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Environmental conditions in the Labrador Sea in 2008

by

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Abstract

The Labrador Sea experienced very variable conditions during 2008. Winter surface air temperatures were up to 6°C below normal south of Davis Strait but near-normal in the southern Labrador Sea. Maximum sea ice coverage followed a similar pattern, greater than normal in the northwestern Labrador Sea and near-normal on the northern Newfoundland Shelf. The central Labrador Sea saw the coldest winter (January–March) surface air temperatures in 16 years. Cooling and densification of the upper levels of the west-central Labrador Sea during the 2008 winter produced winter mixed layers extending to 1350–1600 m depths, based on March 2008 Argo profile measurements. Increased amounts of mode waters in the 27.72–27.74 kg m^{-3} potential density anomaly range were found in the west-central Labrador Sea in the May 2008 AR7W survey. Decreases in average temperature and salinity compared to 2007 were observed in the 200–1600 m layer in the central Labrador Sea. This interrupted a recent warming trend at intermediate depth levels and rolled temperature and salinity properties back to those observed 2–3 years previously, but conditions remain generally warm and saline. The rest of the year saw above-normal surface air and sea temperatures in the central Labrador Sea. Summer (July–September) surface air temperatures were the third warmest in the 61-year NCEP Reanalysis period. Annual average surface air temperatures were the coolest since 2000 but still remained above normal. Monthly mean sea surface temperatures were warmer than normal for all of 2008; near-record-high sea surface temperatures in Spring and Summer 2008 led to the 5th warmest annual average in the 1960–2008 period.

Introduction

Labrador Sea hydrographic conditions depend largely on the changeable contributions of heat lost to the atmosphere, heat gained from warm and saline Atlantic Waters carried northward into the Labrador Sea by the West Greenland Current, and fresh water input as ice from the Arctic. Occasional severe winters 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 lead to lower heat losses and an increased presence of the warm and saline Atlantic Waters.

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 now 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 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. DFO also contributes to the international Argo program by deploying floats in the Labrador Sea. Locations of all Argo profiles during March 2008 are included in Figure 1.

A sequence of severe winters in the early 1990s led to deep convection that peaked in 1993–1994. Milder atmospheric conditions prevailed in the following years and the upper layers gradually regained their vertical stratification in density. A new regime of shallow wintertime overturning seemed to establish itself beginning in the early 2000s. This has led to the formation of warm, saline, and low-density mode waters in the upper 1000 m of the water column.

Results and Discussion

Sea level pressure

Sea level pressure was lower than normal over the central Arctic and Nordic Seas in January–March 2008 [Figure 2(a)] according to NCEP/NCAR reanalysis results (Kalnay et al., 1996). This anomaly projects moderately strongly on the loading pattern of the Arctic Oscillation [Figure 2(b)], with a normalized index of +0.8 compared to a standard deviation of about 1.2 for the 1979–2000 reference period (Climate Prediction Center, 2009). This would tend to drive storm tracks further north and lead to colder than usual conditions in the northern Labrador Sea (Thompson and Wallace, 1998).

Surface air temperature

Winter 2008 (defined as January–February–March, JFM) surface air temperatures over the Labrador Sea were notably colder than normal (the 1971 to 2000 normal period is used throughout unless otherwise indicated). NCEP Reanalysis results show JFM surface temperatures up to 6°C below normal in southern Davis Strait and the northern Labrador Sea. JFM 2008 surface air temperatures over the central Labrador Sea were less extreme but still averaged 1.4°C below normal for a representative 5° x 5° box (50–55N, 55–60W) [Figure 3]. Winter 2008 was the coldest since 1993 (16 years) and the 8th coldest in the 61-year NCEP Reanalysis (1948–2008) for this region. This was a marked change from recent years: 2000–2007 wintertime surface air temperatures averaged 2°C warmer than normal and 2004–2007 wintertime surface air temperatures averaged more than 3°C warmer than normal. The remainder of 2008 saw surface air temperatures 1–2°C warmer than normal. Spring 2008 (April–May–June, AMJ) was the 11th warmest in 61 years and Summer 2008 (July–August–September, JAS) was the 3rd warmest in 61 years, beaten by only 2003 and 2006. The 2008 annual mean Labrador Sea surface air temperature was approximately 0.5°C above normal. This represents a drop of 0.8°C from the 2000–2007 average and makes 2008 the coldest year since 2000 (9 years) and the 22nd coldest in the 61-year NCEP Reanalysis period.

