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Environmental conditions in the Labrador Sea in 2010

by

I. Yashayaev and B.J.W. Greenan
Department of Fisheries and Oceans, Bedford Institute of Oceanography
PO Box 1006, Dartmouth, Canada B2Y 4A2
email: Igor.Yashayaev@dfo-mpo.gc.ca

Abstract

The Labrador Sea experienced very warm winter surface air temperatures in 2010 similar to the previous year; temperatures ranged from approximately 10°C above normal in the northern region near Davis Strait to about 5°C above normal in the southern Labrador Sea. Sea surface temperature anomaly was more than 2°C in the Labrador Sea throughout the whole year. In 2010, wintertime convection was limited to the upper 200 m of the water column, a dramatic change from the deep convection event of 2008 when convection reached 1600 m. Maximum sea ice extent was below the long-term mean for this region. While the upper layer (10-150m) demonstrates a strong trend of increasing temperature since the mid-1990s, the trend in salinity is much weaker. In the layer impacted by convection (20-2000m), there is a strong increasing trend in both temperature and salinity since the mid-1990s.

Introduction

Labrador Sea hydrographic conditions depend largely on the changeable contributions of several factors including heat lost to the atmosphere, heat and salt gained from Atlantic Waters carried northward into the Labrador Sea by the West Greenland Current, fresh water input as ice and melt from the Arctic and Greenland, continental runoff and precipitation. 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 exceeding 1500 m and in extreme cases 2000 m. 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 West) 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 125 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 winters of 2000 and 2008 when deep convection was observed to extend to the depths exceeding 1500 m in the central Labrador Sea. However, the previous trends in temperature and salinity continued in the following years with significantly milder winters.

Results and Discussion

Arctic Ocsillation (AO) and North Atlantic Oscillation (NAO) Indices
A positive AO index is associated with storm tracks passing (shifted) further north causing colder than usual conditions in the northern Labrador Sea (Thompson and Wallace, 1998). In 2010, both the AO and the NAO were observed to reach record lows [Figure 2] during the winter period indicating that conditions in this region should be warmer than normal, which is in agreement with the change recently observed in a variety of the oceanographic/hydrographic variables presented below.

Surface air temperature
NCEP reanalysis of winter 2010 (defined as January–February–March, JFM) indicated surface air temperatures were up to 10°C above normal in southern Davis Strait and the northern Labrador Sea [Figure 3]. The reference period for this analysis was 1968 to 1996. JFM 2010 surface air temperatures over the central and southern Labrador Sea were approximately 5°C above normal. The 2010 winter air temperatures are even warmer than those observed in 2009 and are in strong contrast to the Winter 2008, which was the coldest since 1993 and the 8th coldest in the 61-year NCEP reanalysis (1948–2008) for this region. The Spring (AMJ) and Summer (JAS) temperatures were also above normal for this region, but only by several degrees. The Fall (OND) period of 2010 showed very high positive anomalies in the Labrador Sea which might contribute to a reduction in winter convection in 2011. The warmer than normal air temperatures continues a trend observed from the eight years (2000–2007) preceding the 2008 deep convection event.

Sea ice
The U.S. National Snow and Ice Data Center sea ice index (Fetterer et al., 2010) shows below-normal winter conditions for sea ice extent in 2010 in the Labrador Sea [Figure 4]. This is consistent with the above-normal winter surface air temperatures in the Labrador Sea region. Similar results were also observed in the preceding winter of 2009 during which above-normal air temperature conditions were observed.

Sea-surface temperature
Labrador Sea sea-surface temperatures (SST) during JFM 2010 [Figure 5] indicate that in ice-free areas the winter SST was 1-2°C above normal (climatology for this data set is 1971-2000). This is consistent with the aforementioned large positive anomaly (5-10°C) in surface air temperatures in the central and southern Labrador Sea during this period, which jointly results in reduced heat fluxes from the ocean to the atmosphere. The annual mean anomalies for 2010, which include the underlying seasonal variability, were similar in pattern and magnitude to those observed during the winter. The peak SST anomalies for 2010 occurred in the Labrador Sea during the summer period when they reached values greater that 3°C. These results continue the trend of similar observations for 2009 during which the winter SST was 0.5-1.5°C above normal in the central Labrador Sea.

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 changes 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 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 fresh water inputs both liquid and ice from Arctic and Greenland. 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 of its water column with cold and fresh water. Milder winters in recent years have produced more limited amounts of mode waters, which have also become warmer, saltier, and less-dense than a decade and a half ago. This recent trend changed abruptly during the cold winter of 2008 during which deep convection to 1600 m was observed. The environmental conditions which contributed to the 2008 deep convection have been documented by Våge et al. (2009) and Yashayaev and Loder (2009). The AZOMP survey in May 2009 [left side of Figure 6] shows remnants of Labrador Sea Water (LSW) formed in the deep convection event of 2008. The panels on the right hand side of [Figure 6] indicate that there was very little winter convection observed in 2010 with evidence of this only apparent in the upper few hundred meters of the water column. Such weak convection limits entrainment to the deep water of gases such as carbon dioxide from the atmosphere as well as surface freshwater.

Temperature and salinity of the Labrador Sea basin [Figure 7], based primarily on shipboard data but including Argo data since 2003, indicates the period of 1987-2010 is dominated in the upper 2000 m by a warming trend from mid-1990s onward along with increasing salinity of this ocean layer. The development of the Argo profiling drifter program provides the ability to derive Labrador Sea T/S fields in the upper 2000 m with weekly to seasonal resolution starting in 2003 [Figure 8]. The seasonal cycle is clearly captured by the Argo drifters and interannual variability is demonstrated. The depth of winter convection is observed to decrease from 1600 m in 2008 to 800 m in 2009 to 200 m in 2010. The gradual warming of the upper 2000 m of the Labrador Sea is also clearly captured by the Argo floats.

