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Changes in subarctic and subtropical water masses in the upper layer of the northern North Atlantic during the 1990s

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Multiple occupations of transatlantic hydrographic sections at 58°N and 46°N between 1991 and 1999 reveal a significant redistribution of subarctic and subtropical water masses north of 40°N, following a sharp drop from extremely high to extremely low values of the North Atlantic Oscillation index in 1996 and its slow recovery towards the end of the decade. This led to significant shifts of the Subarctic Front, indicating a contraction and re-expansion of the Subpolar Gyre.

Keywords: interannual changes, North Atlantic Oscillation, Northern North Atlantic Ocean, Subpolar Gyre.

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As a component of the World Ocean Circulation Experiment (WOCE), trans-Atlantic sections WOCE A1E and WOCE A2 were repeated 7 and 5 times, respectively, in the period 1991–1999 (see Figure 1). Here we report on changes in the distribution of cold, low saline subarctic waters and warm, saline subtropical waters in the upper layers of the Northern North Atlantic. They are separated by the Subarctic Front (SAF), which is related to the coldest branch of the North Atlantic Current (Sy *et al.*, 1992). The period under review is a most unusual one in the climatic history of the North Atlantic, one in which the North Atlantic Oscillation (NAO) index evolved to extreme positive values until 1995. Following a sharp drop to extreme negative values in 1996 the index slowly recovered to positive values at the end of the decade (Dickson and Meincke, 2003). Since the NAO index is related to the regime of the westerlies over the North Atlantic, changes have to be expected in the North Atlantic gyre circulation.

After the dramatic drop of the NAO index in winter 1996 a westward shift of the SAF was observed in the Iceland Basin which led to a higher salinity of the upper 600 m along A1E between the Reykjanes Ridge and the Porcupine Bank (Figure 2). The salinity increase in the order of 0.1 is the equivalent of a net evaporation rate of 4.7 mm day^{-1} over 1 year (Bersch, 2001), which is about 5 times the estimated change of the freshwater flux at the sea surface between NAO high and low phases (Hurrell, 1995). The temperature increase of the upper 600 m amounted to about 0.8°C; the density increase was about 0.05 kg m^{-3}.

The westward shift of the SAF was the result of a reduced eastward spreading of cold, low saline, and dense Subarctic Surface and Subarctic Intermediate waters (θ<7°C, S<35.0) from the Labrador Sea and an increased northward spreading of warm, saline, and less dense Subpolar Mode Water from the subtropics. These changes suggest a westward contraction of the subpolar gyre. Observations by Pollard *et al.* (1999) indicate that in October/November 1996 the 35.0 isohaline of the SAF, which was found in the Iceland Basin on A1E until 1995, had shifted to 30°W near the Charlie-Gibbs Fracture Zone, about 350 km westward of A1E. Observations along A1E in 1999 show that with increasing NAO index the low saline subarctic water masses begin to re-occupy the Iceland Basin and the region off the Rockall Plateau and the Rockall Trough (Figure 2) indicating an eastward shift of the SAF and a re-expansion of the subpolar gyre (Bersch, 2001).

Along A2 (Figure 3), similar temporal behaviour was observed east of the Mid-Atlantic Ridge in the West European Basin, where salinity increases are evidence of a northward expansion of the subtropical gyre in 1996–1997. At the western end of A2, in the Newfoundland Basin, Figure 3 shows

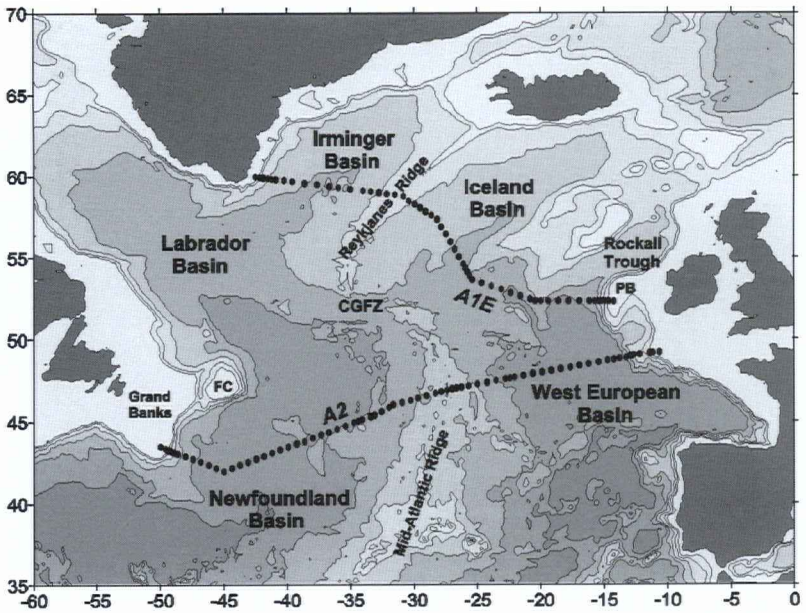

Figure 1. Location of WOCE hydrographic sections A1E and A2 and bottom topography in the northern North Atlantic. CGFZ = Charlie-Gibbs Fracture Zone, PB = Porcupine Bank, FC = Flemish Cap.

