Local versus remote wind forcing of the equatorial Pacific surface temperature in July 2003

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[1] After the moderate El Niño of 2002 the tropical Pacific seemed poised to enter a La Niña phase. Wind anomalies during May and June 2003, however, led to a sudden termination of this event. Counter to earlier predictions, forecasts from July 2003 correctly predicted normal conditions for the remainder of the year. In this paper the causes of this abrupt turn of events are analyzed. It is shown that wind anomalies in the eastern tropical Pacific played a major role in terminating the incipient cold ENSO phase. Although westerly wind bursts in the western Pacific explained most of the ocean subsurface behavior to the west of 110°W, their impact on SST was confined to the central equatorial Pacific. **Citation:** Vintzileos, A., M. M. Rienecker, M. J. Suarez, S. D. Schubert, and S. K. Miller (2005), Local versus remote wind forcing of the equatorial Pacific surface temperature in July 2003, *Geophys. Res. Lett.*, *32*, L05702, doi:10.1029/2004GL021972.

1. Introduction

[2] Sea Surface Temperature (SST) in the equatorial Pacific is an important climate variable because of its effects on global weather statistics. Interannual variations of SST in this area are to a large extent associated with the El Niño–Southern Oscillation (ENSO).

[3] The main reason for the large SST variability in the eastern equatorial Pacific (EEP) is the relatively shallow thermocline. The depth of the thermocline there is affected by oceanic Kelvin waves generated by atmospheric forcing in the western equatorial Pacific (WEP). One form of atmospheric forcing in the WEP, Westerly Wind Bursts (WWB) [e.g., *Harrison and Giese*, 1988], are often associated with the Madden-Julian Oscillation (MJO) [*Madden and Julian*, 1971]. Westerly Wind Bursts and MJO events currently have little predictability (5–7 days for general circulation models [*Jones et al.*, 2000] and up to three weeks for statistical methods [e.g., *Waliser et al.*, 1999]) and so may interfere with ENSO forecasting [e.g., *Penland and Sardeshmukh*, 1995; *Moore and Kleeman*, 1998]. For example, studies of the WWB events that occurred in early 1997 concluded that the extreme amplitude of the 1997/98 El Niño was due to the occurrence of WWB during the early spring [e.g., *Yu and Rienecker*, 1998; *McPhaden*, 1999]. The event was predicted by some models from as early as October 1996, but with much weaker amplitude than observed. The annual cycle of zonal wind also plays a role in the ENSO cycle. *Harrison and Vecchi* [1999] documented the importance of meridional changes in zonal wind anomalies in the WEP, particularly to the shoaling of the thermocline in the EEP (through ocean wave dynamics) and the termination of warm events.

[4] After the moderate warm event of 2002/03 the demise of which is described by *Vecchi and Harrison* [2003], the tropical Pacific seemed poised to enter a La Niña phase with easterly wind anomalies and cold subsurface anomalies in the west. Coupled general circulation models (GCMs) certainly predicted a cold event, but erroneously so. In this paper we analyze ENSO forecasts made with the NASA Seasonal-to-Interannual Prediction Project (NSIPP) forecasting system during 2003. We first review conditions that prevailed in the tropical Pacific in 2003; and then discuss the forecast of conditions late that year and how its accuracy evolved during the year. By experimenting with ocean-only forced runs of the ocean general circulation model (OGCM) we quantify the relative importance of remote WWB in the WEP versus local EEP wind anomalies in modifying the ocean evolution and forecasts during 2003.