Annual means of temperature and salinity anomalies [Figure 9] for the upper layer (10 – 150 m) of the Labrador Sea are derived using a combination of ship and Argo (starting in 2003) measurements over the last six decades. Both the temperature and salinity anomalies had been decreasing since 2003, but the temperature started to rise sharply in 2009 and 2010. Surface salinity in the Labrador Sea is controlled by lateral flux of freshwater from the Labrador and Greenland shelves and, to some degree, by precipitation and continues to decrease in 2010. The longer-term trend in temperature shows a warming of this region since the mid-1990s with the anomaly being the highest on record since the late 1940s.

Results of combined ship and Argo data for the 20-2000 m [Figure 10] indicate that both the temperature and salinity have been increasing since the mid-1990s. While temperature is now the highest in the record, salinity is about 001 less than that observed in the late 1960s. The impact of the deep convection event of 2008 is evident in the temperature time series, but this is quickly overridden by the two subsequent years with warm winters.

Acknowledgments
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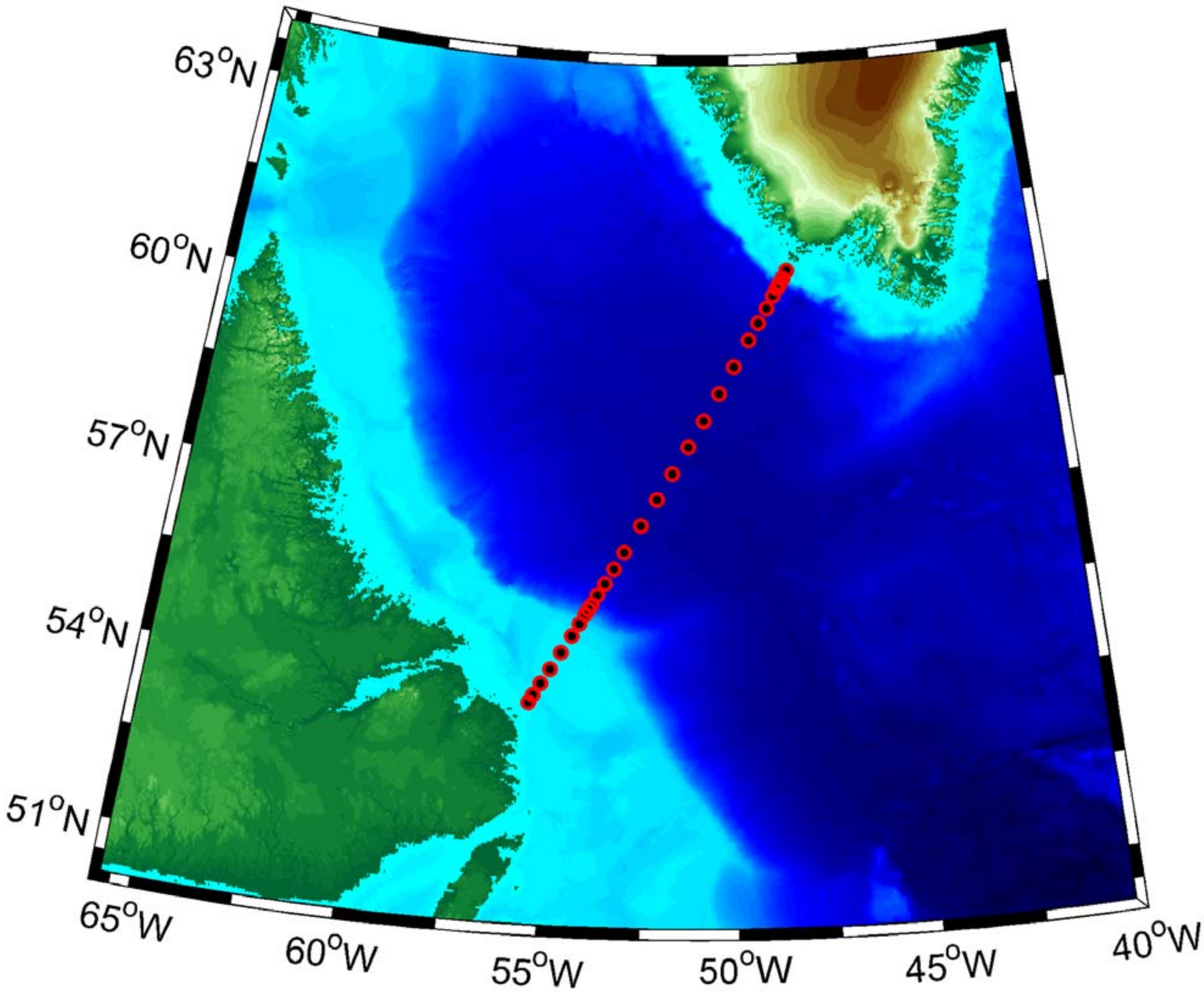

Figure 1: Schematic of the Labrador Sea component of the DFO Atlantic Zone Offshore Monitoring Program (AZOMP). Standard stations along the section are shown as red circles.

