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Environmental conditions in the Labrador Sea in 2009

by

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Abstract

The Labrador Sea experienced very warm winter surface air temperatures in 2009; temperatures ranged from approximately 8°C above normal in the northern region near Davis Strait to about 2-4°C above normal in the southern Labrador Sea. This is in strong contrast to the 2008 winter conditions during which the central Labrador Sea experienced the coldest winter (January–March) surface air temperatures in 16 years and the ocean responded with deep convection to 1600 m. In 2009, convection was limited to the upper 800 m of the water column. Maximum sea ice extent was near the long-term mean for this region, however, sea ice concentration was lower that normal in the region of the northern Labrador Sea. The cooling and densification of the upper levels of the west-central Labrador Sea observed in the 2008 winter interrupted a recent warming trend at intermediate depth levels, however, the milder air temperatures during the winter of 2009 limited convection and the warming trend has resumed in 1000-1500 m layer. Monthly mean sea surface temperatures were slightly warmer than normal (approximately 1ºC) for all of 2009.

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. The AR7W line is the major component of the Canadian Department of Fisheries and Oceans (DFO) Atlantic Zone Off-shelf Monitoring Program (AZOMP) and contributes 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. 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. This trend was interrupted in the winter of 2008 when deep convection was observed to extend to 1600 m in the central Labrador Sea.

Results and Discussion

Sea level pressure
Sea level pressure was close to the long-term mean over the central Arctic and Nordic Seas in January–March 2009 [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 +0.5 utilizing the 1950–2000 reference period (Climate Prediction Center, 2009). A positive AO index 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 2009 (defined as January–February–March, JFM) surface air temperatures over the Labrador Sea were warmer than normal while Summer (July-August-September, JAS) temperatures were near normal for this region. The reference period for analysis was 1968 to 1996. NCEP Reanalysis results show JFM surface temperatures up to 8°C above normal in southern Davis Strait and the northern Labrador Sea. JFM 2009 surface air temperatures over the central and southern Labrador Sea were 2-4°C above normal [Figure 3]. The 2009 annual mean surface air temperature for the northern Labrador Sea was approximately 4°C above normal and about 1°C for the southern region. The 2009 winter air temperatures are in strong contrast to the Winter 2008, which was the coldest since 1993 (16 years) and the 8th coldest in the 61-year NCEP Reanalysis (1948–2008) for this region. Winter 2008 temperatures were about 6°C below normal in the northern Labrador Sea and approximately 1.5°C above normal in the southern Labrador Sea. This was a marked change from the previous eight years (2000–2007) when wintertime surface air temperatures averaged 2°C warmer than normal.

Sea ice
The U.S. National Snow and Ice Data Center sea ice index (Fetterer et al., 2009) shows near-normal March conditions for sea ice extent in 2009 in the Labrador Sea [

Figure 4]. This is somewhat unexpected in the northern region of the Labrador Sea where the JFM surface air temperature was significantly above normal for this period. During the below normal air temperature conditions in the Winter 2008, the March 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.

Sea-surface temperature
Labrador Sea sea-surface temperatures (SST) during JFM 2009[Figure 5] indicate that in ice-free areas the winter SST was 0.5-1.5°C above normal (climatology for this data set is 1971-2000). This is consistent with the surface air temperatures which were 2-4°C above normal in the central and southern Labrador Sea during this period. The annual mean anomalies for 2009, which include the underlying seasonal variability, were less that 1°C for the region. In contrast, JFM 2008 SST was the coldest since 2000, consistent with the relatively cold winter conditions and increased sea-ice coverage which occurred that year.

AR7W hydrography
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 20 spring or early summer surveys completed since 1990 is June 1. The 2009 survey took place slightly earlier than the norm with a midpoint date of May 25th.

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. This recent trend changed abruptly during the cold winter of 2008 during which deep convection to 1600 m was observed during the AZOMP survey in May [Figure 6]. The environmental conditions which contributed to the 2008 deep convection have been documented by Våge et al.

(2009) and Yashayaev and Loder (2009). The 2009 AZOMP survey in May 2009 [Figure 6] shows remnants of Labrador Sea Water (LSW) formed in the deep convection event of 2008; the salinity transect of the AR7W line in 2009 indicates that deep convection was limited to approximately 800 m.

Temperature and salinity of the Labrador Sea basin [Figure 7] indicates the period of 1970-2009 is dominated in the upper 2000 m by a cooling-freshening trend until the mid-1990s which subsequently shifts direction. The development of the Argo profiling drifter program provides the ability to derive Labrador Sea T/S fields in the upper 2000 m starting in 2003 [Figure 8]. The seasonal cycle is clearly captured by the Argo drifters and interannual variability is demonstrated.

Annual means of temperature [Figure 9] and salinity [Figure 10] anomalies for the upper layer (10 – 150 m) of the Labrador Sea are derived using a combination of ship and Argo (starting in 2002) measurements over the last six decades. Both the temperature and salinity anomalies have been decreasing since 2003 and both parameters were slightly above the long-term mean in 2009. The seasonal cycle of salinity is observed using Argo float data for the period of 2002-2010 in Figure 11. This time series demonstrates that salinity does have a consistent seasonal cycle with salinity peaking in first quarter of the year and reaching its freshest point in the last quarter. The strongest freshening event of the 20-50m layer in this 8-year period occurred in the Fall 2008; this could have important consequences for the buoyancy-driven deep convection which takes place in the following winter (2009). The surface-layer freshening appears to be partially linked to increased precipitation rates in the fall 2008 as demonstrated in Figure 12. The 2008 mean daily precipitation in the OND period was approximately 40% higher than that observed in the two preceding years. Surface salinity in controlled by lateral flux of freshwater from the Labrador and Greenland shelves.

The Argo temperature-salinity time series [Figure 8] indicate that deep convection in the central Labrador Sea extended to depths of about 700–1100 m during the winters of 2001– 2007, with the exception of 1200–1300 m in 2003. During this period, the average temperature of the 1000–1500 m layer was slowly and steadily warming [Figure 13a], as the remnant LSW_{2000} class was diffusing and being replaced by waters from elsewhere. The deep convection in 2008 resulted in an abrupt end to this trend, with the temperature of this layer dropping by about 0.2ºC due to the massive production of LSW_{2008}. The upward trend has been observed to continue through 2009 such that the potential temperature of this layer was 0.15ºC above the minimum observed in the winter 2008.

