Shipboard LADCP/χpod Profiling of Internal Wave Structure and Dissipation in the Luzon Strait

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LONG-TERM GOALS

We seek a more complete and fundamental understanding of the hierarchy of processes which transfer energy and momentum from large scales, feed the internal wavefield, and ultimately dissipate through turbulence. This cascade impacts the acoustic, optical, and biogeochemical properties of the water column, and feeds back to alter the larger scale circulation. Studies within the **Ocean Mixing Group** at OSU emphasize observations, innovative sensor / instrumentation development and integration, and process-oriented internal wave and turbulence modeling for interpretation.

OBJECTIVES

Luzon Strait represents a major source of internal tides and NLIWs in the SCS. However, unlike other regions of strong internal wave generation (i.e., Hawaii), Luzon Strait is believed to be highly dissipative. We seek to understand the character of this enhanced nonlinearity and turbulence, and how it affects internal wave generation and transmission. Specifically, we intend to:

- identify hotspots of generation and dissipation,
- quantify the structure and variability of wave energy, its flux and dissipation at the generation site.
- link the broader spatial structure, temporal content, and energetics of the internal wave field to the topography, forcing, and mesoscale influences (i.e., Kuroshio).

APPROACH

Much of the turbulent dissipation in Luzon Strait was anticipated to be deep, outside the range of tethered microstructure profilers, and evolving too rapidly for autonomous profilers. We have used a 2-fold approach to quantify this deep turbulence:

1. rapid profiles at abyssal depths are obtained using standard shipboard CTD, augmented with ADCPs, turbulence sensors, and a motion package. These allow us to systematically obtain 36-

h yo-yo timeseries, from which energy generation, energy fluxes, and energy dissipation can be directly measured.

2. Five moorings were successfully deployed and recovered in 2 of the most energetic regions of the strait. Recovery cruises were mid Aug and early Sept, 2011, so these data are just starting to be analyzed.

WORK COMPLETED

We have developed a self-contained microstructure package that can be lowered on a standard shipboard CTD to measure full water column turbulence. χpod-CTD is a deep version of our equatorial-moored χpod (Moum and Nash, 2009), with two fast-response thermistors, a full motion package and 3000-m depth rating. It is installed on a the ship's CTD rosette, which is vaned to set χpod's orientation into the flow. With the addition of 2-300 kHz ADCPs, this system measures full-water column velocity, density, and temperature microstructure, permitting dissipation rates of temperature variance (χ) and TKE (ε) to be computed.

This system was used for turbulence profiling during the 2010 IWISE pilot (Aug/Sept 2010), and on 4 cruises during the main IWISE-2011 experiment. O(500) profiles are now available for analysis to investigate the generation of internal waves, NLIWs, bores and their associated dissipation within Luzon Strait. In addition, one full water-column mooring and four near-bottom moorings were deployed at the central ridge crest and western ridge crest; the hardware for these were funded through our related DURIP. This year was spent doling preliminary analyses of the IWISE-2010 pilot data and preparing instruments for our 5 moorings deployed this summer. All instruments deployed were recovered except for one ADCP, which unfortunately broke free and was lost.

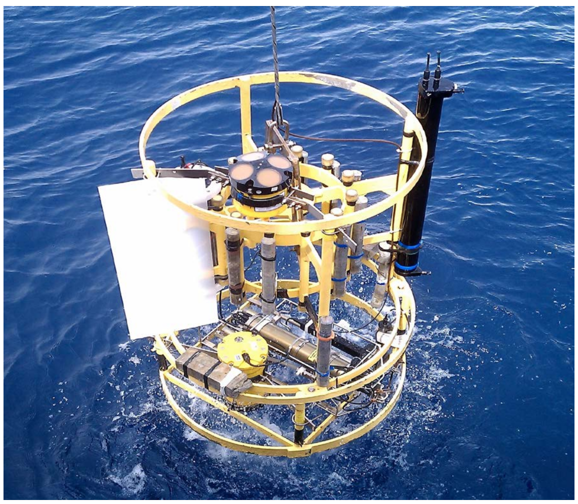

Figure 1: Revelle's CTD as modified during the IWISE pilot to measure full-depth velocity and dissipation rates. 2 ADCPS, a white vane for stabilization, and black χpod are each visible.

