Simulation of Lagrangian Drifters in the Labrador Sea

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LONG-TERM GOALS

The long-term objective for this research is to use our improved knowledge of the turbulent kinetic energy (TKE), Reynolds stress, and scalar flux budgets to develop and test parameterizations of mixed layer dynamics and deep penetrative convection and overturning for inclusion in basin-scale oceanic general circulation models.

OBJECTIVES

A principal technical objective is to simulate and understand the behavior of Lagrangian drifters and floats in the presence of deep convection in the Labrador Sea. The corollary scientific objective for the Labrador Sea Deep- Convection ARI is to understand the production, transport and dissipation of TKE and scalar variances (potential temperature and salinity); and the production and transport of covariances (Reynolds stresses, heat and salt fluxes) from drifter sensor systems.

APPROACH

A nonhydrostatic numerical model for high Reynolds number turbulent flow is used to predict convection. Large-Eddy Simulation (LES) has been adapted to prediction of nonhydrostatic ocean convection (Garwood, 1994; Paluszkiewicz et al., 1994) by including the important thermodynamic effects of the equation of state at low temperature and high pressure (Garwood, 1991) and consideration of appropriate ocean surface and bottom boundary conditions, and improvements in the spectral filter (Harcourt, 1998). The effect of the turbulent fields on both fully Lagrangian and semi-Lagrangian `Isobaric' drifters was simulated by modeling the motion of virtual drifters in tandem with the evolution of the LES fields. These results are used to assess drifter statistics, and to compare float observations of deep convection with the LES.

WORK COMPLETED

LES was used to study the physics of wintertime mixed layer deepening in the Labrador Sea. The simulations predict time series of mixed layer temperature, salinity and layer depth H that are verified by the hydrographic observations of the R/V Knorr in 1997. The effect of the turbulent fields on both fully Lagrangian and semi-Lagrangian `Isobaric' drifters was simulated by modeling the motion of virtual drifters in tandem with the evolution of the LES fields. Methods for including the effects of

