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Super Typhoon Activity over the Western North Pacific and Its Relationship with ENSO

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Abstract This paper analyzes the characteristics of super typhoons (STYs) over the western North Pacific (WNP) from 1965 to 2005 and describes the seasonal variability of STY activity. The relation between STY activity and the El Niño-Southern Oscillation (ENSO) as well as the possible reason for the influence of the ENSO on STY activity are also investigated. The results showed that about one fifth of the tropical cyclones (TCs) over the WNP could reach the rank of STY. Most STYs appeared from July to November while there was a highest ratio between number of STYs and total number of TCs in November. Most STYs appeared east of the Philippine Sea. In El Niño years, affected by sea surface temperature (SST), monsoon trough and weak vertical wind shear, TC formation locations shifted eastward and there were more STYs than in La Niña years when the affecting factors changed.

Key words super typhoon; ENSO; monsoon trough; vertical wind shear

1 Introduction

The western North Pacific (WNP) has the greatest number of tropical cyclones (TC) which accounts for 1/3 of the total number of global TCs (Yang, 2005). China, located on the western north coast of the Pacific, is one of the countries most severely affected by TCs. A Super Typhoon (STY) belongs to the strongest rank, hence the most damaging class of TCs. The occurrence frequency of STYs in recent years has an increasing trend (Wedbster *et al.*, 2005). Therefore, to find the law of their activities over the WNP is significant for predicting STY activities and reducing losses caused by them.

Previous studies of TC activity showed that it is affected by many factors, including sea surface temperature (SST), monsoon trough, subtropical high, Madden-Julian Oscillation (MJO) and long-term air-sea coupling interaction (Chia and Ropelewski, 2002; Chen and Huang, 2006a; Matsuura *et al.*, 2003).

Many researches focused on the effect of ENSO on TC activity. Their results showed that the location of TC formation would shift in strong El Niño or La Niña years, which means that in the summer and fall of strong El Niño years, TCs would be generated, on the average, to the southeast of their locations in neutral years, and as a result, they would have a broader space for their activities before landing and a longer duration over the warm sea surface; consequently the average intensity of the TCs would be stronger in El Niño years (Chan, 2000; Chen and Wang, 2006). However, some other studies suggest that the correlation between annual TC numbers and the ENSO phenomenon is not significant (Chen and Huang, 2006b; Camargo and Sobel, 2005); the impact of local SST is not a significant factor affecting TC activity; it is not certain whether the variability of average TC intensity is the result of a longer duration over the sea surface, while dynamic processes caused by anomalous circulation may be more important factors of TC activity (Chen and Huang, 2006b; Camargo and Sobel, 2005).

In this paper, the characteristics of STYs over the western North Pacific and the circulation anomaly caused by ENSO were analyzed. The variability of STY activity was explained in terms of large-scale circulation anomalies.

2 Datasets and Definitions

This study used the best track data of TCs obtained online from the Joint Typhoon Warning Center (JTWC) website (http://www.usno.navy.mil/JTWC), the National Center for Environmental Prediction/National Centers for Atmospheric Research (NCEP/NCAR) monthly mean reanalysis wind data (2.5˚×2.5˚) and the Simple Ocean Data Assimilation (SODA) reanalysis data for monthly mean SST (0.5˚×0.5˚) for the period 1965 to 2005. The El Niño years and La Niña years referred to in this study were defined on the basis of the ENSO index supplied by the Climate Prediction Center (US), and both meaning the developing years. STY is defined as a TC which reaches Typhoon-4 (TY-4) in the Saffir-Simpson scale, namely, its

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maximum wind speed near the center exceeds 114 kt (58.6 m s^{-1}).

3 Characteristics of STYs over the Western North Pacific

3.1 Classification of TCs and Their Frequency Distribution

Statistics show that during 1965–2005 the total number of TCs over the WNP was 1226, of which 258 TCs reached STY intensity, accounting for 21% of the total number, with TY-4 accounting for 13% and TY-5 (maximum wind speed exceed 135 kt) accounting for 8% (Fig.1).

