mean offset temperature from the calibration sheet as measured by Sea-Bird Electronics (-5.5e-4 ºC)

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 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 (.xmlcon) file, we use the pre-cruise calibration coefficients and use the calculated islope (1.00000716) for the value of slope for conductivity and the calculated offset (-2.34e-4 ºC) for temperature. For Oxygen measurements we use the calculated slope factor iSoc (0.99898) to find the newSoc value (0.475624).

2.1.2. SBE25plus calibration

The sensors on the SBE25plus were calibrated prior to the cruise in 2013.

For the purpose of calibration of the salinity measurements obtained by the CTD, water samples were taken at great depth on stations with depths greater than 500 m in water masses which are to be expected to be relative stable in time due to weak stratification. 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/weakly stratified with a CTD fluctuation of about ±0.002 in salinity, which is similar to the precession of the conductivity sensor. The salinity measurement used is taken as the mean CTD value centred on the expected time of water sampler closure.

Water samples were taken on 5 stations with two replicates on each from the same Niskin water sampler and additional water samples were taken on 3 other stations but without replicates. Bottle salinities were measured by the Greenland Institute of Natural Resources using an Autosal Guildline 8410 portable lab salinometer with a nominal precision of 0.003 in salinity. 5 out of 13 water samples turn out to be problematic, but the remaining 8 water samples were used to determine an offset of salinity of the CTD measurement. The mean offset of CTD salinity measurements minus bottle salinity observations was found to 0.0066 ± 0.0079. The CTD salinity measurements were corrected using this value for all stations.

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. There is no offset at the surface (p=0 dbar at z=0 m) for the two instruments.

2.3. Data processing

The CTD data were analysed using SBE Data Processing version 7.22.4 software provided by Seabird (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: Instrument	Temperature (seconds)	Conductivity/Salinity (seconds)	Pressure (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 pluming 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: Instrument	Temperature relative to pressure (seconds)	Conductivity/Salinity relative to pressure (seconds)	Oxygen relative to pressure (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: Instrument	Thermal anomaly amplitude (alpha)	Thermal anomaly time 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.

3. Atmospheric conditions in 2013

The North Atlantic marine climate is to some extend 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 2012/13 was negative[1] (Figure 6).

The normal route for the low pressure systems during the winter months is from Labrador, across the Atlantic Ocean passing Iceland, and eventually they land in northern Europe, preferable southern Norway. In winter 2012/13 the intensity of low pressure systems culminates in mean over the Irminger Basin (Figure 7a), which is further south than usual. The Icelandic Low and Azores High were both weakening (Figure 7b), resulting in weaker westerlies over the North Atlantic Ocean compared to normal conditions[2] defined as the time period 1981-2010 (Figure 8b).

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[1] The NAO index using December − February was also positive.

[2] Normal conditions/anomaly defined as the difference from normal conditions relative to the period 1981–2010, wchch consists of a relative cold period (first half) and a relative warm period (latter half). Note, that before 2014 the anomalies was calculated relative to the period 1968–1996 (mostly cold period), which is also the case for previous similar reports on the oceanographic conditions off West Greenland.

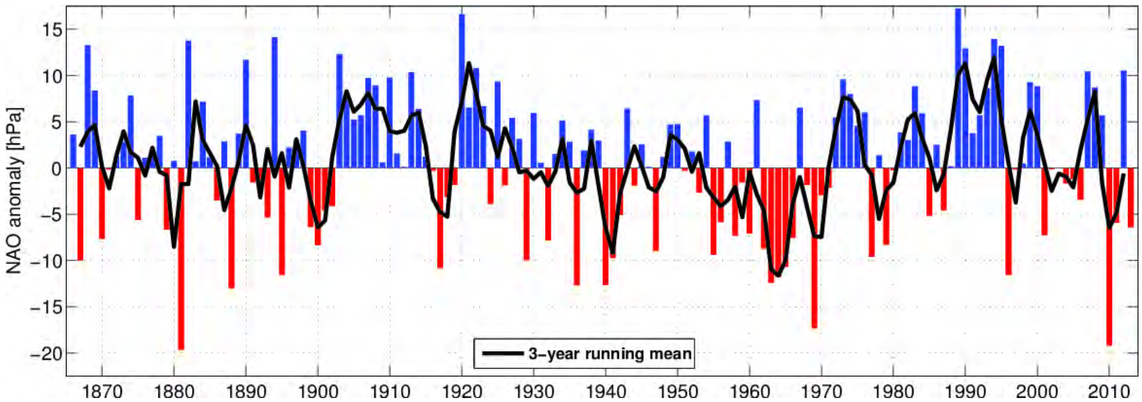

Figure 6. Time series of winter (December–March) index of the NAO from 1865/1866–2012/13. The heavy solid line represents the NAO index smoothed with a 3-year running mean filter to remove fluctuations with periods less than 3 years. In the figure the winter 1865/1866 is labelled 1866 etc.. The mean and standard deviation of the time series is 0.73 ± 7.5 hPa. The 2012/13 value is -6.43 hPa. Data are updated, as described in Buch et al. (2004), from http://www.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. This was also the case during winter 2012/13. The mean temperature was above normal over the West Greenland region and below normal in northern Europe (Figure 9a). In Nuuk the mean winter air temperature (DJFM) was -4.60°C which is 3.1°C above normal corresponding to more than one standard deviation (Figure 10). Southeast Greenland waters did also experience warmer winter temperatures than normal, but not as pronounced as in West Greenland.

The annual air temperature anomaly for 2013 was positive over West Greenland waters and close to zero elsewhere over the North Atlantic Ocean (Figure 9b). Here, the anomaly is calculated relative to the time period 1981-2010, which represent periods with cold conditions (first half) and a period with warm conditions (latter half). The long atmospheric temperature time series for Nuuk and Tasiilaq reveals warmer than mean conditions for both stations, but most pronounced for Nuuk. In Nuuk, the annual mean temperature (-0.46°C) was 1.16°C above average almost corresponding to one standard deviation, whereas the temperature at Tasiilaq (-0.36°C) was only 0.73°C above average and less than one standard deviation.

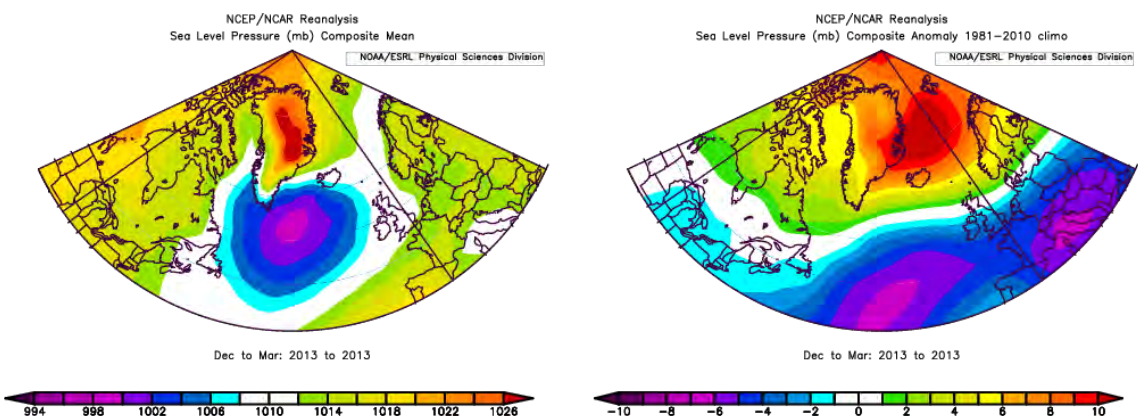

Figure 7. a) Winter (DJFM) sea level pressure for 2012/13 in the North Atlantic region. b) Sea level pressure anomaly. NCEP/NCAR re-analysis (from http://www.esrl.noaa.gov/psd/).

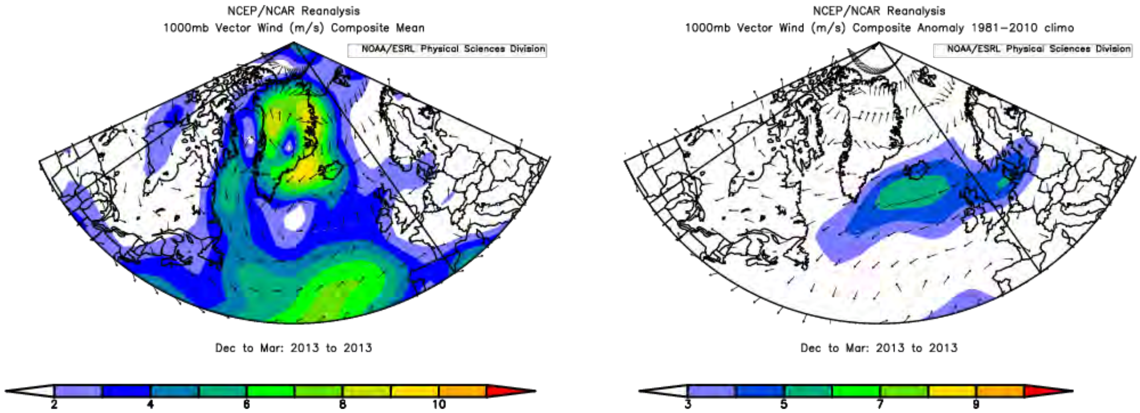

Figure 8. a) Winter (DJFM) wind (left) for 2012/13 in the North Atlantic region. b) Wind anomaly. NCEP/NCAR re-analysis (from http://www.esrl.noaa.gov/psd/).

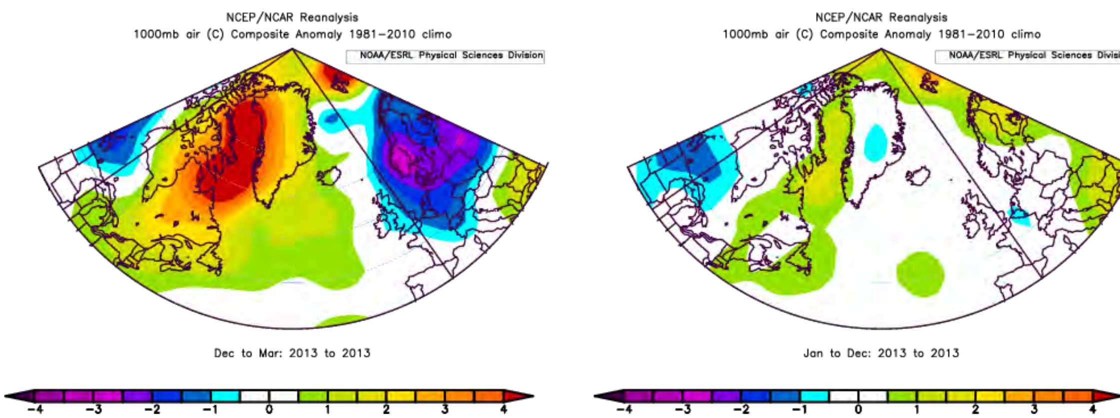

Figure 9. a) Winter (DJFM) mean air temperature anomaly for 2012/13 in the North Atlantic region. b) Annual mean air temperature anomaly for 2013. NCEP/NCAR re-analysis (from http://www.esrl.noaa.gov/psd/).

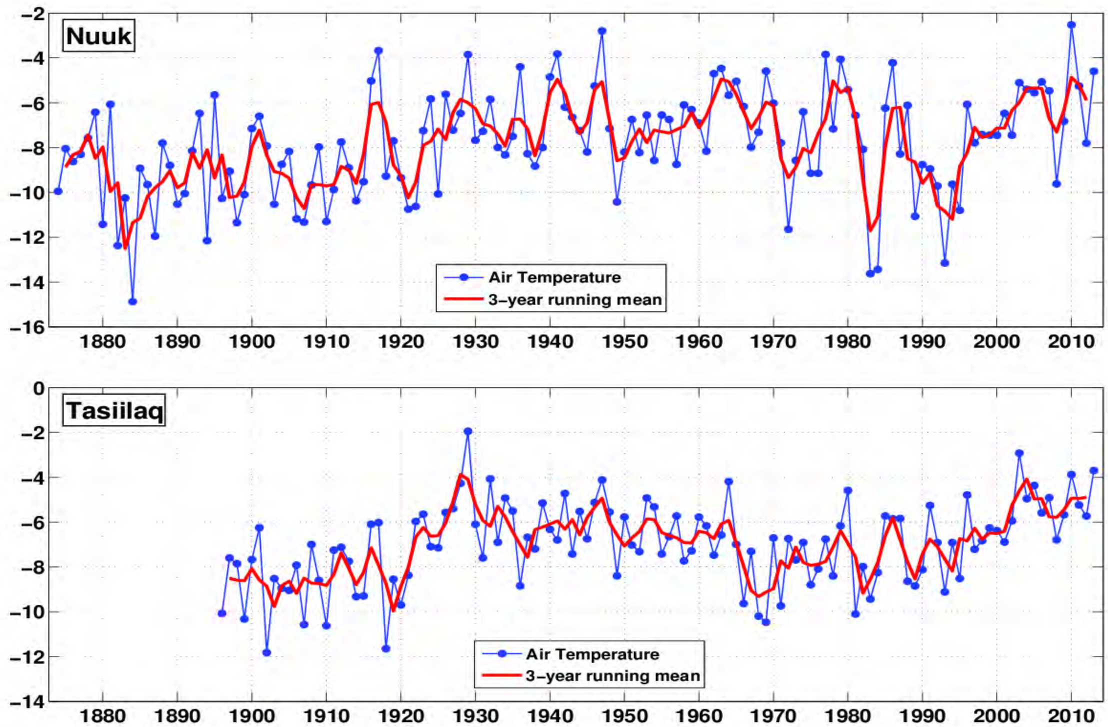

Figure 10. Winter (DJFM) mean air temperature observed at Nuuk and Tasiilaq for the period 1874–2013. The mean and standard deviation for the whole time series is -7.8 ± 2.3 °C for Nuuk and -7.0 ± 1.8 °C for Tasiilaq. Values for 2013 are respectively -4.60 °C and -3.70 °C. Nuuk temperature was taken 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.

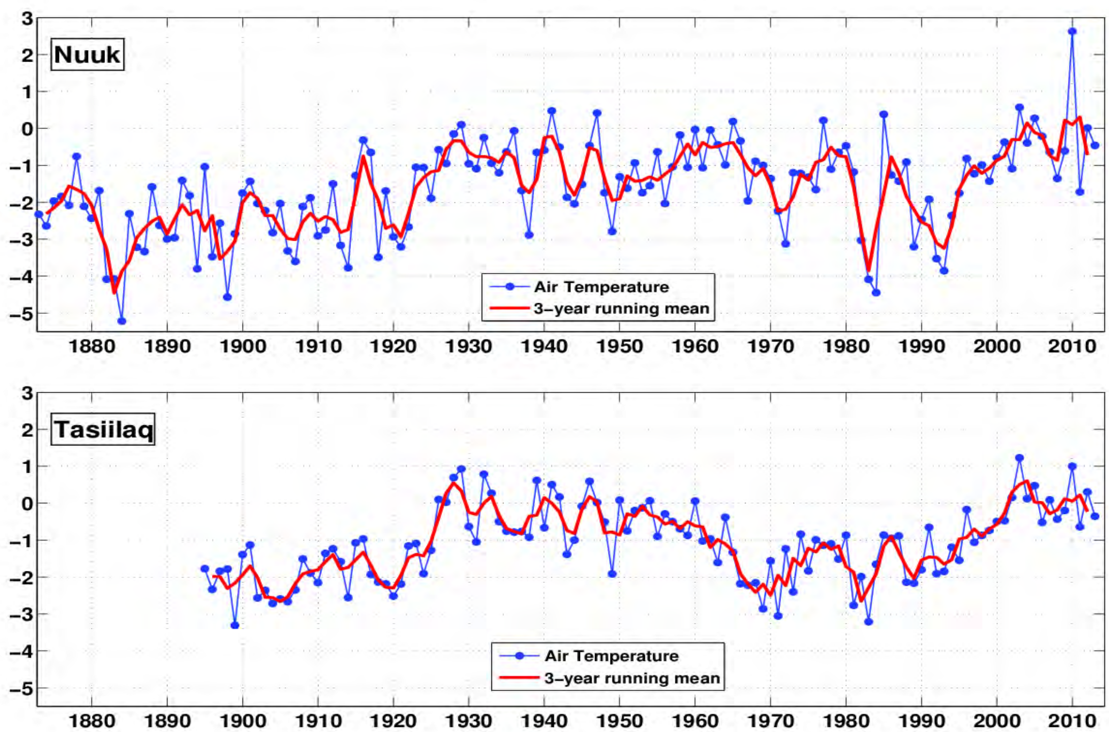

Figure 11. Annual mean air temperature observed at Nuuk and Tasiilaq for the period 1873–2013. The mean and standard deviation is -1.62 ± 1.25 °C for Nuuk and -1.09 ± 1.00 °C for Tasiilaq. Values for 2013 are respectively -0.46 °C and -0.36 °C. Nuuk temperature was taken from the Nuuk airport synop station 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 2013

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 2013 the mean temperature (2.30ºC) was slightly above average while the salinity (33.41) was equal to the mean value on top of Fylla Bank in the middle of June (Figure 12, Table 1). The slightly positive temperature anomaly, despite of average salinity anomaly, is likely a result of direct atmospheric heating over the West Greenland waters, as the atmosphere was warmer than normal (Figure 9).

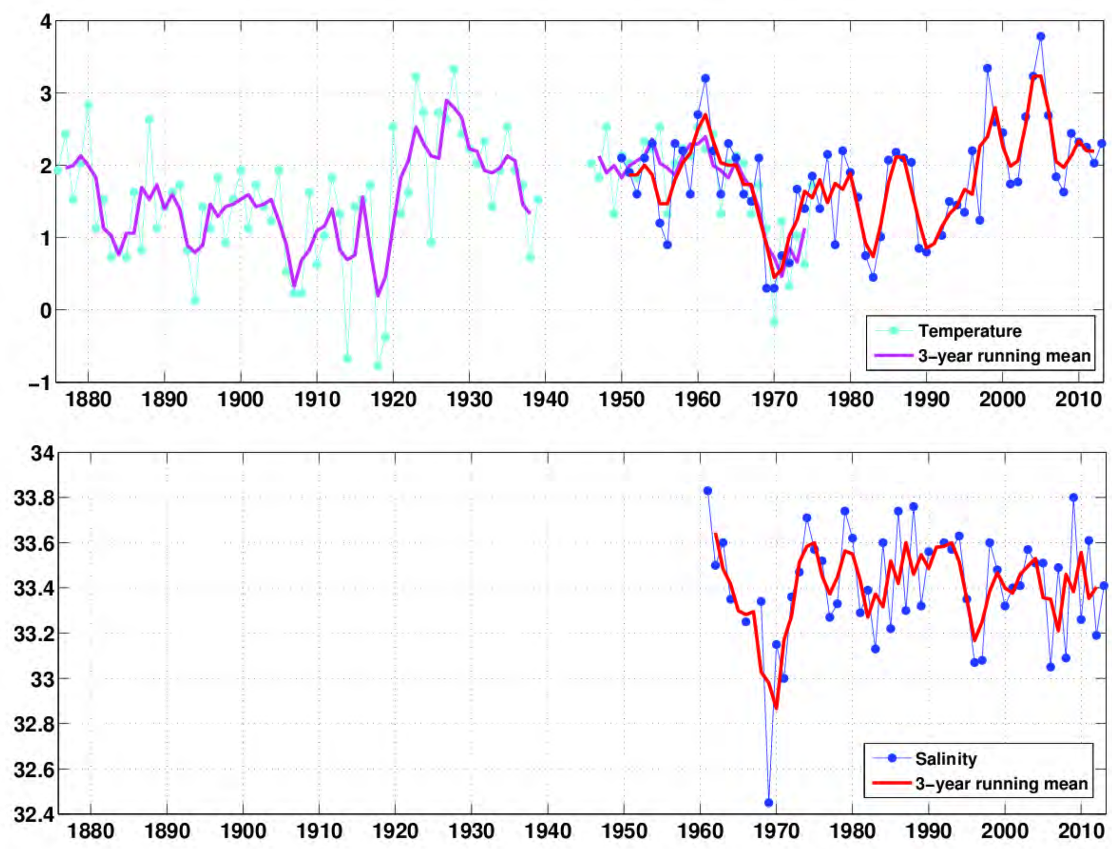

Figure 12. Time series of mean temperature (top) and salinity (bottom) on top of Fylla Bank (Station 2, 0–40 m) in the middle of June for the period 1950–2013. The red curve is the 3 year running mean value. Statistics is shown in Table 1. The time series for temperature (top, magenta/purple) is extended 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 time series are corrected for annual variations in order to get the temperature in mid-June. The Smed temperature data (Smed, 1978) shown in Figure 12 are not included in the statistics.

