Small vertical scale features in the velocity field of the equatorial ocean: implications for both lateral and vertical mixing

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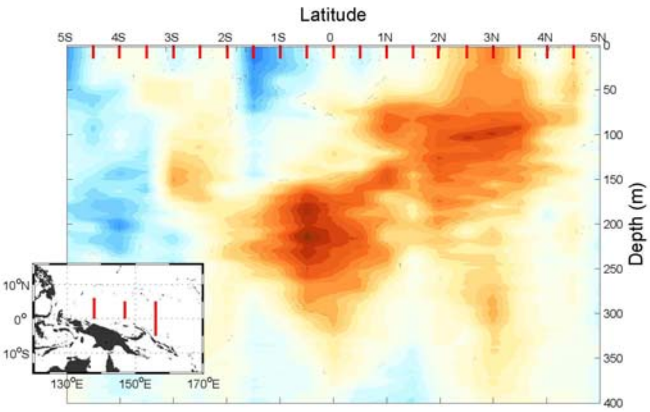
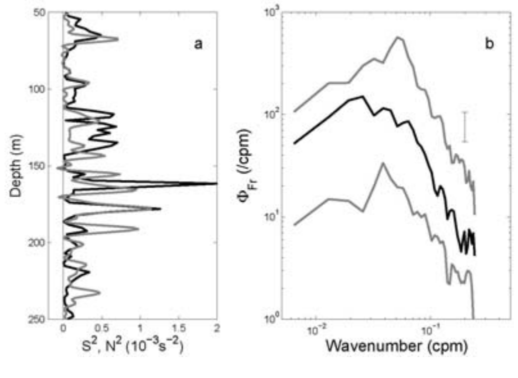
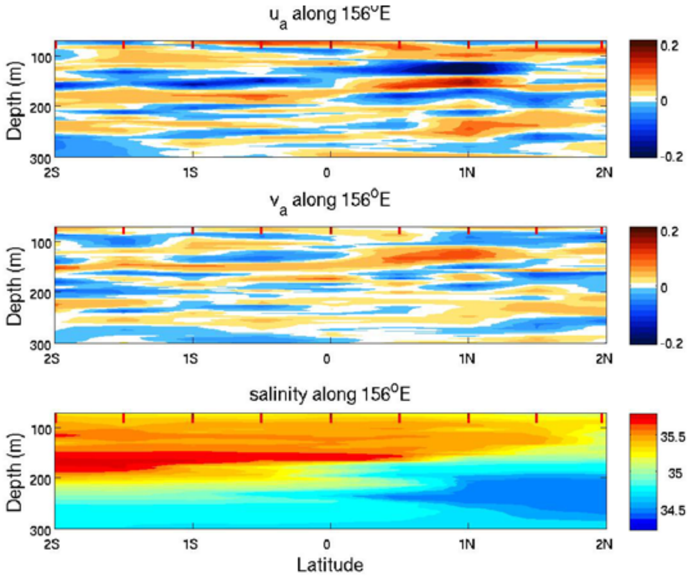
The magnitude and time evolution of El Niño Southern Oscillation climate events depends on the state of the tropical Pacific Ocean. The state of the tropical ocean in turn depends strongly on both the lateral and vertical mixing of water properties and momentum in the equatorial thermocline. Yet the processes controlling the level of mixing are poorly understood. Reason to believe that climate models may not be capturing the relevant physics comes from observations of elevated levels of vertical mixing in the thermocline and the interleaving of water masses. Here we present observations that for the first time show the lateral coherency of small vertical scale features in the velocity field. These features have a vertical scale of order 10m and can extend for a few hundred kilometres in the north--south direction. The observations suggest a linkage between lateral and vertical mixing with the level of both being controlled by a combination of instabilities of the equatorial current system and possibly wind--induced near-inertial oscillations. The picture is very different to that assumed in present--day climate models and calls for a rethinking of the way mixing processes are prescribed in such models.



The eastward (zonal) component of velocity measured along 156°E in July 2008. Red colours indicate eastward flow, blue westward. Contour interval is 0.05 ms^{-1}. Measurements were taken with a high resolution Acoustic Doppler Current Profiler. The major currents seen here are the Equatorial Under Current (EUC), centred just south of the equator at 220m depth, and the North Equatorial Counter Current (NECC) centred around 3°N and 100m depth. Superimposed on the major currents are features with a much smaller vertical scale. The location of the section is indicated by the insert which also shows the location of 2 other sections taken in the same year.

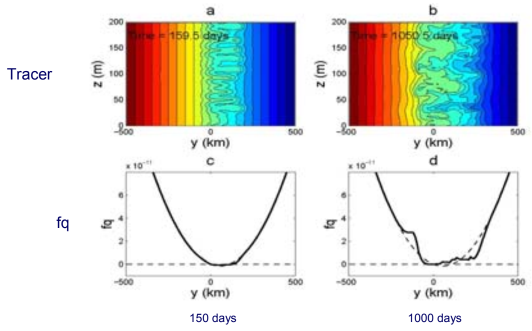


(a) Vertical profiles of S^2 (the square of the vertical gradient of velocity) and N^2 (the square of the buoyancy frequency, which is proportional to the vertical gradient of density) at 1°N, 156°E. Both quantities show regions of small gradient separated by narrow regions of high gradient. It is noteworthy that at this location a number of the spikes in S^2 correspond to a spike in N^2. Low values of the Richardson number, $Ri=N^2/S^2$, indicate a susceptibility to shear induced turbulence. The appropriate critical value of Ri for the vertical resolution of the data is unclear. Here we note that 35%, 17% and 8% of values of Ri are less than 1, 0.5 and 0.25, respectively, in the depth interval 100-250m between 5°S-5°N.(b) vertical wavenumber Froude spectra, Φ_{Fr}, for three latitudinal bands along 156°E. The Froude spectrum is formed by dividing the spectrum of the vertical shear by the mean value of N^2 over the depth range of the measurements. Here we consider velocity shear data between 100-250m depth. Spectra from individual profiles have been averaged over the latitudinal bands: 5°S-2°S, 2°S-2°N and 2°N-5°N. In the figure the spectra from the southern and northern bands have been displaced downward and upward one decade, respectively, and plotted with a grey line.



The velocity data along 156°E after a high-pass filter has been applied in the vertical. The data are plotted on constant potential density surfaces at the mean height of individual density surfaces. Upper panel: eastward component of velocity, u_a. Middle panel: northward component of velocity, v_a. Lower panel: salinity. The red lines at the top of each panel indicate the location of individual profiles. The data show the flow is populated by numerous small vertical scale features. Many of these features extend for a few hundred kilometres in the north--south direction. Close to the equator there is a distinct change in the vertical scale of the features above and below 150m depth with the signature of a high vertical mode mixed Rossby-gravity wave above 150m. The distribution of salinity suggests the small vertical scale velocity structures are responsible for advecting water masses over considerable distances.

Inertial Instability with Oscillation



Results from a numerical experiment investigating the impact of inertial instability in an oscillating flow using parameters pertinent to the equatorial Pacific (from Natarov, et al, JFM, 2008). The instability produces small vertical scale velocity structures that eventually mix tracers, momentum, and fq in both the horizontal and vertical (where q is the potential vorticity). Applying a 3D linear instability analysis (Natarov and Richards, to appear JFM) to the flow shown here indicates two modes of instability, a PSI mode that has characteristics very similar to those of the observed high mode mixed Rossby gravity wave, and a mixed inertial instability/PSI mode that has a vertical scale similar to the lower end of the elevated energy shown in the Froude spectrum opposite.