Experimental Investigations of Nonlinear Internal Wave Generation and Evolution

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LONG-TERM GOALS

The long-term goal of this project is to develop and utilize an advanced experimental facility for the investigation of nonlinear internal waves. The work will both support and inspire theoretical, numerical and sea-going investigations of the Luzon Strait, and other important internal wave sites.

OBJECTIVES

The scientific objective of this project is to elucidate the fundamental mechanisms that underlie nonlinear internal wave generation and evolution in the Luzon Strait. Potential mechanisms include: nonlinear steepening of the internal tide, lee-wave generation and the interaction of internal wave beams with the pycnocline.

APPROACH

We are using state-of-the-art laboratory experimental technology to investigate experimental internal wave fields in a controlled laboratory environment. Our laboratory is at the forefront of developing the novel Synthetic Schlieren technique, which is capable of making high-resolution, non-intrusive density gradient measurements in stratified flows. In addition, this award has supported: the construction of a large wave-tank facility with sophisticated motion control for simulating nonlinear tidal forcing; the development of a nonlinear stratification system; and the purchase of a high-resolution Particle-Image-Velocimetry (PIV) system, which measures velocity fields, to complement the Synthetic Schlieren system. In parallel with the experimental studies we have developed theoretical models to account for supercritical topography. We have also begun a collaborative effort with the McWilliams group at UCLA, the goal of which is to use the laboratory experimental data to benchmark ROMS models.

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WORK COMPLETED

Since 09/05, the focus has been on the construction of the large wave-tank facility in the lab of the PI, which is now complete. The facility contains a sophisticated, computer-controlled filling mechanism to determine the pumping and mixing rates required to establish a desired nonlinear stratification. During this time, we have also: developed theoretical models of internal tide generation by supercritical topography; performed preliminary investigations of the interaction of internal wave beams with the pycnocline, in anticipation of further experiments in large wave-tank facility; and begun our first comparison with the McWilliams ROMS numerical model. A spin-off from these experiments is the development of axisymmetric Synthetic Schlieren capabilities for the PI's lab (Yick, Stocker and Peacock, 2006), with a view to future studies of 3D topography.

Experimental results of the internal wave studies were presented at the APS DFD Meeting (Nov 05), Ocean Sciences Meeting (Feb 06), UBC Applied Math Seminar (Mar 06) and WHOI AOPE Seminar (April 06). Future presentations are planned for ISSF (Dec 06) and Stanford University (Feb 07).

RESULTS

(i) New Wave-Tank Facility

The new wave-tank facility has been completed after extensive work over Summer 06. The glass wave-tank is 5.5 meters long, 0.5 meters wide and 0.6 meters deep, and sits in an 8020 aluminum frame, with custom-designed load-bearing supports. Beneath the tank is the computer-controlled filling mechanism, which uses the latest peristaltic pumps to accurately reproduce the desired filling rates for generating nonlinear stratifications. A rear-mounting at the back of the tank holds the electroluminescent sheet lighting for the Synthetic Schlieren system, and optical access for the PIV system is from either below or above the central section of the tank. This facility will greatly enhance our ability to carry out oceanographically-relevant experimental studies of nonlinear internal wave phenomena relevant to Luzon, and our target is to obtain preliminary experimental results using this new system for the planning meeting in Taiwan (11/06).

(ii) Tidal Conversion by Supercritical Topography

Recent theoretical developments (Petrelis, Lewellyn Smith & Young 2005) have enabled theoretical prediction of internal wave fields generated by supercritical topographic features. We have advanced this approach to consider two important canonical cases: a Gaussian bump and sinusoidal topography. The approach uses a suitably arranged array of sources along the topography, in which case the resulting wave field can be concisely described using a Green's function. The case of an internal wave field generated by a Gaussian bump is shown in Figure 1. Figure 1(a) shows the perturbation the buoyancy perturbation of the up-going wavefield, and Figure 1(b) is a close-up around the Gaussian bump, showing both the up-going and down-going wave beams. Further investigations using this model, and comparison with experiment, will provide insight into the onset of nonlinear behaviour near supercritical topographic features in the Luzon Strait. The case of supercritical sinusoidal topography is also shown, in Figure 2, which also presents some images of the buoyancy field for different criticality parameters. We find that maximum conversion occurs for weakly supercritical topography and does not decrease montonically thereafter, but goes through a series of local maxima.