Fylla Bank	Temperature [°C]	Salinity	2013	
St. 2	Mean ± std	Mean ± std	Tpot	S
0–40 m	1.82 ± 0.74°C	33.41 ± 0.25	2.30°C	33.41

The sea-ice extent was slightly less than average (Figure 15), but with lower concentrations for the Baffin Bay during winter/spring (Figure 16). Contrary, the sea ice concentration off Northeast Greenland was higher than normal until summer, but further south the extent and concentrations was slightly below average. The same pattern is also found in the air temperature anomaly (Figure 9), suggesting that the sea-ice deviations is partly controlled by the air temperature anomalies in 2013.

The surface temperatures and salinities observed during the 2013 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 in the temperature measurements due to surface heating from the atmosphere. During the present surveys it can be traced north almost 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 and a very stable stratification, 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°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) and Myers and Ribergaard (2013). The upper part of this cold water is easily recognized in Figure 22 and in its core at depth with minimum temperature in Figure 23.

A vertical section of salinity, temperature and density over the shelf from Cape Farewell to Upernavik is shown in Figure 26. Polar Water with salinities below 33.4 is found at Cape Farewell in the upper 100 m and further north to Fylla Bank in the upper ~40 m. At Maniitsoq the salinities has increased due to mixing, but the salinity still remains quite low below 33.7 in the upper ~75 m. The surface temperature of the Polar Water is relative high above 2°C in the upper 30 m due to solar radiation. The minimum temperature is mainly above 1°C from Paamiut to Sisimiut. From Aasiaat section and further north to the Upernavik section the surface salinities decreases and a colder layer was found with temperatures below -1°C in its core centred at about 50 m depth. This is likely Polar Water from the Baffin Current as described above.

The normalized near-surface (20–40 m) temperature and salinity indices for the Southwest Greenland Waters are shown in Figure 13. The near-surface salinity index for 2013 were close to zero, whereas the corresponding temperature index was slightly negative compared to the recent time period 1993–2013 (mainly a warm period). This indicates normal salinity conditions in the near surface waters suggesting about normal presence of Polar Water. The slightly negative temperature index is mainly due to lower temperature than normal in the surface waters north of Fylla Bank, revealed by lower than normal surface temperatures (0–50 m) over the continental slope at Maniitsoq (Figure 18 ; Table 3) and Sisimiut (Figure 19, Table 4) sections. Similar indices are obtained for similar calculations using the upper 100 m and using the interval 50–150 m (not shown).

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 ; Table 2). Further north at Maniitsoq st.5 (Figure 18 ; Table 3) and Sisimiut st.5 (Figure 19 ; Table 4), the salinities are close to normal, while the temperatures are slightly above normal for the same depth interval. In Disko Bay at Ilulissat st.3 (Figure 20), the temperature and salinity was higher than normal.

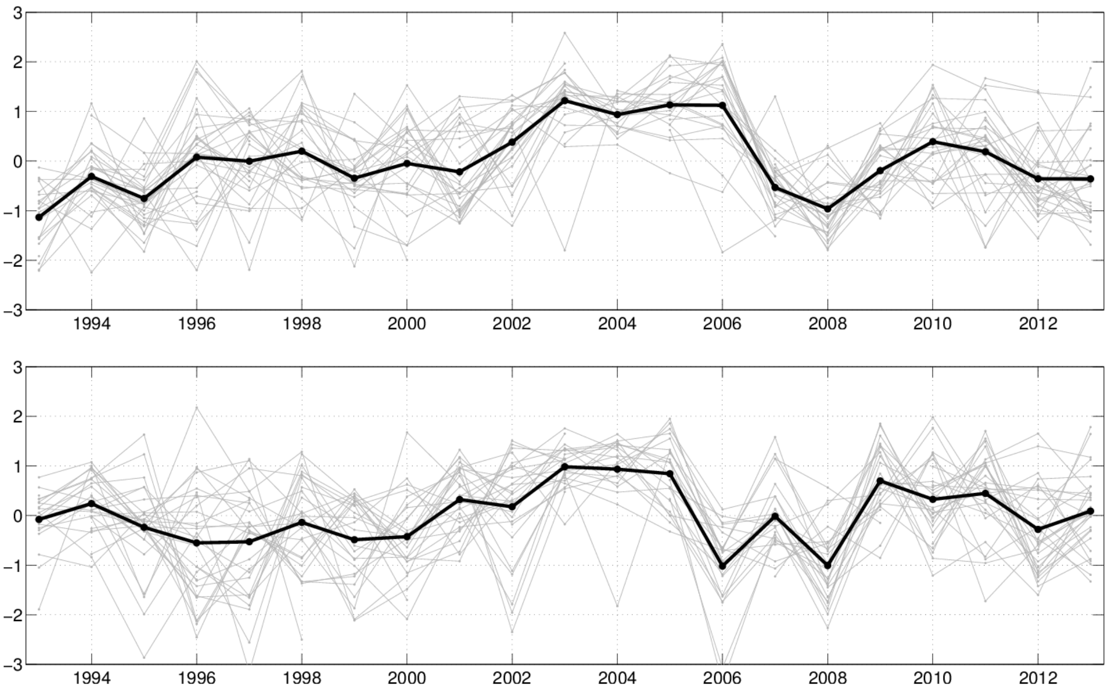

Figure 13. Near-surface (20–40 m) temperature (upper) and salinity (lower) index for the West Greenland waters derived from CTD measurements from Cape Farewell to Sisimiut taken during the time period 1993–2013. Black thick line is the average of all the 5 individual stations on each of the 6 sections, and the thin grey lines are the 30 individual stations. The 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.

At intermediate depths water of Atlantic origin forms a layer with maximum salinity and temperature. Horizontal maps of salinity and temperature at depth of maximum temperature and maximum salinity 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 27. The vertical distribution of temperature, salinity and density at sections along the West Greenland coastline is shown in Figure 28 − Figure 37 and within the Disko Bay in Figure 38 – Figure 41.

Pure Irminger Water (T ≥ 4.5^{o}C; S ≥ 34.95) was traced north to the Paamiut section and modified Irminger Water (T ≥ 3.5^{o}C ; 34.88 ≤ 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, relative warm (> 3°C) water 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 (34.83) of this layer has decreased close to average, whereas temperature (4.55°C) is still above average (Table 2). However, similar time series west of the banks further north at Maniitsoq st.5 (Figure 18 ; Table 3) and Sisimiut st.5 (Figure 19, Table 4) shows, that the Irminger Water component of the West Greenland Current still brings considerable amount of heat and salt to the area in 2013. Similar, the bottom temperature and salinity was among the highest observed within the Disko Bay at Ilulissat st.3 (Figure 20). This indicates that the presence of Irminger Water was still high in 2013.

On the three southernmost sections, the salinity of the Irminger Water is reduced in 2013 compared to recent years. The pure Irminger Water does not occupy as large a volume as in recent years. It has to a large extent been replaced by modified Irminger Water (Figure 14). The presence of Irminger Water is still high and higher than before mid-1990s, but the core salinity has reduced. In contrary, the temperature of the Irminger Water component is still high, which is likely a result of the general warming of the North Atlantic Ocean. West of Fylla Bank and further north, the salinity and temperature of the Irminger Water component is still on historical high levels.

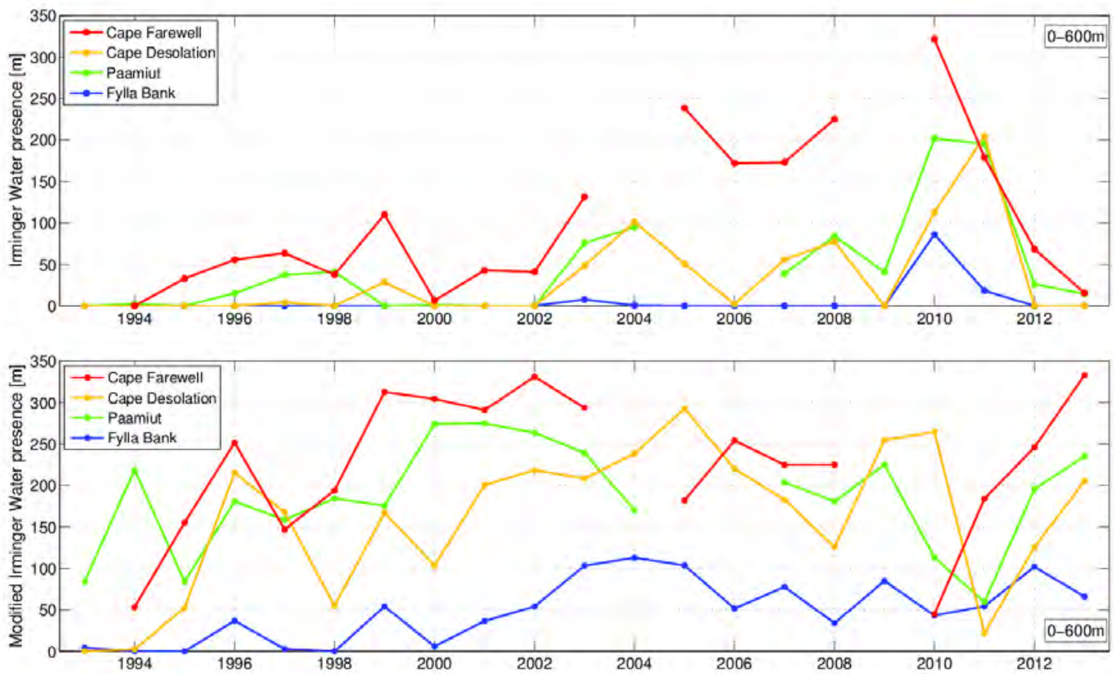

Figure 14. Indices for the presence of pure Irminger Water (upper ; T ≥ 4.5°C; S ≥ 34.95) and modified Irminger Water (lower ; T ≥ 3.5°C ; 34.88 ≤ S < 34.95) for Cape Farewell, Cape Desolation, Paamiut and Fylla Bank sections in the depth interval 0−600 m. The indices are calculated as the mean thickness of the water presence on all the stations on the individual section. The minimum number of stations for each calculation is 3 (out of 5).

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 2013 were characterised by:

- Negative NAO index resulting in strengthen westerlies over the North Atlantic during winter 2012/13.
- Winter air temperature over the West Greenland waters was higher than normal and colder than normal over northern Europe consistent with positive NAO index. The annual air temperature over West Greenland waters was also higher than normal, but not as pronounced as the winter anomaly.
- The sea-ice extent was slightly below average and with lower concentrations for the Baffin Bay and Southeast Greenland during winter/spring.
- High presence of Irminger Water and 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. However, the pure Irminger Water does not occupy as large a volume as in recent years and it has to a large extent been replaced by modified Irminger Water.
    - West of Maniitsoq and Sisimiut, the mean temperature and salinity in 400–600 m depth were higher than normal. High values were also found in Disko Bay off Ilulissat at 300 m depth.
    - Water temperature on top of Fylla Bank was above average whereas the salinity was equal to the long term mean value. The positive water temperature anomaly is likely due to warmer than normal atmospheric conditions.
    - Average near-surface (20–40 m) salinity indices for Southwest Greenland Waters.
    - About normal salinities and slightly above normal temperatures observed at Maniitsoq st.5 and Sisimiut st.5 in the depth interval 50–150 m. Contrary, west of Fylla Bank (st.4) and in Disko Bay at Ilulissat st.3, the salinity and temperature was above normal for the same depth interval.

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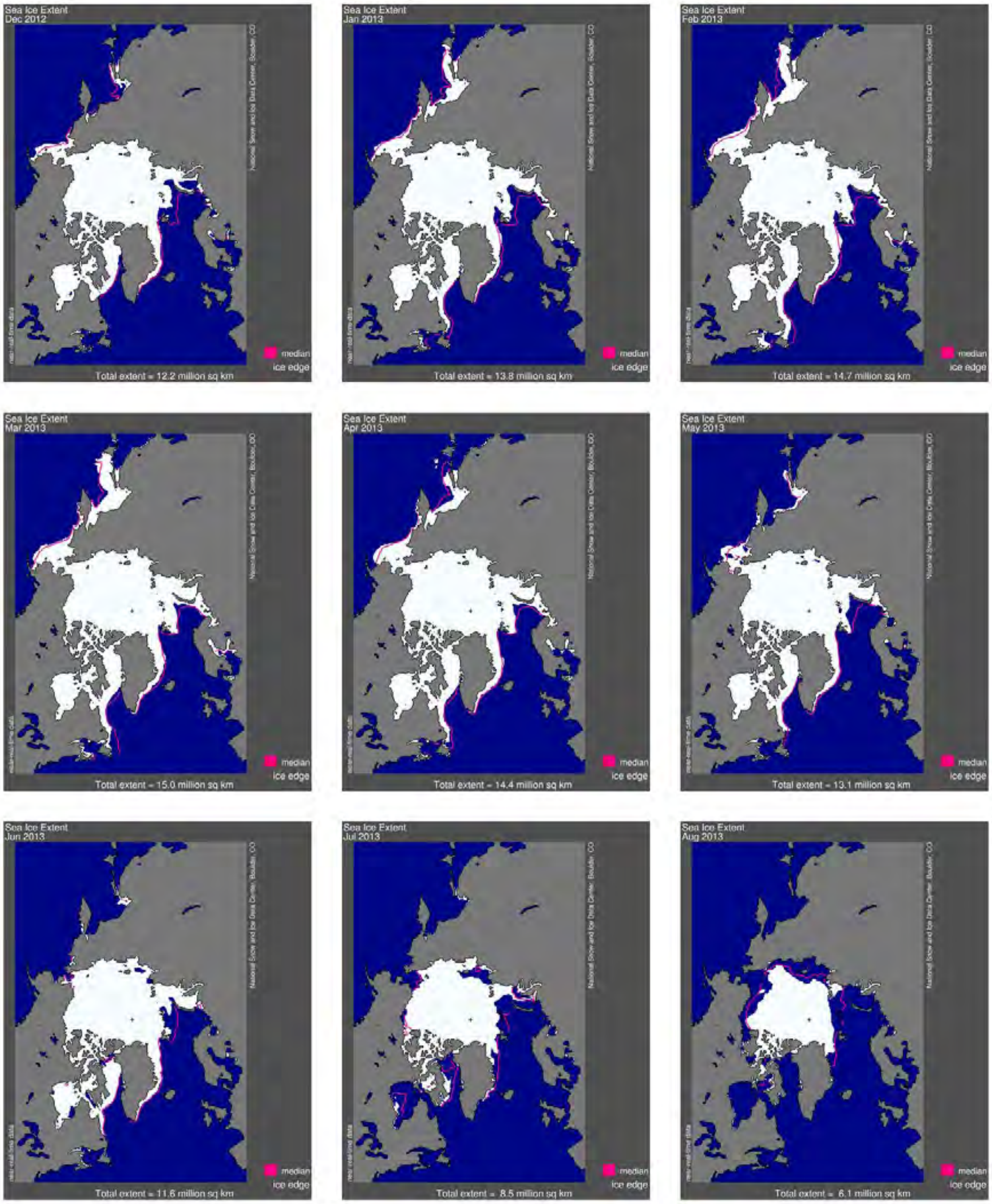


Figure 15. *Sea ice extend (> 15%) for winter (DJF), spring (MAM), and summer (JJA) 2013. Pink line shows the median ice edge for 1981-2010. Figures from National Snow and Ice Center (http://nsidc.org/)*

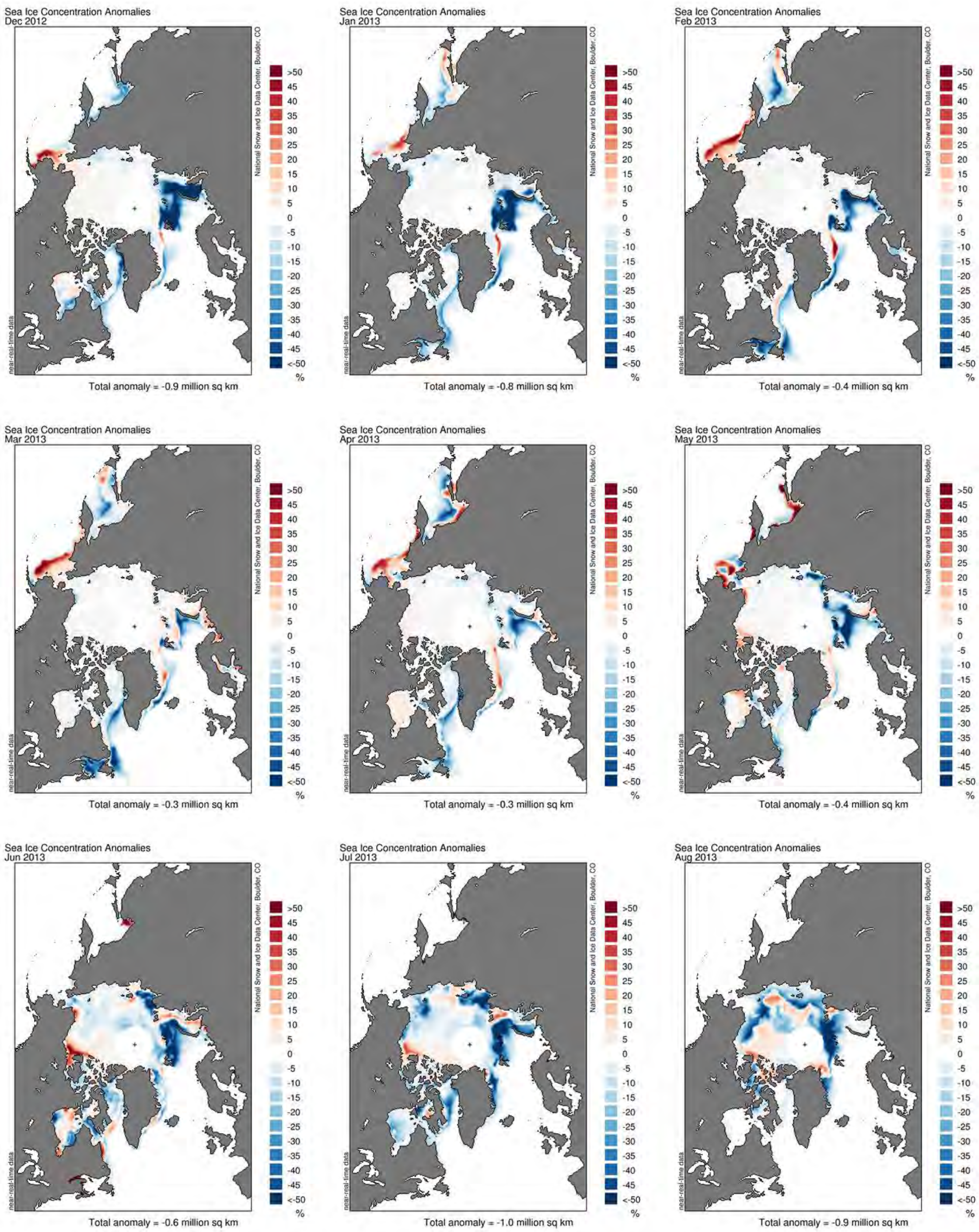


Figure 16. *Sea ice concentration anomalies for winter (DJF), spring (MAM), and summer (JJA) 2013. Anomalies are relative to the median ice concentration for 1981-2010. Figures from National Snow and Ice Center (http://nsidc.org/)*