2. Forecast and Verification of ENSO Conditions in 2003

[5] In January 2003, equatorial Pacific subsurface temperature anomalies from the TAO/TRITON array [*McPhaden et al.*, 1998] were showing signs of an oncoming La Niña event. In the western Pacific, the thermocline was anomalously shallow, with cold subsurface anomalies exceeding −2°C; in the east, surface and near-surface temperatures were anomalously warm, reflecting the end of the moderate El Niño event of 2002–2003. Following the delayed oscillator ENSO theory [*Suarez and Schopf*, 1988], western subsurface equatorial anomalies should affect the eastern Pacific SST two to three months later through Kelvin wave dynamics. Indeed, the canonical ENSO scenario was successful in describing the evolution in nature until May 2003. As cold subsurface anomalies in the western Pacific propagated eastwards, the Niño 3 index dropped from 0.8°C in January 2003 to −0.9°C by May 2003, and the system seemed on the verge of entering a cold event. However, during late May and early June 2003 there was an abrupt change in the subsurface equatorial temperature anomalies. Warm anomalies suddenly

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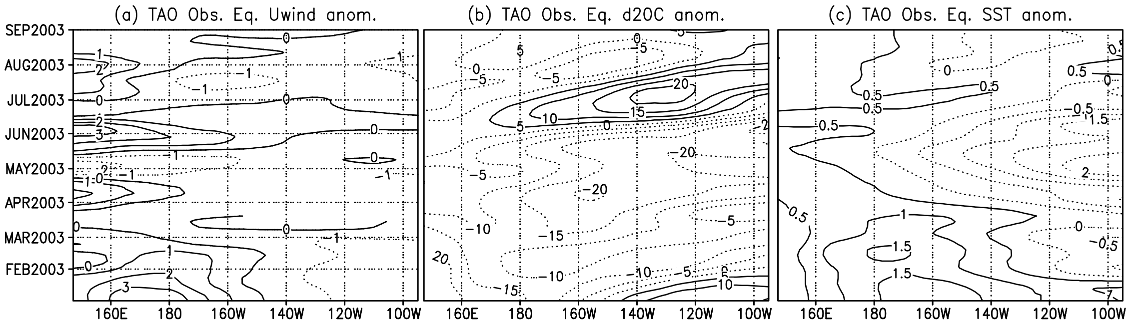

Figure 1. Longitude-time sections of observed 5-day mean anomalies along the equator for (a) zonal wind (ms^{-1}), (b) depth of the 20°C isotherm (m) and (c) SST (°C).

appeared in the western and central Pacific equatorial surface and subsurface, and all indications of a La Niña event disappeared. In fact, the Niño 3 index increased very rapidly, reaching neutral conditions by July, by which time subsurface temperatures throughout the EEP were above normal. In August 2003, subsurface anomalies along the equator had the same structure as in July but with half the amplitude.

[6] Equatorial longitude-time sections of observed (TAO) anomalous zonal wind, depth of the 20°C isotherm and SST (Figure 1) (anomalies shown henceforth are defined relative to the relevant 1993 to 2003 mean annual cycle) show the progression of these events. The demise of the 2002 El Niño and the initial stages of a La Niña event are clearly seen in Figure 1c. This cooling of the EEP surface waters is associated with the arrival from the west of shallow thermocline anomalies (Figure 1b). Considering high frequency zonal wind behavior in the western Pacific (Figure 1a) we note a number of WWB with the strongest occurring in January, April, and again in late May and early June. The first two wind events had little effect on the developing cold conditions; however, the WWB that occurred at the end of May and beginning of June resulted in a strong downwelling signal that propagated eastward and deepened the thermocline in the EEP. At this point SSTs in the EEP were rapidly returning to normal.

[7] We next examine the QuikSCAT wind stresses [*Spencer et al.*, 2000], shown as monthly averaged anomalies from May 15th to June 14th (Figure 2a) and from June 15th to July 14th (Figure 2b). These anomalies are relative to mean annual cycle of the wind stress product used for forcing the ocean model from 1993 to 2003 (see section 3). From mid-May to mid-June 2003 strong westerly anomalies in the western Pacific were centered at around 7°N also affecting the equator and the South Pacific Convergence Zone. There was anomalous meridional divergence on the equator in the EEP and anomalous surface convergence north of the mean ITCZ latitude. Part of this meridional divergence in the EEP may be explained by the effect of cold equatorial SST on the atmospheric boundary layer flow [*Lindzen and Nigam*, 1987]. In the EEP, there is anomalous anticyclonic wind stress rotation between the equator and the ITCZ and this should produce anomalous warming in the subsurface and eventually in the surface layers according to the draining mechanism of *Vintzileos et al.* [1999]. Anomalous southerlies and anticyclonic rotation just to the north of the equator in the EEP persisted until mid-July while activity in the western Pacific decreased significantly.

