

Stratified Flow over Rough, Sloping Topography

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LONG-TERM GOALS

To understand the physics of flows generated by currents passing over small topographic features and to quantify, and parameterize if possible, the mixing these flows produce.

OBJECTIVES

To synthesize emerging measurements and numerical simulations of flow and mixing over rough topography to assess their global importance.

To understand the physics of exchange of momentum and passive tracers between boundary layers over continental slopes and the ocean's interior.

To use laboratory and numerical results to design experiments to illuminate crucial aspects of flow and mixing over rough topography.

APPROACH

To understand better how internal waves break, Gregg and his SECNAV/CNO postdoc, Dr. Matthew Alford, are analyzing data Gregg took in the Banda Sea.

To obtain a quantitative understanding of bottom boundary layers in stratified regimes, Gregg is planning a field program with the US Geological Survey (J. Bureau of the Sacramento office) and Stanford (S. Monismith).

MacCready and his SECNAV/CNO postdoc, Dr. Geno Pawlak, use the Hallberg Isopycnic Model to simulate stratified tidal flow along slopes with varying roughness

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(see figure below). This model is excellent for studying the physics of flow which has negligible diapycnal mixing. It is limited however, in the range of scales it may span, and is hydrostatic. Both of these limitations are overcome in related laboratory experiments being conducted by Dr. Pawlak.

MacCready collaborates with Drs. Chris Garrett and Richard Dewey at the University of Victoria on field work in the Strait of Juan de Fuca. They use arrays of ADCP (Acoustic Doppler Current Profiler) and T-Chain moorings to study internal wave and horizontal eddy generation on the slopes of this stratified, strongly tidal channel.

WORK COMPLETED

The numerical model was modified to include tidal forcing and Lagrangian floats. Several dozen numerical experiments have been completed. A new parallel computer which will be online this month will speed the computations significantly.

Dr. Pawlak has completed many lab experiments, and analyzed the DPIV (Digital Particle Image Velocimetry) data.

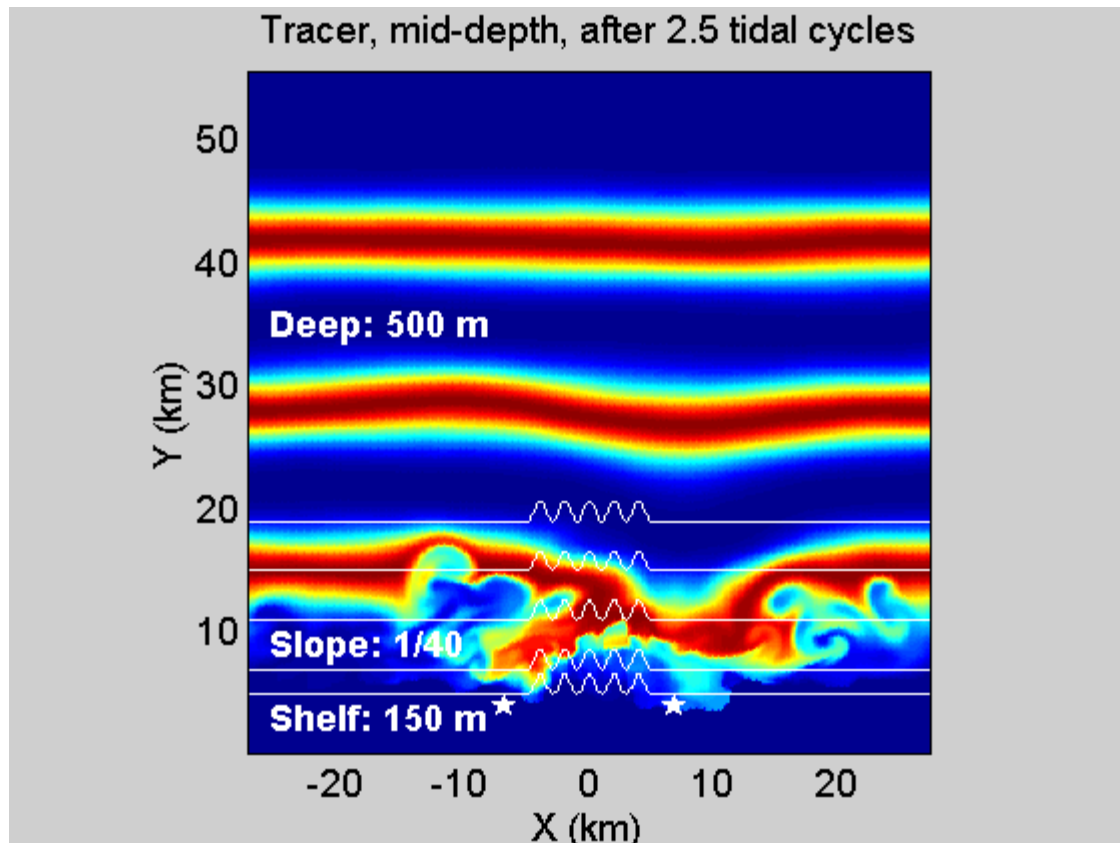
Instruments were deployed and recovered successfully in the Strait of Juan de Fuca for 4 weeks (Summer 1998) and 7 weeks (Summer 1999). The 1998 data are partially analyzed for eddy, boundary layer, and wave signals. The data analysis tools we develop will apply directly to the 1999 data. The data analysis is being undertaken by graduate students: Tiangang Yu (who left the program after a year) and currently Wayne Martin.

RESULTS

Gregg prepared and submitted a summary of his recent mixing work over shelves and slopes.