Total surface heat fluxes (positive upward or outgoing) constructed from the NCEP flux components were averaged over an area of the Labrador Sea closely matching the region used to create the Argo time series (see Figure 3 of Yashayaev and Loder, 2008). Time series of cumulative heat transfer (CHT) from the ocean, computed by progressive integration of the total surface flux from the time in each year when heat loss started to occur and continuing until it ended (fall-winter), are shown in Figure 13b (blue). The integration was then continued through the portion of the year when heat transfer into the ocean was occurring (spring-summer), partially offsetting the earlier cumulative heat loss. This resulted in the pink portions of the CHT curves in Figure 13b which complete the cooling-heating cycle for each year.

The CHT in each year can be compared with ocean heat content (HC) from the Labrador Sea Argo profiles [Figure 8]. To facilitate this comparison, the HC values are referenced to those at the start date of cooling and then reversed in sign to construct the relative heat content (RHC) series shown in Figure 13b. The blue/red RHC curves correspond to the periods with decreasing/increasing HC (net ocean cooling/warming).

The comparison of CHT with RHC confirms the predominant importance of the surface fluxes to temperature variability in the Labrador Sea and, to a lesser extent (because of uncertainty in the NCEP fluxes), also indicates an important contribution from horizontal advective-diffusive exchange. The fall-winter of 2007–2008 had the largest cumulative heat loss from the ocean to the atmosphere of the seven years examined, with magnitude about 50% above the 2002–2007 mean. This indicates that an anomalously high level of atmospheric cooling led to the enhanced production of LSW in 2008. Subsequently, in 2009 surface fluxes were close to the 2002-2007 mean.

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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/. Many staff and associates at BIO have contributed to the

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Figure 1: Schematic of the Labrador Sea region indicating upper ocean current systems and the AR7W hydrographic line occupied each spring as part of the DFO Atlantic Zone Offshore Monitoring Program (AZOMP).

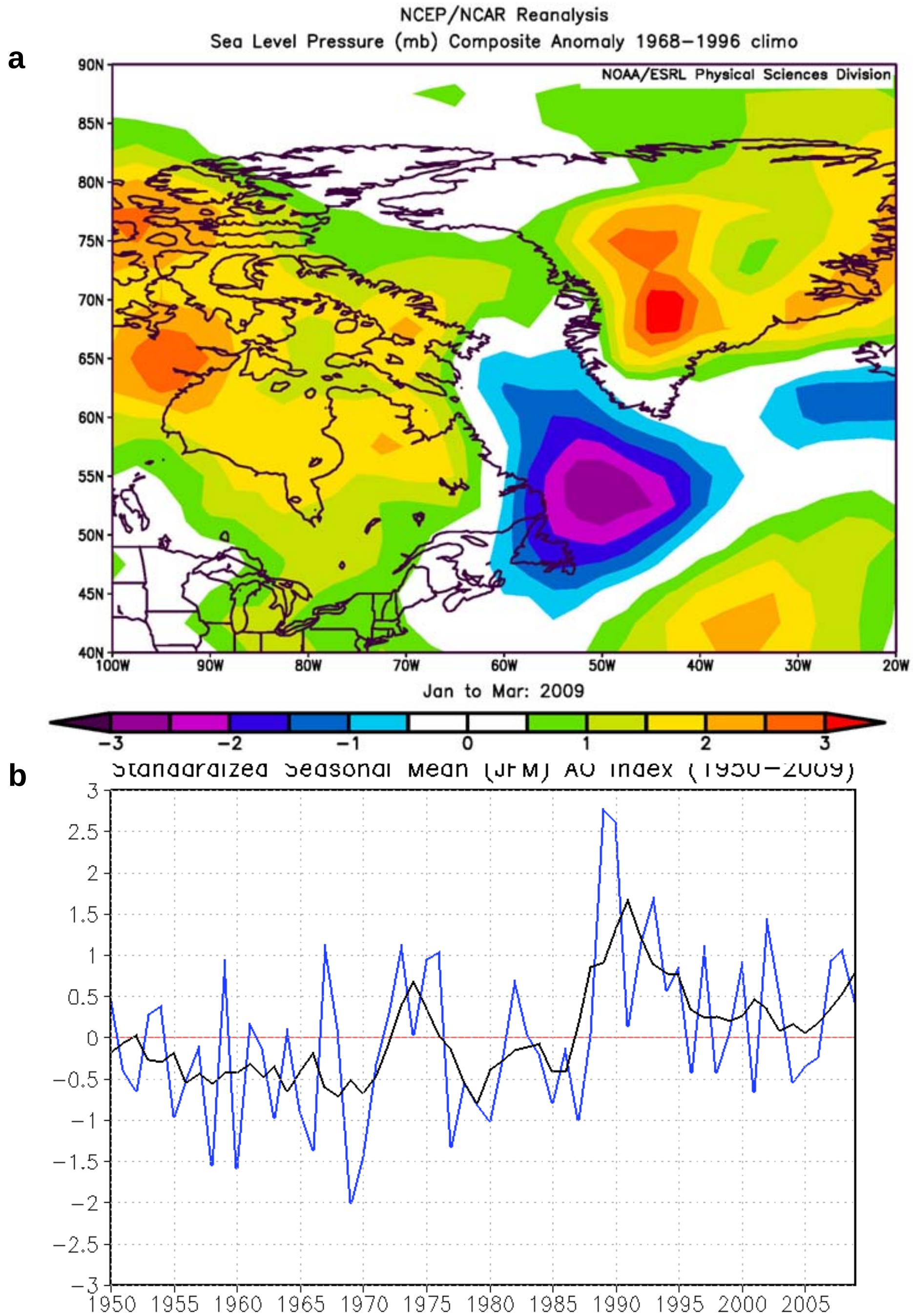

Figure 2: Sea level pressure anomaly (a) for Jan-Feb-Mar 2009 as derived from NCEP/NCAR reanalysis. Winter Arctic Oscillation (AO) index with 1950-2000 as base period. Blue line represents annual estimates and black line is 5-year running mean. http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/JFM_season_ao_index.shtml

