R/V Falkor FK150728
Mixing up the Tropical Pacific
Final Report

30 July – 17 August, 2015
Majuro, Marshall Islands to Honolulu, Hawaii

1. Overview

The cruise extended measurements aimed at determining and quantifying the processes in the tropical ocean that generate turbulence and associated mixing of properties in the upper ocean. Mixing of heat, salt and momentum plays a large role in shaping the upper ocean structure and the way the ocean interacts with the atmosphere. Previous measurements in the western equatorial Pacific identified small vertical scale flow features (SVSs) as major contributors to shear-generated turbulence within and above the thermocline. The SVSs themselves are generated through a combination of wind forcing and flow instabilities. A primary aim of the present cruise was to determine if similar flow features dominate the vertical shear in the central equatorial Pacific and to determine the levels of turbulence generated by them.

The cruise took place during a developing El Niño. This had consequences for the conditions encountered. Figure 1.1 shows the time history of anomalies in the eastward wind, sea surface temperature (SST) and the depth of the thermocline (given by the depth of the 20°C isotherm) along the equator in the Pacific Ocean. El Niño conditions are seen in the slackening or reversal of the easterly trade winds, increasing SST in the central and eastern Pacific, and the deepening of the thermocline in the east.

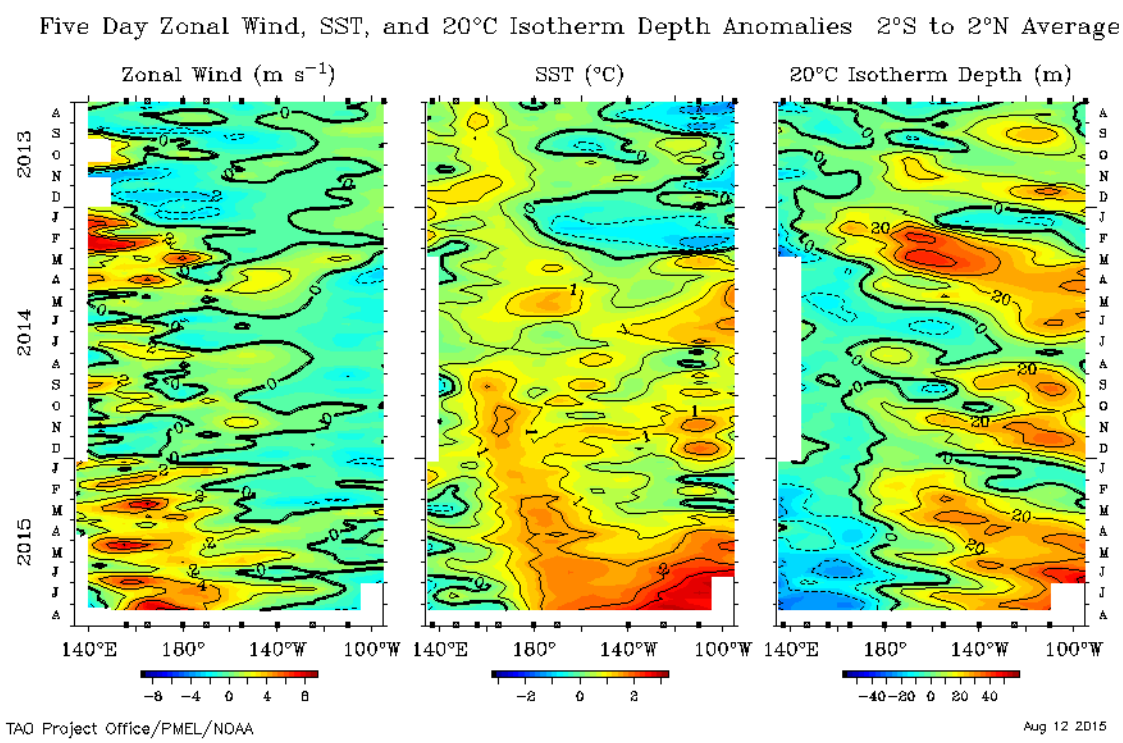

Figure 1.1 Time history of anomalies in the eastward wind, sea surface temperature (SST) and the depth of the 20°C isotherm) along the equator in the Pacific Ocean. (from PMEL TAO web site)

In addition a number of strong westerly wind events occurred in the western equatorial Pacific, starting in February 2015, continuing through to the time of the cruise, August 2015. The eastward limit of these wind events increases with time. Along 170W (the location of the measurements taken on the present cruise) two strong westerly wind events occurred in July, extending from the equator to several degrees north (Figure 1.2). The change in winds led to surface currents being directed towards the east. The expectation is the strength of the Equatorial Under Current had been reduced (although not adequately measured during the cruise), and the variable winds may have generated strong inertia-gravity waves leading to strong SVSs.

