Fine-Grained Ocean Mixing Vital for Modeling Global Climate

To map out the processes responsible for vertical mixing in the equatorial ocean, IPRC scientists **Kelvin Richards** and **Andrei Natarov** and their JAMSTEC colleagues, headed by **Yuji Kashino**, have taken advantage of the cruises of the Research Vessel *Mirai* servicing the TRITON buoys in the western equatorial Pacific. (The TRITON buoys are part of an array that monitors the state of the ocean for ENSO research and prediction.)

Why are these scientists interested in such vertical mixing? Studies have shown that the magnitude and time evolution of El Niño and La Niña depend on the mean state of the tropical Pacific Ocean. The mean state of the tropical ocean and its interaction with the atmosphere, in turn, depend strongly on the vertical mixing of water properties and momentum in the equatorial thermocline. The team's measurements suggest, however, that currently available climate models are missing important physics regarding ocean mixing in, and above, the equatorial thermocline.

Direct measurements of ocean currents are typically made with an Acoustic Doppler Current Profiler (ADCP). *Mirai* has such a device (SADCP), which is attached to the ship's hull and operates at 75kHz. The relative low frequency allows the sound signal to penetrate a few 100 m into the water column but the vertical resolution is relatively coarse (~10 m). To increase the vertical resolution, the team has been making use of a 600kHz ADCP, which has a vertical resolution of ~1 m. The higher frequency, however, means the depth penetration of the sound signal is much reduced. To obtain deep measurements, this higher frequency ADCP is mounted on a CTD frame and lowered through the water column (LADCP).

Figure 1 shows the eastward component of velocity measured by the two types of instruments along 156°E in

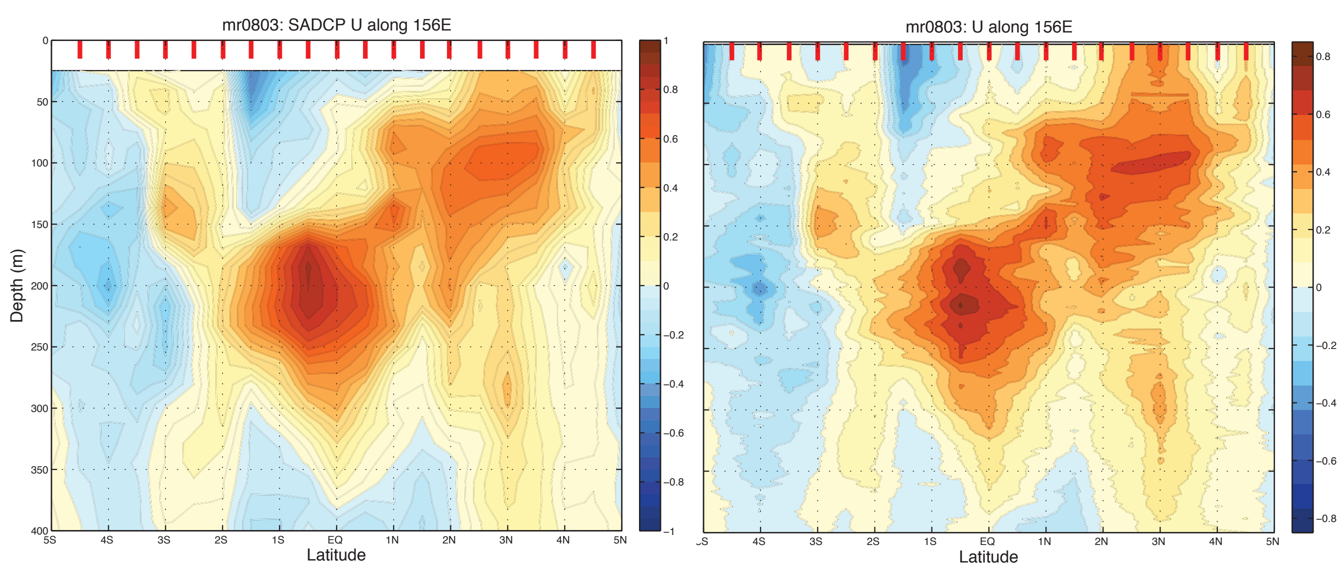


Figure 1. Left: eastward component of velocity measured by the SADCP along 156°E in August 2008 (units: m/s). Right: as for left panel, but measured by the higher frequency LADCP.

