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VARIABILITY OF THE PACIFIC WIND SYSTEM DURING THE 1997-98 EL NIÑO OBSERVED BY TOPEX ALTIMETRY

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ABSTRACT: The 1997–98 El Niño, known as the strongest in recorded history, manifested itself with a number of unusual features associated with the Pacific wind system. These features include: 1) an annual cycle of an east-west migration of a weakened wind speed zone between 2°N–9°N; 2) an asymmetric seesaw process of trade wind variations between the two hemispheres in terms of relative intensity and central position; and 3) an 18–month cycle of meridional oscillations of the Pacific doldrums and trade wind belts. In addition, the commonly-used argument of trade wind relaxation in association with El Niños appears to be introduced, at least in part, by the "tilt effect" of the Pacific zonal winds. These new findings, revealed by the newly available multi-year TOPEX altimeter data, may help to improve existing theories on El Niño formation, and may also have significant impacts on its future prediction.

1. INTRODUCTION

The classic El Niño refers to a relatively sudden warming of near-surface waters off Peru and Chile that occurs quasi-periodically every several years approximately at Christmastime. Great advancement in the understanding of El Niño and its predictability came with the recognition that it is a fundamentally coupled interaction between the atmosphere and the ocean, in which wind changes cause oceanographic changes and changes in tropical sea surface temperature affect atmospheric circulation (Philander 1983). This global pattern of variability is now called the El Niño/Southern Oscillation (ENSO).

It is somewhat a general consensus that the occurrence of an El Niño is correlated with abnormal wind conditions over the Pacific Ocean, although its mechanism is not altogether clear (Philander 1983, McPhaden 1999). The prevailing theory states that an El Niño occurs when the trade winds over the tropical Pacific weaken and even partially reverse (e.g., Neelin *et al*. 1998). Therefore, better understanding of the characteristics and variability of the Pacific wind system is critical for El Niño prediction. In this context, much attention has been paid to El Niño-related pattern changes of the Pacific wind field in terms of intensity and direction, as well as migrations of dominant wind belts (e.g., Rasmusson and Carpenter 1982, Zebiak 1990, McPhaden 1999, Wang *et al*. 1999). In this study, we start with an examination of the zonal behaviour of the Pacific trade winds during the 1997–1998 El Niño, then concentrate the rest of the paper on the meridional aspects of the problem, which have been studied less by previous investigators.

2. SATELLITE DATA

A satellite altimeter is a useful tool for estimating sea surface wind speed from space. In August 1992, the launch of TOPEX/Poseidon opened a new era for satellite altimetry with unprecedented data quality and duration (Fu *et al*. 1994). Six years of TOPEX altimeter wind speed data spanning January 1993 through December 1998 are used in the present analysis (AVISO 1996). The whole dataset is divided into monthly sub-datasets, yielding seventy-two 1°×1° wind speed fields for the tropical Pacific Ocean.

3. REULT AND DISCUSSION

In an attempt to check the validity of the trade-wind generation theory, seasonal maps of tropical Pacific wind speed anomaly are produced for the period from winter 1997 to winter 1998 (Figure 1). The anomaly is relative to the TOPEX-derived wind speed climatology of the same season during 1993–1998. Apparently, the dominant feature in the series of plots is the persistent existence of a negative-anomaly zone immediately above the equator. Following this feature throughout the seasonal maps, one finds that it starts to form and intensify in the far western Pacific during the winter of 1997 (Figure 1(a)). In the following spring, the center of this zone moves slowly to the middle of the Pacific Ocean (Figure 1(b)). When summer comes, it has arrived in its east destination near central America (Figure 1(c)). In autumn a return journey is underway in the central Pacific (Figure 1(d)). Until the beginning of 1998, a split negative-anomaly area seems to have completed the annual cycle and returned to its west origin (Figure 1(e)).

