Ocean Aspects of El Niño

/ Very brief and rather incomplete notes /

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Contents.

0. ENSO and ocean-atmosphere interactions.

Heat fluxes across the ocean surface determine sea surface temperatures over much of the globe. The tropics, however, are different because there the dynamical response of the oceans to the winds is of primary importance. This is because the warm surface waters of the tropics constitute only a very shallow layer floating on the cold water below. The winds, by causing variations in the depth of the thermocline, can expose cold water to the surface. For example, intense westward trade winds along the equator during La Niña drive the warm waters westward while bringing cold water to the surface in the east. A modest disturbance in the form of a brief burst of westerly winds may generate currents that transport some of the warm water eastward, thus decreasing the zonal temperature gradient. The resultant weakening of the trade winds will cause more warm water to flow eastward, causing even weaker winds. That is how El Niño can develop from a modest initial disturbance. Thus, the explanation for El Niño and La Niña, and for the Southern Oscillation, involves a circular argument: changes in sea surface temperature are both the cause and consequence of wind fluctuations. This notes describe the oceanic aspects of this inherently coupled phenomenon.

1. Introduction.

1.1. The mean state of the tropical ocean-atmosphere system.

The mean state of the ocean-atmosphere system in the tropical Pacific is characterized by the mean easterly winds that result in the east-west thermocline slope and in significant zonal SST gradient (Figure 1). The wind stress causes warm water to accumulate in the western Pacific and cold water to be upwelled in the east, creating the “warm pool” in the west and the “cold tongue” in the east (Figure 2). These zonal asymmetries in the background state establish conditions necessary for the growth of ENSO-related anomalies.