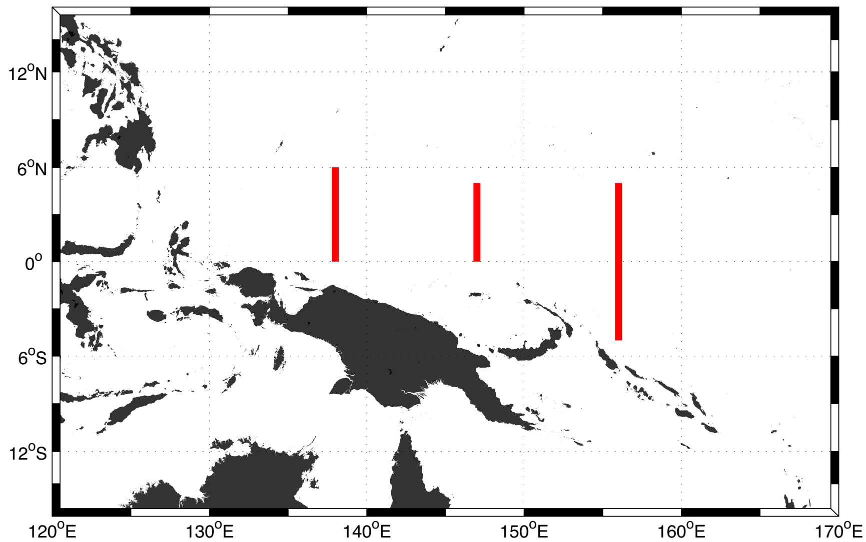


Figure 2. Location of the meridional sections taken on the 3 cruises by the RV *Mirai*.

August 2008. The major eastward flowing currents are the Equatorial Under Current (EUC), seen in the left panel centered around 200-m depth at 0.5°S, and the North Equatorial Counter Current (NECC) centered at 100-m depth at 3°N. The high-resolution measurements with the LADCP in the right panel show a great deal more vertical structure than those with the SADCP and reveal the existence of small vertical scale structures (SVSs) superimposed on the broader scale currents. The strength of the SVSs splits the core of the EUC into several distinct maxima and minima.

To date the team has conducted three surveys along the lines 156°E and 147°E and one along 138°E (Figure 2). The latter line is being surveyed a second time in late summer 2011, at the time of this writing. In all surveys, the vertical shear of the currents is dominated by SVS features, which have a vertical scale of O (10 m). This is illustrated in Figure 3, which shows the mean-squared shear, S^2, observed at the equator, 156°E, averaged over a 24-hour period in December 2010, based on both the SADCP and the higher resolution LADCP current measurements. The blue curve shows the characteristic small vertical scale and high valued peaks measured by the LADCP, whereas the cyan curve reflects the shear measured by the lower frequency SADCP. Both the magnitude and depth of the maximum flows differ greatly.

Figure 3 also shows the time-averaged turbulent kinetic dissipation rate, ε, which is estimated from measurements taken with a microstructure probe (MSP) that was deployed after each CTD/LADCP cast. Above 300-m depth, the peaks in S^2 and ε coincide remarkably, implying that the SVSs are responsible for a significant fraction of the mixing. The average LADCP and MSP measurements taken reveals that high values of ε tend to occur mostly when the Richardson number is around ¼ or less.

