IWISE: Observations of Internal Wave and Tide Generation in the Luzon Strait Using Shipboard Surveys and Oceanographic Moorings

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LONG-TERM GOAL

The long-term goal is to enhance our understanding of coastal oceanography by means of applying simple dynamical theories to high-quality observations obtained in the field. My primary area of expertise is physical oceanography, but I also enjoy collaborating with biological, chemical, acoustical, and optical oceanographers to work on interdisciplinary problems. I collaborate frequently with numerical modelers to improve predictive skill for Navy-relevant parameters in the littoral zone.

OBJECTIVES

The objective of this grant is to improve understanding of how the large-amplitude internal waves and tides in the northeastern South China Sea are generated via interaction of the barotropic tide with the ridges and islands in the Luzon Strait. In addition to the problem's inherent scientific interest, understanding the generation problem is essential for developing a forecast model to predict the wave characteristics in the deep basin and on the Chinese continental slope and shelf.

APPROACH

The approach is to particpate in a major ONR-sponsored field program in the Luzon Strait and northeastern South China Sea during 2010-2011. Called the Internal Waves in Straits Experiment (IWISE), the program is a logical follow-on to the Nonlinear Internal Waves Initiative (NLIWI) but will focus more closely on the generation problem, rather than on free propagation and wave dissipation during the earlier experiments. A large team of investigators from the U.S. and Taiwan will participate. Our primary collaborator in Taiwan is Prof. Y. J. Yang of the Marine Sciences Department, Naval Academy. He and Dr. Ramp will be the co-leaders of cruises on Taiwanese vessels during the pilot study (summer 2010) and the intensive observations program (IOP, summer 2011). We have two key thrusts: Moored and shipboard observations south of Taiwan on the northern Heng-Chun ridge; and two far-field deep-water moorings near 18° 30'E to monitor wave arrivals. The Heng-Chun site has not been previously explored, even though numerical studies suggest it is an important generation site. The far-field moorings are specifically to test the multi-source hypothesis advanced by [Zhang et al., 2011]. The program has an exciting, enlarged numerical modeling component. We work especially closely with Oliver Fringer (Stanford) and Maarten Buijsman (Princeton/GFDL).

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WORK COMPLETED

Following the successful pilot study on the OCEAN RESEARCHER II during June/July 2010, the later calendar year 2010 months were spent processing and analyzing the data. The preliminary results were presented at the ONR hot wash meeting during January 2011 in Taipei, and somewhat more refined results at a seminar at the National Taiwan University in July 2011. The IOP cruises were conducted during July – September 2011 from the OCEAN RESEARCHER III. These included a basin mooring deployment cruise during July (Figure 1), two cruises to the northern Heng-Chun Ridge during August, and a mooring recovery cruise during September. The data return was excellent. All the moorings were successfully recovered and the all the instruments returned full records of temperature (T), salinity (S), and current velocity (u, v). These new data sets are still being processed at this writing.

RESULTS

During the pilot cruise, a series of across-ridge sections were sampled using an underway conductivity-temperature-depth (UCTD) profiler and an anchor station atop the ridge was occupied using at CTD with lowered acoustic Doppler current profiler (LADCP) (Figure 2). A hull-mounted ADCP an EK500 echo sounder were also operated throughout the cruise. The site was a very high energy region, with both the Kuroshio Current and the barotropic tides exceeding 1.5 m s^{-1}. The most remarkable feature observed was a convex-type mode-2 nonlinear internal wave (NLIW) with a westward-propagating core centered near 100 m depth. The wave was clearly visible in the velocity and backscatter data (Figure 3) and had surface expressions visible both on radar and with the naked eye. The horizontal and vertical velocity structure was a good match for theoretical mode-2 waves in the SCS [Yang et al., 2010]. The wave generation was consistent with local lee wave dynamics, which favored mode-2 generation at peak ebb tide but not mode-1 given the currents, stratification, and bottom slope at the site. The wave could not be tracked further west, and apparently did not escape the opposing Kuroshio Current.

