Internal Waves in Straits Experiment Progress Report

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LONG-TERM GOALS

Our long-term goal is to understand how energy is supplied to the ocean, and how it subsequently cascades to the turbulence and mixing important to the circulation, and the transport and distribution of tracers. This problem involves scales spanning sub-inertial motions to turbulence, and therefore requires integrative efforts with other sea-going investigators and numerical modelers. The South China Sea project was an ideal opportunity to investigate the cascade from internal tides to higher frequency waves though the processes of internal wave scattering and non-linear steepening.

OBJECTIVES

- To determine sites of high turbulence dissipation at the generation site.
- To parameterize the turbulence at topography using easy-to-measure parameters such as the surface tidal forcing and the background ocean stratification.
- To determine the nature of the internal wavefield radiating from the generation sites.
- To predict the advent of internal solitary waves in various environments based on external forcing.

APPROACH

To date, my approach for this project has been to use a numerical modeling to understand where turbulence dissipation will occur over supercrtical topography. These numerical models are two-dimensional iterations of the MITgcm, so relatively high resolution runs are attainable as are many iterations allowing the examination of significant parameter space.

I have also strongly believe that numerical modeling must be informed by at-sea measurements, and vice-versa. To that end I have worked with Rob Pinkel and the rest of the IWISE pilot team to help plan the pilot experiment, and participated on Pinkel's leg in June 2010.

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WORK COMPLETED

Preliminary numerical model runs were made in two-dimensions that had idealized tidal forcing over realistic SCS topography. A set of runs with very idealized 3-d forcing was run to examine the interactions of two source sills in producing non-linearities. Finally, I participated in the June 2010 Pilot field program with Rob Pinkel's group from SIO, where I led the at-sea data analysis and partnered with Pinkel for the at-sea planning.

For 2011, I worked closely with Buijsman and Legg on their numerical modelling of the strait, particularly the 2-D work. Using Buijsman's 3-D runs, I worked with Pinkel and Buijsman on determining the locale for Pinkel's high-resolution survey of hydraulics near the sill. I did not participate on the 2011 cruise due to family reasons, but I did send MSc students Ryan Clauston and Emma Murrowinski on the cruise, where they gained valuable at-sea experience.

I have also continued more abstract work on this problem on two fronts. First, I have worked to understand what drives turbulence in idealized models where lee waves near supercritical topography are caused not just by barotropic flow, but also by baroclinic flow. i.e. if there is an incoming mode-1 tide, can we predict the turbulence at the topographic break of an obstacle? This leads naturally to the two-ridge problem, of which Luzon Strait is an example.

Secondly, I have been working with research scientist Johannes Gemmrich on parameterizing turbulence on near-critical slopes. The recipes I have developed apply to super-critical situations, but break down if there is significant regions of topography with near-critical topography to the internal tide.

RESULTS

My major focus has been investigating the dissipation local to the generation site in supercritical topography. As outlined in Legg and Klymak (2008); Klymak et al. (2010a) there are high-mode hydraulic jumps found at the flanks of supercritical topography that contain most of the turbulence in the system. The experiment at Luzon Strait will be a particularly interesting test of this phenomena because the forcing there is very strong compared to at Hawaii. I have been running numerical runs that more closely match the Luzon system to see how large the breaking lee waves might be.

First, observations made by Rob Pinkel's group, that I was teamed with showed very large spectacular turbulent overturns near the ridge (figure 1). At times we observed overturns that exceeded 300 m, in only 1000 m of water, leading to very large turbulence dissipation rates. Exploring this data, and how it related to the numerical modelling will be a fun endeavor.

In applying the simple recipe for barotropic flow over topography (Klymak et al., 2010b) to a two-ridge problem, it became clear that the interactions between the ridges mattered (figure 2). This lead to a backwards step, considering an internal tide impinging on supercritical topography, rather than a barotropic tide. A modified recipe that takes into account the extra shear created in that situation does quite well in predicting turbulence dissipation in a two-dimensional numerical model (figure 3).

The double-ridge system is very interesting. As has been noted by others, two ridges can trap energy, forming what has been termed an "attractor", though I prefer the simpler term "resonance", because