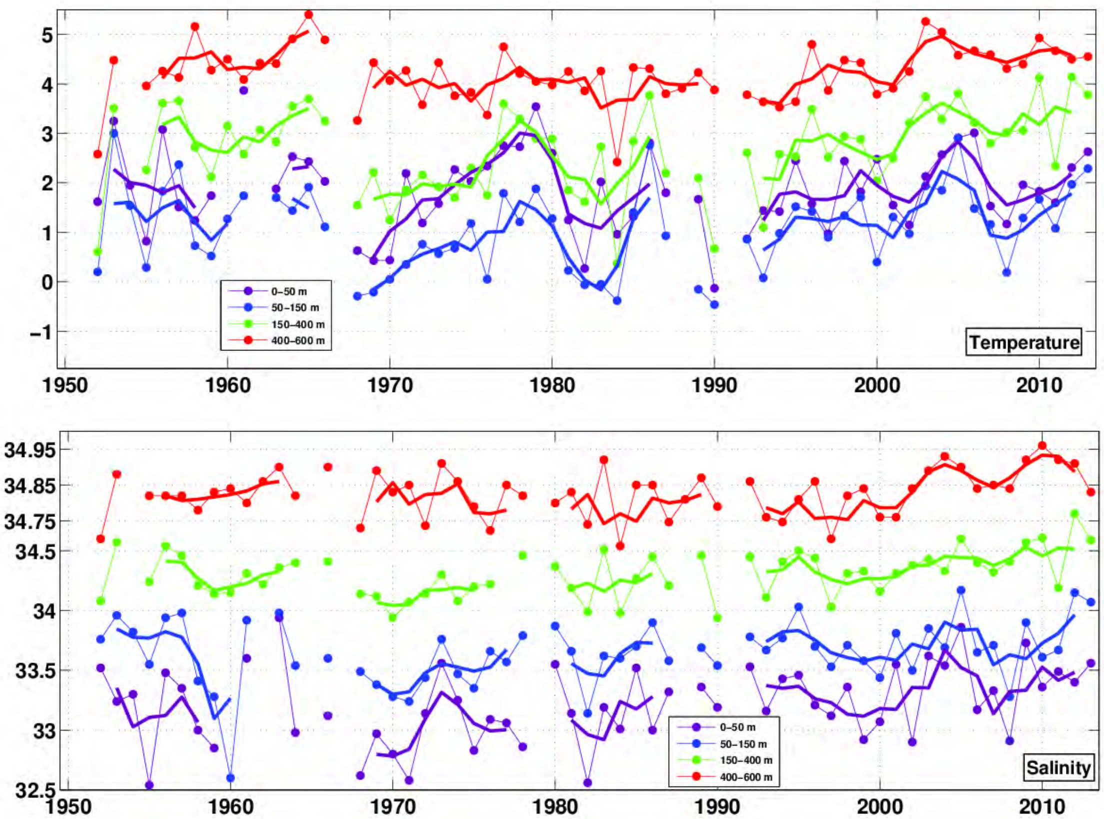
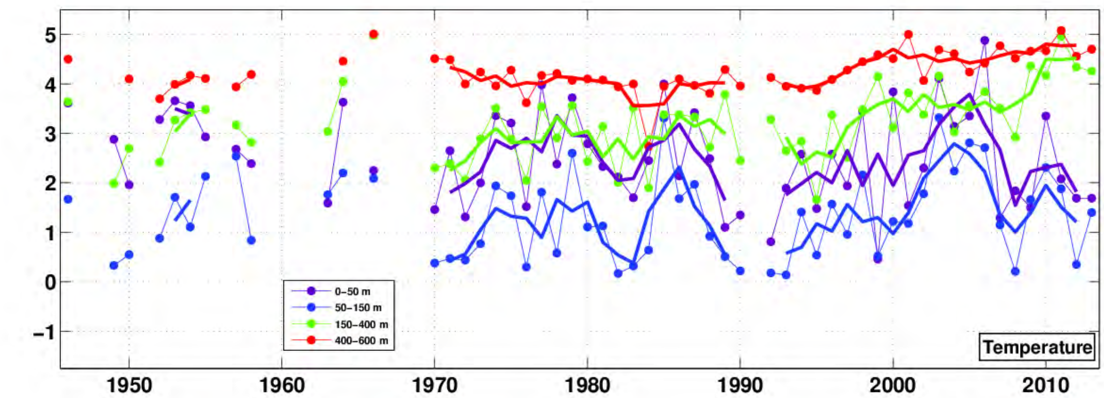


Figure 17. Timeseries of mean June-July temperature (top) and salinity (bottom) for the period 1950–2013 averaged in four different depth intervals west of Fylla Bank (st.4) over the continental slope. Thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics are shown in Table 2.

Table 2. Statistics for potential temperature and salinity at Fylla Bank st. 4. and values for 2013.

Fylla Bank St.4	Temperature [°C]	Salinity	2013	
	Mean ± std	Mean ± std	Tpot	S
0–50 m	1.87 ± 0.83°C	33.22 ± 0.32	2.63°C	33.56
50–150 m	1.08 ± 0.84°C	33.65 ± 0.27	2.29°C	34.07
150–400 m	2.65 ± 0.88°C	34.31 ± 0.19	3.78°C	34.59
400–600 m	4.21 ± 0.56°C	34.82 ± 0.08	4.55°C	34.83



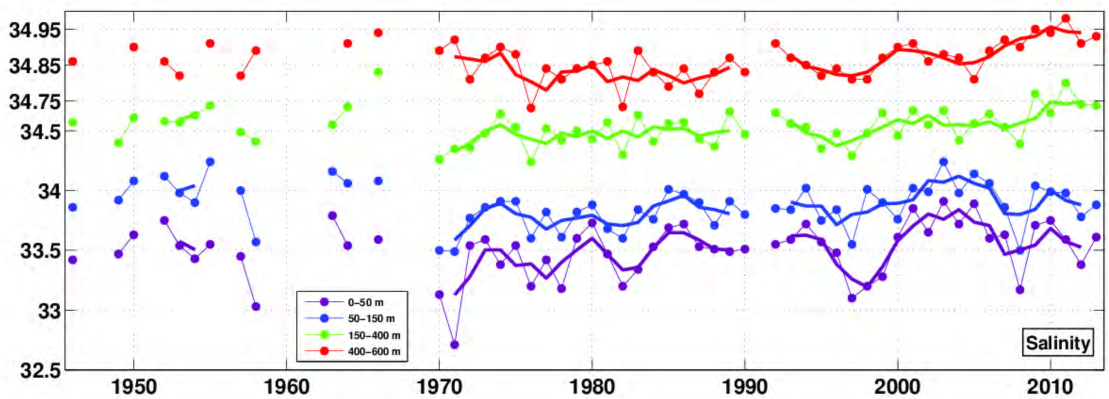


Figure 18. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1946–2013 in four different depth intervals west on Maniitsoq st.5 over the continental slope. The thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics is shown in Table 3.

Table 3. Statistics for potential temperature and salinity at Maniitsoq (Sukkertoppen) st. 5. and values for 2013.

Maniitsoq St.5	Temperature [°C]	Salinity	2013	
	Mean ± std	Mean ± std	Tpot	S
0–50 m	2.50 ± 0.96°C	33.50 ± 0.23	1.69°C	33.61
50–150 m	1.32 ± 0.86°C	33.88 ± 0.18	1.40°C	33.88
150–400 m	3.21 ± 0.75°C	34.53 ± 0.14	4.26°C	34.71
400–600 m	4.23 ± 0.39°C	34.86 ± 0.06	4.70°C	34.93

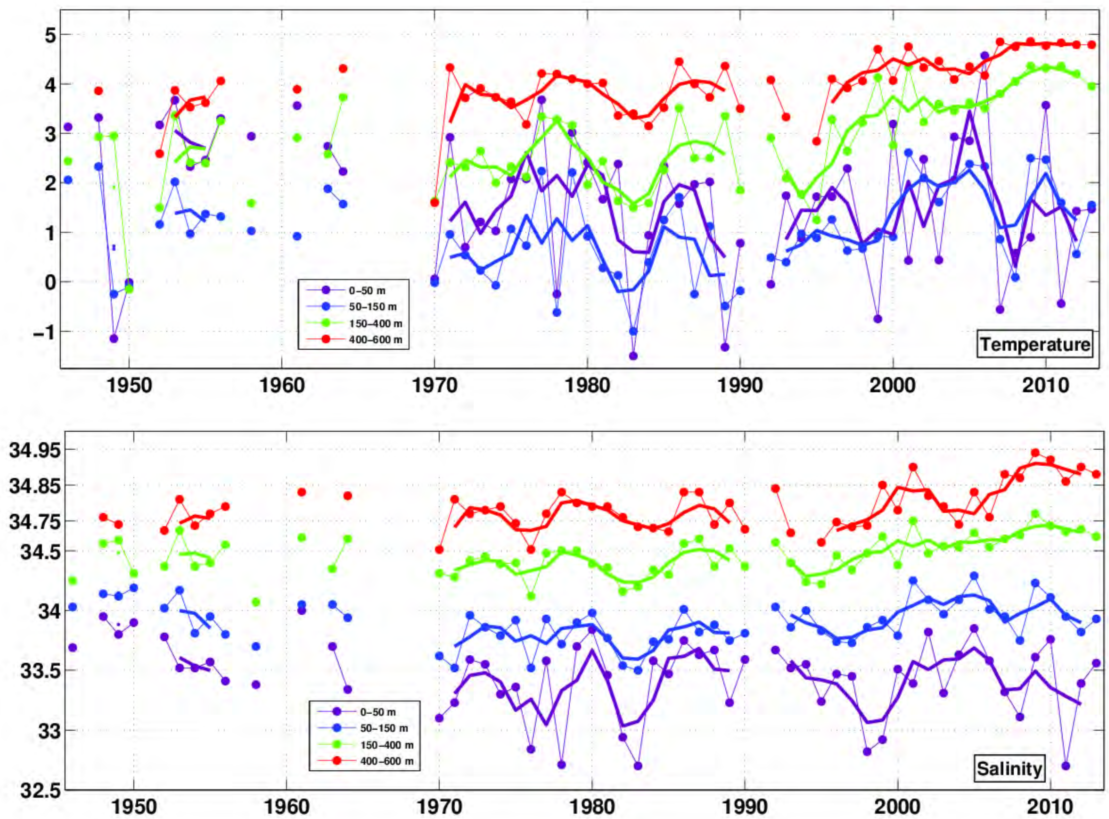


Figure 19. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1946–2013 in four different depth intervals at Sisimiut, st.5 over the continental slope. The thick curves are the 3 year running mean values. Note the change in scales at 34.75 for salinity. Statistics is shown in Table 4.

Table 4. Statistics for potential temperature and salinity at Sisimiut (Holsteinsborg) st. 5. and values for 2013.

Sisimiut St.5	Temperature [°C]	Salinity	2013	
	Mean ± std	Mean ± std	Tpot	S
0–50 m	1.67 ± 1.43°C	33.46 ± 0.32	1.47°C	33.56
50–150 m	1.02 ± 0.90°C	33.90 ± 0.18	1.55°C	33.93
150–400 m	2.81 ± 0.94°C	34.46 ± 0.16	3.95°C	34.62
400–600 m	3.97 ± 0.63°C	34.77 ± 0.09	4.79°C	34.88

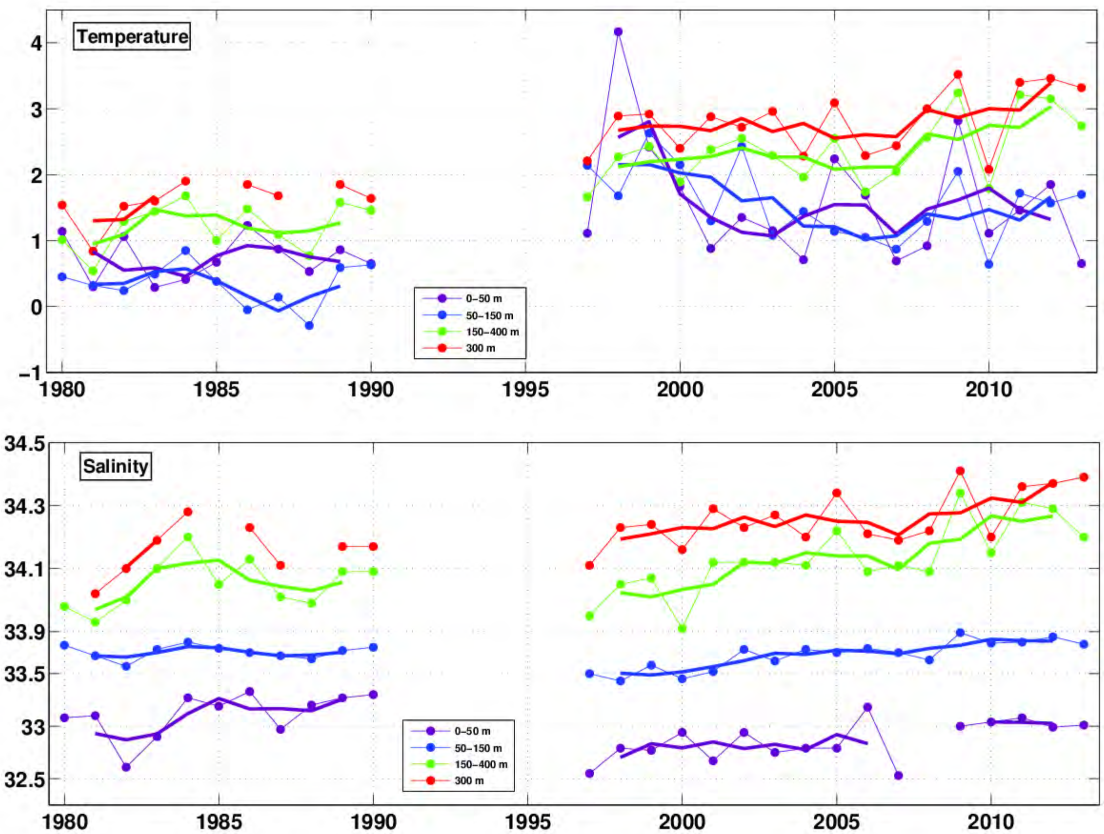


Figure 20. Timeseries of mean temperature (top) and mean salinity (bottom) for the period 1980–2013 in four different depth intervals on Ilulissat st.3 in the Disko Bay close to Jakobshavn Isbrae. The thick curves are the 3 year running mean values. Note the change in scales at 33.9 for salinity. Statistics is shown in Table 4.

Table 5. Statistics for potential temperature and salinity at Ilulissat-Skansen (Jakobshavn-Skansen) st. 3. and values for 2013.

Ilulissat St.3	Temperature [°C] Mean ± std	Salinity Mean ± std	2013 Tpot	2013 S
0–50 m	1.31 ± 0.90°C	32.98 ± 0.25	0.65°C	33.01
50–150 m	1.09 ± 0.76°C	33.69 ± 0.11	1.70°C	33.78
150–400 m	1.90 ± 0.73°C	34.10 ± 0.11	2.74°C	34.20
300 m	2.37 ± 0.71°C	34.23 ± 0.09	3.32°C	34.39

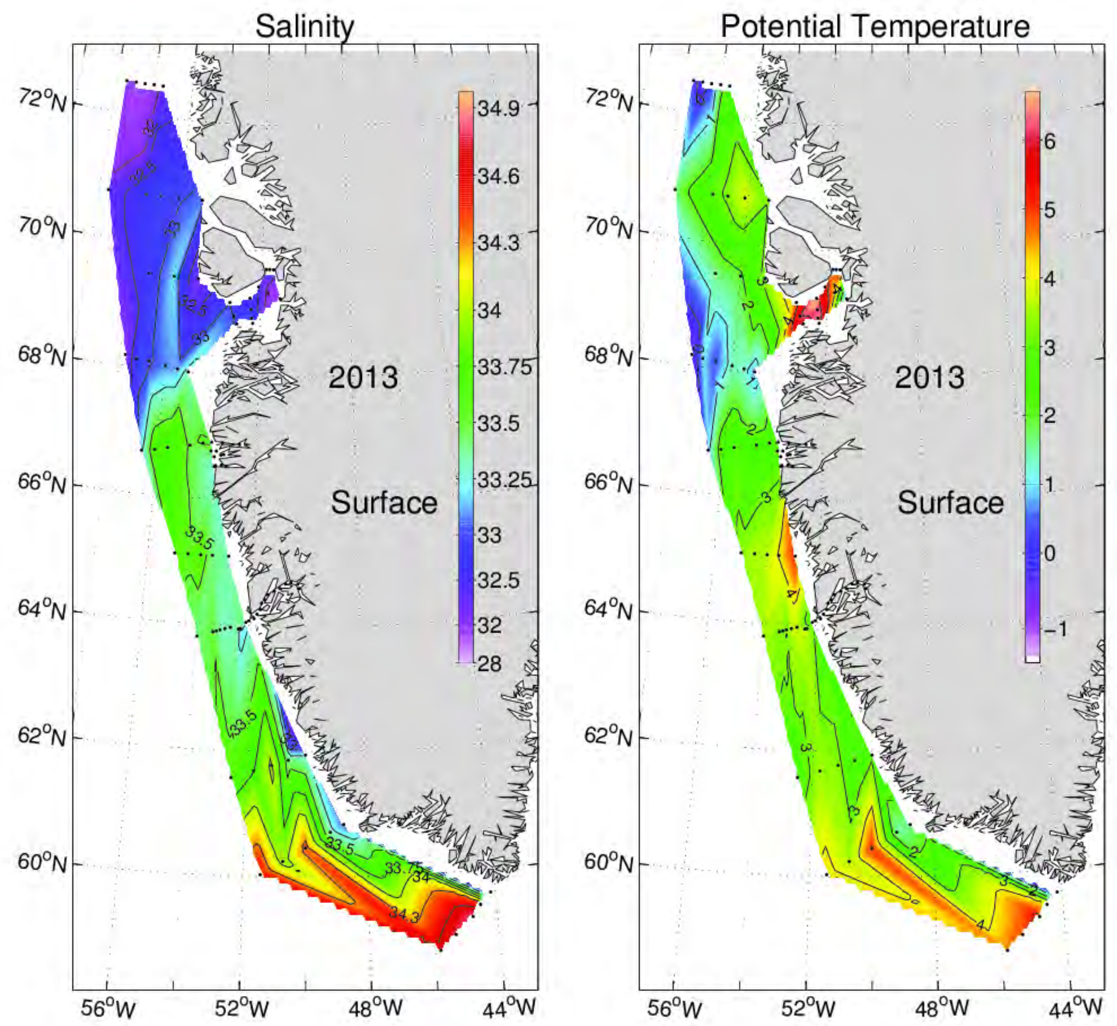


Figure 21. Surface salinity (left) and temperature (right) observed in 2013 taken June 11 – July 01.