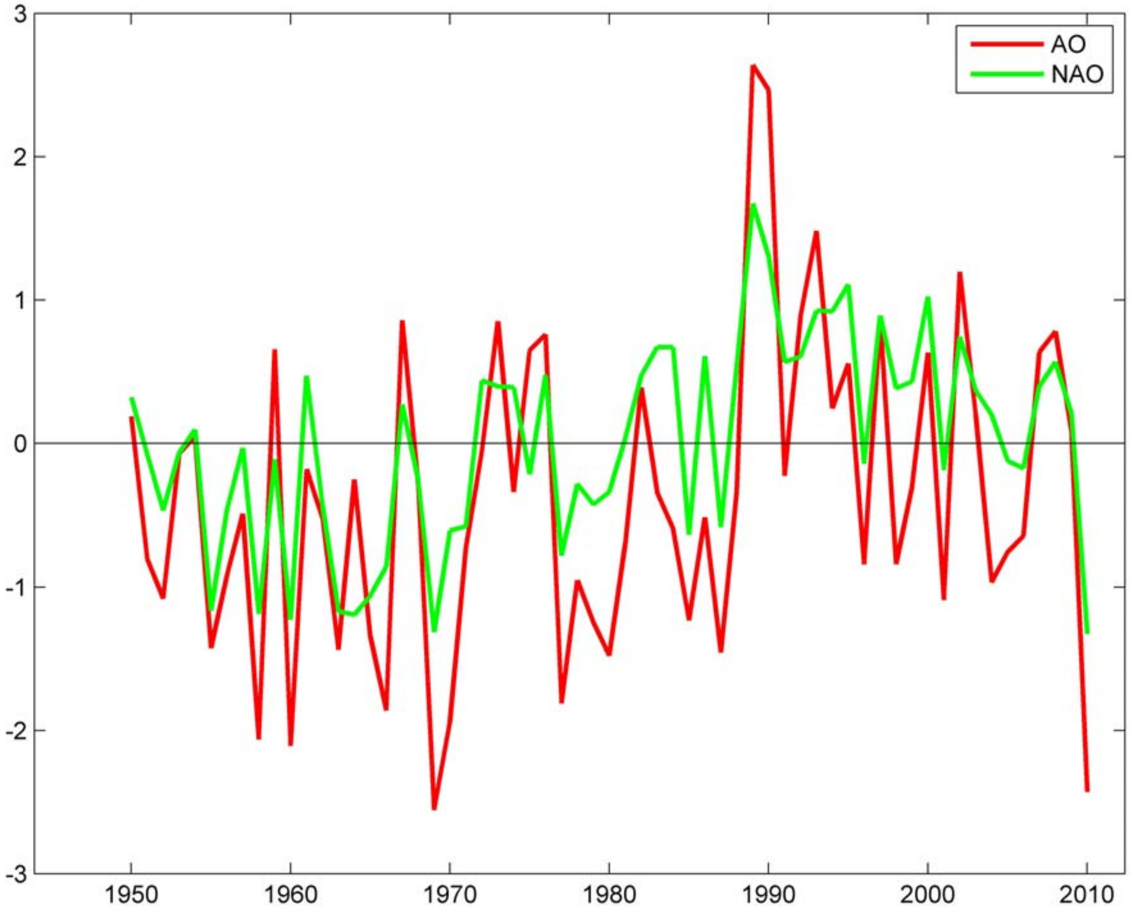

Figure 2: Winter Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) indices with 1950-2000 as base period. Data presented are for the Jan-Feb-Mar winter period.

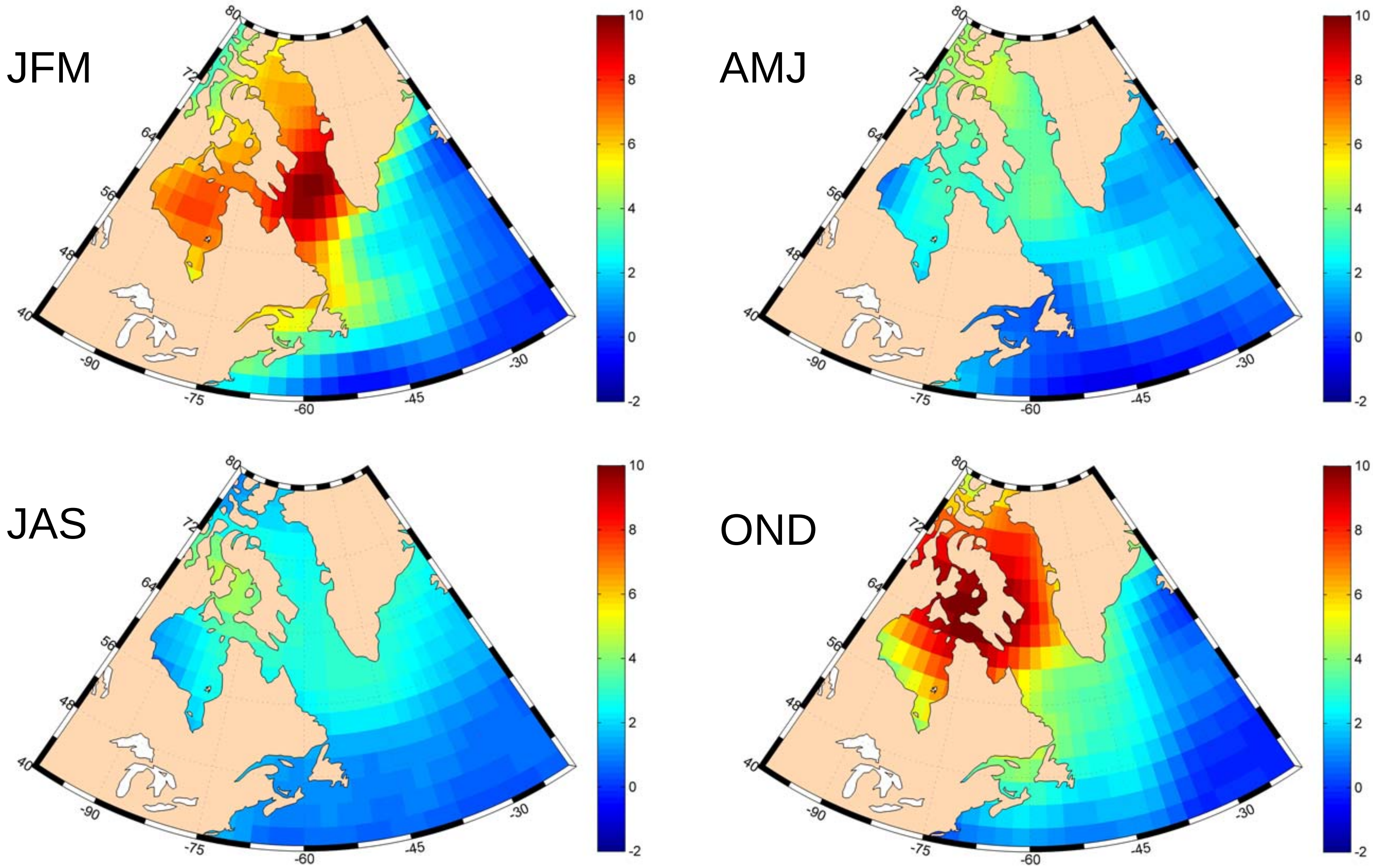

Figure 3: Surface air temperature anomaly for winter, spring, summer and fall periods in 2010 as derived from NCEP/NCAR reanalysis. http://www.esrl.noaa.gov/psd/