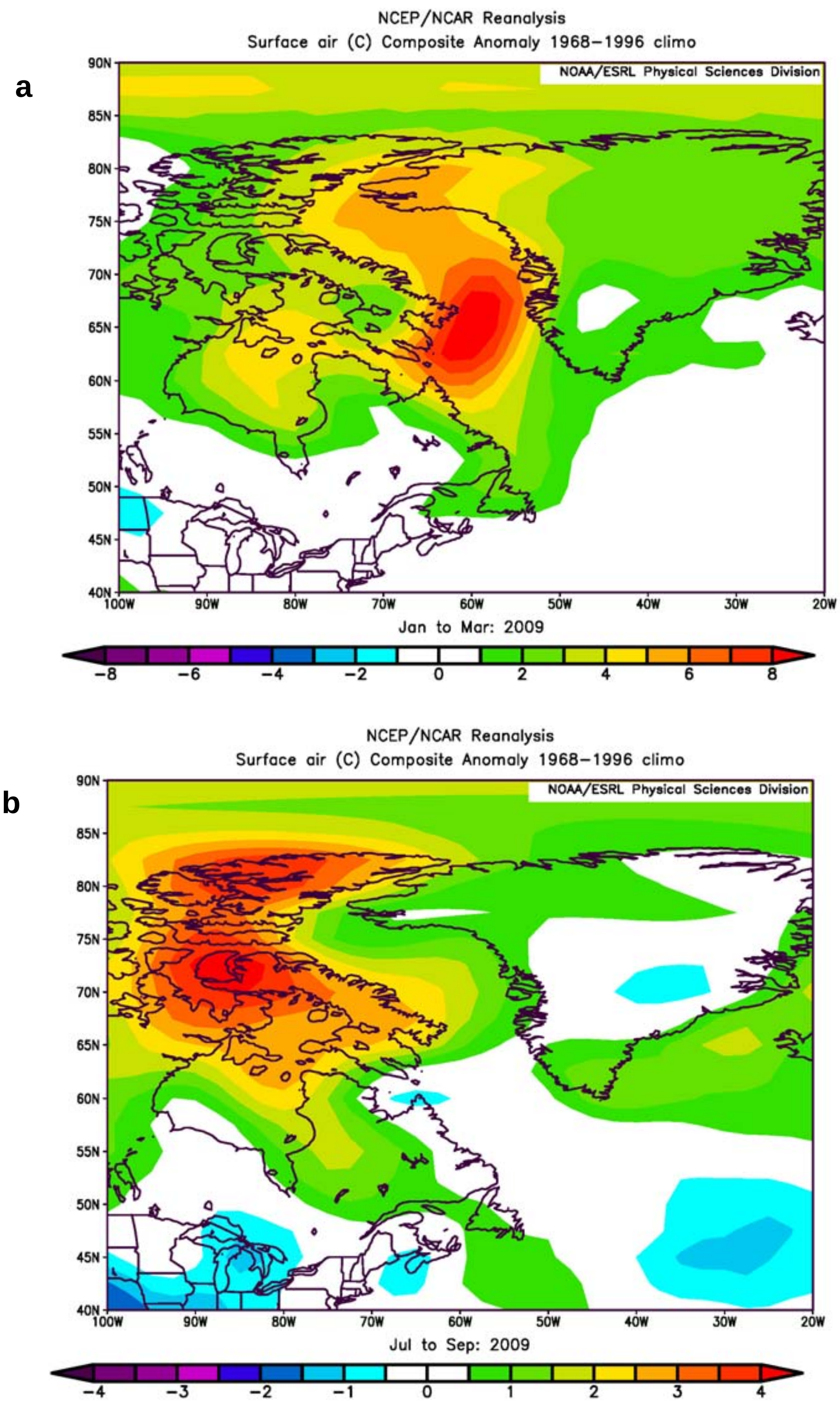

Figure 3: Surface air temperature anomaly for winter and summer periods in 2009 as derived from NCEP/NCAR reanalysis. http://www.esrl.noaa.gov/psd/

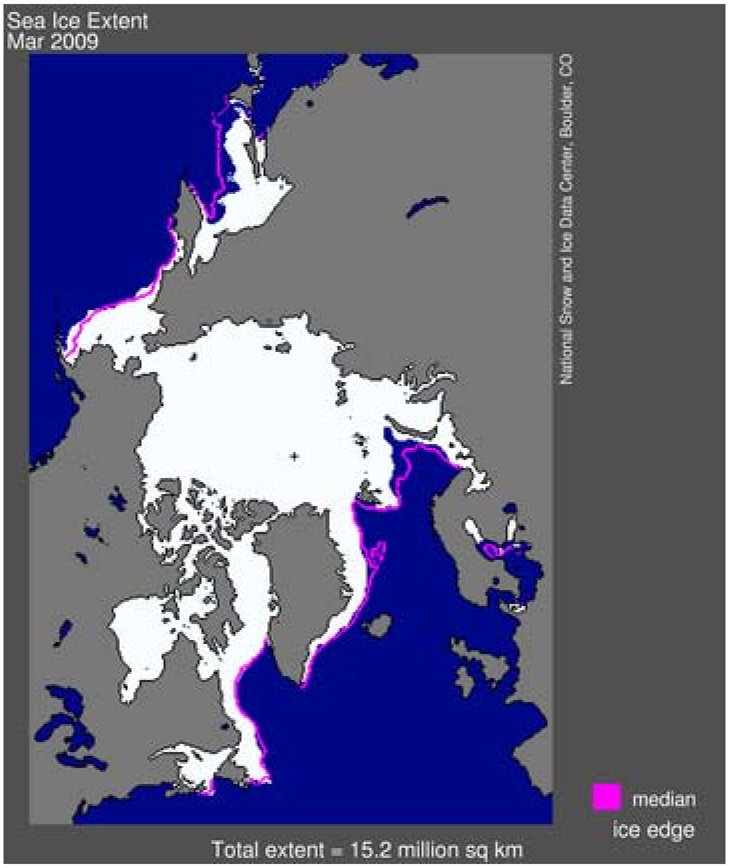

Figure 4: Sea ice extent and concentration anomalies for March 2009 as derived by the US National Snow and Ice Data Center http://nsidc.org/data/seaice_index/archives/index.html. Median ice edge (1997-2000) indicated by the magenta line in the top panel.