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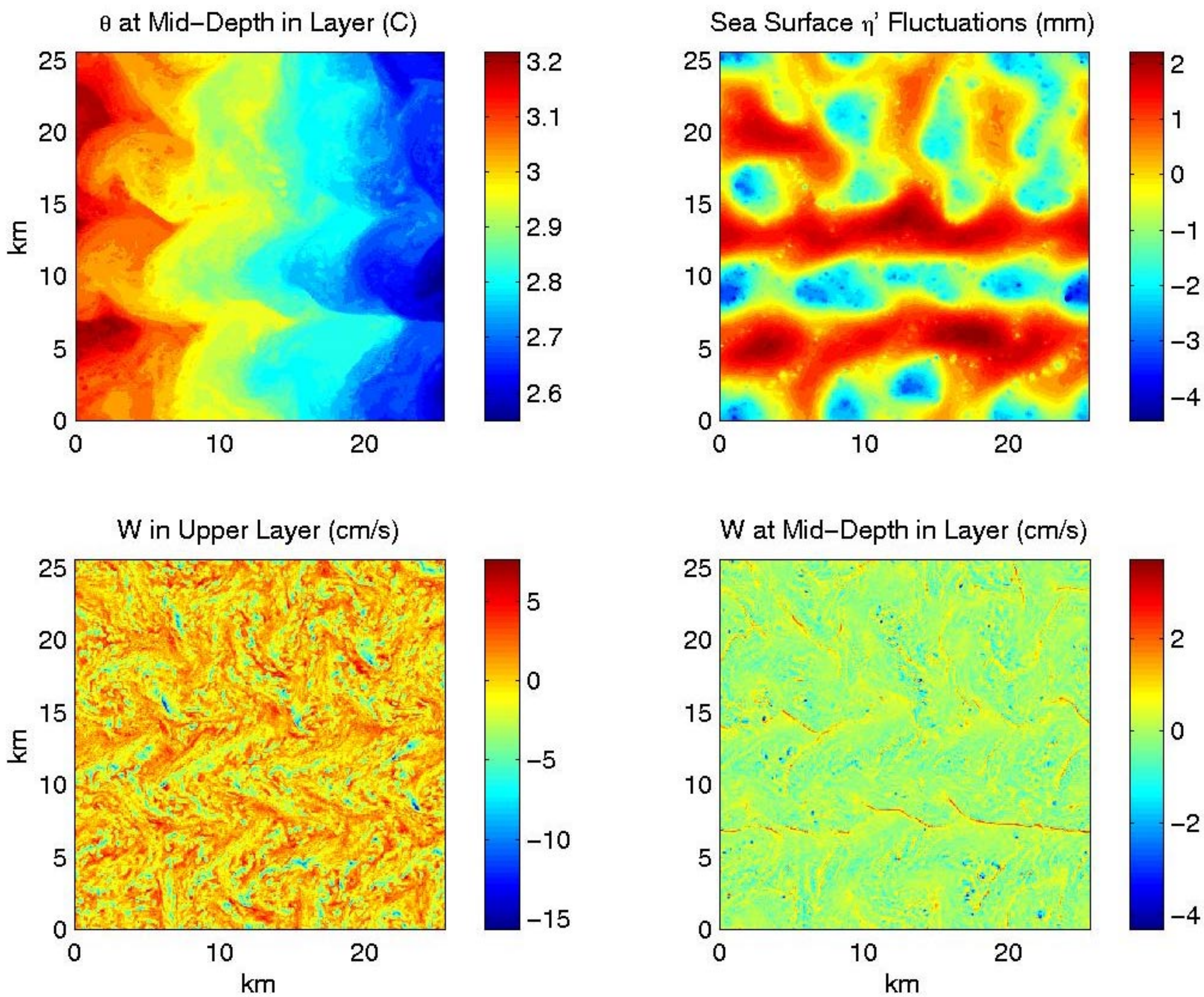
baroclinicity while retaining the high numerical resolution necessary for accurate LES results have been developed at NPS by Stone (1999) and Kruse (2000). These methods are currently being used in efforts to explain remaining differences between observations and model results. Results described in the ONR report for FY99 include a parameterization of the dependence of turbulent deep convection on Rossby number. This parameterization is consistent with the most recent observations from floats and moorings in both the Labrador and Greenland Seas.

RESULTS



1. Horizontal sections of potential temperature at 400m (upper left), sea surface height fluctuations (upper right), vertical velocity at 210m (lower left), and vertical velocity at 425m (lower right) in a 1km deep baroclinic mixed layer responding to 400W/m^2 surface heat loss, where a mean zonal density gradient is dominated by temperature. The simulated domain is 25km X 25km X 1km, and horizontal boundary conditions are doubly periodic for fluctuations. The isotropic grid resolution is 50m.

The subject of internal wave generation by deep convection has been raised by Garwood (1999a). This paper has been submitted to JPO. Of particular interest is the downward propagation of energy from the turbulent boundary layer by pressure transport and the build up of internal wave energy in response to local atmospheric forcing. A near equilibrium internal wave spectrum is approached after about two weeks of episodic storm cooling. A broad band omni-directional internal wave field with peak energy near the buoyancy frequency N is forced mostly by the buoyancy flux. The pressure transport of mixed-layer kinetic energy carries about 30% of the available energy into the stratified zone and causing entrainment. On average, 10^{-4} W/m^2 or about 1% of the winter Labrador Sea mixed layer energy escapes into the pycnocline where it is converted into internal wave energy.

A manuscript (Harcourt, 2000) comparing the fully Lagrangian (DLF) float observations of D'Asaro to drifters embedded in a LES of 1997 Labrador Sea convection has been accepted for publication in JPO. This paper demonstrates that horizontally homogeneous convection, as represented by the LES model, accounts for most of the first and second order statistics from float observations, except that observed temperature variance is several times larger than model variance. Following this successful comparison for 1997, simulations are under way to model the behavior of these floats in 1998, with special attention to the well-measured internal wave field below the pycnocline, and to the effects of horizontal inhomogeneity and baroclinicity arising from large scale and mesoscale horizontal gradients in density and spice.