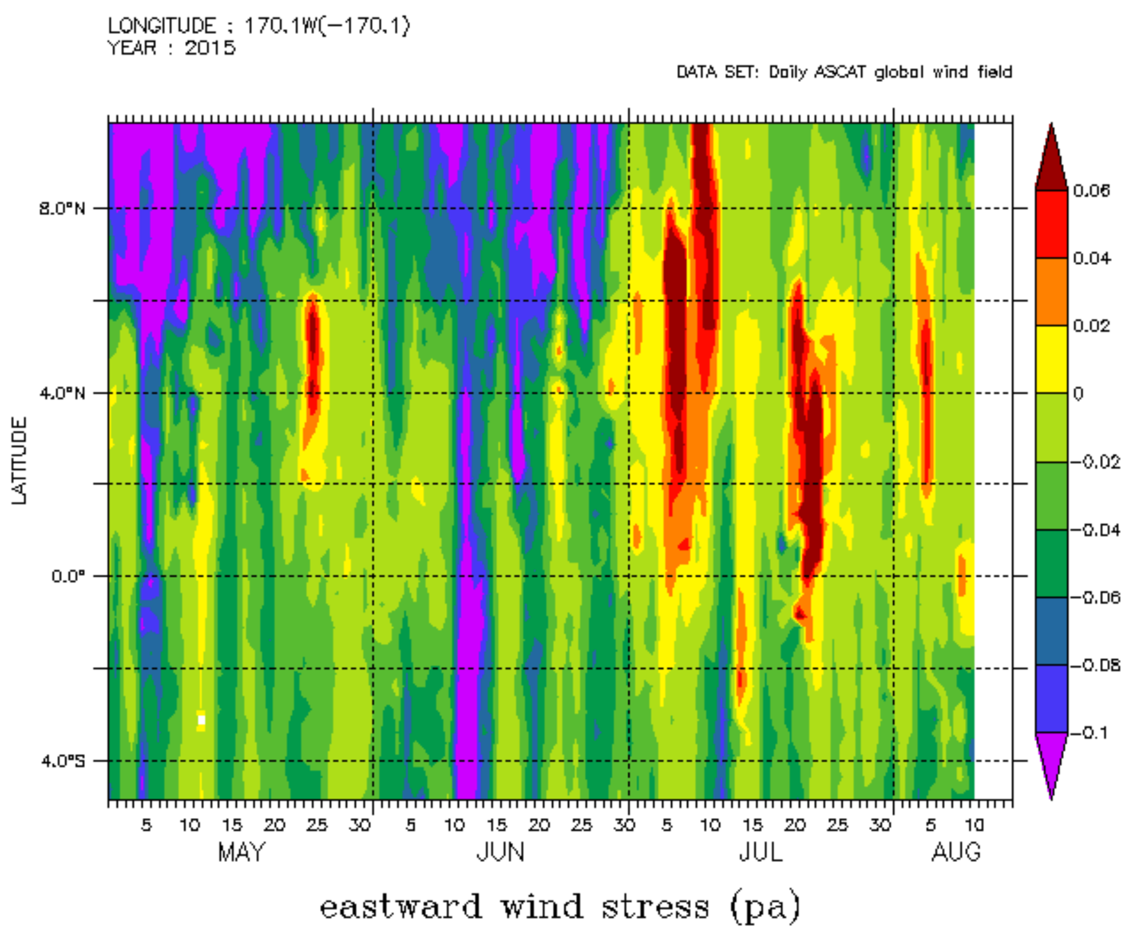

Figure 1.2. Eastward component of the surface wind stress along 170W, May to August, 2015

2 Summary of observations

All *in situ* measurements, apart from underway meteorological and ocean sampling, were taken along 170W (see cruise track, Figure 2.1). Primary instrumentation was a CTD and a 600kHz ADCP attached to the CTD frame operated in lowered mode (LADCP). Casts were typically taken to 500m. Water samples were taken on 6 of the CTD casts for nutrient analysis. A combination of meridional sections, time series and tow-yo's were made: see Figure 2.2 for the time history along 170W. When on station or tow-yo'ing at slow speed a 300kHz ADCP was deployed on the USBL spar to sample currents in the top 50-80m of the water column. It was planned to take turbulence measurements with a VMP500. The instrument had problems throughout the cruise with only a couple of usable profiles produced. Both of the ship's ADCPs, a OS75 and 300, did not function throughout the cruise. A more detailed description of the measurements from the instrumentation is given in the cruise report available at http://schmidtocean.org/wp-content/uploads/FK150728cruise_report.pdf.

