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Environmental conditions in the Labrador Sea in 2007

by

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Abstract

Surface air temperatures in 2007 were notably cooler over northeastern Canada than record conditions experienced in 2006, but continued warmer than normal over the Labrador Sea. Sea surface temperatures also remained about 1°C warmer than normal over much of the Labrador Sea in 2007. The 18^{th} annual occupation of the AR7W Labrador Sea section during 12–18 May 2007 showed a continuation of the warm and saline conditions seen in the upper layers of the Labrador Sea during the past five years. These observations suggest that vertical overturning to depths of less than 1 km occurred during the winter of 2006–2007. Warm and saline Irminger Atlantic Waters continued to be abundant in the eastern Labrador Sea in 2007. Altimetric sea level measurements show a 0.1 m rise in sea level over the entire sub-polar gyre since 1994. Decreases in density in the upper 2 km of the water column associated with warmer temperatures only partially offset by associated increases in salinity account for essentially all the observed sea level rise in the Labrador Sea.

Introduction

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 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 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.

A sequence of severe winters in the early 1990s led to deep convection that peaked in 1993–1994. The shaded area in the west-central Labrador Sea in Figure 1 marks the region where convection to depths as great as 2000 m was observed during this period (Lazier et al., 2002). Much milder atmospheric conditions prevailed after the 1995–1996 winter, and the upper layers gradually regained their vertical stratification in density over the following 5–6 years. A new regime of shallow wintertime overturning has occupied the past 4–5 years. 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

A map of annual mean NCEP/NCAR reanalysis sea level pressure anomaly over the Labrador Sea and adjacent North Atlantic for 2007 [Figure 2(a)] shows a non-NAO-like low pressure cell centred over the western Labrador Sea. This would tend to move warmer air from the south northward on the West Greenland side of the Labrador Sea and cooler air from the north southward over the Labrador side of the Labrador Sea.

Surface air temperature

Annual mean 2007 NCEP/NCAR reanalysis 1000 mbar air temperature anomalies show Labrador Sea conditions about 1^{o}C warmer than normal [Figure 2(b)], warmer in the north and cooler in the south. There was a notable cooling over northwest Canada and the western Labrador Sea compared to 2006 [Figure 3(a)]. In contrast, conditions over Greenland were similar to those observed in 2006.

Sea surface temperature

NOAA Extended sea surface temperature (SST) (Smith and Reynolds, 2004) estimates of the 2007 annual mean SST anomaly for the Labrador Sea and adjacent North Atlantic [Figure 2(c)] show a continuation of above-normal conditions. Anomalies of up to 1.2 ^{o}C relative to the 1971–2000 mean are present in the central Labrador Sea. Changes from 2006 to 2007 show a dipole pattern, with somewhat warmer conditions off southwestern Greenland and much cooler conditions south of the Grand Banks [Figure 3(b)].

Monthly-average SST anomalies from the global HadISST1 data set produced by the UK Met Office Hadley Centre (Rayner et al., 2004) were low-pass filtered and interpolated to the AR7W section. This provides another view of the notable warming that has occurred in the Labrador Sea during recent years [Figure 4(a)]. A time series of annual mean HadISST SST anomalies since 1960 derived by annual averages over the 320–520 km distance range on the AR7W section shows a change in character beginning about 1990. A trend analysis gives a 1.2 ^{o}C increase in SST during the 17-year period since the start of annual AR7W occupations in 1990 [Figure 4(b)].

Hydrography

The 17th annual Fisheries and Oceans Canada AR7W survey took place during 12–18 May 2007 on CCGS Hudson Mission 2007011. This was about one week earlier than typical and relatively heavy ice conditions prevented the occupation of the innermost four stations on the Labrador shelf and the innermost station on the West Greenland shelf.

