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Stratified Flow, Wave Packet Reflection and Topographic Currents

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LONG-TERM GOAL

Our basic aim is to achieve a better understanding of the turbulent flow of the oceans in terms of the laws that govern the behavior of vortices and waves and their interactions.

OBJECTIVES

In our internal-wave project, we are using numerical simulations to study the dynamical evolution of flow in the oceanic buoyancy spectral range (roughly from 1 m to 10 m in vertical scales). Full three-dimensional simulations of structures in that range could help us understand better the observations of oceanic fine structure. Further, we are seeking an understanding of the evolution of internal wave packets. The observations of Alford and Pinkel (2000) show that overturning in the thermocline is often associated with the passage of an internal wave packet. Typical overturns have a vertical scale of about 2 m while the internal vertical wavelength within the packet is order 10 m. The vertical dimension of the observed packets is on the order of 50 m, and they propagate vertically over distances on the order of 200 m. We hope to model numerically and theoretically the evolution of such packets and their interaction with the ambient field. We also plan to study in detail the process of reflection of a packet, as opposed to a continuous beam, from a topographic slope.

In our project on coastal interactions, the questions that we are trying to answer have to do with how the presence of a coast affects the basic processes involved in the evolution of vortices and currents. We wish to understand the role that bottom topography plays in permitting or inhibiting the bifurcations of coastal currents.

APPROACH

These investigations involve analytical and numerical studies. In our internal-wave investigations, we are performing simulations with both spectral and finite-difference three-dimensional simulation codes with subgrid scale models. The flow is either forced by a standing internal wave field or unforced with wave-packet initial conditions. The range of scales in these problems is so large that we need to resort to subgrid parameterizations to render the computations feasible.

In our coastal current investigations, we are comparing the results from barotropic quasi-geostrophic model simulations for specific processes with results from a 41 layer model of flow in the Adriatic. To answer basic questions about the relative importance of fluctuations in wind forcing and topographic effects, we are embarking on a series of simulations in which not only the winds, but also the topography will be modified.

WORK COMPLETED

For our stratified flow work, we have completed preliminary studies on both the continually forced flow at the 20 m vertical scale and the propagation of a wavepacket of the type described above. This work is detailed in three articles: Carnevale and Briscolini (1999), Carnevale, Briscolini and Orlandi (2000) and Carnevale and Orlandi (2000). For our flow over topography studies, we have used the DieCast model to simulate the flow in the Adriatic. With this model, we have begun a series of comparison runs with different winds to achieve the topographic flows that we wish to study. Also, in connection with our earlier quasi-geostrophic models, a question arose about the validity of various boundary conditions, and we have investigated this further in the context of oceanic circulation. This study is reported in Carnevale, Cavallini and Crisciani (2000).

RESULTS

In our numerical simulations of stratified turbulence, we forced the flow by causing the internal modes with a vertical wavelength of 20 m to evolve as if they were purely linear internal waves. This generated a cascade of energy to small scales that filled out the kinetic and potential energy spectra. Using this method, we were able to produce spectra in which there is a transition between the buoyancy range and the inertial range. We found overturning of the flow on vertical scales on the order of 2 m. We found two kinds of overturning and mixing events with this forcing. One kind results from the curling over of an isopycnal, while the other occurs in regions of high strain rate. In the latter type of event, vertical tongues of fluid are pulled from an isopycnal in a dilational phase of the vertical strain and then these are spread out horizontally in the compressional phase. This is shown in detail in figure 1.

We examined the propagation of a packet with some of the characteristics of the packets observed by Alford and Pinkel. We found that such a packet obeying the linear laws of internal-wave evolution would approximately double in extent while traveling 200 m vertically through the thermocline due to linear wave dispersion. Then, assigning a finite amplitude to the packet, we were able to observe breaking on the crests within the packet, much as described in the model put forth by Thorpe (1999). This is shown in figure 2.