These measurements highlight the importance of resolving the structures that cause the mixing. The patch of high ε between 320- and 370-m depth seen in Figure 3b is in a region of weak stratification that requires much weaker vertical shears to promote turbulent mixing. Patches of elevated shear

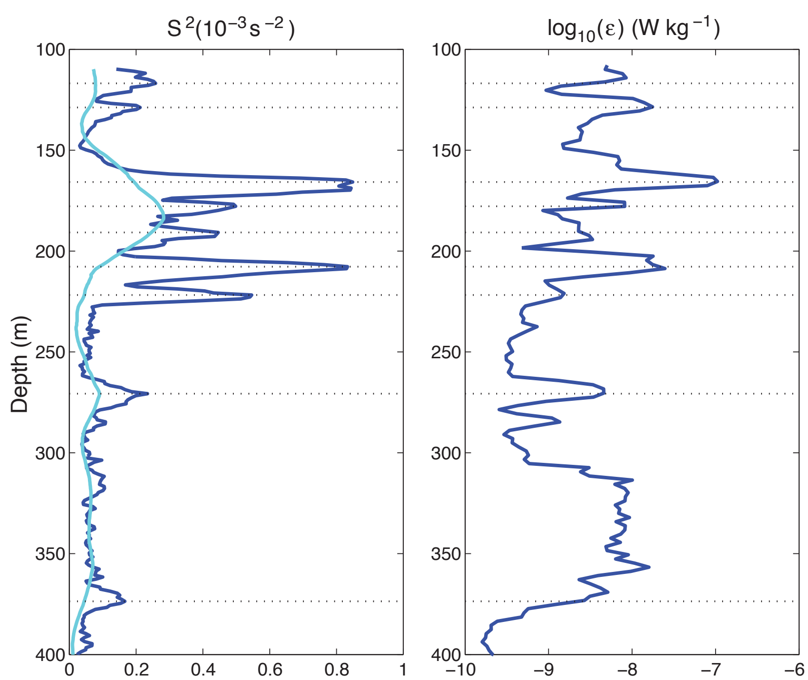
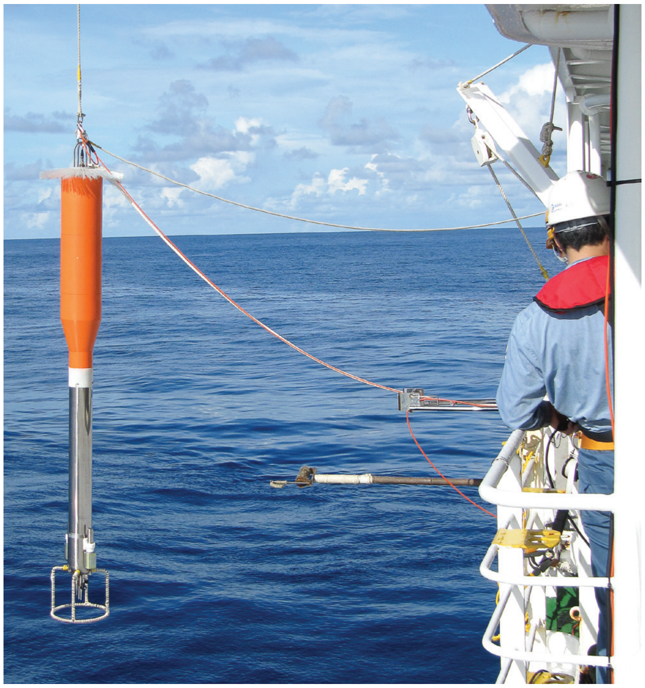


Figure 3. Left panel: time-averaged vertical shear squared, S^2, at the equator, 156°E, as measured by the LADCP (blue curve) and SADCP (cyan curve). Right panel: time-averaged turbulent dissipation rate, ε.



Microstructure profiler before deployment. The shear probes are at the tip of the instrument (protected by a cage). The instrument free-falls through the water and data is transmitted to the ship by a conducting cable. Photo courtesy Kevin Richards.