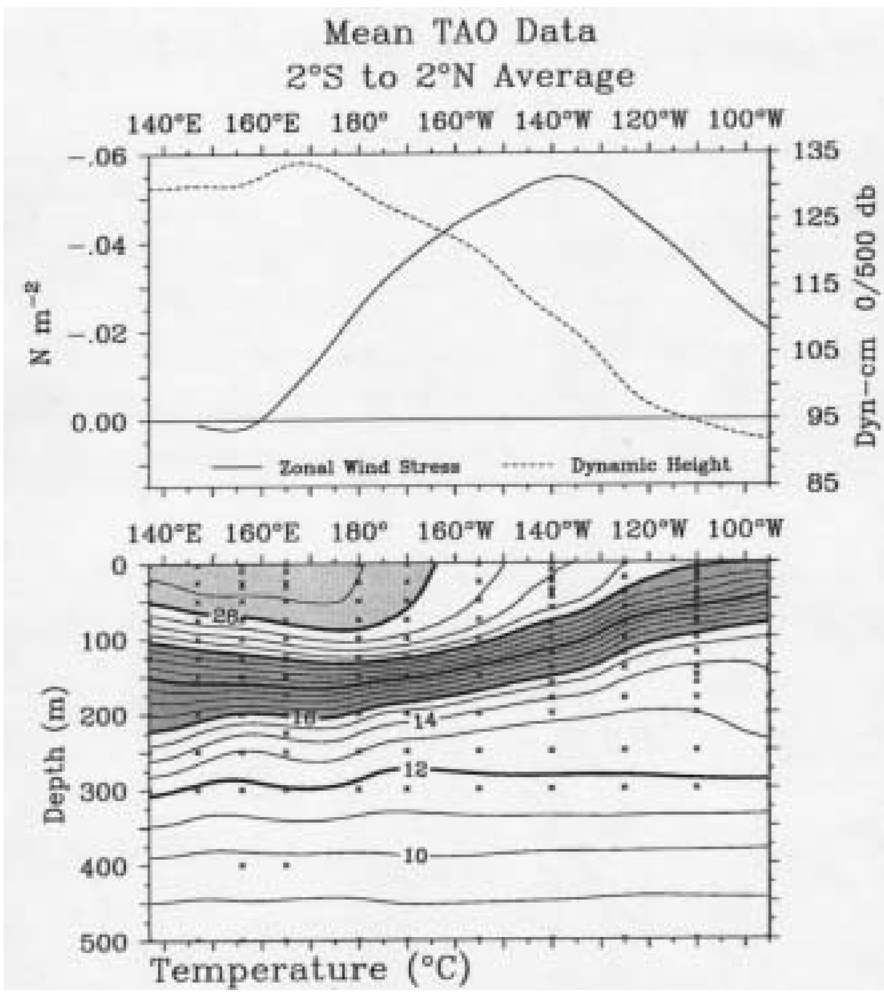


Figure 1. Zonal section of mean temperature along the equator and the corresponding mean zonal stress and dynamic height in the Pacific.

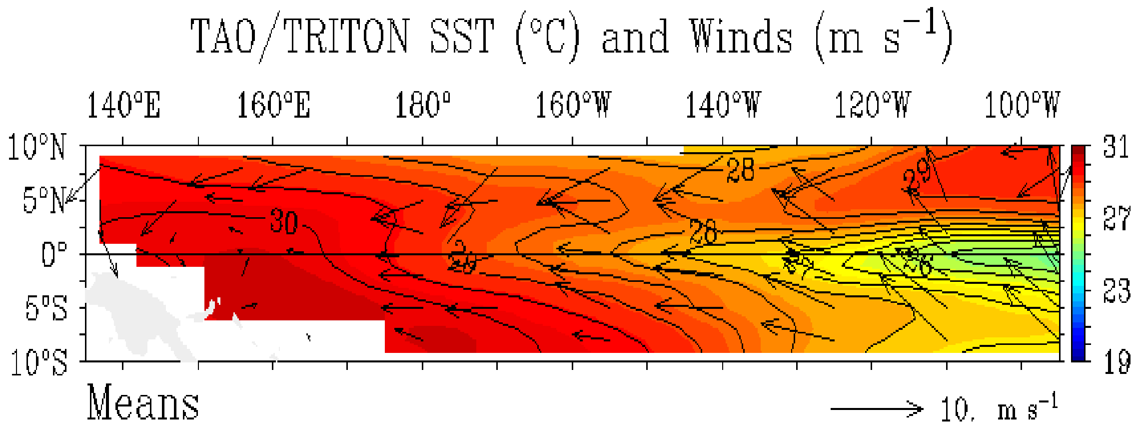


Figure 2. Typical SST and the wind stress field in the tropical Pacific.

The meridional asymmetry of the mean state - there exists a north-south SST gradient in the eastern Pacific - is also important and will be considered later. (The atmospheric Tropical Inter-Convergence Zone (ITCZ) is north of the equator, so that the surface winds in the eastern Pacific have a northward component.)

It is significant that the plots of in Figure 1-2 and several other figures in the notes are possible because now scientists have a very effective scientific (and hopefully forecasting) tool at their disposal - the famous TOGA / TAO / TRITON (Figure 3) array of buoys constantly measuring a number of ocean characteristics, including temperature and current velocities.