During the IOP, several more realizations of this phenomenon were observed. The seven-day mooring captured a wide range of barotropic tidal amplitudes. More mode-2 waves were observed, but near the tidal maximum, some mode-1 waves were also observed. A mode-2 internal tide was tracked passing by the mooring and several of the anchor stations. This phenomenon was not observed during the 2010 pilot study. The IOP cruises were completed just one month ago, and more analysis will be needed before presenting the results.

IMPACT/APPLICATION

The large amplitude NLIW propagating westward across the northeastern SCS have a significant impact on naval operations. They have a large impact on acoustic propagation loss as demonstrated in previous publications [Duda et al., 2004: Chiu et al., 2004]. They also induce large, sharp buoyancy fluctuations and water displacements in the thermocline both in the deep basin and after shoaling onto the Chinese continental shelf. The work described here is intended to facilitate real-time prediction of these phenomena for operational use.

TRANSITIONS

Some progress has been made by the team towards practical tactical decision aids for the Navy, regarding the occurrence and prediction of the large-amplitude, nonlinear interanal waves [Jackson, 2009; Ko et al., 2009]. Some of our data sets were used in developing these tools. The PI retains a courtesy appointment at the Naval Postgraduate School and has regular contact with the U.S. Navy via officer-students and faculty there.

RELATED PROJECTS

The PI is an invited advisor to the Taiwan National Ocean Research Institute (TORI) Taiwan Coastal Observation and Assessment (TaiCOAST) project. This group is founding a national ocean observing system in Taiwan featuring a large pier facility on the northeast coast of Taiwan. The point of contact is Professor Kon-Kee Liu, National Taiwan Central University. The project offers the PI additional opportunities to interact with Taiwanese colleagues at their own institutions.

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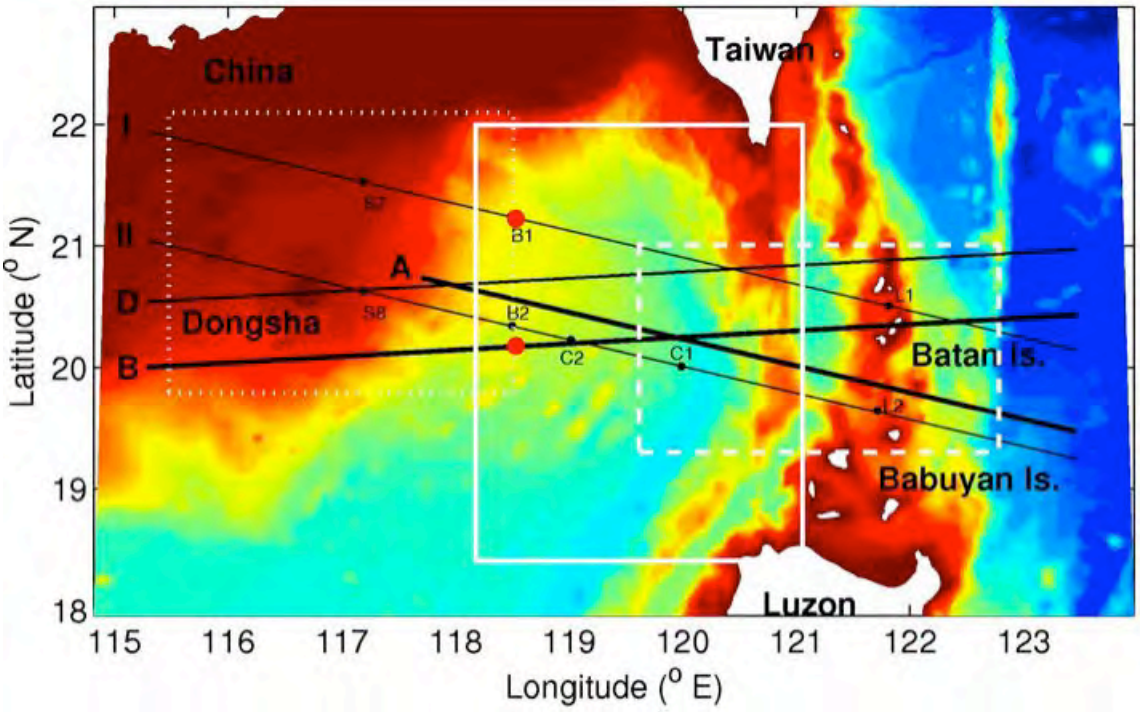

Figure 1. Map showing the locations of the basin moorings (red dots) deployed during July-September 2011 as part of the IWISE IOP. The black lines are the theoretical ray paths for the different sources in the Luzon Strait. The background color indicates bottom depth.