IMPACT/APPLICATION

It is often rather difficult to reconstruct the flow structures in a given volume of ocean from available observational data. Various explanations may be offered to explain a particular overturning event seen in a density profile. By simulating flows that produce similar structures in a three dimensional data set, we hope to be able to decide on the validity of various hypotheses that may be used to explain the occurrence of such structures. We have found strong mixing events in regions of high strain and steep isopycnal slope, and these may be related to the overturning events observed by Alford and Pinkel (2000). We shall study how these events can be triggered by the passage of a strong wavepacket as suggested by Alford and Pinkel.

Our results on coastal current bifurcations may be useful in analyzing the flow in a variety of places where strong topographic variations occur in the along-shore direction. In particular, the flow along the steep side of the Jabuka pit in the Adriatic seems to be a good example of the flow we can predict analytically based on a simple quasi-geostrophic model. We have compared the trajectories of drifter tracks (Poullain, 1997) and found that many line up with the steep gradient of the northwestern edge of the pit indicating a current, very much as our results predicted.

RELATED PROJECTS

In addition to our work discussed above, we completed a study on the effect of thermal perturbation on trailing vortices behind aircraft (Orlandi, Carnevale, Lele and Shariff, 2000). We are also collaborating with R. Kloosterziel (U. Hawaii) on the stability of vortices in stratified flow and on internal wave packet propagation.

REFERENCES

Alford, M.H. and Pinkel, R. 2000. Observations of overturning in the thermocline: The context of ocean mixing. J. Physical Oceanography. 30, 805-832.

Poulain, P-M. 1999. Drifter observation of surface circulation in the Adriatic Sea between December 1994 and March 1996. Journal of Marine Systems. 20, 231-253.

Thorpe, S.A. 1999. On internal wave groups. J. Phys. Ocean. 29, 1085-1095.

PUBLICATIONS

Carnevale G.F. and Briscolini, M., 1999, Large Eddy Simulation of Oceanic Fine Structure, `Aha Huliko`a, Internal Wave Modeling, Proceedings, Hawaiian Winter Workshop, University of Hawaii, January 19-22, 1999 eds. P. Muller and D. Henderson.

Orlandi, P. and Carnevale, G.F. 1999 Large Eddy Simulation of Stratified Flows Proceedings of the ERCOFTAC meeting on 'Direct and Large-Eddy Simulation', Cambridge, UK May 1999.

Carnevale, G. and Orlandi, P. 2000, Propagation of internal wave packets in the thermocline, Proceedings of the 2000 Summer Program, Center for Turbulence Research, Stanford University. (in press)

Carnevale G.F., Briscolini, M. and Orlandi, P. 2000, Buoyancy to inertial range transition in forced stratified turbulence, J. Fluid Mechanics. (in press)

Orlandi, P., Carnevale, G.F., Lele, S.K., and Shariff, K. 2000, Thermal perturbation of trailing vortices, European Journal of Mechanics B/Fluids (accepted)

Carnevale G.F., Cavallini, F. and Crisciani, F. 2000, Dynamic Boundary Conditions Revisited. J. Physical Oceanography. (accepted)