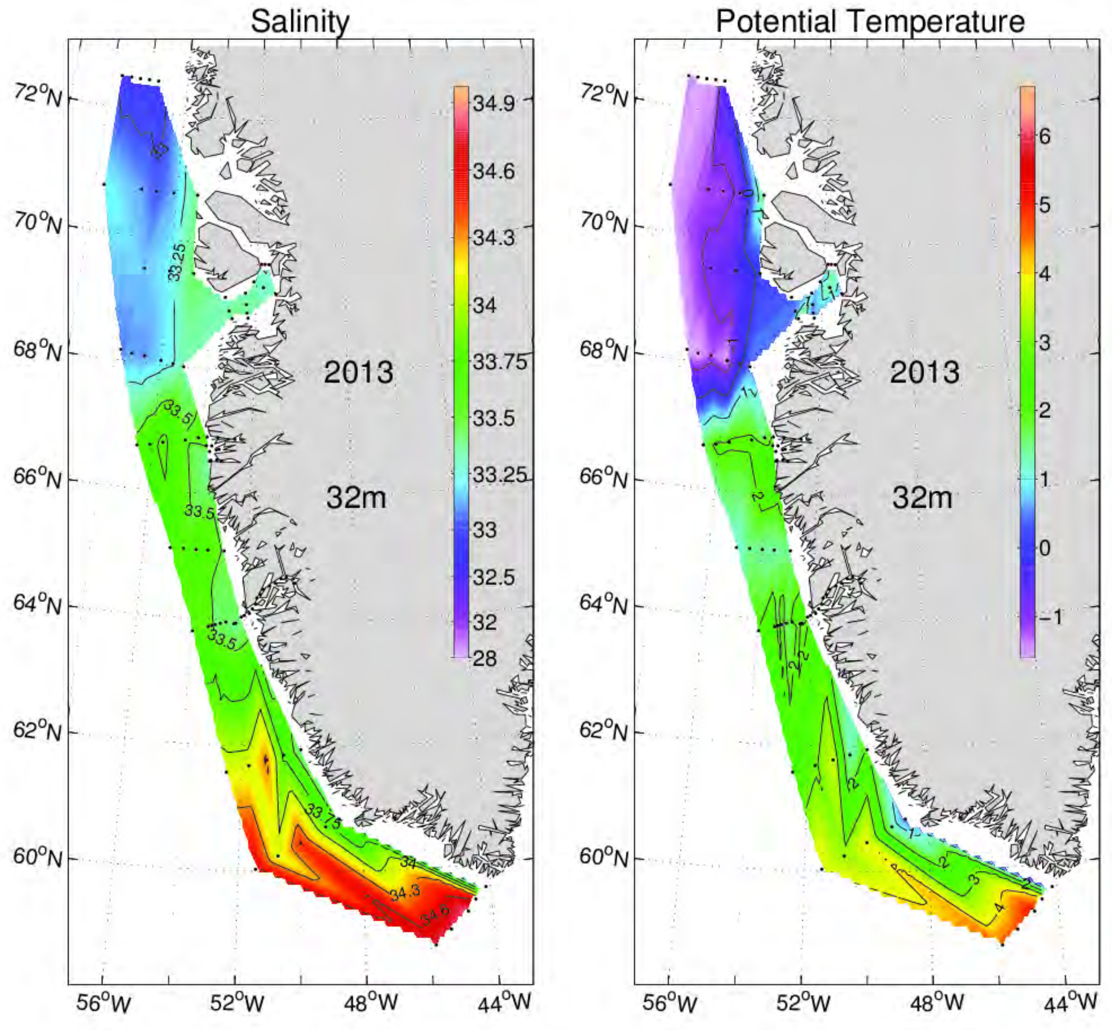


Figure 22. As Figure 21, but for 32 m depth.

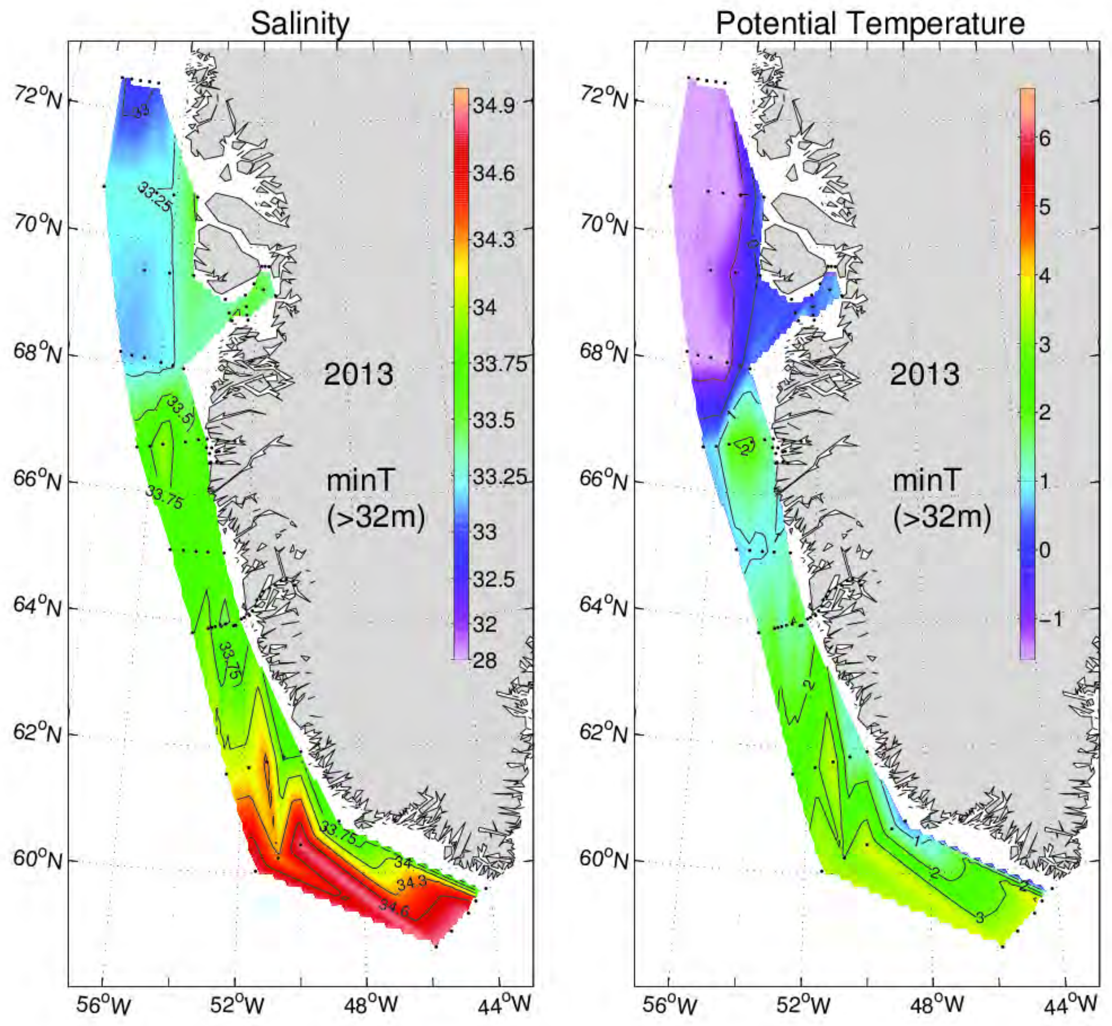


Figure 23. Salinity (left) and temperature (right) observed in 2013 (June 11 – July 01) at the depth of minimum temperature disregarding the upper 32 meters.

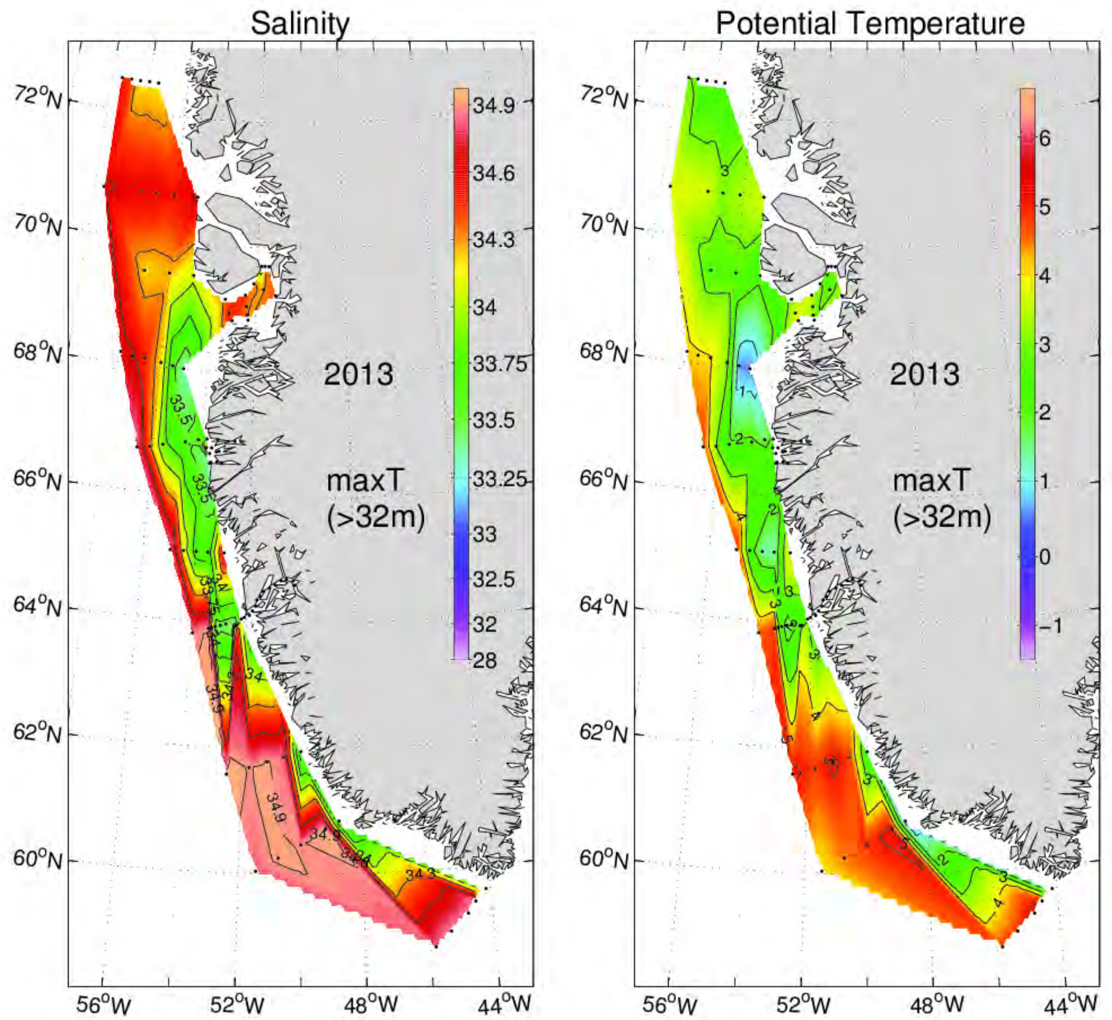


Figure 24. Salinity (left) and temperature (right) observed in 2013 (June 11 – July 01) at the depth of maximum temperature disregarding the upper 32 meters.

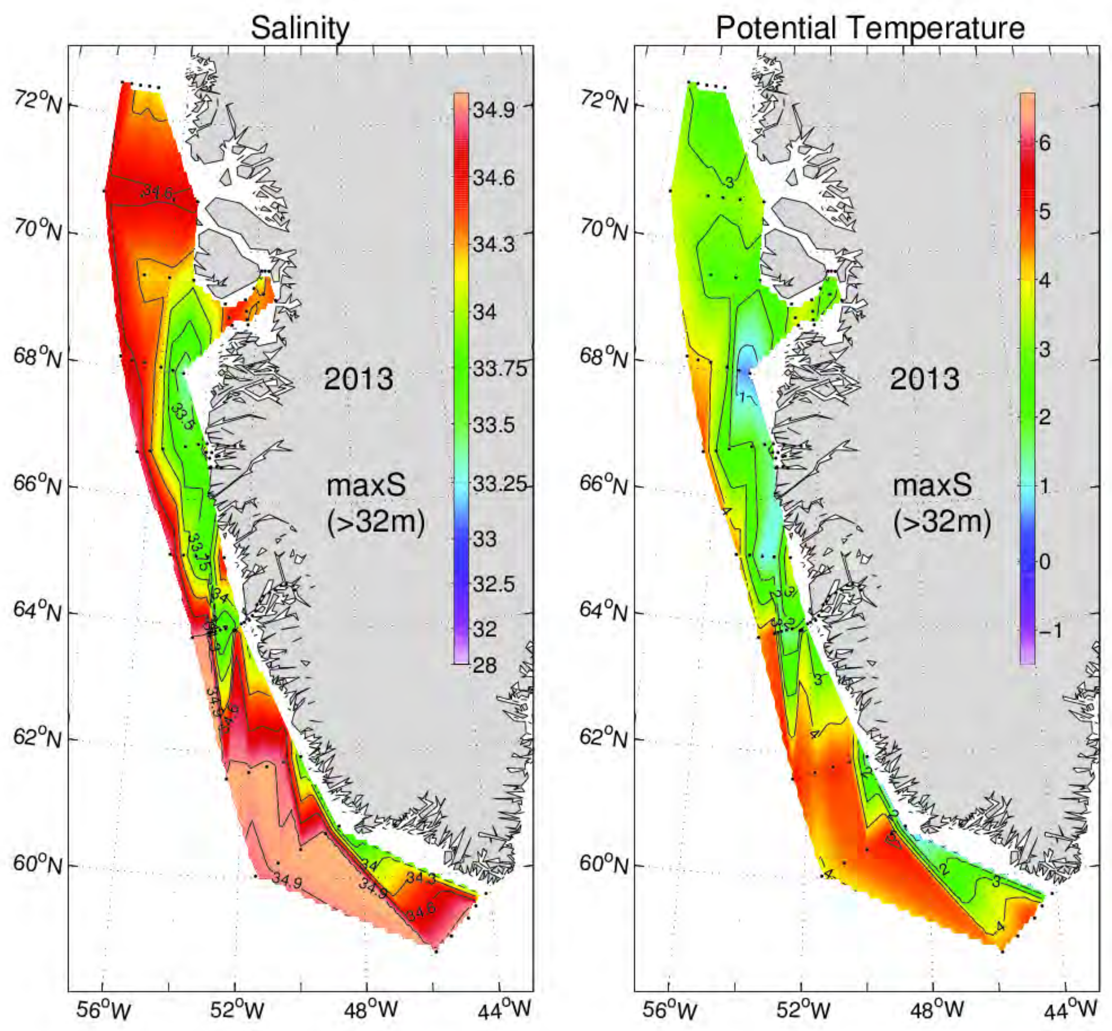


Figure 25. Salinity (left) and temperature (right) observed in 2013 (June 11 – July 01) at the depth of maximum salinity disregarding the upper 32 meters.

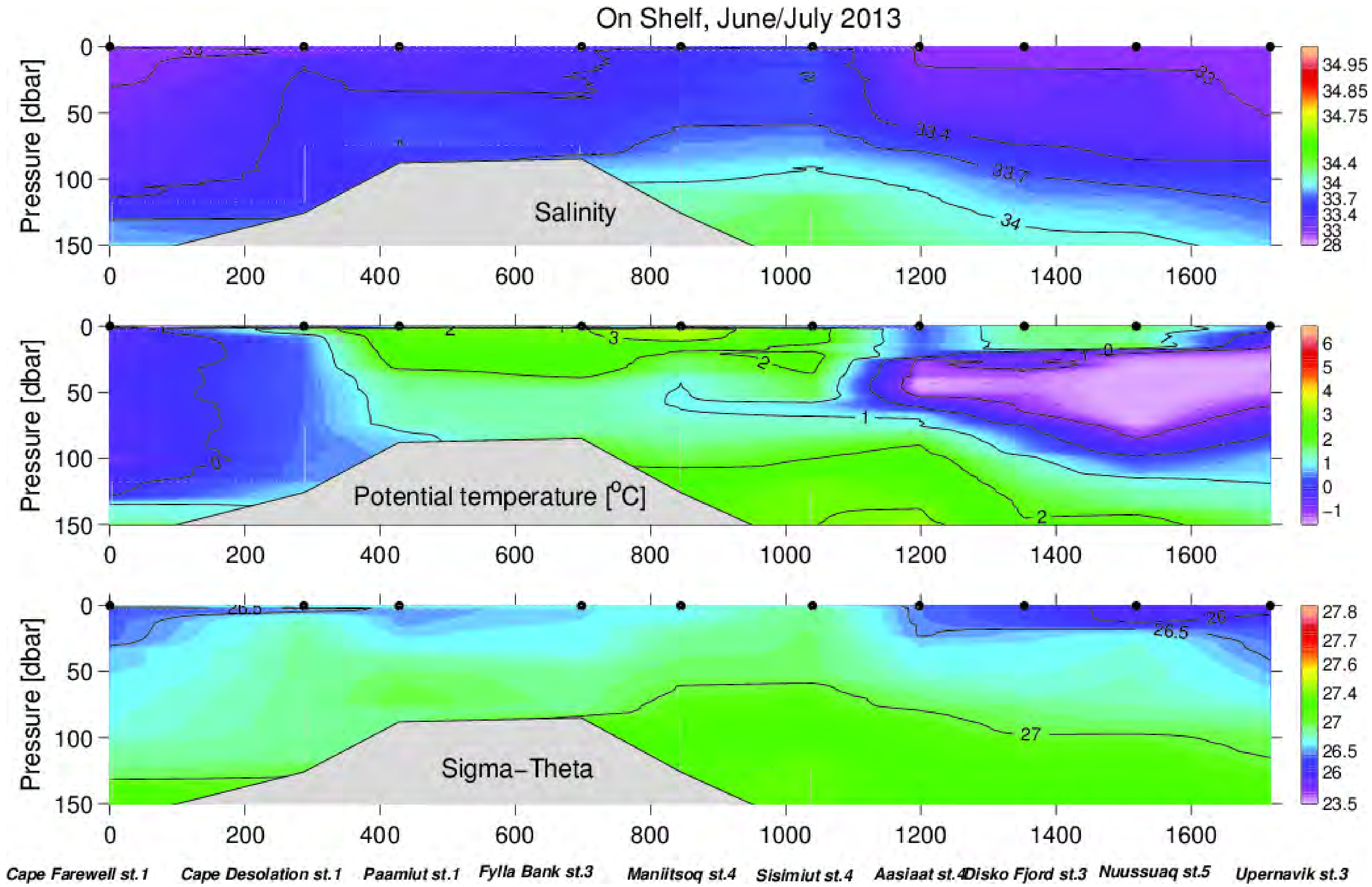


Figure 26. Vertical distribution of temperature, salinity and density over the shelf banks from Cape Farewell to Upernavik, June 11–July 01, 2013.