Before relating the above features to the trade wind collapse in ENSO theory, it is helpful to examine the yearly-averaged zonal wind speeds of 1997 and 1998 shown in Figure 2(a) (the thin solid curve and the dashed curve, respectively). Also superimposed is the climatological mean of the Pacific zonal wind speeds during 1993–1998 (the thick solid curve). Figure 2(b) gives the corresponding wind speed anomalies for 1997. A common feature of the two annual distributions in Figure 2(a) is that they were both above the climatological mean for most of the latitudes. In other words, the overall wind speed of the tropical Pacific appeared to be higher in the1997–1998 El Niño years than in normal years. The most striking feature in Figure 2(a), however, is perhaps the "swaying" or seesaw nature of the tropical Pacific wind system from 1997 to 1998. This can be quickly recognized by comparing the peak/trough positions and intensities of its trade winds and doldrums. A northward shift as large as 2.5° occurs for the Pacific doldrums in 1997, while a southward migration of 0.6° is seen in 1998, contrast to a small fluctuation of less than ±0.2° during non–El Niño years. Moreover, the peak of the northeast trade winds exceeded that of the southeast trade winds by 0.2 ms^{-1} in 1997, but reversed dramatically to –0.2 ms^{-1} in 1998 (a slight northern hemisphere dominance of less than 0.1 ms^{-1} was found for the trade winds during the proceeding years).

As mentioned earlier, the occurrence of a well-defined wind zone with negative anomaly in the tropical Pacific prior to an El Niño, such as the one observed in Figure 1(a), is usually interpreted as the slackening of the trade winds during the warm period of the event. An important fact to be noted for the 1997–1998 El Niño is that the oscillation of the anomalous wind zone only occurred within a limited band between 2°–9° in the northern tropical Pacific, rather than along the equator or in the southern hemisphere (Figure 2(b)). Keeping in mind the "tilt effect" of the zonal wind pattern as displayed in Figure 2(a), it is quite clear that the dominant portions of the Pacific trade winds were actually strengthened, rather than weakened, by a significant amount in both 1997 and

