Correlations between Surface Chlorophyll and SSH in the Tropical Pacific during the 1997-1999 ENSO Event

Cara WILSON[1*] and David ADAMEC[2]

[1]Goddard Earth Sciences and Technology Center, USA and [2]NASA/GSFC, USA

ABSTRACT

Correlations between SeaWiFS surface chlorophyll and TOPEX/Poseidon sea surface height (SSH) are examined in the tropical Pacific (30°S-30°N) using empirical orthogonal function (EOF) analysis. This analysis is done on data from data from Sept. 1997, the start of data from the SeaWiFS satellite, through Dec. 1999, a time period dominated by ENSO oscillations (Fig. 1). The SSH EOF modes are placed in a longer temporal context by an EOF analysis of the SSH height data from 1993 through 1999.

INTRODUCTION

The surface ocean in the tropical Pacific is nutrient limited and biological production is strongly coupled to the physical factors that deliver nutrients to the surface such as changes in the depth of the thermocline or the mixed layer, horizontal and vertical currents and wind forcing. The relative importance of these factors depends on the regional environmental conditions and ecology. For example, the equatorial Pacific is on of the high nitrate-low chlorophyll regions of the world's oceans, where productivity may be controlled by the availability of the micro-nutrient iron (Martin *et al*., 1991; Coale *et al*., 1996). Under normal conditions upwelling along the equator brings iron-rich water from the Equatorial Undercurrent (EUC) to the surface, supporting relatively high levels of biological productivity. However, during El Niño the EUC weakens or even disappears, cutting off the iron supply to the euphotic zone and limiting production (Chavez *et al*., 1999). In contrast the subtropical gyres are nitrate or phosphate limited (Karl *et al*., 1995) and production there is more linked to changes in the depth of the thermocline or mixed layer. Most studies of the biological-physical coupling in the tropical Pacific have been regional, focusing on either the equator or the western warm pool. Here we use satellite data to examine basin-wide physical and biological dynamics in the tropical Pacific during the 1997-1999 ENSO event.

1. NINO3 Index

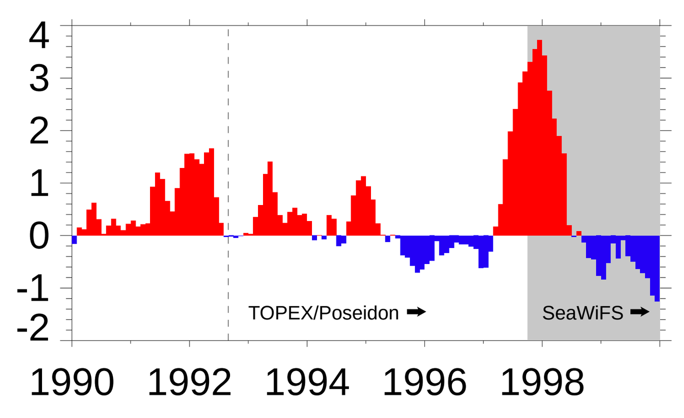


Figure 1. The NINO3 index from 1990-2000. The NINO3 index is the average sea surface temperature anomaly in the eastern equatorial Pacific (90°-150°W×5°S-5°N). Generally indices greater than 0.5°C indicate El Niño events while indices less than -0.5°C indicate La Niña events (Trenberth, 1997). The time period covered by the SeaWiFS satellite chlorophyll data is shaded gray and is dominated by the very strong 1997/1998 El Niño and the subsequent La Niña. The start of the TOPEX/Poseidon data in 1992 is indicated by the dashed line.