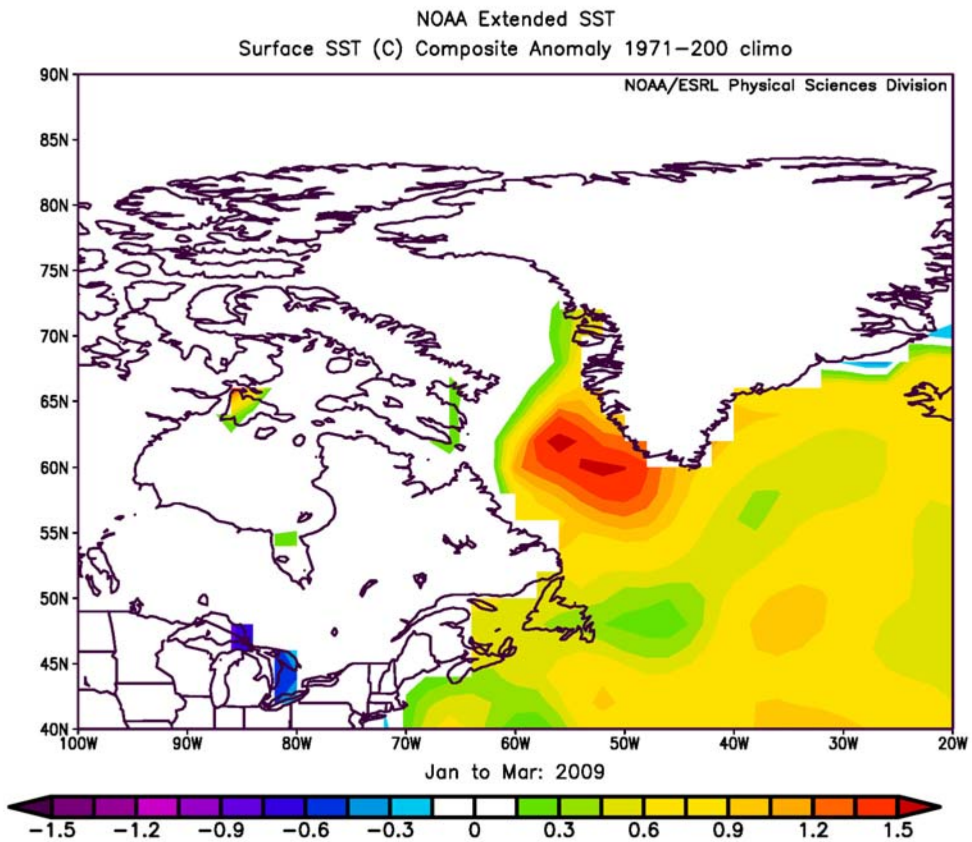

Figure 5: Sea surface temperature analysis for Winter 2009 (JFM) derived from NCEP/NCAR reanalysis. **http://www.esrl.noaa.gov/psd/**

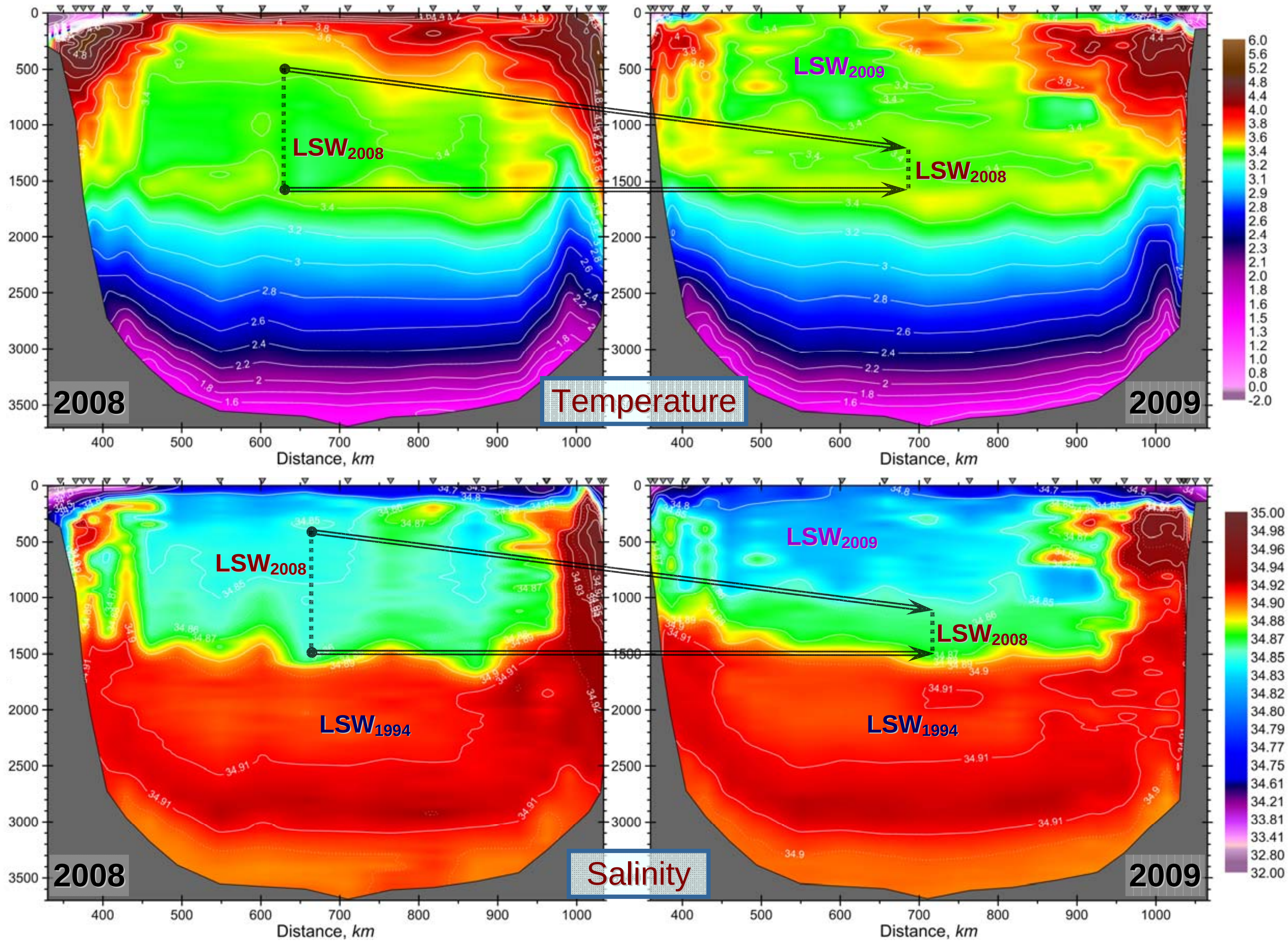

Figure 6: Temperature (top row) and salinity (bottom row) collected along the AR7W line in the Labrador Sea in 2008 and 2009.