[8] Consistent with the background initial states, forecasts made with the NSIPP system initialized during the early months of 2003 were predicting a cold December 2003 (Niño 3 index of about −1°C) (Figure 3). (ENSO is realistically simulated with this coupled GCM [*Vintzileos et al.*, 2003]; its Niño 3 index anomaly correlation skill remains over 0.6 even at lead times of 7–8 months.) However, starting from the initialization in July 2003, the forecast suddenly changed and neutral conditions were

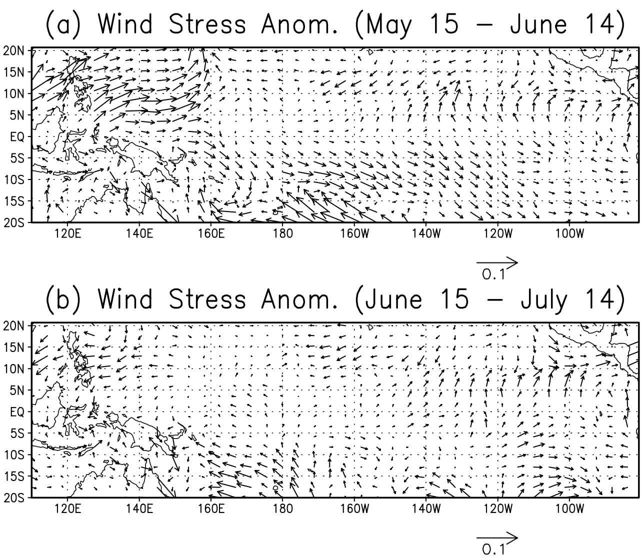

Figure 2. Wind stress anomalies based on QuikSCAT data for (a) May 15th to June 14th and (b) June 15th to July 14th. Arrows at lower right represent 0.1 N/m^2.

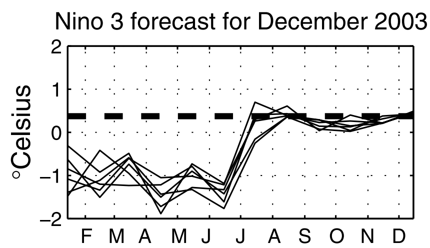

Figure 3. Prediction of the December 2003 Niño 3 Index from forecasts initialized each month from January 1st to December 1st, 2003 (thin lines) versus the observed value for December 2003 (dashed).

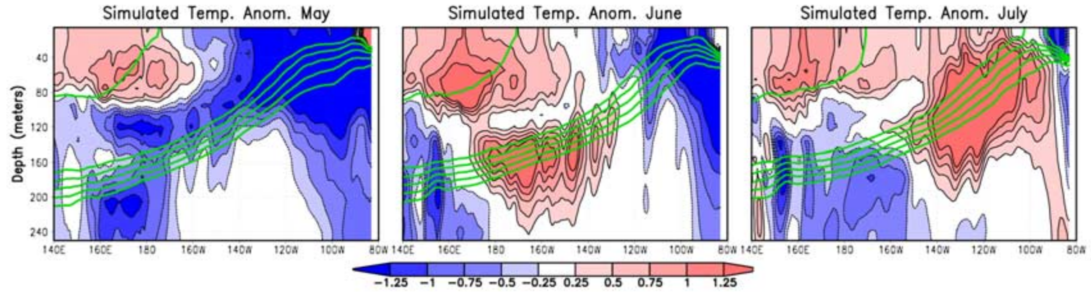

Figure 4. Monthly mean temperature anomalies along the equator for May to July 2003 simulated by the forced ocean model. Green lines show the mean seasonal temperature structure with emphasis on the thermocline and the warm pool. Contour interval is 0.25°C.

predicted for December—remarkably close to what occurred in nature (Figure 3). This is a strong indication that a significant La Niña event was in its formative stages in early 2003, and that the May–June wind stress anomalies, both zonal and meridional, described previously arrested its development. If this is so, we should be able to use the ocean model in forced mode to quantify the relative importance of local (EEP) versus remote (WEP) wind anomalies in derailing the forecast La Niña event.

