Mechanisms of Westerly Wind Events in the Tropical Western Pacific

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1. Introduction

Surface westerly wind (WW) events over the tropical western Pacific (TWP) warm pool region have been suggested as an important high frequency forcing in maintaining and expanding warm equatorial sea surface temperature (SST) anomaly (Lau et al. 1989 and references therein). An observational study by Kessler et al. (1995) found a link between the WW events and oceanic Kelvin waves (30-90 days) in the equatorial Pacific ocean. A recent study by Weickmann (private communication) suggested in specific cases during 1979-1993 that an interaction between tropical intraseasonal oscillations (ISO) and SST anomalies near the dateline is related to the eastward movement of convection and SST anomalies that lead to wide-spread warming. Compared the coupled model forecasts of ENSOs during the 1980s and 1990s at the National Meteorological Center, Ji et al. (1995) found that the two latest warm episodes in the Spring 1993 and the fall/winter 1994 were not well predicted. This might be attributed to the strong intraseasonal variations in the latest warm episodes (especially the subsurface oceanic signal) that cannot be assimilated into the coupled system.

The generation of WW events has been attributed to several mechanisms. A major cause of WW events is the convective heating over the Pacific warm pool often associated with the propagation of tropical ISOs into the western Pacific region (Sui and Lau 1992). Another possible mechanism is the pressure gradient caused by cold surface flow from higher latitudes. Lau et al. (1996) found the genesis and maintenance of the WW events in 92/93 winter are related to the establishment of a large-scale east-west pressure dipole between the Maritime Continent and the equatorial central Pacific. This pressure dipole could be identified in part with the ascending (low pressure) and descending (high pressure) branches of the ISO and in part with the fluctuations of the boreal winter monsoon. Yet the specific evidence of mid-latitude influence on the WW events is still unclear.

The objectives of this investigation is to study the variability and the associated mechanism for the WW events, in order to better understand the linkage of WW events with the annual cycle and interannual variations. A preliminary analysis of surface winds and sea level pressure (SLP) is summarized below. The primary data for the present study is 6-hourly analysis from the 4D assimilation system by the NASA Goddard Space Flight Center for the thirteen winters 1980-81 through 1992-93. The winter season is defined to be the 120-day period from 1 November through 28 February.

2. Results

Surface zonal wind measurements from the three TOGA Tropical Ocean-Atmosphere ATLAS mooring sites at 2N, equator, and 2S along 165E are averaged to form a zonal wind index, u_{TWP}, to show the wind variability in the tropical Pacific warm pool region. The 5-day mean zonal wind index shown in Fig. 1 reveals dominant interannual variations (compares with the SOI index), annual cycle (maximum westerly winds tend to occur in northern winter), and intraseasonal variations.

The maintenance of the WW events in the winter season over the tropical western Pacific region is shown by the spatial distribution of the temporal correlation coefficient between daily mean u_{TWP} and the daily mean sea level pressure at each grids within the domain shown in Fig. 2. Also shown in Fig. 2 is the spatial distribution of the temporal covariance vector between daily mean u_{TWP} and the daily mean surface wind (u and v) at each grids. The spatial pattern shows a zonally oriented pressure dipole along the equator with the two poles located near 130E and 160W, maintaining maximum zonal winds between the two poles and to the west of 130E. The pressure dipole is quite similar to the Southern Oscillation pattern, indicating a shift of atmospheric mass during ENSO episodes. The same statistical analysis applied to each winter season indeed shows distinctly different spatial patterns: for the winter during warm years (82/83, 86/87), u_{TWP} is highly correlated with the broad-scale circulation over the Pacific ocean, Indian ocean, and neighboring regions, but for the winter during cold years (83/84, 88/89), u_{TWP} is weakly correlated with the large-scale tropical circulation. A reversed equatorial zonal pressure gradient is evident in the two contrasting phases. This suggest that WW events in the tropical western Pacific are strongly modulated by the interannual variability.

