Deep Convection in the Labrador Sea: Moorings, Hydrography and Laboratory Simulations

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LONG-TERM GOAL

We are pursuing the physics of oceanic deep convection, its organization into mesoscale eddy structures, and interaction with basin-scale circulation. This will lead to improved understanding of upper ocean, whose properties change so rapidly with time. This fine-scale oceanic turbulence is also important to larger scale circulations and mixing of water masses.

OBJECTIVES

Our objective is to study convection and its context: the physics of wintertime breakdown of the upper oceanic thermocline/halocline, the development of convection to great depth, and its horizontal interactions. These interactions include the spawning of mesoscale eddies, mixing between deeply convected water and its stratified surroundings, interaction with the continental shelf and its water masses, and interaction with intense boundary currents. We want to bring together models and observational data relating to ocean convection, by participating in ocean field experiments, pursing laboratory simulations and numerical models of thermodynamically active fluid circulations. The high-latitude oceans are filled with special dynamical features: severe winds and cooling by the atmosphere, abundant sources of surface freshwater, partial ice-cover, and the inflow of warm, saline water masses from the subtropics.

APPROACH

In the early 1990s we helped to establish the Deep Convection ARI (Lab Sea Group, 1998), began collaboration with the Canadians (particularly John Lazier) in 1993, and established the Bravo site mooring to give continuous time-series of the temperature, salinity and velocity in the central Labrador Sea. This has involved participation in hydrographic cruises on the CSS Hudson annually since 1992. During the intense phase of the 1996-98 experiment we deployed 3 extra moorings with ONR support, spanning the boundary currents and extending out into the convecting Labrador Sea Water.

We have acquired other datasets, including the surface drifter data of Niiler, and the early Palace float data of Davis, and with Jonathan Lilly, a UW graduate student, have concentrated on analysis of intense, 'hard-core' eddies that appear in the mooring data, and on analysis of mixing of temperature and salinity during and after deep convection.
Modelling work in the UW Geophysical Fluid Dynamics Laboratory has proceeded under joint funding between ONR and NSF (who have provided salary support for Dr. Boris Boubnov, a long-term visitor

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with our group). The object is to follow the morphology of rotating convection in basins through a large parameter space. Measurements in more than 70 experiments have involved imaging, density-field measurements, and laser velocimeter time-series and sections (Boubnov and Rhines, 1998).

Leif Thomas, a UW graduate student, and Brian Scansen, a UW undergraduate, have carried out extensive lab- and numerical experiments in which convection occurs in basins of extended size, or in the presence of wind-stress. We are looking at highly idealized models in which the geometry of the basin and forcing is simple. Characterizing the behavior of the wind-driven upper ocean boundary layer in the presence of density fronts and convection is a major goal.

Speaking more broadly (about observations), we need now to begin to synthesize the vast 1996-98 Labrador Sea datasets, which are a treasure-trove of high-latitude oceanography. These must also be merged with measurements (hydrography of ACCE and aerial surveys of FASTEX) that were carried out more broadly in the subpolar gyre. The LabSea ARI group is loosely organized, with no formal committee structure, and works by consensus. It is critically important to carry on the momentum of the experiment into the analysis phase, and to consider what further measurements can be carried out to further the program's objectives. In particular, those of us involved in mooring work look forward to the availability of AUV platforms and continuing float and drifter launches which can be deployed at high latitude (some AUVs, perhaps under sea-ice cover). The knowledge obtained in the past two years will make it possible to design much simpler measurement strategies to continue to observe deep convection.

WORK COMPLETED

On the Oct/Nov 1996 Hudson cruise (led by Lazier and Clarke) we achieved many things, launching huge numbers of drifters, floats and moorings, and carrying out the first 3-dimensional hydrographic survey of the Labrador Sea since 1966. Our moorings were set at this time, apparently successfully, but 20 months later it appeared that a substitution of wire types had led to failure of 3 of the 5 moorings. Instruments were found in Iceland and Ireland, and on the sea-floor. The Kiel group had joined us in the experiment with a large complement of moorings (u,v,w,T,S and tomography)

Meanwhile, an extensive hydrographic data base has been assembled (much of the work by Lazier and Yashayaev of Bedford Institute of Oceanography) to study the spatial aspect of convection and its products.

