Generation and Evolution of Internal Waves in Luzon Strait

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LONG-TERM GOALS

Our long-term scientific goals are to understand the dynamics and identify mechanisms of small-scale processes—i.e., internal tides, inertial waves, nonlinear internal waves (NLIWs), and turbulence mixing—in the ocean and thereby help develop improved parameterizations of mixing for ocean models. Mixing within the stratified ocean is a particular focus as the complex interplay of internal waves from a variety of sources and turbulence makes this a current locus of uncertainty. For this study, our focus is on generation, propagation, evolution, and dissipation of small-scale internal waves and internal tides as the Kuroshio and barotropic tides interact with the two prominent submarine ridges in Luzon Strait.

OBJECTIVES

The primary objectives of this observational program are to quantify 1) the generation of NLIWs and internal tides in the vicinity of Luzon Strait, 2) the energy flux of NLIWs and internal tides into the Pacific Ocean and South China Sea (SCS), 3) the effects of the Kuroshio on the generation and propagation of NLIWs and internal tides, 4) the seasonal variation of NLIWs and internal tides, and 5) to study other small-scale processes, e.g., hydraulics, and instabilities along internal tidal beams and at the Kuroshio front.

APPROACH

Near-field: In the vicinity of the Luzon Strait, observations will be taken using the combined 800-m-long towed CTD chain equipped with ~50 CTD sensors and the Doppler sonar on the R/V *Revelle*. These instruments are capable of taking high-frequency, Δt <1 min, and high vertical resolution, Δz = 5–10 m, measurements of CTD and oceanic velocity from near the surface to ~600-m depth.

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Far-field: Full water-column velocity and temperature observations will be taken using two subsurface moorings with a near-bottom upward-looking 75-kHz ADCP and a series of SBE sensors at a sampling rate of Δt =1 min, capable of measuring internal tides and NLIWs, on the continental slope east of Dongsha Island, ~200 n mi west of Luzon Strait. To help determine the propagation speed and direction of NLIWs, Dr. Yang will deploy four additional moorings with bottom pressure sensors on the Dongsha continental slope.

WORK COMPLETED

We conducted a pilot experiment in Luzon Strait 1–11 June 2010. Our primary tasks were to 1) test performance, operation setup, and sampling strategy of the ADM towed CTD chain (ADM-TCTD), 2) test the data quality of Seabird CTD sensors mounted on the towed chain, 3) identify internal tide generation sites, 4) quantify the Kuroshio, and 5) perform a multi-beam bathymetry survey.

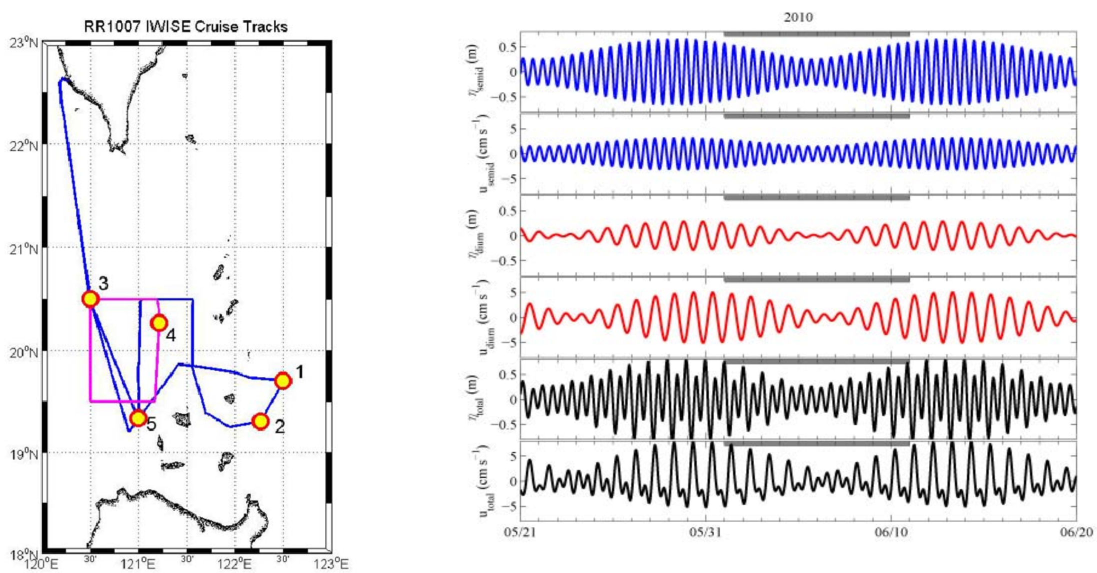

Figure 1. Left: Ship track of the IWISE pilot cruise; the yellow dots indicate CTD stations, and magenta lines mark the track of the towed CTD chain test. Right: Prediction of barotropic tide in Luzon Strait from OTPS; the horizontal grey bar marks the period of the pilot cruise.