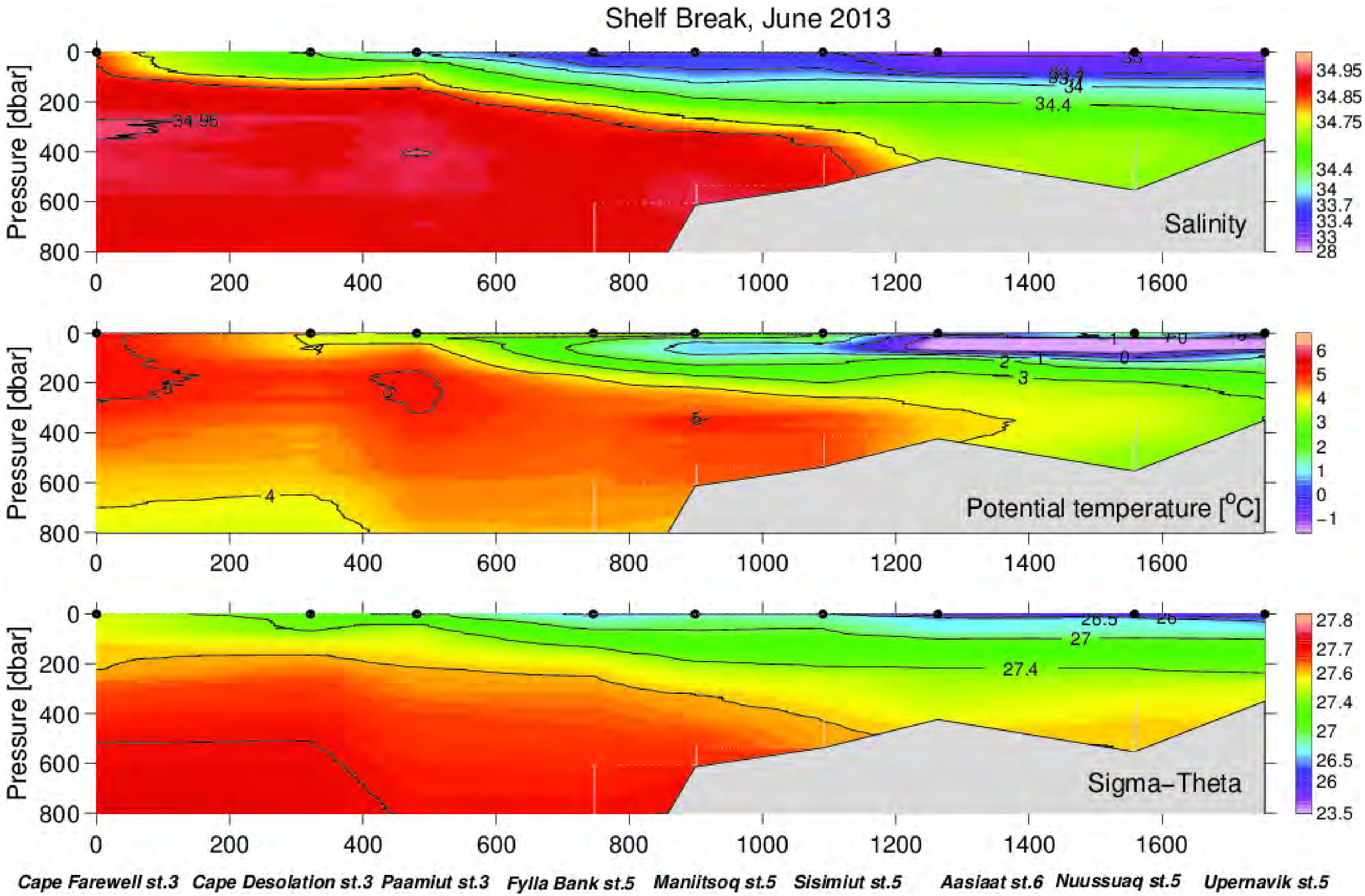


Figure 27. Vertical distribution of temperature, salinity and density over the continental shelf break from Cape Farewell to Upernavik, June 11–30, 2013.

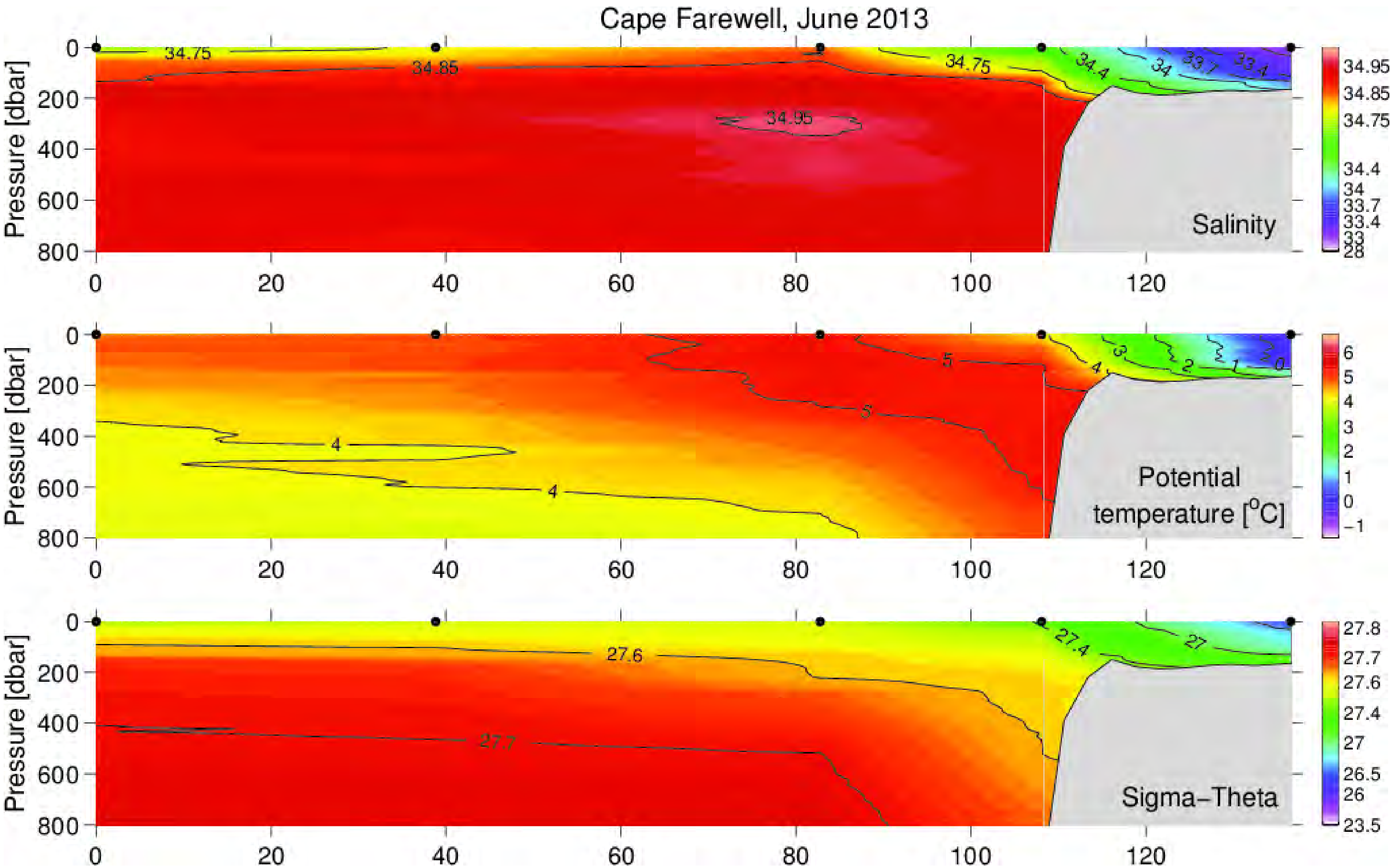


Figure 28. Vertical distribution of temperature, salinity and density at the Cape Farewell section, June 11, 2013.

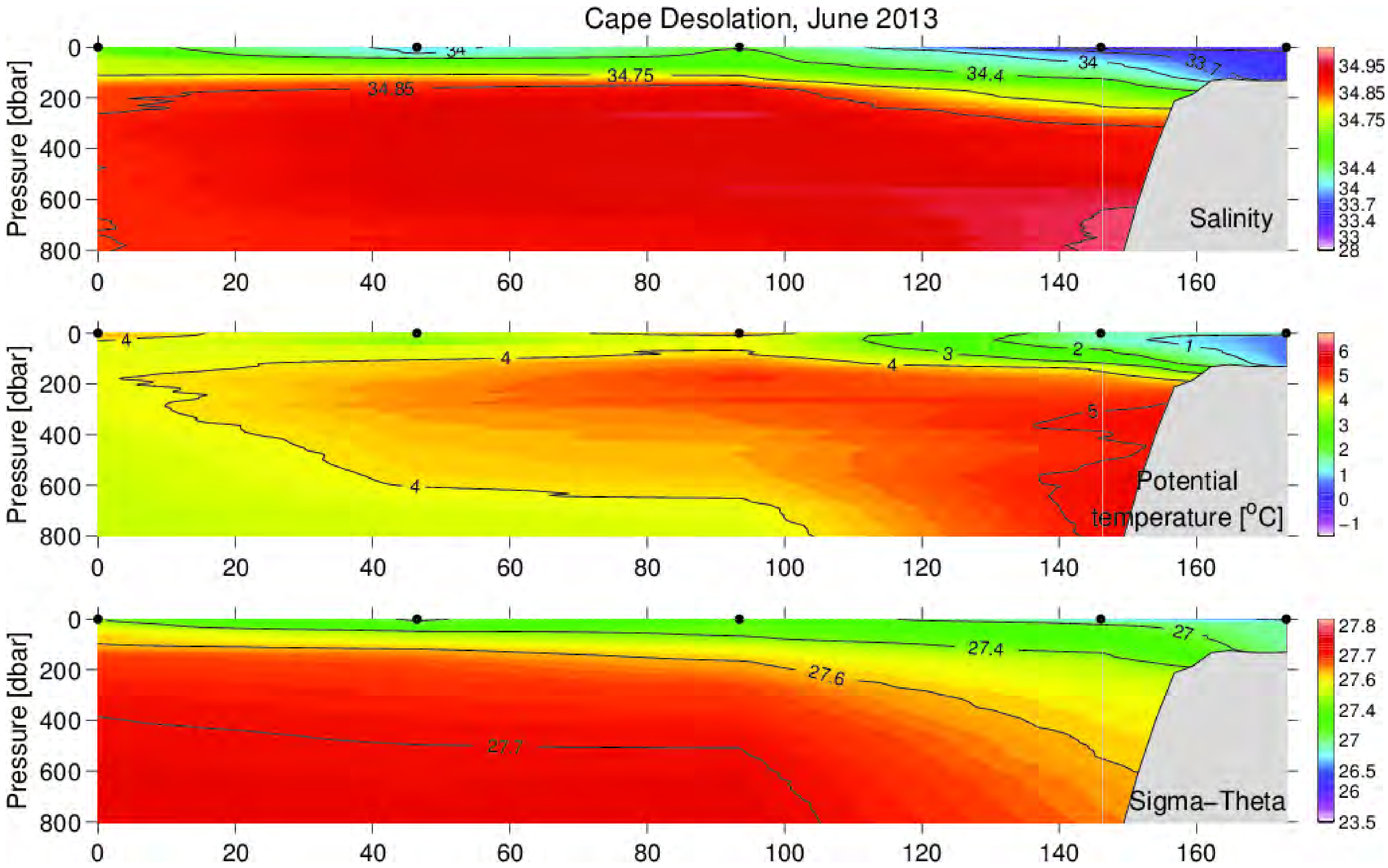


Figure 29. Vertical distribution of temperature, salinity and density at the Cape Desolation section, June 12–13, 2013

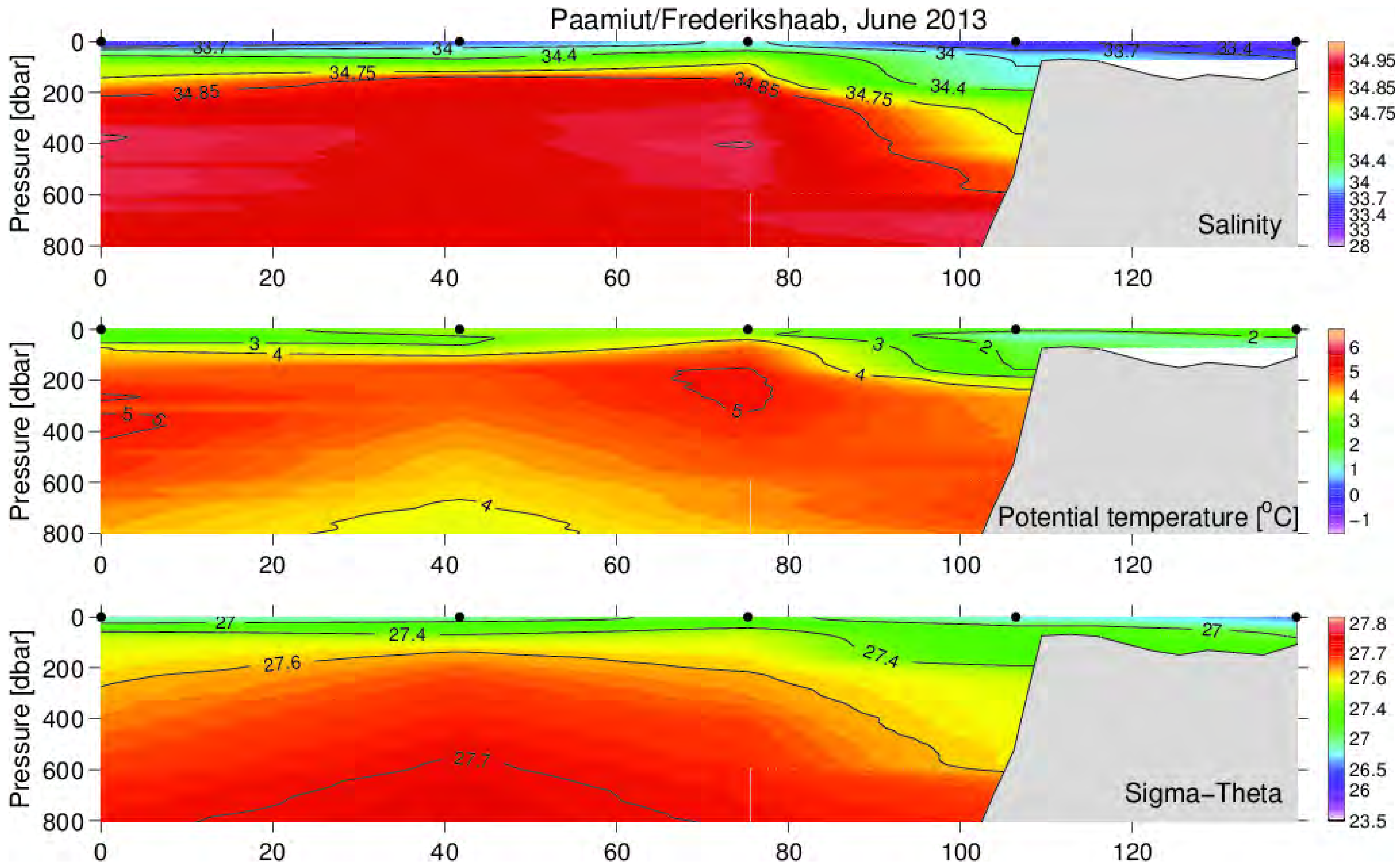


Figure 30. Vertical distribution of temperature, salinity and density at the Paamiut (Frederikshaab) section, June 13, 2013.

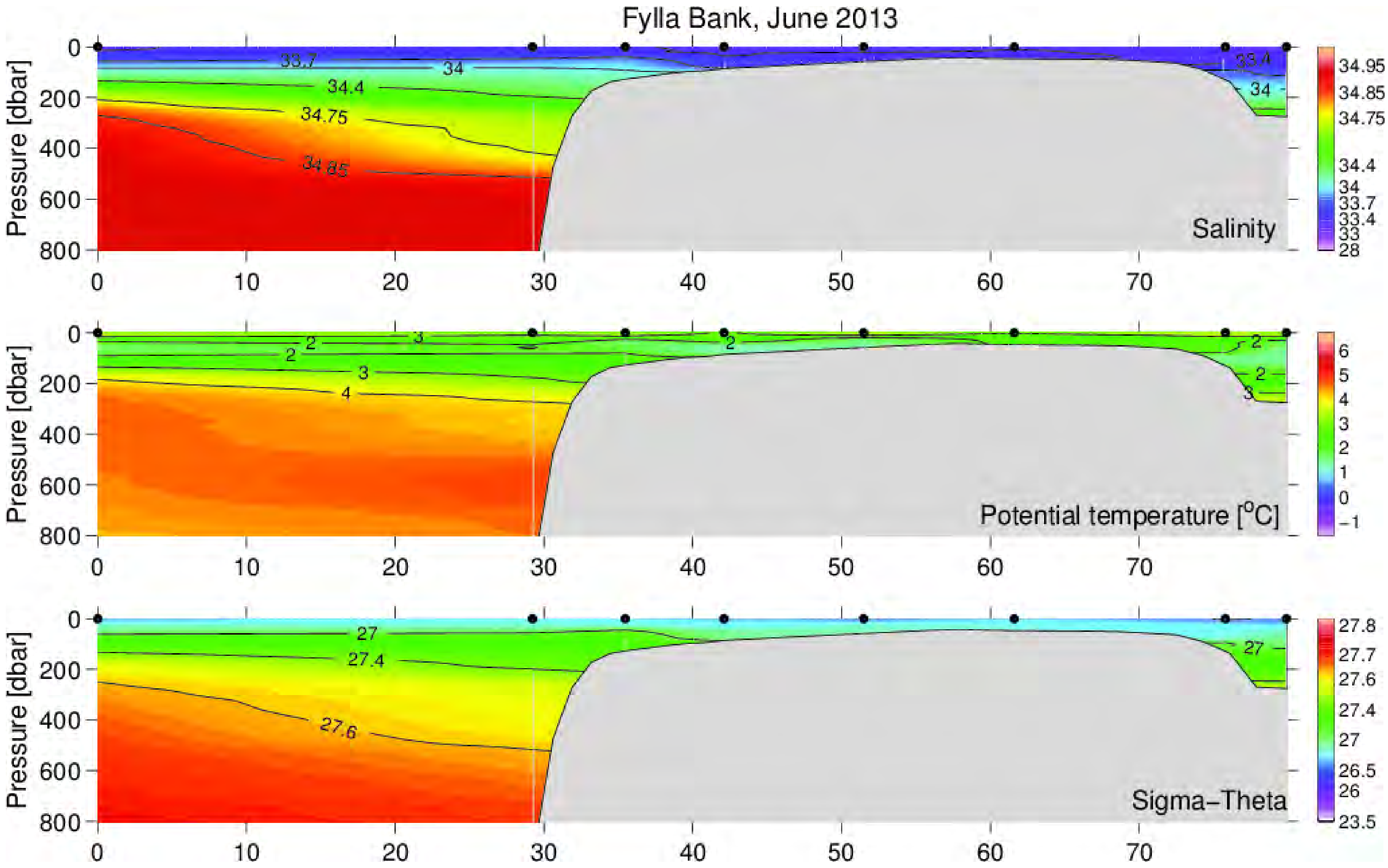


Figure 31. Vertical distribution of temperature, salinity and density at the Fylla Bank section, June 14, 2013. Three intermediate stations were taken too.

