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 understand the modification of internal tides as they encounter the continental shelf.
To understand how energy partitions between linear and non-linear internal waves in the internal tide generation region of the South China Sea
To determine sites of high turbulence dissipation at the generation site.

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.

WORK COMPLETED

A cluster of Apple servers was purchased and set up for this modeling work. A large number of runs have been made to understand the evolution of solitary waves, the effect of the internal tide shoaling on topography, and the non linearities at the generation site. The first two activities have helped with interpreting the 2007 data set, while it is hoped that the latter work will help with siting the IWISE work.

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RESULTS

Recently I have been working with Alford and co-workers to try and understand the timing and evolution of solitary waves as they cross the deep basin. This has led to a number of simple numerical model runs not dissimilar to the work by Buijsmans et al. While this work may not lead directly to a publication, it has helped with Alford's wave timing publication.

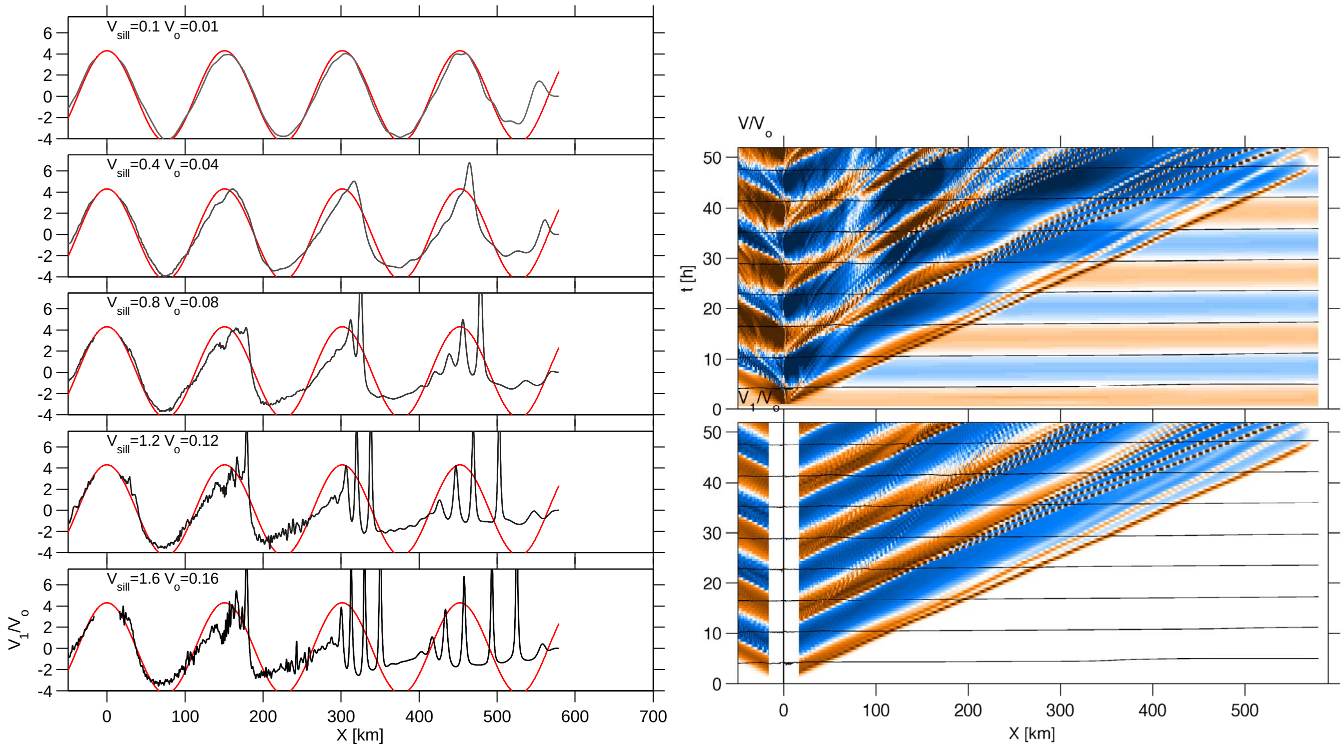

Figure 1: Left: Comparison of how the response of the mode-1 internal tide changes with increased barotropic forcing. This was for a relatively shallow sill depth of 300 m in 3000 m of water. Right: Hovmoller diagrams of the surface velocity and the mode-1 velocity for the strongest barotropic forcing.

The results from this work examine the timing of the solitary waves as they are released from the sill region. First, the waves clearly evolve out of the mode-1 tide, not a lee wave effect. An experiment with a shelf topography generating the mode-1 tide rather than a sharp bump verifies this. The waves are also clearly formed in phase with the barotropic forcing, however phase distortion occurs as the tide steepens and disintegrates into solitary waves. It does seem that there is some work to be done here on what sets the amplitude and therefore the phase speed of the solitary waves that may benefit from further investigation; it is clear from these investigations that the waves are not ever in simple steady state. Comparing to the simplified 2-layer models by Grimshaw that Helfrich and Farmer have been using would also be beneficial.

I have also been investigating the dissipation local to the generation site. As outlined in Legg and Klymak (2008); Klymak et al. (2009) 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.

An example indicates that for moderate barotropic forcings large lee waves of over 200 m in amplitude might be found (figure 2). In this simulation, a 300-m deep sill in 3000 m of water has a 0.16 m/s barotropic deep-water tide passing over it, forcing a barotropic velocity at the sill top of 1.6 m/s. This generates very large trapped waves that fill the water column and produce overturns over 200 m thick with very high dissipations. The model parameterizes the turbulence dissipation based on a method recently submitted to *Ocean Modelling* (Klymak and Legg, 2010).