Sea ice

The U.S. National Snow and Ice Data Center sea ice index (Fetterer et al., 2008) shows greater than normal March 2008 sea ice cover in the northern Labrador Sea [Figure 1]. This is consistent with the cold winter conditions detailed above. The mean March 2008 ice edge in the northern Labrador Sea extended about 200 km seaward of the long-term (1979–2000) median location. At the same time, sea ice extent on the Labrador Shelf south of about 56°N was close to normal. In contrast, March 2007 ice cover was less than normal for the entire Labrador Sea, retreating 100–150 km from its long-term median position in the northern Labrador Sea.

Sea-surface temperature

Labrador Sea sea-surface temperatures (SST) have increased by about 1°C over the past 20 years [Figure 4(a)], based on HadISST fields from the UK Hadley Centre (Rayner et al., 2003). 2008 saw the 5th warmest year since 1960 (49 years), slightly warmer than 2007 but cooler than the record-warm conditions in 2003–2006. The annual mean anomalies include underlying seasonal variability: JFM 2008 was the coldest since 2000 (9 years), consistent with the relatively cold winter conditions and increased sea-ice coverage noted above. Spring and summer conditions were warmer than normal in 2008. Seasonal means for AMJ and JAS 2008 were respectively the 4th warmest and the warmest since 1960, consistent with the observed switch to warm surface air temperatures in spring and summer 2008.

The recent warming trend has been dominated by particularly warm conditions in the west-central Labrador Sea [Figure 4(b)]. Below-normal sea-surface temperature conditions prevailed over the Labrador Shelf in late 2007 and early 2008 but warmer than normal conditions were re-established during the later part of 2008.

AR7W hydrography

The temperature and salinity of the upper layers of the Labrador Sea change from year to year in response to changes in atmospheric forcing, changes in the warm and saline inflows in the West Greenland Current, and changes in Arctic fresh water inputs. Seasonal cycles in each of these three forcing terms drive a strong seasonal cycle in the properties of the upper layers of the Labrador Sea. During the early 1990s, deep winter convection in the Labrador Sea filled the upper two kilometres with cold and fresh water. Recent milder years have produced more limited amounts of warmer, saltier, and less-dense mode waters.

Vertical overturning associated with the cold winter of 2008 was captured in a number of Argo float profile measurements during March 2008. Våge et al. (2009) and Yashayaev and Loder (2009) exploited these Argo profile measurements in their descriptions of the convection that occurred in the Labrador Sea during this period. Four separate Argo floats whose March 2008 profile positions are included in Figure 1 showed vertical overturning to depths of 1350–1600 m in the west-central Labrador Sea. The deep mixed layers seen in the Argo measurements had a maximum potential density anomaly just greater than 27.74 kg m^{-3}. The associated mode waters had potential temperatures varying between approximately 3.26 and 3.30°C. For example, five February–March 2008 profiles from Canadian Argo float 4900667 at locations also shown in Figure 1 provide a detailed view of the development of a 1450-m deep mixed layer [Figure 5(a)].

The annual AR7W surveys take place as early in the spring of the year as practical to provide a consistent view of interannual change in the face of strong seasonal changes in physical, chemical, and biological properties. Sea ice generally prevents access to the Labrador Shelf before mid-May. The median midpoint date for the 19 spring or early summer surveys completed since 1990 is June 1. The 2008 survey took place slightly earlier than the norm with a midpoint date of May 27. No sea ice was encountered on the Labrador Shelf but multi-year ice carried northward by the West Greenland Current prevented the occupation of the four easternmost stations on the West Greenland slope and shelf.

Remnants of the water masses renewed in the winter of 2008 show up in the May 2008 observations in the west-central Labrador Sea as an increased vertical separation of potential density surfaces for particular ranges of potential density [Figure. 5(b)]. Enhanced layer thicknesses with a broad and somewhat bimodal distribution were observed in the 27.72–27.74 kg m^{-3} potential density anomaly range. In spite of the cold 2008 winter and the deep mixed layers observed in March 2008, the May survey results suggest the volume and density range of Labrador Sea water renewal in Winter 2008 were similar to those of recent years (with the notable exception of 2007). For example, the mode waters observed at the same stations in the 2003 survey were denser and of a volume similar to the 2008 results [Figure 5(c)]. This suggests that there was significant spatial variability in the intensity of vertical overturning during the winter of 2008. Both the March 2008 Argo float measurements and the results from the May 2008 AR7W survey suggest that the renewal was confined to the west-central Labrador Sea. The amount and density classes of mode waters formed in recent years contrast with observed conditions in the early 1990s when a sequence of cold winters filled the upper 2 km of the entire Labrador Basin with cold, fresh, and relatively dense mode waters (range ~27.75 to 27.80 kg m^{-3}).

