【104】A Comparison of Characteristics of the Westerly Wind Burst between the Positive Phase and the Negative Phase of the PDO

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Introduction

To understand El Niño-Southern Oscillation (ENSO) diversity under the background of the Pacific decadal oscillation (PDO) during recent decades, the characteristics of westerly wind bursts (WWBs) during the two phases of the PDO were analyzed. It was shown that, during the ENSO developing period, the El Niño evolution may be affected by stronger or more frequent WWBs in the positive PDO phase than in the negative PDO phase. The sustained effects of atmospheric dynamics on the equatorial ocean can be indicated by the accumulated WWB strength, which contains most WWB characteristics, including the accumulated days, occurrence frequency, strength, and spatial range of WWBs. The synoptic/climate systems that are directly related to WWBs show a wider spatial distribution in the positive PDO phase than in the negative PDO phase.

Definition of the Westerly Wind Burst

◆ In the present study, westerly wind burst is defined according to the following criteria:
1) the zonal extension of significant westerly wind anomalies (>5 m s-1) is larger than 1500 km, defined as a zonal fetch;
2) there are at least 4 zonal fetches in the equatorial Pacific (5° S-5° N, 110° E-120° W);
3) the duration of these fetches is no less than 2 days.

Similarly, easterly wind burst (EWB) is defined according to the following criteria:
1) the zonal extension of significant easterly wind anomalies (<-4 m s-1) is larger than 1500 km, defined as a zonal fetch;
2) there are at least 4 zonal fetches in the equatorial Pacific (5° S-5° N, 110° E-120° W);
3) the duration of these fetches is no less than 2 days. A WWB/EWB should be at least 4 strong westerlies with each of them has 1500km zonal fetch at the same time.

◆ To describe the WWB/EWB strength, the cumulant (cumulantWWA) of the westerly wind anomaly (WWA) is defined as the time integral of the positive zonal wind anomaly, integrated within the region (5° S-5° N, 110° E-120° W) over the specified duration, following the definition of wind measure (Harrison et al., 1997). The cumulant of the easterly wind anomaly (EWA) is defined as the time integral of the negative zonal wind anomaly integrated on the same region.

$$cumulant_{WWA} = \frac{1}{S}\iint u'dsdt, (WWA: only\ for\ u' > 0)$$

$$cumulant_{EWA} = \frac{1}{S}\iint u'dsdt, (EWB: only\ for\ u' < 0)$$

S is the total area of the region (15°S-15°N, 110°E-120°W). The daily climatological mean was calculated based on the data over the period from 1980–2009. Similarly, the SST anomalies are obtained based on the same climatological period. The anomaly u' is the departure from the climatological cycle. The developing period of ENSO is chosen from February to June, covering the late winter, the spring and the summer seasons. In the following, the positive phase of PDO is defined as the period from 1980 to 1998, and the negative phase of PDO is from 1999 to 2013

Data and Methods

Before the cumulant calculation, the zonal wind anomalies are first meridionally averaged over the equatorial region (5° S-5° N), and the cumulant is calculated along the longitudinal direction and temporally integrated. Actually, the quantitatively measurement of WWB strength has attracted much attention. The daily climatological mean in PDO positive phase is calculated based on the data over the period from 1980 to 1998. The daily climatological mean in PDO negative phase is calculated based on the data over the period from 1999 to 2013. Similarly, the SST anomalies are obtained based on the climatological period from 1981 to 2010. The anomaly u' is the departure from the climatological cycle. The developing period of ENSO is chosen as the period of February-June, covering the late winter, the spring and the early summer seasons.

The Characteristics of Westerly Wind Burst

◆ As shown by the temporal and spatial distributions of WWBs (Fig. 1), a significant change in the WWB characteristics occurred during a switch of the PDO from a positive phase to a negative phase in approximately 1999. Generally, the WWBs had a longer duration and a wider spatial range during the positive PDO phase (the left panel) than negative PDO phase (the right panel). The WWB frequency decreased in neutral years, and WWB events seldom occurred in La Niña years. In total, the duration, spatial range and occurrence number of WWBs were high in El Niño years, which indicates that WWBs preferentially occur in El Niño years.