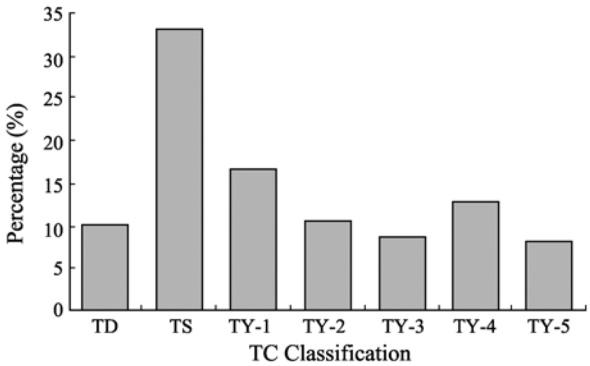

Fig.1 Probability Distribution of TCs in the WNP in 1965–2005. In the Saffir-Simpson scale, TD means tropical depressure with wind speed (WS)≤33 kt, TS means tropical storm with 34kt≤WS<63 kt, TY-1 means hurricane category 1 with 64≤WS<82 kt, TY-2 means hurricane CAT. 2 with 83≤WS<95 kt, TY-3 means hurricane CAT. 3 with 96≤WS<113 kt, TY-4 means hurricane CAT. 4 with 114≤WS<135 kt, and TY-5 means hurricane CAT. 5 with WS>135 kt.)

3.2 Spatial Distribution of STY

Most STYs occurred within the area of 5˚–35˚N, 110˚–170˚E, which is smaller than that for TCs over the WNP. The STY frequency of occurrence with respect to latitude show a single peak distribution and the peak located in the vicinity of 18˚N (Fig.2), which was also the location of the peak of TC activity (Lei and Chen, 2002). The maximum frequency of STYs located east of the Philippine Sea (15˚–25˚N, 125˚–135˚E) and there was a secondary high frequency area in the central and northern part of the South China Sea (Fig.2).

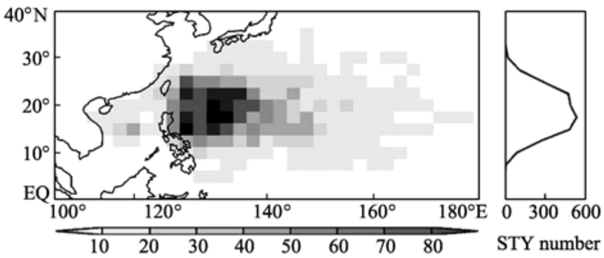

Fig.2 Frequency of STYs (left) and accumulated STY frequency within a 2.5˚ latitudinal zone (right) in the WNP in 1965–2005.

STYs over the WNP mostly formed over the tropical sea surface (5˚–20˚N, 130˚–170˚E) (Fig.3a). The locations of STYs reaching their maximum intensities were east of Taiwan-Philippines (10˚–25˚N, 120˚–160˚E) (Fig.3b), implying that most STYs moved westward or northwestward after their formation. Even the landing STYs reached afterwards their maximum intensities over the ocean east of Taiwan and Luzon, which suggested that STYs had already started to diminish when they moved near the mainland.

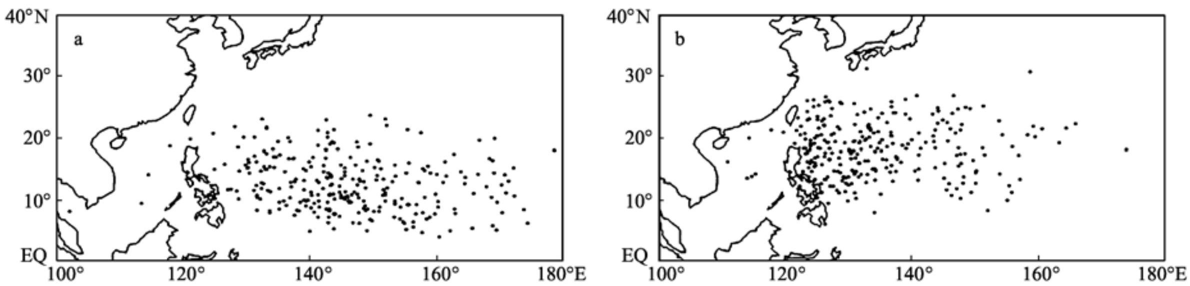

Fig.3 Initial formation location of STYs (a) and locations of maximum intensity (b) in 1965–2005.

