Science in China Series D: Earth Sciences

© 2007 SCIENCE IN CHINA PRESS

Springer

New predictors and a new prediction model for the typhoon frequency over western North Pacific

FAN Ke

Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China (email: fanke@mail.iap.ac.cn)

In this paper, the impacts of the atmospheric circulation during boreal winter-spring on the western North Pacific (WNP) typhoon frequency (WNPTF) are studied. Several new factors in winter-spring influencing the typhoon frequency were identified, including the sea ice cover in the North Pacific and the North Pacific oscillation. Based on these results, the multi-linear regression was applied to establishing a new forecast model for the typhoon frequency by using the datasets of 1965—1999. The forecast model shows a high correlation coefficient (0.79) between the model simulated and the actual typhoon frequencies in the period of 1965—1999. The forecast model also exhibits reasonable hindcasts for the typhoon frequencies for the years 2000—2006. Therefore, this work demonstrates that the new predictors are significant for the prediction of the interannual variability of the WNPTF, which could be potentially used in the operational seasonal forecast of the typhoon frequency in the WNP to get a more physically based operational prediction model and higher forecast skill.

predictors, the western North Pacific typhoon frequency, forecast model

1 Introduction

The western North Pacific (WNP) is a region with frequent typhoon genesis through out a year, with concentrated typhoon genesis in June-July-August-September October (JJASO). It has long been recognized in China that the typhoon genesis is closely associated with the large-scale atmospheric circulation and the sea surface temperature (SST) conditions. Many works have been done in the case studies of the typhoon activities and the related atmospheric circulation.

Chen [1] invested the relationship between the typhoon track and the middle and high latitudes atmospheric circulation. Xu et al.[2] indicated that the transition of the flow pattern in the whole troposphere in the tropical western Pacific from a zonal pattern to a meridional pattern is usually associated with higher typhoon strength and frequency. Fang[3] studied the connection between the cloud types and the environmental flow pattern of upper troposphere during the genesis and development of typhoon. While Ding et al.[4] compared the differences of the atmospheric circulation in both the tropics and the middle and high latitudes between the high and low typhoon frequency years over west North Pacific .

In addition, Chinese meteorologists also noted the potential relationships between the Southern Hemisphere (SH) atmospheric circulation and the East Asian climate and typhoon frequencies[5−15]. They indicated that typhoon genesis is usually associated with meridional flow patterns in SH, frequent cold surges in Australia, strong cross-equatorial flow, and the associated intensification of the convergence zone. Researches also revealed that the SST anomalies in the tropical eastern Pacific could affect the typhoon frequencies, via affecting the zonal circulation of the tropical Pacific and the convergence zone[16−20]. At the same time, there are also

---

Received April 4, 2007; accepted June 4, 2007

doi: 10.1007/s11430-007-0105-x

Supported the National Natural Science Foundation of China (Grant Nos. 40631005, 40620130113 and 40523001) and the International Partnership Project of the Chinese Academy of Sciences

many studies outside China on the typhoon frequency and its variability. Among these, much of the studies were focused on the ENSO effects. In addition, Cray[21] and Chan[22] found the impacts of the quasi-biennial oscillation (QBO) in the stratosphere on the typhoon frequency.

For the operational purpose, it is important to develop a statistical forecasting tool to predict the typhoon activity[23,24]. Chan et al.[25] established the statistical models for the seasonal forecast of tropical cyclone activity over the WNP. The predictors that have been identified include the indices representing the El Niño-Southern Oscillation phenomenon and the environmental conditions over East Asia and the WNP from April of the previous year to March of the current year. However, their model predictions failed in 1997 and in 1998 during which a warm and a cold event of El-Niño-Southern Oscillation (ENSO) occurred, respectively. After that, Chan et al.[26] identified new predictors including Southern Oscillation index, strengthen of Australian monsoon and intensity of subtropical high in the south Pacific to improve the statistical model. However, seeking of the new predictors and improvement of the typhoon activity forecast are of extremely important and urgent, since the disasters caused by typhoon have been increasing recently in many countries like China.