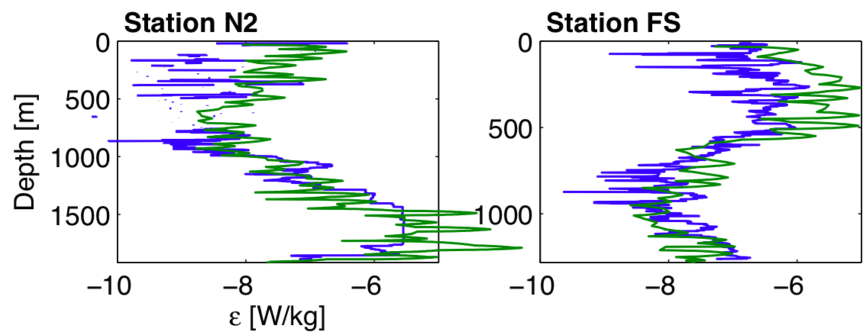

Figure 2: TKE dissipation rate from LADCP/χpods (green) and Thorpe analyses (blue) at two of the most energetic stations observed during the Luzon Strait pilot. These represent the first direct measurements of abyssal turbulence from shipboard CTD/LADCP.

RESULTS

Part 1: CTD/LADCP work.

Initial results are spectacular. From an instrumentation standpoint, χpod/LADCP returned uncontaminated temperature and its gradient on all upcasts during 2010. In 2011, the system was rebuilt to provide greater flexibility for sensor location in order to produce uncontaminated dissipation profiles on both up and down-casts. These have enabled the dissipation rates of temperature variance (χ) and TKE (ε) to be computed to 3000-m depths. A comparison of station-mean dissipation rates from χpod and from Thorpe-scale estimates (figure 2; from 2010 data) is highly encouraging. At abyssal depths, dissipation estimates are consistent in their time-means, but differ in the details (since they are computed from stages of turbulent-billow evolution). In the higher stratification surface waters, Thorpe estimates are biased low due to sensor resolution issues. In the 2011 field season, several hundred additional profiles were acquired, with 160 of them being at the same time/locations as L. St. Laurent's deep microstructure profiler (DMP), which will permit direct statistical comparisons to be made.

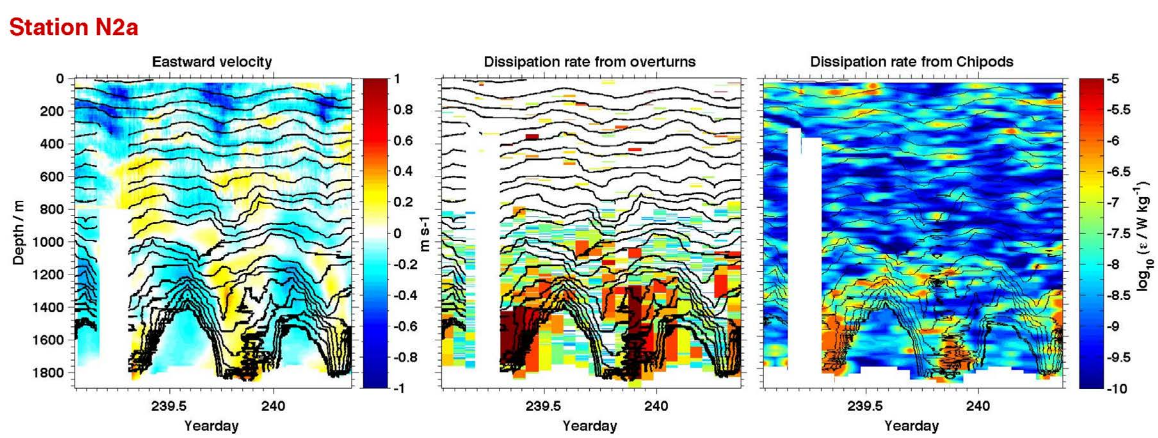

Figure 3 – Timeseries of velocity (left) and TKE dissipation from Thorpe overturns (middle) and from χ (right) for the first occupation of station N2. This was one of the more energetic stations, with vertical displacements and overturns exceeding 500 m, as illustrated by density contours (black).

Within the Strait, internal wave vertical displacements exceed 500 m and TKE dissipation rates are among the largest recorded in the abyssal ocean, exceeding $3x10^{-6}$ W/kg as the newly-generated internal tide interacts with the Western ridge at 1200-1800 m water depths (figure 3). In the upper water column, differences between dissipation rates computed from Thorpe-scales (Fig 3, center), and χpods are due to Thorpe-estimate resolution; however, deep in the water column, these differences are real and provide important clues as to the mechanism and evolution of the turbulent overturns. These dynamics appear to have significantly more nonlinearity and dissipation than other sites of strong internal tide generation, such as the Hawaiian Ridge system (Nash et al 2006; Klymak et al, 2006).

Part 2: Moored T-chains, Stablemoor mooring and χpods.

One focus of our 2011 observations was the structure of wave and dissipation events on the western ridge near station N2. At that site, 5 moorings were deployed at 1-km spacing to capture the evolution of billowing as the waves break at the ridge crest. An example of data from these moorings (recovered 3 weeks ago) is shown in figure 4.