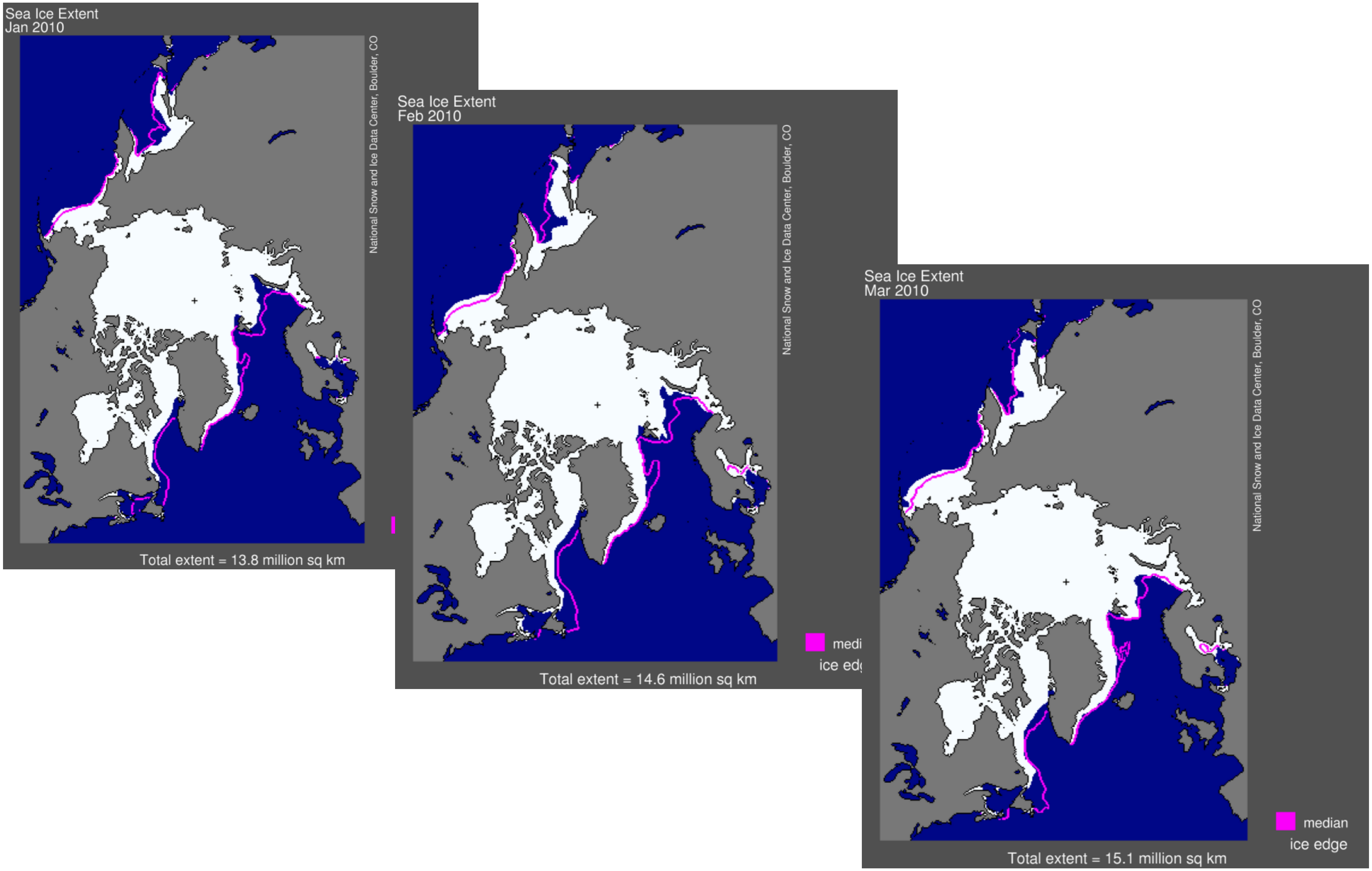

Figure 4: Sea ice extent and concentration anomalies for Jan-Mar 2010 as derived by the US National Snow and Ice Data Center http://nsidc.org/data/seaice_index/archives/index.html. Median ice edge (1997-2000) indicated by the magenta line.