2. SSH and Chlorophyll Correlation Map

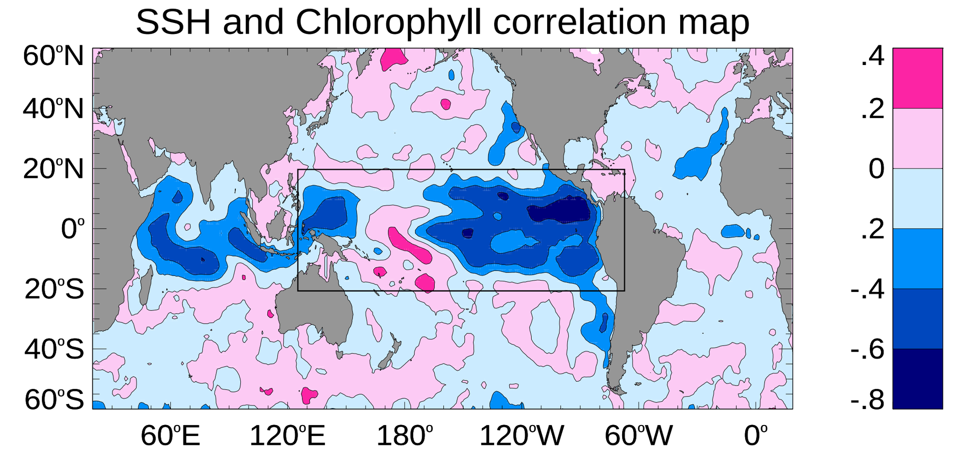


Figure 2. Global correlation map between SSH and chlorophyll. Negative correlations are shaded blue, while positive correlations are red, the contour interval is 0.2. SSH and chlorophyll are predominately negatively correlated because a larger SSH implies a deeper thermocline which will reduce the availability of nutrients for biological production. The highest correlations are in the Indian and Pacific basins. In the Pacific the largest negative correlations (<-0.4) are seen in the western warm pool and in the eastern cold tongue. In areas where the thermocline is very deep, thermcocline depth changes will have less of an impact on the surface biology. Indeed, within the Pacific the strongest correlations occur in the regions that have the shallowest thermocline, as indicated in Fig. 3. The boxed area delineates the region depicted in Fig. 3. Absolute correlations greater than 0.23 are significant at the 99% confidence level.

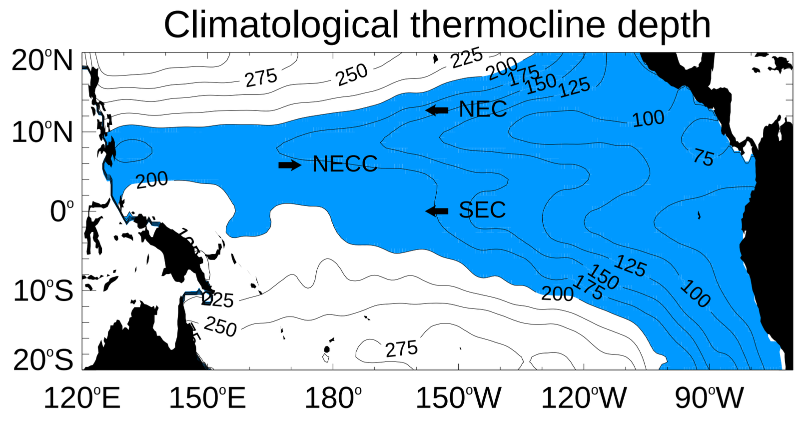


Figure 3. The climatological thermocline depth in the tropical Pacific overlaid with schematic arrows representing the surface currents. The depth of the σ_θ=25.9 isopycnal from the Levitus dataset is used to represent the thermocline. The region where the thermocline is less than 200m is shaded blue. NEC=North Equatorial Curent, NECC=North Equatorial Countercurrent, SEC=South Equatorial Current.

