

## **Laboratory Modeling of Internal Wave Generation in Straits**

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### **LONG-TERM GOALS**

The long term research goal of this project is to develop a clear picture of the key processes involved in internal tide generation at the Luzon Strait through the use of laboratory experimentation supported by analytical modeling, and thereby assist the predictive capability for large amplitude solitary waves in the South China Sea.

### **OBJECTIVES**

To design and execute the necessary laboratory experiments in appropriate dynamic regimes. To use this to clearly determine the big picture regarding internal tide generation at the Luzon Strait. To share these results with researchers performing numerical simulations and field studies and support the interpretation of their data sets.

### **APPROACH**

The primary approach is to perform a large scale laboratory experiment at the Coriolis platform in Grenoble, France, in which a realistic model of the topography is used and care is taken so that the key geometrical and dynamical parameters in the experiment are consistent with those of the ocean. The internal wave fields generated in the laboratory are studied using a variety of experimental techniques, in particular Particle Image Velocimetry to obtain velocity field data. The data from these experiments is processed and visualized in a variety of ways in order to explain the observed wave dynamics.

### **WORK COMPLETED**

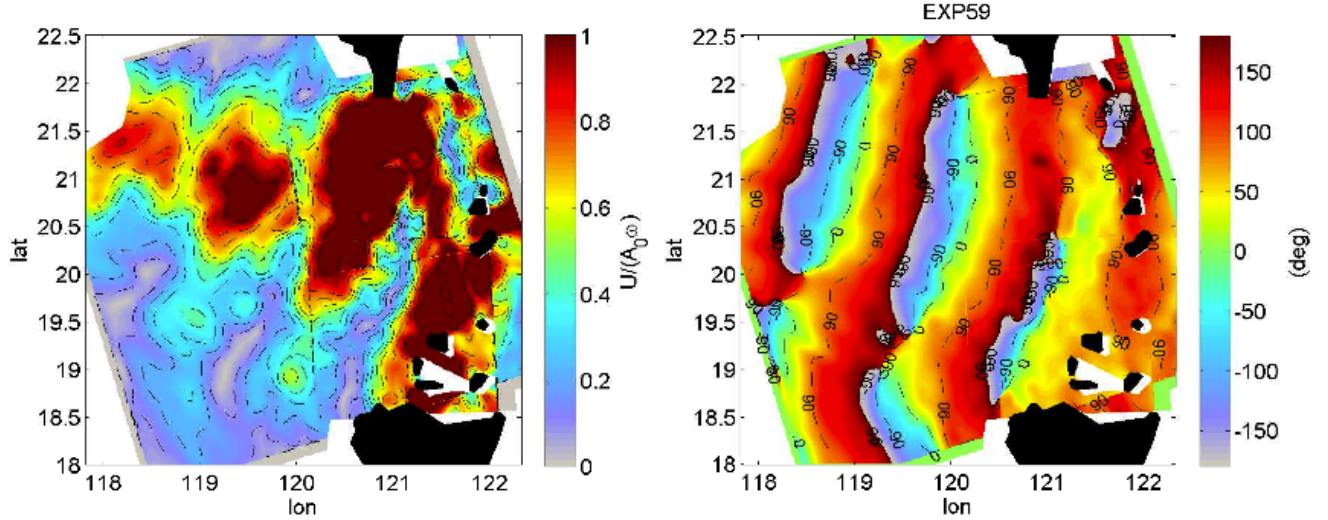
The experiments were performed in Fall 2010, producing a vast amount of data. Experiments were run for a wide range of forcing amplitudes, single and multiple forcing frequencies, and stratifications. Since then, the PIV data sets for these experiments have been processed to obtain velocity field data for all the key experiments, and further processing of this data has been used to generate our results.

### **RESULTS**

We have obtained substantial results from these experiments that have helped clarify the most important aspects of the internal tide generation process at Luzon.