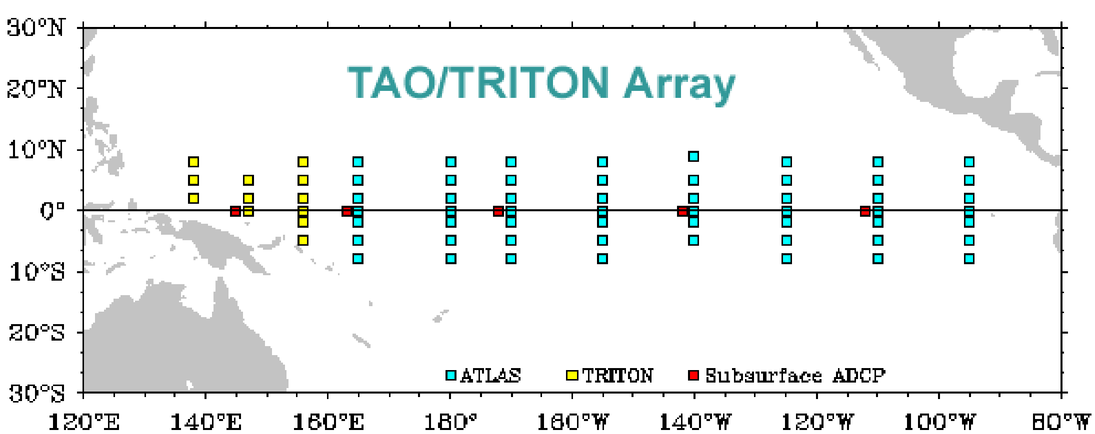


Figure 3. The TOGA / TAO / TRITON array.

1.2. ENSO variability.

The mean state described in the previous section is actually unstable to small perturbations. As a result, an oscillation is possible (known as the Southern Oscillation), with El Niño as its warm phase, and La Niña as its cold phase. Figures 4 - 7 give a good idea of what happens during the two phases.

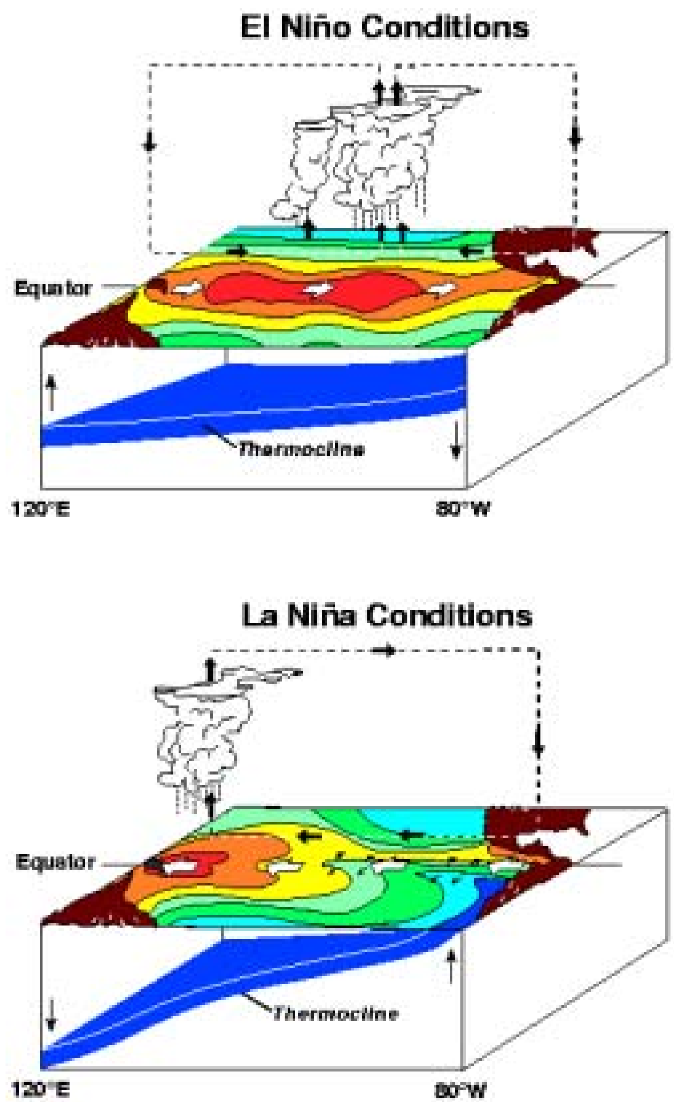


Figure 4. Schematic plot of El Niño and La Nina conditions. A normal condition would look like a weak La Niña.