3.3 Seasonal Variation of STY

STY activity over the WNP had obvious seasonal variation. There were 261 STYs over the WNP from 1965–2005 and 54 of them were generated in September which represented the highest frequency. Only one STY formed in February and one in March (Fig.4a). There were 217 STYs that formed in July to November (JASON), accounting for 83% of the total number; therefore we defined JASON as the STY season. The STY season was deferent from the TC season (JASO) defined by Zhou *et al.* (2002). The main difference was in November when the ratio of STY/TC was the largest (Fig.4b), which was similar to the characteristics of the rapid intensification of TCs (Wang and Zhou, 2008). Although the TC activity in August was most frequent, the ratio of STY/TC in August was minimal during the STY season.

The seasonal evolution of STY activity can be seen more clearly by reference to TC track diagrams (Fig.5). From February to March, the frequency of occurrence of STY activity was the least and the field of activity could mostly extend southward, about beyond of 15˚N. In April and the following months, the area of STY activity continually migrated to the northwestward and the frequency of occurrence of STY was in an increasing trend. And then, STY activity attained its peak in September. The area for maximum STY frequency of occurrence located near 22˚N at this time. The location of STY activity migrated southeastward from October to December with a decreasing frequency of occurrence of STY. STYs had mostly the turning-type of track in January-June, because their locations were far from land. There were more westward-type and northwestward-type STYs in July-September and their locations were near land, hence a great number of landing STYs. In October and November the number of westward-type and northwestward-type STY decreased, with a decrease in the number of landing STYs. There were few STYs in December and most of them were turning-type.

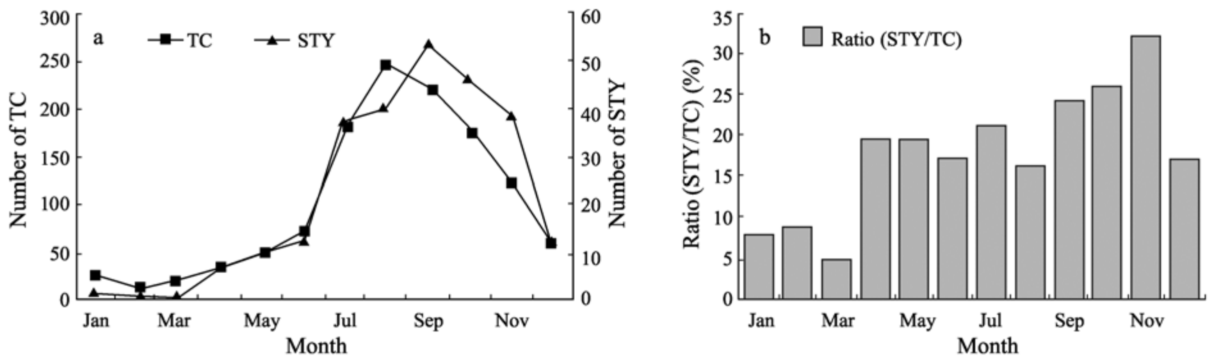

Fig.4 Variation of number of TC and STY by month (1965–2005) (a); Ratio of (STY to TC) by month (1965–2005) (b).