Recently, Wang et al.[27] documented the relationship between the North Pacific oscillation NPO in JJAS (positive phase of NPO denotes a weakened Aleutian Low and the North Pacific High) and the annual WNP typhoon frequency as well as the annual tropical Atlantic hurricane frequency. They also proposed plausible mechanisms for the impact of NPO on the typhoon frequency over WNP. Fan [28] revealed the negative correlation between the winter-spring North Pacific sea ice cover and the WNP typhoon frequency and discussed the possible mechanism. Thus, NPO and sea ice cover over the North Pacific in boreal winter-spring are two new potential predictors for interannual variability of annual typhoon frequency over WNP. It is also worth mentioning that Wang et al.[29] made a first seasonal experimental prediction of the typhoon frequency over WNP by using the numerical climate model based on their previous studies.

Therefore, this paper will discuss the impacts of the winter-spring atmospheric circulation on the annual WNP typhoon frequency, identify new predictors including NPO and sea ice cover over the North Pacific and other circulation indexes in winter-spring, and try to establish a new seasonal prediction model of the typhoon frequency over WNP. Such model should also be suitable for the operational use. Combined with the GCM-based numerical prediction approach, the predicted model could provide a better forecast with higher prediction skill.

2 Datasets

The WNP typhoon frequency (WNPTF) is defined as the numbers of the typhoons in a year. The typhoon is identified by the criteria of the maximum winds larger than 74 m/h (miles per hour) or 119.1 km/h. The region of WNP includes the South China Sea. The dataset is obtained from the Joint Typhoon Warning Center (JTWC). The Hadley 1°×1° resolution monthly sea ice extent dataset is also employed. We also make the use of the National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) monthly atmospheric reanalysis with the resolution of 2.5°×2.5°. The length of the datasets is 43 years covering 1964—2006. The NINO34 index is defined as the mean SST anomaly over the region of 120°W—170°W, 5°S—5°N. Following Fan[28], the North Pacific sea ice occupation index is defined as the mean sea ice extent over the North Pacific. All the time series have been detrended before the analysis. The winter mean denotes December-January-February (DJF) mean and spring average denotes the March-April-May (MAM) average.

3 The new predictors from the winter-spring atmospheric circulation and the typhoon frequency over WNP

In this section, we will try to identify several new predictors based on the previous studies mentioned above and the analysis of the boreal winter-spring atmospheric circulation which will be described in the following.

Figure 1 depicts the correlation coefficient between WNPTF and 850 hPa geopotential height in DJF and the correlation coefficient between WNPTF and SLP in MAM. We find that the significant positive correlation coefficients are located at high latitudes over the North Pacific. The negative correlation coefficients are located in the low-middle latitudes over the North Pacific, and the low-middle latitudes in SH. The variability in low-middle latitudes of SH are related to Australian monsoon activity. The positive phase of NPO is clearly exhibited in Figure 1. (NPO can be defined as the normalized SLP difference between the point (65°N, 175°E) and the point (25°N, 165°E)). The spring NPO is correlated with WNPTF at 0.49, significant at 99% significant level, indicating that spring NPO is an important factor for WNPTF. The physical nature of the NPO-typhoon linkage, according to the recent study by Wang et al. [27], may be illustrated through changes of the westerly jet in the middle latitudes Pacific at upper level (then resulting in variation of the vertical zonal wind shear). Therefore, based on their study and the analysis here, NPO in spring may be used as a new predictor for WNPTF.