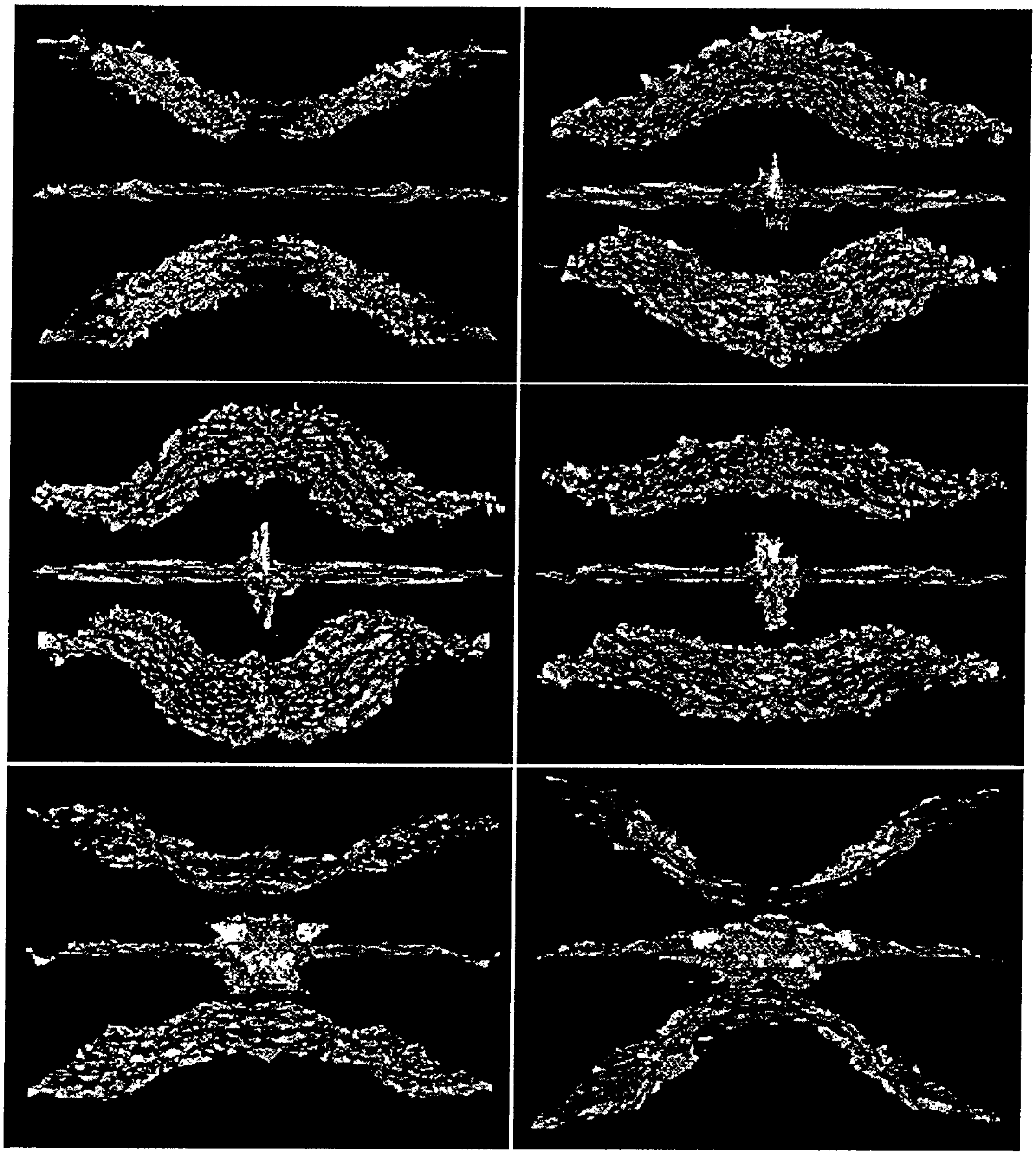

Figure 1. Mixing in a region of high strain rate forced by a large-scale (20 m) standing internal wave. Each panel shows three density isosurfaces. The middle isosurface corresponds to the nodal plane of the standing wave. The isosurfaces above and below it are those that are most strongly perturbed by the standing wave. The panels are temporally ordered from left to right top to bottom. In the first three panels, in the middle of the domain, the upper and lower isosurfaces are retreating from the nodal plane causing a region of high dilational vertical strain. This pulls tongues or spouts of heavy fluid into lighter fluid and vice versa. These spouts are then pushed back toward the nodal plane in the compressional phase, but this motion results in horizontal spreading and significant mixing in this region as seen in the last panel. The full computational domain is a cube, 20 m on a side, and only a portion of the vertical extent is shown in these images. The Brunt-Vaisala frequency is N=3 cph, and the period of the standing wave is about 0.5 hr.