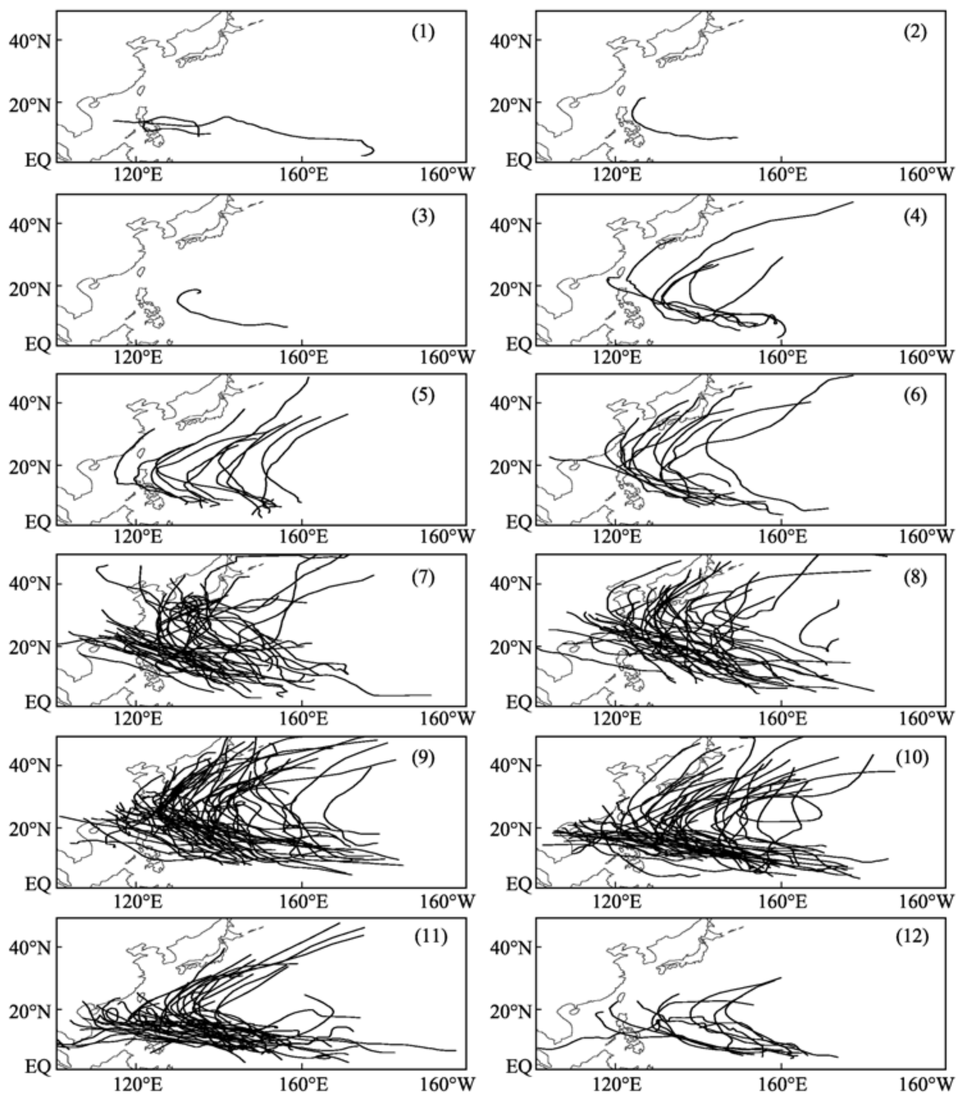

Fig.5 STY tracks over the WNP by month in1965–2005.

4 Effects of ENSO on STY

4.1 The Relation Between ENSO and STY Activity

Previous studies showed that in El Niño years, positive SST anomaly (SSTA) occurred in the eastern tropical Pacific and negative SSTA occurred in the western tropical Pacific. This distribution of SSTA weakens the Walker Cell, making its rising branch drift eastward, ITCZ and subtropical high drift southward in these years, meaning that convections over the western Pacific were suppressed. These conditions were disadvantageous to TC formation over the WNP (Li, 2000). However, statistical results show that there were more STYs in El Niño years than in La Niña years over WNP (Fig.6). Seven strong El Niño years (1965, 1972, 1982, 1987, 1991, 1997 and 2002) and seven strong La Niña years (1970, 1973, 1975, 1984, 1988, 1998 and 1999) were selected according to the value of Niño 3.4 SSTA to compare the difference of STY activity during ENSO events. The results showed that the average number of TCs (30.4/year) in strong El Niño years was almost equal to that in strong La Niña years (26.9/year), while the average number of STYs (8.4/year) in strong El Niño years was greater than that in strong La Niña years (4.7/year). The number of STYs in strong El Niño years accounts for 27.7% of the TC number, and this ratio in strong La Niña years is 17.5% (Fig.6). ENSO events influence STY activity more effectively than TC activity. This may suggest that the factors that control TC formation are different from those that determine TC intensity (Frank and Young, 2007).