RESULTS

<u>Kuroshio</u>

The magnitude and the spatial structure of the Kuroshio current within the Luzon Strait are quantified using the shipboard ADCPs on the R/V *Revelle*, including the 50-kHz HDSS, 140-kHz HDSS, and the newly installed 75-kHz RDI ADCP (Fig. 2). The maximum current speed of the Kuroshio is about 1 m s^{-1}, restricted east of 120.75 E. The maximum vertical extent is about 400 m.

<u>Internal Tide</u>

We occupied a time series station #5 (see Fig. 1) for nearly 65 hr. Shipboard yoyo CTD and ADCP measurements were taken continuously. The CTD cast reached within 100 m off the bottom, about

3300-m water depth. Both velocity and CTD measurements indicate strong diurnal and semidiurnal tides. Vertical overturnings as large as 100 m are suggested from CTD observations near the bottom at a diurnal period (Fig. 4).

ADM Towed CTD Chain

A multi-beam bathymetry survey was conducted along the track of and prior to the planned ADM-TCTD performance test (magenta line in Fig. 1). The ADM-TCTD performed poorly providing few reliable CTD observations. We conclude that this system is not suitable for the 2011 IWISE IOP.

Seabird Towed CTD Chain

Four Seabird SBE37 CTD sensors were mounted on the 800-m chain during the ADM-TCTD test. The primary goal is to test the data quality of SBE37 CTD measurements on a towed chain. All four Seabird CTD sensors provided data of excellent quality (Fig. 5). For 2011 IWISE IOP, we plan to build a Seabird Towed CTD chain (STCTD). It will consist of a series of SBE37 sensors. All SBE37 sensors will be powered by internal batteries, record internally, and be pumped. Some of these SBE37 sensors will have an inductive function and transmit data in real time. The real-time observations will allow us to identify oceanic processes of interest and allow active adjustment of our observational scheme.