This appraoch allows us to investigate the downward propagation of internal wave beams into canyons, such as that between the East and West ridges in Luzon.

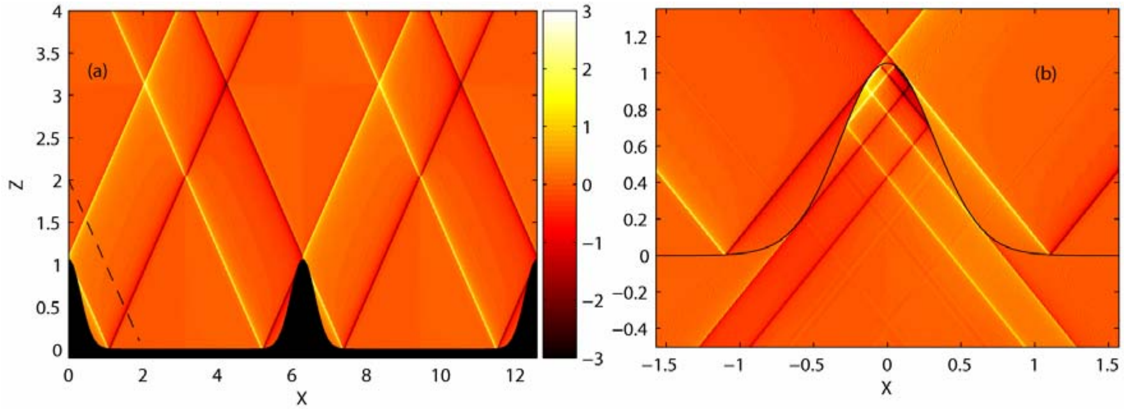


Figure 1: (a) The buoyancy-field generated by periodic tidal flow past Gaussian topography. (b) A close up of the wavefield in the vicinity of the Gaussian. Note that the theory also determines the downward propagating wave beams associate with the supercritical topography.

