STATISTICAL PHYSICS FOR STRONGER OCEAN MODELING

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LONG-TERM GOALS

Our overall goal is to develop and evaluate practical parameterizations of subgrid-scale mixing for use in ocean circulation models. We seek also to apply such models toward improving understanding of ocean circulation and transports.

OBJECTIVES

Several types of subgrid-scale transport are being considered. Early efforts have concentrated on representing momentum transport by mesoscale eddies, not resolved by many ocean models. From statistical mechanics applied to geophysical turbulence, we found that such eddies should drive mean currents correlated with topography, contrary to usual eddy drag parameterizations. We have further refined the theory, and evaluated performance of practical parameterization (the neptune formulation of Holloway). The connection between this approach and eddy transports of layer thickness or potential vorticity fluxes is explored, as is relevance to coastal zone/open ocean exchange.

Recent effort has focussed on improved representation of diapycnal mixing processes, which strongly influence water mass formation and structure. We employ numerical simulations of salt fingering, diffusive interleaving, and differential property transport by weak turbulence to obtain fluxes as functions of governing parameters. Work will commence in the upcoming FY on a statistical parameterization of deep convection which accounts for its sporadic occurrence in space and time.

APPROACH

Fundamental theoretical investigation is used to characterize mean currents in stratified quasigeostrophic turbulence (Merryfield). Numerical processes studies employ layer models to represent eddy fluxes (Merryfield and Holloway) and coastal-zone transport (grad student D. Eurin, co-sponsored by S. Allen, UBC), as well as a two-dimensional Boussinesq code to investigate double-diffusive and other microscale processes (Merryfield, undergrad M. Grinder). Mixing parameterizations are implemented in the GFDL Ocean Model (MOM 2), and results compared with observations (postdocs L. Nazarenko and X. Zhang, Holloway, research asst. T. Sou, undergrad A. MacFadyen, Merryfield, A. Gargett [IOS]).

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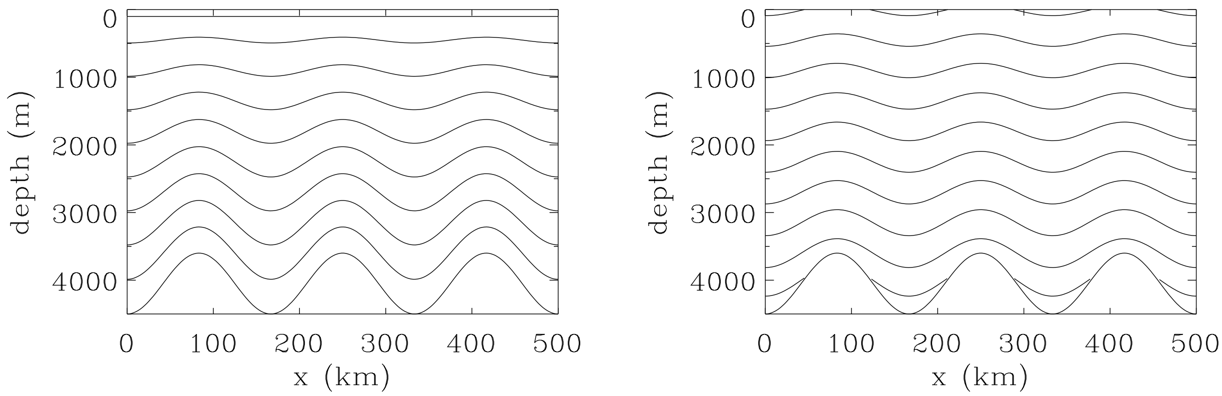

Figure 1: Equilibrium mean isotherms for stratified quasigeostrophic turbulence over a sinusiodal ridge. (left) Constant boundary temperature (continuously stratified limit of layer model). (right) Boundary temperature variance allowed.

WORK COMPLETED

The GFDL Ocean Model (MOM 2) was modified to accommodate the benthic boundary transport parameterization of Beckmann and Doescher (1997), the double-diffusive mixing parameterizations of Schmitt (1981) and Federov (1988), and enhanced mixing in grid cells adjacent to boundaries. An associated sea ice model was further developed to a include a probability distribution of subgrid thicknesses, effects of snow, and distinction between level and deformed ice.

