Northwest Atlantic Fisheries Organization

Serial No. N5398 **NAFO SCR Doc. 07/46**

SCIENTIFIC COUNCIL MEETING – JUNE 2007

Environmental conditions in the Labrador Sea in 2006

by

R. M. Hendry

Department of Fisheries and Oceans, Bedford Institute of Oceanography
PO Box 1006, Dartmouth, Canada B2Y 4A2
email: hendryr@mar.dfo-mpo.gc.ca

Abstract

Surface air temperatures and sea surface temperatures in the Labrador Sea were notably warmer than normal in 2006. Record-high air temperatures were observed over the eastern Canadian Arctic. Sea surface temperatures were nearly 1°C warmer than normal over much of the Labrador Sea. The 17th annual occupation of the AR7W Labrador Sea section during 24 May – 8 June 2006 showed a continuation of warm and saline conditions in the upper layers of the Labrador Sea. These observations suggest that vertical overturning to depths of less than 1 km occurred during the winter of 2005–2006. Warm and saline Irminger Atlantic Waters continued to be abundant in the north-eastern Labrador Sea in 2006.

Introduction and Summary

Labrador Sea hydrographic conditions depend on a balance between heat lost to the atmosphere and heat gained from warm and saline Atlantic Waters carried northward into the Labrador Sea by the West Greenland Current. Severe winters under high North Atlantic Oscillation (NAO) conditions lead to greater cooling: in exceptional cases, the resulting increases in the surface density can lead to convective mixing of the water column to depths of 2 km. Milder winters under low NAO conditions lead to lower heat losses and an increased presence of the warm and saline Atlantic Waters. A sequence of severe winters in the early 1990s led to the most recent period of deep convection that peaked in 1993–1994.

Figure 1 shows a map of Labrador Sea and surrounding land areas. The map shows the locations of selected meteorological stations discussed below, the position of Ocean Weather Station Bravo which operated in the area from 1963 to 1974, and hydrographic station locations for the annual AR7W surveys. The circled area in the west-central Labrador Sea marks the region where convection to depths as great as 2000 m was observed during the cold period of the early 1990s (Lazier et al., 2002). Wintertime convection to depths as little as 200 m and as great as 1500 m was observed in the OWS Bravo record (Lazier, 1980).

Annual mean 2006 surface air temperatures from representative land stations bordering the Labrador Sea in the west and northwest were about 3°C warmer than normal, reaching record-high values in the context of a decade-long period of warmer than normal conditions. The annual anomalies were dominated by exceptionally warm winter months. Annual mean 2006 surface air temperatures at Nuuk on the West Greenland coast were about 1.5°C above normal, slightly cooler than in 2005.

Annual mean 2006 NOAA Extended SST sea surface temperatures in the west-central Labrador Sea were about 1°C warmer than normal. Corresponding SST anomalies in the eastern Labrador Sea were 0.5°C warmer than normal, also slightly cooler than in 2005. A warm anomaly running from the southern Grand Banks into the Northwest Corner gave annual mean SST anomalies greater than 1.8°C.

The 17th annual Fisheries and Oceans Canada AR7W survey took place during 24 May – 8 June 2006. Conditions in 2006 continued warm and saline, generally similar to conditions in the previous 2–3 years. The upper 2000 m of the water column averaged across the AR7W section at stations where the bottom depth was at least 2000 m in the Labrador Sea was more than 0.6 warmer in 2006 than the average for the period 1990-1995. The corresponding 2006 average upper 2000 m salinity was about 0.4 higher than the 1990-1995 average.

The 2006 survey generally encountered conditions similar to those observed in 2004 and 2005. Warm and saline waters in the offshore branch of the West Greenland Current dominated the upper layers of the eastern Labrador Sea. A layer of reduced vertical stratification centered near 950 m was observed in the west-central Labrador Sea. This layer could be interpreted as a remnant of vertical mixing during the winter of 2005-2006. Characteristic potential temperature, salinity, and potential density anomalies in this layer were 3.4°C, 34.85, and 27.73 kg/m3 respectively. Low-stratification layers with similar properties have been observed during the past several years.

There has been a gradual decrease in upper-layer density since the end of the deep convection of the early 1990s. The net density changes over the upper 2000 m during the past few years have been relatively small, with changes linked to temperature and salinity nearly in balance. This layer is about 0.03 kg/m3 less dense than the average for 1990-1995. These changes in hydrographic conditions largely account for observed changes in sea level from satellite altimetry.