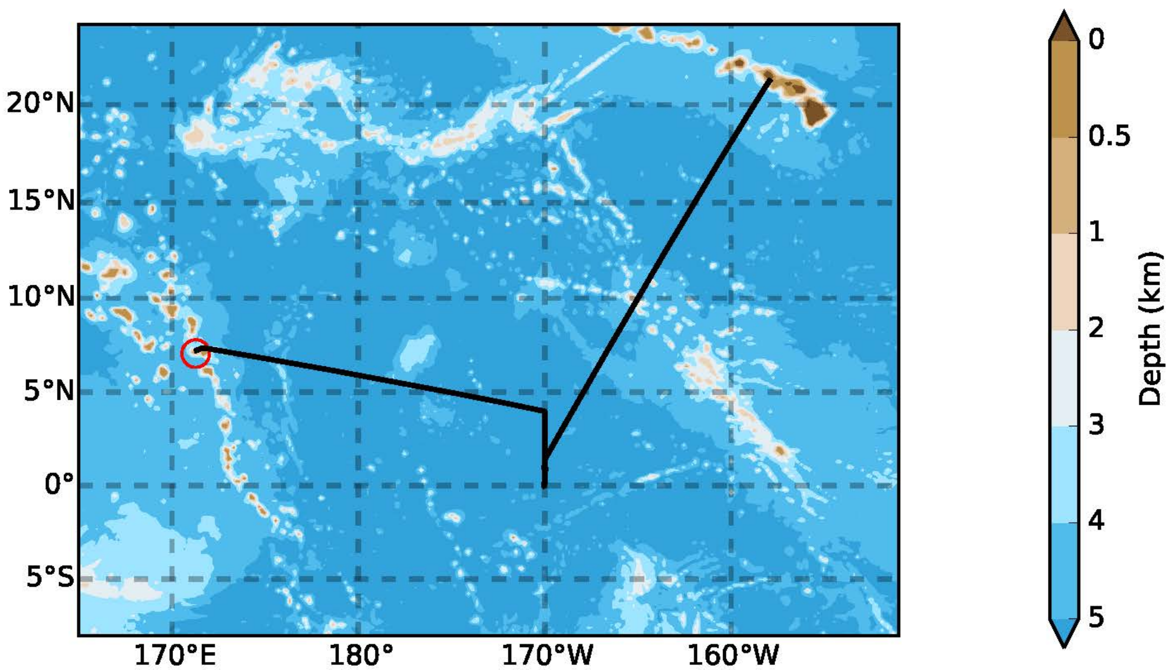

Figure 2.1. Cruise track

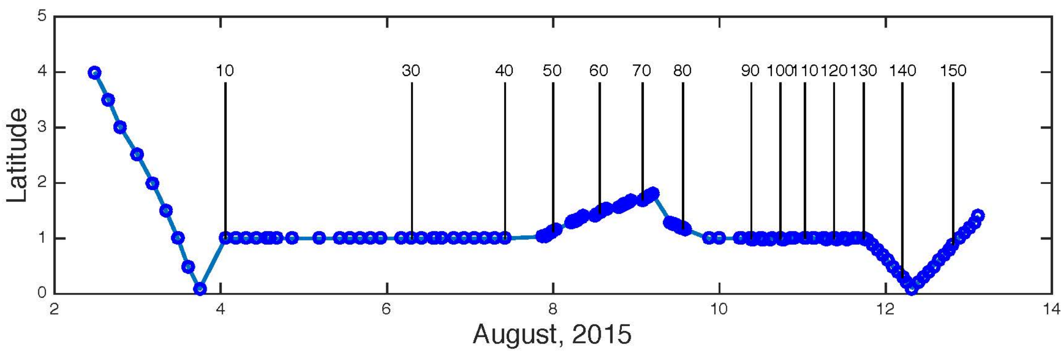

Figure 2.2. Ship's position along 170W as a function of time. Circles indicate casts. Numbers indicate cast numbers.