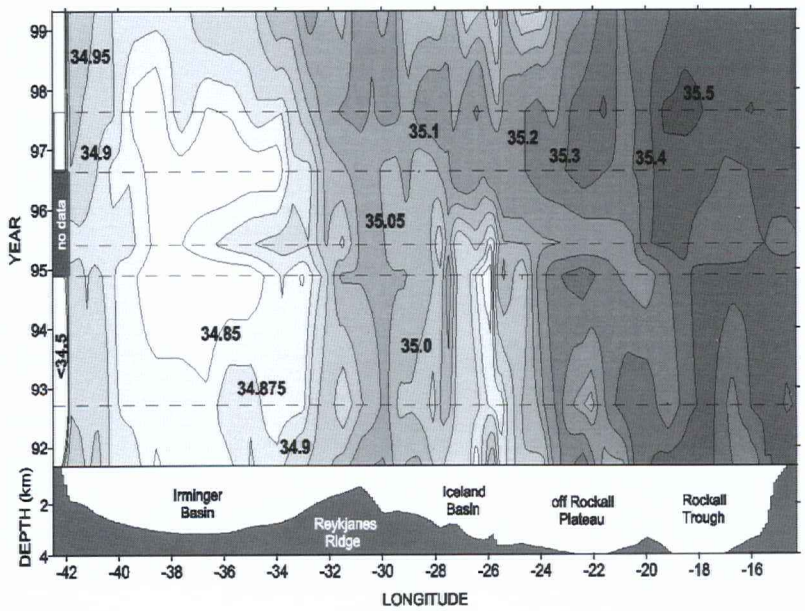

Figure 2. Temporal changes in the mean salinity of the upper 600 m along section A1E, recorded 7 times between September 1991 and May 1999. The beginning of each year is indicated on the vertical axis. The lower panel shows the bottom topography along the section (extended from Bersch *et al.*, 1999).

evidence of an eastward shift of the SAF in the period 1996 to 1998 and was found at 45°W in 1997, about 200 km farther east than in 1993. A corresponding southward shift of the north wall of the Gulf Stream at 70°W in 1996 and 1997 was observed by Rossby and Gottlieb (1998).

The redistribution of subarctic and subtropical water masses north of 40°N, associated with the pronounced weakening of the westerlies in 1996 and 1997, resulted in an increase of the mean salinity of the upper layer in the eastern basins and a decrease in the Newfoundland Basin especially west of 45°W

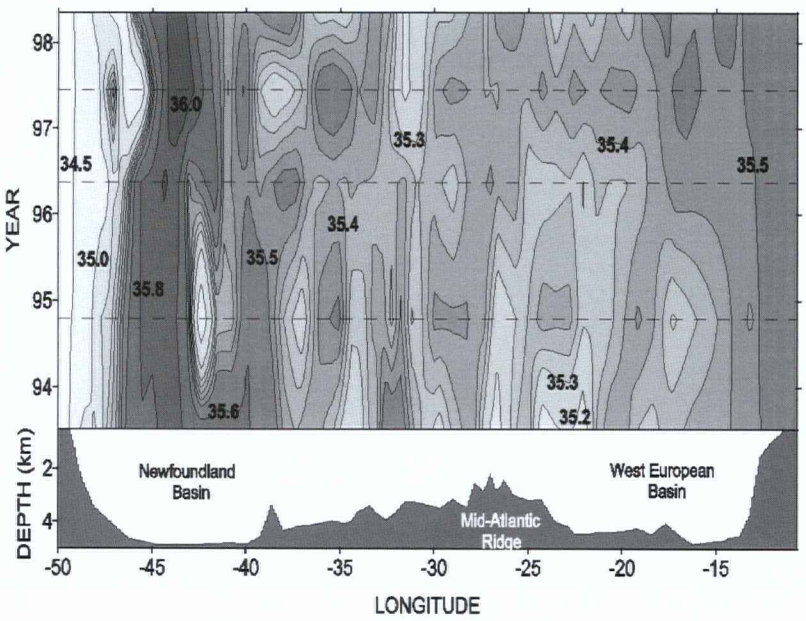

Figure 3. Temporal changes in the mean salinity of the upper 1000 m along section A2, recorded 5 times between July 1993 and May 1998. The beginning of each year is indicated on the vertical axis. The lower panel shows the bottom topography along the section (after Bersch, 2001).

above the continental slope. A reduced eastward spreading of subarctic waters with the North Atlantic Current and an intensified southward spreading of subarctic waters with the Labrador Current were suggested, while the northward spreading of subtropical waters was intensified in the northeastern North Atlantic. This led to the corresponding shifts of the SAF in the different regions and thus a change of the shape of the subpolar gyre.

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