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Movements of the Western Pacific Warm Pool Centroid and Their Relationship to Sea Surface Temperature Changes in Niño Regions

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Abstract By using monthly historical sea surface temperature (SST) data for the years from 1950 to 2000, the Western Pacific Warm Pool (WPWP) climatology and anomalies are studied in this paper. The analysis of WPWP centroid (WPWPC) movement anomalies and the Niño-3 region SST anomalies(SSTA) seems to reveal a close, linear relation between the zonal WPWPC and Niño-3 region SSTA, which suggests that a 9° anomaly of the zonal displacement from the climatological position of the WPWPC corresponds to about a 1℃ anomaly in the Niño-3 region area-mean SST. This study connects the WPWPC zonal displacement with the Niño-3 SSTA, and it may be helpful in better understanding the fact that the WPWP eastward extension is conducive to the Niño-3 region SST increase during an El Niño-Southern Oscillation (ENSO) event.

Key Words Western Pacific Warm Pool (WPWP); WPWP centroid; El Niño; Niño regions; sea surface temperature (SST)

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1 Introduction

The Pacific tropical regions have a permanent surface of warm water on the top of deeper colder subsurface water. The warmest surface water is in the west of the ocean, where the Western Pacific Warm Pool (WPWP) is located (Yan *et al.*, 1992). The studies of Yan *et al.* (1992, 1998, 2002) and Ho *et al.* (1995) show that the time series of the WPWPC movement are mainly related to the onsets of the El Niño events and their annual cycles. Zhao *et al.* (2003) also used a WPWP-related index to show the great impact of this movement on climate changes.

On the other hand, to characterize the nature of the ENSO events, Trenberth and Stepaniak (2001) calculated the SSTAs in different regions of the Pacific. They pointed out that an event could be called El Niño only when the mean SSTA in the Niño-3 region (5°N–5°S, 150°–90°W) exceeds 0.5℃ or when the mean SSTA in the Niño-3.4 (5°N–5°S, 170°–120°W) region exceeds 0.4℃ (Trenberth, 1997) and the anomalies continue for more than 6 months. The SSTA magnitude in Niño regions has been a primary measure of the ENSO events.

Since the WPWPC movement and the SST anomaly in Niño regions are both closely related to the El Niño event, the quantitative relation between the WPWPC movements and the local Niño region SSTA should be checked. Because all Niño regions are highly related to each other (Trenberth and Stepaniak, 2001), the Niño-3 region is chosen as the research area of this study.

The data used in this study are introduced briefly in section 2 and the methods to process them are introduced in section 3. In sections 4 and 5 our analyses and conclusions are given.

2 Data

The reconstructed monthly historical sea surface temperature data using Empirical Orthogonal Functions (EOFs) (2° longitude × 2° latitude resolution, January 1950 to December 1998, from the National Centers for Environmental Prediction, USA) was used in this study. The monthly NCEP SST analyzed fields (1° longitude × 1° latitude resolution, also from the National Centers for Environmental Prediction, USA) were used to extend the former data to 2000 by being mapped to the 2° × 2° grids of the above data. As a whole, SST data of 51 years have been used in this study. These data have been frequently used by other researchers since they were developed and introduced by Reynolds and Smith (1994, 1995) and Smith *et al.* (1996).

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3 Method

Ho *et al.* (1995) and Yan *et al.* (2002) suggested a simple method to calculate the centroid movement of the Western Pacific Warm Pool. The water mass was assumed to be homogeneous in their researches. The centroid of the WPWP was defined by:

$$\bar{x} = \sum_{i=1}^{n} x_i / n, \quad \bar{y} = \sum_{i=1}^{n} y_i / n, \tag{1}$$

where x_i is the zonal position of the SST grid, y_i is the meridional position of the SST grid, and n is the total number of SST grids within the WPWP region (where SST$\geqslant$28℃). In this study, this method is slightly modified by considering the spherical shape of the earth:

$$\bar{x} = \frac{\sum_{i=1}^{n} Area_i \cdot x_i}{\sum_{i=1}^{n} Area_i}, \quad \bar{y} = \frac{\sum_{i=1}^{n} Area_i \cdot y_i}{\sum_{i=1}^{n} Area_i}, \tag{2}$$

where $Area_i$ is the spherical area of the i^{th} grid. The water mass was also assumed to be homogeneous in this study. Eq. (2) does not differ much from Eq. (1) in the tropical ocean, but seems more meaningful physically and convincing.