Results and Discussion

General environmental indicators

Surface air temperature

Time series of annual mean surface air temperature anomalies for 1960-2006 relative to the 30-year 1971-2000 normal were created for Cartwright, Labrador; Iqaluit, Nunavut; and Nuuk, Greenland (Figure 2). The Cartwright and Labrador data were obtained from Environment Canada while the Nuuk data were obtained from the Danish Meteorological Institute, largely from Cappelen et al. (2006). The two North American stations show marked increases in annual mean temperatures from 2005 to about 3°C warmer than normal in 2006. Nuuk annual mean surface air temperature cooled about 0.4°C relative to 2005 but remained warmer than normal. The greatest variability occurs during winter months. Particularly warm conditions were observed in winter at Cartwright and Iqaluit.

Sea surface temperature

NOAA Extended SST (Smith and Reynolds, 2004) estimates of the 2006 annual mean for the Labrador Sea and adjacent North Atlantic (Figure 3a) and the associated anomalies relative to 1971-2000 (Figure 3b) show that 2006 was considerably warmer than normal, by about 1°C in the west-central Labrador Sea and about 0.5°C in the eastern Labrador West Greenland coastal areas.

Monthly averages sea surface temperature data for the Labrador Sea were extracted from the global HadISST1 data set produced by the UK Met Office Hadley Centre on a 1-degree latitude-longitude grid (Rayner et al., 2004). A space-time plot of HadISST1 SST anomalies relative to 1971–2000 created by interpolating from this grid to the AR7W line and low-pass filtering in time (Figure 4a) shows the notable warming that has occurred in the Labrador Sea during recent years, particularly on the western side. A SST time series from the west-central Labrador Sea represented by an average over the 320–520 km distance range on the AR7W section is shown in Figure 4b.

Sea level

The French SSALTO/DUACS group uses TOPEX/POSEIDON and JASON-1 altimetric sea level measurements to produce weekly gridded Maps of Sea Level Anomalies (MSLA) with near-global geographic coverage on a 1/3^{o} Mercator grid. These are distributed by the French AVISO group with support from the French national space agency CNES. Data coverage begins with the TOPEX/POSEIDON mission in late 1992 and continues to the present. The gridded MSLA are produced by a statistical interpolation that is most reliable at points close to the measurements (Le Traon et al., 1998).

A space-time plot of MSLA interpolated along the AR7W line and low-pass filtered in time shows a section-wide increase in sea level from a minimum during the cold period in the early 1990s to the present-day maximum (Figure 5a). A time series of annual mean anomalies for the distance range 320–520 km representative of the west-central Labrador Sea shows an increase of about 6 cm in the 6-year period between 1994 to 2000 and a slower increase of about 3 cm in the subsequent 6-year period from 2000 to 2006 (Figure 5b).

AR7W Hydrography

Since 1990, Ocean Sciences Division at the Bedford Institute of Oceanography has carried out annual occupations of a hydrographic section across the Labrador Sea (Figure 1). The section was designated AR7W (Atlantic Repeat Hydrography Line 7) in the World Ocean Circulation Experiment (WOCE). These surveys include chemical and biological measurements. They contribute to the Canadian Department of Fisheries and Oceans (DFO) Atlantic Zone Monitoring Program and to the international Global Climate Observing System (GCOS). Related physical oceanography research programs are linked to the international Climate Variability (CLIVAR) component of the World Climate Research Programme (WCRP).

The 2006 occupation of AR7W stations took place during 24 May – 8 June 2006 on CCGS Hudson Mission 2006016. The section spans approximately 880 km from the 130 m contour on the inshore Labrador shelf to the 200 m contour on the West Greenland shelf. Sea ice sometimes limits coverage at the ends of the section but little ice was encountered in 2006 and all planned stations were occupied.

