Relationship Between the Number of Summer Typhoons Engendered over the Northwest Pacific and South China Sea and Main Climatic Conditions in the Preceding Winter and Spring*

XIAO Ziniu[1,3†](肖子牛), LIANG Hongli[2](梁红丽), and LI Chongyin[1](李崇银)

1 *Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing* 100029

2 *Yunnan Meteorological Bureau, Kunming* 650034

3 *National Climate Center, China Meteorological Administration, Beijing* 100081

(Received August 31, 2009)

ABSTRACT

Based on the monthly NCEP/NCAR reanalysis data, OLR (outgoing longwave radiation) data, and tropical cyclone data from the *Typhoon Annual* and *Tropical Cyclone Annual* edited by China Meteorological Administration, the relationship between the number of tropical cyclones (with the strongest wind $\geqslant 17$ m s^{-1}, including tropical storm, strong tropical storm, and typhoon, simply called typhoon in this paper) engendered over the Northwest Pacific and South China Sea in summer and the associated climate conditions is studied. First, the characteristics and differences of the climatic conditions between the years with more typhoons and those with fewer typhoons are compared. The results show that the summer typhoon has a close relationship with SST (sea surface temperature) and ITCZ (intertropical convergence zone) anomalies in the preceding winter and spring. With a La Niña like SST anomaly (SSTA) pattern in the preceding winter and spring, the ITCZ will move northwestward and be enhanced around 160°E in the equatorial central Pacific from the preceding winter to spring. The activity of the Pacific ITCZ is in general stronger and its location is more northward than usual, especially in the typhoon genesis region in West Pacific. This background is propitious to have more typhoons in summer. On the other hand, an El Niño like SSTA pattern in the preceding winter will be companied with weaker ITCZ activities, and its location is more southward over the equatorial western Pacific from the preceding winter to spring; this background is propitious to have fewer typhoons in summer. In the year with more typhoons, the warm SST over West Pacific in the preceding winter provides a favorable condition for typhoon fromation in the following summer. It enhances the convergence in the troposphere and increases the water vapor supply to the warm SST region. In the following spring, the perturbation of the tropical ITCZ plays a more important role. When the ITCZ moves northward in spring, anomalous convergence will appear over the warm SST region and inspire the positive feedback between the large-scale moisture flux at low levels and the latent heat release in the atmosphere, which benefits the typhoon genesis in summer. Otherwise, if cold SST maintains over the northwestern Pacific during the preceding winter and spring, the convergence in the troposphere is disfavored and the water vapor supply to the cold SST region is reduced, which will bring about weaker ITCZ activities and the perturbation is lacking in the following spring. It then results in fewer summer typhoons.

Key words: summer typhoon, preceding winter and spring, ITCZ (intertropical convergence zone), SST (sea surface temperature)

Citation: Xiao Ziniu, Liang Hongli, and Li Chongyin, 2010: Relationship between the number of summer typhoons engendered over the Northwest Pacific and South China Sea and main climatic conditions in the preceding winter and spring. *Acta Meteor. Sinica*, **24**(4), 441–451.

1. Introduction

The tropical cyclone may cause the most destructive natural disaster in China. It comes along with gale, heavy rainfall, billow, and storm tide, and results in tremendous losses in life and property. For instance, typhoons frequently impacted China during the summer 2004, among which Typhoon Rananim landed over Wenling, Zhejiang Province on 12 August. It directly resulted in an economic loss of 20.1 billion

*Supported by the National "973" Program of China under Grant No. 2006CB403600.
†Corresponding author: xiaozn@cma.gov.cn.
(Chinese version published in Vol. 67, No. 1, 90–99, 2009)

RMB and more than 18 million people suffered. The Northwest Pacific is the place where most numerous (more than one third of all in globe) and most violent tropical cyclones (half of which develop into typhoons) are recorded (Qiu and Fang, 1995; Andreas and Peter, 1998). As we know, typhoons landing over or influencing China occur mainly over the Northwest Pacific and South China Sea. For the prediction of the summer tropical cyclones, it is important to study the relationship between the typhoon genesis over the Northwest Pacific and South China Sea in summer and the climate conditions in the preceding seasons.

The number of tropical cyclones in a period (such as a month, a season, or a year) varies and is influenced by large-scale climatic conditions of the atmosphere and ocean. In general, the occurrence of a tropical cyclone needs a perturbation existing in advance (Chen and Ding, 1979). Xie and Ye (1987) suggested that a synoptic-scale disturbance such as typhoon could have nonlinear interactions with the large-scale atmospheric general circulation. The active phase of OLR (outgoing longwave radiation) low frequency oscillation can provide the favorable environment for the generation and development of typhoon. The intensity of the OLR low frequency oscillation is also correlated with the number and intensity of typhoon. Based on observations, it is noticed by Ding and Reiter (1981) that the intensity and position of ITCZ (intertropical convergence zone) is important for the generation of typhoon. Anomalous tropical cyclone activities are closely related to the anomalous SST (sea surface temperature) variations (Li, 1987). The wind convergence anomalies in the low troposphere induced by anomalous warm SST are one of the dominating mechanisms for typhoon generation (Wu, 1992).

Lin and Zhang (2004) indicated that, in an El Niña year, typhoons influencing China are fewer but stronger than normal. The reverse is true for a La Niña year. Duan and Yu (2002) analyzed the variation of the tropical cyclone intensity and suggested that the typhoon intensity showed an increasing trend after the 1980s. Wu et al. (2003) indicated that the subsurface temperature of the equatorial western Pacific warm pool can influence the formation time, intensity, and number of tropical cyclones over the Northwest Pacific. Xu (1998) analyzed the relationship between the SST of the Northwest Pacific and typhoons influencing Southeast China and suggested that the SST in the equatorial Northwest Pacific has a positive relationship with the typhoon numbers, and moreover, this relationship also exists in the preceding seasons, particularly in the preceding autumn and winter.