The two modal densities observed in the west-central Labrador Sea in the May 2008 survey are associated with different depths. The less-dense mode (found at two stations) centred at 27.725 kg m^{-3} was found at an average depth of 710 m compared to an average depth of 1150 m for the denser mode (found at three stations) centred at 27.733 kg m^{-3} [Figure 5(b)].

The 2008 survey found abundant amounts of the warm and saline Atlantic waters from the Irminger Current that enter the Labrador Sea as an offshore branch of the West Greenland Current and play an important role in the regional heat and salt balance [Figure 5(b)]. Remnants of these waters also appeared over the Labrador Slope.

A time series of potential temperature averaged over the 200–1600 m depth range for stations in the west-central Labrador Sea during the 1990–2008 period of AR7W surveys shows a rapid warming following the from 1992–

1994 minimum into the early 2000s, followed by a more moderate warming during the past decade and a downturn in 2008 [Figure 6]. The corresponding salinity time series shows a slightly less-regular increasing trend in salinity during the past decade, with a decrease in 2008. Both temperature and salinity properties are rolled back to those observed 2–3 years previously, but conditions remain generally warm and saline.

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The NCEP Reanalysis data were provided by the NOAA-CIRES Climate Diagnostics Center, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/. The HadISST 1.1 Global Sea Surface Temperature data were provided by the Hadley Centre for Climate Prediction and Research (http://www.metoffice.com). Many staff and associates at BIO have contributed to the Labrador Sea programme led by Dr. John Loder of Ocean Sciences Division and Dr. Glen Harrison of Ecosystem Research Division. These efforts, together with those of the officers and crew of CCGS Hudson, are gratefully acknowledged.

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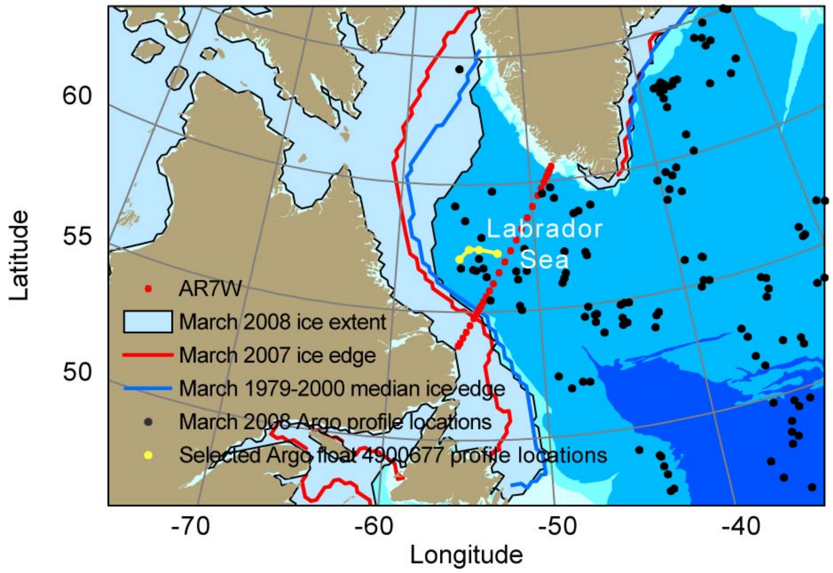

Figure 1 Map of the Labrador Sea showing the AR7W section. The mean March 2008 ice extent (filled area), March 2007 ice edge (red line), and 1979–2000 median March ice extent (ice concentration greater than 15%) from the U.S. National Snow and Ice Data Center are also shown. Filled black circles show March 2008 Argo profile positions. Locations of Argo float 49000677 profiles 63–67 at 10-day intervals from 9 February 2008 to 20 March 2008 discussed in the text shown as connected yellow-filled circles, with Profile 63 being closest to the AR7W line. The locations of Profiles 63 and 64 were separated by less than 1 km and are indistinguishable.