Contoured gridded sections of potential temperature from the 1993 and 2006 surveys show a marked change from the cold period of the early 1990s to the present (Figures 6a and 6b). Along-section distance in kilometres increasing from southwest (Labrador) to northeast (Greenland) is used as the horizontal coordinate. Deep convection in the winter of 1992–1993 produced a vertically homogeneous water mass that filled the upper 2–km of the entire Labrador Sea and left a large pool of water with potential temperature near 2.8°C in the 500–2000 m depth range (Figure 6a). The upper 500 m had restratified through a combination of seasonal heating and advection from the eastern boundary of the Labrador Sea during the 2–3 months before the 1993 survey took place (Lazier et al., 2002). By 2006 these waters had warmed to 3.4°C (Figure 6b). A time series of potential temperature averaged over the upper 2 km for all stations at least that deep during the 1990–2006 period of AR7W surveys shows a rapid recovery from 1992–1994 into the early years of the 21st century and a more moderate warming during recent years (Figure 6c). AR7W survey times vary from mid-May to late July. Seasonal changes in potential temperature in the 0–150 m depth range were estimated from climatological hydrographic data from the U.S. National Ocean Data Center (Conkright et al., 2002) and removed before construction of this time series.

The offshore branch of the West Greenland Current carries warm and saline water into the Labrador Sea. Lee (1968) defined Irminger Atlantic Water as water with potential temperatures between 4^{o}C and 6^{o}C and salinities between 34.95 and 35.10. Buch (2000) introduced the term Irminger Mode Water properties for waters in the same range of temperatures but with slightly lower salinities in the range 34.85–34.95. These two water masses are highlighted in Figures 6a and 6b. They were almost completely absent in the 1993 survey but have become abundant in recent years.

Surveys since 2000 have detected the presence of layers with reduced vertical density gradients in the 600–1200 m depth range that could be interpreted as remnants of renewed winter overturning that have not been completely removed by seasonal restratification. The low-stratification layer is most prominent in the west-central Labrador Sea and has been especially notable during the past 3–4 years. Time series of the pressure on selected potential density anomaly surfaces from average profiles in the 320-520 km distance range for each survey as a function of the median station time show an increase in the separation of isopycnals with potential density anomalies in the range 27.72-27.75 kg/m^3 (Figure 7a). In 2000, this layer developed a prominent relative minimum in potential temperature with core potential temperature 3.2^{o}C, salinity 34.83, and potential density anomaly 27.73 kg/m^3. The temperature-salinity properties in the core of this recurring layer have varied from year to year, becoming warmer and more saline in during the past three years (Figure 7b).

Acknowledgments

Monthly mean surface air temperatures for Cartwright and Labrador data were provided by the Canadian National Climate Data and Information Archive, operated and maintained by Environment Canada. [http://climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html]

Nuuk monthly mean surface air temperatures up to 2005 were provided by the Danish Meteorological Institute [http://www.dmi.dk/dmi/tr05_05_recommended2005.zip] as documented in Technical Report No. 05-05 by Cappelen et al. (2006).
http://www.dmi.dk/dmi/index/viden/dmi-publikationer/tekniskerapporter.htm

Recent monthly mean surface air temperatures for Nuuk were provided by the Danish Meteorological Institute. [http://www.dmi.dk/dmi/index/gronland/verdensvejr-gron.htm]

The HadISST1 Global Sea Surface Temperature data set was provided by the Hadley Centre for Climate Prediction and Research, Met Office, Bracknell, UK.
[http://www.metoffice.com/research/hadleycentre/obsdata/HadISST1.html]

NOAA Extended SST images were provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.cdc.noaa.gov/.

MSLA altimeter products were provided by the French AVISO/Altimetry operations centre at the CLS Space Oceanography Division. [http://www.aviso.oceanobs.com/]

Climatological hydrographic data were provided by the U.S. National Oceanographic Data Center. [http://www.nodc.gov/]

Many staff and associates at BIO have contributed to the Labrador Sea programme. John Loder presently leads the associated Ocean Sciences Division Ocean Circulation and Variability Programme. Glen Harrison presently leads the associated biological research program within Ecosystem Research Division. Allyn Clarke provided crucial leadership to this program in recent years. These efforts, together with those of the officers and crew of CCGS Hudson, are gratefully acknowledged.

References

Buch, E. 2000. Air-sea-ice conditions off southwest Greenland, 1981-97. Journal of Northwest Atlantic Fishery Science, 26, 123-126.

Cappelen, J., E.V. Laursen, P.V. Jørgensen, and C. Kern-Hansen. 2006. DMI monthly Climate Data Collection 1768-2005, Denmark, The Faroe Islands and Greenland. Technical Report No. 05-05, Danish Meteorological Institute. [http://www.dmi.dk/dmi/index/viden/dmi-publikationer/tekniskerapporter.htm]

Conkright, M.E., R. A. Locarnini, H.E. Garcia, T.D. Brien, T.P. Boyer, C. Stephens, J.I. Antonov. 2002. World Ocean Atlas 2001. National Oceanographic Data Center Internal Report 17, 17 pp.