Sun and Ding (2002) analyzed the characteristics of tropical cyclones in 1998 and 1999 and found that the anomalous westward and northward movement of the monsoon trough during mid-summer led to the tropical cyclones being fewer than normal and more westward and northward. The characteristic of the summer monsoon in the Northwest Pacific and the influences of the monsoon trough on the typhoon occurrence were studied by Wang et al. (2006). On the other hand, the influence of the MJO (Madden-Julian Oscilation) on typhoons over the Northwest Pacific was studied by Zhu et al. (2004). It is suggested by Li et al. (2004) that the cross-equatorial flow played an important role in the anomalous typhoon activity in 1998. Besides, the vertical shear of wind in the troposphere is also related to the typhoon occurrence. Weak (strong) vertical shear is favorable (unfavorable) for the initial disturbance to develop into a tropical cyclone (Li, 1984; Qian, 2004).

Furthermore, taking into consideration of the circulation, OLR and SST conditions in the preceding autumn and winter, a conceptual prediction model was constructed for forecasting the frequency of typhoon influencing Shanghai and eastern China (Lei, 1998; Jiang and Deng, 1998). In the conceptual model, the favorable conditions for typhoon occurrence include a strong East Asian winter monsoon in the preceding autumn and winter, a "$+-+$" pattern of 500-hPa height anomalies from north to south over East Asia, positive 500-hPa height anomalies over 20°–45°N, prevailing meridional circulation, stronger cold air and frequent cold surge activities, stronger convection over the tropical West Pacific, positive SST anomalies in the Northwest Pacific, negative SST anomalies in the equatorial central-eastern Pacific, and associated weaker Walker and Hardley circulations. Conditions that are unfavorable for typhoon formation are almost opposite to the above. In addition, when the ITCZ is more southward (northward) and inactive (active), the ridge of the western Pacific subtropical high tends to be more southward (northward), and therefore, fewer (more) than normal tropical cyclones come into play and influence East China.

The above conceptual model was established in the "National 9th Five-Year Plan (2006–2010)" period and it focused on the circulation anomalies in the preceding autumn and winter. Since the effect of oceanic conditions can last for a long time, the tropical cyclone frequency is supposed to have a close relationship with the oceanic conditions in the preceding seasons. Summer (JJA) is the flood season in China. The prediction and warning of typhoons in summer is very important. In this paper, the relationship between the tropical cyclone frequency over the Northwest Pacific and South China Sea in summer and the atmospheric and oceanic conditions in the preceding seasons (winter and spring) is investigated. Autumn is the second peak season in typhoon frequency (44.6% in summer and 40.4% in autumn) (Li, 1987; He et al., 1999) and the highest number of landfalling typhoons occur in autumn (Zhou et al., 2002). The relationship between the typhoon frequency in autumn and the climatic conditions in the preceding summer will be discussed in another paper.

2. Data

The data used in this study include: 1) NCEP/NCAR monthly mean reanalysis data with a resolution of 2.5°×2.5°, including horizontal wind field and vertical velocity at standard pressure levels from January 1948 to December 2004; 2) monthly mean SST with a resolution of 2°×2° from January 1950 to December 1999; 3) OLR data of NOAA from January 1982 to December 2004.

The typhoon data in 1949–2004 is taken from the *Typhoon Annual* and *Tropical Cyclone Annual* edited by China Meteorological Administration. Typhoons in this paper are defined as the tropical cyclones with wind grades equal to or exceeding 8 beaufort scale (17 m s^{-1}) in its center, which include tropical storm, severe tropical storm, and typhoon. Seasons of winter, spring, summer, and autumn are defined respectively as December–January, March–May, June–August, and September–November.

3. Interannual and interdecadal variations of the summer typhoon frequency

Figure 1 displays the normalized time series of the typhoon frequency in the Northwest Pacific and South China Sea in summers of 1949–2004. A significant interdecadal variation is noticed. Typhoons are a lot more than normal in the period from the 1950s to 1970s and fewer than normal after 1975, which is associated with the interdecadal warming of summer SST in western Pacific from the 1970s (Zhang and Peng, 2003). The summer typhoon frequency also has a large interannual variability; for instance, there are 19 typhoons in 1994 while there are only 4 in 1998. Here, we define a typhoon frequency index using the normalized typhoon generation frequency:

$$I = \frac{X_i - \overline{X}}{S},$$

in which, $$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i,$$

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \overline{X})^2},$$

where X_i is the time series of typhoon occurrence frequency, $\overline{X}$ is the climate mean, and S is the standard deviation. A year is defined as a more typhoon year

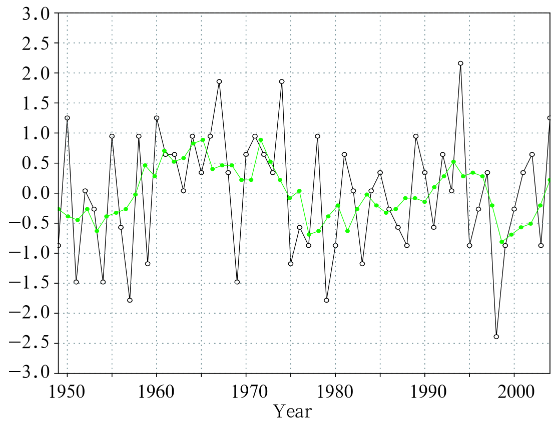

Fig. 1. Variations of the standardized summer typhoon occurrence frequency during 1949–2004 (black line: interannual change; grey line: after a 5-yr smoothing).

when the typhoon frequency index is > 1 and as a fewer typhoon year when this index is < -1. Then, 6 more typhoon years (1950, 1960, 1967, 1974, 1994, and 2004) and 9 fewer typhoon years (1951, 1954, 1957, 1959, 1969, 1975, 1979, 1983, and 1998) are identified for the period 1949–2004.