Gregg and his group completed preparations and packed for a field program in the Suisun Cutoff, between the Sacramento Delta and San Francisco Bay. With USGS and Stanford, in October 1999 they will attempt to evaluate all terms of the turbulent kinetic energy budget in a stratified tidal channel.

MacCready and Pawlak focused initially on non-rotating, stratified tidal flow along a slope with some localized topographic irregularity. Figure 1 shows the tracer field at mid-depth in a numerical simulation. They forced a barotropic semidiurnal tide (1 m/s) along the re-entrant channel. Five small ridges on the slope are the 'roughness'. These ridges have horizontal wavelength of 2 km, and the whole roughness patch is 10 km long in the alongslope direction, shorter than the tidal excursion (14 km).



1. *Tracer fields from day 1.24 of a numerical experiment. Tidal flow is forced along a reentrant channel with a slope and five small ridges on the south side. The fluid is stratified, has 5 layers, and results are shown from mid-depth. The tidal excursion (stars) has a strong effect on both the strength and direction of tracer exchange between the boundary layer and the interior. The field is shown at slack water after a tidal flow to the right.*

The Froude number of the flow allows for the formation of internal waves during most of the tidal cycle, although an interesting feature of such waves on a slope is that there is both a high speed and a low speed cutoff for wave generation. Faster flow tends to go over the bumps while slower flow goes around. The ability of the fluid to 'choose' from these options makes the slope case fundamentally different from the case of coastal headland eddies which must always go around the feature. Separation of the frictional boundary layer into the interior is apparent in the advection of the tracer field, which is responding to persistent vorticity features. This advected vorticity is another aspect of slope flows which is different from that of shallow coastal seas. In the coastal case frictional damping is strong, and vorticity rarely escapes far from the generation source. One well known result of this is the characteristic tendency of residual flows near headlands to eject boundary fluid away from the coast. However in figure 1 exactly the opposite tendency is present in the residual (and Lagrangian) flow: interior flow is pulled toward the roughness region and pushed to the sides.

In many numerical and laboratory experiments performed so far the same pattern emerges: for flow with tidal excursion longer than the roughness patch length the residual horizontal circulation pulls interior fluid toward the rough region. The opposite pattern is seen when the tidal excursion is small compared with the patch length. Our analysis indicates that this pattern is the result of the interaction and self advection of vortices from the edges of the roughness patch.

IMPACT/APPLICATION

The mechanism described above by MacCready could be an important way in which interior fluid is persistently pulled into regions of strong mixing.

TRANSITIONS

In January 1999, Gregg participated in the invitation-only Hawaii Winter Workshop about the dynamics of internal waves. He summarized some of the results from the related projects below.

Kurt Polzin (WHOI) and MacCready are convening a special session on Flow Over Rough Topography at the American Geophysical Union Ocean Sciences meeting in San Antonio, January 2000. Three of the presentations in that session relate to this work.

Gregg is on the organizing committee for the Fifth International Symposium on Stratified Flows, to be held in Vancouver, B.C. in July 2000. Many of the sessions will deal with flows over rough topography.

Gregg visited NRL-Stennis and NAVO in May 1999 to give a seminar about recent results and to meet with the NAVO commanding officer and technical staff to propose setting up an academic advisory group for NAVO. He also proposed to NRL a collaborative project measuring flow and mixing over rough continental slopes.

RELATED PROJECTS

1 - While Leslie Rosenfeld (NPGS) and Eric Kunze (APL/UW) observed currents and internal waves in the Monterey submarine canyon during 1997, Gregg measured shear and mixing. These data are being analyzed to determine whether canyons are major factors in global mixing budgets and to relate the rates and patterns of mixing to the mechanisms producing them. MacCready hopes to compare the canyon measurements with his simulations of vorticity-carrying horizontal eddies over similar scales.

2 - As an adjunct to the NSF-funded work in Monterey Canyon, Gregg spent several days as part of the ONR-funded Littoral Internal Waves Initiative (LIWI) measuring shear and mixing on the continental slope north of the canyon. Following up on this work has become a major focus of Gregg's efforts.

3 - In 1994 Gregg worked with Turkish oceanographers to observe the exchange flow in the Bosphorus and the density current exiting the Bosphorus to flow across the narrow continental shelf and down the slope. Two papers were published this year and a third is nearly ready for submission. This work provides an invaluable reference for studying the effects of rough topography owing to the absence of significant tides in the Black Sea.

4 - In 2000 Gregg will participate with many other investigators in the NSF-funded Hawaii Ocean Mixing Experiment (HOME). He will concentrate on discovering areas close to the islands and banks where barotropic tidal energy is converted to internal tides and turbulence.

5 - LuAnne Thompson and Barbara Hickey (UW) are doing numerical modeling of the California Current. This involves stratified, rotating flow along irregular slopes, concentrating on scales somewhat larger than the ones MacCready is studying.

6 - In 1995 Gregg participated with other investigators in an ONR-funded of the flow over the sill in Knight Inlet, B.C. His student, Jody Klymak, is now submitting papers and giving talks documenting the three-dimensional nature of this flow. Previously, there were hints of three-dimensionality but data were taken as simple sections across the major topographic feature and interpreted without serious consideration of three-dimensionality. As these results have become known, other investigators are planning their measurements to include the possibility that flows are three-dimensional.

PUBLICATIONS

Alford, M.H. and M.C. Gregg, Diapycnal mixing in the Banda Sea: Results of the first microstructure measurements in the Indonesian Throughflow, *Geophys. Res. Ltrs.*, 26, 2741-2744, 1999.

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