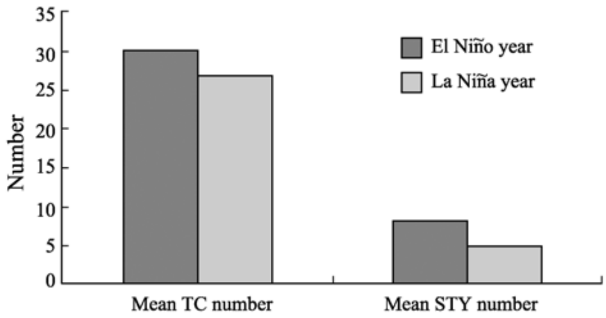

Fig.6 Mean TC number and STY number during El Niño and La Niña.

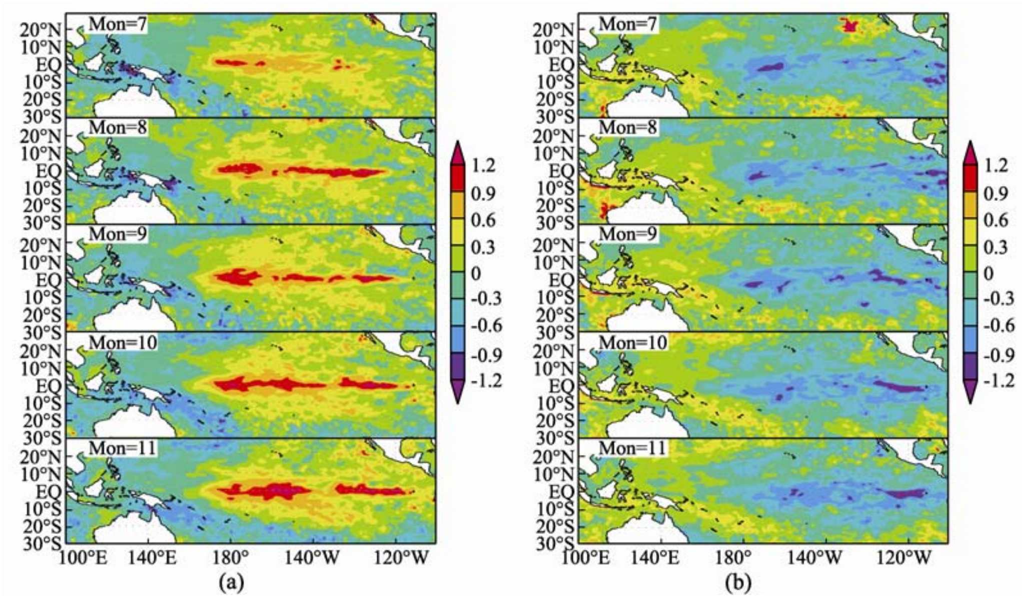

Fig.7 Composite SST anomaly fields from July to November for maximal and minimal STY number years.

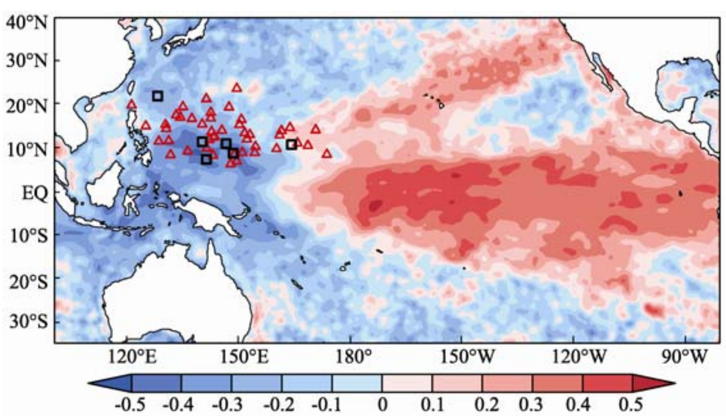

Fig.8 Correlation between STY Number and SSTA , the red triangles (black squares) denoting the formation locations of STYs in the maximal (minimal) STY number years.