4. Relationship between typhoon frequency and the preceding climatic conditions

This study aims to find the factors that influence the summer typhoon genesis, to discuss the differences of the dynamical and thermodynamical conditions in the preceding winter and spring between more and fewer typhoon years, and to further understand the favorable/unfavorable preceding environments for typhoon occurrences.

4.1 SST anomalies

Figure 2 shows the composite SST anomaly (SSTA) fields in the preceding winter and spring for more and fewer typhoon years. It can be seen that, in the preceding winter of more typhoon years, SSTA in the typhoon genesis region of the western Pacific reaches 0.2°C, and the equatorial central and eastern Pacific are dominated by a stretch of significant negative SSTA with the maximum value less than −1°C (Fig. 2a). In the following spring (Fig. 2c), the positive anomaly in the western Pacific extends to central North Pacific, and the center of values >0.2 °C also moves eastward to the middle part of North Pacific, and the obvious negative anomaly still maintains in the equatorial mid-eastern Pacific. It seems that the SSTA pattern in the preceding season of a more typhoon summer resembles the La Niña condition. For fewer typhoon years, in the preceding winter (Fig. 2b), the western Pacific and the middle part of North Pacific are dominated by negative SSTA and the equatorial mid-eastern Pacific is dominated by large positive SSTA. In the following spring (Fig. 2d), the SST in the typhoon genesis region of western Pacific decreases further and the positive anomaly in the equatorial mid-eastern Pacific weakens, compared with the preceding winter. The SSTA distribution in the fewer typhoon years is similar to the El Niño pattern. The above results are consistent with the previous studies (e. g., Li, 1987).

4.2 ITCZ anomalies

Figure 3 is the same as Fig. 2 but for OLR anomaly fields. It is noticed that the tropical convective activity in the preceding winter and spring also displays different characteristics between more and fewer typhoon years. In the preceding winter of more

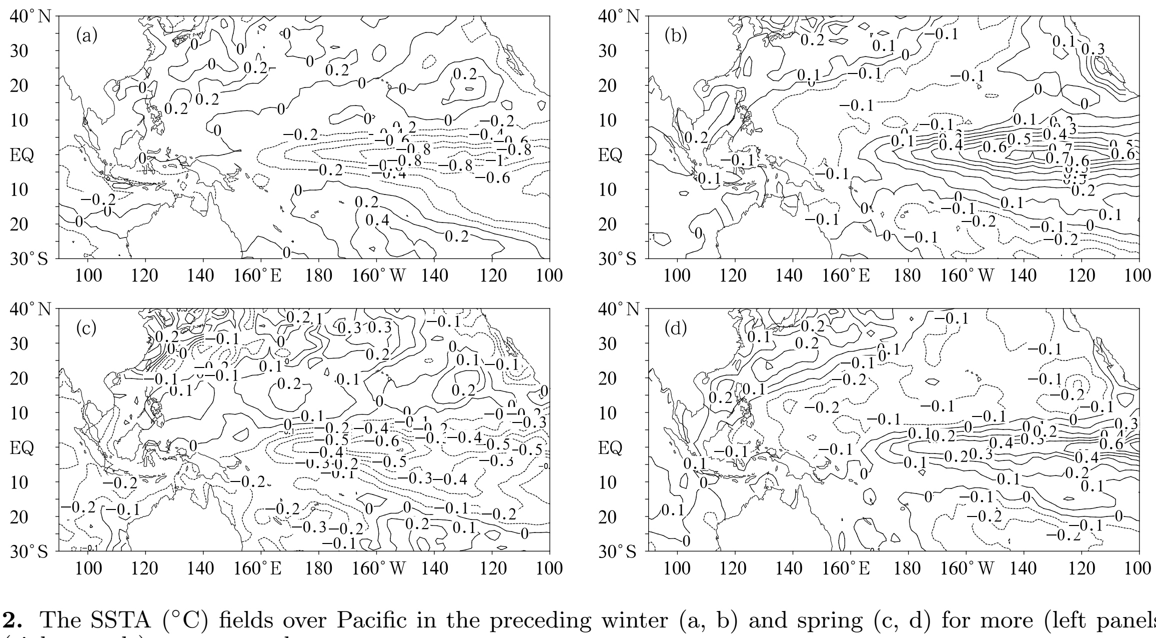

Fig. 2. The SSTA (°C) fields over Pacific in the preceding winter (a, b) and spring (c, d) for more (left panels) and fewer (right panels) summer typhoon years.

typhoon years, negative OLR anomalies appear over a large range from the South China Sea to West Pacific and then to the north of 5°N of the East Pacific, and the maximum negative value center (smaller than –12 W m^{-2}) is located over 160°E in the neighborhood of the equatorial central Pacific, which indicates that the ITCZ becomes more active over there. Meanwhile, a negative anomaly area is seen over the Northwest Pacific. In the preceding spring (Fig. 3c), the negative anomalies near 160°E have strengthened to –15 W m^{-2} and extended northwestward to 10°N in the neighborhood of the West Pacific, indicating that the ITCZ has strengthened and moved northward. In the following summer (figure omitted), strong convections over 10°N in the neighborhood of the West Pacific move further northward to 15°N, just over the typhoon genesis region. In the preceding winter and spring of fewer typhoon years (Figs. 3b, d), strong and positive OLR anomalies dominate the tropical West Pacific, indicating a weak and southward ITCZ.

The above analysis suggests that, in more typhoon years, the ITCZ near 160°E of the equatorial central Pacific undergoes a process of strengthening and northwestward moving from the preceding winter to summer and the ITCZ is more northward and stronger than normal. In fewer typhoon years, the ITCZ in the tropical West Pacific is more southward and weaker than normal.