The mooring failures described above have reduced our coverage of the convection zone, but fortunately our German collaborators have had moorings in complementary locations which will mean a relatively small scientific loss. For example, their heavily instrumented K1 mooring was sited just 15 km from the Bravo mooring in order to look at horizontal eddy structure. Both moorings operated successfully in 1996-7, but ours failed in 1997-8. Thus we have an 8 month comparison rather than the planned 20 month comparison. But, otherwise, the data coverage is still quite good. We are arranging to synthesize our mooring and hydrographic data with that of the Kiel group, who have already produced interesting transport picture of the boundary currents at the Labrador continental slope.

RESULTS

J.Lilly, working under this grant, has produced an analysis of intense, 'hard-core' eddies seen at our Bravo mooring and in hydrography. We so far see a propensity for cold anticyclones and warm cyclones. The mooring velocity data has been essential to the analysis (hydrography alone would suggest the opposite sense of rotation). These are 10 to 20 km diameter eddies that dominate the kinetic energy of that Sea. They have wider 'wings' which reach out much farther. The statistical properties of the oceanic current record have many similarities with laboratory simulations. Of particular importance is the moderately strong intermittency level (the extent to which ocean eddies are 'close-packed' or 'sparse'). This is crucial to our models of the ocean, as a mix of homogeneous geostrophic turbulence and 'hard-core' eddies.

A study of the space/time structure of temperature and salinity fields has shown the life-cycle of mixing and fine-structure production following convection: simply put, convection produces (almost) well-mixed regions, with respect to the vertical, but with strong horizontal contrasts owing possibly to the non-uniform initial conditions prior to convection. This horizontal fine structure decays over the following 6 months at depth, but meanwhile fine-structure builds up at shallower depth. This is the result of in-mixing of warm, saline water from the Irminger boundary current. We think we can now quantitatively describe the residence time ('life-time') of Labrador Sea Water using fine-structure as a tracer. Some of this work appears in a long paper on the Bravo mooring (Lilly et al., 1998), and the rest is in newer manuscripts.

Our new current-meter data is from sites near the Labrador continental slope, where the ocean depth is 1000m, 2750m and 3600m. Two of these are in the boundary currents at the edge of the deep convection region. The 2750m mooring (55.48N, 53.66W) was located near the core of the strongest boundary current at depth, the Denmark Strait Overflow Water. The velocity structure there (fig. 1) has a strong barotropic component; the deepest level does show the strongest flow, but at all levels the mean current is within 40% of that strongest value (thus showing how essential it is to make direct velocity measurements). The data extend from Oct. 96 through June 98, thus capturing two complete winter cycles. The temperature series (fig.2) illustrate the strong arrival of cold water at the upper levels in winter. At 200m depth this may be locally convected water, although it is very unlikely that the cooling at deeper levels (about 0.2C at 1000m) is due to local convection.

In the 'laboratory sea' we have produced regime diagrams for rotating convection into both unstratified and stably stratified fluid. The buoyancy forcing occurs over an isolated portion of the constant-depth cylinders and bowl-shaped basins. This work with B.Boubnov has involved approximately 70 experiments. It shows in detail the transition from symmetric to wave-like to turbulent regimes, but with great differences between the stratified and unstratified cases. The flows are always turbulent in the region of buoyancy forcing, but we find the outer region distant from the forcing to pass through regimes of laminar circulation, discrete eddy production, and baroclinic waves. With a stratified environment there is striking dipole eddy production with deep anticyclones and weaker, shallow cyclones. These provide a model for the more monopole structures seen in the Labrador Sea.