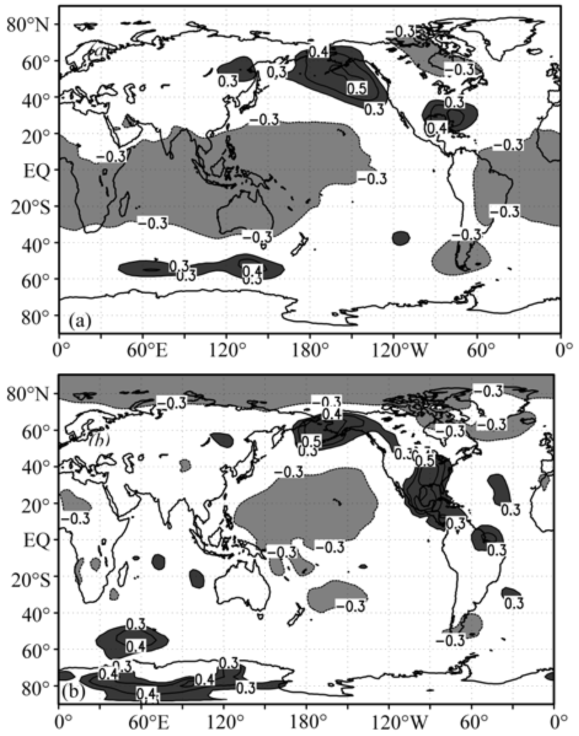

Figure 1 The correlation coefficients between WNPTF and 850 hPa geopotential height in DJF (a) and the sea-level pressure in MAM (b) during 1965—1999. Shaded areas indicate significant correlation coefficients at 95% level, estimated by a local Student's t-test.

Another new predictor for WNPTF is the sea ice area in North Pacific in winter-spring as indicated in Fan[28]. It is found that the index for the sea ice area in the North Pacific both in DJF and MAM have out-of-phase relationship with WNPTF during 1965—2004, with correlation coefficients of −0.42 and −0.49 (above 99% significant level). Large sea ice areas over the North Pacific in DJF and MAM tend to decrease WNPTF. They revealed that positive sea ice (MAM) anomaly over the North Pacific is associated with the tropical circulation and SST anomaly over WNP that may lead to unfavorable dynamic and thermal conditions for typhoon genesis in JJASO. Therefore, the index of sea ice cover over the North Pacific in DJF and in MAM should be considered in the formation of the seasonal forecast model for WNPTF.

The correlation coefficients between WNPTF and 1000 hPa air temperature in DJF are depicted (Figure not shown), showing the significant positive correlation at high latitudes over the North Pacific and significant negative correlation over WNP, tropical western Pacific as well as the low latitudes in SH. East Asia is also a region with negative correlation coefficients. This result demonstrates that the East Asia cold air activity and the cold surge in the South China Sea region are favorable to the typhoon genesis. Li et al.[30] suggest that persistent East Asia cold air activity favors the intensification of the convective activity and the zonal winds over the western Pacific, which is favorable to the ENSO occurrence, consequently, the ENSO occurrence is usually followed by more typhoon geneses. Therefore, the cold air activity over the western Pacific at low latitudes maybe selected as another key predictor for the WNPTF.

As has been noted before, the negative SST anomaly in the tropical eastern Pacific is favorable to the typhoon genesis, and *vice versa*[10,12,14]. Hence, we use the SST as a predictor as well. Now, we consider the impact of the vorticity in low troposphere on WNPTF. The correlation coefficients between WNPTF and the 850 hPa vorticity fields in MAM and JJASO are analyzed. The tropical western Pacific (5°N—20°N) is a region with significant positive coefficients during both the spring case and JJASO case. This means that the influences of the vorticity in the tropical western Pacific on the WNPTF are persistent from MAM to JJASO due to the low frequency oscillation. Thus, we consider the vorticity in MAM at 850 hPa as another key dynamic predictor for the typhoon frequency.

The magnitude of the vertical zonal wind shear (MWS) is an important dynamic factor related to WNPTF[22,23]. The MWS is defined as the absolute value of the zonal wind difference between 200 hPa and 850 hPa. The MWS both in MAM and JJASO cases are analyzed. The WNP is a region with weak MWS in climatology in JJASO, the major typhoon genesis season. The MWS over WNP and WNPTF have negative correlation coefficient from MAM to JJASO due to the low frequency oscillation. Therefore, the MWS of MAM in WNP is a very important predicitor for the interannual variability of the typhoon frequency (see Figure 2(b)).