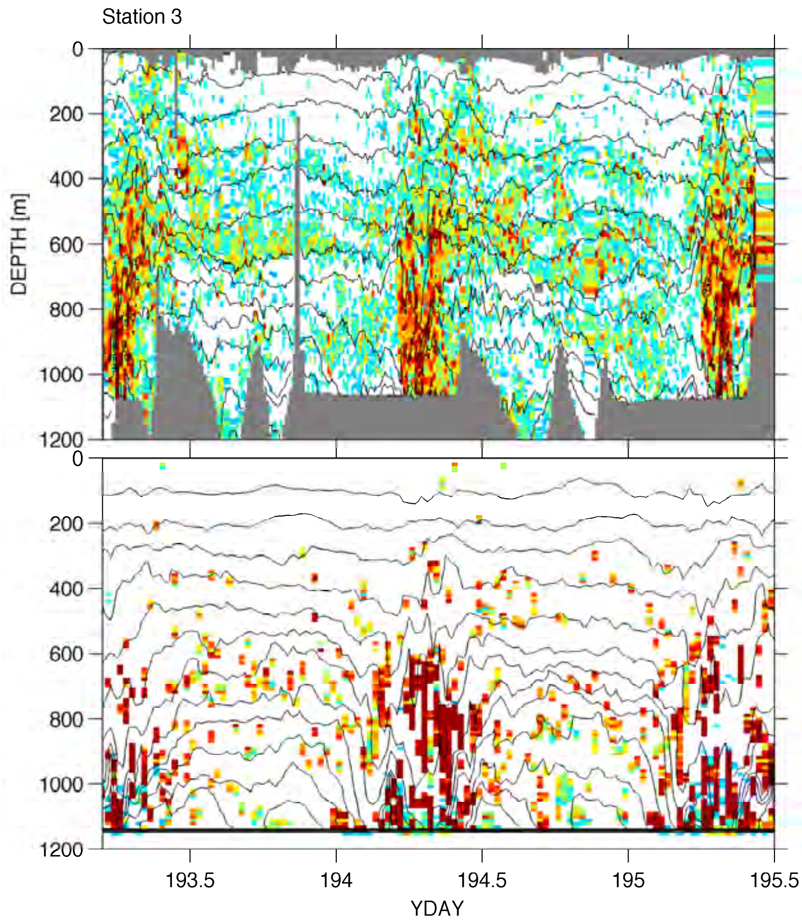

Figure 1: Observations of tidally forced overturns at the crest of Luzon Strait a) observed from* R/V Revelle *by Rob Pinkel's group; grey are regions with no sampling, and b) as simulated in a preliminary 3-D model by Maarten Buijsmann. There are many similarities, but also some differences in the results.

what is really happening is that mode-1 energy is able to be trapped between the two ridges (figure 4, second row). In this case, there is no ready-made linear solution available; The infinite energy trapped between the ridges is of course modified by turbulence, and thus never occurs, but the subtleties of this interaction are beyond our ability to model.

However, if the water column is WKB-stretched, then Luzon Strait falls in the case that only has a "weak" resonance (figure 4, upper row), that occurs when the beam interacting between the two ridges has and odd number of reflected bounces, either from the seafloor or from the surface. No energy is "trapped", but the two ridges re-enforce each other, and an enhanced internal response is noted. However, it is not so resonant that we cannot hope to parameterize the turbulence in this situation, and indeed doing so yields very promising results (figure 6).

Our work on reflection from continental shelves has begun, with graduate student Emma Murrowinski making simulations and beginning to analyze them as in Klymak et al. (2011). So far theory and model results are agreeing quite well (figure 6), and we are about to move onto dissipation parameterizations.