The relationship between the typhoon frequency in the tropical West Pacific and South China Sea and the ITCZ activity in the preceding winter and spring is further examined in Fig. 4. The results indicate that in the preceding winter (Fig. 4a), a negative correlation is found over the region (10°S–10°N, 135°–165°E) and a positive correlation is found over the equatorial East Pacific. In the following spring (Fig. 4b), the negative correlation region over the West Pacific extends polarward, and the significant positive correlation region over the equatorial East Pacific shrinks obviously. In summer (figure omitted), when the ITCZ moves northward, the negative correlation region over the West Pacific also moves northwestward to 15°N in the neighborhood of the Northwest Pacific, and meanwhile, significant negative correlation appears over the South China Sea. The correlation analysis results here are consistent with the composite analysis in the previous section.

To sum up, it is found that in the preceding winter and spring, when the SSTA distribution is similar to the La Niña pattern, active ITCZ in the equatorial Pacific will move into the typhoon genesis region in West Pacific, which favors the typhoon formation in summer; on the contrary, when the SSTA distribution resembles the El Niño pattern, the ITCZ in the

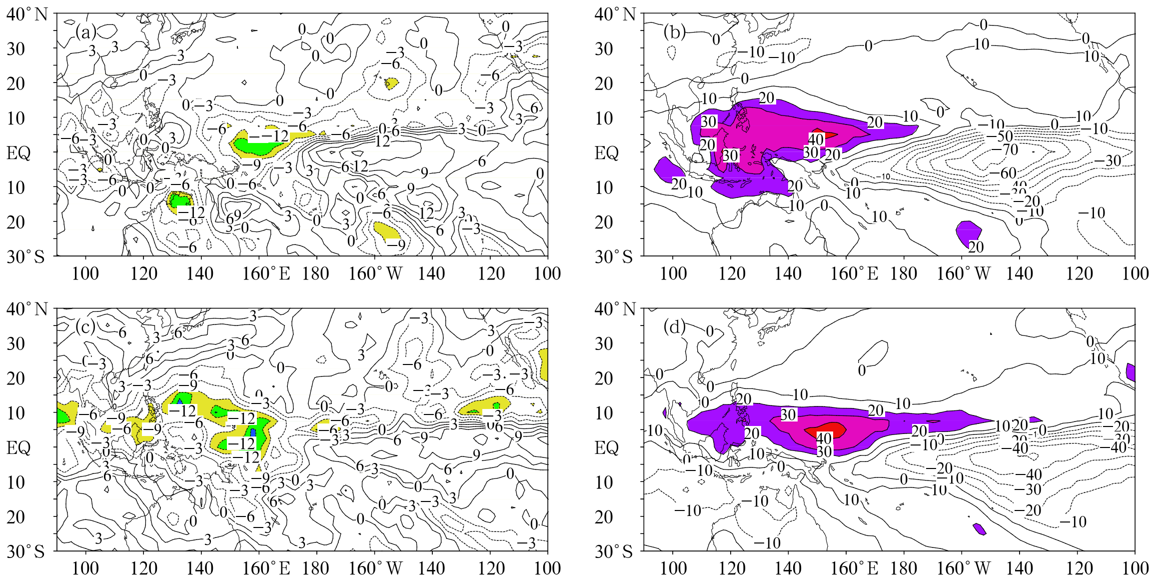

Fig. 3. As in Fig. 2, but for OLR fields. Shadings denote areas with values bigger than 20 W m^{-2} or less than –9 W m^{-2}.

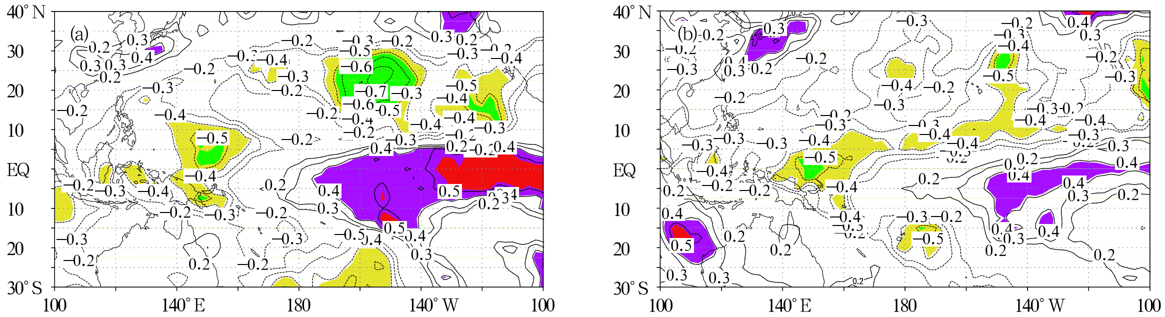

Fig. 4. Distributions of the correlation coefficient between the summer typhoon frequency and OLR in the preceding (a) winter and (b) spring. Light shadings: above the 95% significance level; dark shadings: over the 99% significance level.

equatorial West Pacific will weaken and become more southward, which is not beneficial for typhoon formation in summer.

5. How the preceding-season SST and ITCZ influence the typhoon genesis

The above analyses indicate that the climatic conditions in the preceding winter and spring are obviously different between more and fewer typhoon years. Then, how can the preceding-season SSTA and ITCZ influence the summer typhoon genesis? In different periods of time, do the SSTA and ITCZ act together to influence the typhoon genesis, or only one factor plays a more important role? To answer these questions, we analyze the zonal vertical circulation (Fig. 5) and vertical velocity anomalies (Fig. 6) averaged between 5° and 20°N in this section.

