



Distribution and ventilation of water masses in the Labrador Sea inferred from CFCs and carbon tetrachloride

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Abstract

An extensive study of halocarbon tracers, chlorofluorocarbons (CFCs) and carbon tetrachloride (CCl_4), based on over 100 stations in the Labrador Sea, demonstrated water mass structure and ventilation processes. Regional convection and isopycnal mixing of four water masses including newly ventilated Labrador Sea Water ($\text{LSW}_{\text{shallow}}$), Labrador Sea Water produced in the winter of 1993–1994 (LSW_{deep}), North East Atlantic Deep Water (NEADW) and Denmark Strait Overflow Water (DSOW) from the surface to the bottom of the Labrador Sea were resolved from tracer distributions.

Saturation levels varied spatially with different tracers and with convection regimes during the production of water masses. Average saturation levels in the $\text{LSW}_{\text{shallow}}$ for the entire Labrador Sea were 77% for CFC-12, 73% for CFC-11 and 92% for CCl_4 , respectively. Saturation levels during the time of LSW formation estimated from the area of deep convection were over 84% for CFC-12, 77% for CFC-11 and 99% for CCl_4 . Regional convection and subsequent horizontal mixing resulted in further reduction in saturation levels to 76%, 70% and 88%, respectively, when $\text{LSW}_{\text{shallow}}$ exited out to the south at the mouth of the Labrador Sea. LSW_{deep} was produced during the exceptionally deep convection winter of 1993–1994 and contained lower saturation levels than the Labrador Sea Water produced during weak convection regimes ($\text{LSW}_{\text{shallow}}$). CFC-12, CFC-11 and CCl_4 saturation levels in the LSW_{deep} were 66%, 61% and 76%, respectively, indicating that convection regime influenced tracer saturation levels.

Estimates of ventilation ages depend strongly on the saturation levels. We calculated ventilation ages using CFC-12 with a range of saturation levels and with the saturation level calibrated tracer ratio, CFC-12/ CCl_4 . The best estimates of ventilation ages for the NEADW and DSOW, obtained using the CFC-12/ CCl_4 ratio, were 11–13 and 5–8 years, respectively.

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1. Introduction

In the winter, strong northwesterly winds cool the surface of the Labrador Sea. The mixed layer may reach to over 2000 m depth in extreme winters. This convection produces the relatively fresh and cold Labrador Sea Water (LSW) (Lazier, 1980; Clarke and Gascard, 1983). During the formation of LSW, atmospheric gases are incorporated into the deepening mixed layer. The LSW subsequently spreads through the North Atlantic and transfers atmospheric signals to the intermediate depths of the ocean. The rate of deepwater formation in the Labrador Sea, together with that in the Nordic seas, has been suggested to have a significant influence on global ocean circulation, and therefore on long-term climate change (Dickson, 1997; Sy et al., 1997). Water masses produced in the Nordic seas, North East Atlantic Deep Water (NEADW) and Denmark Strait Overflow Water (DSOW), flow into the Labrador Sea at depth, i.e., almost all of the deep water formed in the North Atlantic flows through the Labrador Sea. Thus, the Labrador Sea is an ideal region to study variability in the major water masses that contribute to the lower limb of the global thermohaline circulation.

The surface circulation in the Labrador Sea is cyclonic. The West Greenland Current flows northward along the west coast of Greenland. The Labrador Current flows southward along the Labrador Shelf and Slope and the North Atlantic Current flows northeastward across the mouth of the Labrador Sea. In the deep layer, NEADW and DSOW flow around the basin cyclonically as a deep boundary current (Clarke and Gascard, 1983). A recent study (Lavender et al., 2000) has demonstrated the existence of an anti-cyclonic flow at the mid-depth in the Labrador Sea.

Halocarbon tracers in the ocean have sources in the atmosphere, whose concentration histories are well understood. Chlorofluorocarbons (CFCs) and carbon tetrachloride (CCl_4) are some of the most widely used halocarbon tracers to study the ventilation and transport processes in the ocean. The CFCs, CFC-11 (CCl_3F), CFC-12 (CCl_2F_2) and CFC-113 ($\text{CCl}_2\text{FCClF}_2$), are inert anthropogenic compounds. CFC-11 and CFC-12 came into use in the 1930s and CFC-113 in the mid-1960s. Following the adoption of the Montreal Protocol in 1988 to phase out the production of CFCs, CFC-11 and CFC-113 concentrations in the atmosphere started decreasing in the mid-1990s, while the CFC-12 concentration is still increasing slowly (Walker et al., 2000; Fig. 1). CCl_4 has a longer input

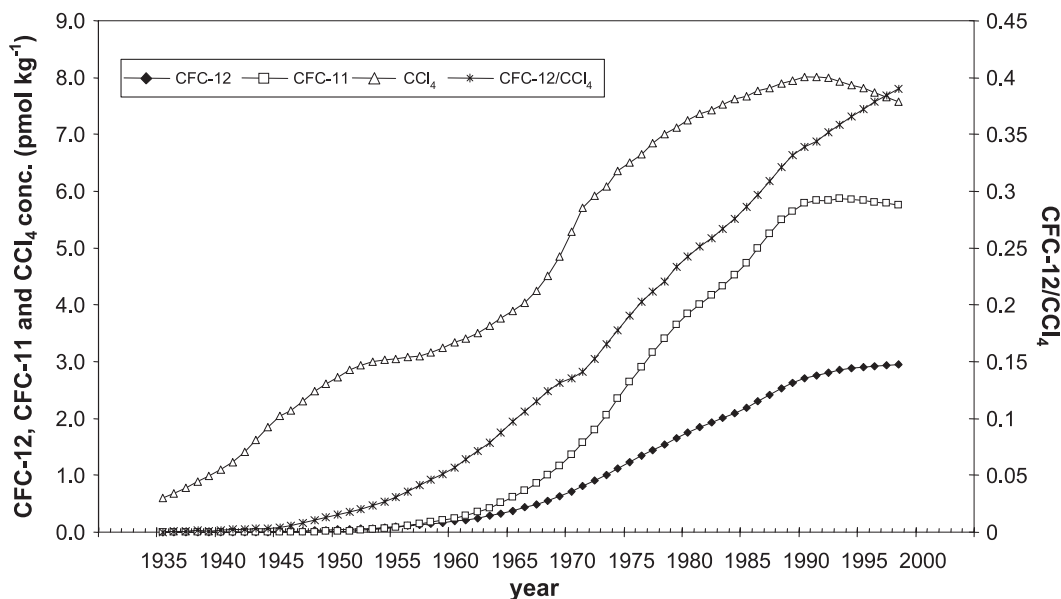


Fig. 1. CFC-11, CFC-12, CFC-113 and CCl_4 concentrations versus time in the northern hemisphere atmosphere from data by Walker et al. (2000) and the solubilities for CFCs and CCl_4 of Warner and Weiss (1985) and Bullister and Wisegarver (1998).

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