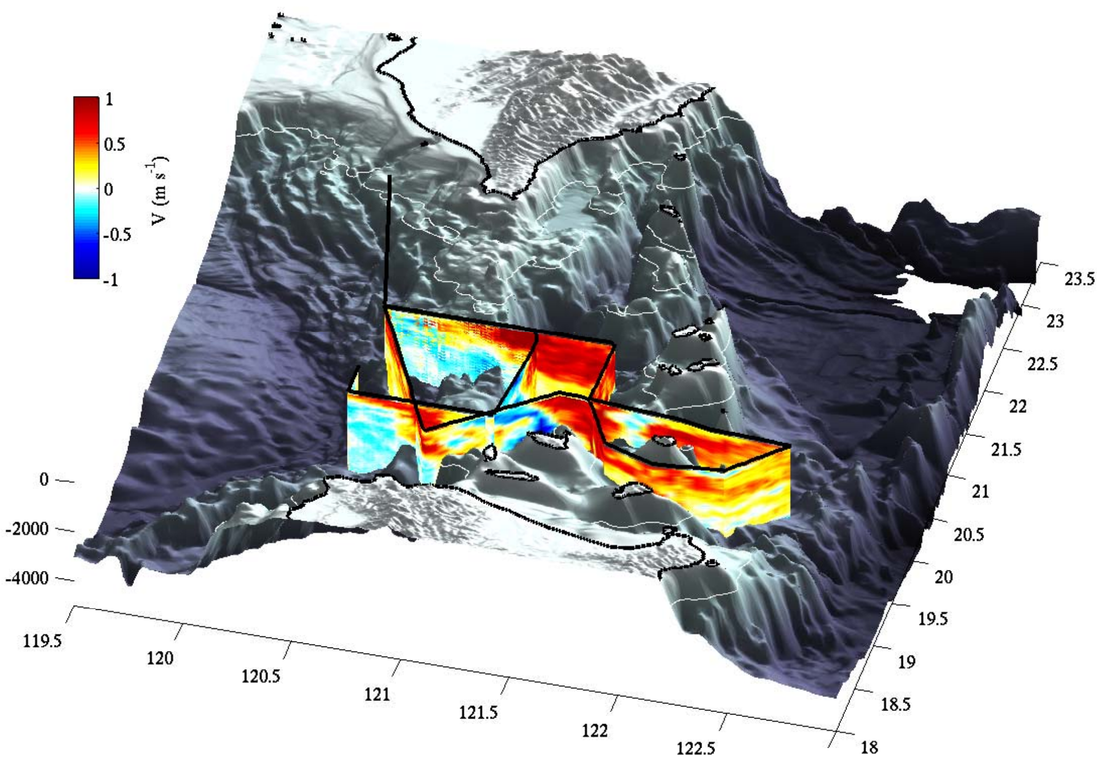

Figure 2. Meridional velocity measured by shipboard ADCP on R/V* Revelle*. The magnitude and spatial structure of the northward flowing Kuroshio are quantified.

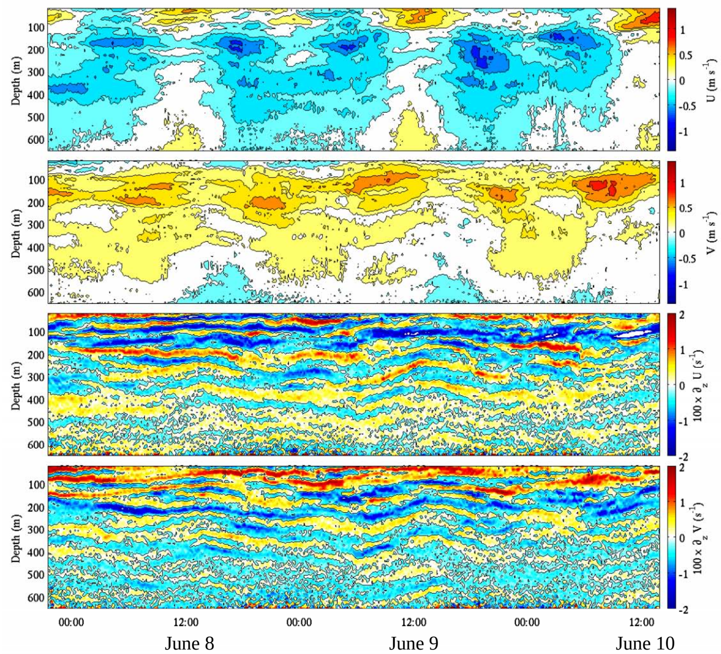

Figure 3. Contours of velocity and shear observations at Station #5 (see Figure 1).

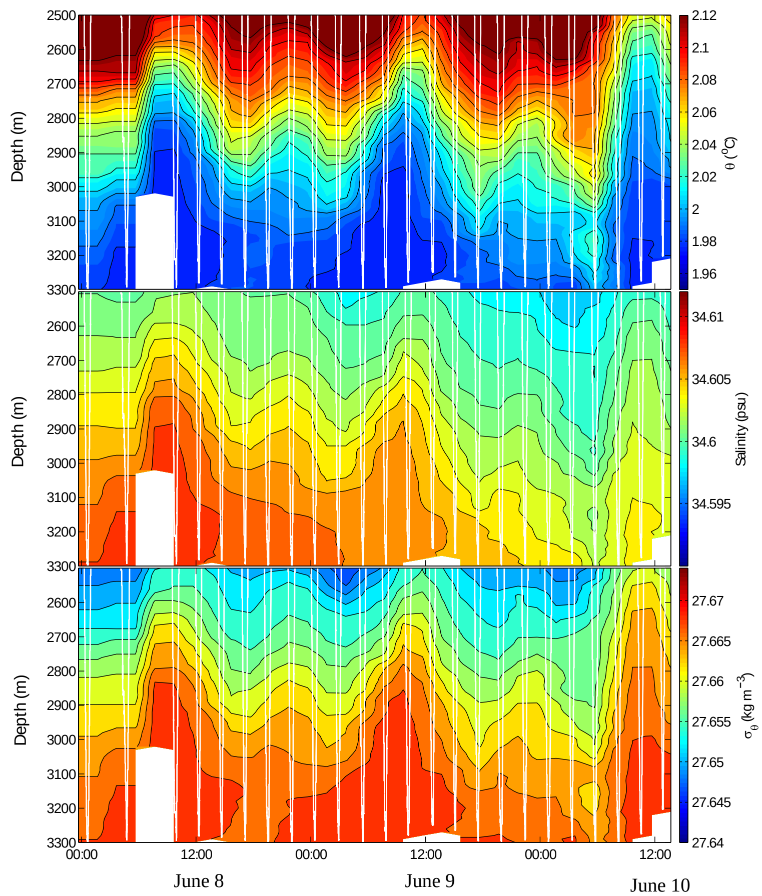

Figure 4. Contour plot of shipboard yoyo CTD measurements near the bottom at Station #5. The white zigzag line marks the track of the CTD casts.