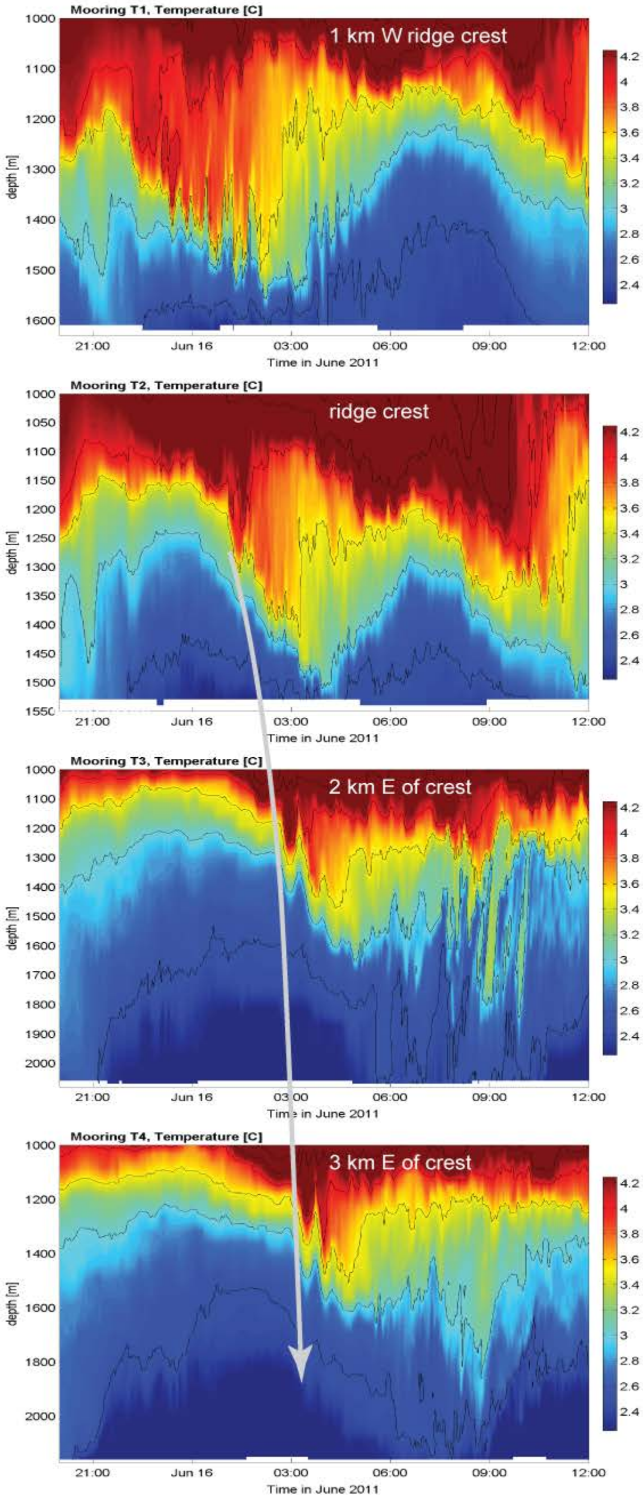

Figure 4: The figure at right shows a 16 h segment of temperature data from the 4 T-chains deployed over the ridge near N2. These moorings were spaced 1 km apart and capture displacements and turbulence in x,z,t space. The depictions at right rival numerical simulations in resolution but capture the represent the true reality and breadth of scales of the real ocean. These figures show the evolution and spatial structure of a 300-m tall wave which grows to 500 m and breaks. Short-wavelength features are coherent across the mooring array and can be tracked (grey arrow). 100-500 m tall turbulent overturns are also visible, particularly at mooring T3 at 0900.

This example represents one 16-h time window within the 3-month deployment. Our objectives are to analyze these records in detail in order to quantify both internal wave and turbulent components. We will combine data from LADCP/χpod, MP-χpods, the moorings shown here, the stablemoor (at A1) and other ancillary moored and model data in these analyses. Ultimately, we will

1. characterize the spatial and temporal variability of high-dissipation events
2. determine the physics of high-wavenumber generation from the surface and internal tides, and the subsequent breakdown into turbulence
3. assess how these dynamics are related to those which have been numerically modeled, with a goal of understanding whether these can be parameterized.

RELATED PROJECTS

Profiling and moored operations are being coordinated with M Alford (UW); analysis of turbulence data are being conducted in conjunction with J MacKinnon (UCSD), H Simmons (UAF) and L. St. Laurent (WHOI). Data/model integration and comparisons will be made with Simmons, Klymak, and Buijsman.

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PUBLICATIONS

Alford, M.H., J.A. MacKinnon, J.D. Nash, H. Simmons, A. Pickering, J.M. Klymak, R. Pinkel, O. Sun, L. Rainville, R. Musgrave, T. Beitzel, K-H Fu and C-W Lu, 2011: Energy flux and dissipation in Luzon Strait: two tales of two ridges. *J. Phys. Oceanogr.* doi: 10.1175/JPO-D-11-073.1 [published]