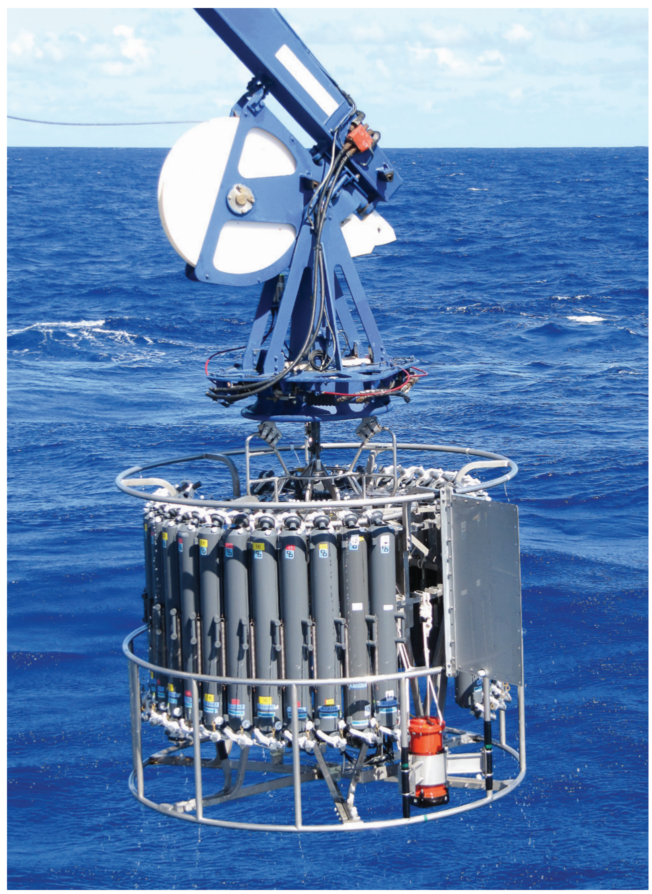
persist over the 24-hour period but much less than those in and above the thermocline, indicating that a different flow regime causes the mixing there.

Why do these small-scale vertical features exist? Theory and models point to a combination of instabilities in the current system (inertial and parametric subharmonic instabilities) and high vertical-mode, wind-generated, inertia-gravity waves, both of which have scales similar to those observed. Moreover, observations during different states of the El Niño – Southern Oscillation show a large modulation of mixing and of the effective vertical diffusion coefficient: the level of mixing induced by small vertical structures in December 2011 during La Niña conditions was considerably greater than in December 2009 during El Niño conditions.

Conventional climate models do not have sufficient resolution to resolve the small-scale vertical structures and are thus missing an important source of mixing in the equatorial ocean. Initial tests performed by **Wataru Sasaki**, JAMSTEC, using the climate model SINTEX-F2 run on the Earth Simulator, suggest the impact of the small-scale vertical-induced mixing is large. Parameterizing their impact will require taking their generation mechanisms into account.

To gain a better understanding of the generation of small-scale vertical structures and their impact on mixing, more observations are needed. In 2012 an experiment, funded by the National Science Foundation and called MIXing in the Equatorial Thermocline (MIXET), will take place. A collaborative effort among the IPRC, the Department of Oceanography at the University of Hawaiʻi at Mānoa, JAMSTEC, Woods Hole Oceanographic Institute, and Seoul National University, the experiment calls for observations that include long-term moorings and intensive sampling using the LADCP and a microstructure probe. The effort should yield more information on the controls of the formation of small-scale vertical structures and their impact on mixing. Such information is vital for improving the representation of mixing processes in climate models.

This story is based on: Richards K.J., Y. Kashino, A. Natarov and E. Firing (in press): Mixing in the western equatorial Pacific and its modulation by ENSO. *Geophys. Res. Lett.*



Recovery of the CTD/LADCP after deployment. The LADCP is the orange instrument attached to the frame. The transducer heads point downwards. Photo courtesy Kevin Richards.