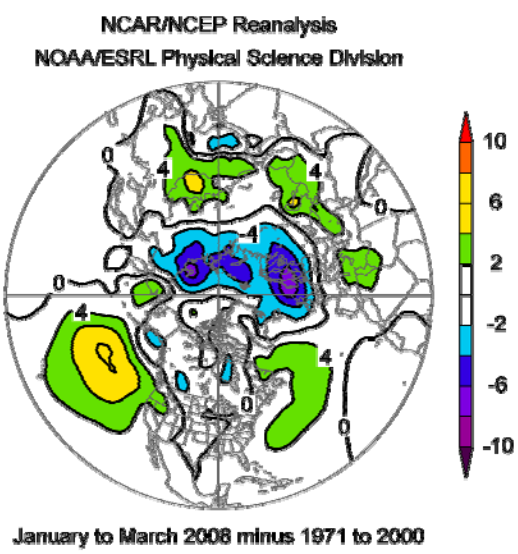

Figure 2(a) NCEP/NCAR reanalysis January–March 2008 northern hemisphere sea level pressure anomaly (mb).

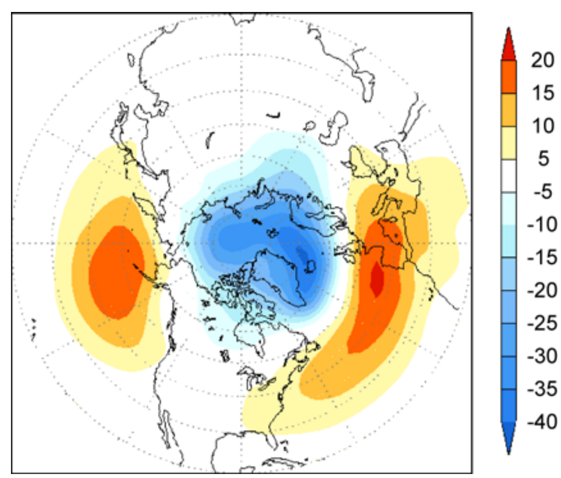

Figure 2(b) The loading pattern of the Arctic Oscillation, defined as the leading empirical mode (19% of variance) of monthly mean 1000 mb height during 1979-2000.

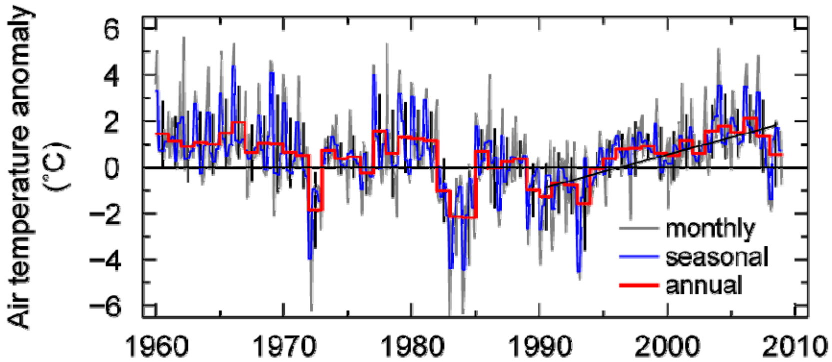

Figure 3. Surface air temperature anomalies relative to 1971–2000 averaged over the central Labrador Sea for 1960–2008 from NCEP (National Centers for Environmental Prediction) Reanalysis data. Monthly, seasonal, and annual means are shown. A regression line for the recent 1990–2008 period gives an increase of about 2.7°C over that period.

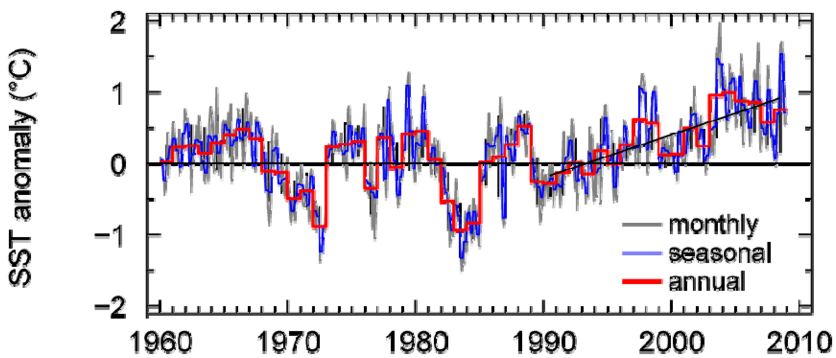

Figure 4(a) HadISST sea-surface temperature anomalies relative to 1971–2000 interpolated to the AR7W line and averaged over the distance range 55–915 km for 1960–2008. Monthly, seasonal, and annual means are shown. A regression line for the recent 1990–2008 period gives an increase of about 1.1°C over that period.