Lazier, J.R.N. 1980. Oceanographic conditions at Ocean Weather Ship Bravo, 1964-1974. Atmosphere-Ocean 18: 227-238.

Lazier, J., R. Hendry, A. Clarke, I. Yashayaev, and P. Rhines. 2002. Convection and restratification in the Labrador Sea, 1990-2000. Deep Sea Research, 49, 1819-1835.

Lee, A. 1968. NORWESTLANT Surveys: Physical Oceanography. ICNAF Special Publication Number 7, Part I, 31-54.

Le Traon, P.-Y., F. Nadal, and N. Ducet. 1998. An improved mapping method of multisatellite altimeter data. Journal of Atmospheric and Oceanic Technology, 15, 522-534.

Rayner, N. A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, D. P. Rowell, E. C. Kent, and A. Kaplan. 2004. Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century, Journal of Geophysical Research, 108(D14), 4407, doi:10.1029/2002JD002670.

Smith, T.M., and R.W. Reynolds. 2004. Improved Extended Reconstruction of SST (1854-1997). Journal of Climate, 17, 2466-2477.

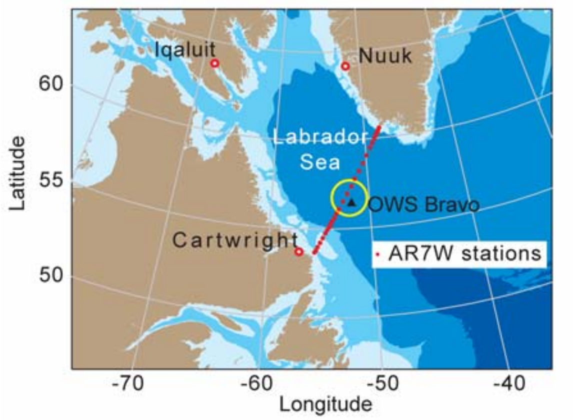

Figure 1 Map of the Labrador Sea showing the AR7W section, selected meteorological stations, and Ocean Weather Station Bravo. Historical studies of winter convection have focussed on the west-central Labrador Sea (circled area).

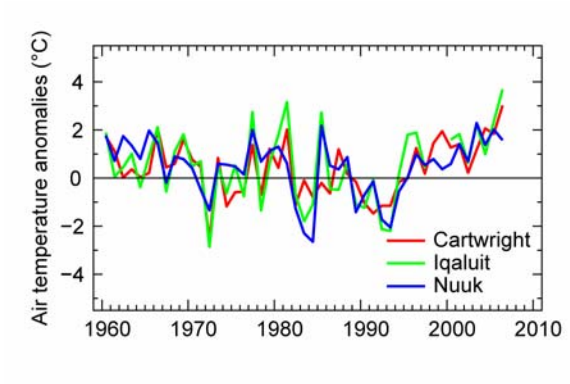

Figure 2 Annual mean air temperature anomalies for 1960-2006 relative to1971-2000 for Cartwright, Labrador; Iqaluit, Nunavut; and Nuuk, Greenland.

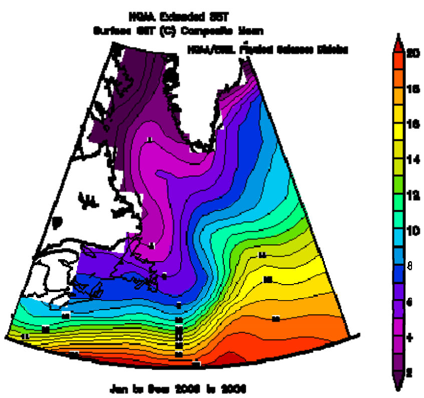

Figure 3(a) NOAA Extended SST estimates of 2006 annual mean sea surface temperature in the Labrador Sea and adjacent North Atlantic.

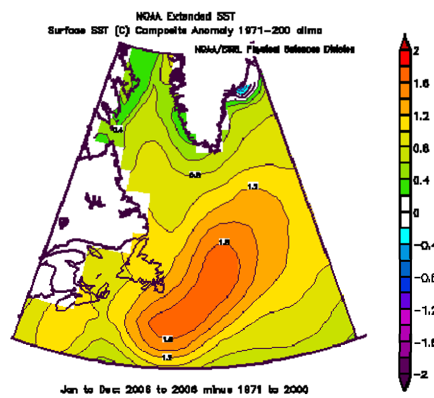

Figure 3(b) SST anomalies for 2006 relative to 1971-2000 corresponding to Figure 3(a).