But in recent years after 1989, interannual variability in the tropical ocean-atmosphere is weaker than that of the previous decade. A prolonged warm

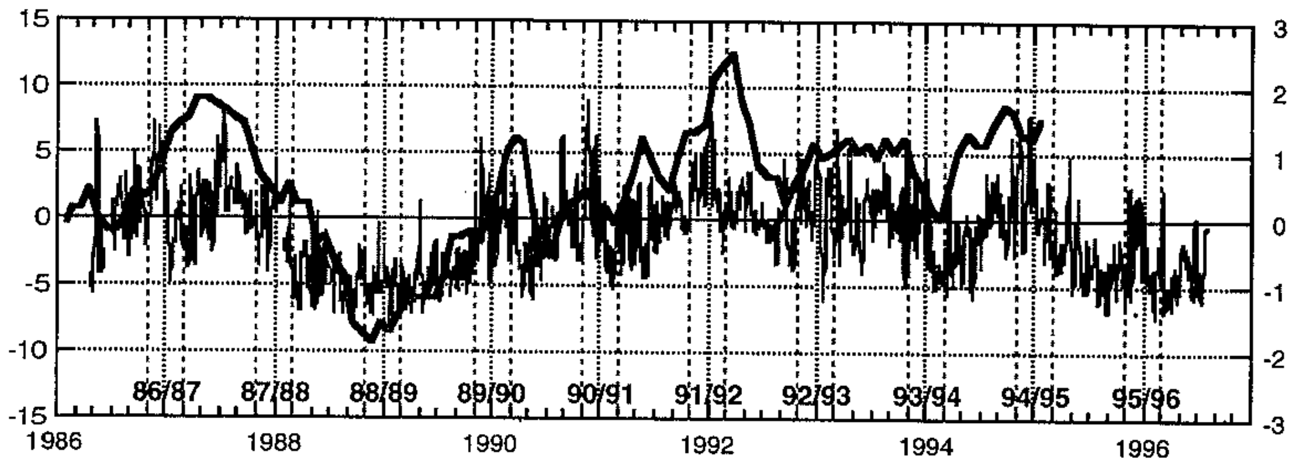

Fig. 1 Time evolution of 5-day mean zonal wind near equator and 165E (thin curve) and 3-month mean negative SOI index (thick curve).

episodes from 1989 to 1995 is evident in Fig. 1. The causes of such a difference in the coupled climate system is an important question to be answered. Here an attempt is made to contrast the correlation patterns for the individual winters from 80/81 to 88/89 and those from 89/90 to 92/93. An unique feature in the latter period appears to be represented by the winter of 89/90 and 92/93. The correlation pattern for 89/90 (Fig. 3) shows a pressure dipole with the high pressure center near 0-20N and 120E, and the low pressure center near 20S and 170W, and u_{TWP} is highly correlated with the mid-latitude circulation in both the north and south Pacific regions. Fig. 3 indicates a clear influence of tropical circulation by mid-latitude disturbances. A similar correlation pattern is also evident in the winter of 92/93 reported in Lau et al (1996).

Because the correlation pattern of the individual winters are contributed by synoptic-scale to intraseasonal disturbances, the next step to understand the contrasting feature is to further identify the relative control on WW events by mid-latitude forcing vs tropical forcing. First note that Fig. 3 is distinctly different from the composite circulation pattern at 850 mb level for the tropical ISOs (category 8 of the composite life cycle by Knutson and Weickmann 1987). A major difference is in the northern Pacific region where Fig. 3 shows a cyclonic/anticyclonic circulation pattern within the 140E-140W sector. This is shown to be a dominant signal by an EOF analysis of the daily SLP field over the northern Pacific ocean and Asian region for the 13 winters. Superimposed on a dominant winter circulation (about 50% of the total variance of SLP represented by the first eigenfunction), the second eigenfunction (Fig. 4a) shows a dominant dipole over the northern Pacific, consistent with the circulation pattern in Fig. 3. The third eigenfunction (Fig. 4b) shows a strong north-south pressure gradient over the whole Pacific region north of the equator.

The principle components (PC) corresponding to the second and third eigenfunction of SLP oscillate at 10 to 60 days. The temporal scale of PC3 is longer than that of PC2. The correlations between u_{TWP} and PC2 and PC3 at each winter are shown in Table 1 (negative lag means PC leading u_{TWP}). The correlation suggests a tendency that mid-latitude disturbances affect the tropical circulation more efficiently in recent years (89-93) than the previous decade. It should be noted that PC2 and PC3 cannot be separated from each other completely. A more careful analysis is needed to further identify the extratropical-tropical interaction problem.