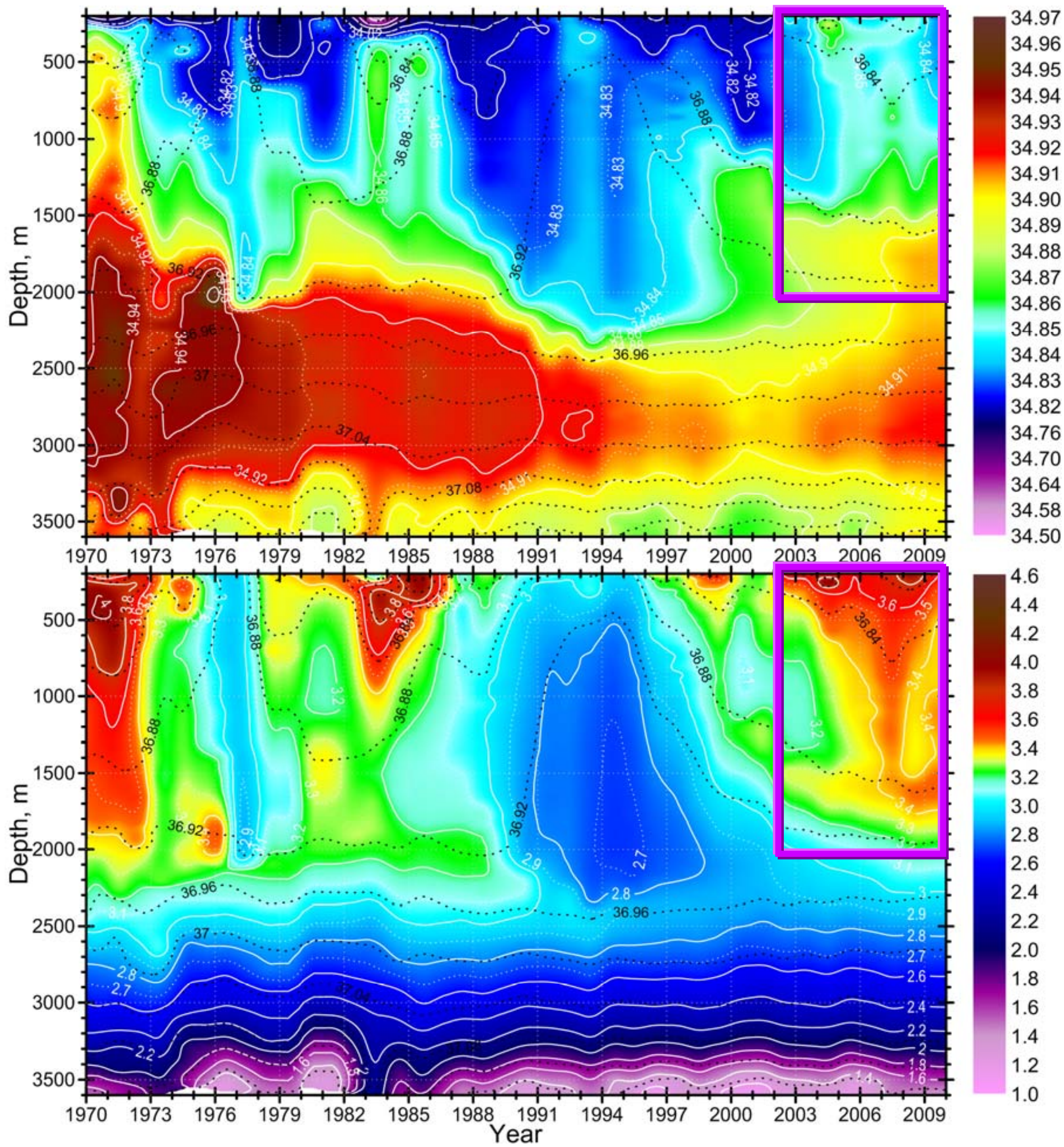

Figure 7: Labrador Sea salinity (top) and potential temperature (bottom) for the period 1970-2009. Areas in magenta boxes represent the time-depth coverage provided by Argo floats as shown in Figure 8.

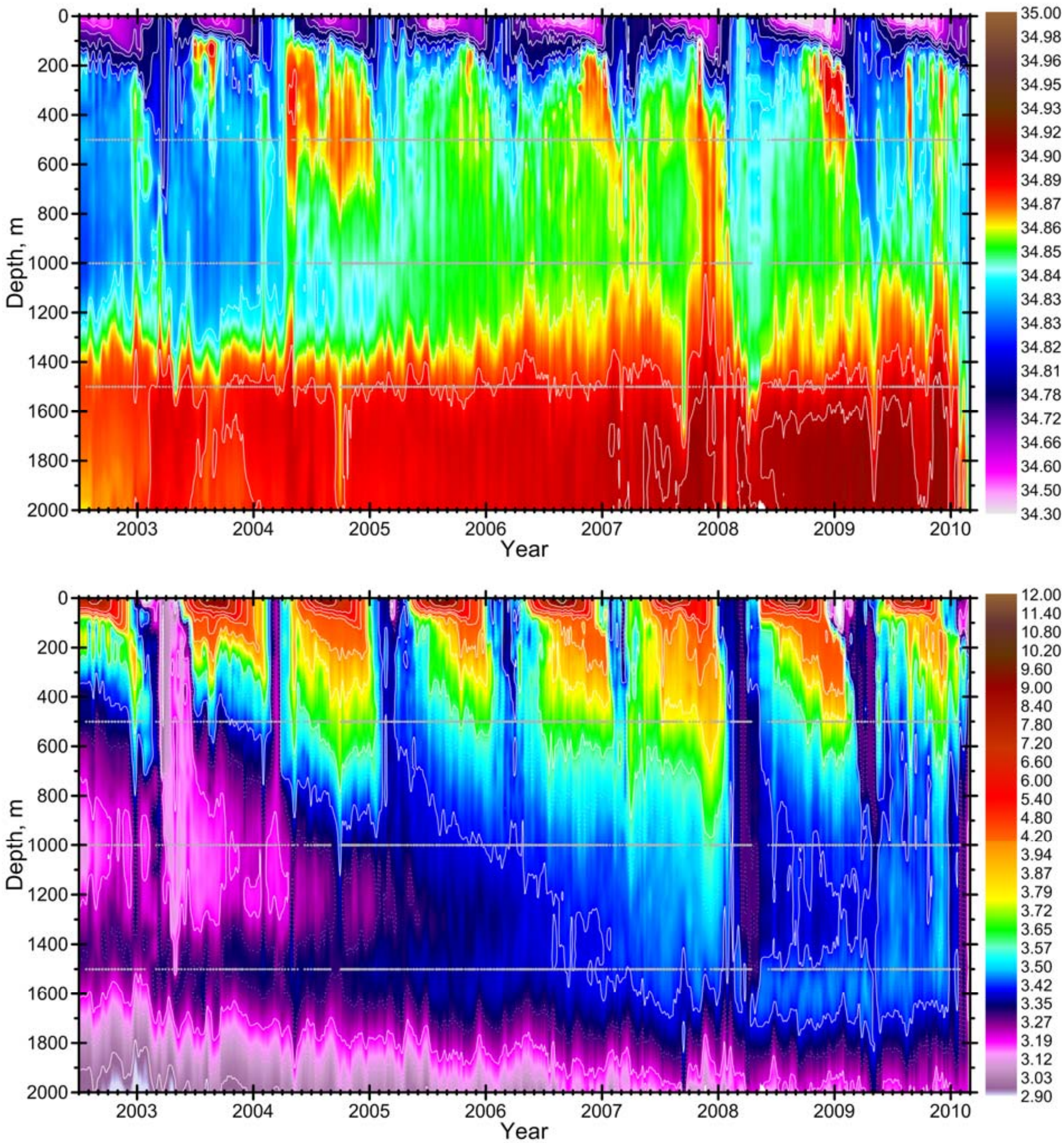

Figure 8: Salinity and potential temperature from Argo drifters in the Labrador Sea. The winter 2008 deep convection event is clearly evident to a depth of 1600 m. Convection was limited to a depth of 800 m in the winter 2009.

