

## **Internal Waves in Straits (IWISE): Observations of Wave Generation**

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### **LONG-TERM GOALS**

The long term goals are to use observations and analysis of stratified flow past complex topography to understand how internal tidal interaction in straits is responsible for the generation of large amplitude high frequency internal waves.

### **OBJECTIVES**

Our objectives are to build and deploy a 2-D array of pressure equipped inverted echo sounders so as to observe the generation of internal waves generated by tidal interaction with topography in Luzon Strait, and to interpret the results using appropriate models of internal wave formation and evolution.

### **APPROACH**

Our approach requires construction of an array of pressure equipped inverted echo sounders (see Li et al. 2009). Our plan called for eight instruments, but the size of the planned array has now been increased as a result of a separate ONR-DURIP, motivating redesign of the array based on model calculations at different sections across the ridges.

### **WORK COMPLETED**

At this time model analyses of the generation region using the MITgcm have been carried out. Together with modeling and data analysis activities completed under the NLIWI project (see Farmer et al., 2009), these results are providing guidance for the array deployment. Instrumentation construction is underway, with acquisition of components and building of electronic boards. Model calculations are being carried out by PhD student Li Qiang; instrument development is being carried out by Randy Watts and the Equipment Development Lab.

### **RESULTS**

Our measurements of the internal tide between the two ridges carried out under the NLIWI program at inverted echo-sounder deployment location A1, 20.65N 121.30E, show little sign of nonlinear modification such as steepening or high frequency nonlinear wave development; wave steepening and accompanying nonhydrostatic effects take place further west. However, in preparation for the IWISE

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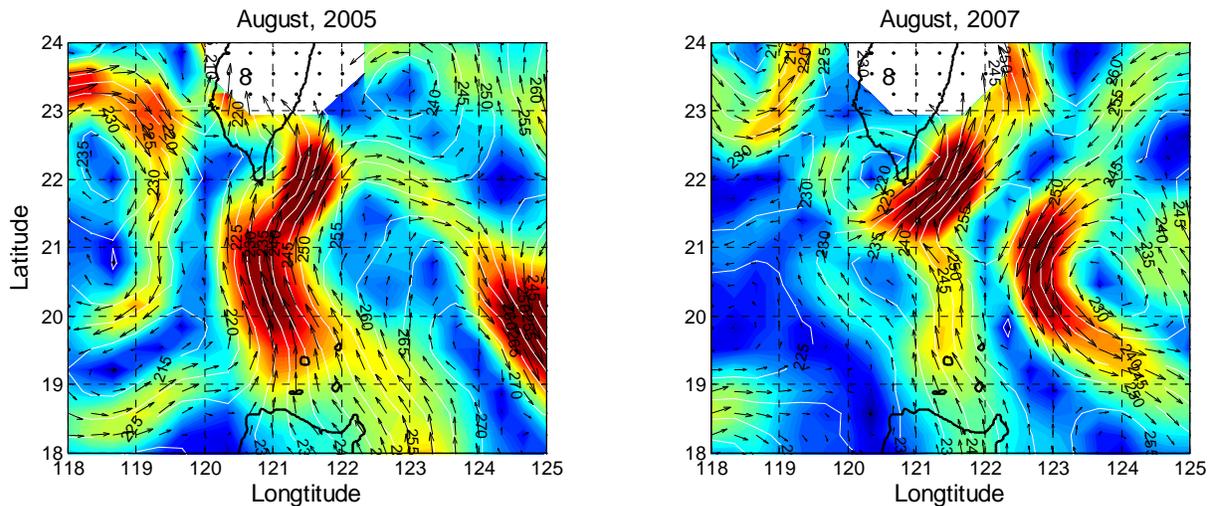
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Pilot study to be carried out in 2010, a more complete model is required both to identify an optimum instrument array distribution and to assess other factors influencing nonlinear internal wave generation, including seasonal variations.