Table 1

Year (-SOI)	Integrated amplitude of PC1	Correlation PC2/u_{TWP} (lag in day)	Correlation PC3/u_{TWP} (lag in day)
80/81 (0.2)	3.0		
81/82 (-0.6)	2.7	0.45 (-2)	
82/83 (3.4)	3.2	0.46 (-5)	
83/84 (-0.2)	3.1		
84/85 (0.0)	2.9		
85/86 (0.2)	3.1		
86/87 (1.5)	3.2		
87/88 (0.6)	3.0		
88/89 (-1.4)	2.7	-0.35 (-3)	
89/90 (1.1)	2.8		-0.35 (-2)
90/91 (0.0)	2.4		-0.67 (0)
91/92 (2.4)	3.1	-0.38 (-1)	
92/93 (1.1)	2.8	0.36 (0)	

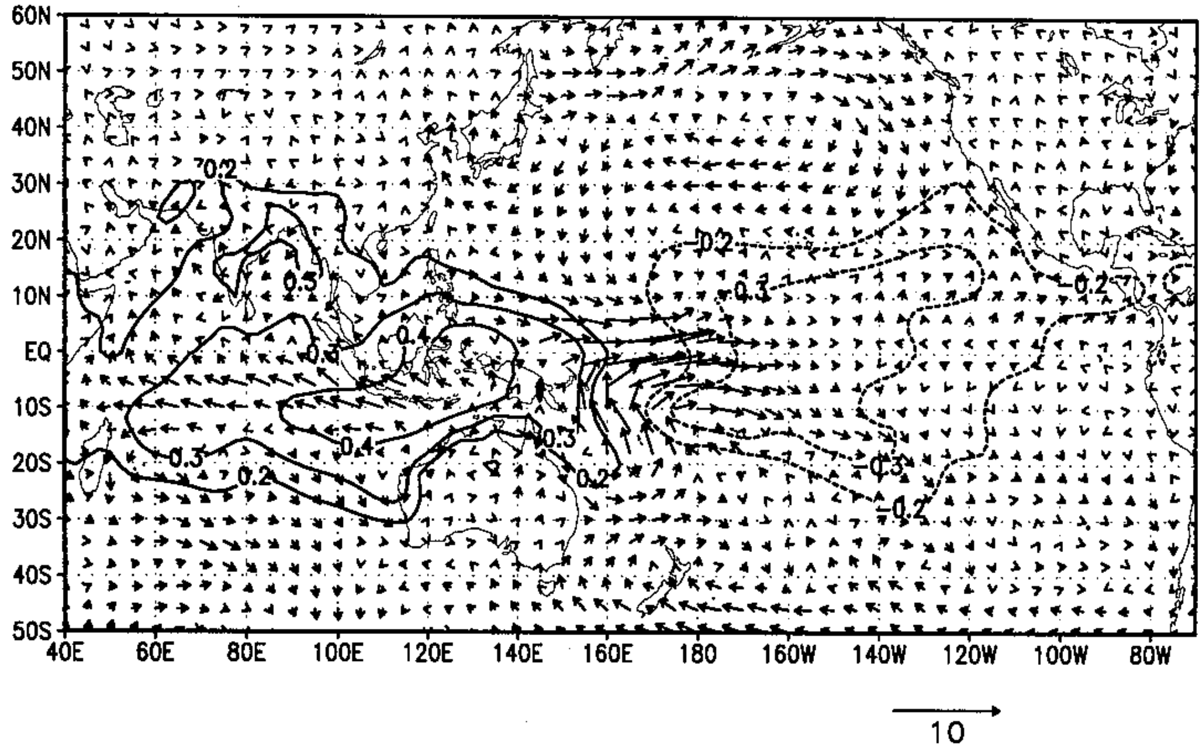

Fig. 2 One-point correlation pattern between u_{TWP} *and SLP, and the covariance vectors* between u_{TWP} and *surface winds (u and v) computed based on daily mean data for the eight winters from 1985-86 through 1992-93.*