For more typhoon years, it is shown in Figs. 5 and 6 that anomalous upward motions over 120°E–120°W are corresponding to the long-lasting warm SST in the Northwest Pacific in the preceding winter and spring (Figs. 5a, c). In the meantime, anomalous downdrafts over east of 120°W correspond to the lasting cold SST in the equatorial East Pacific. It is more obvious in the vertical section of the vertical velocity anomalies (Fig. 6a) that the strongest upward motion (greater than 1 m s^{-1}) is located around 130°E between 5° and 20°N in the preceding winter, corresponding to the anomalous warm SST region centered at 15°N, 130°E with the SSTA exceeding 0.2°C (Fig. 2a) and negative OLR anomalies smaller than –3 W m^{-2} (Fig. 3a). Therefore, in the preceding winter of the more typhoon year, large-scale low-level airflow converges in the warm SST region and enhances the moisture supply to this region, which provides an important climatic condition for typhoon formation. In the meantime, weak ICTZ disturbances appear and they increase the low-level convergence over the warm SSTA region. In the preceding spring, the strongest upward motion moves slightly eastward to near 140°E, right the place with the most typhoon occurrences in the West Pacific. Meanwhile, strong convergence (divergence) dominates the low (high) levels. It can be found through further analysis that the West Pacific typhoon genesis region is still controlled by anomalous warm SST in the preceding spring; the largest positive SSTA center with the values exceeding 0.2°C moves eastward to the central North Pacific, strengthens, and extends northwestward to around 10°N of the West Pacific, as compared with the situation in the preceding winter. Meanwhile, the northward movement of the ITCZ strengthens the positive feedback between the large-scale moisture convergence at low level and latent heat release of the free atmosphere. Therefore, in the preceding spring, different from the preceding winter, the ITCZ disturbances play a more important role in the summer typhoon genesis.

In fewer typhoon years, there exist anomalous downdrafts over the West Pacific, corresponding to cold SSTA in the preceding winter (Fig. 5b). The anomalous downdrafts extend eastward to the East Pacific while the cold SSTA in the West Pacific is strengthened in the following spring (Fig. 5d). Seen

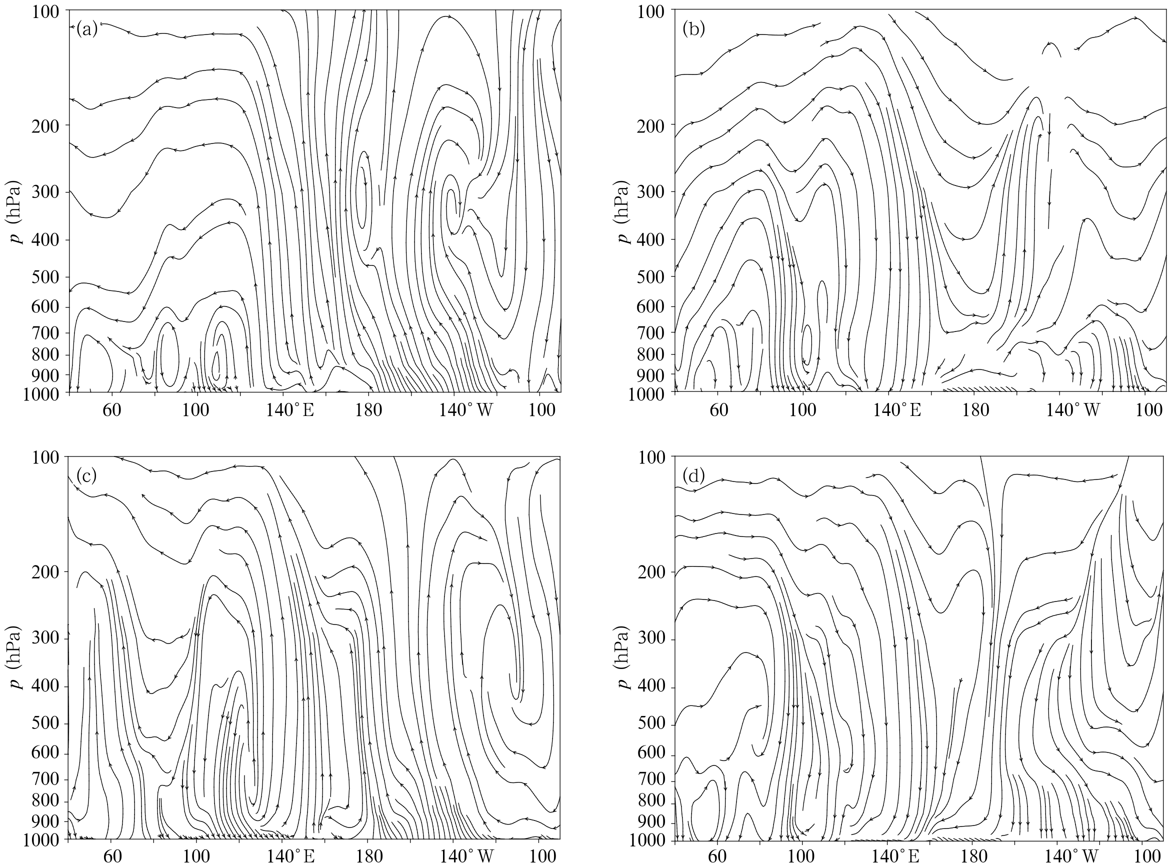

Fig. 5. Vertical cross-sections of mean u and w winds averaged between 5°–20°N in the preceding winter (a, b) and spring (c, d) for more typhoon years (a, c) and fewer typhoon years (b, d). Note, w is multiplied by 100.

from the vertical section of vertical velocity (Figs. 6b, d), the strongest downdraft anomaly is located over 140°–150°E, and then it strengthens and moves westward to around 140°E. Because the large-scale low-level flow would diverge over the cold SST region, which decreases the moisture supply to the negative SSTA region, the ITCZ becomes more southward and weaker under the lasting cold SST background, leading to fewer typhoons in the western Pacific in summer.