3. Simulation of the Demise of the 2003 La Niña

[9] The OGCM used in the NSIPP coupled forecasts is the Poseidon hybrid coordinate model [*Schopf and Loughe*, 1988]. To analyze events in 2003, we use this ocean model in stand-alone mode forced with observed wind stresses from QuikSCAT, monthly heat fluxes from the NCEP reanalysis with a relaxation to observed SST using a seasonally varying relaxation coefficient obtained from COADS, and monthly mean precipitation from GPCPv2 [*Huffman et al.*, 1997]. The model was spun-up using seasonal climatological wind forcing until 1981 after which daily wind analyses were used (ECMWF reanalysis until 1987, then SSM/I until 2002 and QuikSCAT since October 2002, each from an analysis following *Atlas et al.* [1991]).

[10] The evolution towards La Niña conditions, which started as the aftermath of the 2002 El Niño event, resulted in cold eastern surface and near-surface temperature anomalies in May 2003. This is well simulated by the ocean-only run (Figure 4). The run also shows conditions changing abruptly as a strong warming of the western and central Pacific subsurface in June 2003 was followed by warming of subsurface and surface layers in the eastern Pacific in July 2003.

[11] To quantify the relative importance of wind anomalies in the eastern Pacific (local forcing) *vs.* western Pacific (remote forcing) in controlling eastern equatorial SST, two additional experiments initialized from the control run (CTL) were performed simulating the May to July 2003 period. In the first (NoW), wind stress anomalies in the western Pacific (120°E–160°W, 20°S–20°N) were damped to their seasonal climatology with an e-folding time of 7 days, so that by June only eastern Pacific wind stress anomalies were used. In the second experiment (NoE), the winds were damped in the eastern Pacific sector (160°W–80°W, 20°S–20°N). Effects of western and eastern Pacific wind anomalies in the July subsurface temperature field along the equator, computed as the difference of the control minus the perturbed experiments, are shown in Figure 5.

[12] The effects of the westerly zonal wind stress anomalies in the western Pacific were a deepening of the thermocline in the western-central Pacific in June (not shown) and an eastward propagation of this deepening in July. However, although the eastern Pacific thermocline was deeper in July 2003 due to the arrival of the signal from the west, there was not a significant impact of this deepening on surface temperature anomalies. Indeed, Figure 5 indicates that the July 2003 surface warming was mostly the result of local wind forcing.

[13] Next, we consider depth averaged equatorial temperature anomalies for July. The anomalies are averaged from the surface to 75 m, i.e., representing the ocean mixed layer (Figures 6a and 6b) and from 75 m to 250 m, i.e., representing the thermocline (Figures 6c and 6d). We compare the sum of the effects from the western and eastern Pacific perturbed experiments to the anomalies from the control experiment in Figures 6a and 6c. Discrepancies between these quantities indicate the presence of nonlinearities in the response of the ocean to atmospheric forcing and therefore areas where these experiments cannot be interpreted straightforwardly. For surface layers, the two perturbed experiments sum up to the control run from 170°W to 100°W (Figure 6a) which is the main region for ENSO-related ocean-atmosphere coupling. Discrepancies

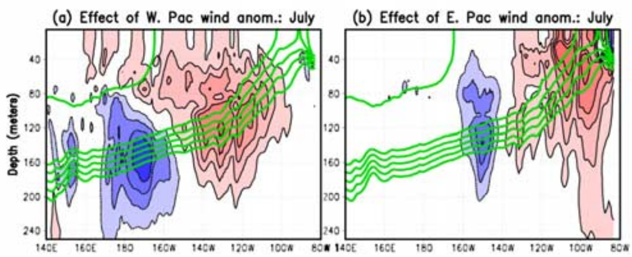

Figure 5. Effects of wind stress anomalies on equatorial temperature anomalies in July. These effects are the difference between the control (CTL) and the perturbed experiments; green lines represent isotherms for the given month from CTL: (a) effects from western Pacific wind anomalies (CTL-NoW) and (b) effects from eastern Pacific wind anomalies (CTL-NoE). The color shading is identical to Figure 4.