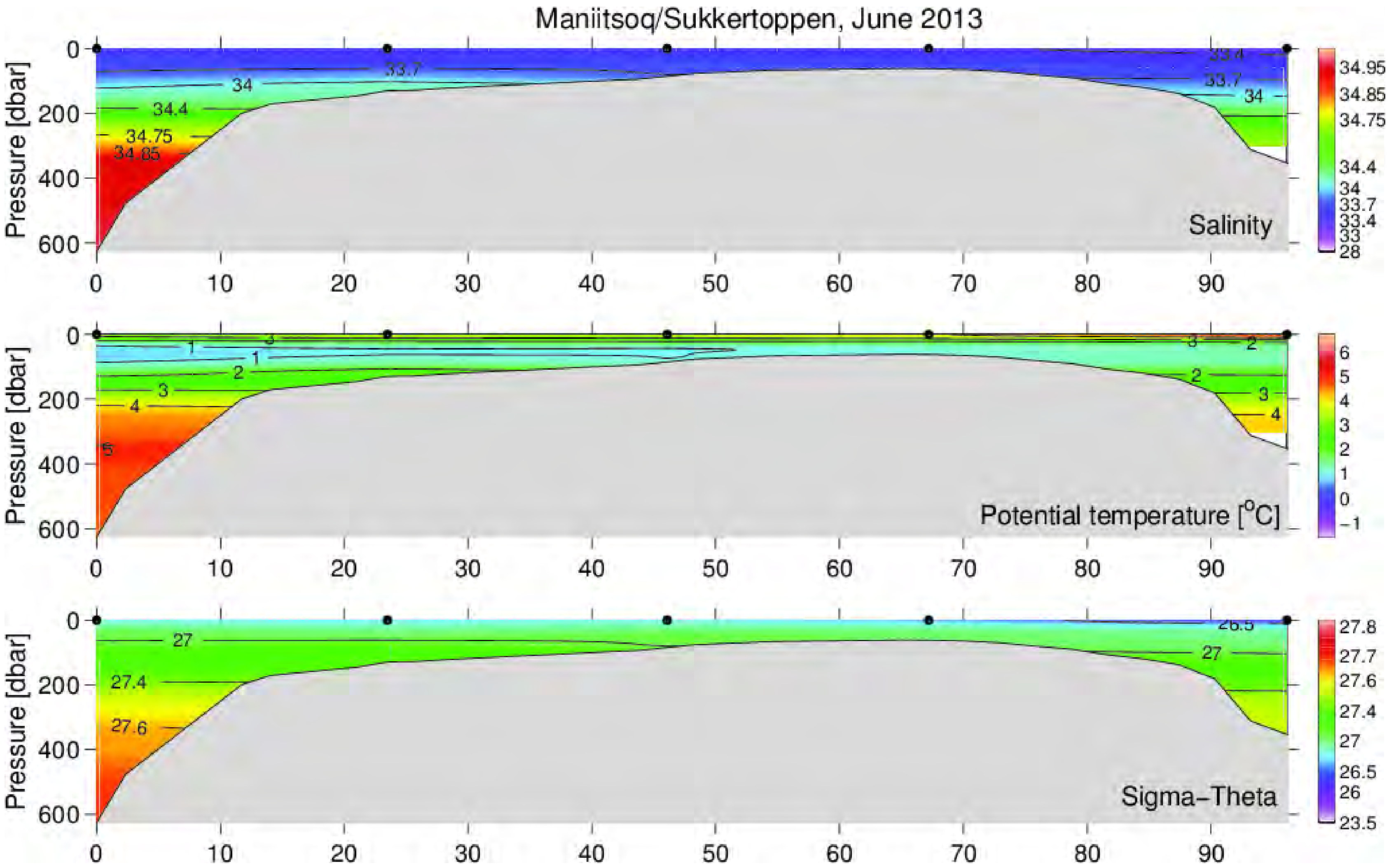


Figure 32. Vertical distribution of temperature, salinity and density at the Maniitsoq (Sukkertoppen) section, June 18–19, 2013.

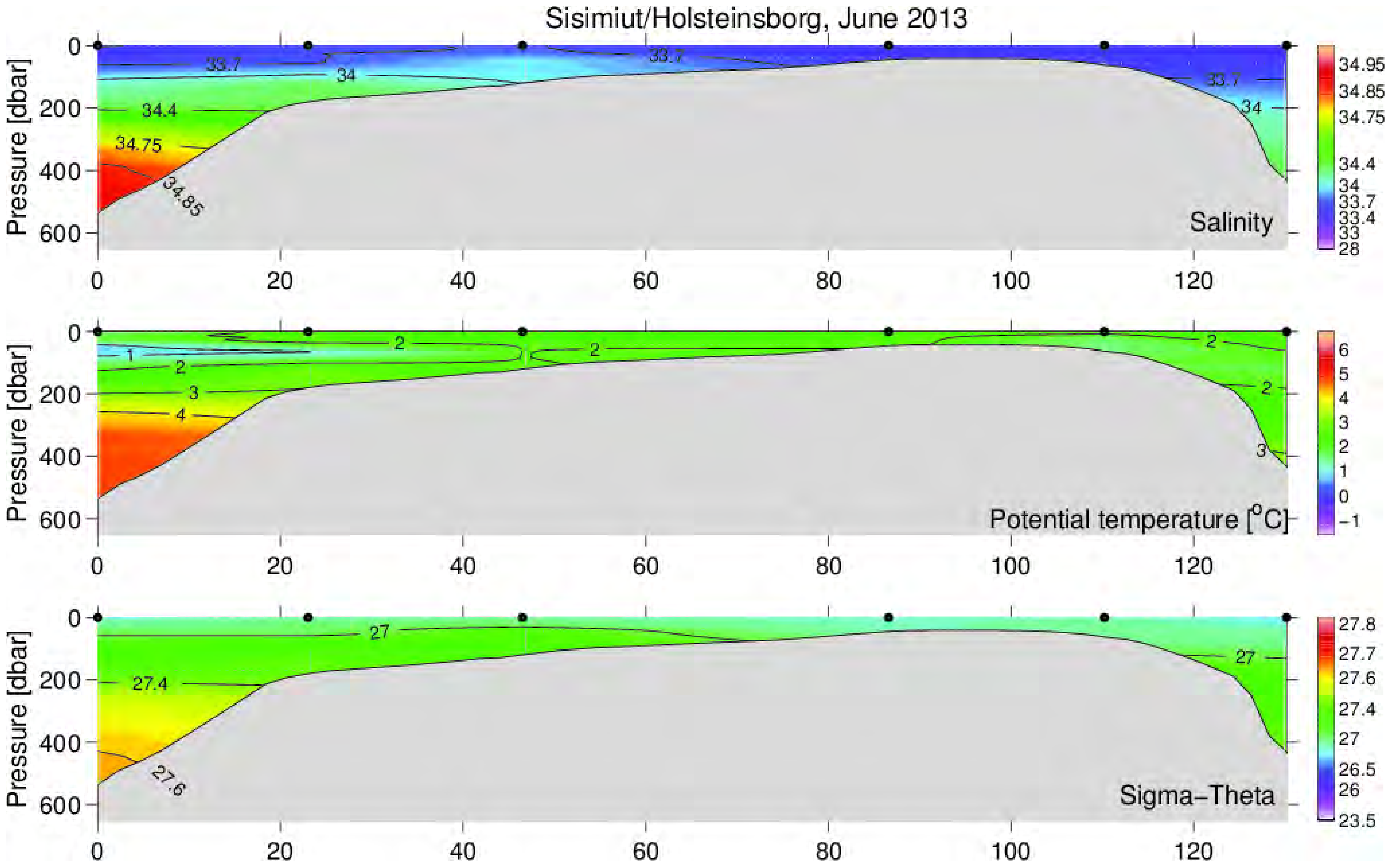


Figure 33. Vertical distribution of temperature, salinity and density at the Sisimiut (Holsteinsborg) section, June 19–20, 2013.

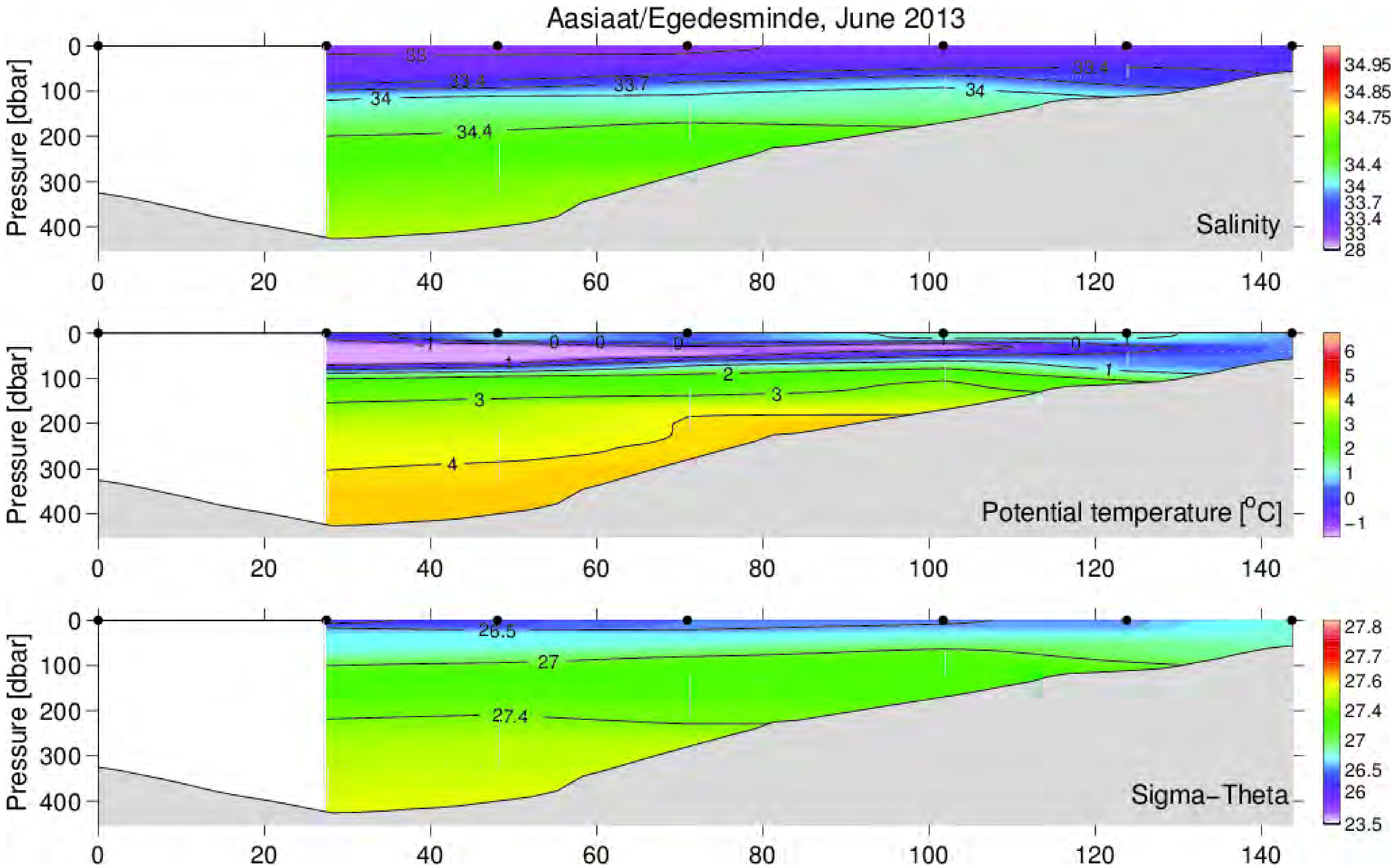


Figure 34. Vertical distribution of temperature, salinity and density at the Aasiaat (Egedesminde) section, June 13–15, 2013.

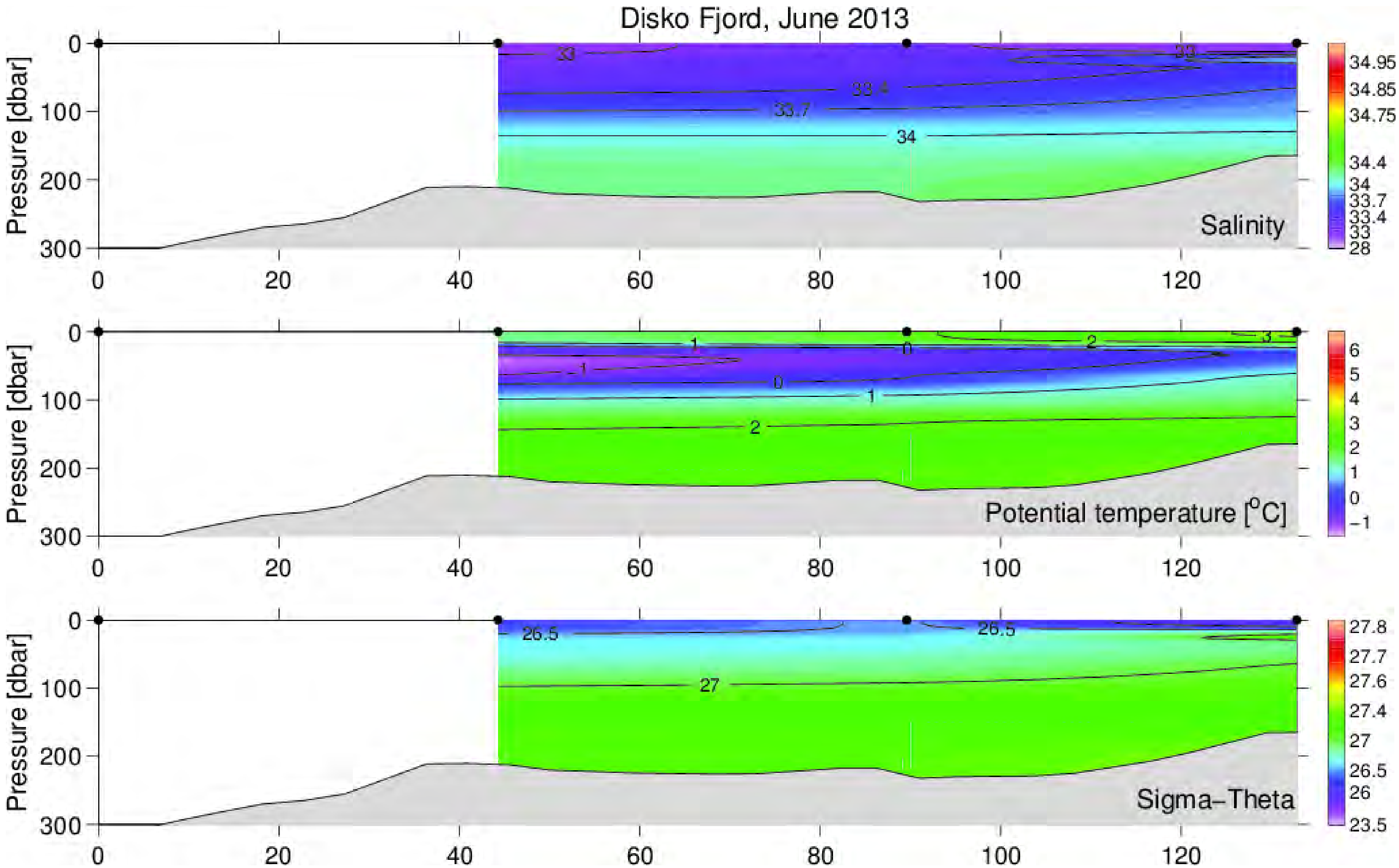


Figure 35. Vertical distribution of temperature, salinity and density at the Kangerluk (Disko Fjord) section, July 17–18, 2013.

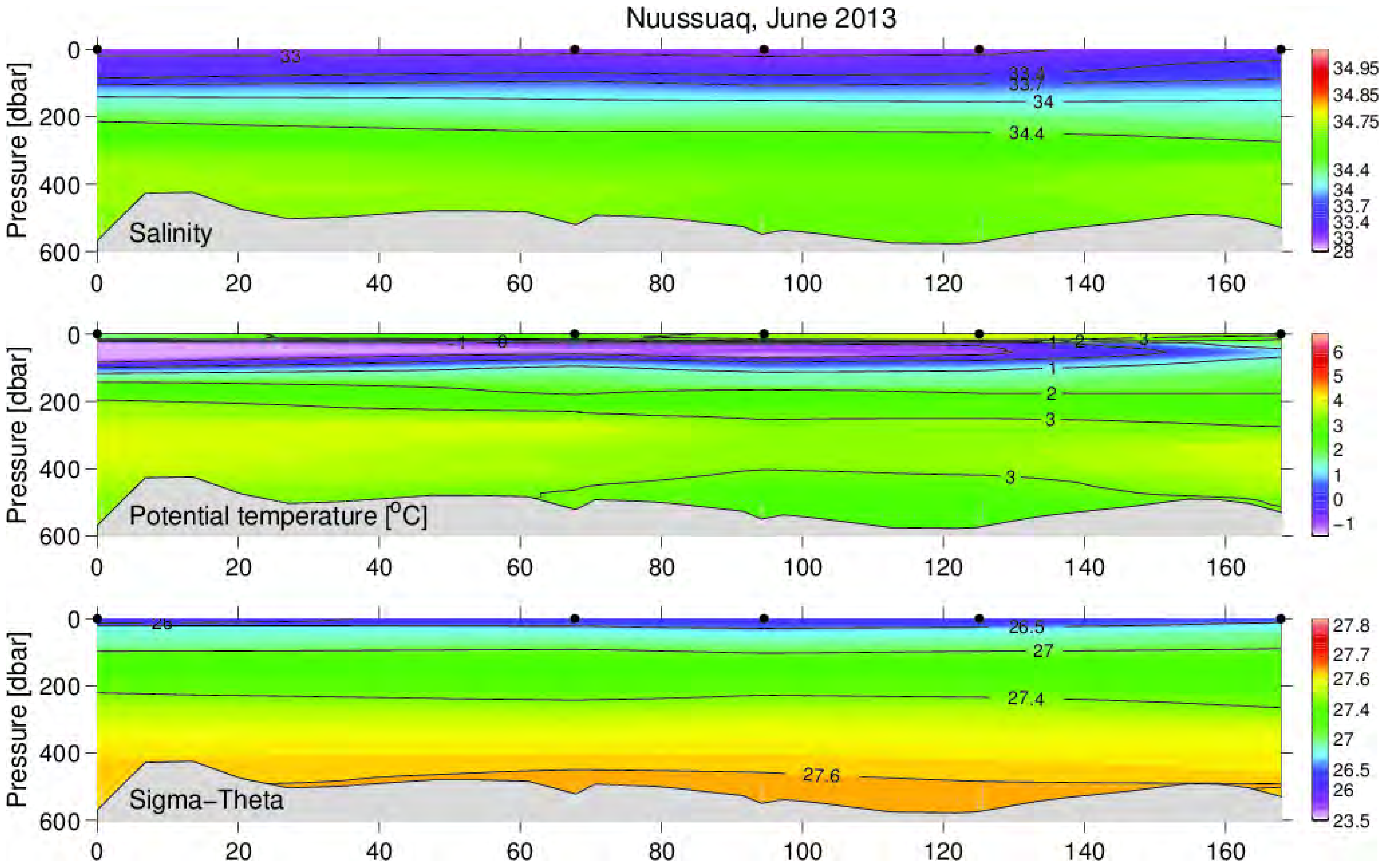


Figure 36. Vertical distribution of temperature, salinity and density at the Nuussuaq section, June 28-29, 2013.