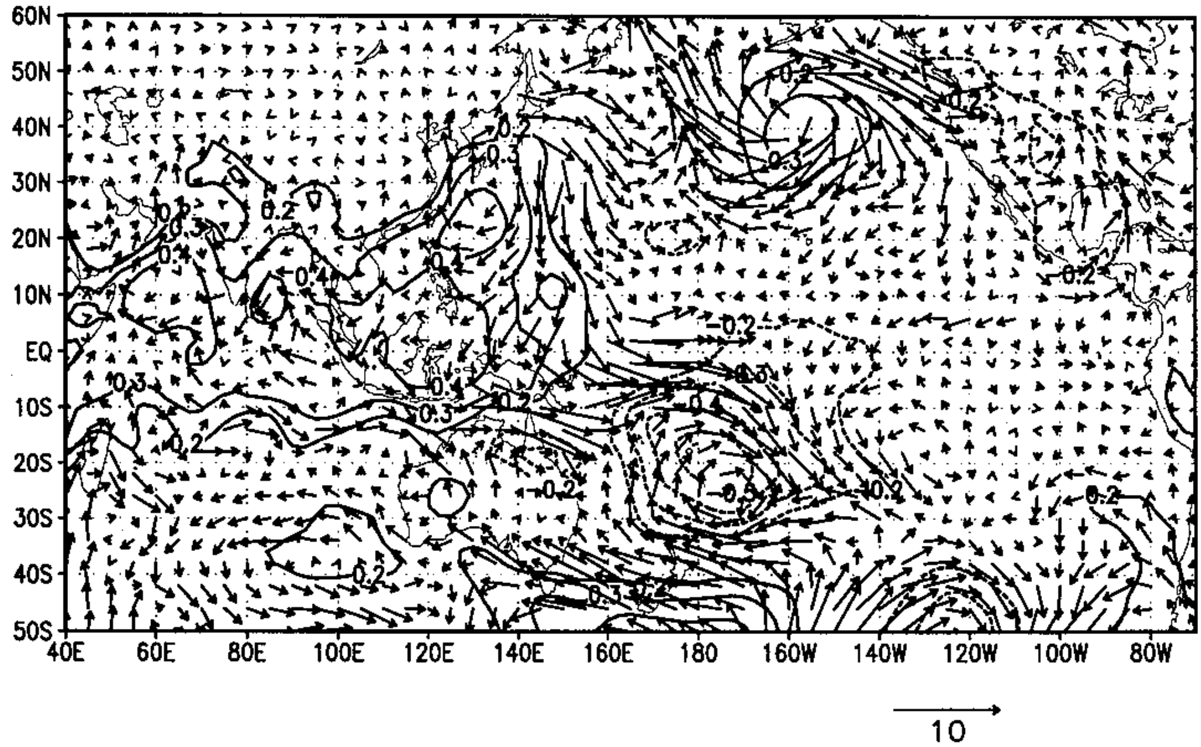

Fig. 3 Same as Fig. 2 except for the winter of 1989-90.

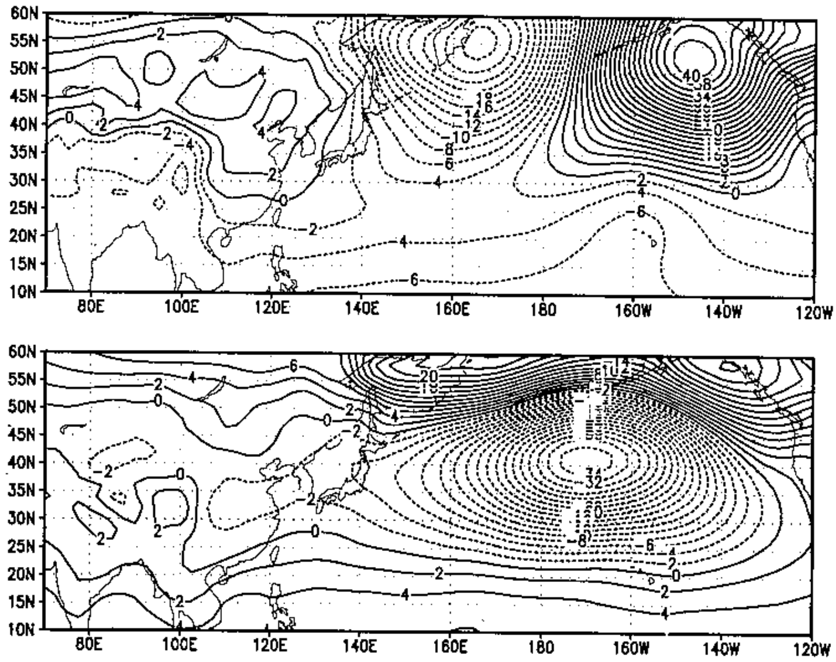

Fig. 4 The second and third eigenfunction of the EOF analysis of daily SLP. They are responsible for 8.6%, and 6.9% of total variance, respectively

3. Discussion

The current analysis suggests that mid-latitude oscillations associated with the winter monsoon circulation have a notable influence on the tropical circulation over the tropical Pacific warm pool, especially in recent years after 1989. There have been many studies on multiscale tropical-extratropical interactions that suggest extratropical wave disturbances both force and respond to tropical convection. Such an interactive nature has prompted a number of observational studies to consider global synoptics of the ISOs (Weickmann 1987; Hsu 1996). While the coupling between tropical convection and extratropical circulation is evident, more specific knowledge about the evolution of the coupled phenomenon and the degree of the coupling between extratropical and tropical ISOs are required to enable a better understanding of the problem.

The current study also suggests a need to further investigate the tropical-extratropical interactions on the interannual time scale. In this regard, the role of air-sea interaction in the tropical ISOs (Sui et al. 1995) is another relevant issue toward the understanding of interannual variability of the climate system.

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