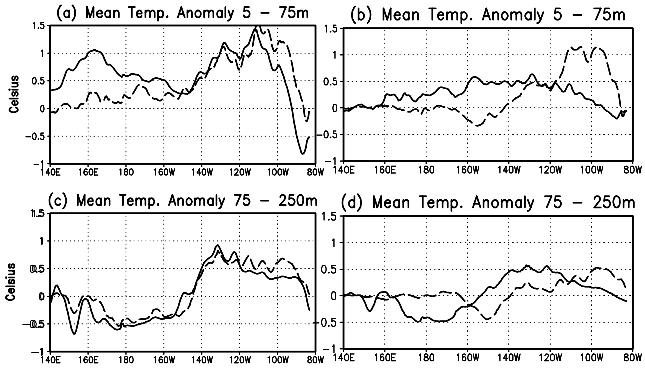

Figure 6. (a) Depth-averaged near-surface equatorial temperature anomalies for CTL (continuous) versus the sum of effects from the perturbed experiments (dashed), (b) Contributions of the eastern Pacific (dashed) versus western Pacific (continuous), (c) and (d) same as (a) and (b) for the thermocline region.

are found in the western and extreme eastern Pacific. In deeper layers (Figure 6c) the sum of the effects from the perturbed wind stress experiments and temperature anomalies from the control run are almost identical. Figures 6b and 6d quantify the impact of each of the perturbed experiments on the sums shown in Figures 6a and 6c. On surface layers, western Pacific wind stress anomalies dominate the weak central Pacific signal from 170°W to 135°W. Eastward from 120°W local eastern Pacific wind stresses have the strongest impact on temperature (Figure 6b). Clearly, without the eastern Pacific wind stress anomalies the response of the ocean to the WWB event would have been very different. In the interior ocean (Figure 6d) the western Pacific wind stresses control most of the temperature anomalies along the equator to the west of 110°W.

4. Summary and Discussion

[14] In January 2003, the western equatorial Pacific subsurface was characterized by negative temperature anomalies at the thermocline depth, consistent with the declining El Niño event of 2002. These western cold temperature anomalies propagated eastward and appeared to set the initial stages for a La Niña event. Until May 2003, forecasts with the NSIPP system were indeed predicting a La Niña in December 2003 with a forecast Niño 3 index of -1°C. However, wind anomalies over the tropical Pacific from mid-May to mid-June 2003 arrested the evolution towards a La Niña. The observed Niño 3 index returned to neutral conditions in July 2003 and the forecasts began to correctly predict near-normal conditions.

[15] As expected, westerly anomalies in the western tropical Pacific from mid-May to mid-June forced a deepening of the equatorial thermocline that propagated eastward. Forcing the ocean model with observed winds demonstrated that although this deepening explained surface warming in the central Pacific, it only explained a small fraction of the warming of surface layers in the eastern Pacific in July. The more important contribution to the surface warming there was from local wind anomalies.

[16] Although it is difficult to generalize from a case study, other events suggest that the relation between thermocline depth anomalies and SST in the eastern Pacific is far from being straightforward. For example, according to observations from the TAO moorings, in June 2001 a strong WWB forced a downwelling, eastward-propagating wave which reached the EEP in August. However, at this time, SST anomalies which were cold became even colder. This study suggests that local winds may explain this behavior. Studies with a simplified ocean model [*Wang et al.*, 1995] and with a GCM [*Kirtman and Schneider*, 1996] further support this view.

[17] There are many factors affecting winds in the EEP. One factor is the latitude of the ITCZ which, in turn, depends on a myriad of factors (e.g., land-sea contrast, proximity of the Andes, equatorial SST). Another is direct forcing by SST anomalies in this region (implying potential predictability). More research has to be conducted to determine the importance of eastern tropical Pacific winds on the evolution of ENSO events in general and to quantify the factors influencing these winds.

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