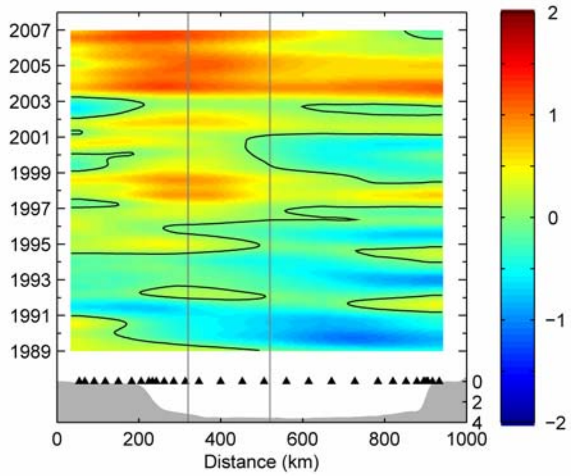

Figure 4(a) HadISST1 SST anomaly (^{o}C) regridded along the AR7W section as a function of time. Vertical lines mark 320 and 520 km along-section distances. Bathymetry and nominal AR7W station positions are shown at the bottom of the figure.

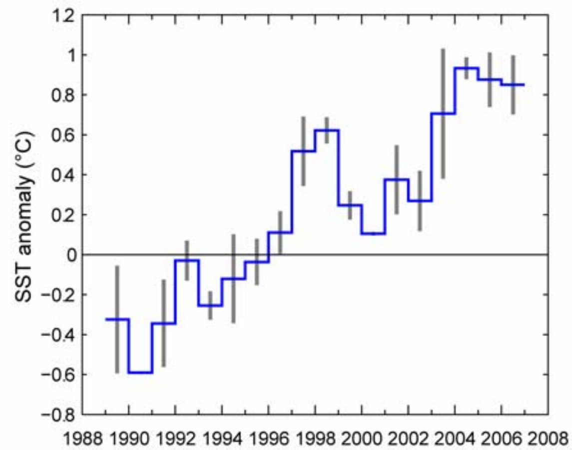

Figure 4(b) Time series of annual anomalies of HadISST1 SST for the 320–520 km distance range in Figure 4(a).

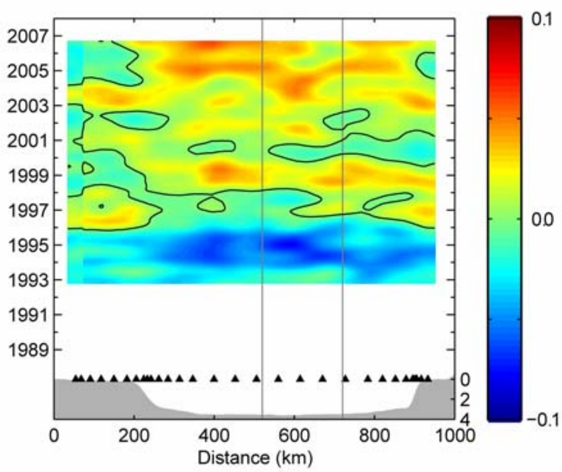

Figure 5(a) Aviso MSLA (m) regridded along the AR7W section as a function of time. Vertical lines mark 320 and 520 km along-section distances. Bathymetry and nominal AR7W station positions are shown at the bottom of the figure.

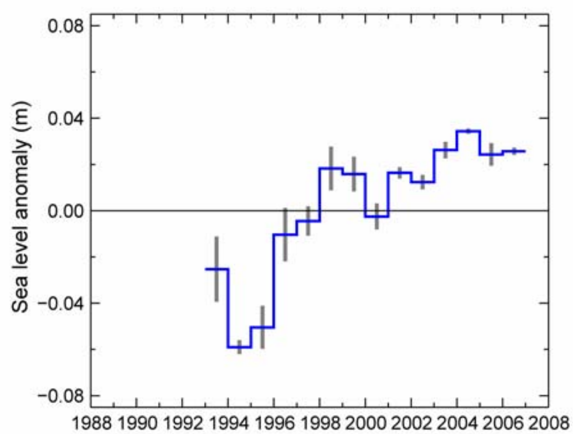

Figure 5(b) Time series of annual mean Aviso MSLA for the 320–520 km distance range in Figure 5(a).