3 Data Availability

The CTD, LADCP, WH300 ADCP and nutrient data are available from the University of Hawaii at

ftp://currents.soest.hawaii.edu/pub/outgoing/Falkor/clean/FK150728/

together with the metadata file readme_FK150728.txt

Additional data, including underway, swarth bathymetry and navigation data can be found at the Rolling Deck to Repository and Marine Geoscience Data System (see http://schmidtocean.org/cruise/mixing-up-the-tropical-pacific/)

4 Initial Analysis

As found in the western equatorial Pacific, the vertical shear of the ocean currents was dominated by relatively small vertical scale (~20m) features. Figures 4.1 and 4.2 show the vertical shear of the zonal (eastward) and meridional (northward) velocity components in the upper 300 meters for the entire cruise as a function of time, respectively. A time series was performed at 1N, Aug 4-7 (casts 010-044, see Figure 2.2). We can clearly see upward phase propagation at around 150m depth which is consistent with the dynamics of the inertia-gravity waves (IGWs) radiated from the mixed layer into the ocean interior. Further evidence for the downward energy propagation was gathered by the high horizontal resolution northward section (Aug. 7-9, casts 045-074) in which the phase lines between 100 and 200m depths slope upward at a steeper angle suggestive of phase lines sloping up towards the north. The phase lines during a second time series (Aug 9-11) and northward section (Aug 12-13) have similar characteristics. The remaining portions of the plot provide further data that will be used in post cruise analysis of the flow field.

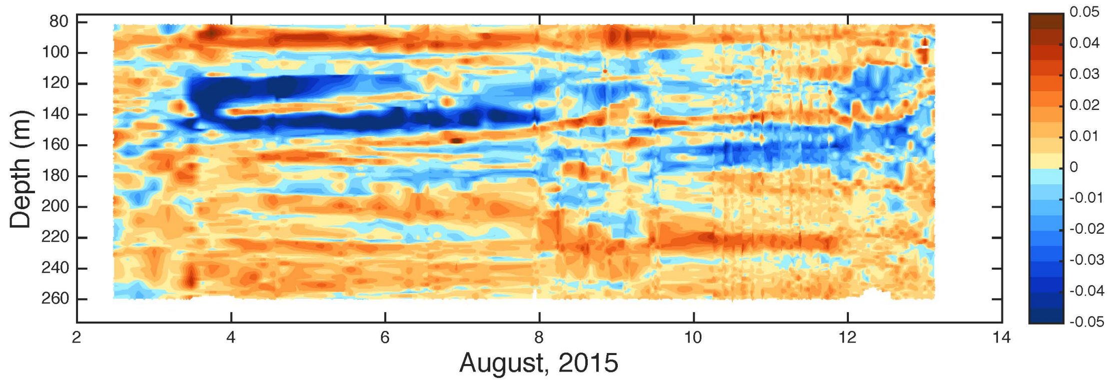

Figure 4.1 Vertical shear of the zonal (eastward) component of velocity, du/dz, as function of time. Vertical profiles have been aligned with respect to density.

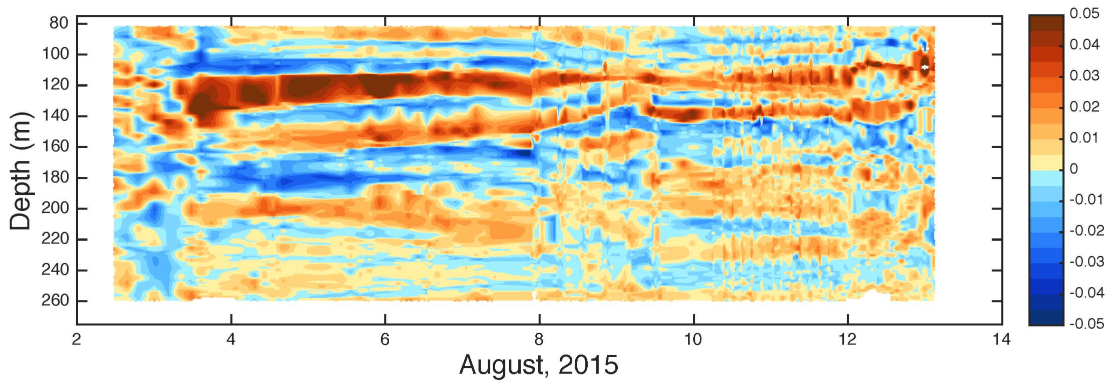

Figure 4.2 Vertical shear of the meridional (northward) component of velocity, dv/dz, as function of time. Vertical profiles have been aligned with respect to density.

Figure 4.3 shows the power spectra of the shear of the zonal (solid blue line) and meridional (solid red line) components of velocity. Both spectra peak at a wavelength of around 50m. To further investigate the properties of the observed flow features and their source a regional Ocean Model has been run, with the necessary high vertical and horizontal resolution, forced with observed winds for a period that includes the time of the cruise. The power spectra of the vertical shear of the model flow at the location of the observations is also shown in Figure 4.3 (dashed lines). It is pleasing to see the model captures very similar small scale features in the shear suggesting the model will be a useful tool in elucidating the physics of flow feature and their contribution to turbulence and mixing.