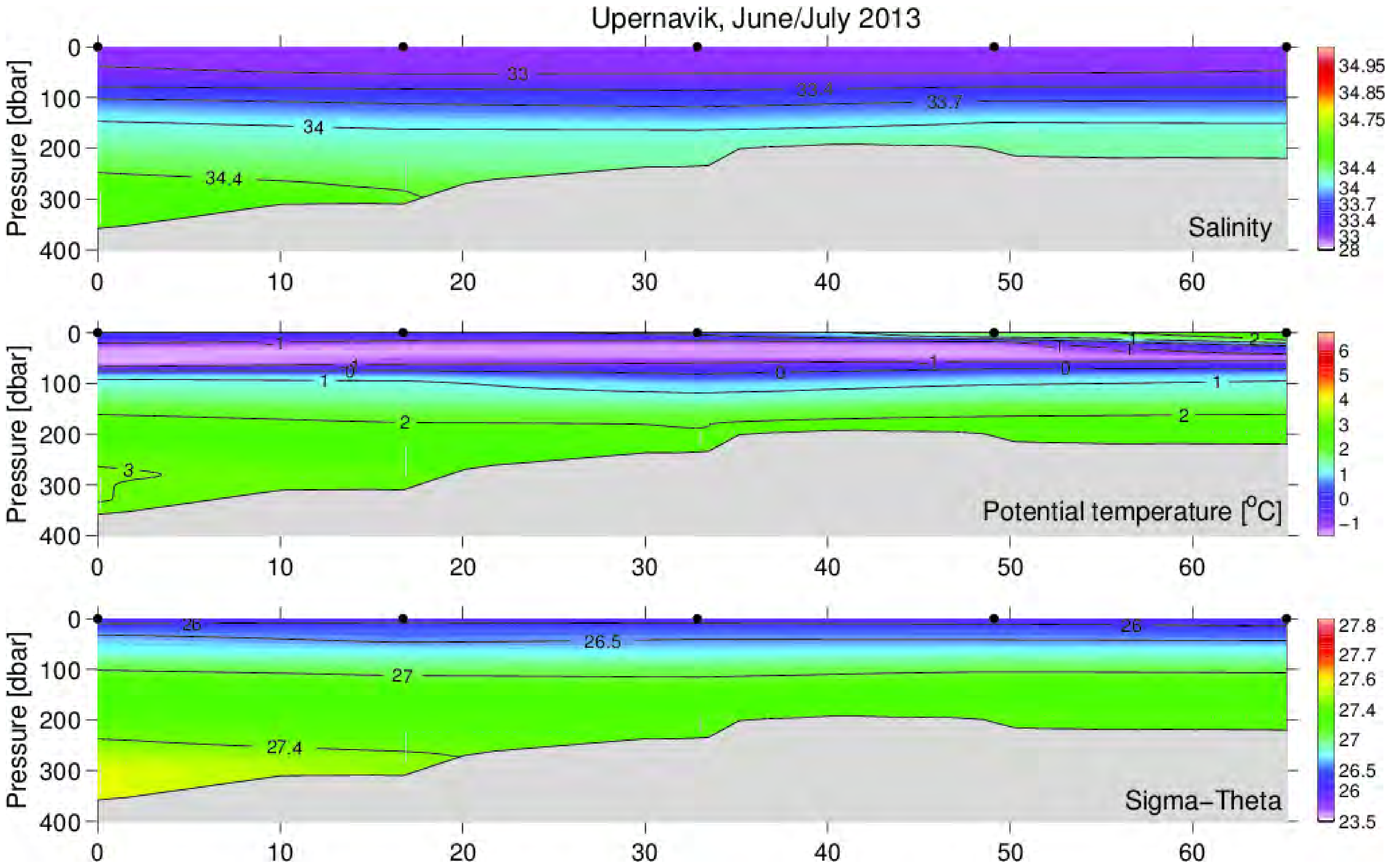


Figure 37. Vertical distribution of temperature, salinity and density at the Upernavik section, June 30 - July 01, 2013.

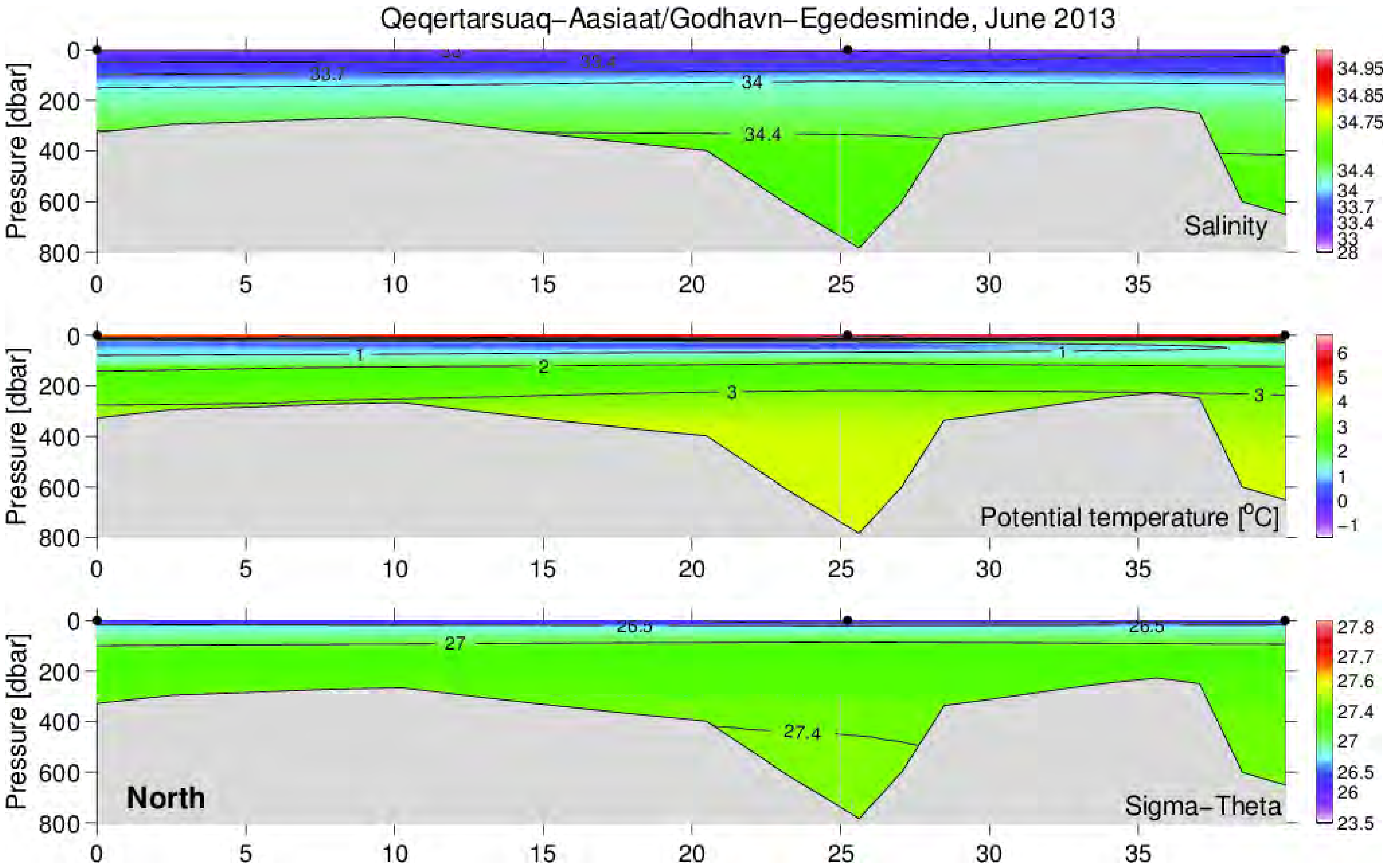


Figure 38. Vertical distribution of temperature, salinity and density at the Aasiaat–Qeqertarsuaq (Egedesminde–Godhavn) section, June 20–22, 2013.

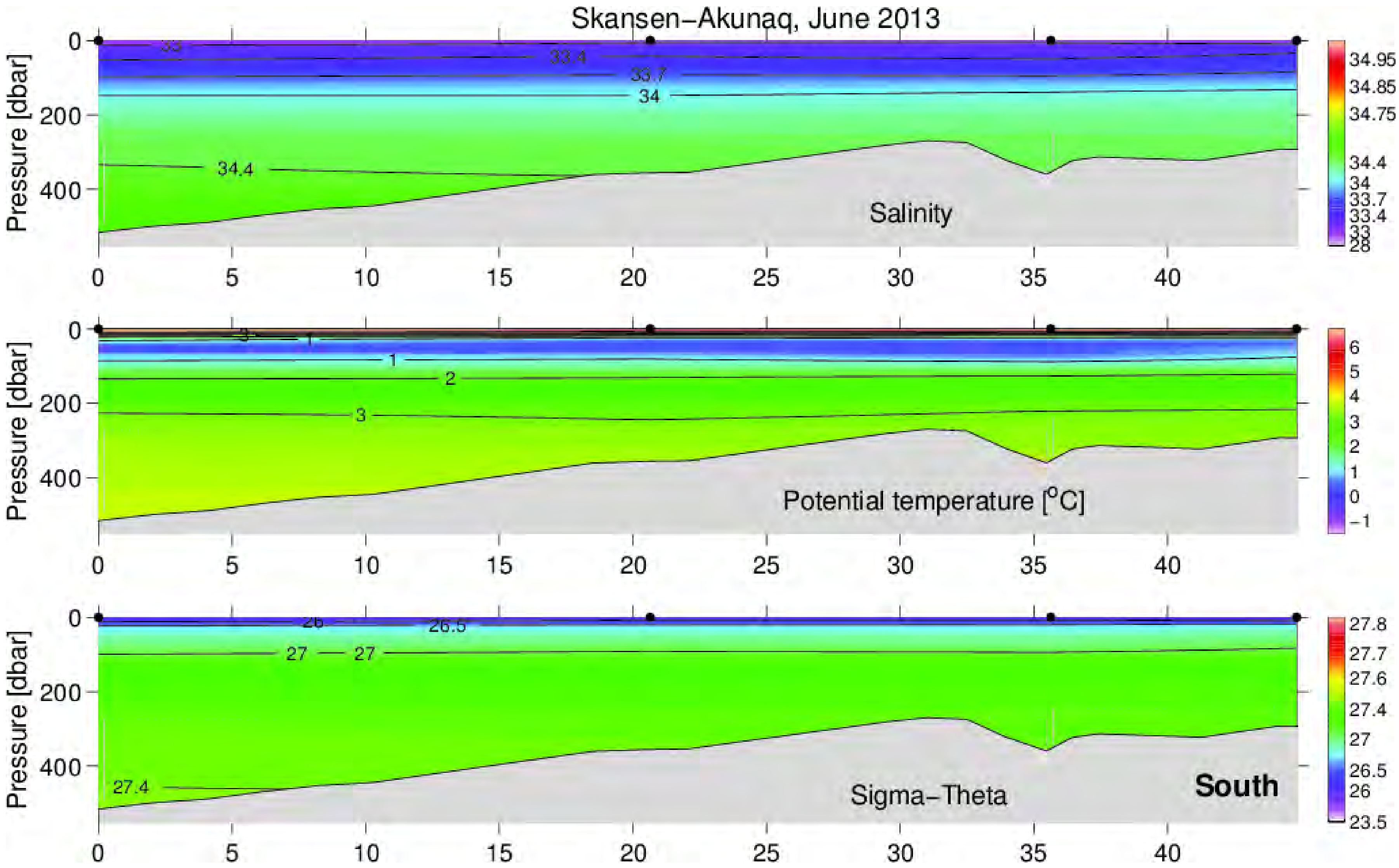


Figure 39. Vertical distribution of temperature, salinity and density at the Skansen–Akunaq section, June 21, 2013.

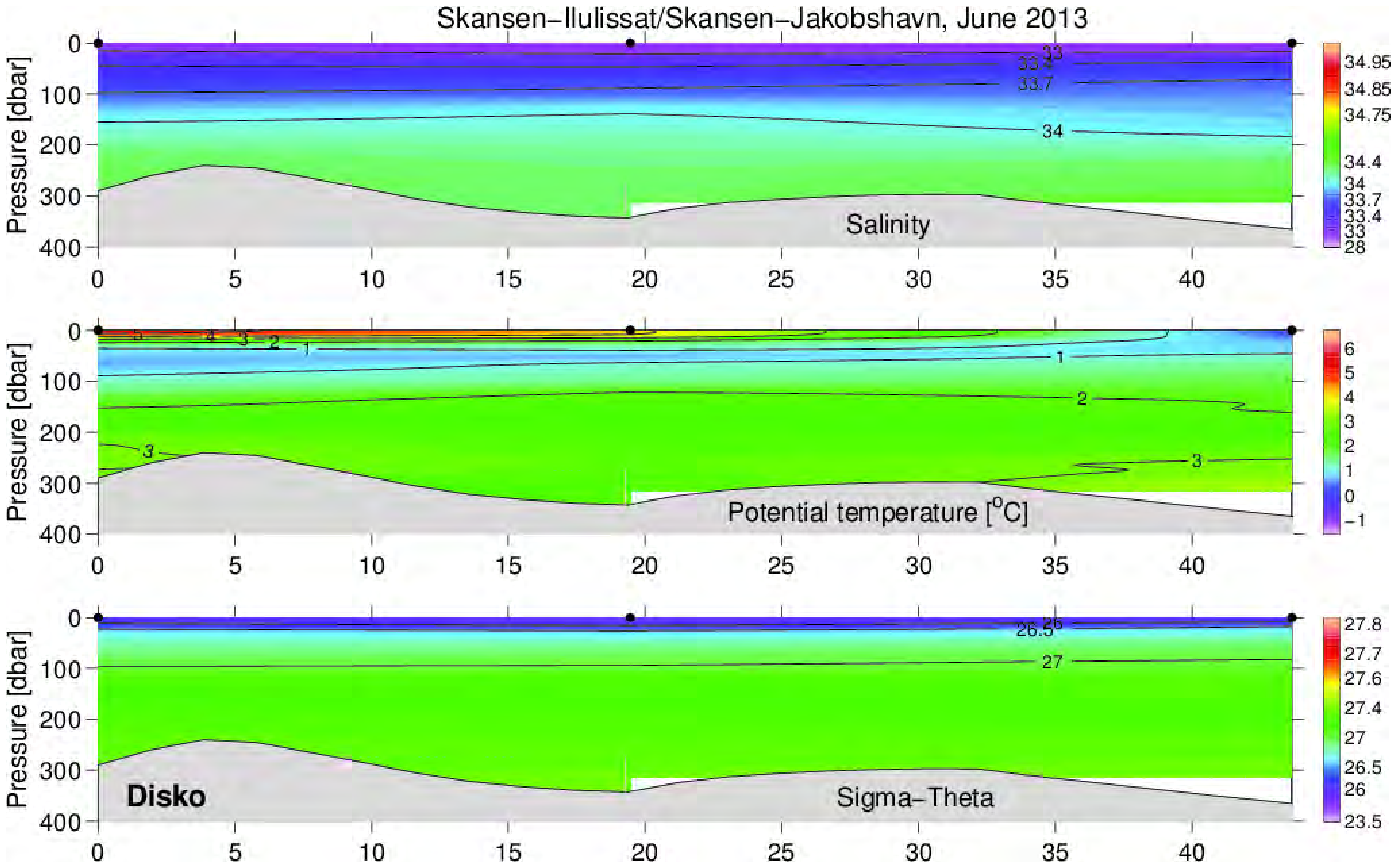


Figure 40. Vertical distribution of temperature, salinity and density at the Skansen–Ilulissat (Skansen–Jakobshavn) section, June 22–23, 2013.

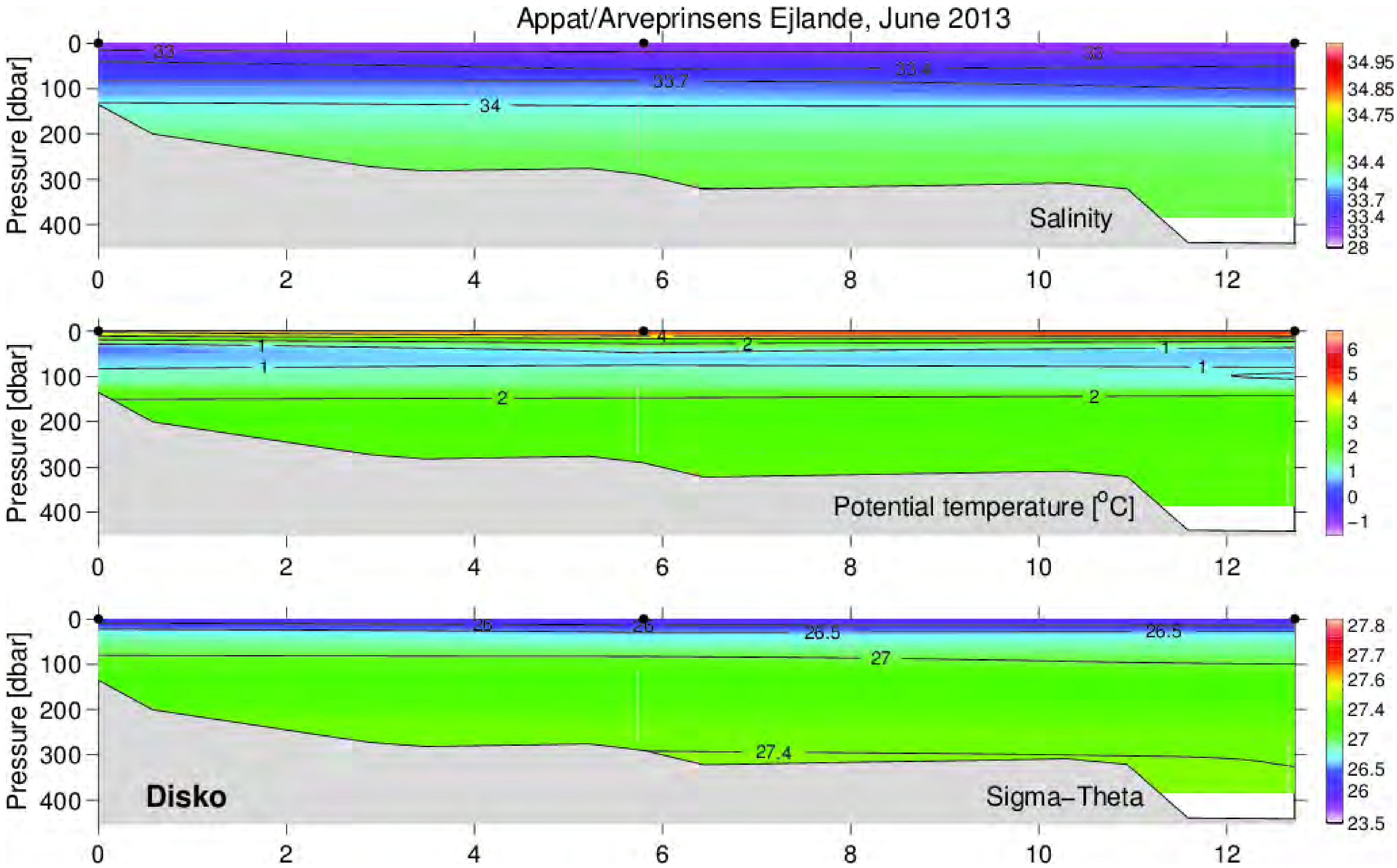


Figure 41. Vertical distribution of temperature, salinity and density at the Appat (Arveprinsens Ejlande) section, June 22, 2013.