Contoured gridded sections of potential temperature from the 1993 and 2007 surveys show a marked change from the cold period of the early 1990s to the present [Figure 5(a)]. Along-section distance in kilometres increasing from southwest (Labrador) to northeast (Greenland) is used as the horizontal coordinate. The 2.8°C water produced by the deep convection in the winters of 1992–1993 and 1993–1994 has been replaced by waters warmer than 3.5°C.

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 Figure 5(a). They were almost completely absent in the 1993 survey but have become abundant in recent years.

A time series of potential temperature averaged over the upper 2 km for all stations at least that deep during the 1990–2007 period of AR7W surveys shows a rapid recovery from 1992–1994 up to about 2004, and a much more moderate warming during the past 4–years [Figure 5(b)]. 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 2007 survey encountered conditions generally similar to those observed in the past few years. A layer of reduced vertical stratification in the 500–1000 m depth range has persisted in recent years [Figure 6(a)]. This layer can be interpreted as a remnant of vertical mixing during the previous winters. The potential temperature and salinity at the potential vorticity minimum have changed somewhat, with a trend to warmer and more saline conditions [Figure 6(b)].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.

Sea level

Changes in sea level due to thermal expansion and salinity variations are referred to as steric sea level changes. They can be calculated from observed temperature and salinity fields relative to a deep pressure level. Steric sea level in the west-central Labrador Sea has risen by about 0.09 m since 1994 [Figure 7(a)]. Increases in temperature alone would have given a rise in steric sea level of close to 0.15 m, but the increases in temperature have been accompanied by increases in salinity that have the opposite effect on density and steric sea level.

The French SSALTO/DUACS group uses 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 time series of low-pass filtered MSLA from the west-central Labrador Sea shows an increase of about 0.1 m from 1994 to the present [Figure 7(a)]. There is remarkable agreement between the altimetric sea level changes and the steric sea level changes relative to 2000 dbar. A spatial map of the change in altimetric sea level in the northern North Atlantic between 1994 and 2007 shows a broad pattern of sea level rise of about the same magnitude [Figure 7(b)]. The spatial coherence of the sea level changes suggests that the hydrographic properties of the upper layers of the larger sub-polar gyre have undergone changes similar to those observed in the Labrador Sea over the past decade.

Acknowledgments

NCEP/NCAR reanalysis images and 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/.

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]

The altimeter products were produced by Ssalto/Duacs and distributed by Aviso with support from Cnes. [http://www.aviso.oceanobs.com/]. Data for Figure 7(b) was obtained via the Aviso Live Access Server (LAS) [http://las.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. Dr. John Loder presently leads the associated Ocean Sciences Division Ocean Circulation and Variability Programme. Dr. Glen Harrison was Senior Scientist on CCGS Hudson Mission 2008011 and presently leads the associated biological research program within Ecosystem Research Division. These efforts, together with those of the officers and crew of CCGS Hudson, are gratefully acknowledged.

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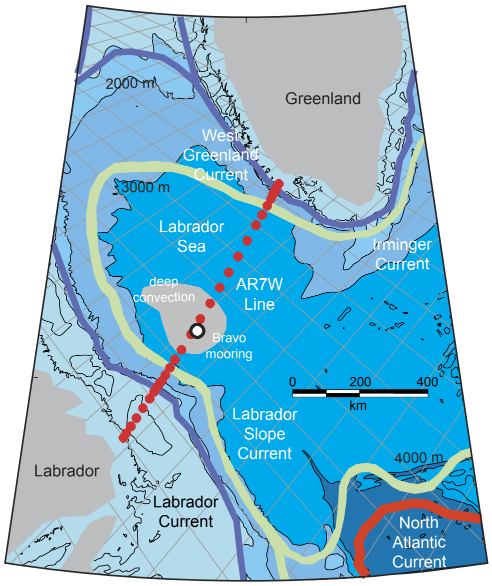


Figure 1 Map of the Labrador Sea showing the AR7W section and a schematic representation of the major upper-layer currents. Studies of winter convection have focussed on the west-central Labrador Sea (shaded area).