3. SSH and Chlorophyll RMS Variance

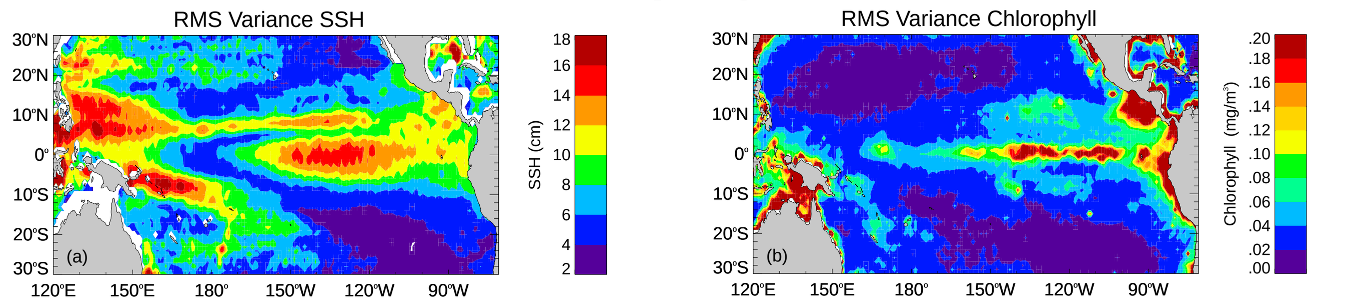


Figure 4. The RMS variability of (a) SSH and (b) chlorophyll. The data has been deseasoned by removing the climatological monthly mean. The SSH has high variability (> 10 cm) in four regions: Along the eastern equator (to 160°W) and extending into the Costa Rica dome in the east, the western warm pool, the South Pacific Convergence Zone, and a thin band along 8°N that stretches across the Pacific from the western warm pool to 120°W. High chlorophyll variability (> 10.1 mg/m^3) is seen in the areas of strong upwelling along the eastern equator (100°W-160°W), in the Costa Rica dome, and off of the coast of South America. The equatorial band of high chlorophyll variability is more tightly confined to the equator (within 2° latitude) than the band of high SSH variability (within 5° latitude).

4. SSH and Chlorophyll EOF Modes

Spatial patterns of the individual EOF analyses of (a) SSH and (b) chlorophyll and the (c) normalized principal components for SSH (blue line) and chlorophyll (red line) alongside the normalized NINO3 index (black line). For a given time and location the sign and magnitude of the spatial component is determined by the product of the principal component at that time and the spatial component at that location. Overlain on the spatial component maps are contours of the homogeneous correlation, the correlation at each point between the times series of the data and the principal component. The contour interval is 0.1, and the minimum contour shown in 0.4. Negative portions of the principal component plots are shaded gray to better distinguish the periods where the principal components change sign.

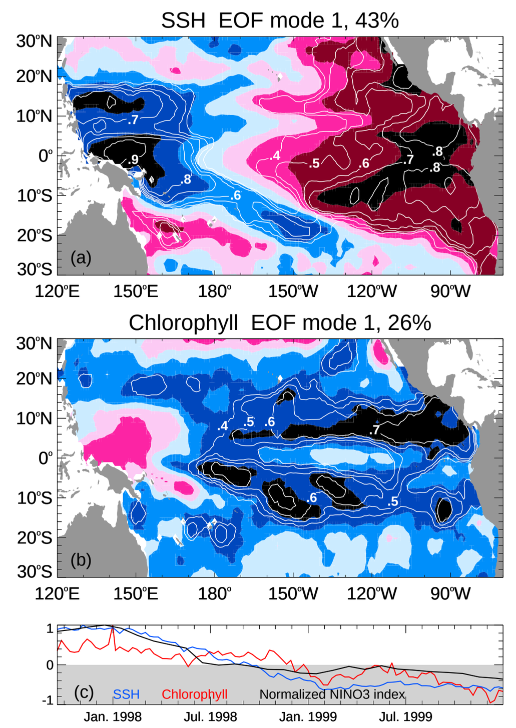


Figure 5. The east-west SSH seesaw seen in this mode is the canonical ENSO thermocline depth oscillation and the NINO3 index is highly correlated with and SSH (r=0.95) and chlorophyll (r=0.79) principal components. The chlorophyll spatial pattern has oscillations of reduced/elevated chlorophyll both north and south of the equator in the central and eastern Pacific (80°W-180°) during El Niño/La Niña. This basin-wide off-equatorial chlorophyll response has not been seen before. While mode 1 does show typical El Niño chlorophyll changes, an equatorial decrease and an increase in the western warm pool, neither of these regions has very large spatial loadings and their homogeneous correlations are less than 0.4. Equatorial chlorophyll changes are better represented in modes 2 and 3.