A LES prediction of deep convection with baroclinicity is shown in Figure 1. A mean zonal density gradient dominated by temperature produces a surface current to the south, while turbulent deep convection to 1km across the baroclinic shear leads to current meanders and submesoscale features at scales of 5-10 km. Sea surface height fluctuations show the signatures of plumes at scales less than 1km are embedded in the larger baroclinic eddies. Evidence of the cellular submesoscale pattern at the 6-12km scale has been observed by Fischer (Lab. Sea ARI workshop presentation, 1999) in SAR imagery. The two lower panels of vertical velocity profiles from the upper and central mixed layer demonstrate that while plumes are amplified, suppressed, and organized by the larger scale features, most of the vertical mixing and transport is still carried out by turbulent structures at scales comparable to the mixed layer depth.

Numerical results from fixed-depth LES-embedded floats (Harcourt, 1998; Harcourt, 1999) have, since the early years of the Labrador Sea Deep Convection ARI, predicted the existence of systematic statistical biases in isobaric drifter measurements. This sampling bias results in a reduced vertical TKE and fluxes computed from float time series, and in a particularly measurable mean upward (downward) vertical velocity at floats in the lower two-thirds (upper one-third) of the mixed layer. These predictions have been verified in parallel modeling, analysis, and comparison work with isobaric floats deployed by Gascard in the Greenland Sea (Lherminier, 2000), and have been demonstrated to arise from the coherence of convergence and vertical velocity. Yet for several years, data from isobaric floats deployed in this experiment were reported to show no significant biases in mean vertical velocity. The existence of such biases for isobaric floats was reproduced by Legg and McWilliams (2000) in a simulation of convection that includes mesoscale features. This year, Lavender et al. (2000) reported the existence of a mean vertical velocity bias in the P/ALACE float observations, and a vertical heat flux that is significantly less than the flux deduced from the heat budget. Since that time we have been engaged in deeper analysis and discussion. One of the main difficulties in this discussion is that if the statistical bias of isobaric floats is assumed negligible, the float data are interpreted to support competing theories of convection at a very slow time scale (>88hrs), or as a reduction in vertical heat flux due to horizontal flux divergence at the mesoscale. Simulations of isobaric drifters embedded in baroclinic mixed layer deep convection that resolve baroclinic eddies (Figure 1) yield time series of potential temperature more consistent with Labrador Sea P/ALACE float observations, but do not alter our fundamental conclusions on the existence and significance of systematic sampling biases for isobaric drifters.

A manuscript on the difference between Eulerian statistics and isobaric float observations is in preparation. It will show that isobaric and Eulerian profiles of turbulence statistics can be related by a single generating profile that expresses the overall effect of nonuniform float sampling. The upshot of this analysis is that in order to calculate Eulerian statistics of convection from isobaric time series, fixed-depth float measurements must either be coupled with a high resolution nonhydrostatic model, or they must be redesigned to record a time series of horizontal convergence along the float trajectories. Another manuscript in preparation is a description of the LES model employed to simulate the motion of drifters, and the scaling relations found (Harcourt, 1999) for the dynamics of rotating convection in deep mixed layers.

IMPACT/APPLICATIONS

The simulations of Lagrangian floats in the Labrador Sea, and comparisons between model and actual float statistics, have demonstrated that the Drifting Lagrangian Floats (DLF) deployed in the Labrador Sea are an accurate and effective tool for measuring deep convection. The model-experiment comparisons have been largely successful, but have also revealed unanticipated features of the dynamics of deep convection that motivated current research efforts to understand the effects of baroclinicity and wind-driven currents on deep convection.

Preferential sampling of convergence zones by isobaric floats bears upon all measurements obtained with these instruments. In general, values obtained for the variance and covariance of vertical velocity and temperature fluctuations along drifter trajectories are significantly reduced by comparison to their Eulerian counterparts. This reduction is the direct result of the biased sampling by isobaric drifters which manifests in the appearance of net vertical fluid transport along drifter trajectories. This fundamental result is not altered by the presence of baroclinicity or mesoscale features.

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