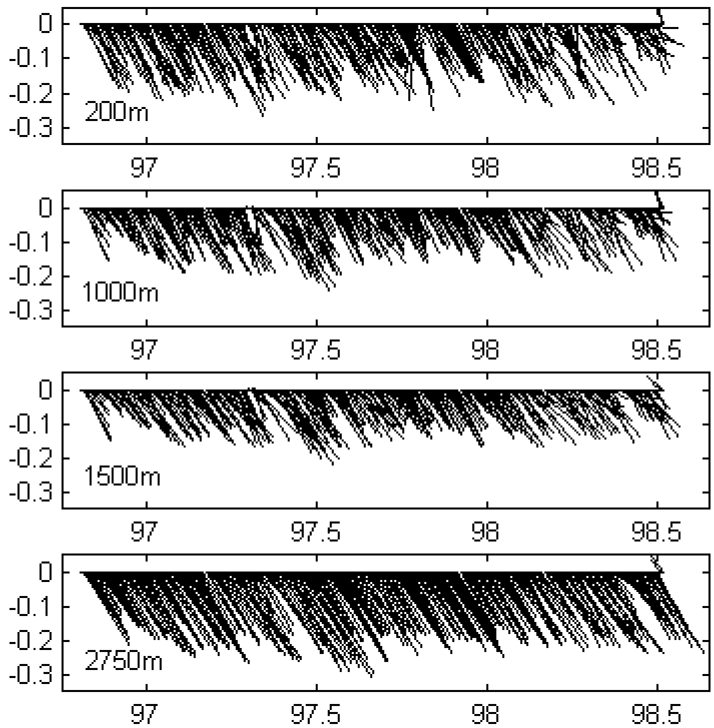

Figure 1. Labrador Sea boundary current vectors at the 2750m isobath, Oct. 96- June 98. The mean speeds are 15.8, 18.4, 15.1, 23.7 cm sec^{-1} from top to bottom; the deepest instrument is near the core of the energetic the Denmark Strait Overflow water. On top of the strong flow along constant-depth contours there is a broad spectrum pulsation, which reaches through most of the water column.

IMPACT/APPLICATION

Techniques developed in the laboratory will, we hope, find applications. These include the use of our unusual laser velocimeter (built by Quest, Inc., of Kent WA), one of the very few such velocimeters to be mounted on a rotating experimental platform. The general expertise of laboratory techniques is rapidly accumulating, and we are seeking ways to publish what we now know: either as a textbook or Web-based courseware. The laboratory, its research and teaching functions may be visited at www.ocean.washington.edu/faculty/rhines

Much more broadly, the Lab Sea group as a whole has supported the development of new measurement technologies which promise to revolutionize the way we observe the ocean, and ONR has supported these advances.

TRANSITIONS

None.

RELATED PROJECTS

We have support from NOAA for maintenance of the Bravo mooring, and for climate studies. Our NSF grant is directed toward general circulation of the oceans and topographic influences. Because buoyancy-driven circulation is a part of that grant, we have used some of the funding for support of Dr. Boubnov, from Oboukhov Inst. of Atmospheric Physics, Moscow. His work on laboratory convection is a point of collaboration between these grants.

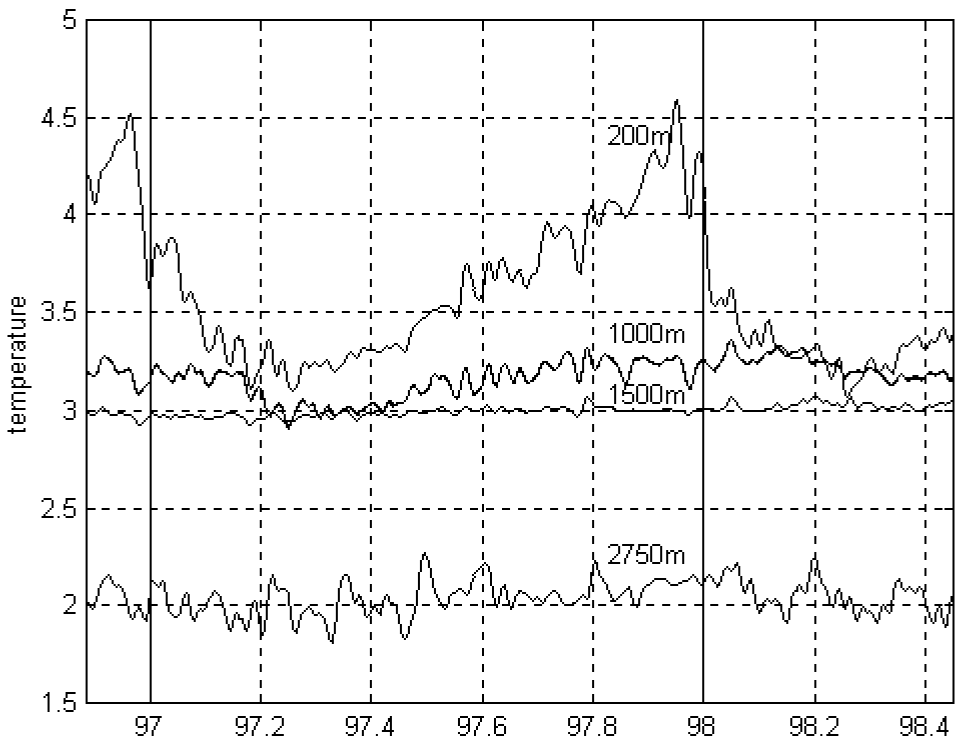

Figure 2. Temperatures from Oct 96 to June 98 at the same locations as the currents shown in Fig. 1. Note the strong wintertime cooling penetrating right through the warm, saline Irminger Water. The deeper cooling is likely advection from a distance rather than local convection.

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