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Formation and export of deep water in the Labrador and Irminger Seas in a GCM

Julie Deshayes[a,*], Claude Frankignoul[a], Helge Drange[b,c,d,e]

[a]*LOCEAN, IPSL, Université Pierre et Marie Curie - Paris 6, Paris, France*
[b]*Nansen Environmental and Remote Sensing Centre, Bergen, Norway*
[c]*Bjerknes Centre for Climate Research, University of Bergen, Bergen, Norway*
[d]*Geophysical Institute, University of Bergen, Bergen, Norway*
[e]*Nansen-Zhu International Research Centre, Beijing, China*

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Abstract

The influence of changes in the rate of deep water formation in the North Atlantic subpolar gyre on the variability of the transport in the Deep Western Boundary Current is investigated in a realistic hind cast simulation of the North Atlantic during the 1953–2003 period. In the simulation, deep water formation takes place in the Irminger Sea, in the interior of the Labrador Sea and in the Labrador Current. In the Irminger Sea, deep water is formed close to the boundary currents. It is rapidly exported out of the Irminger Sea via an intensified East Greenland Current, and out of the Labrador Sea via increased southeastward transports. The newly formed deep water, which is advected to Flemish Cap in approximately one year, is preceded by fast propagating topographic waves. Deep water formed in the Labrador Sea interior tends to accumulate and recirculate within the basin, with a residence time of a few years in the Labrador Sea. Hence, it is only slowly exported northeastward to the Irminger Sea and southeastward to the subtropical North Atlantic, reaching Flemish Cap in 1–5 years. As a result, the transport in the Deep Western Boundary Current is mostly correlated with convection in the Irminger Sea. Finally, the deep water produced in the Labrador Current is lighter and is rapidly exported out of the Labrador Basin, reaching Flemish Cap in a few months. As the production of deep-water along the western periphery of the Labrador Sea is maximum when convection in the interior is minimum, there is some compensation between the deep water formed along the boundary and in the interior of the basin, which reduces the variability of its net transport. These mechanisms which have been suggested from hydrographic and tracer observations, help one to understand the variability of the transport in the Deep Western Boundary Current at the exit of the subpolar gyre.

Keywords: North Atlantic subpolar gyre circulation; Labrador Sea Water; Convection; Deep water spreading; Deep Western Boundary Current; Interannual variability

1. Introduction

The oceanic Meridional Overturning Circulation (MOC) and the associated poleward heat transport contribute substantially to the present energy balance of the Earth (Trenberth and Caron, 2001).

*Corresponding author. WHOI, MS #21, Woods Hole, MA 02543, USA.
E-mail address: jdeshayes@whoi.edu (J. Deshayes).

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One fundamental driver of the MOC is the formation of intermediate to deep water masses in the northern North Atlantic resulting from the winter densification of the surface water. The variability of the MOC can be related to changes in the rate of deep water formation in the northern North Atlantic in simulations with oceanic General Circulation Models (GCMs) (Eden and Willebrand, 2001; Bentsen et al., 2004; Mignot and Frankignoul, 2005). Coupled climate GCMs suggest that the MOC is highly sensitive to surface salinity perturbations in the regions of formation of intermediate to deep water (e.g., Manabe and Stouffer, 1995; Stouffer et al., 2006): an anomalous input of freshwater will reduce the deep water formation rate, resulting in a weakening of the Atlantic MOC. This will tend to reduce the poleward heat transport and have therefore considerable impact on, in particular, the Atlantic-European climate (e.g., Vellinga and Wood, 2002). However, the link between changes in the rate of deep water formation and the variability of the MOC is not clearly established. For instance, Mauritzen and Häkkinen (1999) suggested that changes in the rate of deep water formation might not affect the MOC but influence the characteristics of the water masses at depth. The role of the wind-driven circulation is also unclear, and Straneo (2006) suggested that the overturning and the poleward heat transport might vary because of changes in the wind-forced circulation even if the rate of deep water formation remains unchanged.

The deep water formed in the North Atlantic is mostly carried southward by the Deep Western Boundary Current (DWBC), which constitutes the lower limb of the Atlantic MOC. The DWBC originates from the southward slopes of the Greenland–Scotland Ridge, and in the Irminger and Labrador Seas (Dickson and Brown, 1994, see the location of these geographical features in Fig. 1). Once formed, the DWBC follows the topography along the western boundary of the North Atlantic basin. The densest water masses are formed in the Nordic (Greenland, Iceland and Norwegian) Seas and in the Arctic Ocean, and overflow through the deepest sills of the Greenland–Scotland Ridge. The lighter water masses are formed in the Labrador Sea (therefore called Labrador Sea Water, LSW) and in the Irminger Sea (Pickart et al., 2003; Bacon et al., 2003). Although the characteristics of the DWBC and its variations on the monthly timescale have been described (e.g., Lazier and Wright, 1993; Fischer et al., 2004), its interannual variability remains poorly documented because of the scarce-

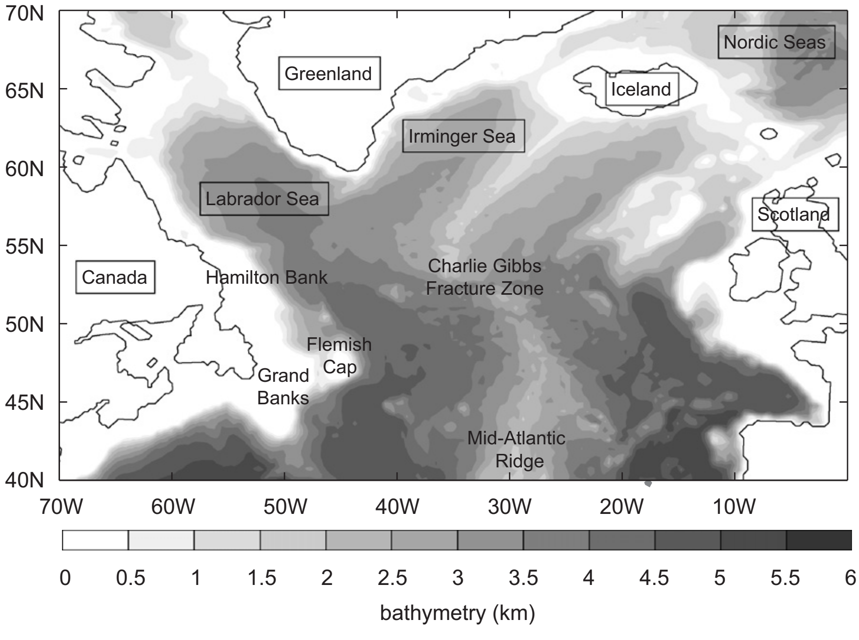

Fig. 1. Bathymetry of the model between 40°N and 70°N (based on the ETOPO-5 data base, Data Announcement 88-MGG-02, Digital relief of the Surface of the Earth, NOAA, National Geophysical Data Center, Boulder, Colorado, 1988) and location of key geographical features in the North Atlantic.