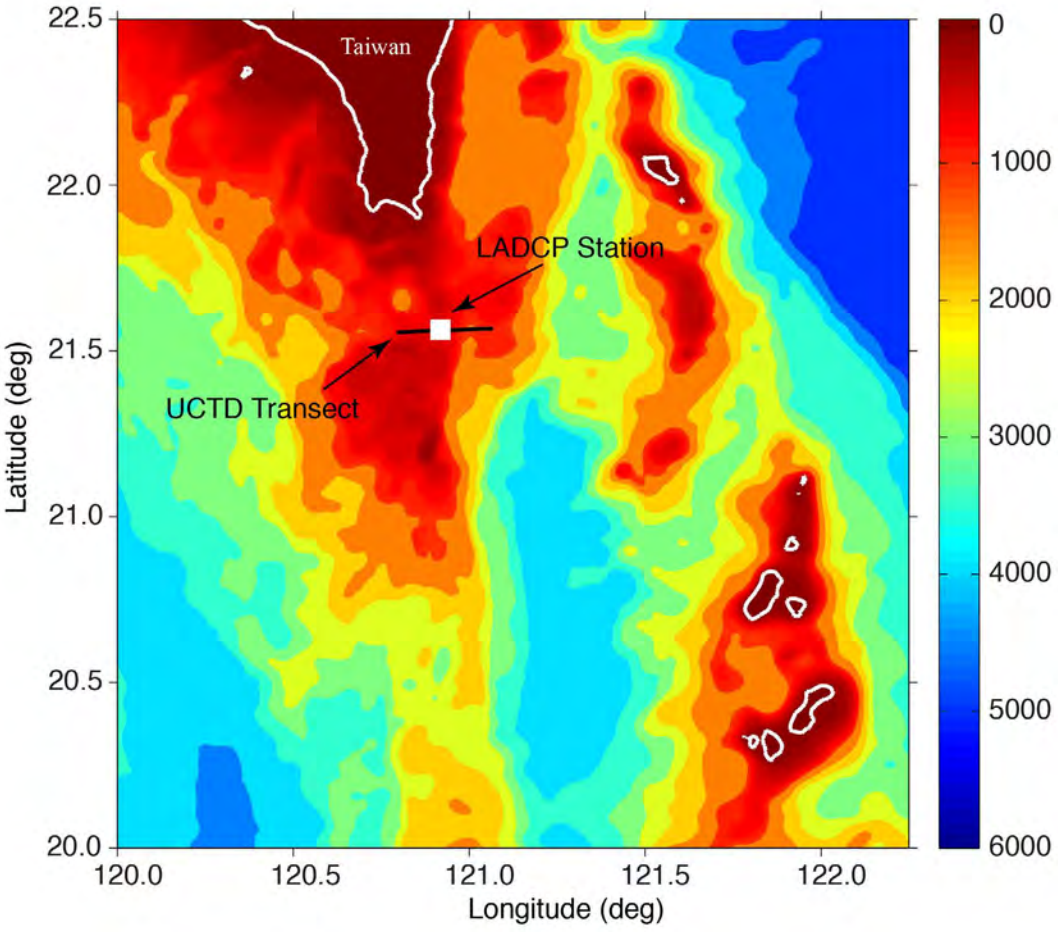

Figure 2. The locations of the UCTD repeat transects and LADCP anchor station during the IWISE pilot study 2010. The white square is also very close to the mooring position for the IOP during August 2011.