A two-dimensional spectral code describing a Boussinesq fluid stratified by salinity and temperature was developed and tested.

Additions were made to an inventory of long-term current meter data, which now exceeds 3000 records.

Papers on eddy layer thickness and potential vorticity fluxes, effects of double diffusive mixing in global ocean models, and Beaufort Sea circulation were submitted to journals.

RESULTS

A statistical mechanics description of topography-induced mean flows in inviscid stratified quasigeostrophic turbulence was extended to admit nonuniform temperatures at the surface and benthic boundaries. (Previous results pertained to the continuously-stratified limit of layer models, in which boundary temperatures are constrained to be uniform.) In the new formulation, eddies tend to maintain cold surface anomalies over seamounts, and seamounts can penetrate isotherms (Fig. 1).

Fluxes of layer thickness and potential vorticity were quantified in quasigeostrophic layer models of forced and dissipative flow over ridges and seamounts. Directions of the fluxes were found to depend on the functional form of the dissipation law, and were not always downgradient as is often assumed. The flux directions were, however, consistent with the notion that eddies drive the flow toward higher statistical entropy, opposing effects of forcing

Figure 2: Two-dimensional salt fingering in seawater at buoyancy ratio $R_\rho = 1.25$, from a 1024×1024 numerical simulation. Lighter shades indicate higher concentrations of salt, and dark shades lower concentrations; velocity is indicated by arrows. The domain is approximately 16 cm wide.

and dissipation. These results suggest that eddy parameterizations formulated in terms of layer thickness and potential vorticity fluxes can readily be modified to account for topographic effects.

Vertical fluxes of heat and salt due to salt fingering were numerically simulated for buoyancy ratio $R_\rho = \alpha\partial_z T/\beta\partial_z S$ ranging from 1.25 to 20 (Fig. 2). For the range $1 < R_\rho <\approx 3$ characterizing fingering activity in the oceans, eddy diffusivities for heat and salt are given approximately by $\kappa_S \approx 0.1/(R_\rho - 1)$ cm^2 s^{-1} and $\kappa_T \approx \kappa_S R_f/R_\rho$, where $R_f \approx 0.56$ is the buoyancy flux ratio. These are much smaller than fluxes inferred by reference to laboratory results, but are roughly in accord with values deduced from microstructure measurements.

Preliminary calculations have been undertaken using the Boussinesq code with background T and S gradients both stabilizing. Initial overturning motions are allowed to decay, and the cumulative fluxes of T and S (in excess of the background diffusive fluxes) are computed. Results indicate greater fluxes of T than S in all cases. The ratio is an order of magnitude when overturning is weak, and is closer to unity when overturning is stronger. Parameter dependence is being investigated.