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An example of perhaps the most significant experimental result is presented in figure 1, which shows the amplitude and phase of the scaled M2 internal tide radiated by the Luzon Strait in the experiment (note that the laboratory experimental results have been scaled back up to geophysical lengthscales). There are several key features that are consistent with field observations and the results of numerical simulations. From these experimental results it is clear that the overall shape of the double ridge system in the Luzon Strait results in a coherent phase propagation of the M2 internal tide that is directed slightly northwest, consistent with the preferred orientation of the direction of propagation of internal solitary waves in the South China Sea. The shaping of the M2 internal tide by the topography is a consequence of the fact that the wavelength of the M2 internal tide is on the same scale as the widths and separation of the ridges in the Luzon Strait. In the more northerly region of the Luzon Strait, where the East and West ridges are comparable in scale, the phase results reveal nontrivial phase propagation between the two ridges due to interference between the wave fields created by the East and West ridges. Further to the south, there is a more clear connectivity between the phase of the radiated wave field and the phase across the Luzon Strait, revealing that the dominant generating feature in the southern section is the East ridge (due to the West ridge being significantly shorter).

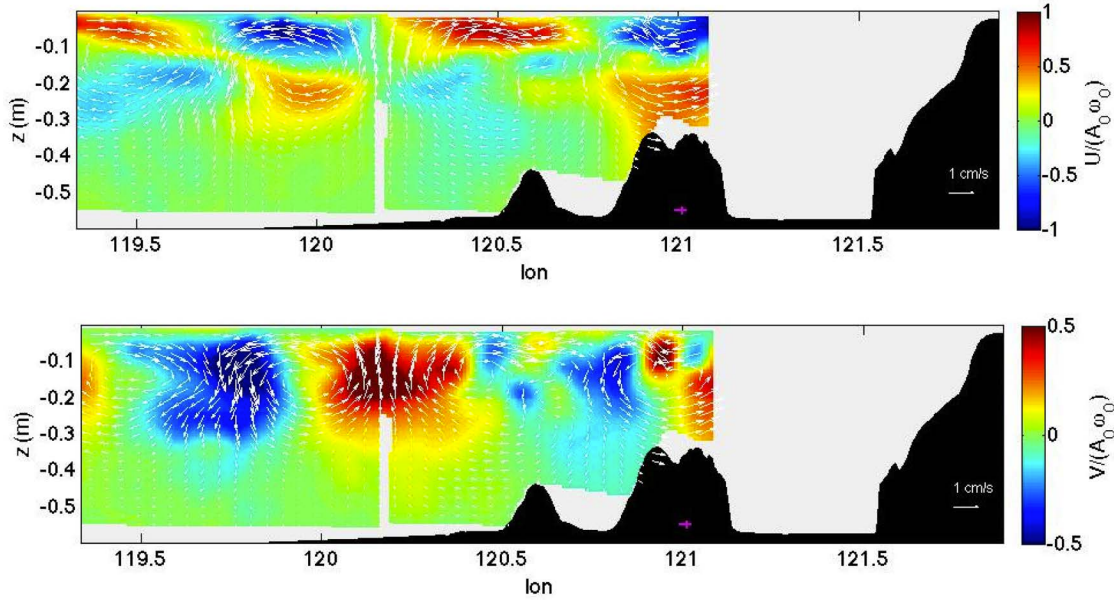


***Figure 1: The magnitude (left) and phase (right) of the scaled M2 internal tide radiated by the model Luzon Strait. The structure of the ridge system results in a radiated M2 internal tide that is oriented in a west-northwest direction, consistent with the observed preferred direction of propagation of large amplitude solitary waves in the South China Sea.***

Vertical transects of the radiated M2 internal tide, oriented along the preferred direction of propagation away from the Luzon Strait, show that the wave field is dominated by mode-1, as presented in figure 2. This strongly supports the understanding that the large amplitude solitary waves in the South China Sea result from nonlinear steepening of a weakly nonlinear, mode-1 dominated internal tide radiated by the Luzon Strait.

Note that while these laboratory experiments can capture the internal tide generation process, due to a rescaling of the vertical compared to the horizontal that was required to make the experiments feasible, it is not possible to also capture the nonlinear steepening process as clearly as it takes place in the ocean.