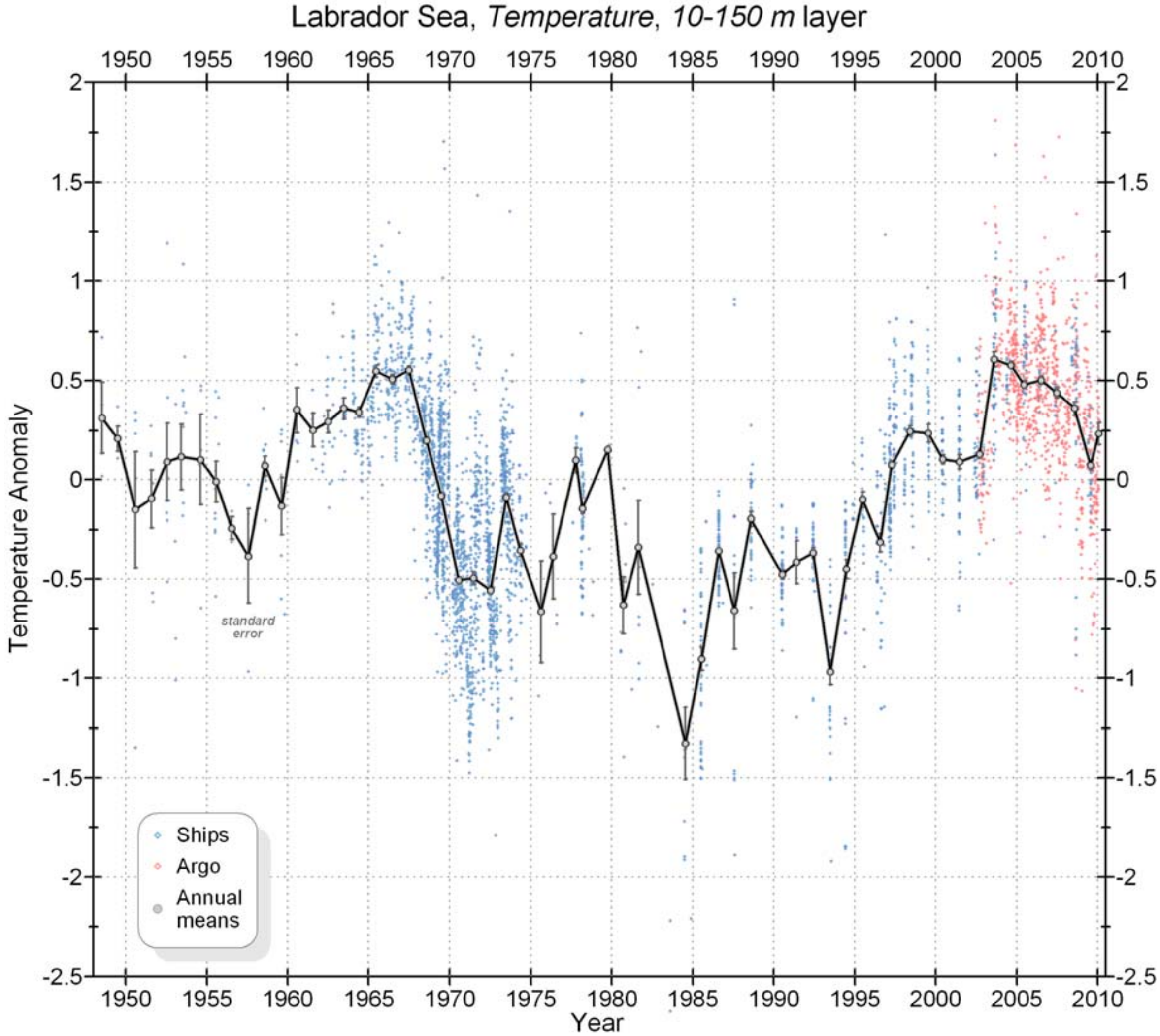

Figure 9: Upper layer temperature in the Labrador Sea based in a combination of ship and Argo drifter measurements. Black line represents annual mean with standard error estimates.