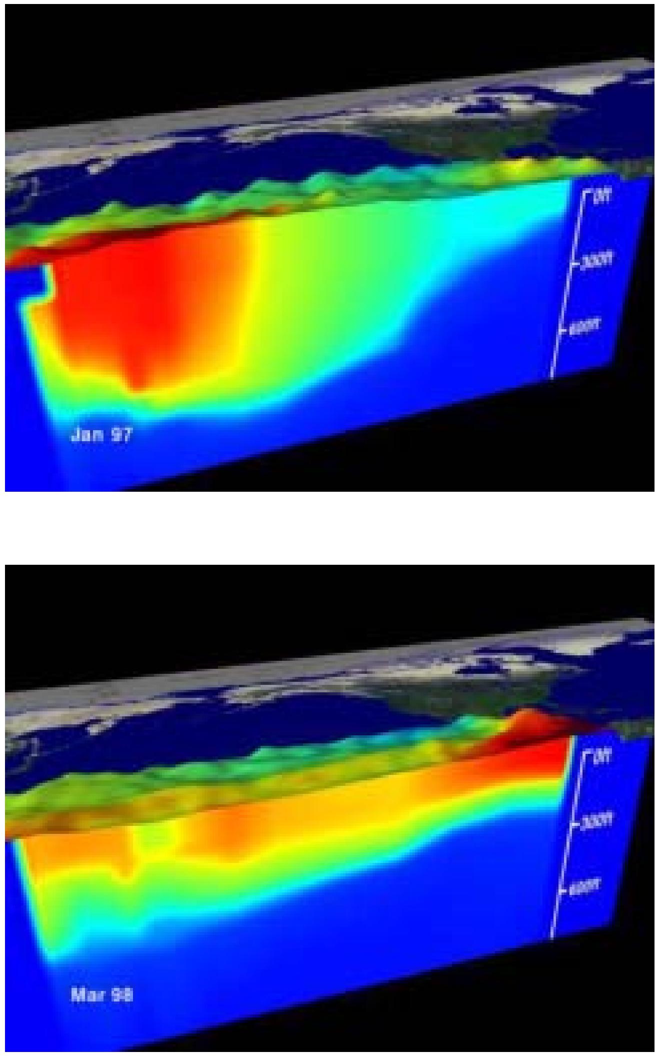


Figure 5. An east-west vertical section along the equatorial thermocline during La Niña and El Niño conditions.

The trade winds relax during El Niño, so that the thermocline becomes almost horizontal. The warm pool expands towards the east, and the cold tongue virtually disappears. During La Niña this reverses, resulting in a stronger cold tongue and larger thermocline slope. Figure 6, B and C, depicts conditions at the peaks of particularly intense El Niño and La Niña episodes.

