

Recent Decline of the Labrador Sea Water

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Convection in the Labrador Sea forms the Intermediate water mass known as the Labrador Sea water (LSW). The LSW can be identified as a homogeneous layer of low stability and salinity throughout the Labrador Sea (Figure 2) and the North Atlantic Sub Polar Gyre. The salinity maximum beneath the LSW identifies the Northeast Atlantic Deep Water (NEADW). NEADW originates in the eastern basin of the North Atlantic as the deepening, dense outflow from the Faroe Bank Channel and flows into the western basin through gaps in the Mid-Atlantic ridge. The deepest layer of the basin is occupied by the Denmark Strait Overflow Water (DSOW) with low temperature and salinity. DSOW originates in the deep dense overflow from the Denmark Strait sill and is the densest water in the northern North Atlantic.

Hydrographic observations across the Labrador Sea (the WHP repeat section AR7W, Figure 1) reveal significant year-to-year changes of all the components of North Atlantic deep and intermediate waters. From 1990 through to 2000, this section was occupied at least once in a year, between mid May and mid July. The CTD data from the 1990, 1994 and 2000 occupations of the AR7W line were presented in Figure 2 in the form of potential temperature, salinity and potential density section plots. Figure 3 shows the changes in potential temperature, salinity, potential density and inversed density gradient in the entire watercolumn as a function of depth and time. Another view on the most recent change in the deep Labrador Sea is presented in the form of T-S diagram in Figure 4. Figure 5 summarizes more than half-century history of potential temperature and salinity variability in the three main water masses.

A series of severe winters in the early 1990s caused intense deep convection, which created an extremely cold and dense modification of LSW. In 1990, LSW reached the depth of 2100 m and continued getting deeper through to 1994 in the expense of NEADW. In the spring of 1994, the dense and cold LSW reached down to 2300 m in the central Labrador Sea (Figure 2). In 1993-1994, LSW was the coldest, freshest and densest ever observed in the deep Labrador Sea (Figure 5).

The coldest LSW was found in 1994, while the minimum in LSW salinity was observed in early 1990s. This can be explained as a result of penetration of the underlying higher salinity and higher density layer as convection developed to its maximum intensity. Since 1994, when the coldest water was found (), convection has become gradually weaker leading to “relaxation” of intermediate layers and the coexistence of multiple versions of the water

mass. Since that time, the deeper-most fraction of LSW hasn't been renewed, and is steadily becoming warmer and saltier. In 1996, the LSW formation of 1993-1994 was about half a volume of that in the time of origin (Figure 3). The water column above it was occupied at that time by more recent generation(s) of LSW. Temperature and salinity of the deep LSW continued to increase through to 2000 (Figure 5). The rate of this temperature and salinity change remained practically the same through the years - $0.04^{\circ}\text{C}/\text{year}$ and $0.007 \text{ psu}/\text{year}$ for temperature and salinity, respectively. In 2000, the deep LSW was 0.3°C warmer and 0.03 psu saltier compared to 1994. Density of the deeper-most LSW and the whole upper 2000 m layer decreased between 1994 and 1999. However, the rate of the change of LSW density reduced between 1994 and 1999, and was close to 0 between 1999 and 2000. Another major change in density structure in the response to the weakening in convection activity was restratification in the upper 2000 m of the Labrador Sea. If in 1994 the change in density between 500 m and 2000 m was about 0.01, the corresponding change in 2000 was 0.07 (Figure 2c).

If the deeper-most version of LSW was the warmest and saltiest in the year 2000, the upper 1000 m experienced considerable cooling and freshening in the winter of the same year. The winter 2000 convection in the Labrador Sea was the strongest since 1996. It created a relatively homogeneous, fresh and cold layer, which can be detected between 500 m and 1000 m in the temperature, salinity and density distributions from the spring 2000 survey (Figure 2). Another remarkable feature found on AR7W in the spring of 2000 was a mesoscale eddy in the middle of the section. The most recent version of LSW at the eddy location was found between 1000 m and 1500 m that is 500 m deeper than on the stations on either side of the eddy.

Underlying the convectively-formed LSW, the deep and bottom water masses of the Labrador Sea (NEADW and the DSOW) have also undergone remarkable variations in their temperature and salinity on interannual (Figure 3, 4) and interdecadal (Figure 5) timescales. The changes in NEADW are of lower amplitude than those in LSW and DSOW, but steadier in trend. The salinity and temperature of NEADW has decreased steadily by around 0.014 and 0.1, respectively, per decade for the past 3 decades (Figure 5). In 2000, the NEADW was freshest and coldest than ever recorder. The divergence in the LSW and NEADW trends resulted in reduction of temperature and salinity contrasts between LSW and NEADW (Figure 4).