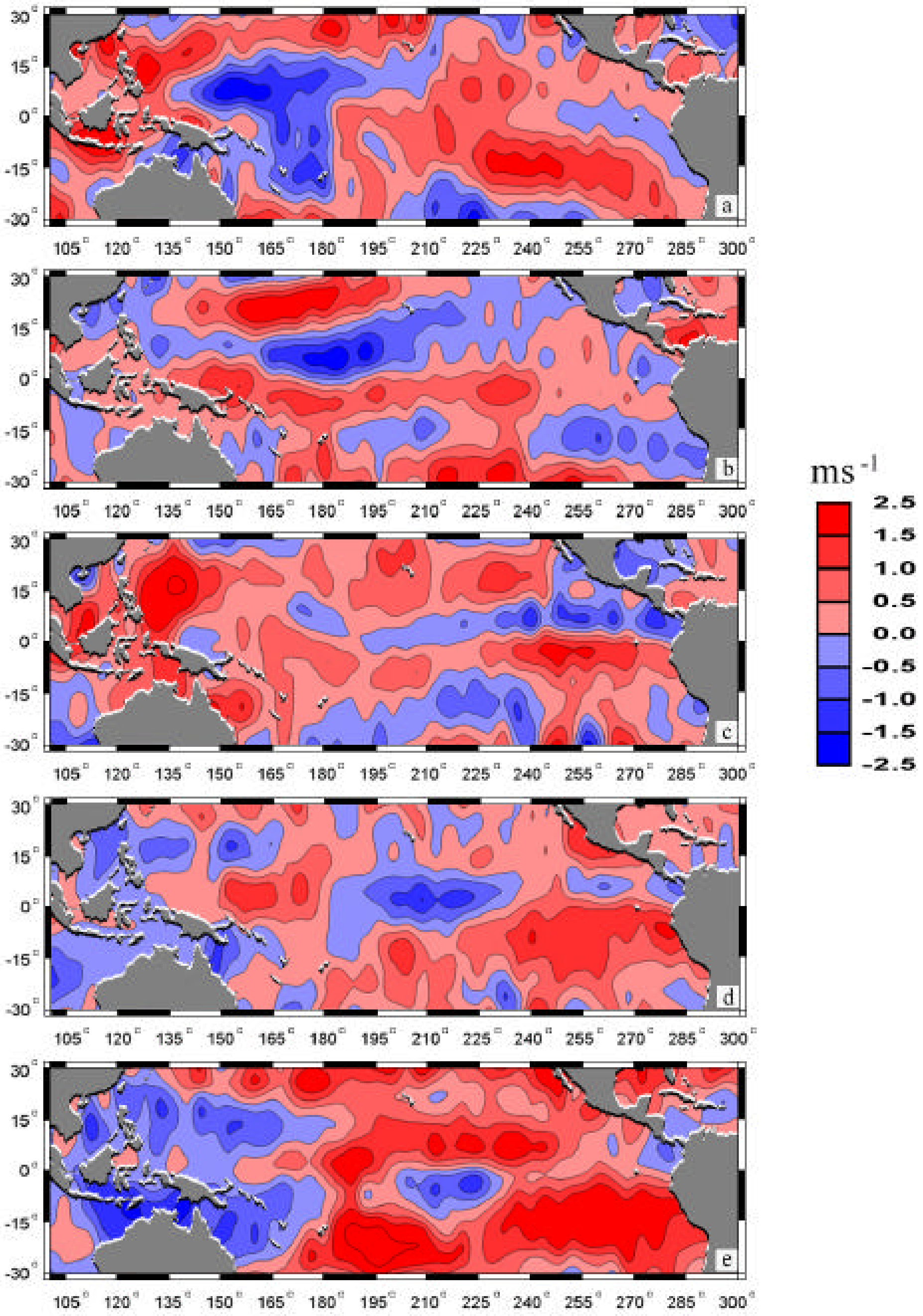

Figure 1. Seasonal maps of tropical Pacific wind speed anomaly derived from TOPEX altimeter data. (a) Winter 1997 (01/12/96–28/02/97); (b) Spring 1997 (01/03/97–31/05/97); (c) Summer 1997 (01/06/97–31/08/97); (d) Autumn 1997 (01/09/97–30/11/97); (e) Winter 1998 (01/12/97–28/02/98). The averaged wind speeds for the same months of 1993–1998 are used as seasonal climatologies.

1998, thus violating the traditional interpretation. Nevertheless, our results suggest that, as far as the Pacific wind system is concerned, the zonal band between 2°N–9°N is of particular importance for the initiation and development of an El Niño.

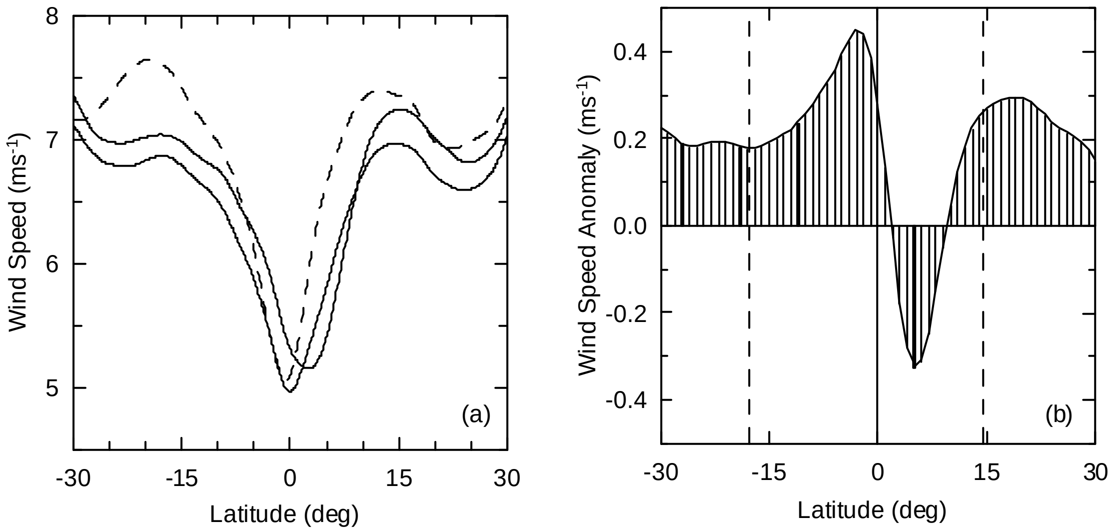

Figure 2. (a) Zonal distributions of sea surface wind speeds for the tropical Pacific derived from TOPEX altimeter data. The six-year average from 1993 to 1998, and the annual means for 1997 and 1998 are depicted by the thick solid line, the thin solid line and the dashed line, respectively. (b) Zonal variation of Pacific wind speed anomaly for 1997. The two vertical dashed lines indicate the mean positions of the southeast and northeast trade winds.