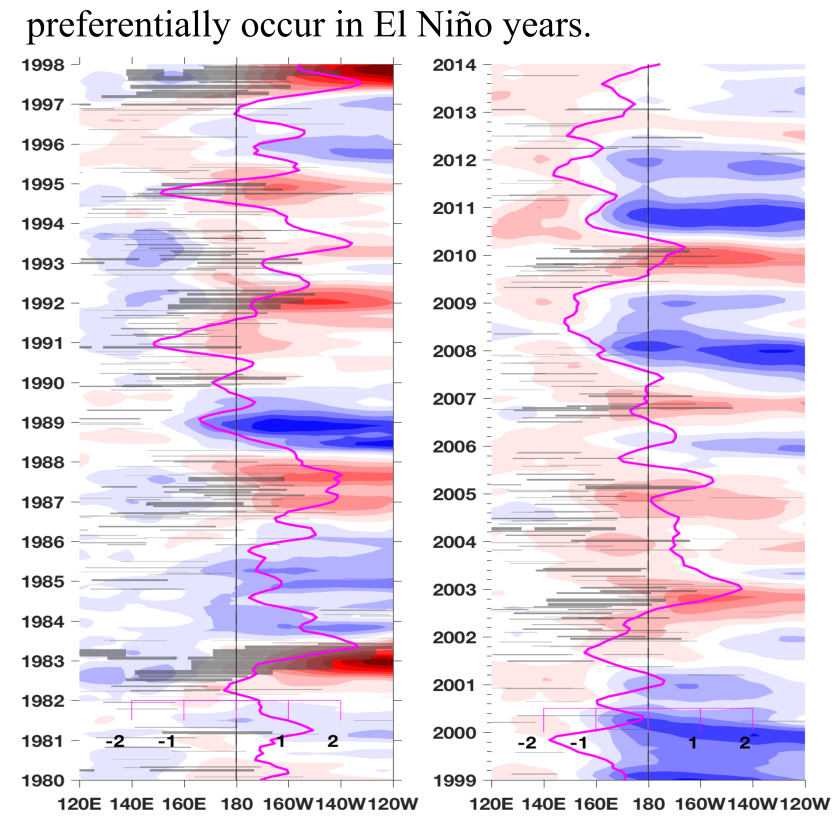

Figure 1. The SSTAs (shading) along the Equator (within 5°N-5°S) for the period of 1980-1998 (left) and period of 1999-2013 (right). The grey shaded patches indicate the episodes of westerly wind events. The SST fields are from the ERSSTv5 SST dataset. The PDO index is plotted in (a) with a magenta line.