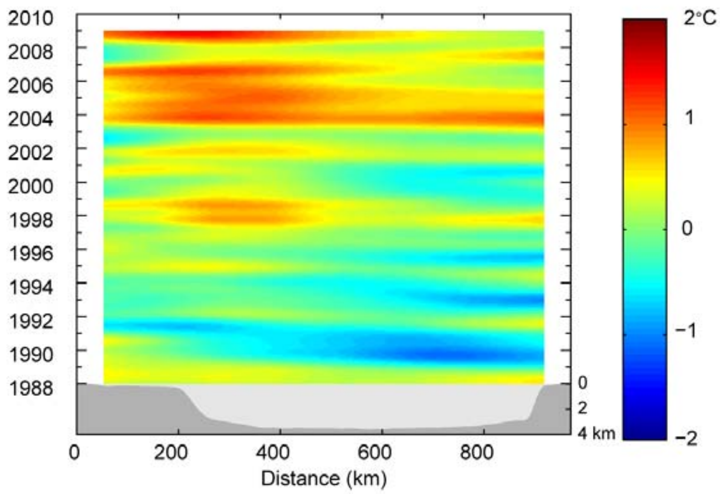

Figure 4(b) Low-pass filtered 1988–2008 HadISST sea-surface temperature anomalies relative to 1971–2000 interpolated to the AR7W line. The bathymetry along the AR7W line is shown at the bottom of the figure.

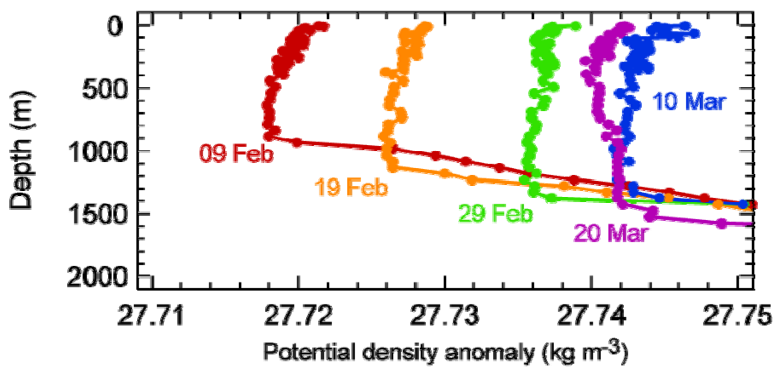

Figure 5(a) Observations from Canadian Argo float 4900677 of the deepening of the surface mixed layer in the west-central Labrador Sea from 9 February to 20 March 2008 (Profiles 63–67). The float moved approximately 180 km from west to east during this 40-day period. Profile locations are shown in Figure. 1. Profile 67 on 20 March 2008 observed a mixed layer extending from the surface to about 1450 m depth homogeneous in potential density within ~0.002 kg m^{-3} [27.740 to 27.742], potential temperature within ~0.017 °C [3.261 to 3.278], and salinity within ~0.003 [34.850 to 34.853].

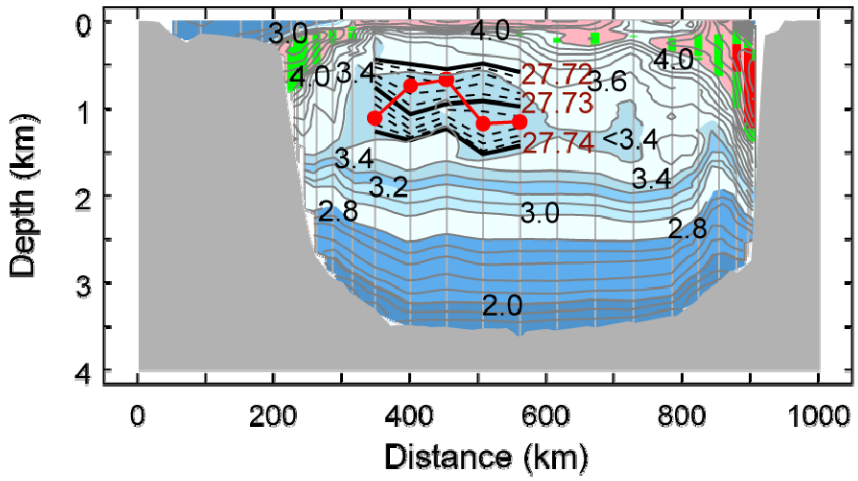

Figure 5(b) Section plot of potential temperature from the 2008 occupation of AR7W. Station positions are marked by vertical lines. Waters with potential temperatures in the range 4–6°C are highlighted for salinities in the range 34.95–35.10 (red) or 34.85–34.95 (green). Selected potential density anomaly contours at 0.002 kg m^{-3} intervals are overlaid for five stations in the west-central Labrador Sea. The filled circles indicate the centre depths of the thickest potential density layers for each of the selected stations.