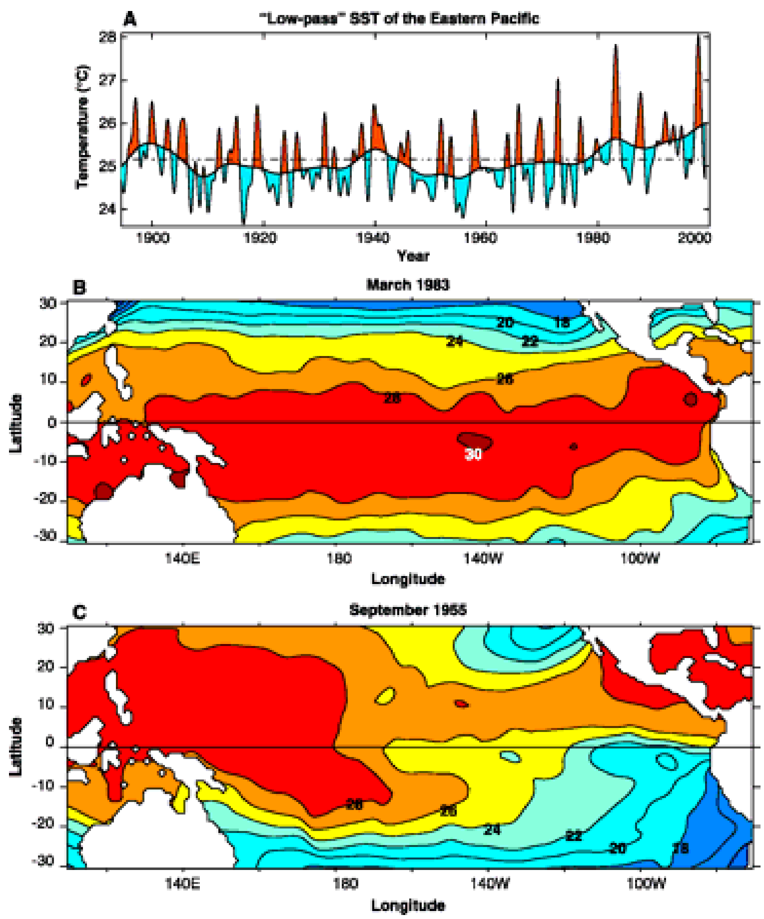


Figure 6

(A) The interannual oscillations in sea surface temperature (SST) at the equator in the eastern Pacific shown on the background of the decadal fluctuation (obtained by means of a low-pass filter) after removal of the annual cycle and higher frequency variability. The horizontal dot-dashed line is the time average for the record.

(B) - (C) Sea surface temperatures at the peaks of typical El Niño (B) and La Niña (C).

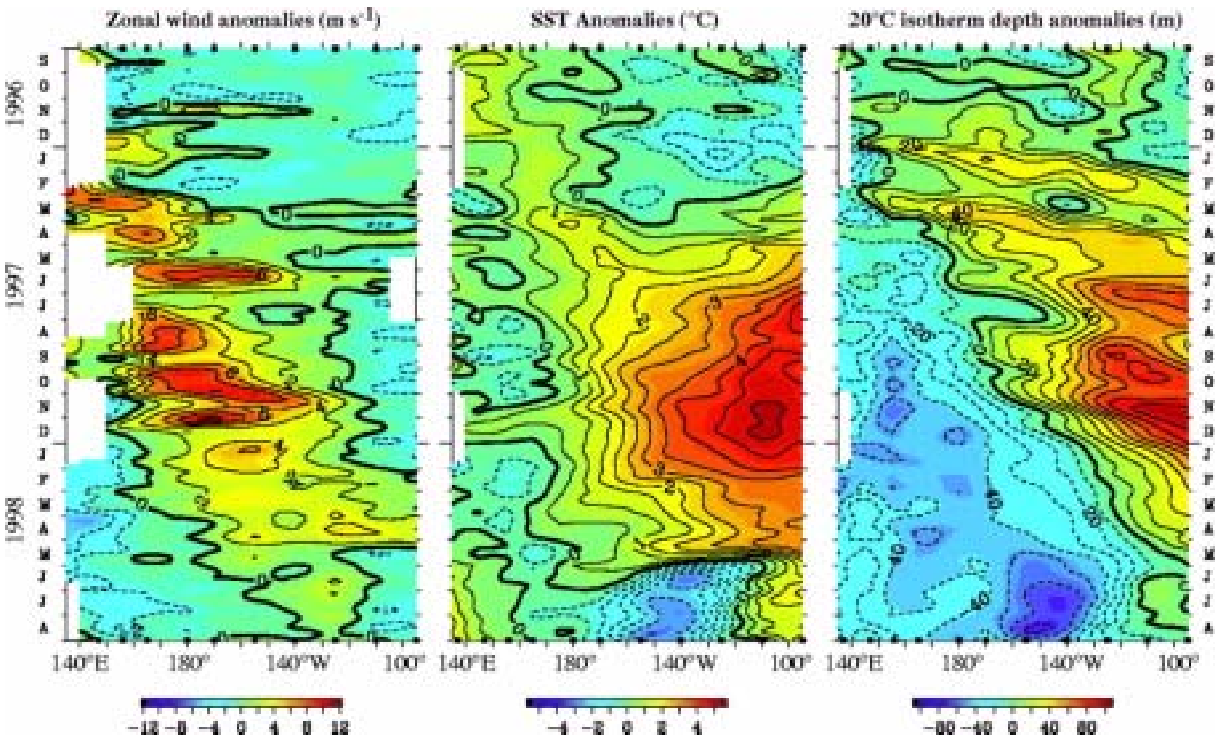


Figure 7. The simultaneous changes in the wind, SST, and the depth of the thermocline during El Niño of 1997/1998, shown as time-longitude diagrams (also known as Hovemoller diagrams).