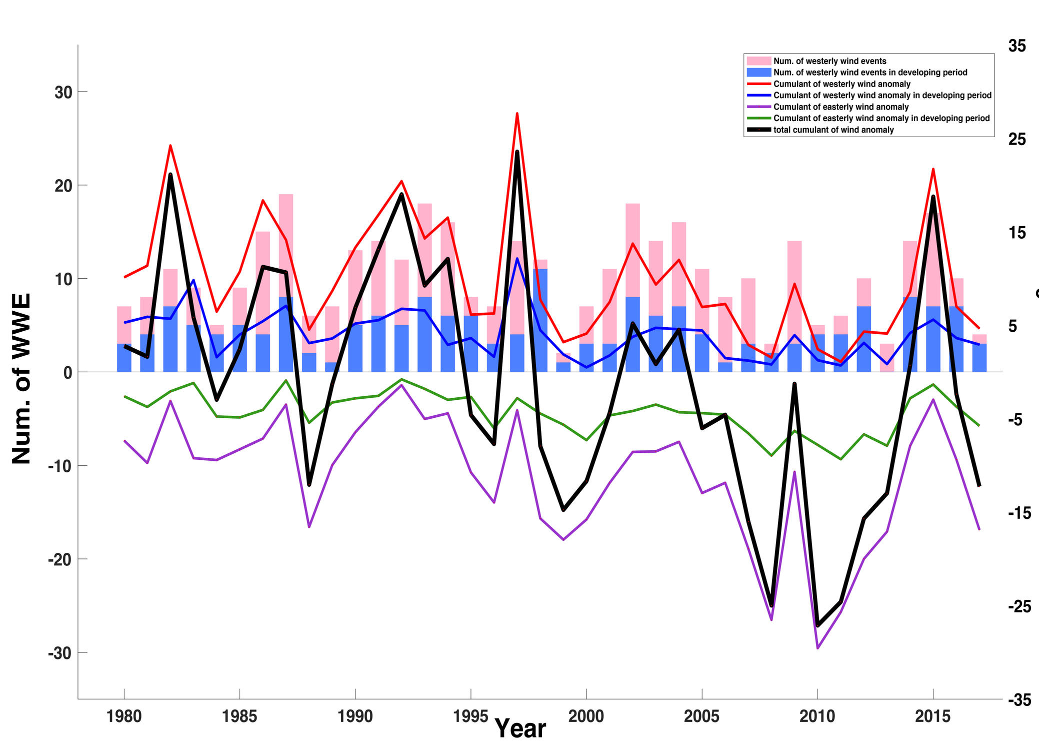

Figure 2. Time series of the occurrence number of westerly wind events (bar) for each year and time series of the cumulant of anomalous wind for westerly/easterly wind events (line; m) along the equator area (within 15°N-15°S) for each year. The pink bar which is covered with the blue bar indicates the occurrence frequency of WWB per year and the blue bar indicates the occurrence frequency of WWB during February-June for each year. The red line indicates the WWA/EWA cumulant per year and the blue line indicates the tendency of WWA/EWA cumulant during February-June for each year. The black line indicates the total cumulant of anomalous wind for each year.

◆ The interannual variability of the occurrence frequency of WWBs/EWBs was consistent with that of the cumulant of WWAs/EWAs in both the developing period and the whole year. There was a remarkable negative correlation (r=-0.81) between the time series of the annual WWA cumulant and the absolute values of the annual EWA cumulant. For the cumulants during the ENSO developing period, a similar relationship (r=-0.76) also existed between the WWA cumulant and the absolute values of the EWA cumulant. During the positive PDO phase, there were more WWBs than EWBs, which could provide favorable environmental conditions for extreme El Niño events. During the negative phase of PDO, the total cumulant depicted more EWAs than WWAs, indicating unfavorable conditions for an intense El Niño.

◆ Moreover, the total occurrence frequency and the annual WWA cumulant during the positive PDO phase were both larger than those during the negative PDO phase. The number of WWB was 182 during the positive PDO phase, while it was 144 during the negative PDO phase (Table 1). The mean annual WWA cumulant was $0.5*10^6$ m during the positive PDO phase and $0.5*10^6$ m during the negative PDO phase. During the ENSO developing period, the mean WWA cumulant reached $0.2*10^6$ m (approximately 40% of the annual mean) in the positive PDO phase, which was larger than that in the negative PDO phase ($0.15*10^6$ m; approximately 38% of the annual mean).

◆ Generally, the interannual variabilities of the WWBs match well the ENSO variabilities. But the two main factors of WWB, the number of WWB and the WWA cumulant, may have different characteristics in certain El Niño years which have similar strength.