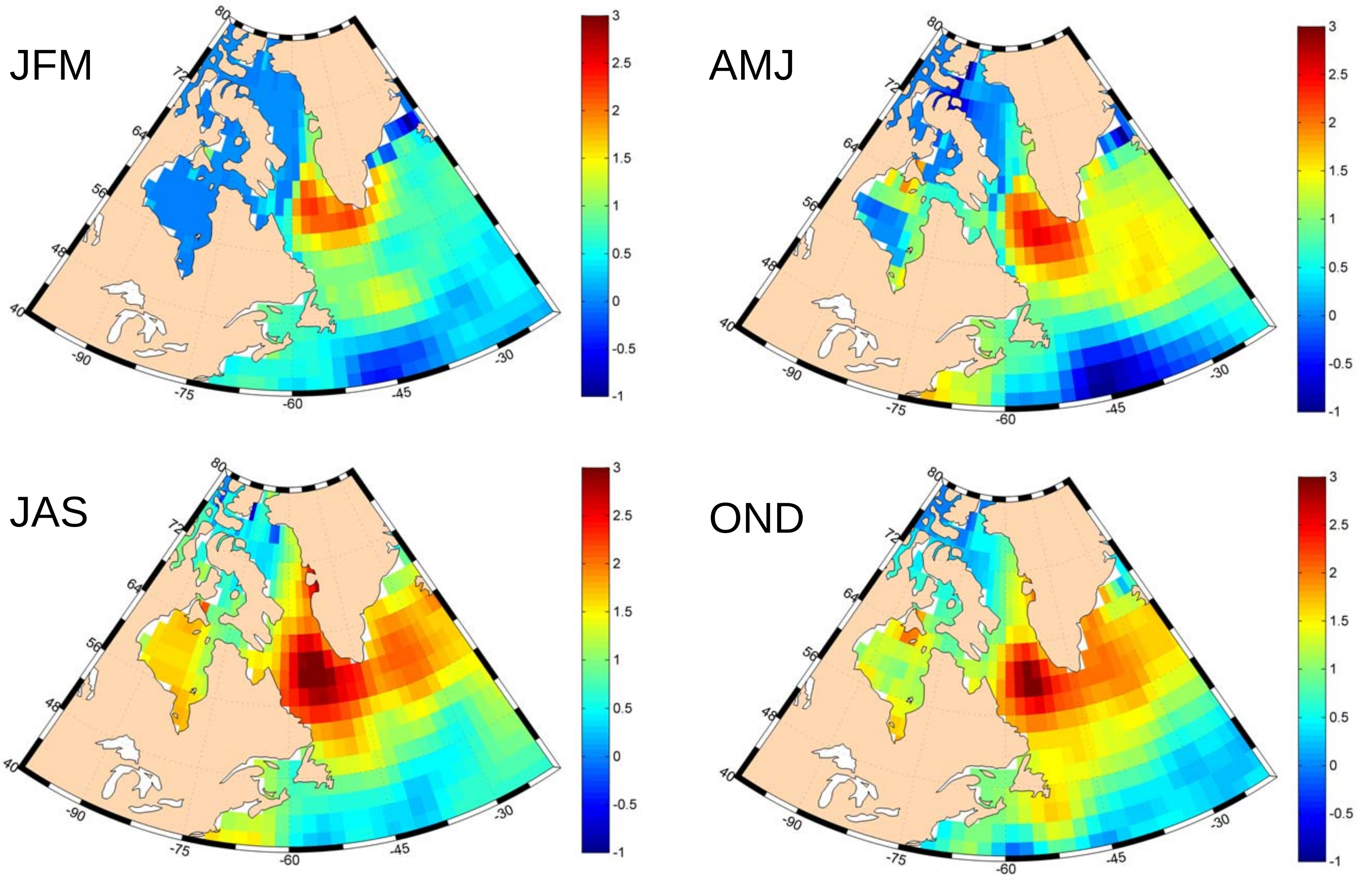

Figure 5: Sea surface temperature anomalies for winter, spring, summer and fall 2010 derived from NCEP/NCAR reanalysis. http://www.esrl.noaa.gov/psd/