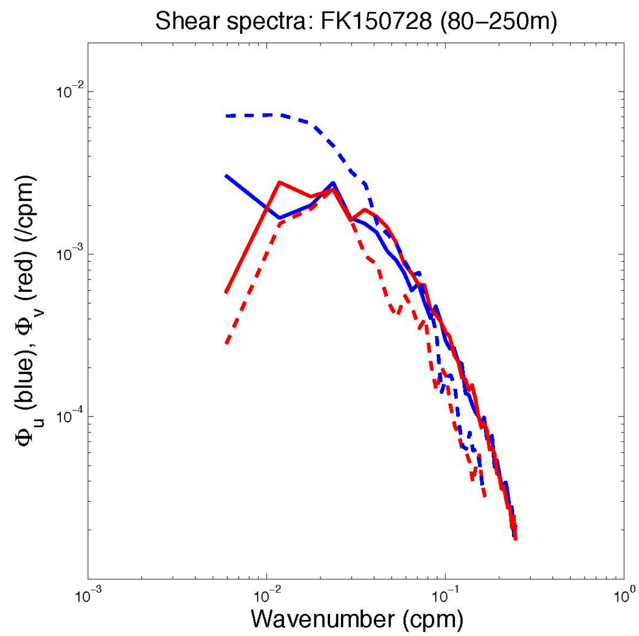

Figure 4.3 Power spectra of the vertical shear of the zonal and meridional components of velocity (blue and red lines, respectively) around 1°N, 170°W, August 2015. Solid lines: Observations. Dashed lines: Model results.

It is unfortunate that because of instrument failure very few turbulence measurements were taken during the cruise. We can make use, however, of earlier observations that show a strong relationship between turbulence activity and the measured shear and stratification (Richards *et al*, 2015). The vertical diffusion coefficient, κ_v, estimated from shear and stratification measurements taken around 1°N, 170°W on the present cruise is shown in Figure 4.4. There are elevated values of κ_v down to the bottom of the thermocline which is at a depth of approximately 200m. The elevated values centered on 140m are a consequence of the downward propagating inertia-gravity wave.

Also shown in Figure 4.4 is the time averaged chlorophyll concentration estimated from the observed florescence and the nutrient (nitrate plus nitrite) concentrations got from bottle samples. These data will be used to estimate nutrient fluxes to be compared with daily rates of change of bio-mass.

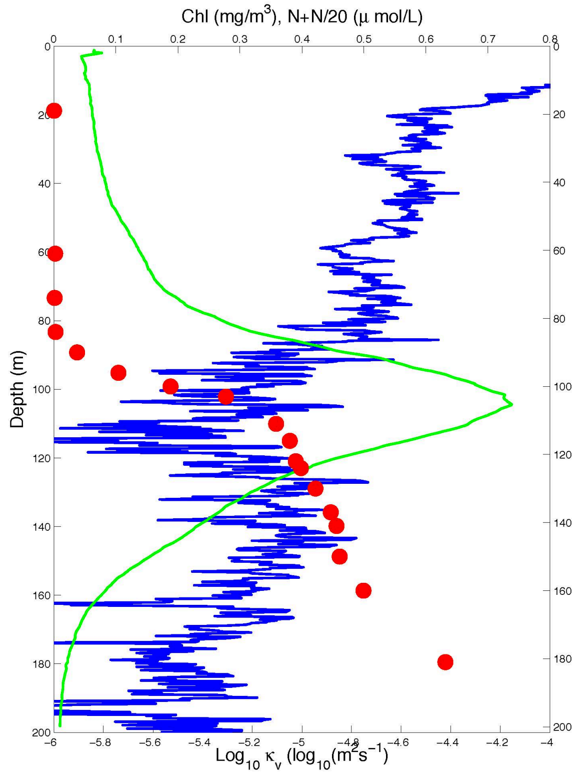

Figure 4.4 Vertical profiles of the estimated vertical diffusion coefficient (blue line), chlorophyll concentration (green line) and nutrient (nitrate plus nitrite) concentration (red dots)

5 Expected Outcomes:

Analysis of the the observations and model results will continue leading to the preparation of two papers:

Factors influencing mixing in the central equatorial Pacific (from observations and model results)

Impact of mixing on biological production in the deep chlorophyll maximum in the central equatorial Pacific

Reference:

Richards K.J., A. Natarov, E. Firing, Y. Kashino, S.M. Soares, M. Ishizu, G.S. Carter, J.H. Lee and K.I. Chang, Shear--generated turbulence in the equatorial Pacific produced by small vertical scale flow features. J. Geophys. Res. 120, doi: 10.1002/2014JC010673, 2015.