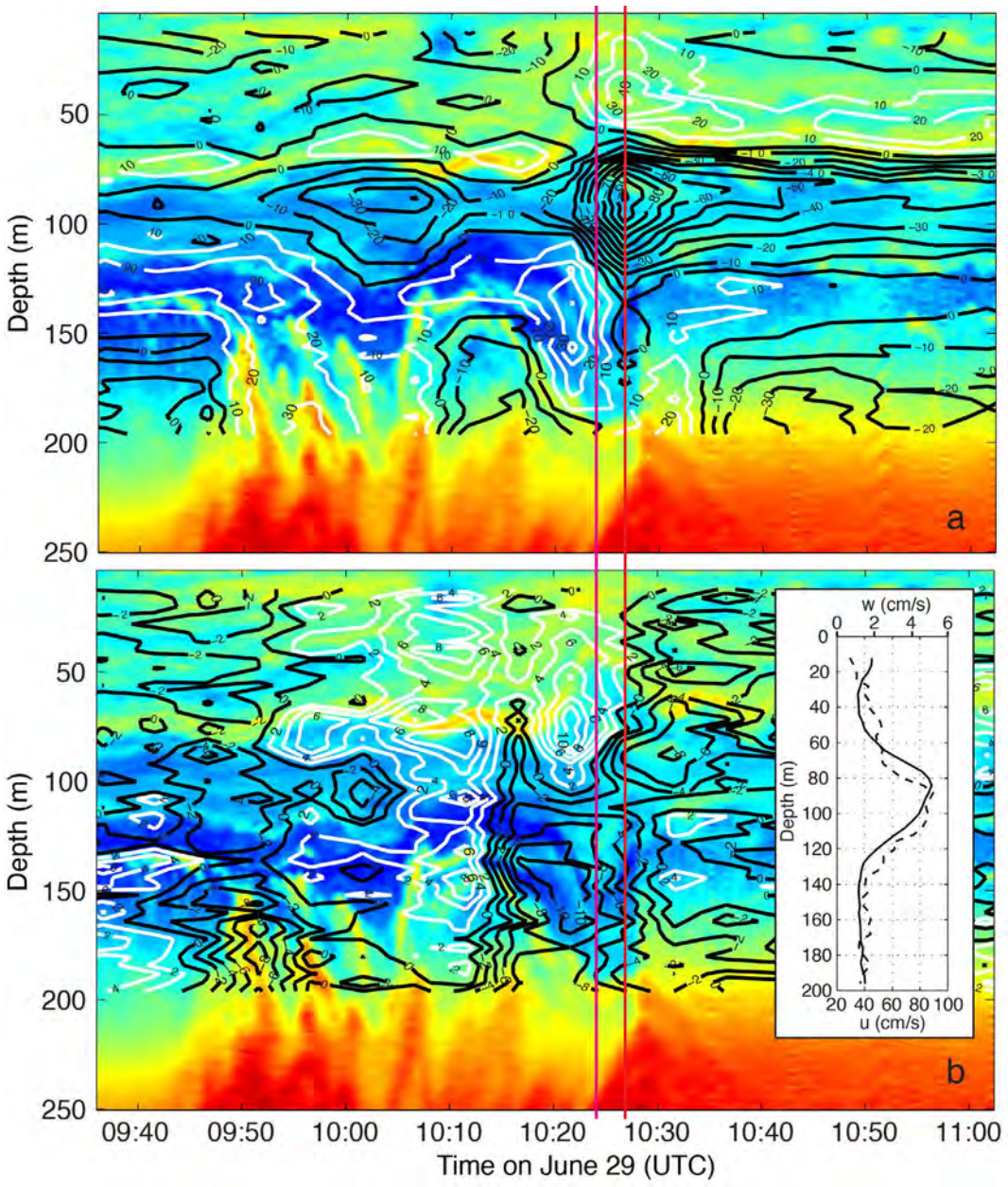

Figure 3. The mode-2 NLIW observed over the northern Heng-Chun Ridge during the IWISE pilot study (at white square in Figure 2). The zonal (a) and vertical (b) velocity data from the ship's ADCP are overlain on the backscatter data (120 kHz) from the EK500 echo sounder. Black contours are westward (down) and white eastward (up) for the zonal and vertical velocity components respectively. The vertical magenta line at 10:24 indicates the time of maximum wave amplitude as indicated by the backscatter data, while the red line at 10:27 indicates the wave core position as indicated by the horizontal velocity maxima and the zero crossing of the vertical velocity component. The insert shows the background current profile that was removed from the u (solid line) and w (dashed line) data.