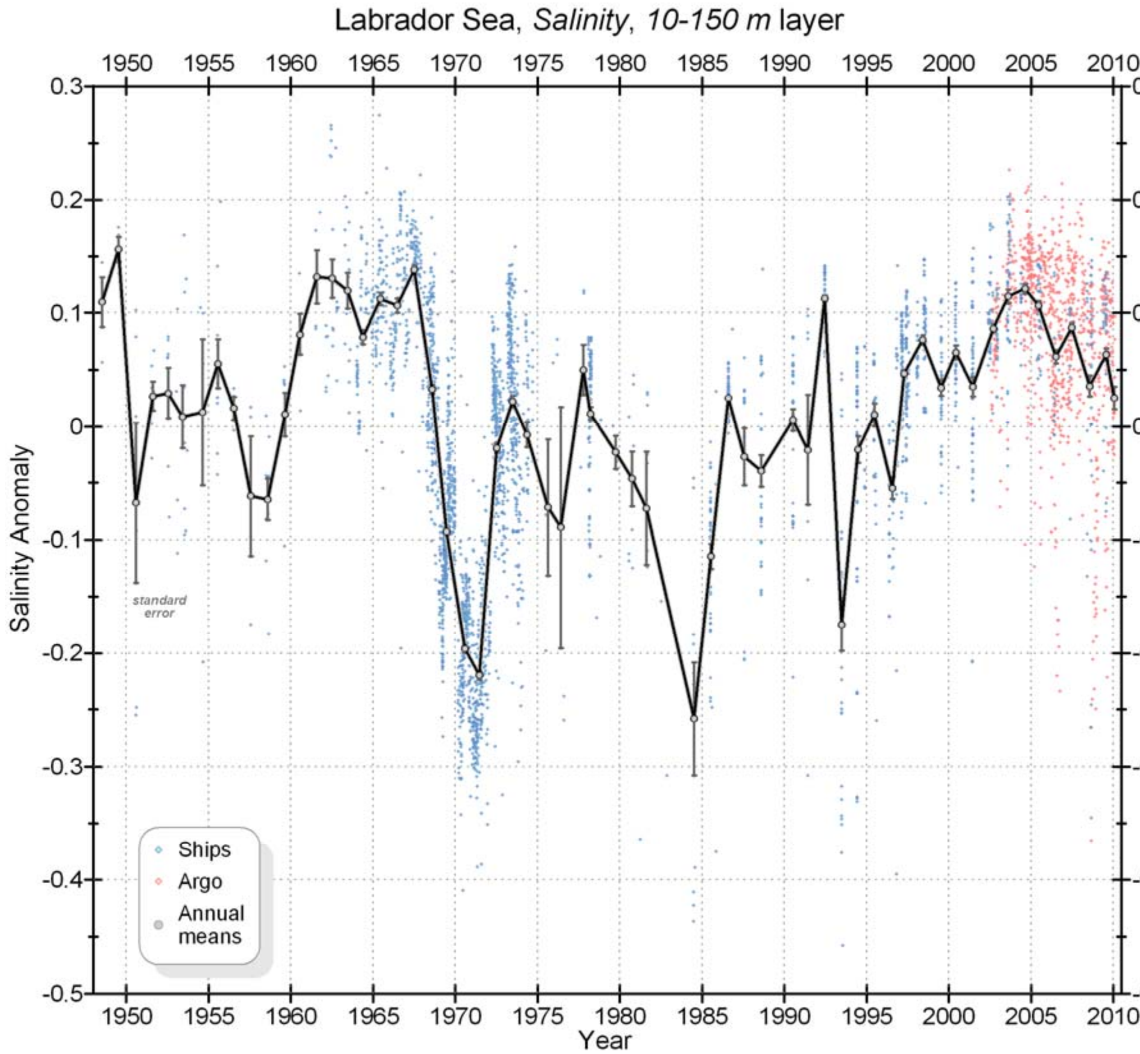

Figure 10: Upper layer salinity in the Labrador Sea based in a combination of ship and Argo drifter measurements. Black line represents annual mean with standard error estimates.

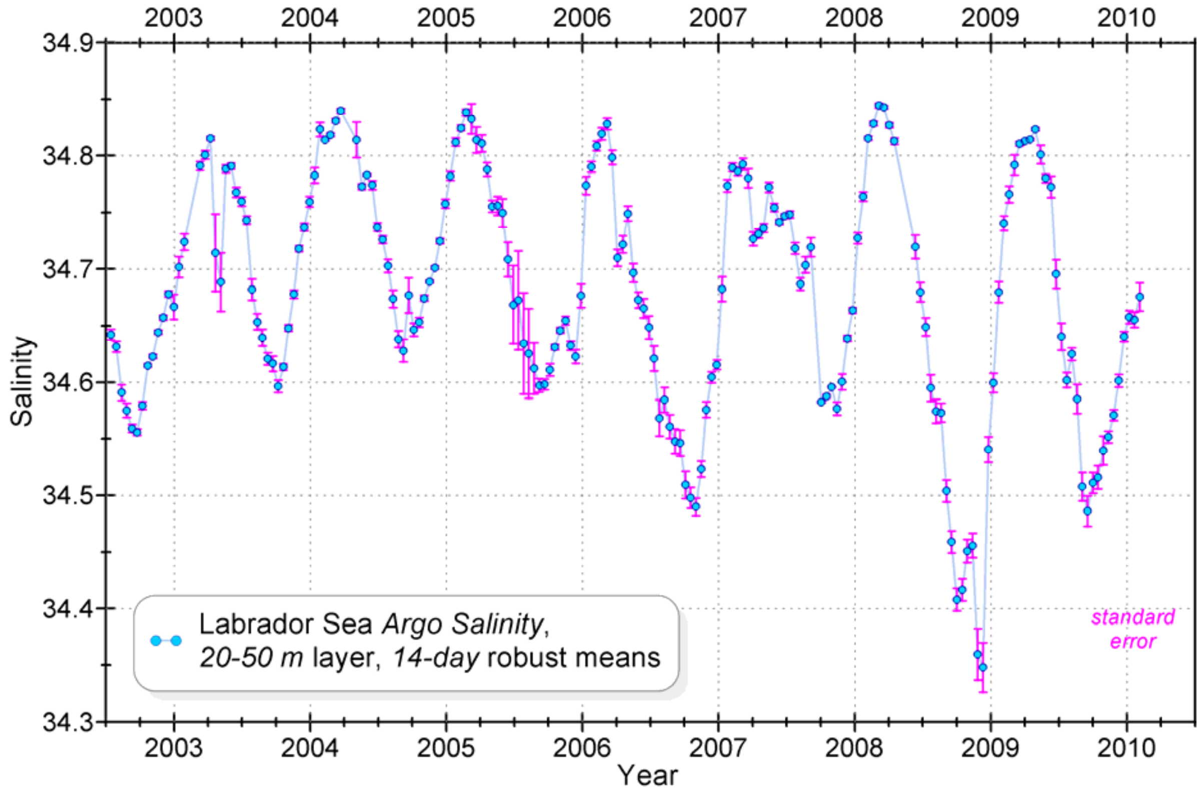

Figure 11: Time series of 14-day mean values of near-surface salinity measured by Argo drifters in the Labrador Sea.