The temperature maximum in the upper NEADW (Figures 2a,3a) is a result of the LSW cooling in the late 1980s – early 1990. The depth of this maximum varied in time and along the line. However, through to 1998, this feature can be detected on all stations within 3200 m isobath between 2200 m and 2500 m. The intensification of convection in 1993-1994 and the deeper penetration of LSW caused a partial erasure of this maximum. The last traces of this feature were finally wiped in a result of the recent warming of the deep LSW and cooling of NEADW.

Besides the long-term trend the DSOW in the Labrador Sea experiences quasi-pentadal oscillations (Figure 5). DSOW found in the 2000 occupation of the AR7W section was the coldest ever observed.



Figure 1. Map of the study area showing positions of the AR7W section and the BIO Labrador Sea mooring.

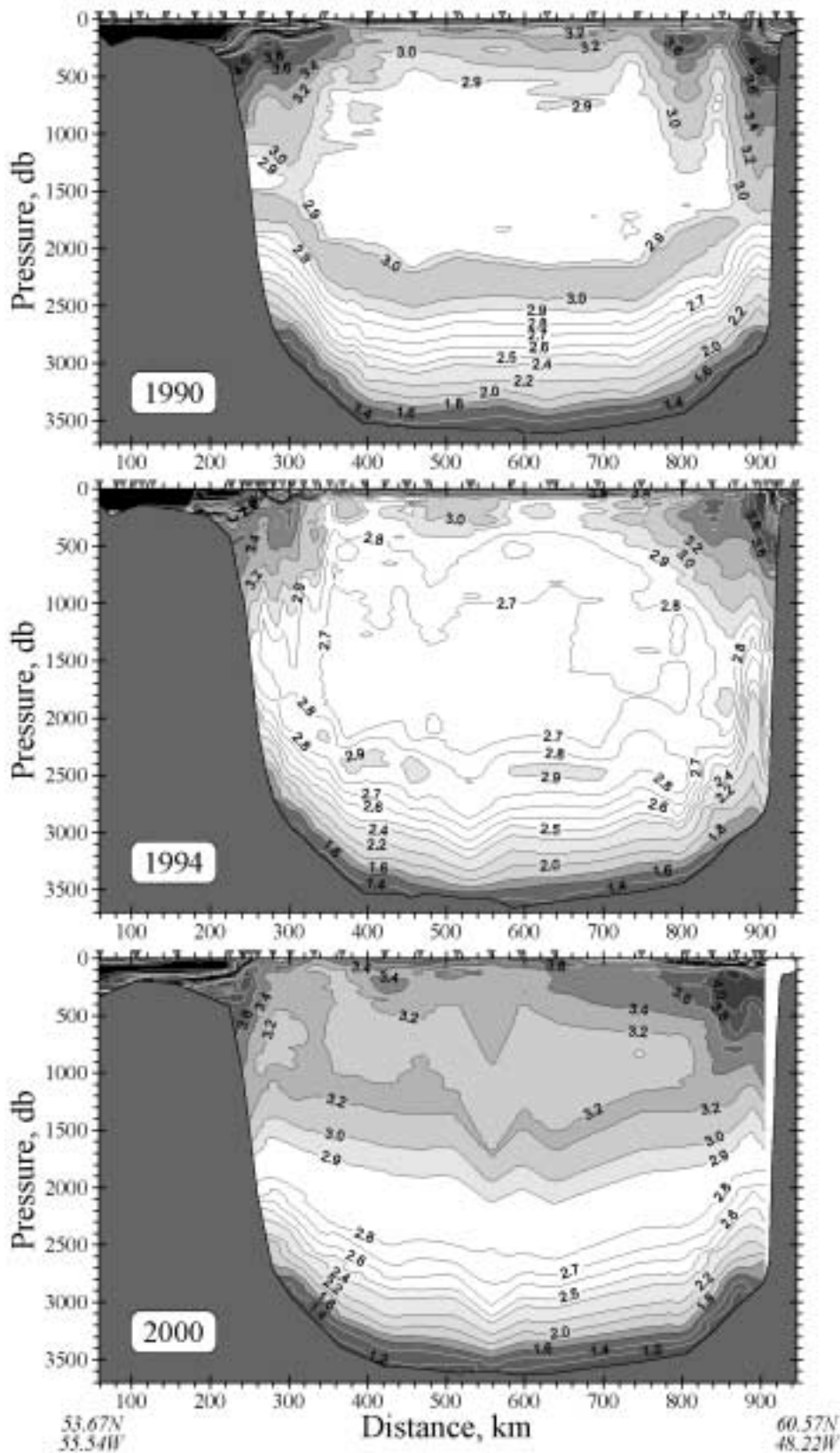


Figure 2a. Potential Temperature on AR7W in spring-summer of 1990, 1994 and 2000

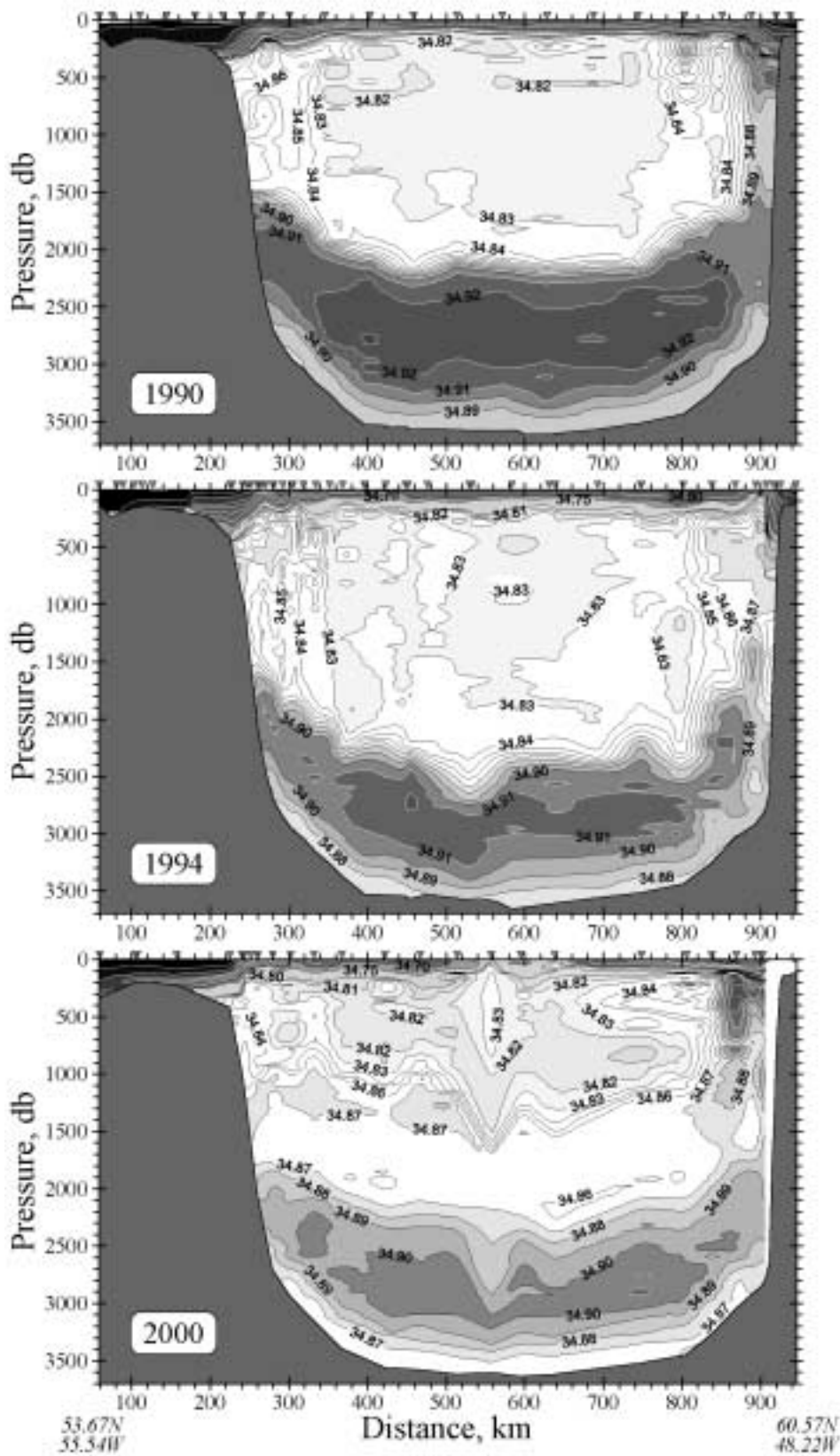


Figure 2b. Salinity on AR7W in spring-summer of 1990, 1994 and 2000