Based on the above analysis, new predictors for WNPTF are identified including the NPO of MAM, the index of sea ice area over North Pacific both in DJF at in MAM. Based on the previous researches, the other predictors including the 850 hPa geopotential height fields of DJF in the high latitudes and low latitudes of the North Pacific, as well as the low latitudes of the southern Pacific (which is associated with the Australian monsoon), the air temperature at low latitudes in both Hemispheres at 1000 hPa in DJF representing the cold air activity; the index Niño 34 in DJF, the vorticity over WNP at 850 hPa in MAM, and the MWS over WNP in MAM as well.

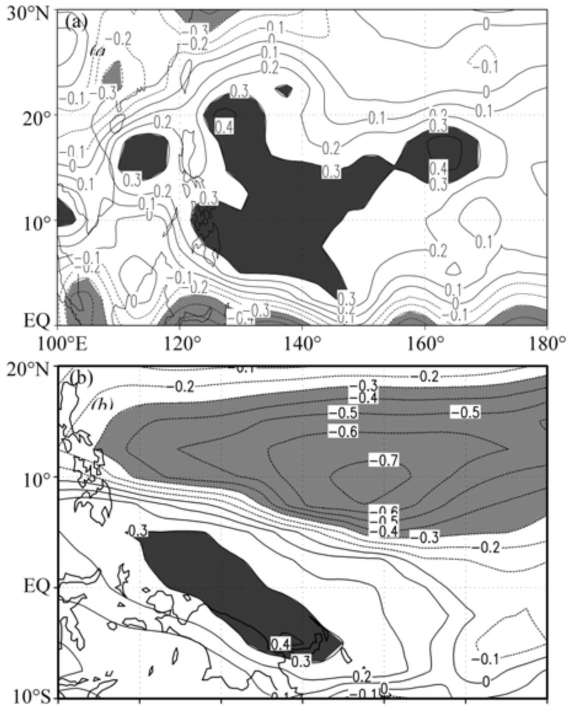

Figure 2 The correlation coefficients between WNPTF and 850 hPa vorticity (a) and the magnitude of zonal wind shear between 200 hPa and 850 hPa (b).

4 Discussion on the possible mechanisms and the case study

Wang et al.[27] revealed that the variability of NPO in JJAS is concurrent with the changes of the magnitude of vertical zonal wind shear, sea-level pressure patterns, as well as the sea surface temperature, which are physically associated with the typhoons and hurricanes genesis. In their research, the NPO-associated atmospheric circulation variability is analyzed to explain how NPO is linked with variability of the tropical atmospheric circulation in the western Pacific and the tropical Atlantic, via the atmospheric teleconnection patterns. Besides, the NPO anomaly is connected to the change of the westerly jet at upper level which is associated with the MWS change in the tropical western Pacific. In our work, it is found that NPO of MAM has significant impact on WNPTF as well. The correlation coefficients between the NPO and SLP in MAM as well as in JJAS are plotted in Figure 3(a) and (b), respectively, in which the linear regressions on SOI have been removed so as to remove linearly the possible impacts of ENSO on the typhoon frequency. Figure 3 shows that NPO is a new predictor of WNPTF.