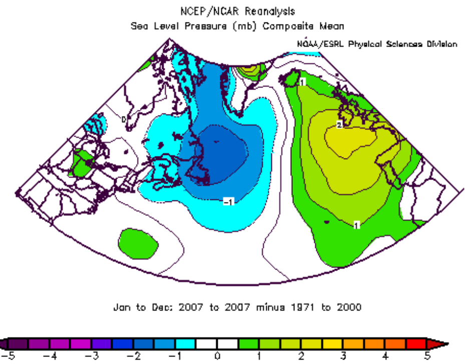


Figure 2(a) NCEP/NCAR reanalysis of annual sea level pressure anomaly over the Labrador Sea and adjacent North Atlantic for 2007.

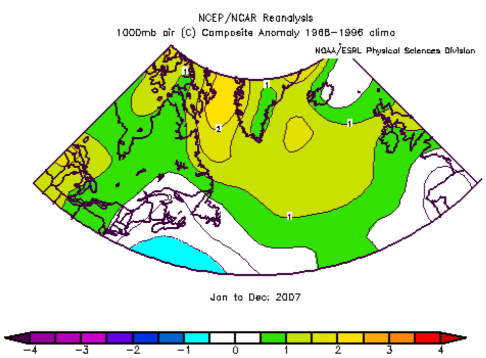


Figure 2(b) NCEP/NCAR reanalysis annual 1000 mbar air temperature anomaly over the Labrador Sea and adjacent North Atlantic for 2007.

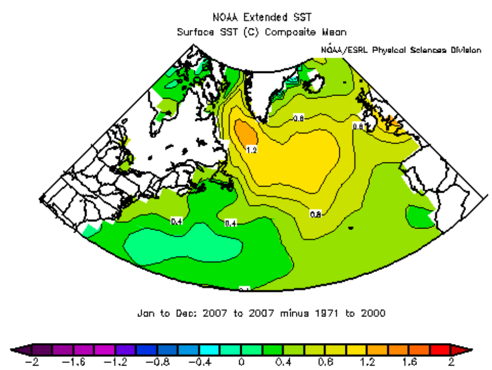


Figure 2(c) NOAA extended sea surface temperature annual anomaly for the Labrador Sea and adjacent North Atlantic for 2007.

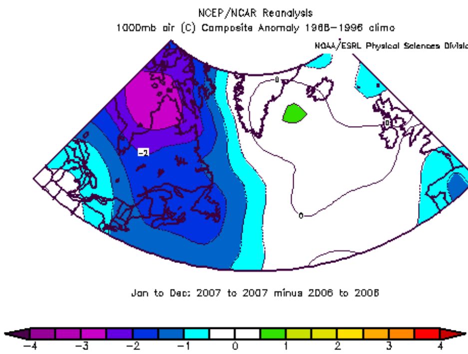


Figure 3(a) NCEP/NCAR reanalysis of change in annual mean 1000 mbar air temperature over the Labrador Sea and adjacent North Atlantic from 2006 to 2007.

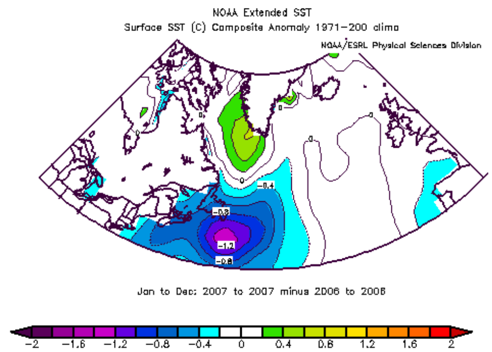


Figure 3(b) NOAA extended sea surface temperature change in annual mean over the Labrador Sea and adjacent North Atlantic from 2006 to 2007.