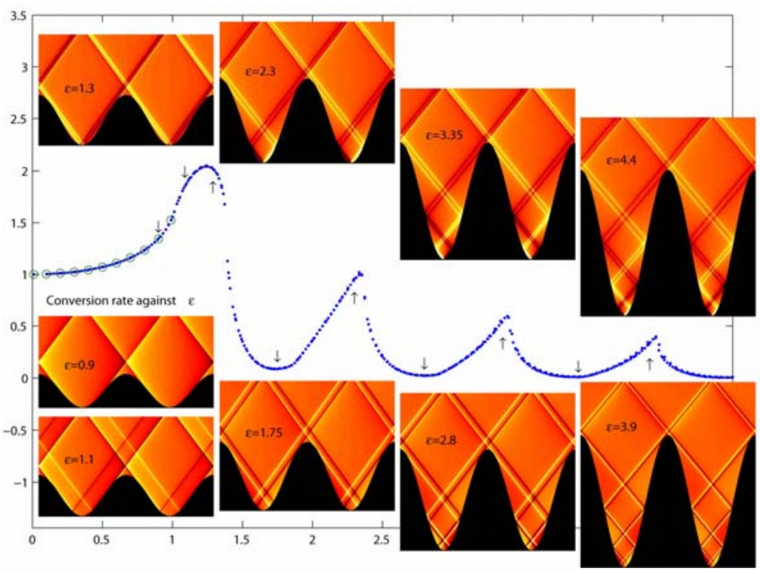


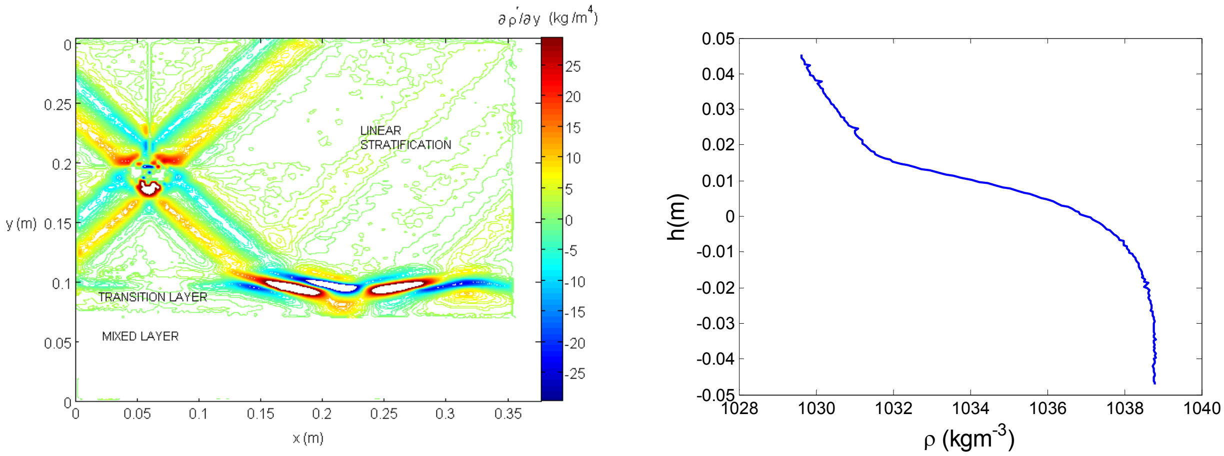
Figure 2: Tidal conversion rate for sinusoidal topography as a function of the criticality parameter, with snapshots of the wave field.

(iii) Interaction of a Wavebeam with the Pycnocline

The interaction of a wavebeam with the pycnocline has been previously identified as a possible mechanism for the generation of solitary waves (Gerkema 2001), and may be relevant to the region of Luzon. Much remains to be understood about this mechanism, however. As an example, recent observations off Hawaii by Rudnick and Pinkel (personal communication, 2006) report the apparent disappearance of an M2 tidal beam as the location it strikes the pycnocline. In preliminary laboratory experiments we have simulated this situation, and a data set is presented in Figure 3. As shown in

Figure 3(a), four wave beams were generated by oscillating a cylinder in a region of linear stratification. One wavebeam was allowed to impinge on a relatively strong pycnocline, below which was a mixed layer. The denisty profile in the region of the interaction site is shown in Figure 3(b). The internal wave beam appears trapped in the pycnocline, which acts as a waveguide.

On the basis of this preliminary study we are developing a model of the interaction processes and plan further experiments to invesitgate this mechanism in the new wave tank, in the hope to better understand the conditions necessary for wave-beam trapping, and possibly the generation of solitary waves.



(a) (b)

Figure 3. (a) Synthetic Schlieren image of the interaction of a wavebeam with a pycnocline and mixed-layer. Note that the wave beam appears to get trapped in the pycnocline. (a) The density profile in the vicinity of the pycnocline.

IMPACT/APPLICATIONS

The experimental wave-tank and accompanying Synthetic Schlieren and PIV systems will support the development of the next generation of theoretical and numerical models for nonlinear internal wave generation and evolution in the vicinity of Luzon, and elsewhere. Our analytical work on tidal-conversion by supercritical topography has advanced the ability to predict the nature of internal wave fields generated by pertinent, supercritical topographic features. Finally, the experimental work on internal wave beam reflection from a pycnocline has received much interest from field researchers, and we anticipate further synergy between laboratory and ocean experiments on this particular topic.

RELATED PROJECTS

Through the support of the NLIWI program, we have begun a collaborative effort with the McWilliams group at UCLA. The thrust of this long-term effort is to make a series of direct comparisons between experimental investigations and ROMS numerical simulations of nonlinear internal wave generation by pertinent 2D topographic features. To further facilitate these comparisons, we have developed our theoretical models to account for finite depth. An example for a Gaussian of height 0.1 m, standard deviation 6.7 cm in a fluid of depth 0.15 m with uniform stratification N=0.5

rad/s and a forcing frequency of 0.15 rad/s is shown in Figure 4. This arrangement is also being simulated by the McWilliams group and will be the first experiment in the new wave tank.