The two-dimensional spatial distribution of WWB and WWA strength

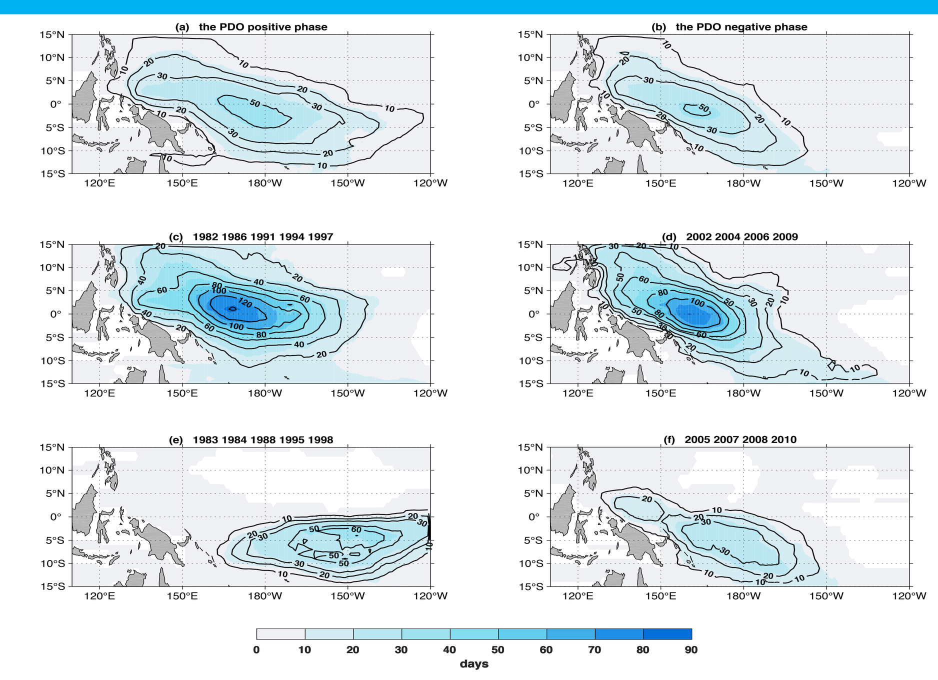

Figure 3. The spatial distribution of the occurrence frequency (shading; %) related to WWBs for each local grid (of WWAs on local grid) and the daily accumulated westerly anomalous strength (contour, cm s^{-1}) during (a) the positive phase of PDO, (b) the negative phase of PDO, (c) the El Niño years (1982, 1986, 1991, 1994, 1997) of the positive phase of PDO, (d) the El Niño years (2002, 2004, 2006, 2009) during the negative phase of PDO, (e) the La Niña years (1983, 1984, 1988, 1998) in the positive phase of PDO, (f) the La Niña years (2005, 2007, 2008, 2010) during the negative phase of PDO. Concerning the accumulated occurrence frequency of WWBs and the accumulated westerly anomalous strength, one value is calculated each year. Here presents the average value each year.

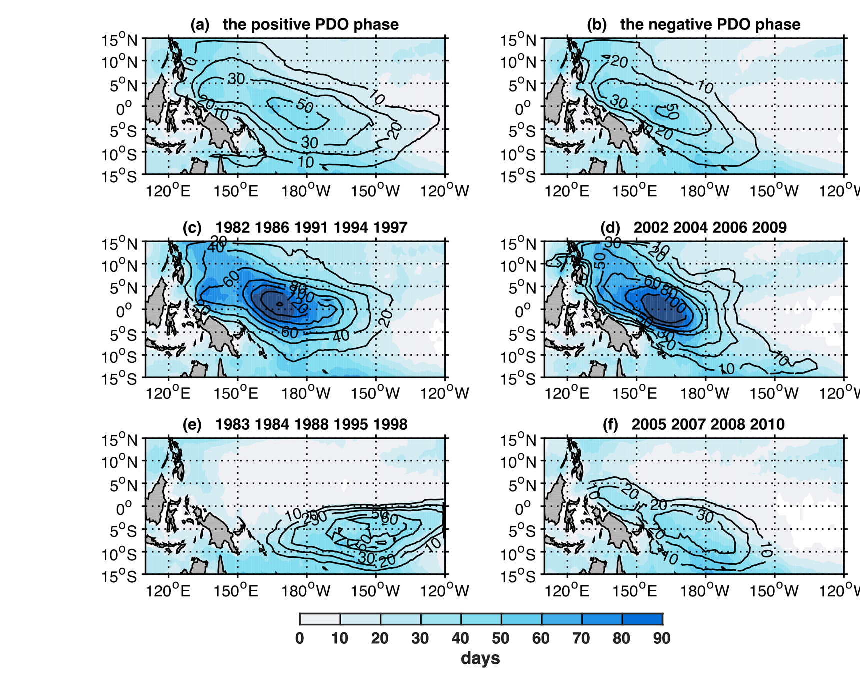

Figure 4. The spatial distribution of the mean accumulated days (shading; days) of WWAs in the local grid for each year and the accumulated westerly anomalous strengths (contour, cm s-1) during (a) the period of the positive PDO phase, (b) the negative PDO phase, (c) the El Niño years (1982, 1986, 1991, 1994, 1997) of the positive PDO phase, (d) the El Niño years (2002, 2004, 2006, 2009) during the negative PDO phase, (e) the La Niña years (1983, 1984, 1988, 1998) in the positive PDO phase, and (f) the La Niña years (2005, 2007, 2008, 2010) during the negative PDO phase. The calculation method is the same as that in Fig. 3.