The above analyses suggest that in the summer of more typhoon years, the SSTA of the western Pacific in the preceding winter provides an important and favorable background for the development of typhoon. Under the effect of the persistent warm SST, convergence in the low troposphere strengthens and then the moisture supply to the warm SST region increases. In the preceding spring, additional anomalous convergence is added over the warm SST region due to the northward shift of ITCZ, which strengthens the positive feedback between the large-scale moisture convergence at low level and latent heat release of the free atmosphere and then further promotes the typhoon genesis. On the contrary, when cold SSTA is maintained in the Northwest Pacific throughout the preceding winter and spring, low-level winds diverge abnormally, which decreases the moisture supply to the cold SST region. Moreover, the ITCZ is weakened and few disturbances are generated. All these effects contribute to fewer typhoons in summer.

6. The typhoons in summer 2004

In 2004, the number of typhoons is larger than the climate average. Total 30 tropical storms formed over the western Pacific and South China Sea and among them, 20 developed into typhoons, accounting for 66.67% of the total, which is higher than normal (61.7%). Sixteen typhoons occurred in summer, which ranks the third in summer typhoon numbers since 1949. Meanwhile, most tropical storms lasted for a long time. For example, 18 typhoons lasted for more than 5 days, which accounts for 60% of the total, and 5 typhoons lasted for more than 10 days. On the other hand, the typhoon source regions are more eastward. Twenty storms are generated over the region between 120° and 150°E, which is slightly more in number than normal. Similarly, more typhoons formed over east of 150°E than normal. The earlier analyses indicate that anomalously active ITCZ in the preceding winter and spring contributes to more typhoon activities over the western Pacific and South China Sea. To verify whether this is true for the summer typhoon case in 2004, discussions are followed.

Figures 7a-c demonstrate OLR anomalies from last winter to summer. It can be seen that OLR anomalies with values smaller than –10 W m^{-2} appear over the equatorial western Pacific in the preceding winter, indicating strong ITCZ activities. In spring, the ITCZ near 160°E further strengthens and extends northwestward to east of the Philippine archipelago with a center OLR value lower than –25 W m^{-2}. In summer, ITCZ develops over the central Pacific and a wide east-west convergence belt is located over 15°N and 120°–180°E. It is worth noticing that ITCZ activities occur over the sea west of 150°E from the preceding winter to summer, and they develop and strengthen northward. All these conditions are advantageous for more typhoons in 2004. Figures 7d-f show the SSTA in the preceding winter, spring, and summer, respectively. It is obvious that the SST in the tropical Pacific is anomalously warm, which provides favorable thermal conditions for the development of tropical cyclones.

Therefore, the characteristic distributions of the ITCZ and SST from the preceding winter to summer

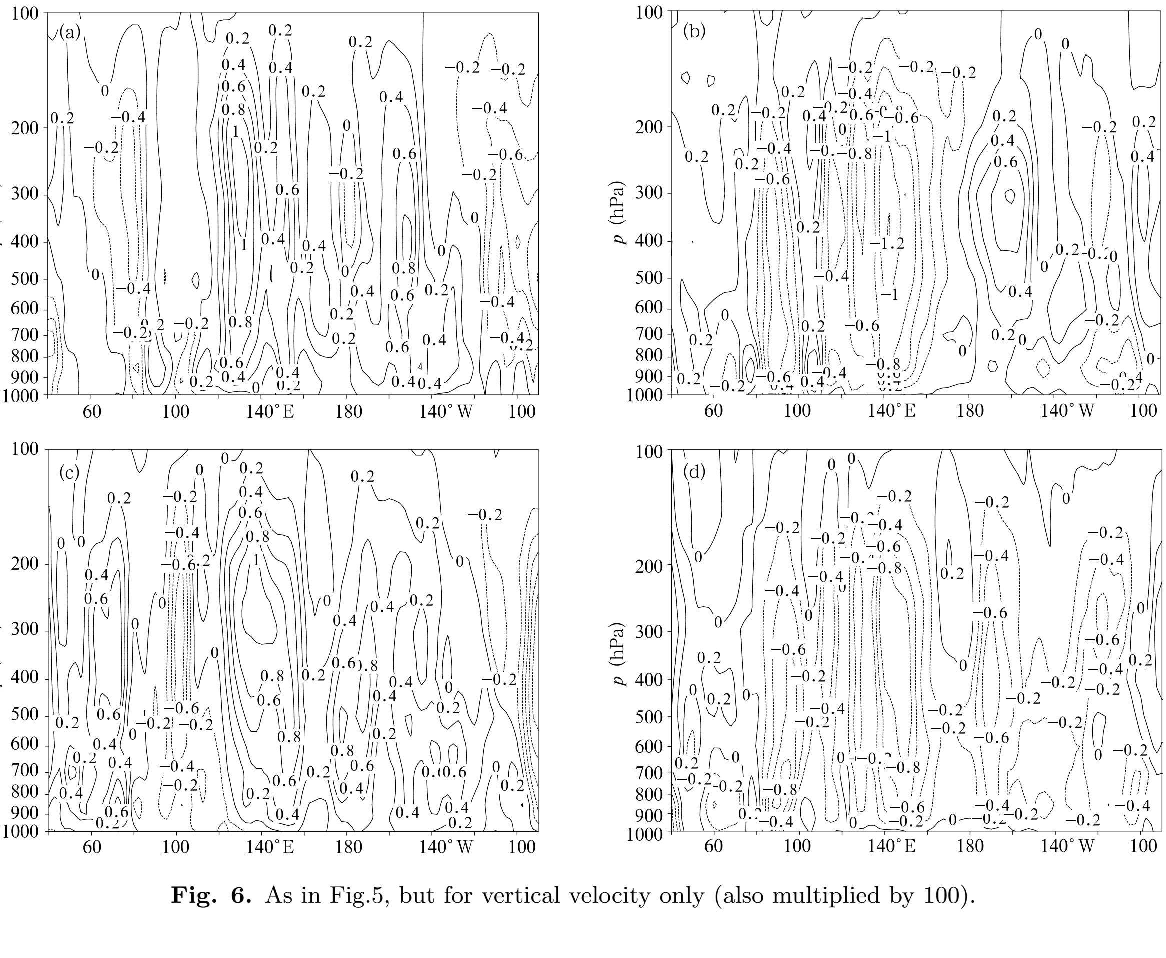

Fig. 6. As in Fig.5, but for vertical velocity only (also multiplied by 100).