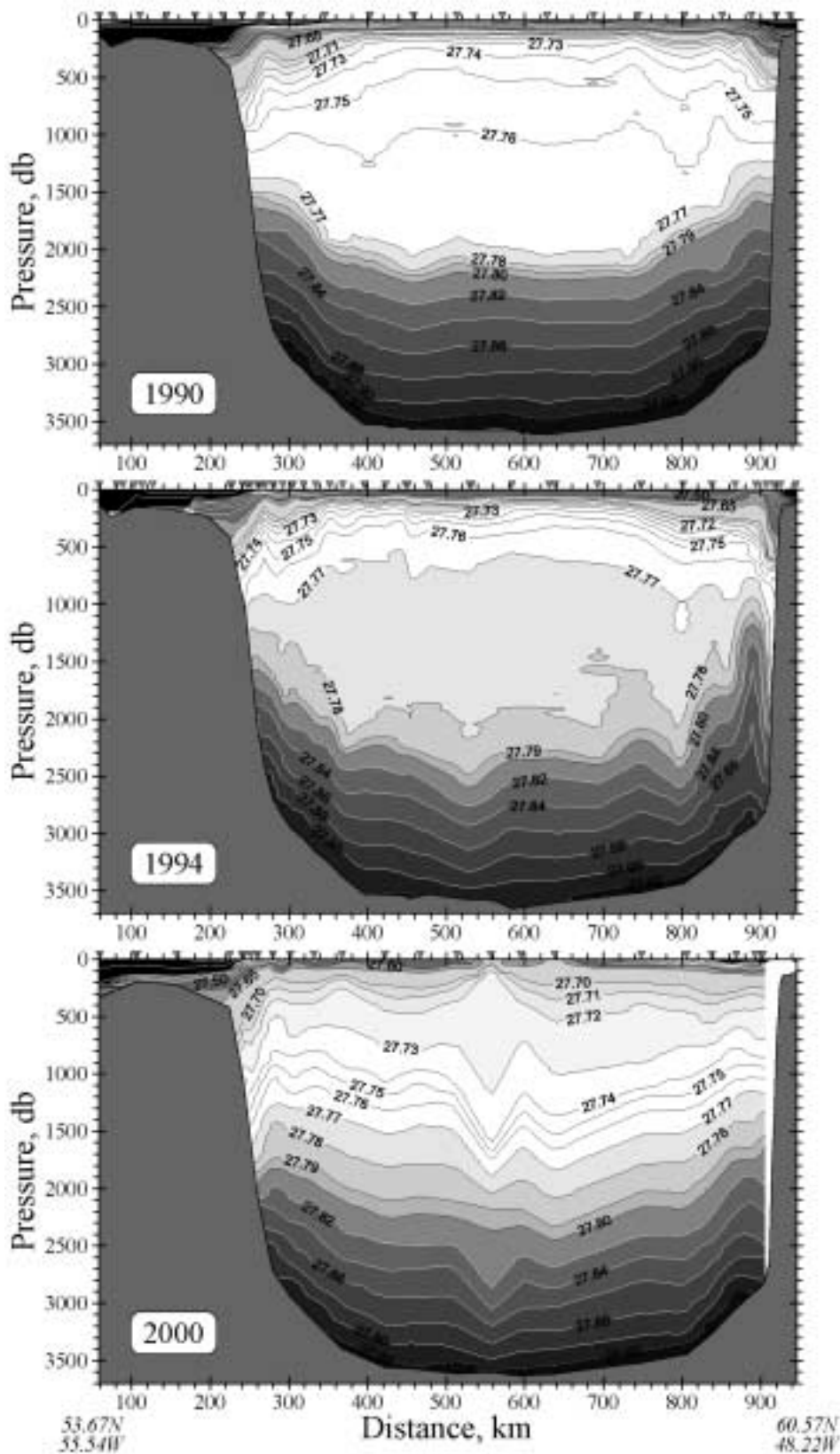


Figure 2c. Potential Density on AR7W in spring-summer of 1990, 1994 and 2000

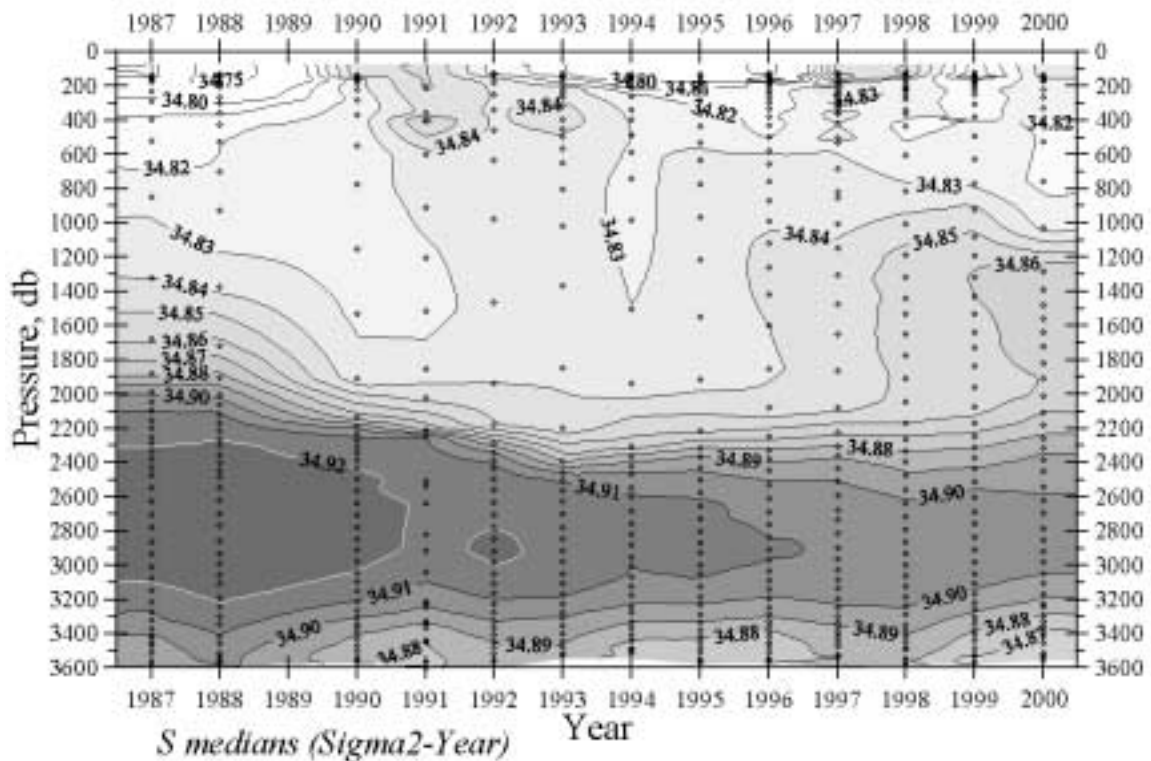
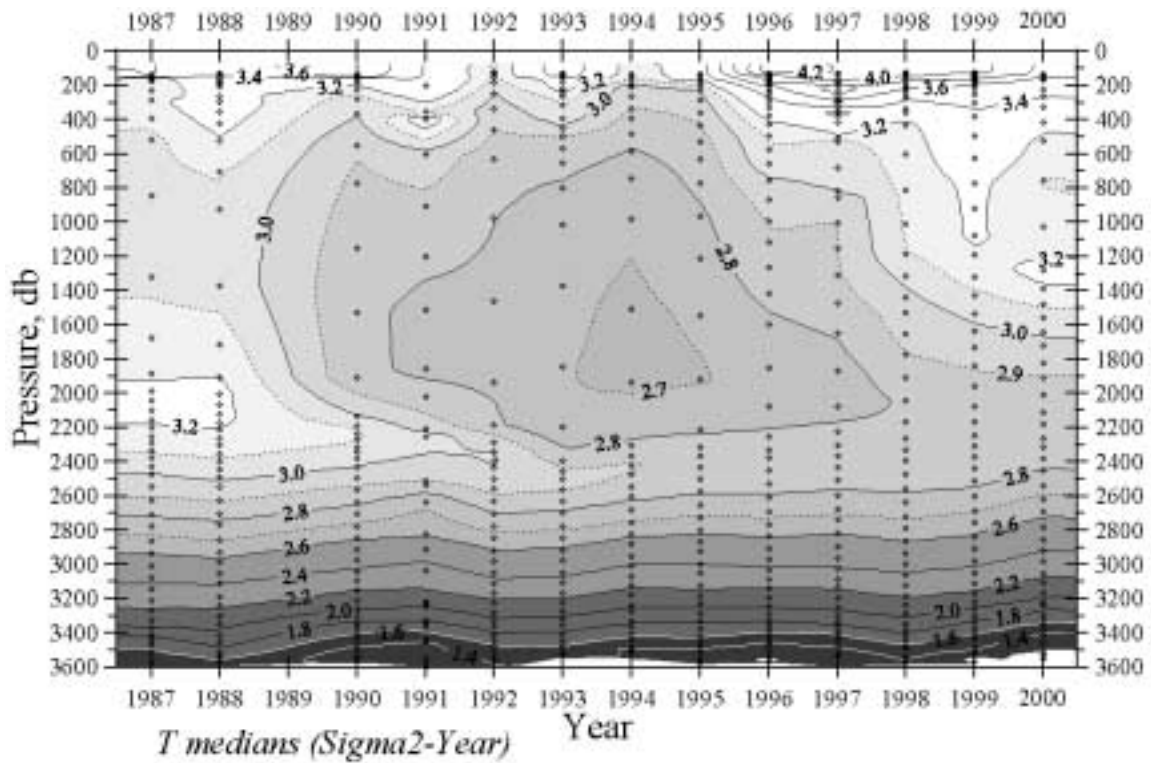


Figure 3a. Changes in potential temperature and salinity in the central part (restricted by 3300 m isobath) of the Labrador Sea as a function of depth and time.