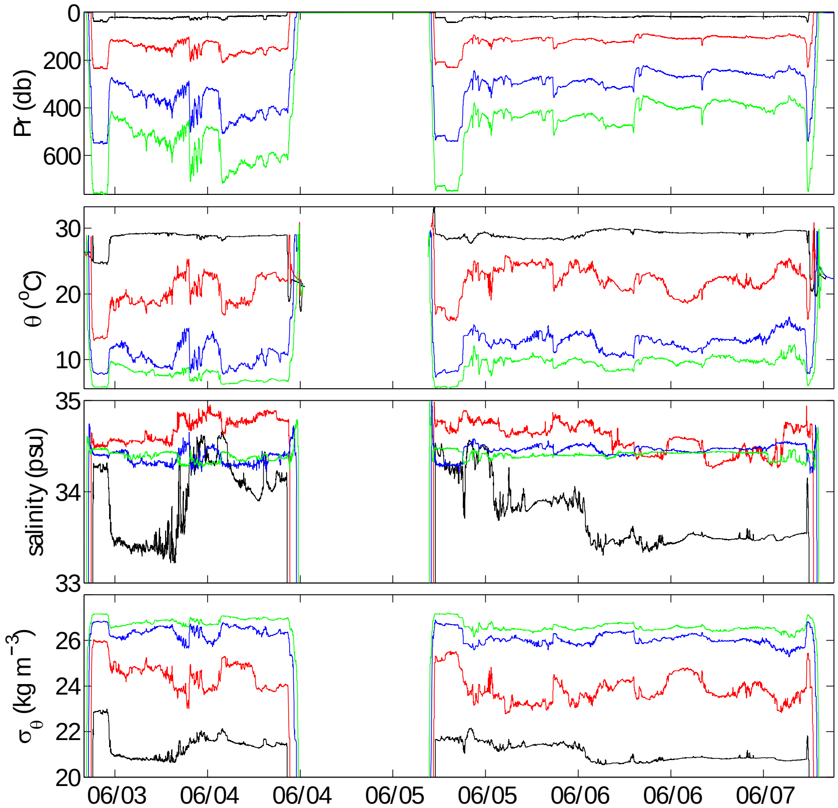

Figure 5. Time series plot of pressure, temperature, salinity, and density measurements taken from four Seabird CTD sensors mounted on the 800-m towed chain at four different depths.

IMPACT/APPLICATION

Numerical models suggest strong internal tides are generated as barotropic tides interact with two prominent submarine ridges in Luzon Strait. These internal tides are believed the sources of nonlinear internal waves often observed in the South China Sea. The strength of internal tides is modulated by the barotropic tidal forcing, the strength of the Kuroshio current, the background stratification, and the strength of the Kuroshio front. It is important to quantify the barotropic to baroclinic tidal energy conversion, dissipation within the Luzon Strait, the energy fluxes toward the South China Sea and Pacific Ocean, and the ultimate fate of the internal tidal energy.

RELATED PROJECTS

Energy Budget of Nonlinear Internal Waves Near Dongsha (N00014-05-1-0284) as a part of NLIWI DRI: In this project, we study the dynamics and quantify the energy budget of nonlinear internal waves (NLIWs) in the South China Sea using observations taken from two intensive shipboard experiments in 2005 and 2007 and a set of nearly one-year velocity-profile measurements taken in 2006–2007 from three bottom-mounted ADCPs across the continental slope east of Dongsha Plateau in the South China Sea. Results of NLIWI DRI will help improve our understanding of the dynamics of NLIWs and will apply to the present project.

Process Study of Oceanic Responses to Typhoons Using Arrays of EM-APEX Floats and Moorings (N00014-08-1-0560) as a part of ITOP DRI: We will study the dynamics of the oceanic response to and recovery from tropical cyclones in the western Pacific using long-term mooring observations and an array of EM-APEX floats. Pacific typhoons may cause cold pools on the continental shelf of the East China Sea. The cold pool dynamics are likely related to the Kuroshio and its intrusion as well as the shelf/slope oceanic processes.