SSTA fields from July to November were composed for the maximal STY number years (1965, 1992, 1994 and 2004) and minimal STY number years (1974, 1978, 1985 and 1999) are shown in Fig.7. In the maximal STY number years, positive SSTAs expanded in the central and eastern tropical Pacific and negative SSTAs occurred in the western tropical Pacific (Fig.7a). This pattern was similar in shape to that of El Niño events. In the minimal STY number years, positive SSTAs expanded in the western tropical Pacific and negative SSTA occurred in the central and eastern Pacific (Fig.7b). This pattern was similar in shape to that of La Niña events. It means that the STY number had a close relationship with ENSO events. Fig.8 shows the correlation between annual STY number and SSTA in the STY season. The positive values are located in the central and eastern Pacific while the negative values are located in the western Pacific, suggesting that there were more STYs in El Niño years and fewer in La Niña years.

4.2 Possible Mechanism of ENSO Affecting STY Activity

During El Niño years, most of STYs formed in the region 5˚–22˚N, 130˚–170˚E, whereas in La Niña years, most of STYs formed west of 150˚E (dots in Fig.9). The zonal drift of STY location was similar to that of Typhoon (TY) during ENSO events (Wang and Chan, 2002). The location of STY was affected by monsoon trough and SST. Higher SST can maintain low-level humidity conditions and enhance the local convections. Both of them are propitious to the generation of STYs (Wang *et al.*, 2006). The monsoon trough can provide low-level vorticity, which is advantageous to STY activity. Fig.9 composes the initial formation locations of STYs in seven strong El Niño years and seven strong La Niña years. In El Niño years the highest SST of the tropical Pacific occurred between 140˚E and 180˚E, and the monsoon trough extended to 170˚E. Because warm water and monsoon trough overlapped in 140˚–170˚E, there were warm and humid atmosphere, abundant convections and proper low-level vorticity (Fig.9a). Therefore, most of the STYs formed in this area. In addition, there was enough heat and CISK processes for STY to intensify, because its location drifted eastward. In La Niña years, the highest SST of the tropical Pacific occurred west of 160˚E, and the monsoon trough was short and weak and situated to the west. Therefore, the initial formation locations of STYs shrank westward in La Niña years (Fig.9b).

For the development of a TC, strong vertical wind shear will destroy the vertical structure of the TC and dissipate the energy of the warm core. Therefore, weak vertical wind shear is a necessary condition for a tropical cyclone to intensify (Paterson *et al.*, 2005). According to the above results, ENSO events could affect the intensity but not the number of TCs through anomalous circulations. In El Niño years, there was weaker vertical wind shear over the WNP due to the change of the Walker Cell and other large scale systems. Because of the weaker vertical wind shear and the eastward drift of their formation locations, TCs could remain in areas with weak vertical shear during their movements (Fig.10a). Therefore, they were more likely to reach the rank of STY level in these