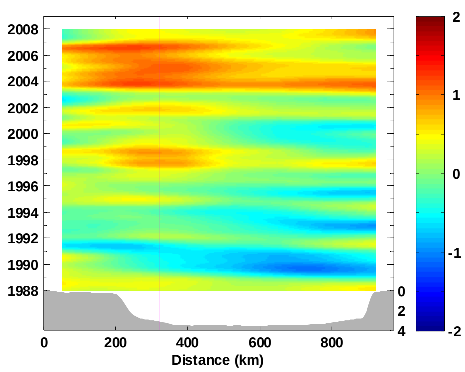


Figure 4(a) HadISST sea surface temperature anomalies relative to 1971–2000 low-pass filtered in time and interpolated along the AR7W line for the period 1988–2007. The bathymetry along the AR7W line is shown at the bottom of the figure. Vertical lines mark 320 and 520 km along-section distances.

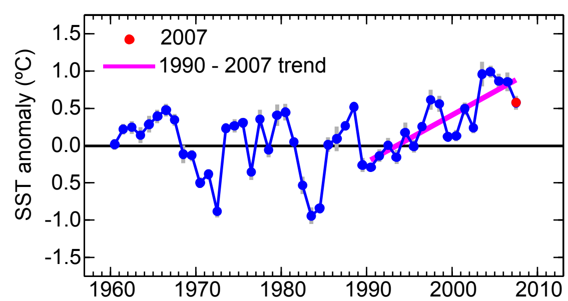
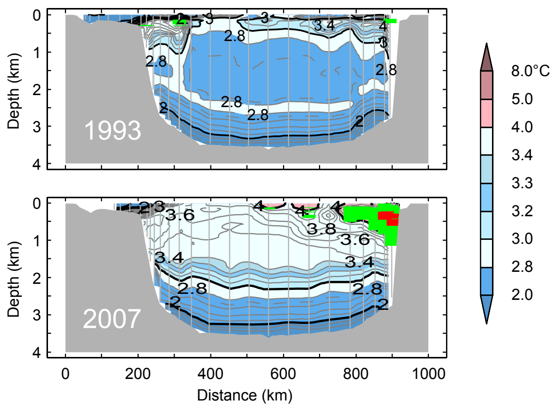


Figure 4(b) Time series of annual anomalies of HadISST sea surface temperature averaged over the 320–520 km distance range along the AR7W section as in Figure 4(a). The trend line gives a 1.2°C rise over the 17-year period 1990– 2007.



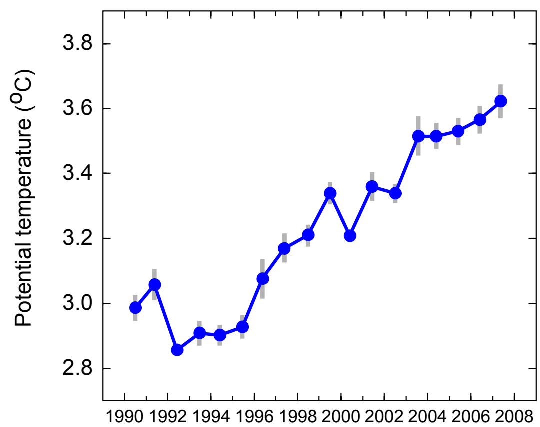
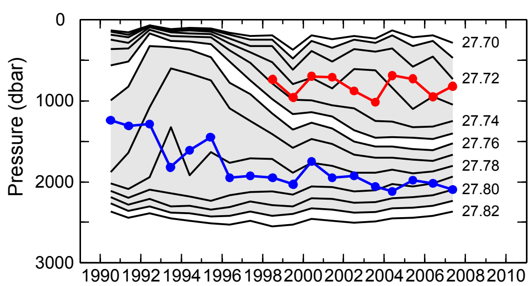


Figure 5(a) Potential temperature (°C) on the AR7W section in May–June 1993 (upper) and May 2007 (lower). Station positions are indicated by vertical lines. Colour highlighting marks the presence of Irminger Mode Water (green) and Irminger Atlantic Water (red) as defined in the text.