It would be interesting to examine the stability of the Pacific doldrums from a meridional perspective. In doing so, the monthly time series of the central latitudinal positions of the Pacific doldrums during 1993–1998 are plotted in Figure 3. It was found that this zone is generally stable for the first four years, but a dramatic north-south shift took place during 1997–1998. The shift evolved so rapidly that each month from June to October 1997 (and from February to May 1998) a new monthly record high (or low) was set. This coincided extremely well with the rapid onset and sudden demise of the 1997–1998 El Niño event (McPhaden 1999), implying that an unusual meridional departure of the Pacific doldrums from its normal position might be an important precursor for the occurrence of an extraordinary El Niño. We may even go one step further in postulating that it was the abnormal meridional shift of the tropical Pacific wind belts, rather than the resulting change of the trade wind pattern, that helped to trigger such a strong El Niño.

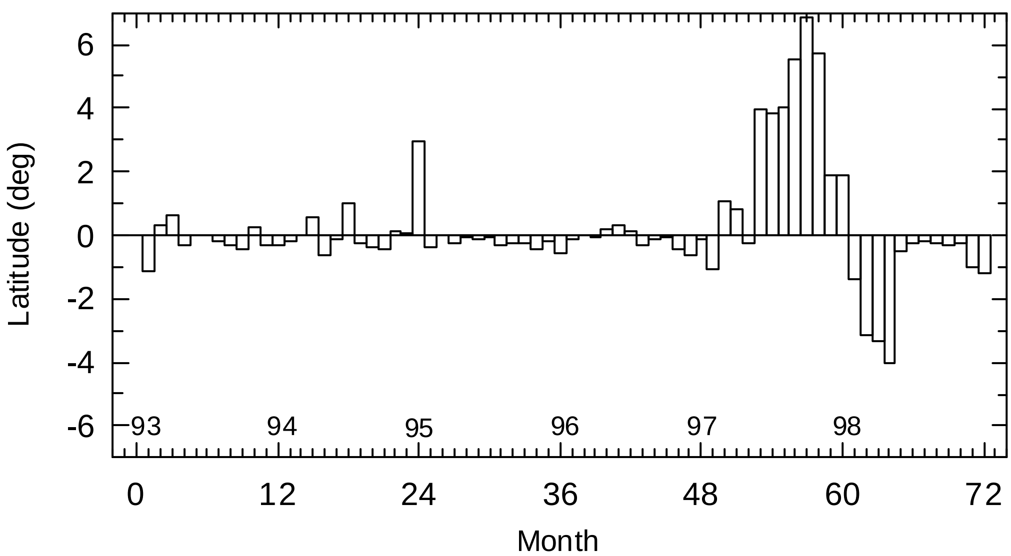

Figure 3. Monthly time series of the central latitudinal position of the Pacific doldrums during 1993–1998.

4. CONCLUDING REMARKS

The availability of six years of high-quality TOPEX altimeter data from 1993 to 1998 offers an excellent opportunity to examine the Pacific oceanic wind system from a climatological perspective, which is particularly needed for ENSO studies. Coincidentally, the 1997–1998 El Niño, which is the strongest of the twentieth century, was fully captured by this unprecedented mission, leading to a number of interesting findings. First, a weakened wind speed zone north of the equatorial Pacific was maintained through the warming phase of the event. It completed a cycle of east-west migration from winter 1997 to winter 1998. Second, both the southeast and the northeast trade winds in the Pacific Ocean were found to be enhanced and shifted during the 1997–1998 El Niño, rather than collapsed as assumed by the prevailing theory. Third, the distinct cycle of north-south shifts of the Pacific doldrums and trade winds appear to be perfectly in phase with the evolution of the 1997–1998 El Niño. The unique contribution of this study is perhaps the discovery of a link between the unusual meridional oscillation of the tropical Pacific wind system and the occurrence of a strong El Niño event. It is hoped that further investigation of this relationship with continued altimeter data from on-going TOPEX, and forthcoming Envisat and JASON missions, will provide useful clues to improve the understanding and prediction of future ENSO cycles.

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