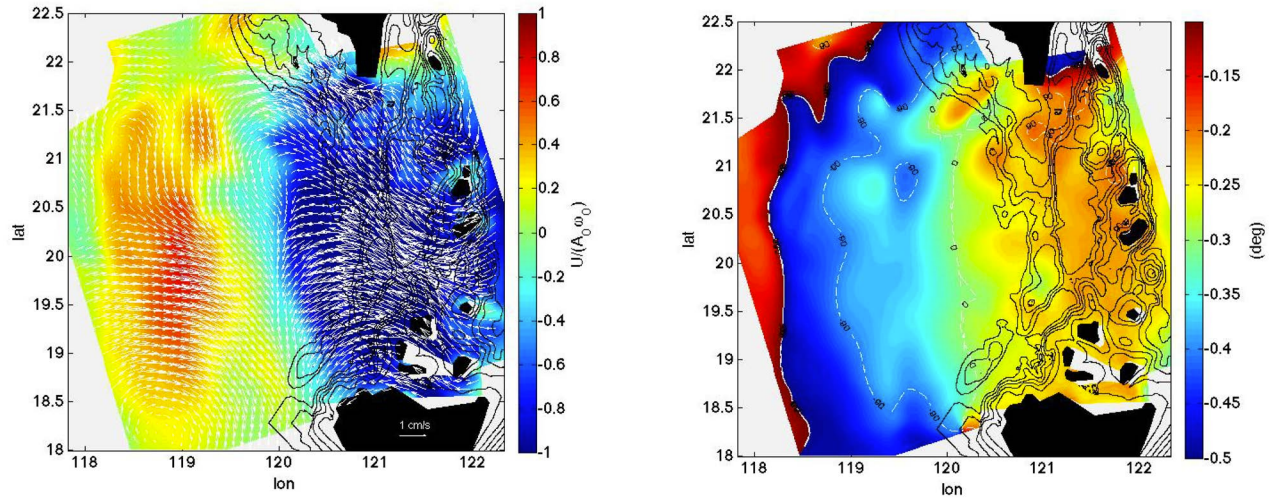
This is because in the lab the balance between nonlinearity and nonhydrostatic dispersion is such that the solitary waves are actually on the same scale as the internal tide.



***Figure 2: The spatial structure of the vertical (top) and horizontal (bottom) velocity fields in the laboratory experiment reveal a scaled M2 wave field, radiated by the Luzon Strait, that is dominated by mode-1.***

For comparison, our results regarding the scaled K1 internal tide show that the larger wavelengths associated with this lower frequency internal tide mean that it is less impacted by the variation of the ridge features within the Luzon Strait than the M2 internal tide. As a result, there is no shaping of the K1 internal tide by the Luzon Strait, per se. As demonstrated by the results presented in figure 3, the amplitude and phase of the radiated K1 internal tide correspond to a wave field that propagates essentially in a westerly direction, with little fine scale structure. As such, the addition of a K1 internal tide is expected to simply modulate the amplitude of the M2 internal tide.

We are continuing to perform further studies of the experimental data in order to further refine these results, but already the experiments have provide a very clear and simple picture of the nature of internal tide generation at the Luzon Strait.



**Figure 3: Snapshot of the (left) amplitude and (right) phase of the radiated scaled K1 internal tide. In contrast to the M2 internal tide, this longer wavelength wavefield is little impacted by the structures within the Luzon Strait and essentially behaves as if generated by a single, simple ridge between the Pacific Ocean and the South China Sea.**

## IMPACT/APPLICATIONS

The laboratory experimental results have had a significant impact on the understanding of internal tide generation in the Luzon Strait and the origin of the large amplitude solitary waves in the South China Sea. The requirement to reduce the problem to its essential ingredients (topography, stratification, forcing) in order to make laboratory experiments tractable has lead to a set of results that clarify and present in a simple manner the most important aspects of internal tide generation by the Luzon Strait. This project has also reasserted the useful role that laboratory experiments can play in geophysical fluid dynamics research.

## RELATED PROJECTS

None.

## PUBLICATIONS

Matthieu M., Gostiaux, L., Saidi, S., Sommeria, J., Didelle, H., Viboud, S., Helfrich, K., Dauxois, T. & Peacock, T., “Large-scale, realistic laboratory modeling of internal tide generation at the Luzon Strait, in preparation for *Geophysical Research Letters*.