EUROMECH Colloquium 567: Turbulent mixing in stratified flows
22-25 March 2015, DAMTP, Centre for Mathematical Sciences, Cambridge, UK

Two-dimensional measurements of turbulence and mixing driven by internal waves impinging on a slope

C. R. Rehmann[1]*, Z. Li[1], Z. Wang[2], R. Waldman[2], H. Hu[2]

[1]Dept. of Civil, Construction, and Environmental Engineering., Iowa State University, Ames, IA, USA
[2]Dept. of Aerospace Engineering, Iowa State University, Ames, IA, USA

Introduction

Fluxes in stratified water bodies such as lakes and oceans are often controlled by turbulence and mixing at sloping boundaries. One mechanism of boundary mixing is the reflection of internal waves from slopes; when the angle α that the internal wave ray makes with the horizontal is equal to the slope angle β—that is, when the ratio $\gamma = \sin\alpha/\sin\beta = 1$, critical reflection occurs. Critical reflection is thought to increase vertical mixing in lakes and contribute to the shaping of continental shelves in the ocean. We conducted experiments to measure in detail the turbulence generated by near-critical internal waves impinging on a slope.

Methods

Experiments were conducted in a 3 m x 0.5 m x 0.6 m tank with a boundary sloping at $\beta = 15^o$. The double-bucket method was used to establish a linear salt stratification, and waves were generated with a wavemaker that followed the design of Gostiaux et al. [1]. Particle image velocimetry was used to measure velocities; image pairs were acquired for 200 wave cycles for 12 phases per wave cycle. The rate ε of dissipation of turbulent kinetic energy was computed by using the four measured velocity gradients and assuming axisymmetry about the vertical direction. The image size and processing were sufficient to compute gradients over a distance of less than $3L_K$, where L_K is the Kolmogorov length scale. This resolution is sufficient to resolve the dissipation [2].

Results and discussion

The dissipation was largest near the slope. (Fig. 1). For the case of $\gamma = 1$, the dissipation reached $O(10^{-7})$ to $O(10^{-6})$ m^2/s^3 in the bottom 2 cm and dropped about two orders of magnitude to background levels in the interior. The dissipation was not uniform along the slope, however; instead, packets of high dissipation 2-4 cm long appeared to propagate up the slope. The packets corresponded to patches of high turbulent kinetic energy (TKE). These results are similar to observations from field experiments and direct numerical simulations. Measurements of Lorke [3] with an acoustic Doppler current profiler in a lake showed a similar sharp decrease in dissipation away from the slope, and simulations of Chalamalla et al. [4] showed that patches of high dissipation were associated with high TKE and overturns in the density field.

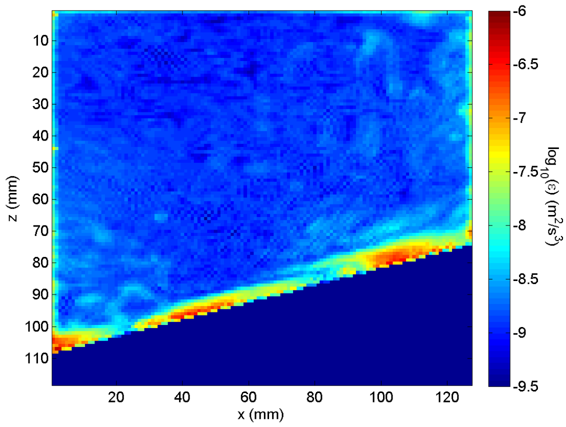

Fig. 1. Dissipation (log scale) for $\gamma = 1$.

Although the dissipation was largest near the slope, values of $\varepsilon/\nu N^2$, where ν is the kinematic viscosity and N is the buoyancy frequency, did not exceed $O(1)$. Similar values were observed in the laboratory experiments of Ivey et al. [5] and the simulations of Chalamalla et al. [4]. Although many field studies report much higher $\varepsilon/\nu N^2$, $\varepsilon/\nu N^2 \sim 1$ is measured in the metalimnion of lakes [6]. Such low values of $\varepsilon/\nu N^2$ are usually thought to indicate an absence of downgradient flux by turbulence, but Ivey et al. [5] argued the eddy diffusivity can exceed the molecular diffusivity even when $\varepsilon/\nu N^2 \sim 1$.

References

[1] Gostiaux L, Didelle H, Mercier S, & Dauxois T. *Exp. Fluids* **42**:123-130, 2007.
[2] Saarenrinne P & Piirto M. *Exp. Fluids* **29**:S300-S307, 2000.
[3] Lorke A. *J. Geophys. Res.* **112**, doi:10.1029/2006JC004008, 2007.
[4] Chalamalla VK, Gayen B, Scotti A, & Sarkar S. *J. Fluid Mech.* **729**:47-68, 2013.
[5] Ivey GN, Winters KB, & De Silva IPA. *J. Fluid Mech.* **418**:59-76, 2000.
[6] Saggio A & Imberger J. *Limnol. Oceanogr.* **46**:392-409, 2001.

*corresponding author: rehmann@iastate.edu