In this study Eq. (2) is used to obtain the climatology (averaged over 51 years for each month) and the anomalies (original minus climatology) of the WPWP centroid movement. Basically, the anomaly time series is now free of annual cycles since the monthly climatology is removed. The climatology and anomalies of the area mean SST of the Niño-3 region are also calculated by using the same SST data.

4 Results and Analyses

Many fitting methods have been tried to find out the best way to model the climatologies of the WPWPC and the Niño-3 region mean SST. The selected good-fitting results are shown in Figs.1 and 2 (with the standard deviation 'S' and correlation coefficient 'r' at the top-right corners of the plots).

Fig.1 shows the plots of the climatology and anomalies of the Niño-3 region mean SST. The climatology of the Niño-3 region mean SST in Fig.1 A is close to a sinusoidal line. In Fig.1 B, all the strong El Niño events, such as those during 1957 – 1958, 1965 – 1966, 1972–1973, 1982–1983 and 1997–1998, can be detected from the anomalies above the linear fitting line.

Fig.2 gives the plots of the zonal and meridional climatologies of the WPWPC. It suggests that the climatology track of the WPWPC looks like a footprint. Fig.2 C looks quite different from those original time

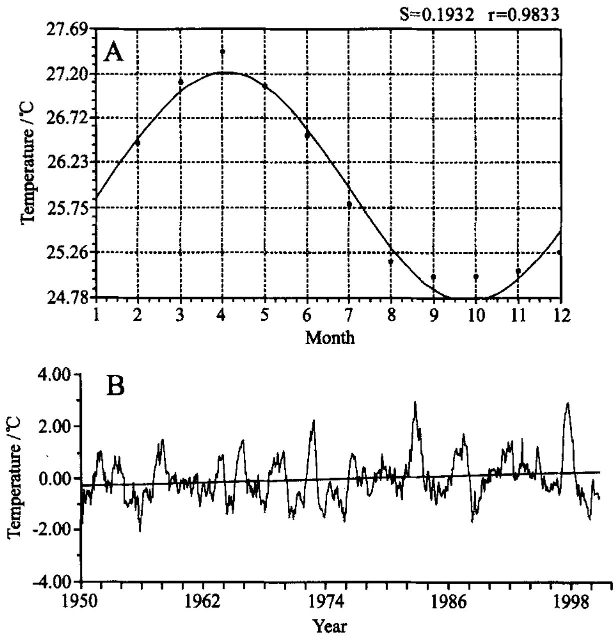

Fig.1 Climatology and anomalies of the Niño-3 area mean SST. (A) Climatology, sinusoidal fitting: temperature = 25.99 + 1.23 cos(0.55 Month−2.23)'; (B) Time series of the anomalies. The straight line shows the linear fitting result.

series of the WPWPC trajectories of Ho *et al.* (1995) and those of Yan *et al.* (1998), which might give a hint that the WPWPC has recently changed in the Pacific Ocean. Fig.3 shows the time series of the anomalies of the WPWPC after the climatology of Fig.2. The meridional anomalies of the WPWPC will be further studied in future researches; here only the zonal anomalies of the WPWPC are focused on.

Intuitively, it can be found that the plot of the Niño-3 region mean SST anomalies (Fig.1 B) is very similar (and almost with no phase difference) to that of zonal WPWPC anomalies (Fig.3 A). These two plots are combined in Fig.4. Fig.5 shows the correlation between these two time series. Although both have different physical meanings and their different climatological annual cycles have been filtered out, a high correlation is found between them, which suggests that an eastward (or westward) shift of the WPWPC anomaly of about 9° corresponds to a warmer (or colder) anomaly of the Niño-3 region mean SST of 1℃. Compared with the result of Zhao *et al.* (2003), the zonal WPWPC anomaly is more closely related to the Niño-3 region mean SSTA than the WPWP area index. The above analysis suggests that the eastward WPWP extension is conducive to the Niño region SST rises or vice versa. To a certain extent, it also means that the zonal WPWPC anomalies and the Niño region mean SSTA are telling almost the same story.