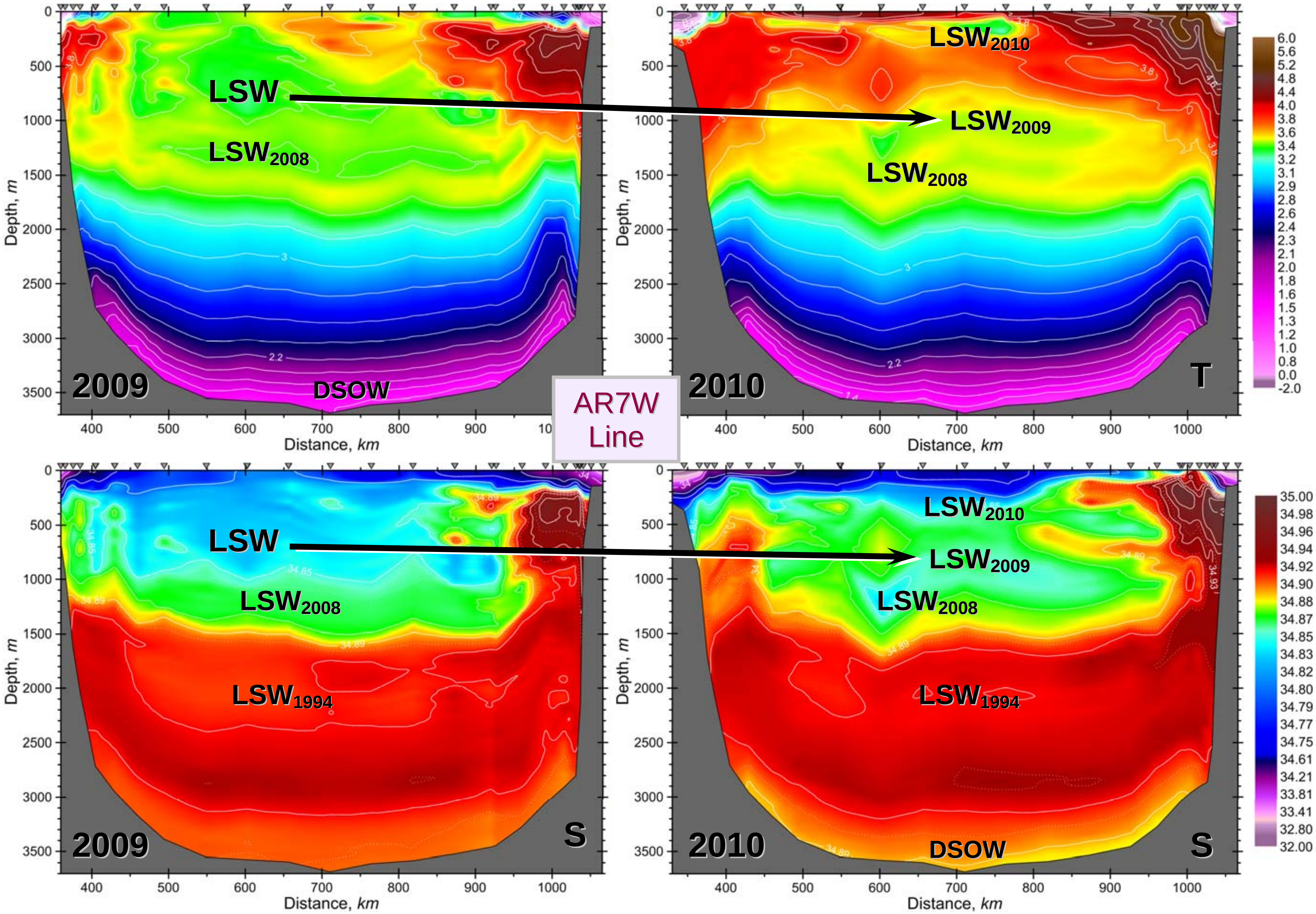

Figure 6: Temperature (top row) and salinity (bottom row) collected along the AR7W line in the Labrador Sea in 2009 and 2010.

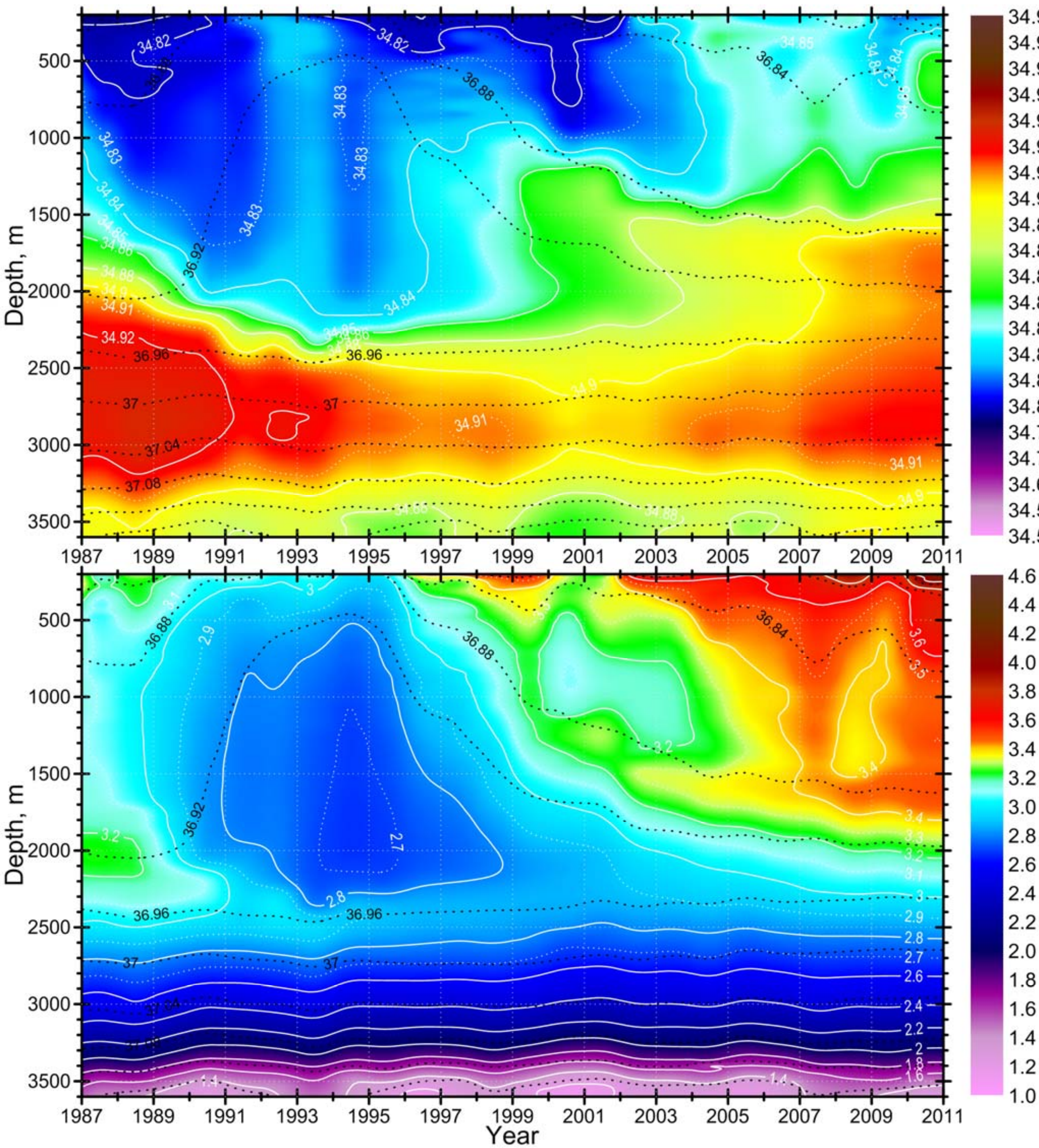

Figure 7: Labrador Sea salinity (top) and potential temperature (bottom) for the period 1987-2010 based on a combination of ship and Argo float data.