◆ The mean WWB-related accumulated days had a similar distribution as the mean WWB-related strength .

◆ Furthermore, the amplitude of the WWA duration period was generally larger than that of the WWB-related duration period, even in the region of 5°S-5°N. It can be deduced that a large fraction of the WWAs failed to match the definition of a WWB.

The spatial distribution of the WWA occurrence frequency and the accumulated westerly anomalous strength

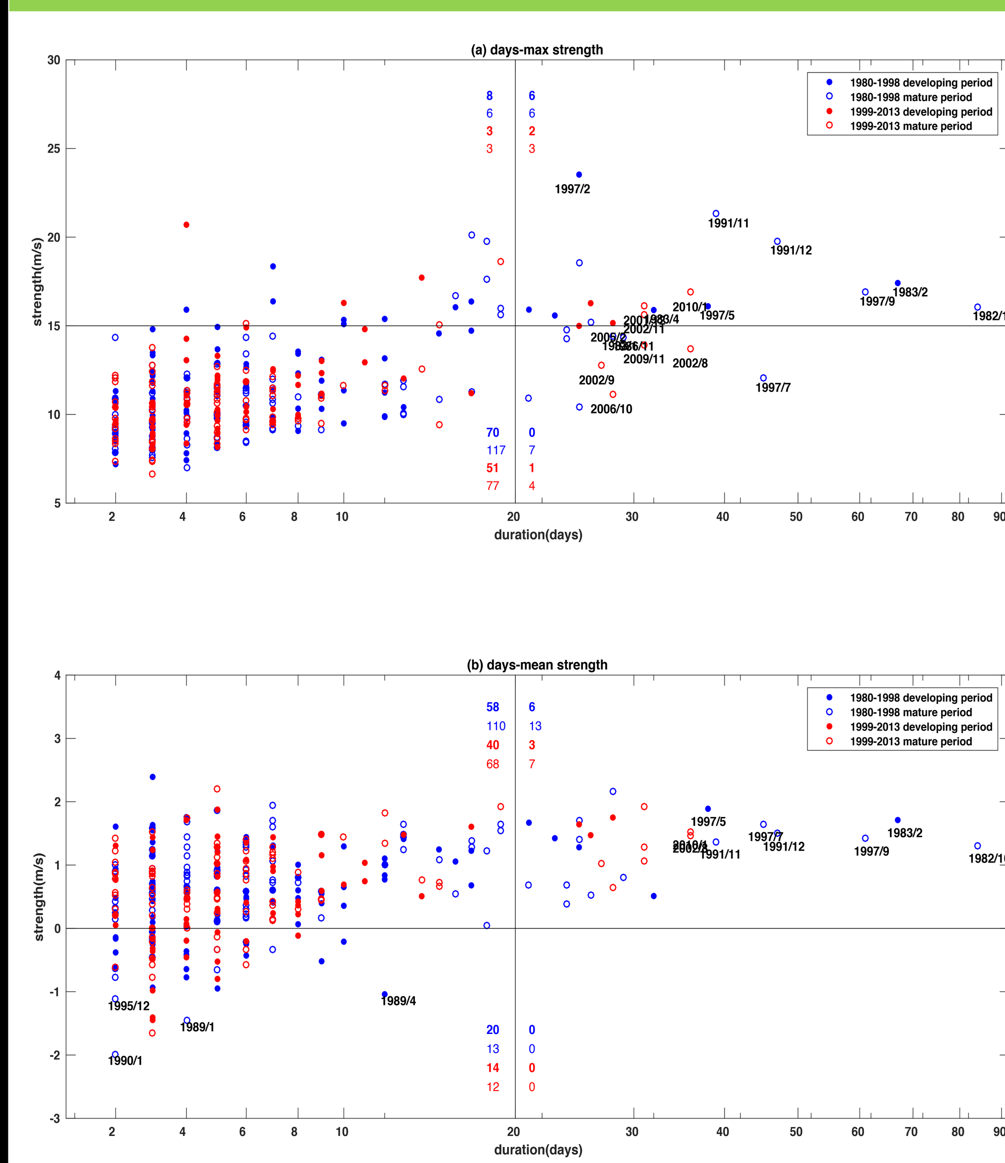

Figure 5. Scatter plot of the WWB duration compared to the (a) maximum u-wind anomaly and (b) mean u-wind anomaly. The blue (red) dots represent a westerly wind event during the ENSO developing period of the positive (negative) phase of the PDO, and the values during the ENSO mature period are indicated by blue (red) circles. The events are separated into four groups according their period and strength. The numbers of WWBs in each group are shown at the corner of each quadrant, following the order listed by the legend

Here, we choose 20 days as the appropriate threshold to discriminate the brief events and the sustained events. In addition, the WWB events were classified into another two categories based on their maximum strength: strong westerly wind events with a maximum strength larger than 15 m s^{-1} and moderate westerly wind events with a maximum strength less than 15 m s^{-1}. Similarly, the events were classified into another two categories according to the mean zonal wind anomaly strength: positive wind events with a positive mean strength and negative wind events with a negative mean strength. The maximum/mean strength-duration distribution tended to have an inherent relationship with the brief/sustained categories (Fig. 5).

The strength includes zonal maximum strength and zonal mean strength of a certain WWB process. In the positive PDO phase, some (26; 70%) strong westerly wind events (>15 m s^{-1}) lasted longer than 20 days. The strong WWB with a sustained duration (>20 days) and large strength (>15 m s^{-1}) occurred mostly in the mature period (6; the first quadrant in Fig. 5a). The mean strength of westerly wind events in the negative PDO phase was less than that in the positive PDO phase (the first and the second quadrant in Fig. 5b), and there were fewer events with a sustained duration and large mean strength in the ENSO mature period in the negative PDO phase (3) than in the positive PDO phase (6; the first quadrant in Fig. 5b).