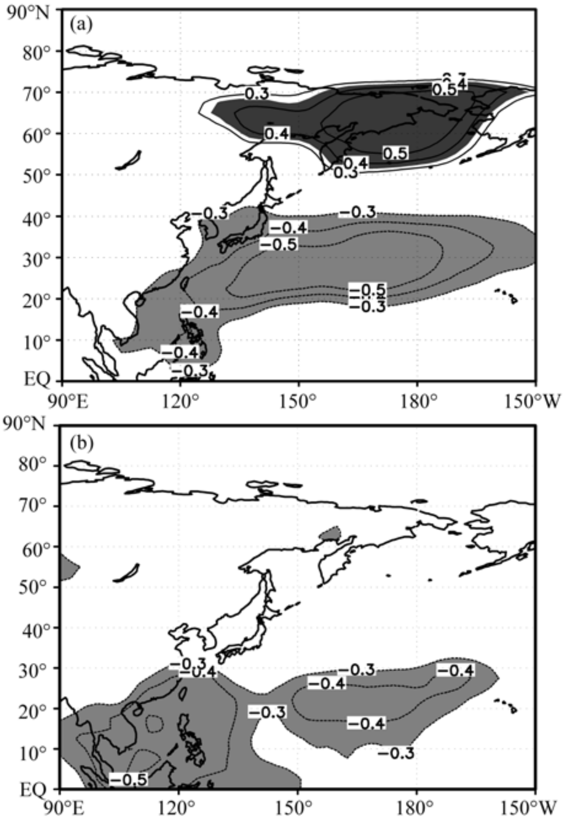

Figure 3 The correlation coefficients between NPO in MAM and the sea-level pressure in MAM (a) and in JJAS (b) during 1965－1999. Shaded areas indicate significant correlation coefficients at 95% level, estimated by a local student-t test. The linear regressions on the SOI have been removed before the plotting.

Fan[28] studied how the sea ice cover over the North Pacific both in DJF and MAM is connected with the tropical atmospheric condition related to the typhoon activity in the interannual variability. It shows that the variability of the atmospheric circulation over the North Pacific, associated with the sea ice area index anomaly in MAM, is connected to the tropical atmospheric circulation variability in MAM via the teleconnection wave train (see Figure 4) and then to the WNPTF in JJAS due to good seasonal persistency of tropical circulations.

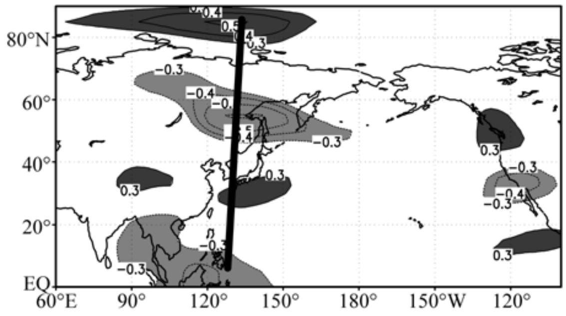

Figure 4 The correlation coefficients between SLP at grid point (65°N, 170°E) and zonal wind at 200 hPa in MAM, with shading areas as Figure 1. The black line indicates the teleconnection train.

To further illustrate the relationship between the new predictors and WNPTF, the years 1997 and 1998 are selected to make a case study. There are more (less) than normal WNPTF and less (more) than normal sea ice cover over the Pacific in 1997 (1998). The differences of the circulation between 1997 and 1998 are analyzed. The positive NPO anomalous pattern in MAM can be seen in Figure 5(a), with positive SLP anomalies at the high latitude over the Pacific and negative SLP anomalies at subtropical WNP. Figure 5(a) is consistent with Figure 3.

Our previous studies suggested that sea ice over Pacific Ocean in MAM is linked with the tropical circulation over WNP via the NPO or the teleconnection pattern (see Figure 4). The teleconnection pattern between the high latitudes and low latitudes is remarkable in Figure 5(b), which is similar to Figure 4. Thus, Figure 5(b) supports our conclusions. Figure 5(c) shows that the tropical WNP has much better seasonal persistency, in which the easterly wind anomaly still prevailes. We also analyzed the difference of vorticity at 850 hPa between 1997 and 1998 (Figure not shown). The positive vorticity anomalies at 850 hPa in tropical WNP are remarkable from MAM to JJASO which is favorable to the WNPTF genesis (Figure not shown). Therefore, the case study on the typical years well demonstrates our previous results, indicating that the new predictors found in this study are physically based important predictors.