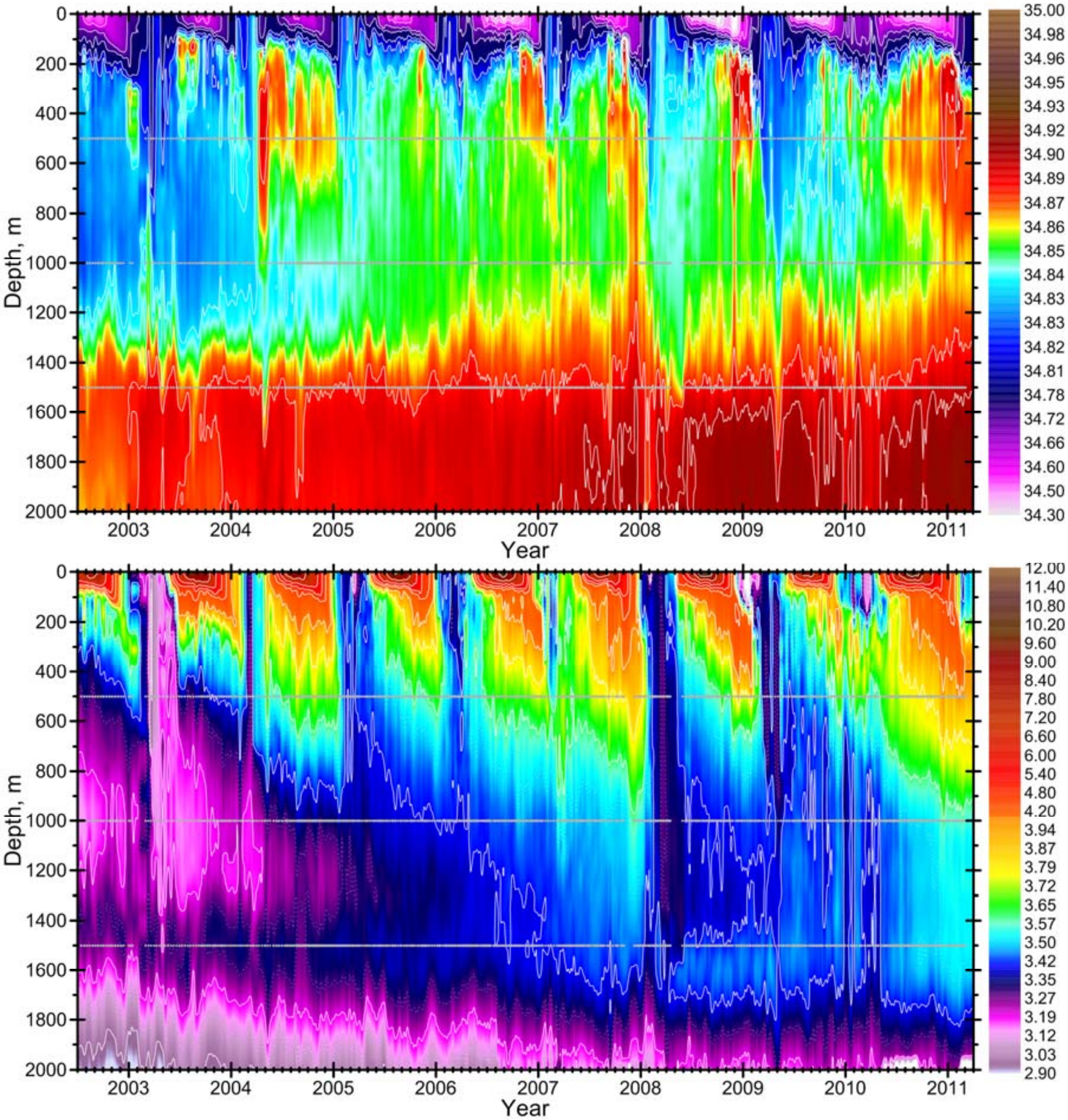

Figure 8: Salinity (top) and potential temperature (bottom) from Argo drifters in the Labrador Sea. The winter 2008 deep convection event is clearly evident to a depth of 1600 m. Convection was limited to a depth of about 200 m in the winter 2010.