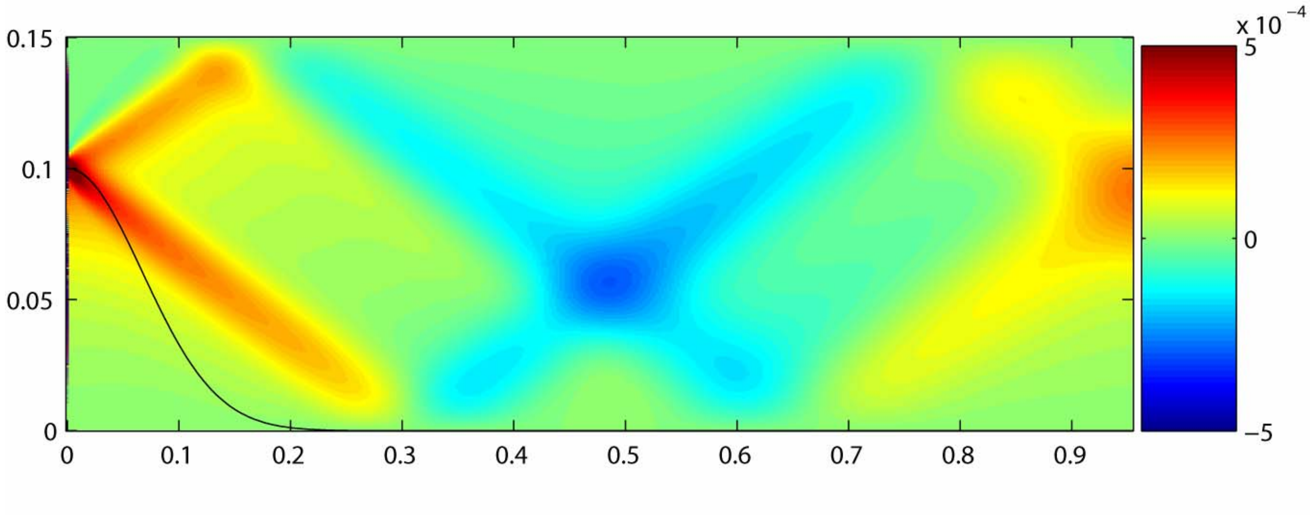


Figure 4: Internal wave field generated by a Gaussian in a uniformly stratified fluid. The depth ratio is 0.66, and the contour levels indicate the buoyancy field.

In addition, through the NLIWI program the PI has established many close connections with numerical and sea-going researchers. The PI and his graduate student recently participated in the NSF funded IWAP study with Matthew Alford, spending 16 days at sea in 06/06. The goal of this study was to investigate the role of the Parametric Subharmonic Instability at the critical latitude. The PI has discussed his experimental results on the interaction of a wavebeam with the pycnocline with Rob Pinkel and Dan Rudnick, and anticipates further interactions with these NLIWI researchers. The PI has also given an invited seminar at WHOI, and will visit Oliver Fringer at Stanford in 02/07 to give an invited seminar. Jim Lynch, David Farmer and Oliver Fringer have accepted invitations to give seminars at MIT in Fall 06.

REFERENCES

Gerkema, Internal and interfacial tides: beam scattering and local generation of solitary waves, J. Mar. Res. 59, 227-255 (2001).

Petrelis, Llewllyn-Smith & Young, Tidal conversion at a submarine ridge, J. Fluid Mech., in press (2006).

PUBLICATIONS

Yick, Stocker, & Peacock, Microscale Synthetic Schlieren, Experiments in Fluids, submitted (accepted).

HONORS/AWARDS/PRIZES

1. Thomas Peacock (MIT), ARCO Career Development Chair, Atlantic Richfield Corporation.

2. Thomas Peacock (MIT), Abkowitz Travel Award, Abkowitz Endowment (to present results of Internal Wave Experiments at International Symposium on Stratified Flows, Perth, Australia, 12/06).