5 Conclusions

The climatology and the anomalies of the WPWPC

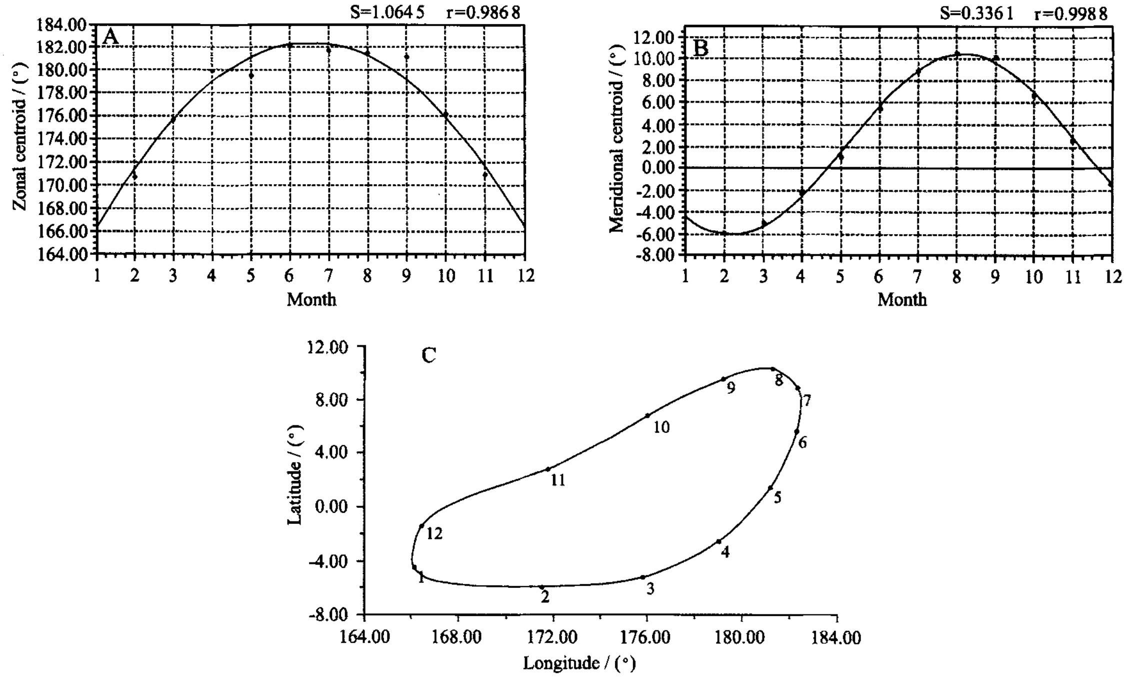

Fig.2 Climatologies of the WPWPC. (A) Zonal centroid, quadratic fitting: zonal centroid = $182.44-0.53\,(\text{Month}-6.53)^2$; (B) Meridional centroid, sinusoidal fitting: meridional centroid = $2.17+8.20\cos(0.53\,\text{Month}-4.29)$; (C) WPWC climatology, combined by the fittings of A and B. Numbers are the month indices.

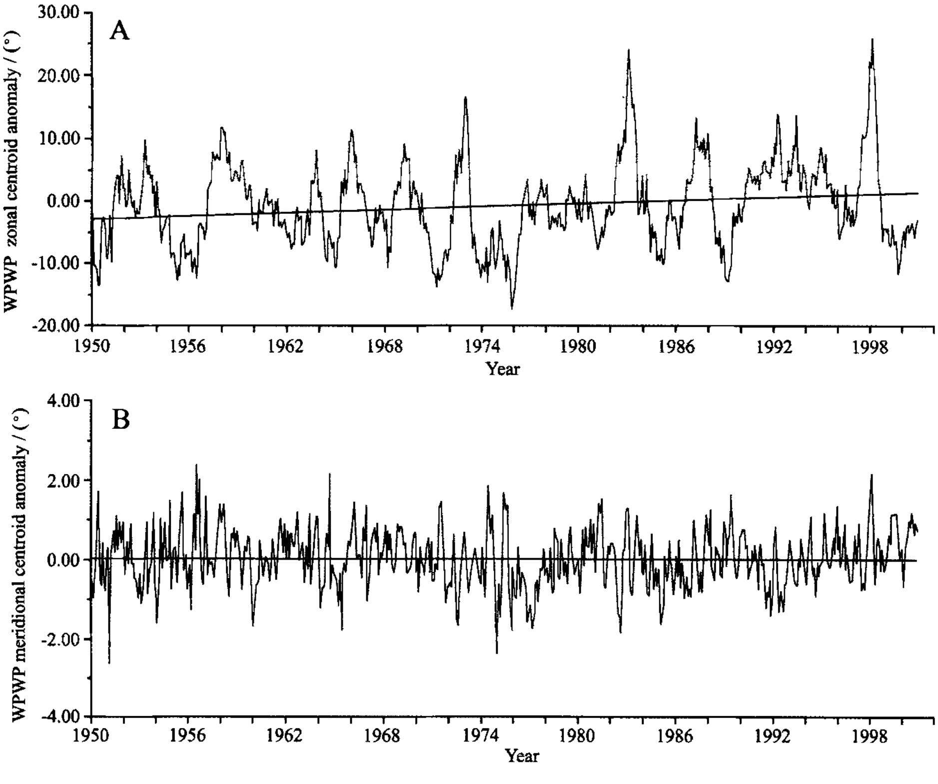

Fig.3 Time series of the anomalies of the WPWP centroid movements after the climatology of Fig.2. (A) Zonal centroid anomalies. The straight line shows the linear fitting result; (B) Meridional centroid anomalies. The straight line shows the linear fitting result.