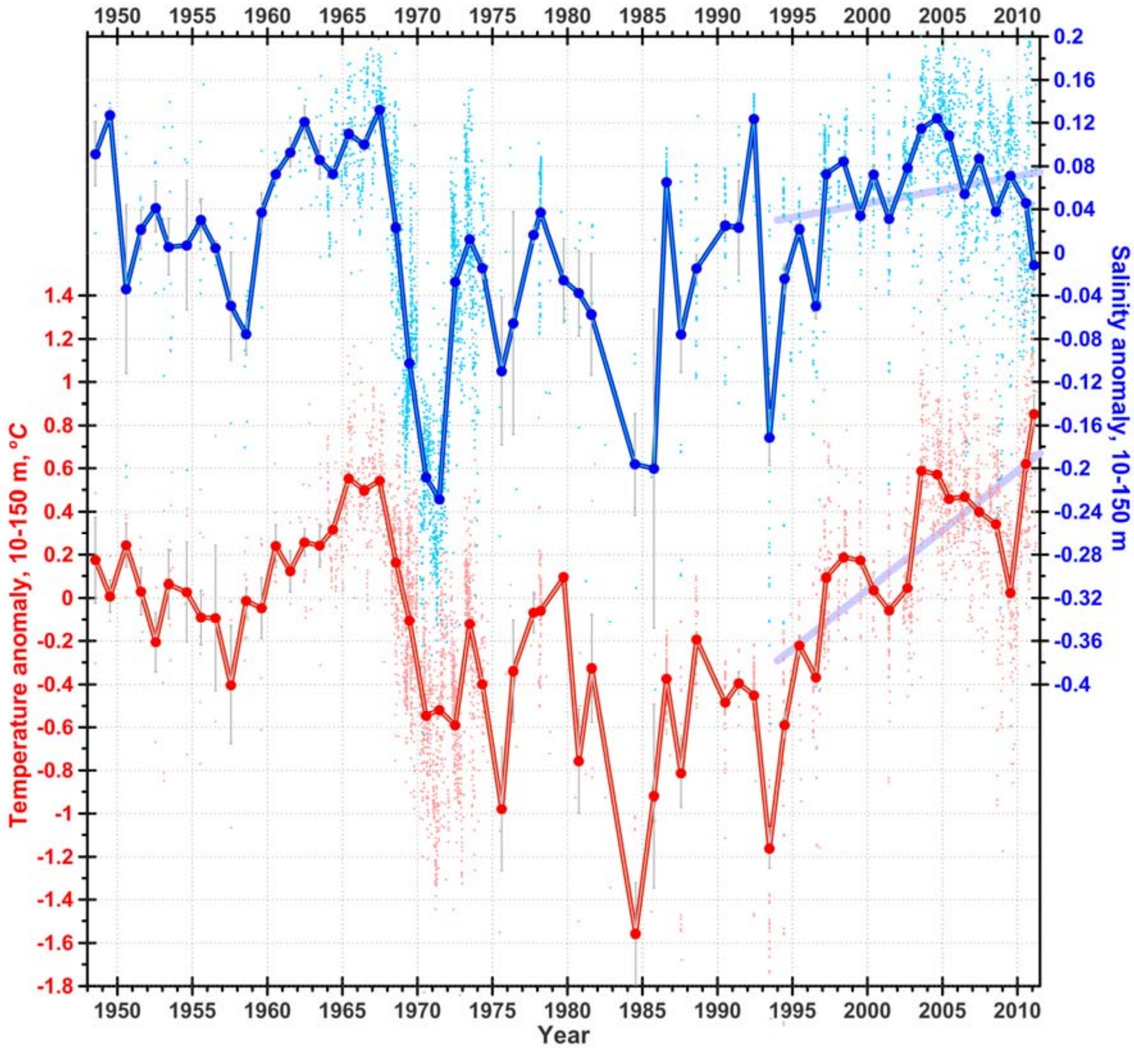

Figure 9: Upper layer (10-150 m) temperature (red) and salinity (blue) anomalies in the Labrador Sea based in a combination of ship and Argo drifter measurements.

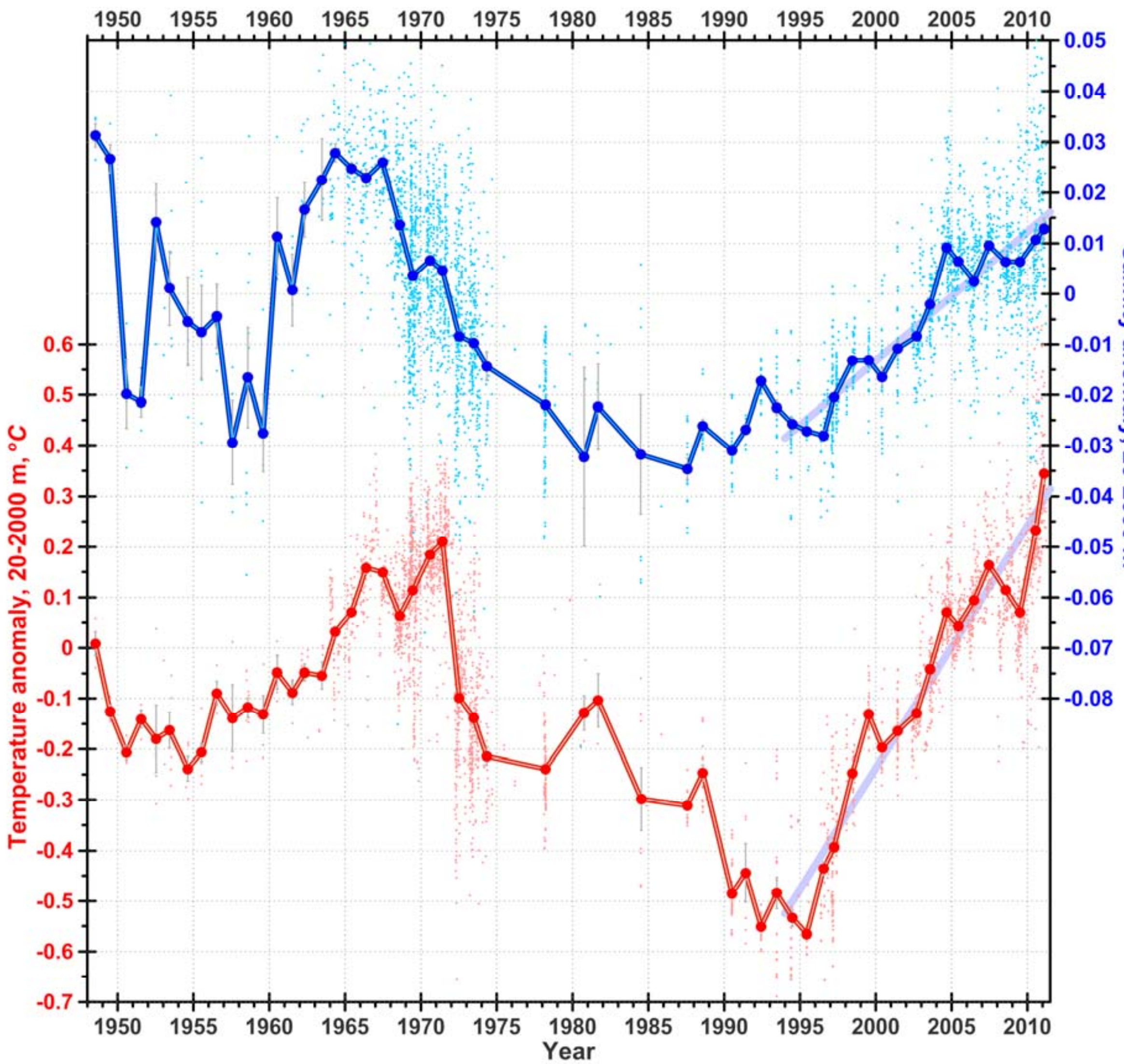

Figure 10: Temperature (red) and salinity (blue) anomalies in the Labrador Sea for the 20-2000 m layer based in a combination of ship and Argo drifter measurements.