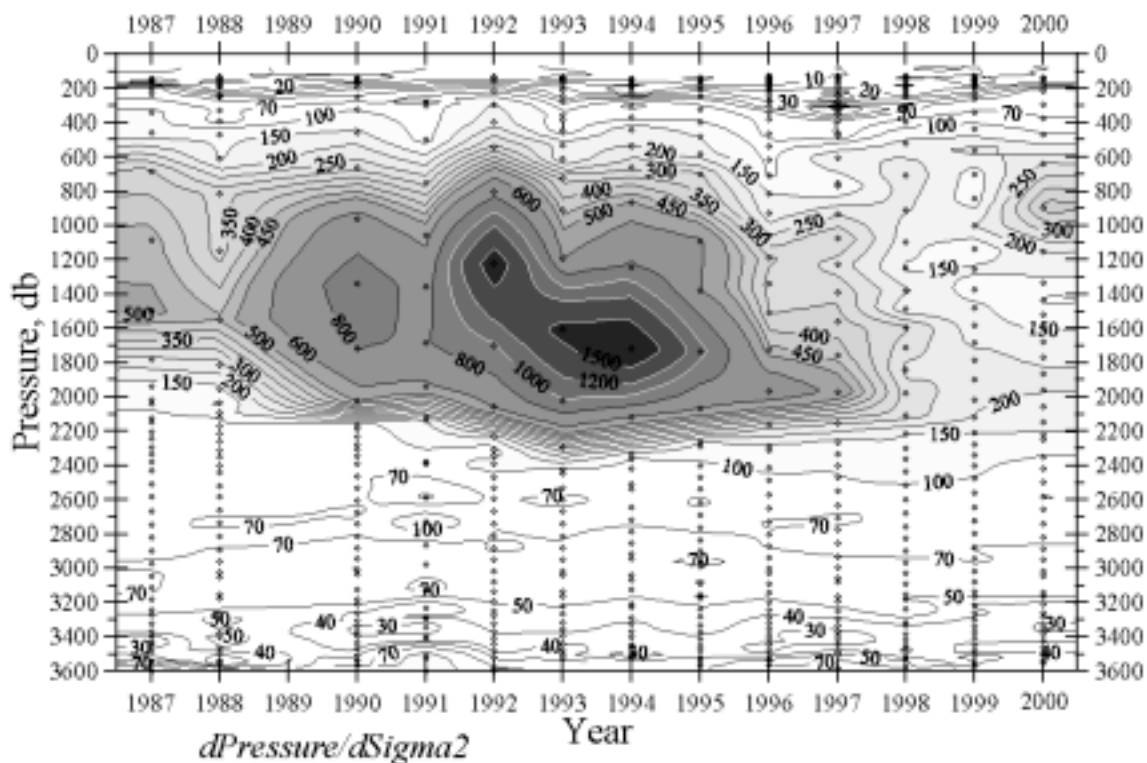
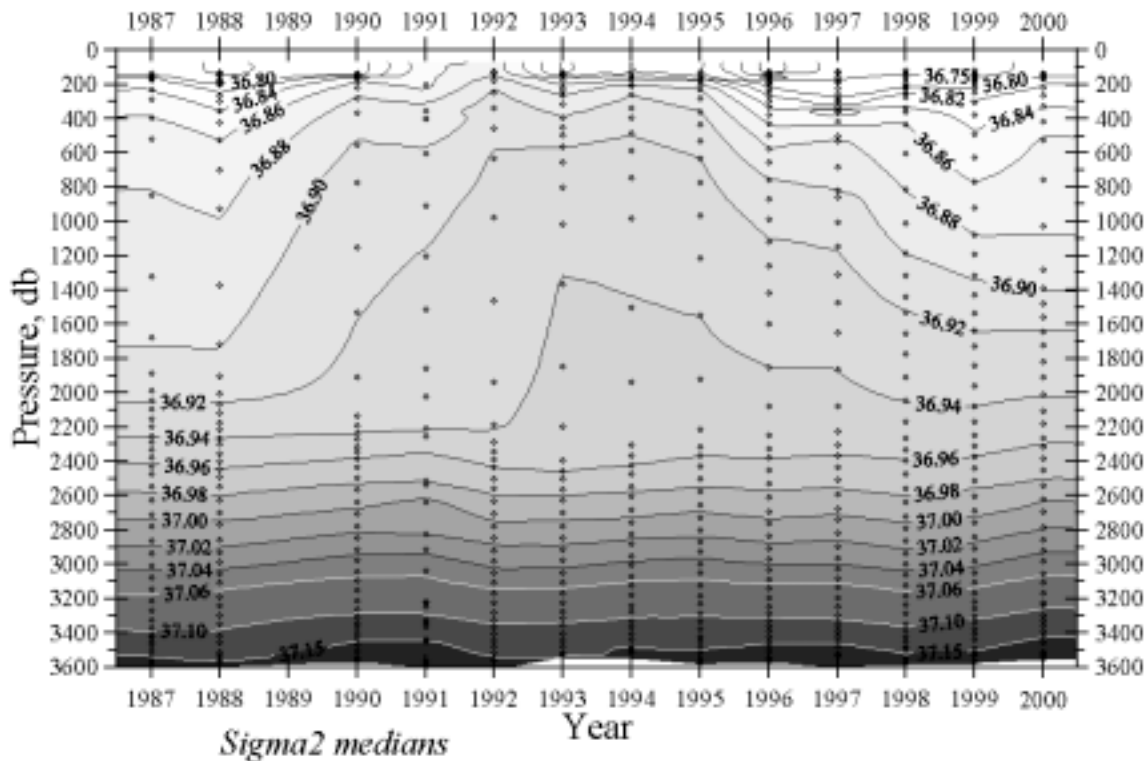


Figure 3b. Changes in density (referred at 2000 db) and thickness of 0.01 density layers in the central part of the Labrador Sea as a function of depth and time.

