

CRITICAL-LAYER ABSORPTION IN STRATIFIED FLOWS

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LONG-TERM GOALS

The long-term goal of this research program is to study the fundamental mechanisms responsible for the formation and maintenance of oceanic microstructure and to develop parameterizations for the transport of heat, salt and momentum through oceanic layers that are rich in microstructure.

SCIENTIFIC OBJECTIVES

The objective of this research program is to investigate the interaction of stratified shear layers with internal waves forced by ambient sources (such as bathymetry, turbulence and wind forcing) through various mechanisms, for example, the critical-layer absorption and degeneration due to enhanced local shear.

APPROACH

The approach is mainly laboratory experimental, wherein internal waves are mechanically forced by using an oscillating flap or a corrugated topography. The waves are allowed to interact with the shear flow and break due to critical-layer absorption or another instability mechanism, thus dissipating energy and producing a turbulent patch. Two types of water channels are employed for the study, namely, either an Odell-Kavasznay type recirculating water channel or a counter-flow type stratified water tunnel. In the former case, the stratified shear flow is driven over the topography by a disk pump whereas in the latter the internal waves are generated in the stratified shear layer by the oscillating flap. Laser-induced fluorescence, laser-Doppler velocimetry, hot-film anemometry, Particle-image velocimetry and vertically traversing (shooting) conductivity probes are used for flow diagnostics. The measurements include the buoyancy flux, dissipation of turbulent kinetic energy, local and bulk gradient Richardson numbers and the production of turbulent kinetic energy in the shear layer.

WORK COMPLETED

The design, construction and testing of the counter-flow stratified shear flow tunnel were completed as a part of the M.S. thesis work of Mr. David Corder. In addition, he carried out an investigation on the possible enhancement of turbulent intensity within a turbulent patch in a stratified shear flow due to the interaction of patch Reynolds stresses with background mean shear. This study was performed by generating an artificial turbulent patch in the shear layer and monitoring its evolution under different external parameters. Experiments on the propagation of forced internal waves in the shear layer are now being conducted by Ms. Heather Norton who is a

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first year graduate student in environmental fluid dynamics.

RESULTS

The experiments carried out using the counter-flow water tunnel, with fluid layers of different densities flowing in opposite directions while maintaining a zero mean velocity at the density interface, showed interesting trends of shear-layer evolution depending on the governing parameters. It was found that the main governing parameter for the problem is either the bulk gradient Richardson number $Ri_g = (b/\sigma)/(U/\sigma_v)^2$ or the bulk Richardson number $Ri_B = b/\sigma_v(U)^2$, where b and U are the jumps of buoyancy and velocity across the shear layer and σ_v and σ are the thicknesses of the velocity and salinity interfaces, respectively. A quasi-steady state was found to establish in the stratified shear layer, with the velocity interfacial thicknesses given by $\sigma_v/H = 0.17$ for $Ri_g > 1.45$ and $\sigma_v/H = Ri_g - 0.73$ for $Ri_g < 0.45$, where H is the depth of the water layer. Typically, the salinity interface was thinner than the velocity interface, with a thickness of $\sigma/H = 0.083$ for $Ri_g < 1$ and $\sigma/H = 0.07$ for $Ri_g > 1$. When a turbulent patch is artificially introduced into the stratified shear layer, both the velocity and salinity interfacial layers grow under certain conditions indicating enhanced vertical transports of buoyancy and momentum. The thickness of the salinity interfacial layer with and without background shear was evaluated for different overall interfacial stabilities with forcing on the patch remaining the same. The patch was found to expand beyond its non-sheared counterpart when the bulk Richardson number Ri_B falls below about 0.5 (equivalent to a gradient Richardson number of about 1.4); see Figure 1.

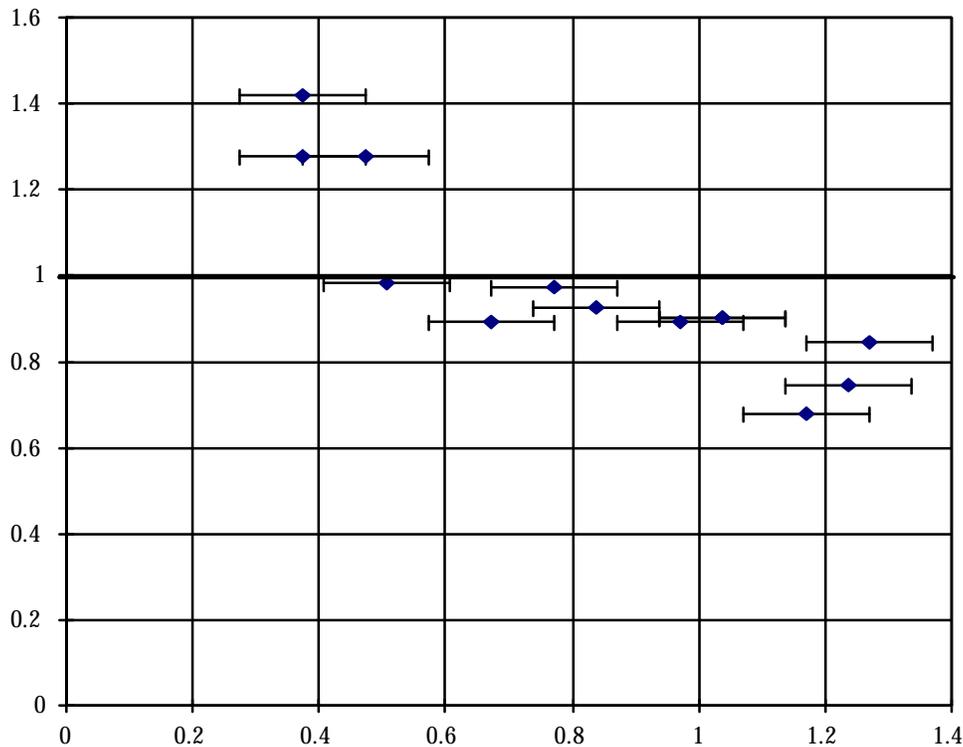


Figure 1: The ratio of the sheared to unsheared salinity interfacial thickness (ordinate) in the presence of a forced turbulent patch as a function of the bulk Richardson number (abscissa). The salinity interfacial thickness is an indicator of the turbulent patch thickness.

IMPACT/APPLICATIONS

Although a few laboratory experiments have been reported on turbulent patches in stratified shear flows (Hughes 1994), to our knowledge this is the first laboratory experiment directly dealing with the energy exchange between the mean flow and patch turbulence. As such, it will be of immense utility in interpreting and modeling of the evolution of oceanic microstructure patches under various hydrodynamic conditions.

TRANSITIONS

The question of how and when oceanic microstructure patches absorb energy from the mean shear has been posed in many microstructure investigations (Dillon 1983; Crawford 1986), yet it remains to be one of the outstanding questions in microstructure research. Lacking of a reliable basis to account for the shear/microstructure interactions, most previous microstructure evolution theories have failed to explicitly account for the background shear (e.g. fossil turbulence theory of Gibson (1980)). The fundamental understanding gained by the present work will be a useful tool in developing a refined microstructure classification scheme based on velocity shear, among other parameters, and hence the present work is expected to have a significant impact on oceanic microstructure interpretations.

RELATED PROJECTS

The P.I. is involved in a project funded by the Army Research Office dealing with the dynamics of K-H billows in stratified shear layers. The critical-layer absorption experiments in progress are also expected to yield K-H billowing, and hence the two projects can cross-fertilize with each other.

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