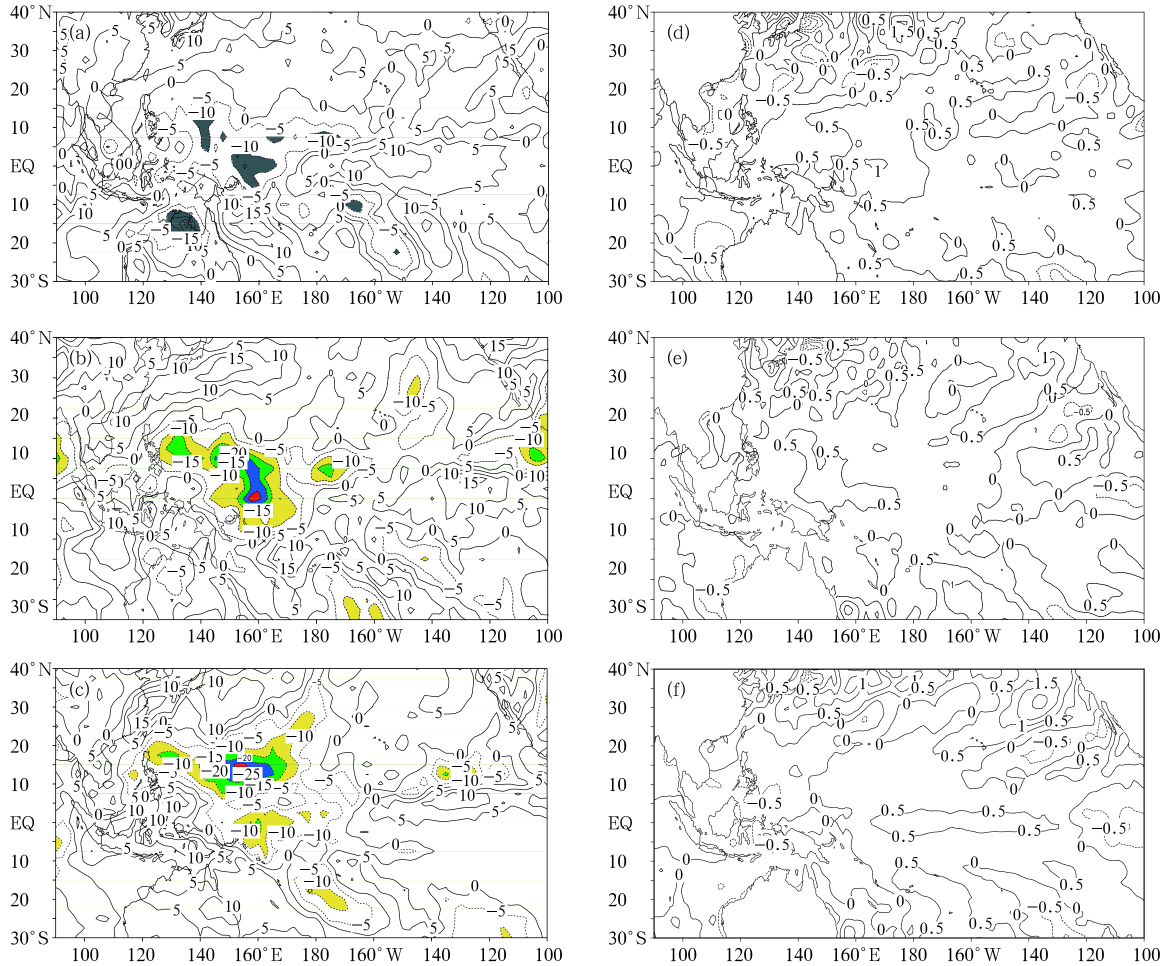

Fig. 7. The OLR anomaly (left panels; W m^{-2}) and SSTA fields (right panels; °C) in the preceding winter (a, d), spring (b, e), and summer (c, f) of 2004.

foreshow that 2004 is a typhoon-active year, consistent with observations.

7. Conclusions

In this paper, we compare and analyze the climatic conditions in the preceding winter and spring for more and fewer summer typhoon years in the western Pacific and South China Sea. The results indicate that the SSTA and ITCZ anomalies in the preceding winter and spring and summer typhoon formation are closely associated. Main conclusions are summarized as follows:

(1) The summer typhoon frequency in the western Pacific and South China Sea shows obvious interdecadal variability and large interannual variability. Typhoons are significantly more than normal from early 1950s to mid 1970s and fewer than normal after 1975.

(2) Anomalous SST and ITCZ in the preceding winter and spring are closely related to typhoon genesis in summer. Warm SST in the western Pacific in the preceding winter provides a favorable background for the typhoon development. Under the effect of persistent warmer SST, wind convergence at low levels would strengthen and then the moisture supply to the warm SST region is increased. In the preceding spring, additional anomalous moisture convergence is produced over the warm SST region due to the northward shift of ITCZ, which strengthens the positive feedback between the large-scale moisture convergence at low levels and latent heat release of the free

atmosphere and then further promotes the typhoon formation. On the contrary, when anomalous cold SSTA is maintained in the Northwest Pacific throughout the preceding winter and spring, low-level winds diverge abnormally, which decreases the moisture supply to the cold SST region. In addition, the ITCZ is weakened and few disturbances are generated. All these effects contribute to fewer typhoon formations in summer.