This extreme environment will be a good test bed for the ideas I have been developing about parameterizing the dissipation due to internal tides over supercritical topography. The first step of this parameterization is about to be submitted to *J. Phys Oc.* (Klymak et al., 2010). This method uses the linear generation of internal tides to predict how much energy is available to go into these arrested lee waves, and is therefore relatively simple and amenable for inclusion in numerical models. Whether these simple models are borne out in the more extreme environment afforded by Luzon Strait, both numerically and in the observations remains to be tested.

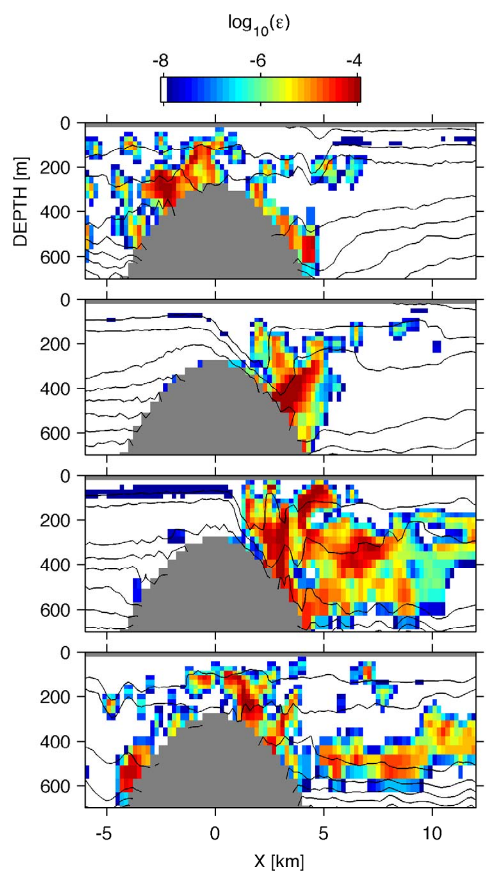

Figure 2: Breaking lee wave over a shallow sill such as might be found in the Luzon Strait. Contours are isopycnals, colors are turbulence dissipation rate estimated from model-generated overturns. Note the lee wave that forms during the eastward flow and fills the water column.

Finally, I am still working with Pinkel, Alford, and Lien on the scattering of internal tides from continental slopes. Certainly in the Luzon Strait much of the internal tide disintegrates into solitary waves (figure 1), however the remaining flux scatters off the continental slope, and to some extent back reflects, transmits further upslope, or dissipates near the slope (figure 3). The transmission/reflection problem can be approached linearly, just like the generation problem, and the amount of dissipation perhaps predicted according to the ideas used for the generation sites. However, in both cases there is a significant complication in the form of upslope bores over near-critical topography.

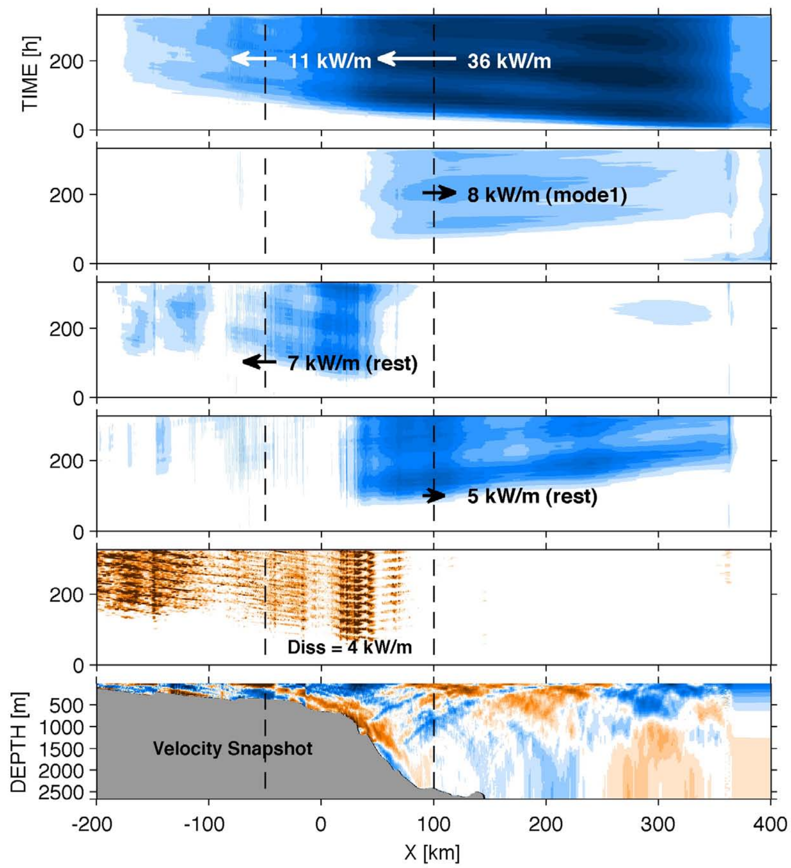

Figure 3: Result of a mode-1 K1 tide impacting the continental slope in the South China Sea. Over half the energy fluxes onshore of the slope region to dissipate as bores and solitary waves in the shallow water, while over one-third reflects back into the open water, setting up a partial standing wave. Note that the continental shelf is almost critical to the K1 tide at this location.

We have a data set in hand that addresses this question, both from Alford and Lien's mooring array, and from shipboard measurements made on the *OR1*. We have reported very large turbulence dissipation at both Alford's mooring and at a site on the slope in 700 m of water, both demonstrating a clear tidal signal and a spring-neap cycle echoing the forcing at the Luzon Straits.

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 and Alford. We are collaborating extensively with them in data analysis.

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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