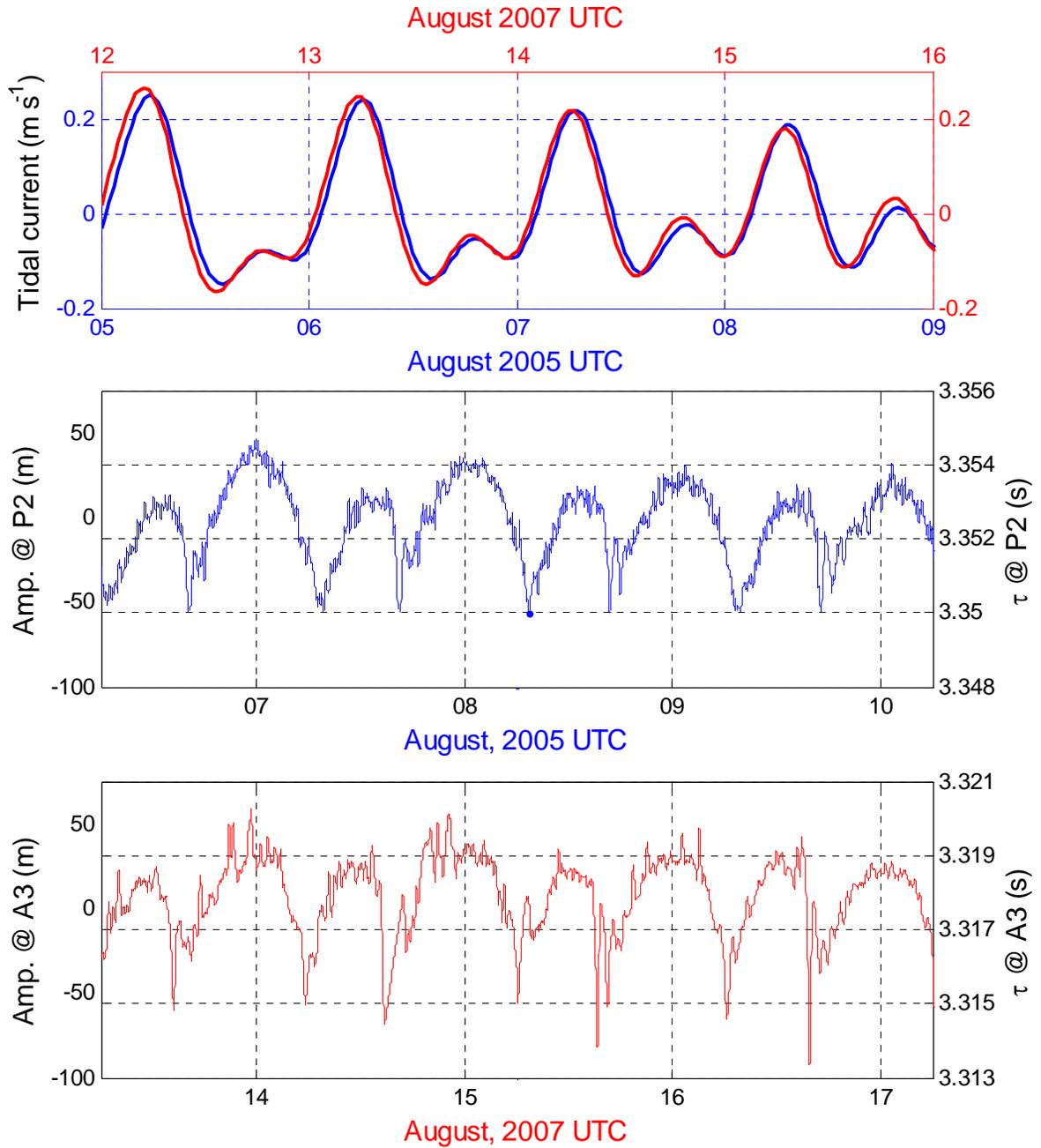
High frequency nonlinear internal waves are less often seen during winter months. Moreover, the amplitude and nonlinear development of the internal tides seen in the deep basin during 2005 are somewhat greater than observed during 2007. Remote sensing images show little evidence of nonlinear internal wave trains east of Luzon Strait at any time of year, which can be explained by the deeper stratification to the east. It has been proposed that diminished internal wave signals in winter may be explained by the obscuring effects of higher sea states. It might also be expected that changes in the barotropic currents across the eastern ridge associated with changes in the intrusion of the Kuroshio would also impact internal tide generation. We have started to examine these effects with a 2-D implementation of the MITgcm, carrying out preliminary interpretations using both remotely sensed characteristics of the Kuroshio and our simultaneously acquired inverted echo-sounder measurements.

Altimetry measurements of the Kuroshio are shown in Fig. 1 in August 2005 (*left*) and August 2007 (*right*). In 2005 the Kuroshio followed a slightly curved path over the eastern ridge,



**Figure 1: Sea surface height based on radar altimetry (white contour) for August 2005 and August, 2007. Black arrows correspond to surface geostrophic velocity ( $u,v$ ) derived from SSH and the color represents the corresponding speed.**

imposing a quite modest adjustment to the zonal barotropic component, whereas in 2007 there was a significantly stronger easterly component, especially north of 21N. However, it can be demonstrated with internal tide generation models that an easterly flow over the eastern ridge leads to a larger and steeper internal tide radiating to the west. Figure 2 shows the corresponding measured internal tide for each case (predicted tidal forcing over the ridge is almost identical in each year (*red and blue time series in upper panel*)).



**Fig. 2:** Top panel shows TPXO tidal current predictions over the east ridge of Luzon Strait. Middle panel shows corresponding inverted echo sounder time series at station P2 in 2005. Lower panel shows inverted echo sounder time series at the nearly identical location of station A3 in 2007. Note that the internal tide and nonlinear internal waves are larger in 2007 than 2005, an effect attributed to the easterly component of the Kuroshio in 2007.

Note the significantly larger amplitude internal tides and high frequency nonlinear internal waves in the 2007 time series, coincident with the stronger eastward component of the Kuroshio. These results are consistent with the MITgcm calculations.

## **IMPACT/APPLICATIONS**

The impact of our work to date is two-fold: instrumentation currently being constructed will be available for a pilot study in 2010 and for a comprehensive field program in 2011. Our preliminary modeling and analysis provides guidance in the planning of both the pilot and primary study.

## **RELATED PROJECTS**

ONR project – Nonlinear Internal Wave Initiative

## **REFERENCES**

Li, Q., D. Farmer, Jae-Hun Park, Timothy F. Duda & Steve Ramp (2009), Acoustical measurement of nonlinear internal waves using the inverted echo-sounder, *J Atmos & Oceanic Technol.*, 2009, v. 26, 2228-2242.

David Farmer & Li, Q.: Observations of nonlinear internal waves in the South China Sea, *Atmosphere-Ocean, special issue on The Interacting Scales of Ocean Dynamics (in press)*.