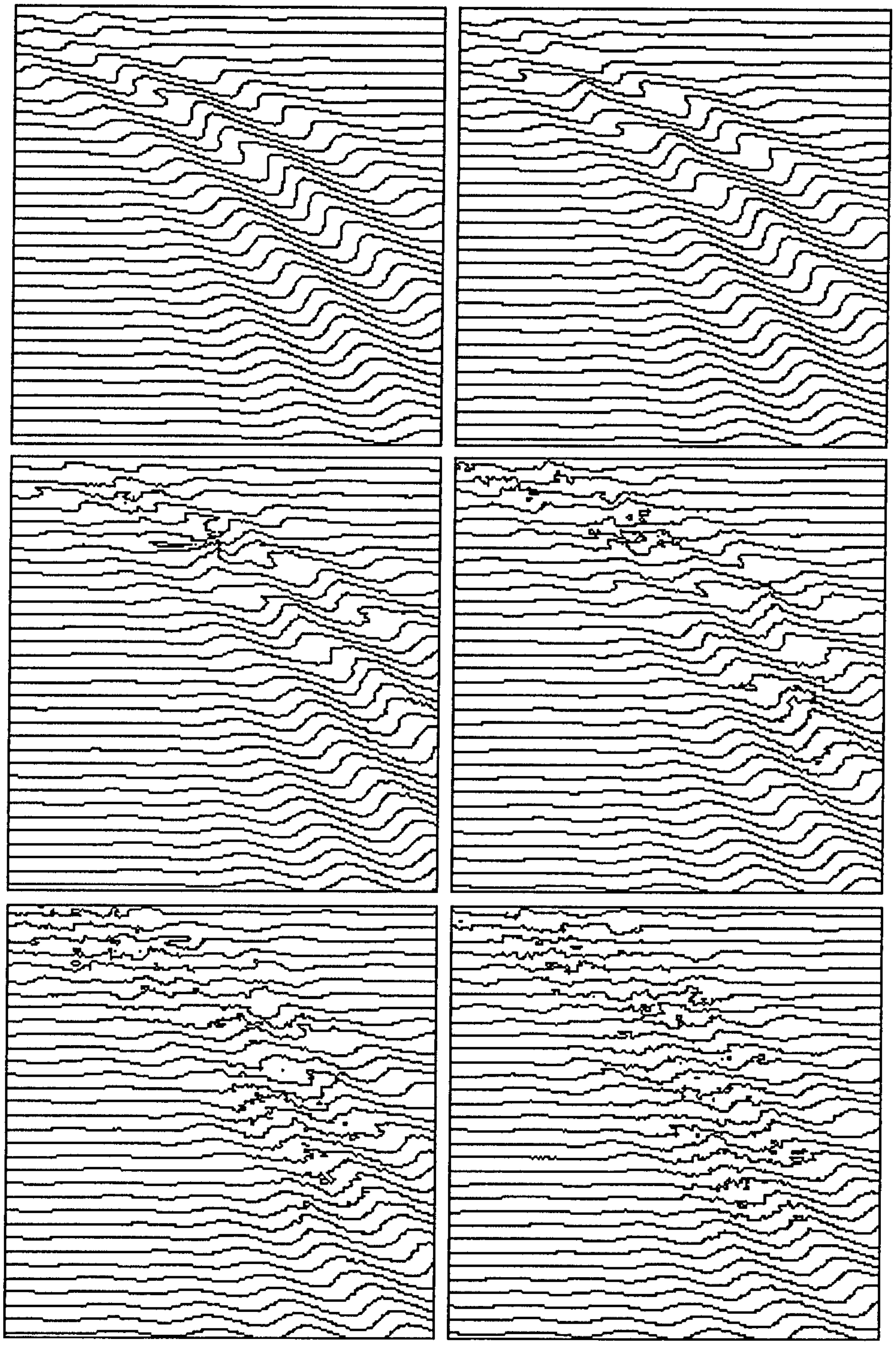

Figure 2. Density contour plots of wave breaking within a propagating wavepacket similar to the packets observed by Alford and Pinkel (2000). The panels are centered on the packet and are in sequence from left to right, top to bottom. Phase propagates from lower left to upper right in the packet. The weak side crest on the lower left in the first panel propagates through the packet becoming the weak crest on the upper right side of the packet in the final panel. The crests breaking in the packet create overlapping scars of turbulence, much as predicted by Thorpe (2000). The computational domain is a square 200 m on a side. The panels are subsections 67 m on a side.