(3) Both the SST and ITCZ anomalies over the Pacific Ocean in the preceding winter and spring have obvious impacts on the typhoon frequency in the Northwest Pacific and South China Sea in summer, but the role of SST can last for a longer time, while the ITCZ mainly plays an important role in spring and summer. Impacts of the above two factors are most significant when they are in specific collaboration. When ITCZ is more active, more northward and appears over the warm SST background, typhoon frequency in summer is higher than normal. When opposite conditions dominate, typhoon frequency in summer is lower than normal.

(4) In 2004, the SST of the Northwest Pacific is warmer than normal and the ITCZ is also very active in the preceding winter and spring, which is the main reason for many more typhoons formed in that year.

In this paper, we focus on the role of SST and ITCZ anomalies in the summer typhoon occurrences. However, there may exist other influencing factors in certain years, which need to be studied further. In addition, it is proposed (Chen and Ding, 1979) that tropical cyclones in Northwest Pacific have intraseasonal, interannual, and interdecadal variability. Characteristics of occurrences of the supper typhoon and its relationship with environmental conditions also need in-depth research.

REFERENCES

Andreas, H. Fink, and Peter Speth, 1998: Tropical cyclones. *The Science of Nature*, *Geophysics and Meteorology*, **85**(10), 482–493.

Chen Lianshou and Ding Yihui, 1979: *The Introduction on the Typhoon over the West Pacific Ocean.* China Science Press, Beijing, 491 pp.

Ding, Y. H., and E. R. Reiter, 1981: Some conditions influencing the variability in typhoon formation over the West Pacific Ocean. *Arch. Meteor. Geophys. Bioklim.*, **A30**, 327–342.

Duan Yihong and Yu Hui, 2002: A statistical analysis on intensity change of tropical cyclone over the northwestern Pacific. *Acta Meteor. Sinica*, **60**(6), 680–687. (in Chinese)

He Min, Song Wenling, and Chen Xingfang, 1999: Typhoon activity in the Northwest Pacific in relation to El Niño/La Niña events. *Journal of Tropical Meteorology*, **15**(1), 17–25. (in Chinese)

Jiang Leyi and Deng Zhihao, 1998: The analyses on the frequency anomaly of tropical cyclones over East China and characteristics of the atmospheric general circulation. *Atmospheric Science Research and Application*, **1**, 29–35. (in Chinese)

Lei Xiaotu, 1998: Advances in the studies on predication of the frequency of tropical cyclones and the operational prediction skill level. *Atmospheric Science Research and Application*, **1**, 196–202. (in Chinese)

Li Chongyin, 1984: On the CISK with shearing basic current. *Adv. Atmos. Sci.*, **1**(2), 256–262.

——, 1987: The impact of the eastern equatorial Pacific Ocean heat condition on the frequency of typhoon over western Pacific Ocean. *Acta Meteor. Sinica*, **45**(2), 229–235. (in Chinese)

Li Zhengzhong, Cheng Minghu, and Yang Zhengbin, 2004: Analyses of the annual frequency anomalies of typhoons and hurricanes in 1998. *Journal of Tropical Meteorology*, **20**(2), 161–166. (in Chinese)

Lin Huijuan and Zhang Yaochun, 2004: Climatic features of the tropical cyclone influencing China and its relationship with the sea surface temperature in the Pacific Ocean. *Journal of Tropical Meteorology*, **20**(2), 218–224. (in Chinese)

Qian Weihong, 2004: Tropical cyclone weather. *Synoptic Meteorology.* Peking University Press, 218–219.

Qiu Guoqing and Fang Weimo, 1995: *The Guidance to Tropical Cyclone Prediction.* China Meteorological Press, Beijing, 235 pp.

Sun Ying and Ding Yihui, 2002: Anomalous activity of tropical cyclones over the western North Pacific and the related large-scale circulation features during 1998 and 1999. *Acta Meteor. Sinica*, **60**(5), 527–537. (in Chinese)

Wang Hui, Ding Yihui, and He Jinhai, 2006: Influence of western North Pacific summer monsoon changes on typhoon genesis. *Acta Meteor. Sinica*, **64**(3), 345–356. (in Chinese)

Wu Disheng, Bai Yiping, and Zhang Hongmei, 2003: The influence of variation of subsurface ocean temperature in the equatorial western Pacific warm pool on tropical cyclones. *Journal of Tropical Meteorology*, **19**(3), 253–259. (in Chinese)

Wu Guoxiong, 1992: Tropical storm formulation in response to sea surface temperature anomaly. *Chinese J. Atmos. Sci.*, **16**(3), 322–332.

Xie An and Ye Qian, 1987: A discussion on the relationship between the OLR low-frequency oscillation and typhoon activities over the western Pacific Ocean. *Meteorological Monthly*, **13**(10), 8–13.

Xu Jinjing, 1998: Primary analysis of relation between SST of West Pacific near equator and typhoon along Southeast China. *Journal of Oceanography in Taiwan Strait*, **17**(3), 278–281.

Zhang Qingyun and Peng Jingbei, 2003: Interannual and interdecadal variations of East Asian summer circulation and its impact on the landing typhoon frequency over China during summer. *Chinese J. Atmos. Sci.*, **27**(1), 97–106. (in Chinese)

Zhou Junhua, Shi Peijun, and Chen Xuewen, 2002: Spatio-temporal variability of tropical cyclone activities in the western North Pacific from 1949 to 1999. *Journal of Natural Disasters*, **11**(3), 44–49. (in Chinese)

Zhu Congwen, T. Nakazawa, and Li Jianping, 2004: The effects on Indian Ocean-western Pacific tropical low pressure/cyclone formation of meteorological intraseasonal oscillation. *Acta Meteor. Sinica*, **62**(1), 42–50. (in Chinese)