Figure 5(b) Average potential temperature in the upper 2000 m for spring occupations of AR7W from 1990 to 2007. The averages are based on typically 17 stations in each survey that reached as deep as 2000 m. Standard errors of the mean value for each survey are also shown.



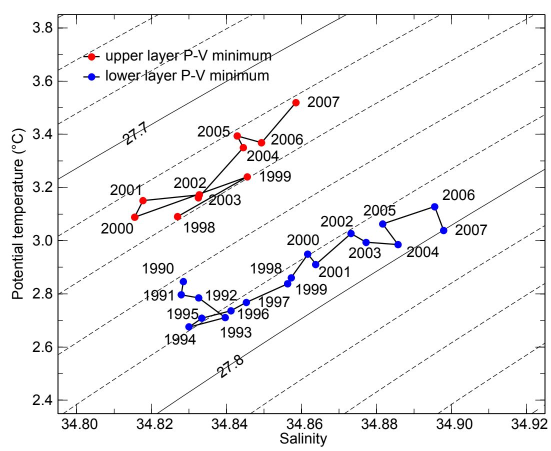


Figure 6(a) Black lines show pressure on potential density surfaces averaged over stations in the 320–520 km distance range for spring AR7W surveys from 1990 to 2007. Red and blue lines connect pressures at potential vorticity minima in the two shaded layers 27.72–27.75 kg m^{-3} (upper) and 27.77–27.79 kg m^{-3} (lower).

Figure 6(b) Potential temperature–salinity properties corresponding to the potential vorticity minima in the two shaded layers in Figure 6(a).

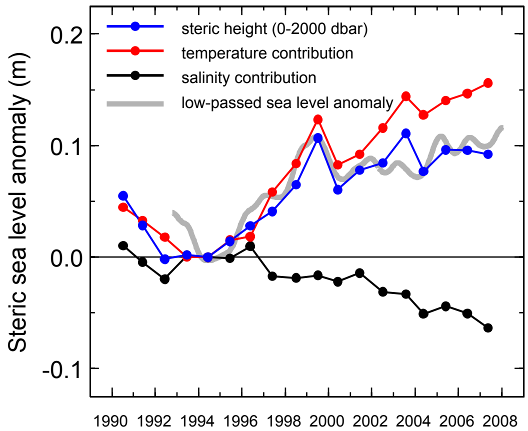


Figure 7(a) The blue line shows 0–2000 dbar steric sea level anomaly averaged over stations in the 320–520 km distance range for spring AR7W surveys from 1990 to 2007. The red and black lines show the contributions of temperature and salinity to 0–2000 dbar steric height anomaly. All fields are relative to 1994 values. The observed salinity effect is approximately 40% as large as the temperature effect, with opposite sign. The thick grey line shows low-passed altimetric sea level anomaly relative to 1994 mean values averaged within a 1-degree by 1-degree square centred at 55.5N, 52.5W.

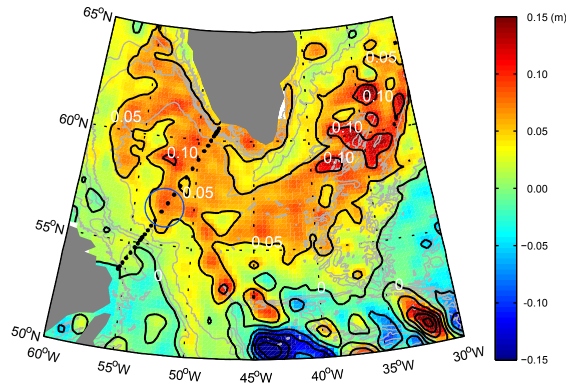


Figure 7(b) Map of changes in annual mean sea level in the northern North Atlantic from 1994 to 2007. The small filled circles show AR7W station positions. The time series of altimetric sea level anomalies in Figure 7(a) is representative of the spatial region contained within the blue circle.