The Southern Oscillation, the dominant signal in Figure 6(A), shows sea surface temperature variations as measured on the equator to the west of the Galapagos Islands. The typical period of the oscillation is 3-5 years as seen from a wavelet analisys in Figure 8.

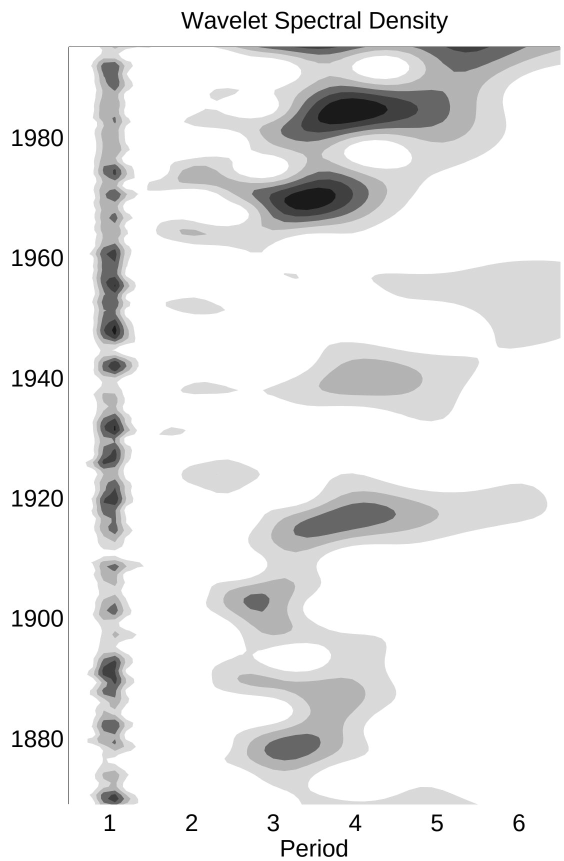


Figure 8. Energy density, from a wavelet spectral analysis, as a function of period (in years) and time for the SST signal used in figure 1. Dark / light shading corresponds to high / low values, respectively. The annual cycle is also shown.

1.3. Ocean circulation in the tropics.

The winds, ocean stratification and the complicated geometry of the basin create a complex current system in the tropical Pacific (Figure 9). Because the winds are stronger during La Niña, the currents are more pronounced as well. The strength of the current is significantly reduced during El Niño (Figure 10).