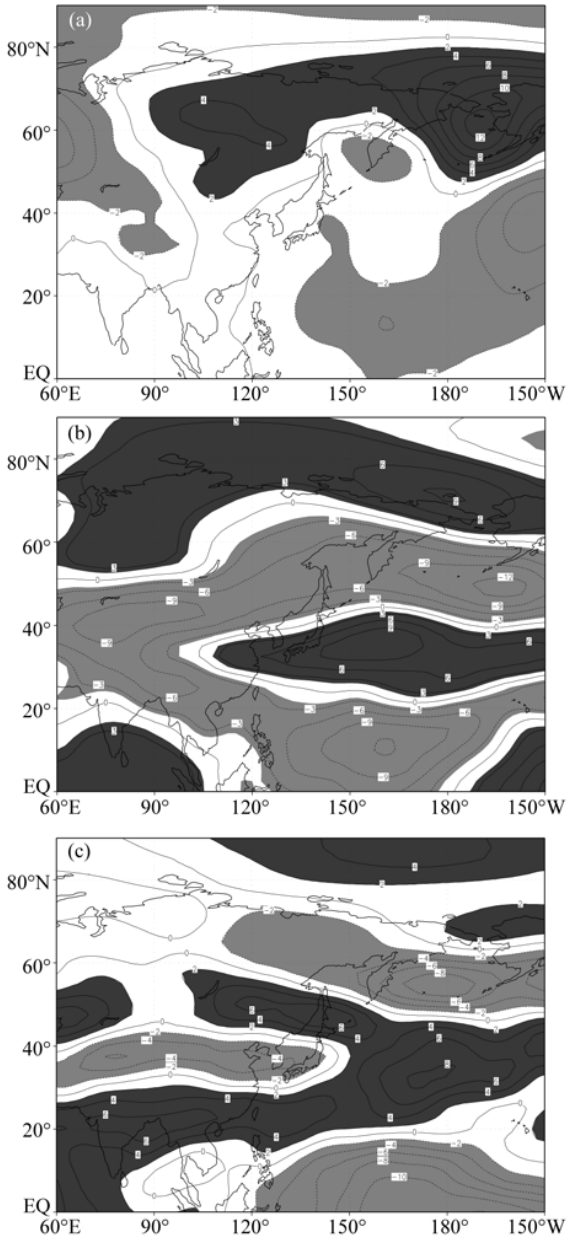

Figure 5 The differences between 1997 and 1998 for (a) sea level pressure in MAM, (b) the zonal wind at 200 hPa in MAM (in m/s), and (c) the zonal wind at 200 hPa in JJAS (in m/s).

5 The Seasonal Forecast Model for the WNPTF

Through the analysis above, the major factors that have significant impacts on the WNPTF have been analyzed and selected. Since all these factors are for the winter or spring season, they have important implication for the seasonal forecast of the WNPTF. Therefore, the multi-factor linear regression method is used for the formation of the forecast model of WNPTF. Nine factors (including the newly identified predictors in this research) have been used in the regression process to build a new prediction model, and they are: X_1 is NPO index in MAM, X_2 area mean geopotential height in the region of （30°S—20°N，90°E—180°E） in DJF representing the circulation of North Pacific and the Southern Hemisphere, X_3 area mean geopotential height in the region of (50°N—60°N, 180°E—140°W) in DJF representing the circulation of North Pacific at high latitudes, X_4 area mean 1000 hPa air temperature in the region of (20°S—20°N, 100°E—140°E) in DJF representing the cold activity at low latitudes in both hemispheres, X_5 Niño34 index in DJF, X_6 North Pacific sea ice cover (averaged over North Pacific) index in DJF, X_7 North Pacific sea ice extent index in MAM, X_8 area mean vorticity at 850 hPa in the region of (5S°—15°N, 130°E—145°E) in MAM, X_9 area mean MWS in the region of (5°—15°N, 140°E—160°E) in MAM. Let y stand for the typhoon frequency over WNP. The correlation coefficients between WNPTF and these predictors are shown in Table 1, which are all significant above 95% level. Therefore, we get the following forecast model through the regression analysis:

$$y = 0.08x_1 - 0.05x_2 + 0.08x_3 - 0.21x_4 + 0.08x_5 \\ - 0.11x_6 - 0.29x_7 + 0.14x_8 - 0.3x_9.$$