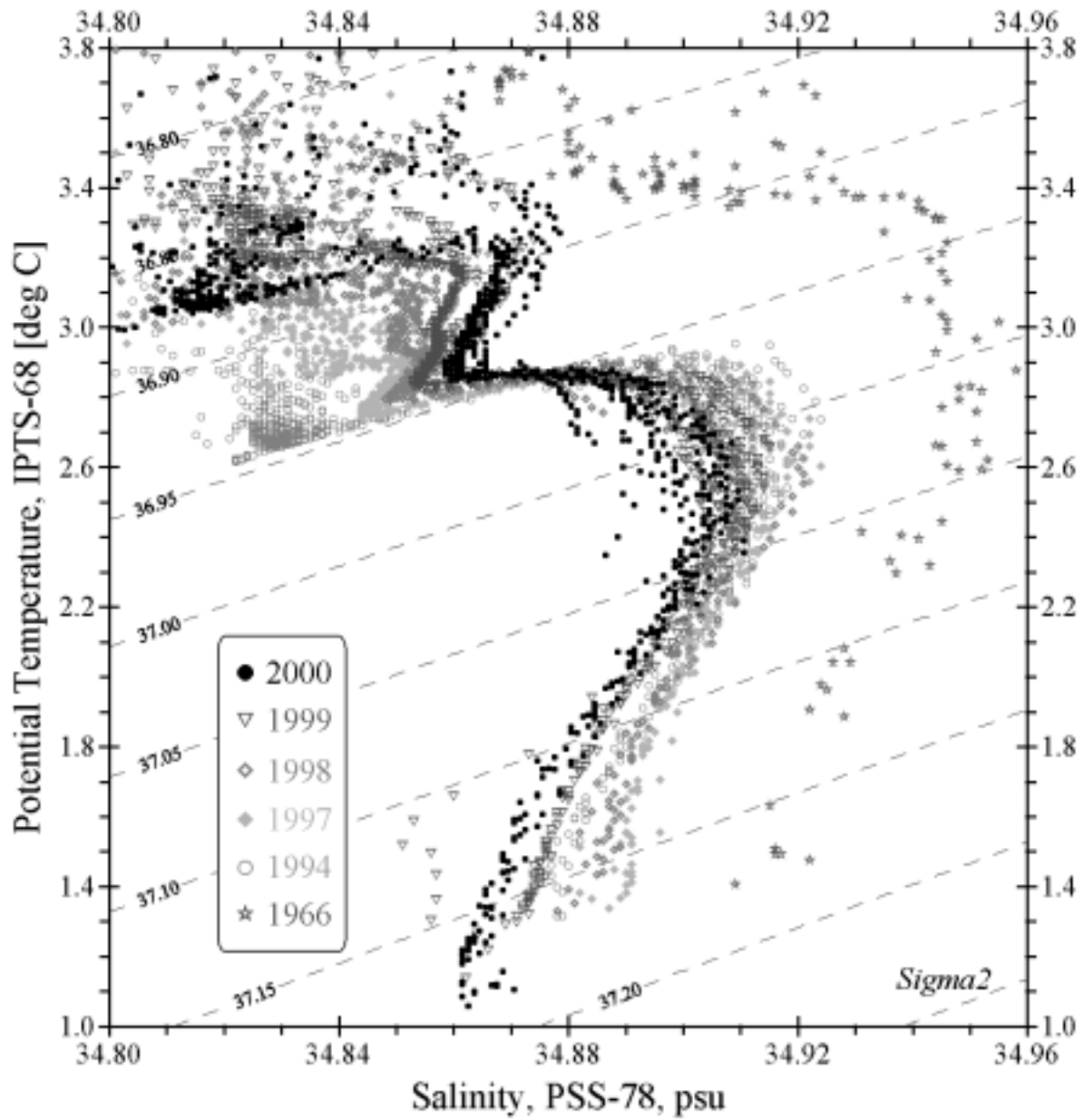
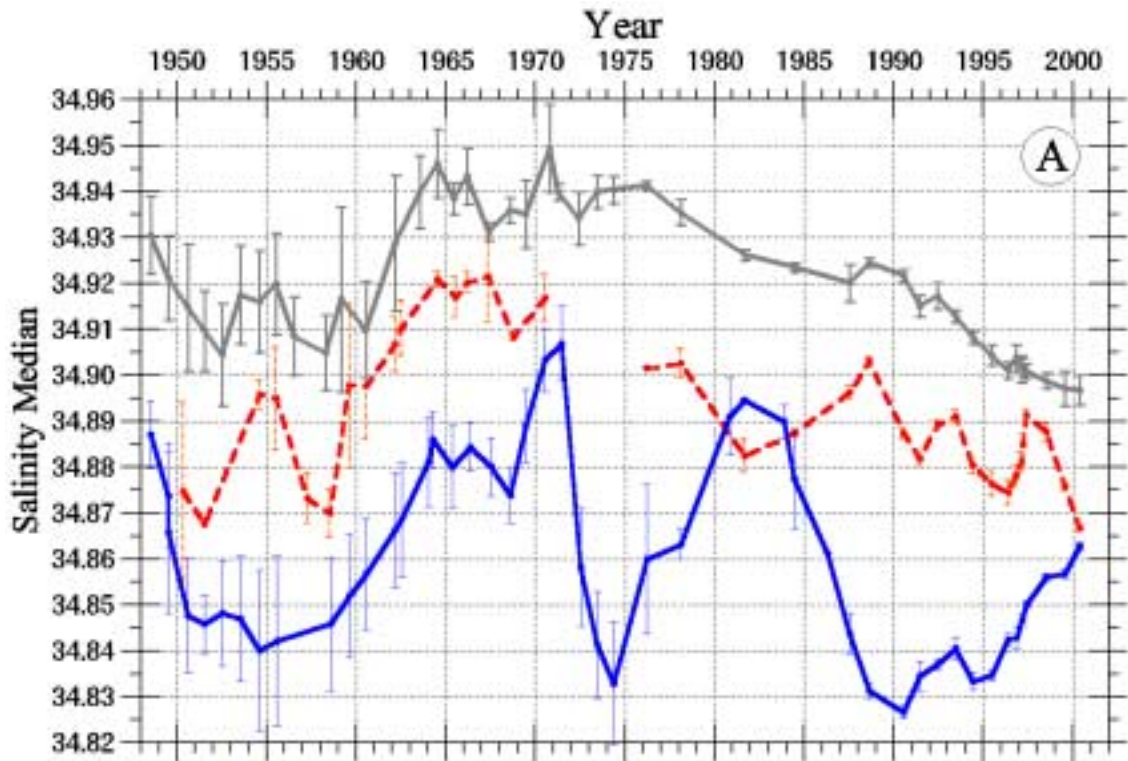