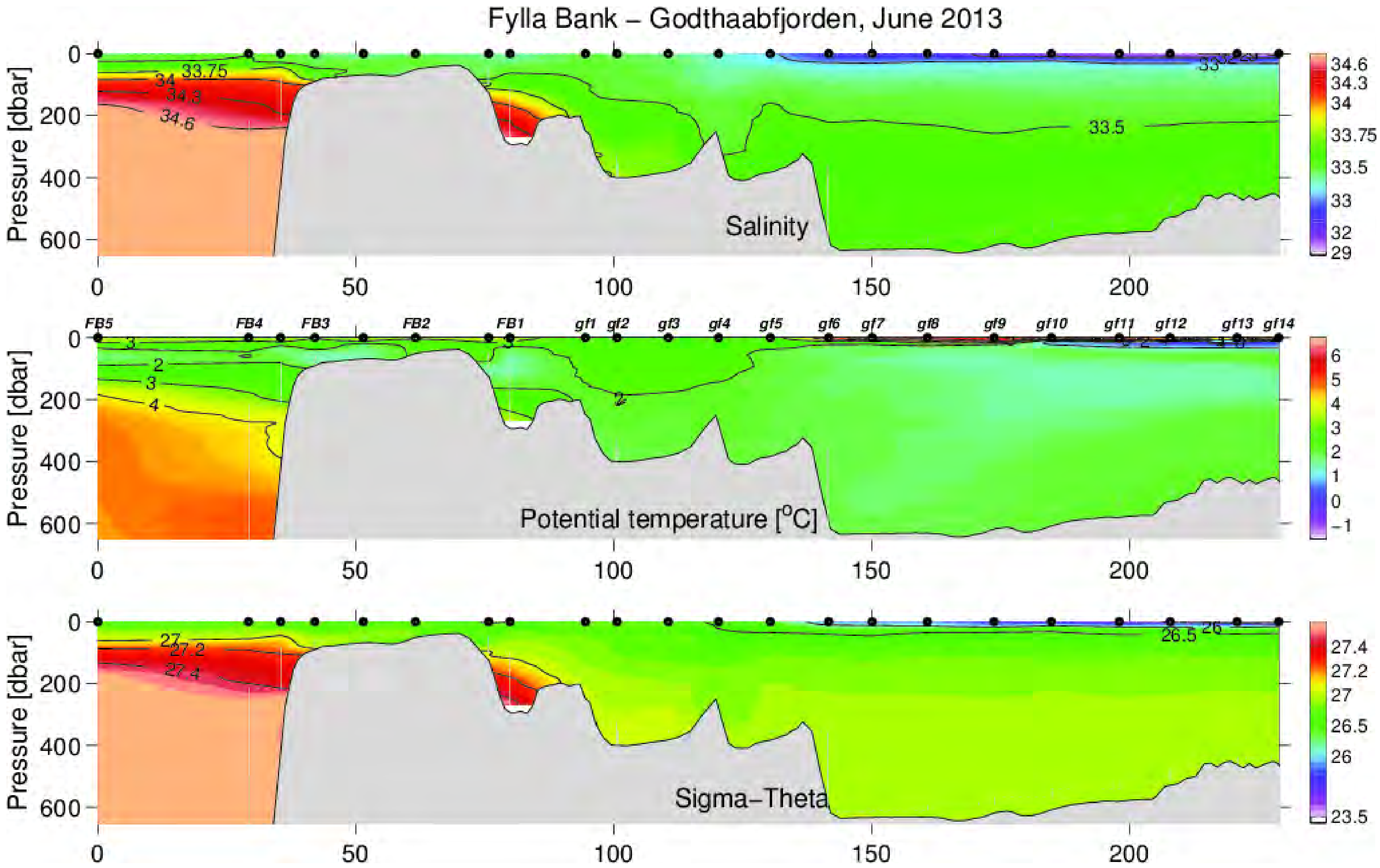


Figure 42**.** Vertical distribution of temperature, salinity and density at the Godthaab fjord section, June 14–15, 2013. Fylla Bank section left (as in Figure 31).

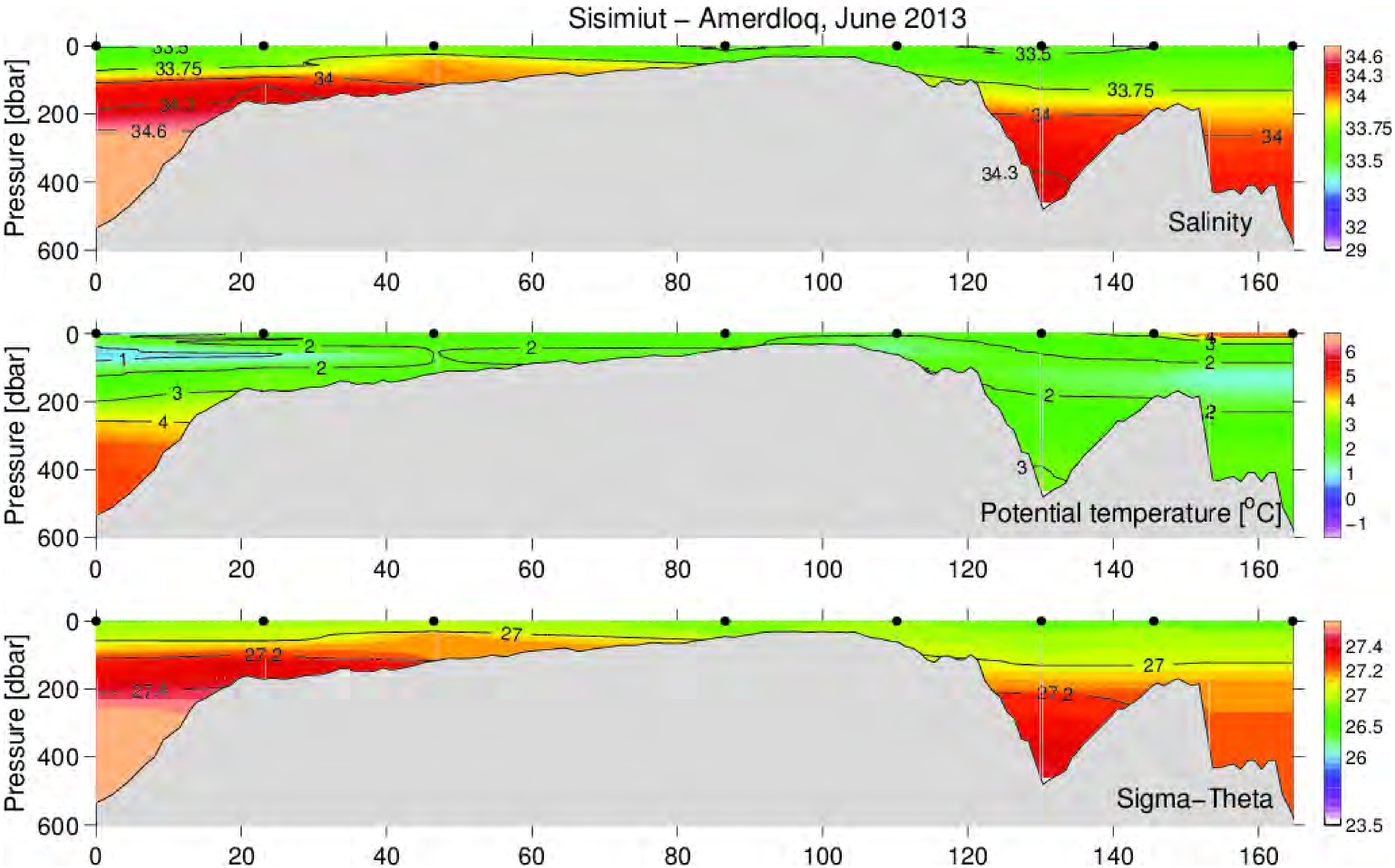


Figure 43**.** Vertical distribution of temperature, salinity and density at the Amerdloq fjord, June 19–20, 2013. Sisimiut section left.

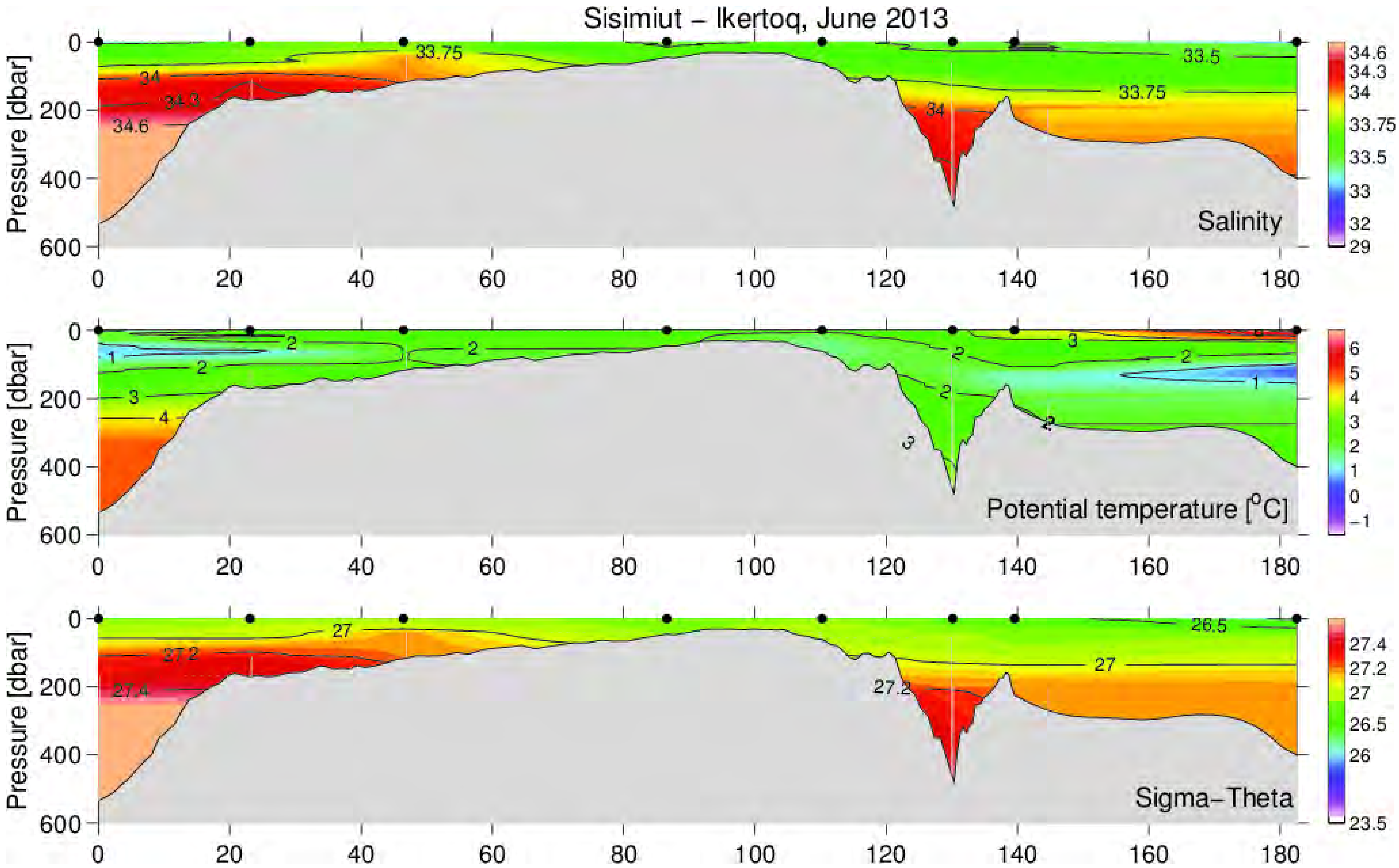


Figure 44**.** Vertical distribution of temperature, salinity and density at the Ikertoq fjord, June 19–21, 2013. Sisimiut section left

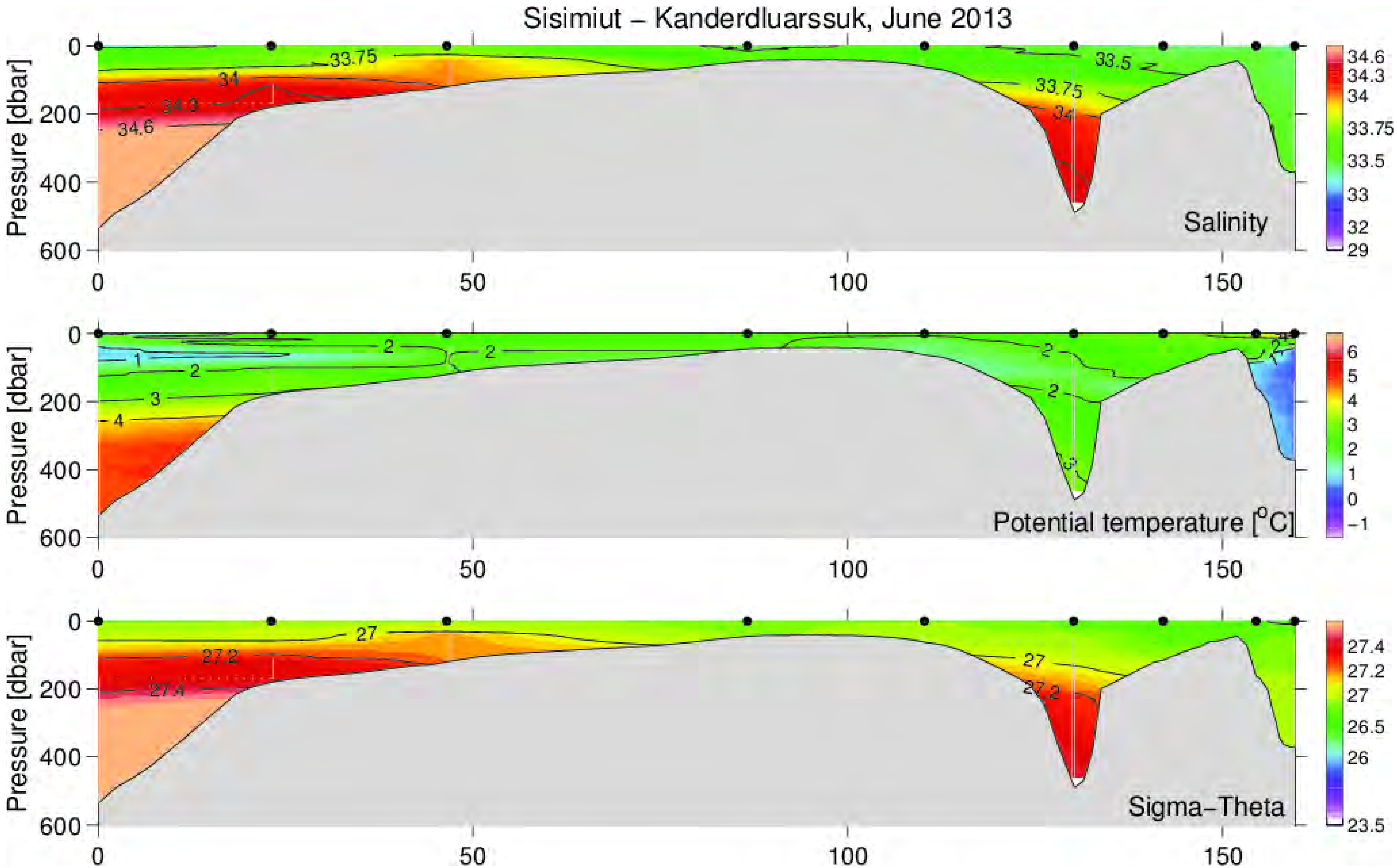


Figure 45**.** Vertical distribution of temperature, salinity and density at the Kangerdluarssuk fjord, June 19–21, 2013. Sisimiut section left.

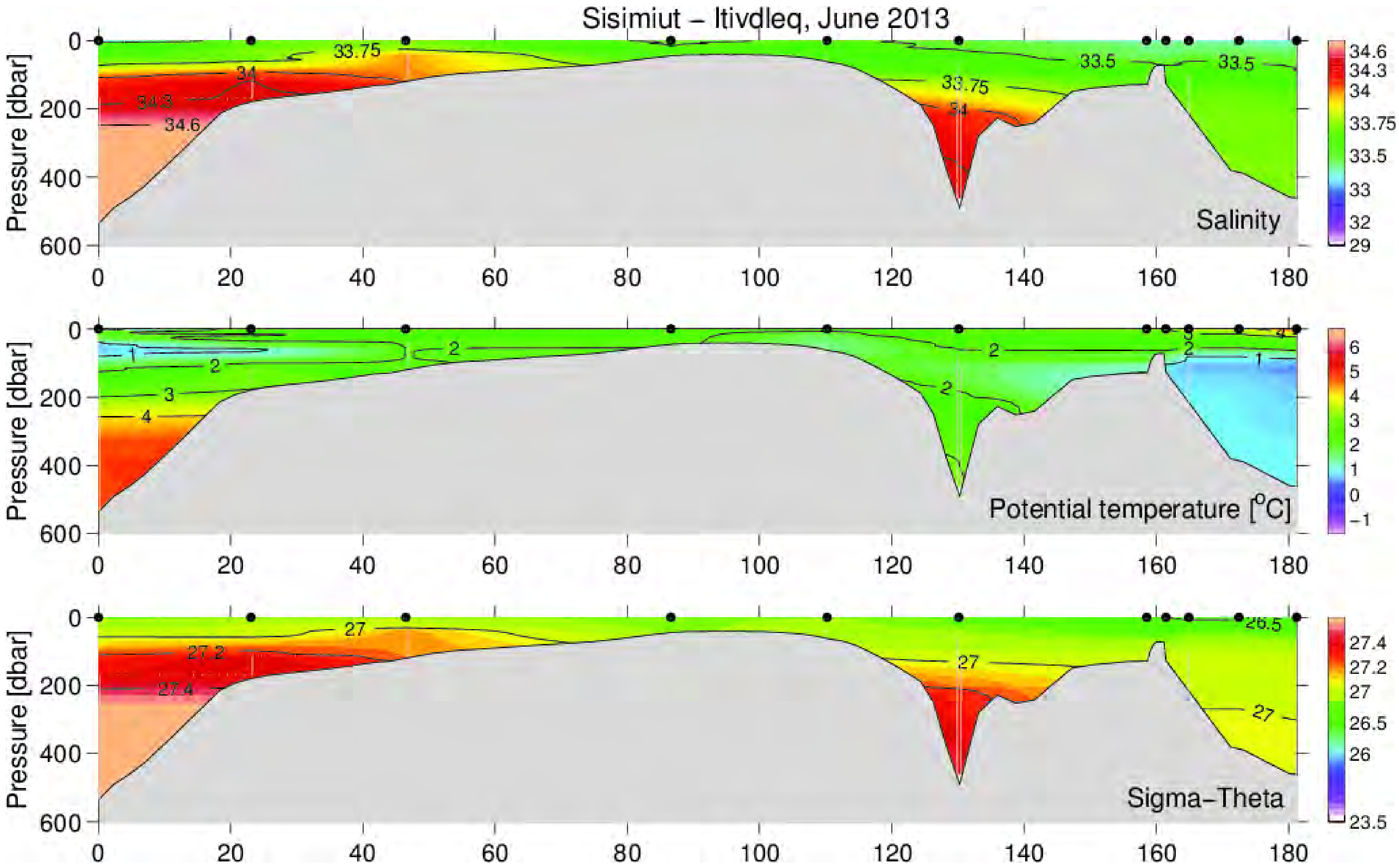


Figure 46**.** Vertical distribution of temperature, salinity and density at the Itivdleq fjord, June 19–20, 2013. Sisimiut section left.