Table 1 The correlation coefficients between the WNPTF and each predictors For the periods of 1965—1999

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_8
WNPTF	0.48	–0.49	0.51	–0.50	–0.44	–0.4	–0.48	–0.48	–0.63

The correlation coefficient is 0.79 between the modeled typhoon frequency y and the actual WNPTF for the period of 1965—1999. The coefficient for each item is very close to the respective correlation coefficient, except the Niño34 index in DJF. This implies that the impact of SST in the central and eastern equatorial Pacific in DJF on the typhoon activity is very complex, and there may be nonlinear relationships among the nine factors. Figure 6 shows the temporal variations of the actual WNPTF and the model simulated y, indicating a good agreement. The model can capture well the variability of WNPTF in 1997 and in 1998, during which a warm and a cold event of El Niño-Southern Oscillation (ENSO) occurred respectively. It also demonstrates the accuracy of the model established and indicates each of predictors in model has physical reasoning.

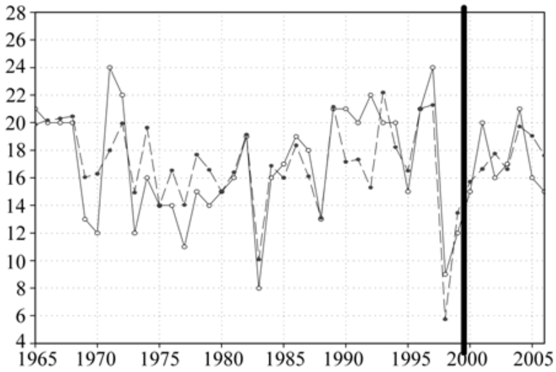

Figure 6 The time series for actual WNPTF (solid line) and the model simulated (dashed line) and predicted WNPTF (dashed line). The model simulated WNPTF is for the period of 1965—1999, and the forecasted WNPTF is for the period of 2000—2006.

6 The validation of the forecast model

By using the new model, we made the hindcasts of the WNPTF for the years of 2000—2006, in order to make a preliminary validation of the model. The results are also depicted in Figure 6. It can be seen that the hindcast results are consistent with the actual typhoon numbers for the years 2000—2006. The model predicted (actual) typhoon numbers for the years 2000—2006 are 15.7(15), 16.6(20), 17.8(16), 16.6(17), 19.7(21), 19(16), 17.6(15). The hindcast results are reasonable both qualitatively and quantitatively. Therefore, the model has a reasonable skill in forecasting the typhoon frequency, and can be potentially used in the operational forecast of the typhoon frequency in the future.

7 Conclusions

Major WNP typhoon activities happen in JJASO. Therefore, the study of the effects of the atmospheric circulation in winter-spring on the typhoon frequency is crucial for establishing the forecast model of the typhoon frequency. In this research, we tried to detect new predictors of the typhoon frequency, based on the analysis of the atmospheric circulation associated with the typhoon genesis. Then we established a new prediction model for the typhoon frequency, by using the NPO index, the index of sea ice area over the Pacific in DJF and MAM, the area mean geopotential height in the region of (30°S—20°N, 90°E—180°E), the area mean geopotential height in the region of (50°N—60°N, 180°E—140°W), the area mean 1000 hPa air temperature in the region of (20°S—20°N, 100°E—140°E), Niño34 index, the area mean 850 hPa vorticity in the region of (5S°—15°N, 130°E—145°E), as well as the area mean MWS in the region of (5°—15°N, 140°E—160°E) as key predictors. Some of the predictors are newly identified in this research. Each of the factors in the established model has not only a significant correlation with the typhoon frequency over WNP but also a physical basis.