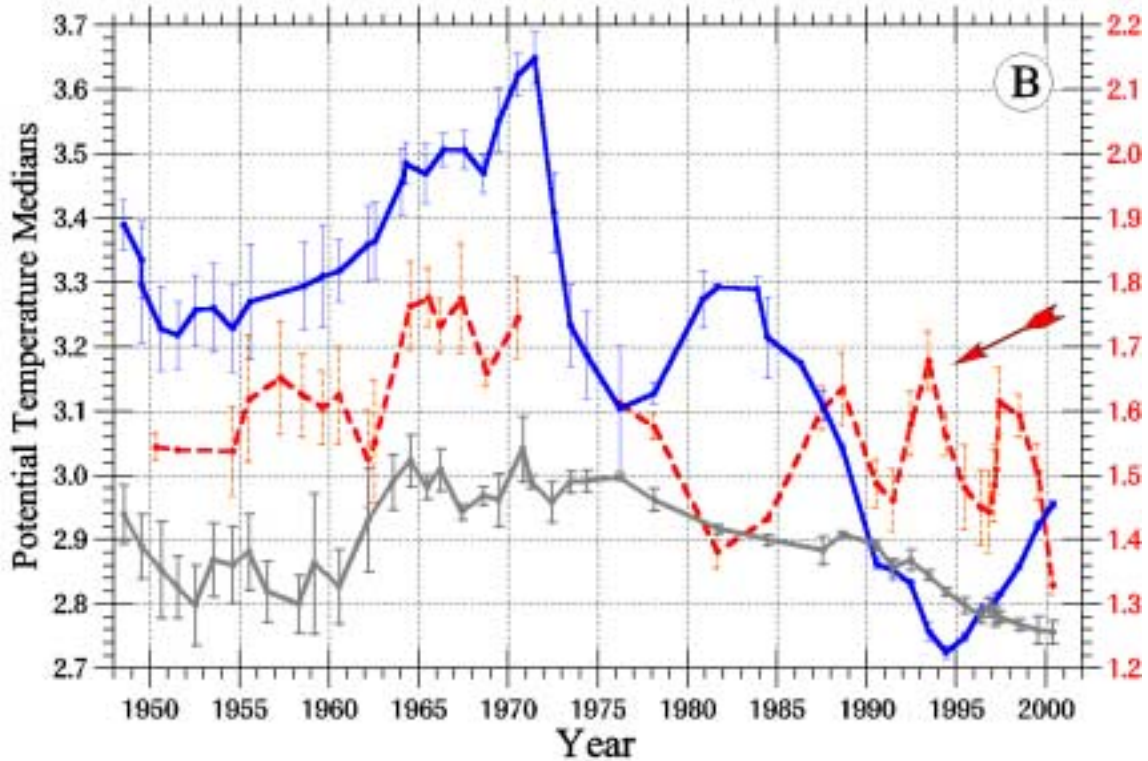
Figure 4. T-S characteristics of the water column in the central part of the Labrador Sea (restricted by 3300 m isobath) in 1966, 1997, 1998, 1999 and 2000.



Salinity (A) and Temperature (B) of three Major Water Masses of the Labrador Sea

Figure 5.

- LSW
- NEADW
- - - DSOW



The error bars represent median absolute deviation