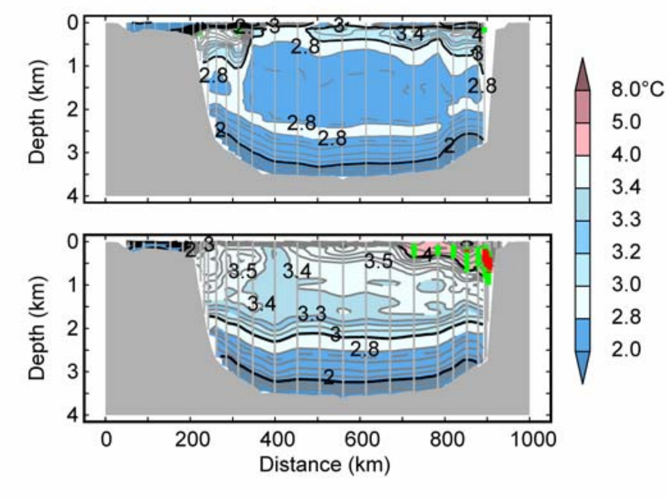

Figure 6(a) Potential temperature (°C) on the AR7W section in mid-June 1993 (upper) and mid-May 2006 (lower). Station positions are indicated by vertical lines. Coloured bars highlight Irminger Mode Water (green) and Irminger Atlantic Water (red) as defined in the text.

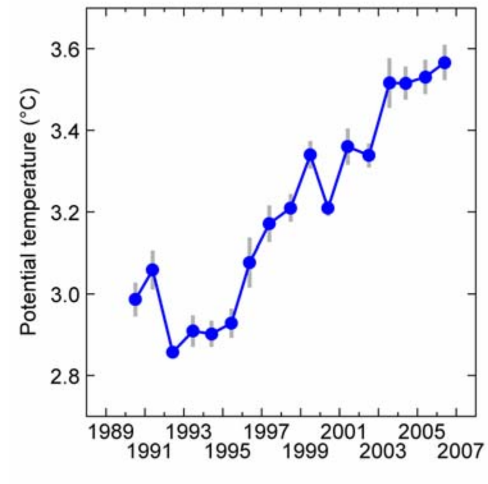

Figure 6(b) Potential temperature (0–2000 m) averaged over the AR7W section.

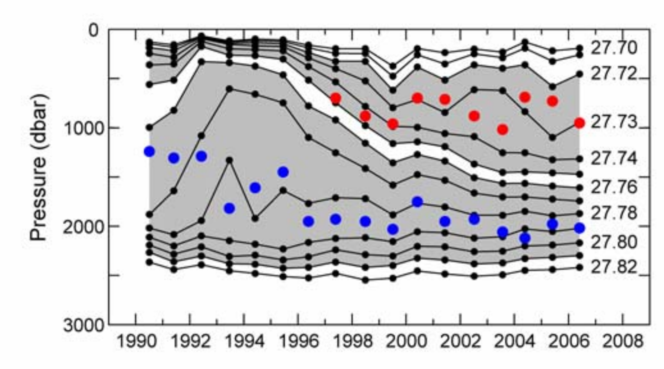

Figure 7(a) Time series of pressure on selected potential density surfaces averaged over stations in the 320-520 km distance range for spring and early summer AR7W surveys from 1990 to 2006. Filled circles mark pressures at potential vorticity minima in the two shaded layers 27.72–27.75 kg/m^3 (upper) and 27.76–27.79 kg/m^3 (lower).

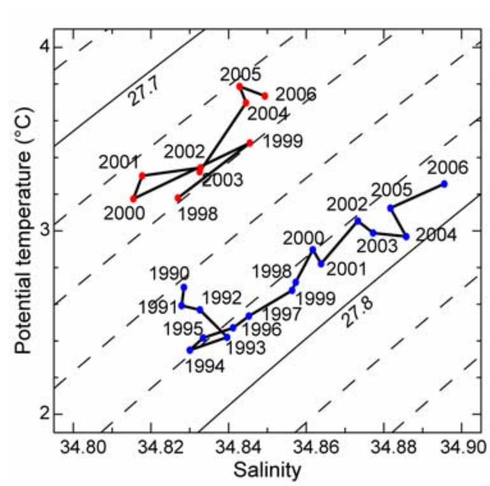

Figure 7(b) Potential temperature–salinity properties at the potential vorticity minima in the two shaded layers in Figure 7(b).