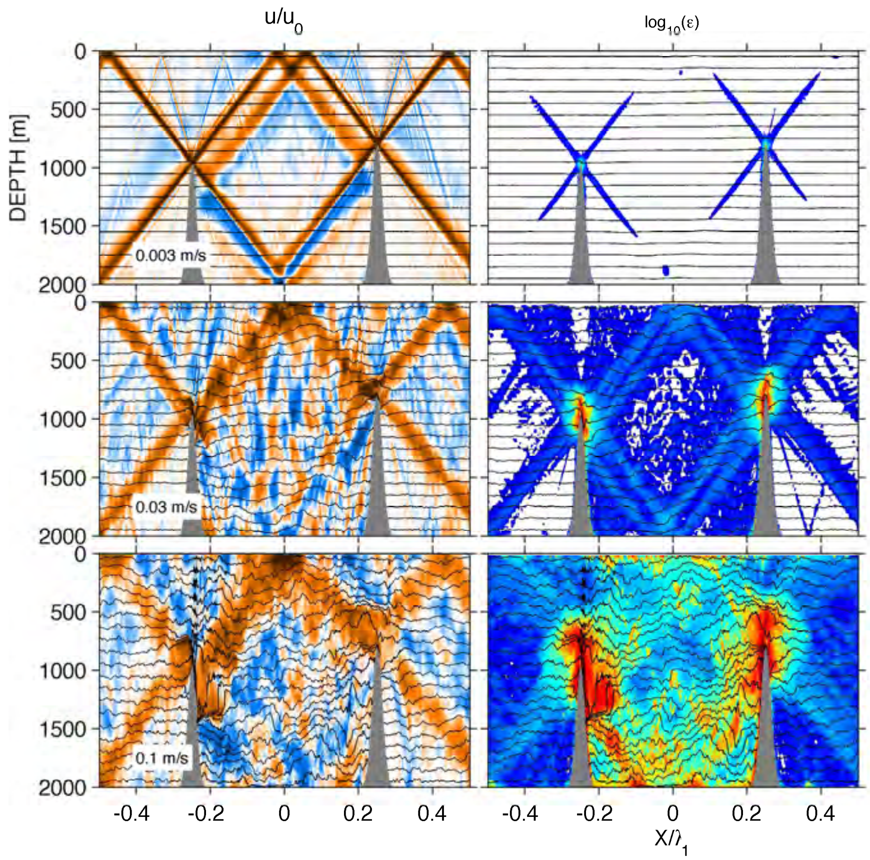

Figure 2: Dissipation in a 2-D numerical model as predicted by a recipe based on (Klymak et al., 2010b), and measured in a numerical model. In this case, the forcing are mode-1 or mode-2 incident internal tides.

Similarly, our project with Johannes Gemmrich to understand turbulence on near-critical slopes is just getting started (figure 7). However, turbulence dissipation on such slopes is following a regular power law, and we expect to be able to derive a parameterization soon.

IMPACT/APPLICATIONS

Understanding the transformation of the relatively easy to observe trans-basin waves to the zoo of shelf waves is a major challenge to predicting sound properties on the continental shelf. The modeling and observation work described here will help improve our understanding of these phenomena.

We think we have identified an important mechanism for scattering and dissipating low-mode internal tides. This set of observations and the accompanying modeling should help in our ultimate goal of making simple models of these processes in the ocean.

RELATED PROJECTS

This work is strongly tied to the work by PIs Pinkel, Lien, Simmons, and Alford. I am collaborating extensively with them in data analysis and modeling.

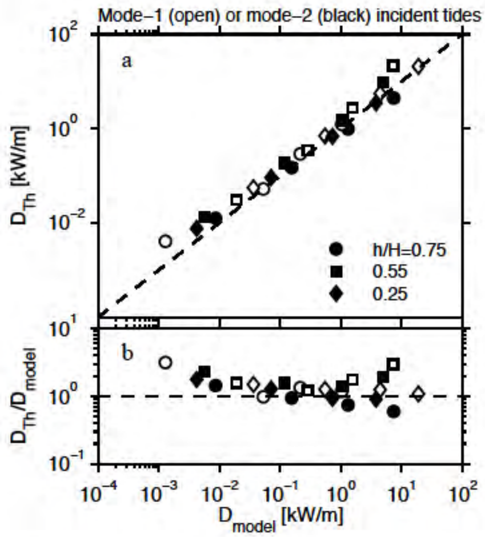

Figure 3: Mean dissipations in tidal simulations with and without the western ridge. Dissipations are due to the method of Klymak and Legg (2010). Note the very high dissipations on the western ridge.

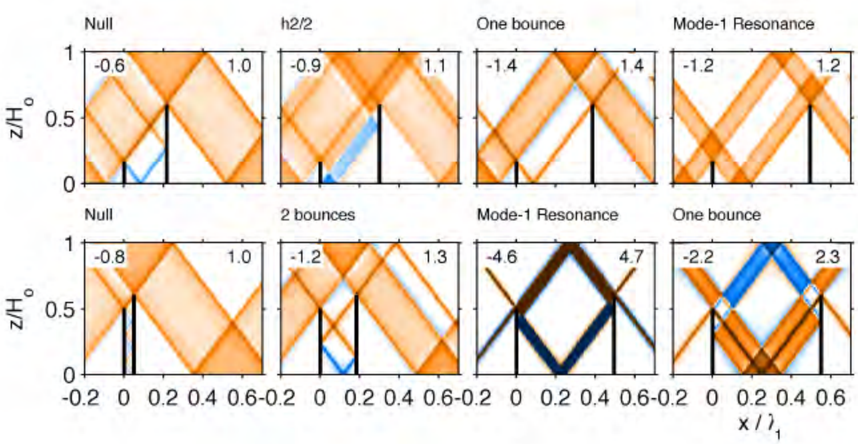

Figure 4: Idealized two-ridge solutions. The upper row corresponds to a "Luzon Strait" case. The lower row to the case where $h_1 + h_2 >= H$ and a full mode-1 resonance can occur. In this case, the energy between the ridges becomes infinite.

It is related to the work being done in the AESOP DRI, which also seeks to understand the mechanisms that break low-mode energy down into high-mode unstable waves.

Finally, it is complimentary to Klymak's work at UVic, funded through the Canadian National Science and Engineering Research Council, to look at coastal internal wave processes.

