Horizontal Stratification during Deep Convection in the Labrador Sea

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ABSTRACT

Deep convection—the process by which surface waters are mixed down to 1000 m or deeper—forms the primary downwelling of the meridional overturning circulation in the Northern Hemisphere. High-resolution hydrographic measurements from Seagliders indicate that during deep convection—though water is well mixed vertically—there is substantial horizontal variation in density over short distances (tens of kilometers). This horizontal density variability present in winter (January–February) contains sufficient buoyancy to restratify the convecting region to observed levels 2.5 months later, as estimated from Argo floating platforms. These results highlight the importance of small-scale heterogeneities in the ocean that are typically poorly represented in climate models, potentially contributing to the difficulty climate models have in representing deep convection.

1. Introduction

Deep convection occurs when intense wintertime heat fluxes cool weakly stratified surface waters, resulting in well-mixed surface layers hundreds of meters thick. In the Labrador Sea, the major region for open ocean deep convection in the Northern Hemisphere, cyclonic circulation reduces the surface stratification, while cold, dry winds from over Canada and Siberia cool the ocean (Lazier et al. 2002). This cooling increases the density of the surface water, allowing it to sink in plumes with narrow horizontal scales (100 m) and fast vertical speeds (up to 10 cm s^{-1}), mixing waters down to 1000 m or more (Lilly et al. 1999; Steffen and D'Asaro 2002). During periods of deep convection, density differences between the surface and the base of the mixed layer are small by definition (less than 0.01 kg m^{-3}) (Lazier et al. 2002). When surface buoyancy losses no longer exceed the lateral input of buoyant waters from surrounding regions, the area again becomes stratified with light waters overlying denser waters, via some process of restratification (Marshall and Schott 1999).

While observations have established that convection has a finescale texture and restratifies rapidly to a state with strong "spice" (where temperature and salinity, T and S, variability are nearly compensating in density), (Lilly et al. 1999), restratification time scales in models are longer (e.g., Jones and Marshall 1997; Katsman et al. 2004). These numerical studies used a simplified initial density state, either a preconvection state with horizontal isopycnals (Visbeck et al. 1996), or a central well-mixed (horizontally and vertically) column of convected water in a so-called "cylinder collapse" experiment (Jones and Marshall 1997). While the numerical modeling study of Legg and McWilliams (2000) allowed for heterogeneous properties, they found that T and S were largely compensating in density.

The longer, annual time scales of restratification require lateral inputs of buoyant water from the boundary currents to maintain observed heat and salt budgets in the Labrador Sea (Straneo 2006; Schmidt and Send 2007). Recirculating boundary currents have been observed using floats (Lavender et al. 2005), while eddy fluxes have been the focus of several more recent papers. The flux of buoyant waters has been divided into fluxes by three classes of eddies in recent numerical modeling

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