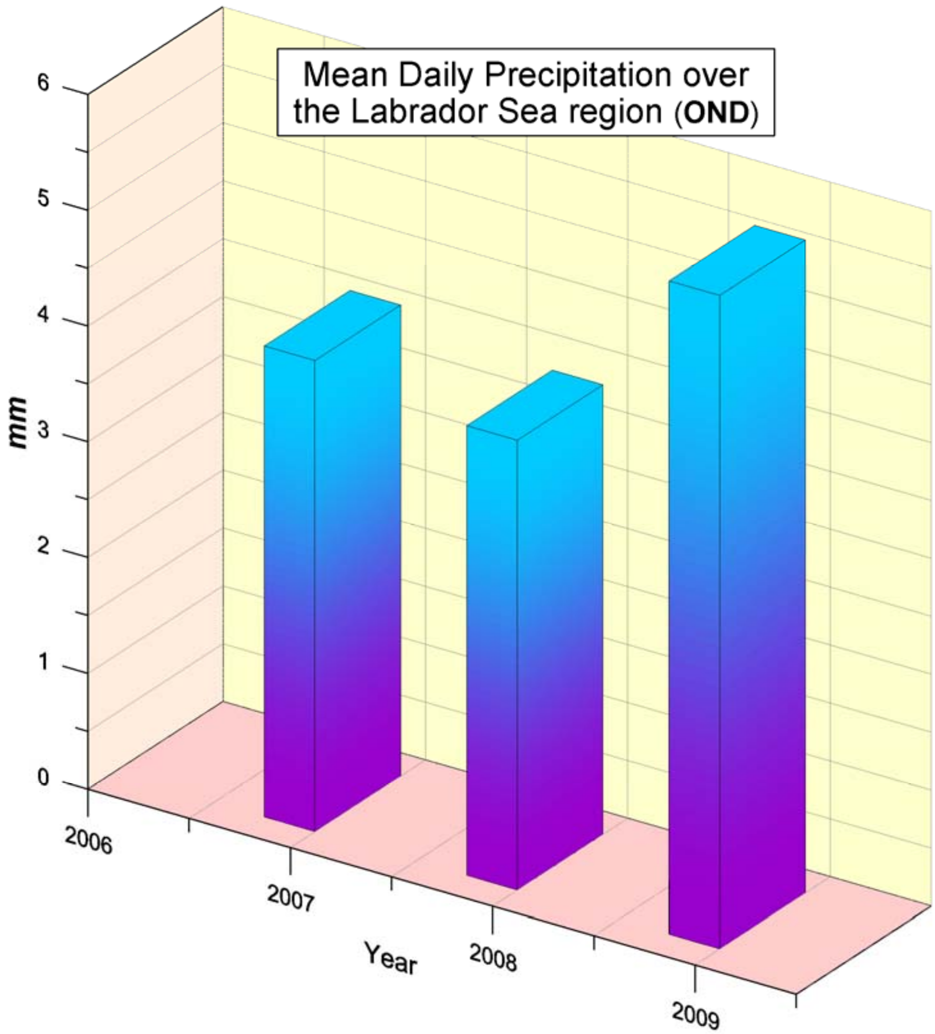

Figure 12: NCEP-derived mean daily precipitation for the fall period (October-November-December, OND) in central Labrador Sea.

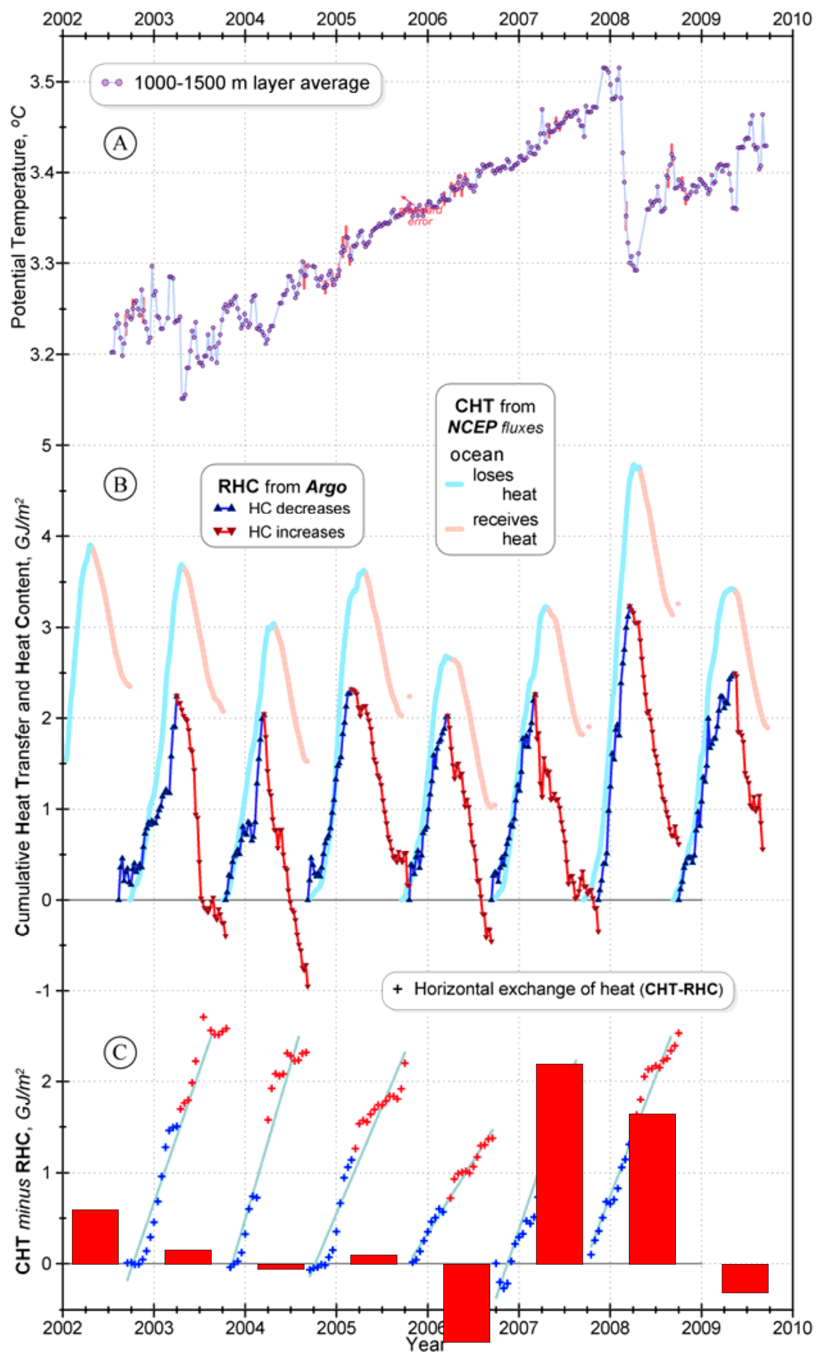

Figure 13: (a) Evolution of the 10-day running mean of the 1000–1500 m layer average temperatures from the Labrador Sea Argo profiles in Figure 3. (b) The annual cycles of cumulative heat transfer (CHT) through the surface from the NCEP data and Argo-based relative heat content (RHC) in the 10–1600 m layer in the Labrador Sea. The CHT curves start from zero at the time when persistent heat loss (from the ocean) starts each year. RHC is relative to the start of ocean cooling each year and reversed in sign to facilitate comparison with CHT. (c) The differences between CHT and RHC for each cooling/warming cycle. Positive values correspond to heat input to the 10–1600 m layer in the Labrador Sea, such as via horizontal advection. Red bars represent the NAO anomaly. *Updated Yashayaev and Loder (2009)*.