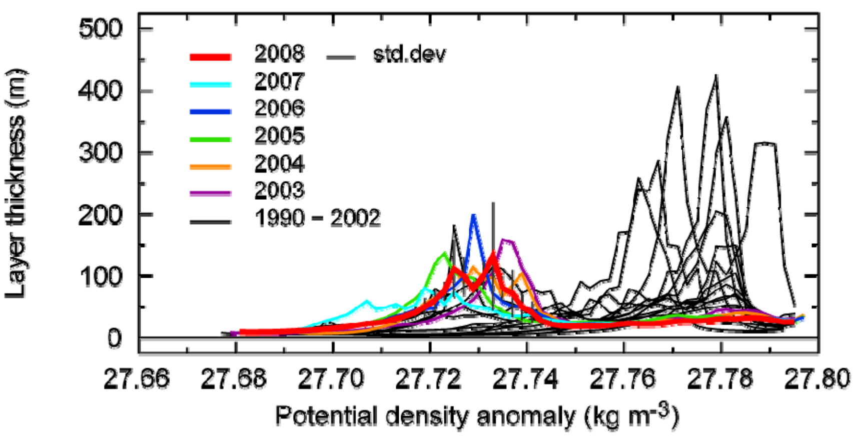

Figure 5(c) Census of the average thickness of layers bounded by selected potential density surfaces for spring and early-summer occupations of AR7W from 1990 to 2008. The 27.68–27.80 kg m^{-3} range of potential density anomaly is sampled at equal 0.002 kg m^{-3} intervals. The averages are taken over typically five stations in the 325–600 km along-track distance range in Figure 5(a). The last six years are colour coded as identified in the legend. Standard deviations for 2008 are also shown. Recent years have seen limited production of mode waters in the 27.72–27.74 kg m^{-3} potential density anomaly range, in contrast to voluminous classes formed in the 27.76–27.79 kg m^{-3} range during the early 1990s. 2007 stands out as a year of limited mode water production. The 2008 census shows a bimodal distribution with peaks centred at 27.725 and 27.733 kg m^{-3}. The central depths of the thickest layers are marked on the potential temperature section in Figure 5(a). The two 2008 modes are associated with mean depths of approximately 700 and 1150 m respectively.

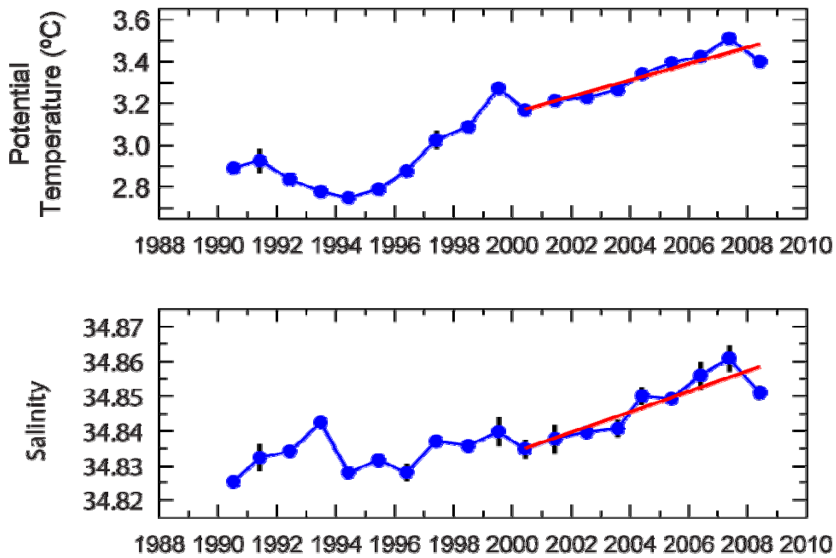

Figure 6 Potential temperature (upper panel) and salinity (lower panel) in the west-central Labrador Sea from 1990 to 2008 averaged over the 200–1600 m depth range. Trend lines are shown for the period 2000–2008.