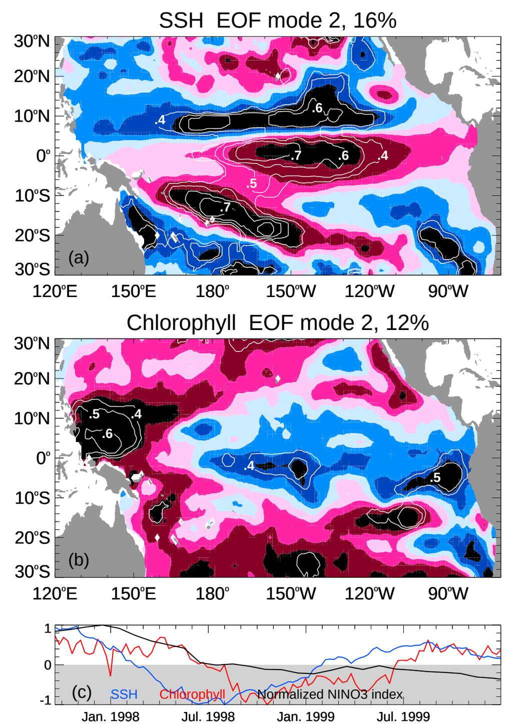


Figure 6. The SSH spatial component shows the temporal changes associated with the depth of the 10°N thermocline ridge and the associated strength of the NECC. The dominant negative loadings lie along the 10°N thermocline ridge and when the principal component is positive, as during the El Niño, the thermocline is shallower and the NECC is stronger. Although mode 1 appears to be the primary ENSO mode, mode 2 better depicts the typical equatorial chlorophyll changes associated with El Niño. The areas with the highest correlations (<-0.4) are in the western warm pool, which has a chlorophyll increase during El Niño, and in small patches along the equator where there is a chlorophyll decrease during El Niño.

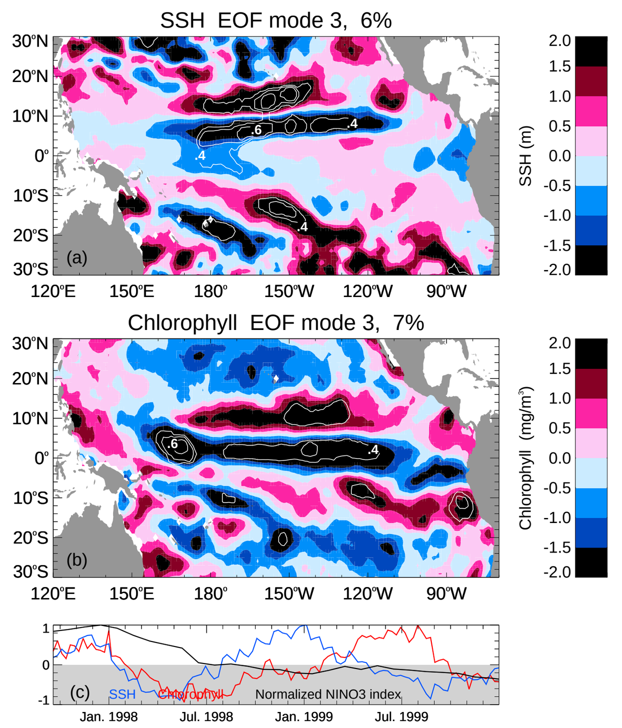


Figure 7. This modes best demonstrates the the typical equatorial chlorophyll changes associated with El Niño. During the peak of El Niño chlorophyll is low along the entire equator and the homogenous correlation is greater than 0.4 across most of the equator. The regime switches to high equatorial chlorophyll in Jan 1998, six months prior to the onset of La Niña. This change can be connected to changes in the Equatorial UnderCurrent (EUC), shown in Fig. 8. Mode 3 also shows elevated chlorophyll during El Niño in small regions north and south of the equator between 4-10° in the central and eastern Pacific. The off-equatorial chlorophyll increase is asymmetric, spanning a larger area and having larger magnitudes in the north than in the south. In the north, this feature is centered over the 10°N thermocline dome. Simultaneously lower SSH, indicating an elevated thermocline/nitricline and stronger NECC, is seen in this area in mode 2 (Fig. 6a).

5. EUC Magnitude

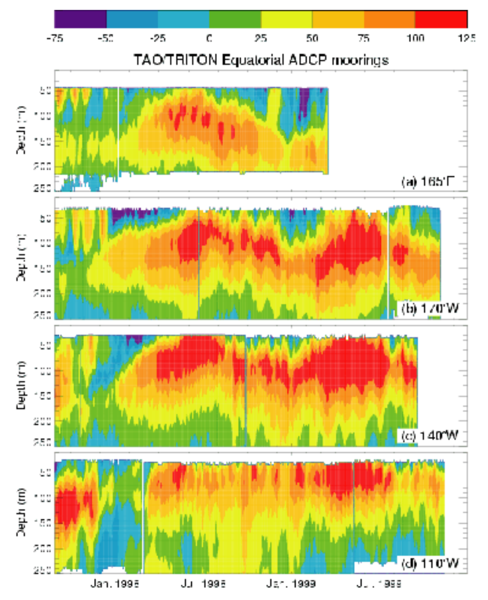
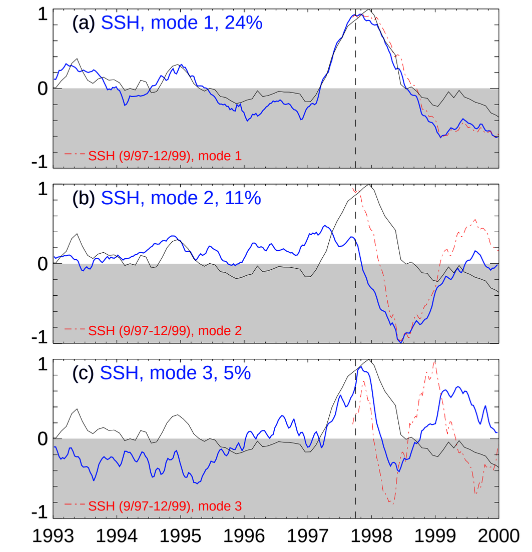