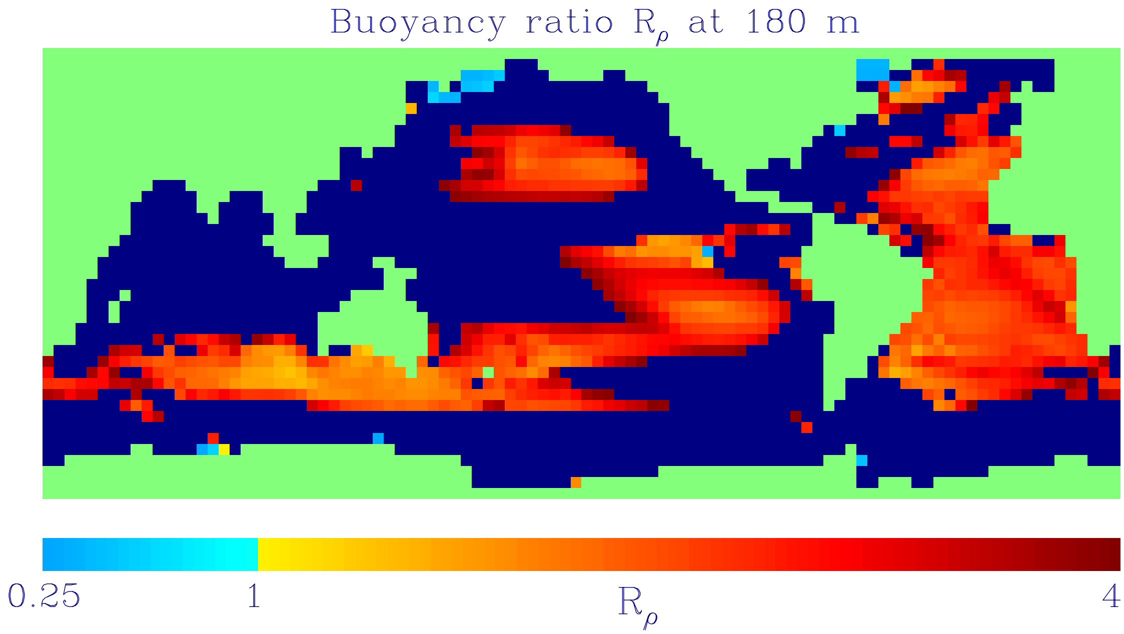

Figure 3: Buoyancy ratio R_ρ at 180 meters depth in a coarse-resolution global ocean model. Salt fingering tends to occur in regions where $R_\rho > 1$, and diffusive convection in regions where $R_\rho < 1$.

A global ocean model was run in which parameterized double-diffusive mixing is added to stability-dependent background diffusion (Fig. 3). Introducing double-diffusive mixing tended to bring temperature and salinity distributions closer to climatology, while only weakly affecting model circulation.

In conjunction with DFO/Ocean Climate Program (see RELATED PROJECTS), new modeling initiatives have been made for the Arctic Ocean and Baffin Bay/Labrador Sea regions. ONR support enabled refinements to open boundary treatments and representations of sea ice (beyond widely-used thickness-compactness form). This combined work has led to a new, quantitative synthesis of Arctic Ocean circulation.

IMPACT/APPLICATIONS

Extension of statistical mechanical theory to stratified flows paves the way toward modifying parameterizations of mean-flow generation by eddies to account for stratification.

Ocean modeling results suggest that water mass properties may be improved by including double-diffusive mixing effects. Numerical simulations of salt fingering assist in providing a more reliable basis for such a parameterization.

TRANSITIONS

The neptune formulation of eddy momentum transport is being used by the LLNL Climate System Modeling Group in models of bomb radiocarbon transport (Caldeira, et al. 1996), and has been incorporated in a model of Gulf of California circulation (Marinone 1997).

Several investigators are examining the role of eddies in generating mean flows, and relating their results to ours (Fanning 1997; Frederiksen 1997; Greatbach 1997; Kazantsev, et al 1997).

RELATED PROJECTS

The Department of Fisheries and Oceans (DFO) has launched an Ocean Climate initiative, within which Holloway was selected to lead a modeling effort addressed to Arctic ice/ocean/atmosphere climate interaction. Initial funding for Holloway's part is 60k/year (Canadian $) for two years with notional commitment to third and fourth years. This work reinforces our ONR-sponsored research by extending practical exercise as well as further specific model-oriented research in areas of open boundary conditions, ocean-ice interaction, and shelf-basin exchange.

REFERENCES

Beckmann, A. & Doescher, R. 1997 A method for improved representation of dense water spreading over topography in geopotential-coordinate models. *J. Phys. Oceanogr.*, **27**, 581-591.

Fanning, A., 1997 Comments on "Representing topographic stress for large-scale ocean models". *J. Phys. Oceanogr.*, submitted.

Federov, K. N. 1988 Layer thicknesses and effective diffusivities in the diffusive thermocline convection in the ocean, in *Small-Scale Turbulence and Mixing in the Ocean*, J. C. J. Nihoul and B. M. Jamart, eds., pp. 471-479.

Frederiksen, J. 1997, preprint.

Greatbach, R., & Lee, G. 1997 Potential vorticity mixing: a manifestation of Neptune? *J. Mar. Res.*, submitted.

Kazantsev, E., Sommeria, J. & Verron, J. 1997 Subgridscale eddy parameterization by statistical mechanics in a barotropic ocean model. *J. Phys. Oceanogr.*, to appear.

Marinone, S. G. 1997 Effect of topographic stress on the tidal and wind induced residual currents in the Gulf of California, *J. Geophys. Res.*, submitted.

Schmitt, R. 1981 Form of the temperature-salinity relationship in the Central Water: evidence for double-diffusive mixing. *J. Phys. Oceanogr.*, **11**, 1015-1026.