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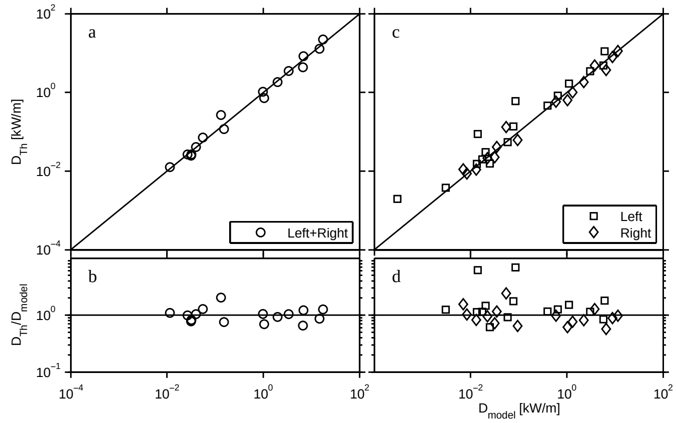

Figure 5: Dissipation in the theory and the model for a two-ridge system with $h_1 + h_2 < H$ for various forcings.

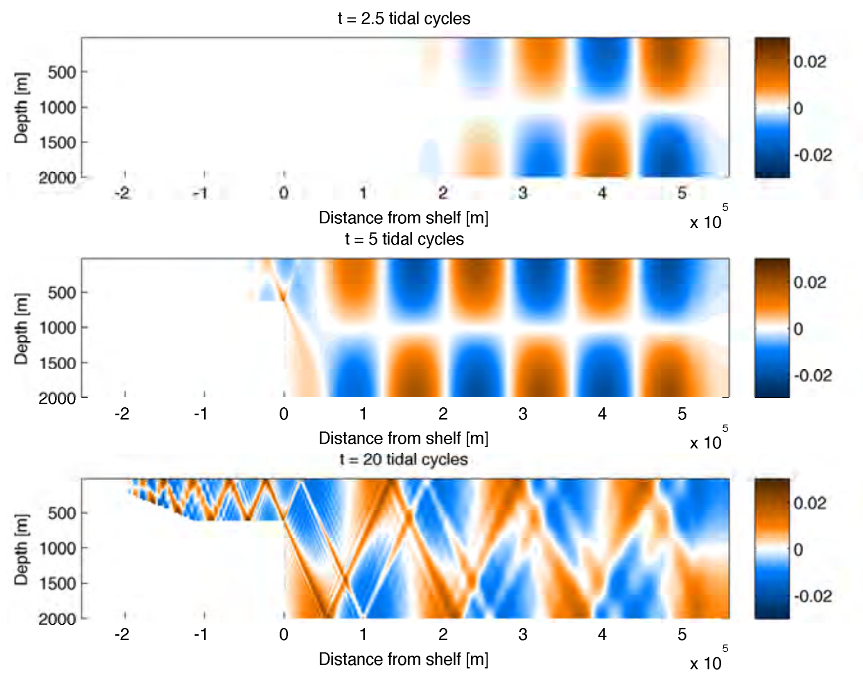

Figure 6: Reflecting incoming mode-1 tide on a continental shelf for relatively weak forcing.

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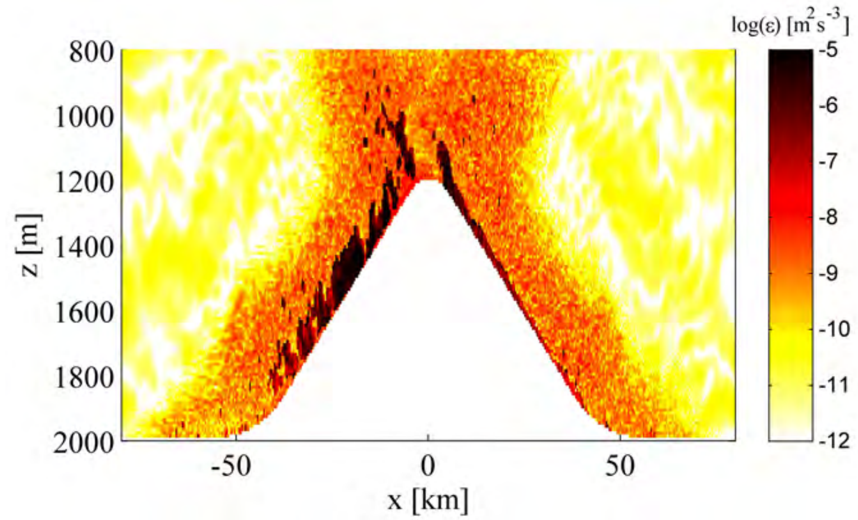

Figure 7: Example of critical slope dissipation in numerical model. The region being parameterized is on the flanks away from the ridge crest and the sea floor.

Legg, S., and J. M. Klymak, 2008: Internal hydraulic jumps and overturning generated by tidal flow over a tall steep ridge. *J. Phys. Oceanogr.*, **38**, 1949–1964.