Figure 8. Zonal velocity data from the TAO/TRITON ADCP equatorial moorings showing the strength of the EUC between September 1997 through 1999 at (a) 165°E (b) 170°W (c) 140°W and (d) 110°W. Across the Pacific the Equatorial Undercurrent (EUC) was absent or weakened during the peak of the El Niño, winter 1998, when the equatorial chlorophyll in mode 3 (Fig. 7b) is low. The sudden reappearance of the EUC in Jan./Feb. 1998 coincides with the mode 3 chlorophyll increase. A comparison between the maximum velocity, the depth of the maximum velocity and the chlorophyll principal component (not shown) indicates two regimes- before 1999 the chlorophyll component is correlated with the depth and strength of the EUC, while during 1999 it is not. The chlorophyll changes in 1999 could be due to other factors affecting iron flux, such as the strength of local upwelling or temporal changes in the iron levels of the EUC, or they could be impacted by zooplankton grazing, which plays an important role in regulating equatorial chlorophyll levels (Frost and Franzen, 1992; Landry *et al*., 1997).

6. SSH Principal Components, 1993-1999

Figure 9. Normalized principal components (blue line) of EOF modes (a) 1, (b) 2 and (c) 3 and for the TOPEX/Poseidon SSH record between Jan. 1993-Dec. 1999. The spatial components are not shown as they are very similar to those from the Sept. 1997-Dec. 1999 analysis shown in Fig. 5-7. The black line is the normalized NINO3 index, and the dashed red line is the principal component from the Sept. 1997-Dec. 1999 analysis. The vertical dashed line indicates the start of the data shown in Fig. 5-7. It is clear that while modes 2-3 are not correlated with the NINO3 index, they are all obviously impacted by the 1997/1998 El Niño. For all modes changes in the principal component between 1993-1996 are small compared to the changes between 1997-1997, when all modes have sharp changes in the principal components that are obviously connected to the El Niño. The main point from of the longer EOF analysis is that the temporal changes seen during the Sept. 97-Dec. 99 analysis are all clearly driven by the ENSO oscillations.



SUMMARY

- o Dynamics in the Pacific during Sept 1997 Dec. 1999 are dominated by responses to the strong El Niño of 1997/1998 (Figs. 1 & 9).
- o There are four distinct biological responses to the El Niño, which arise from a combination of ecological and physical dynamics.
- o The dominant response is a symmetric off-equatorial decrease/increase during El Niño/La Niña that extends from the eastern Pacific to the dateline between 2-18° both north and south of the equator (Fig. 5b), resulting from the change in nitrate supply due to the thermocline changes. This basin-wide biological response to El Niño has not been documented before.
- o The well-known equatorial decrease/increase in chlorophyll during El Niño/La Niña is tied to the shutdown and recommencement of the iron-rich EUC (Figs. 7b and 8).
- o In the western warm pool the El Niño chlorophyll bloom terminates at the end of the El Niño (Fig. 8b), and there is another bloom at the end of 1999.
- o There is an asymmetric off-equatorial bloom during the peak of the El Niño (Fig. 7b). While seen south of the equator, this response is better developed northof the equator, where the chlorophyll increase is associated with the shoaling of the 10°N thermocline ridge and the strengthening of the NECC (Fig. 6a).

*Contact Information: GEST, NASA/GSFC, Code 971, Greenbelt MD 20771, USA. wilson@mohawk.gsfc.nasa.gov, http://mohawk.gsfc.nasa.gov/~wilson

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