have been studied with simple methods and the quantitative relation between the WPWPC and the Niño region mean SST has been estimated. It is found that an eastward shift of the WPWPC anomaly of about 9° corresponds to an anomaly of the Niño-3 region mean SST of 1 ℃. The Niño region mean SST anomalies are highly related to the zonal WPWPC movement though it has a different climatology from the Niño-3 SST climatology, which might suggest that the WPWP-view of El Niño and the Niño-SSTA-view of El

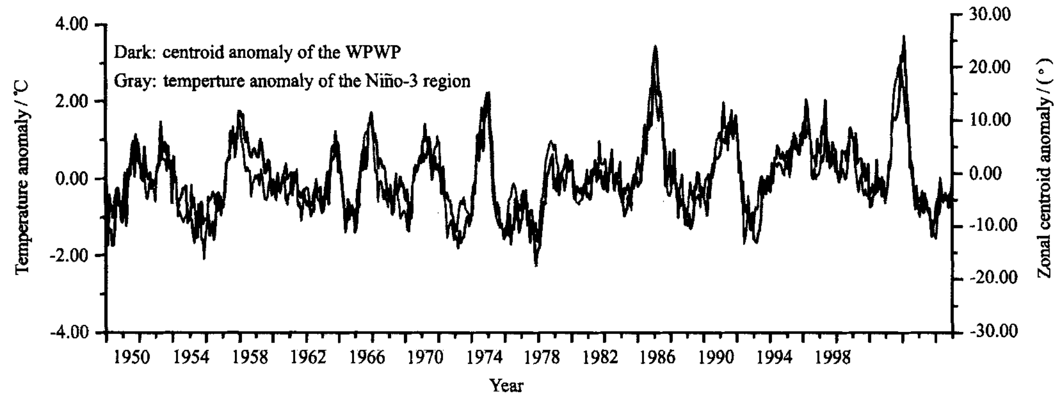

Fig.4 Combination of Fig.1 B (gray) and Fig.3 A (dark).

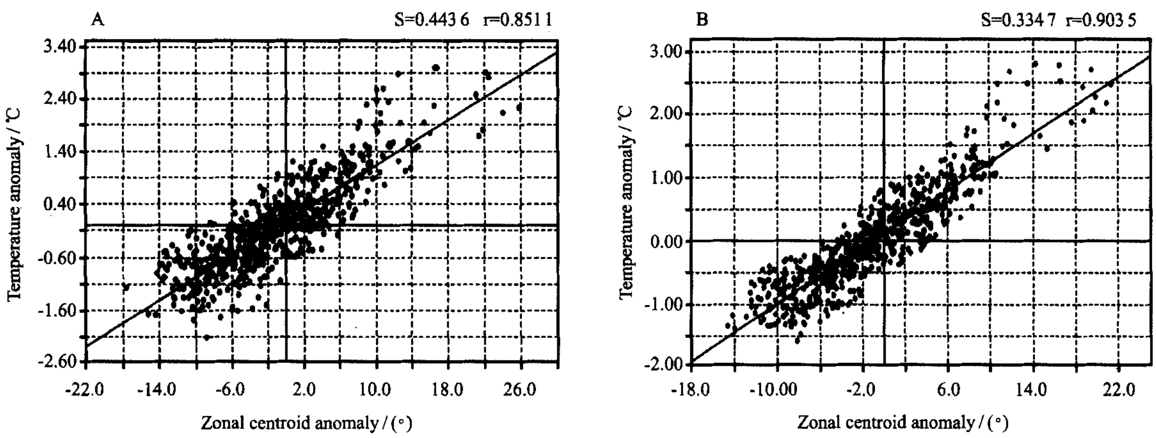

Fig.5 Correlation between zonal WPWPC anomalies and Niño-3 region area mean SST anomalies. (A) Original data, linear fitting: temperature anomaly = 0.091 + 0.106 · zonal anomaly; (B) 5-month-running-mean, linear fitting: temperature anomaly = 0.099 + 0.112 · zonal anomaly.

Niño are almost equivalent to each other. Although the physical connections between them are not revealed in this study, the results could be helpful in our better understanding the fact that the WPWP eastward extension is conducive to the Niño-3 mean SST increase.

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