In Fig. 5b, the mean zonal strength of the wind anomaly may be positive or negative. The negative values indicate that the strength of the EWA is larger than the strength of the WWA over the specified area. The WWB generally have a positive mean strength (323; 82%), and most (293; 75%) are brief WWB (<20 days) (the second quadrant in Fig. 5b). The mean wind anomaly strength and duration decreased during the negative PDO phase compared the positive PDO phase. Meanwhile, the occurrence frequency of WWBs decreased during the switch from the positive PDO phase (210) to the negative PDO phase (138).

Summary & Discussion

◆ The predictability of El Niño has been degraded after 2000. The potential direct reason for this decrease is that the characteristics of ENSO in the positive PDO phase (1980-1998) are different from those in the negative PDO phase (1999-2013). To investigate the mechanism of ENSO diversity changes in recent decades, it is necessary to clarify the comparison of WWB differences between the positive PDO phase and the negative PDO phase.

◆ Both the WWB numbers and the WWA cumulant are important for ENSO formation. During the El Niño years, the WWA cumulant reached high values, and the WWB number was relatively high, both during the developing period and during the whole year. On the other hand, the WWB number and the WWA cumulant were relatively low both in the normal years and in the La Niña years.

◆ Because equatorial WWB events are commonly caused by synoptic activities beyond the equatorial region, the spatial patterns of westerly anomalies related to WWB events were further investigated. The spatial distribution of the WWB-related duration in the positive PDO phase was wider than that in the negative PDO phase. This characteristic is consistent with the spatial pattern of WWB-related strength. Compared to the positive PDO phase, the WWB spatial range and WWB-related strength during the ENSO developing period in the negative PDO phase were decreased. Meanwhile, the spatial distribution of the WWB-related duration during the ENSO developing period in the positive PDO phase was also larger than that in the negative PDO phase.

◆ The spatial and temporal distribution of WWBs reveals obvious interannual variability and apparent decadal change. The typical ENSO diversity during the two phases of the PDO can be well explained by the changes in the WWBs near the equatorial region. As the climatological mean state of the tropical Pacific during the different PDO phases has changed, such decadal changes in WWBs may be related to large-scale climate shifts. Considering the difficulties arising in ENSO prediction in recent years, a more thorough investigation of WWB variabilities could provide potential precursor signals for ENSO prediction.