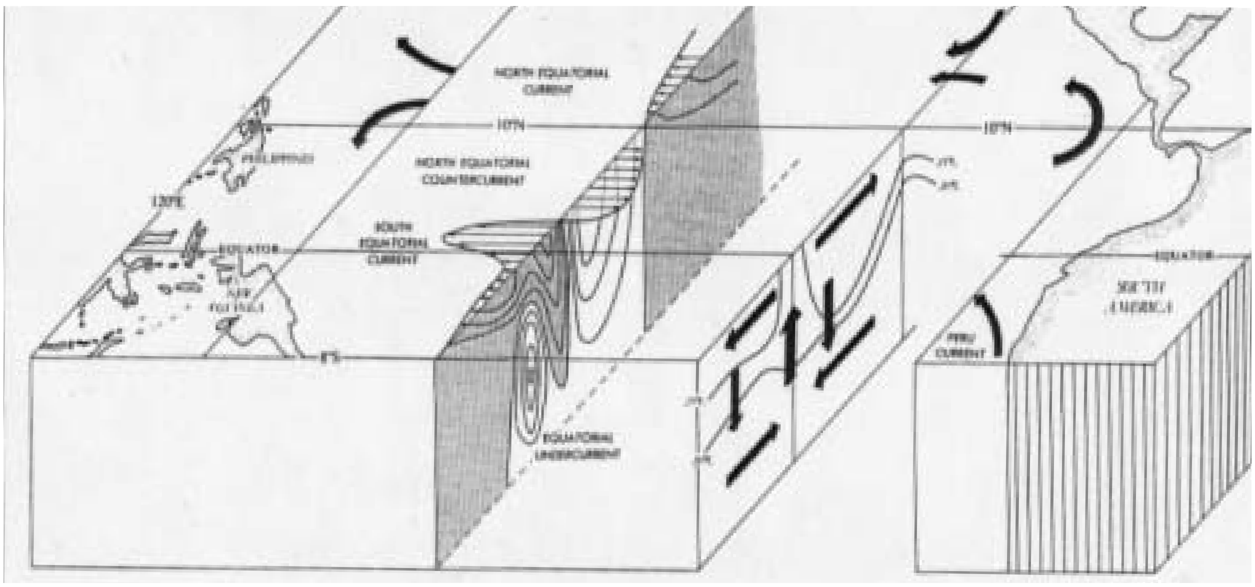
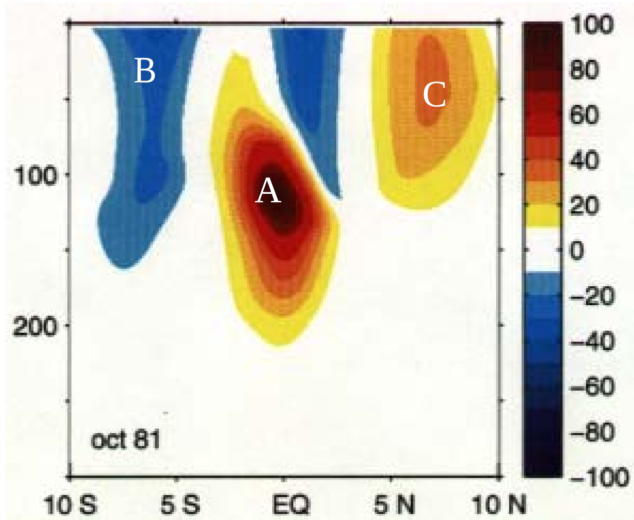


Figure 9. A schematic picture showing the main current systems in the tropical Pacific ocean.

The plots in Figure 10 are obtained by means of a realistic General Circulation Model forced by observed wind stress, and restored to the observed temperatures at the surface (see section 4). Note the weakening of the eastward Equatorial Undercurrent (A), weakening of the westward South Equatorial Current (B), and the disappearance of the westward North Equatorial Countercurrent (C) during El Niño.

(I)



(II)

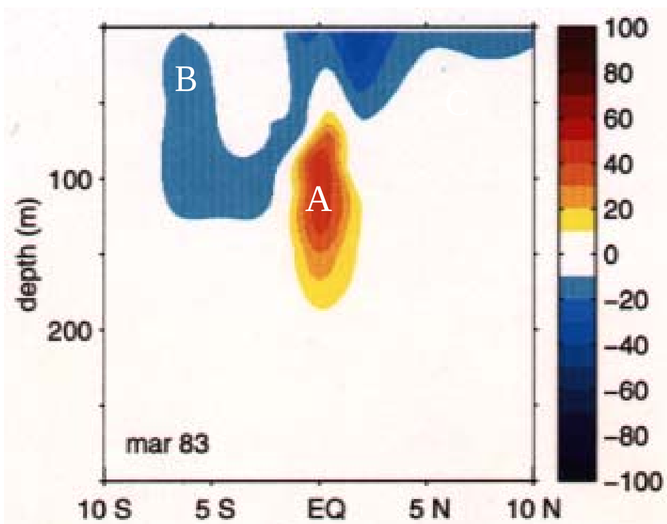


Figure 10. A vertical north-south section of the ocean velocity field (in cm / s) at the middle of the basin during La Niña-like conditions (I) and during El Niño (II).

In summary, from the point of view of an oceanographer, during El Niño (and La Niña) changes in the trade winds produce profound changes in the thermostructure and circulation of the ocean. Thus, to explain and study ENSO, we must address the problem of ocean adjustment under varying winds.