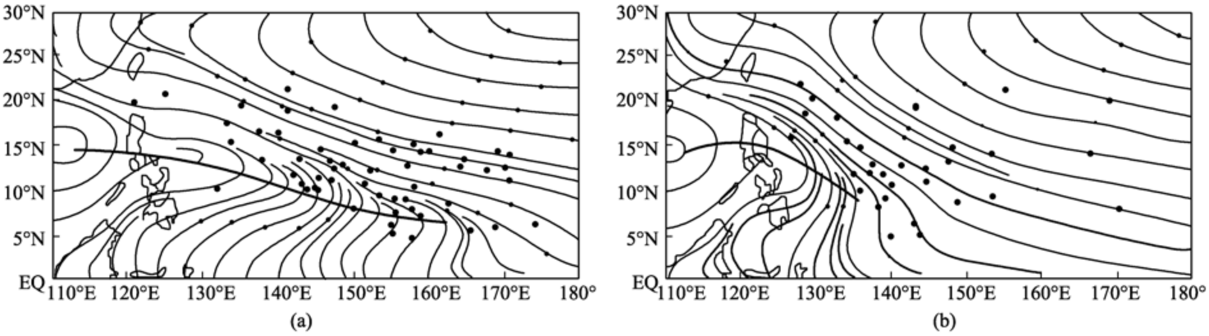

Fig.9 Stream of 850 hPa and initial formation locations of STYs in El Niño years (a) and La Niña years (b). The monsoon trough is denoted by a black heavy line.

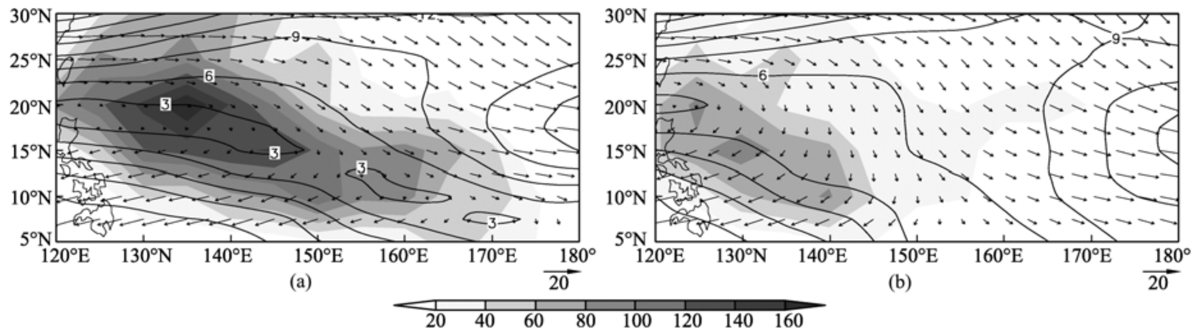

Fig.10 Vertical wind shear (200–850 hPa) and frequency of STY in El Niño years (a) and La Niña years (b). The contours denote isotachs and shaded contours show the frequency of STY.

years. In La Niña years, vertical wind shear over WNP was stronger than that in El Niño years and the initial locations of TCs drifted westward. It was difficult for a TC to obtain a favorable vertical wind shear in La Niña years (Fig.10b). In addition, TCs had longer time to intensify before landing in El Niño years due to the eastward drift of their formation locations (Chan and Liu, 2004). This is also conducive to TC developing to STY. As a result, there were more STYs in El Niño years and fewer in La Niña years.

5 Summery

This paper analyzes the statistical features of STY over the WNP from 1965 to 2005 and describes the seasonal variability of STY activity. The relation between STY activity and ENSO as well as the mechanism of ENSO affecting the STY activity are also investigated. The results are as fallows:

1) The number of STYs accounted for 21% of the total TC number.

2) STY activity over the WNP had obvious seasonal variability. Most STYs appeared from July to November with the greatest number of occurrence in September. There were less STYs from December to next June, and the minimal STYs numbers were in February and March.

3) The area for the maximum frequency of STYs was in the east of the Philippine Sea. STYs occurred south of 15˚N in February and March. The locations of STYs moved northwestward from April to September and the STY number increased month by month during this time. The locations of STYs moved northeastward from October to the next spring and the STY number decreased month by month during this time.

4) STY activity was related to the ENSO events. There were more STYs in El Niño years than in La Niña years.

5) In El Niño years, affected by SST, monsoon trough and weak vertical wind shear, the formation locations of the TCs drifted eastward, so they could be in a weak vertical shear environment during their movements. As a result, there were more STYs in El Niño years, and less in La Niña years.

Weak vertical wind shear, positive low-level vortex and longer developing time are all advantageous to TC intensity in El Niño years. The connections between these factors need further analysis.

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