The new model shows a reasonable skill for the period of 1965—1999, including the variability of typhoon frequencies over WNP in 1997 and 1998 (some previous models have failed in the prediction for these two special years). The model provides a reasonable hindcast of the WNPTF for the years of 1965—2006. However, the validation of the model by more challenging cases needs to be done. We should also try to improve the model in future works by considering other factors that are physically important for the typhoon genesis.

1 Chen L S. The summertime middle and high latitudes flow pattern in Asia and the western North Pacific typhoon tracks. Acta Meteorol Sin (in Chinese),1965,35: 476—485

2 Xu J M, Gu M R. The boreal summer western Pacific atmospheric circulation features and their relationships with the typhoon activities. Chin J Atmos Sci (in Chinese), 1978, 2: 174—178

3 Fang Z Y. The cloud characteristics during the typhoon occurrence and development and its relationship with high-level environmental circulation. Chin J Atmos Sci (in Chinese), 1982, 6: 274—282

4 Ding Y H. The large-scale circulation conditions for the western North Pacific typhoon formation. Acta Oceanogr Sin (in Chinese), 1983, 5: 561—574

5 Li X Z. Theory of typhoon genesis. Acta Meteorol Sin (in Chinese), 1956, 27: 87—89

6 Tao S Y, Xu S Y, Guo Q Y. Characteristics of zonal and meridional circulation patterns in the tropics and subtropics during boreal summer. Acta Meteorol Sin (in Chinese), 1963, 32(4): 91—103

7 Wang Z S, He S X, Fang Z Y, et al. A preliminary study on the multi-typhoon occurrence of the ITCZ in the west Pacific. Sci Meteorol Sin (in Chinese), 1982, 1, 2: 132—139

8 He S X, Zhang B Y, Fu X Q. The summer typhoon frequency in the western North Pacific and the large-scale atmospheric circulation conditions. Tropical Meteorol (in Chinese), 1986, 2: 251—256

9 Li Z Z. Statistical analysis of Cross equatorial and weather in China. Meteorology (in Chinese), 1986, 4: 11—14

10 Pan Y H. The impact of the thermal conditions in the tropical eastern Pacific on the typhoon frequency. Acta Meteorol Sin (in Chinese), 1982, 40: 25—33

11 Chan J C L. Tropical cyclone activity in the northwest Pacific in relation to the El Niño/Southern Oscillation phenomenon. Mon Wea Rev, 1985, 113: 599-606, doi: 10.1175/1520-0493(1985)113<0599

12 Li C Y. El Niño and the typhoon activity. Chin Sci Bull (in Chinese), 1984, (14): 1087—1089

13 Wang B, Chan J C L. How does ENSO regulate tropical storm activity over the western North Pacific? J Climate, 2002, 15:1643-1658, doi: 10.1175/1520-0442(2002)015<1643[DOI]

14 Wu G X, Lau N C. A GCM simulation of the relationship between tropical-storm formation and ENSO. Mon Wea Rea, 1992, 120: 958-977, doi: 10.1175/1520-0493(1992)120<0958[DOI]

15 Fan K, Wang H J. Antarctic oscillation and the dust weather frequency in North China. Geophys Res Lett, 2004, 31, L10201, doi: 10.1029/2004GL019465

16 Xue, F, Wang H J, He J H. Interannual variability of Mascarene high and Australian high and their influences on East Asian summer monsoon. J Meteorol Soc Japan, 2004, 82(4): 1173—1186[DOI]

17 Wang, H J, Fan K. Central-north China precipitation as reconstructed from the Qing dynasty: Signal of the Antarctic Atmospheric Oscillation. Geophys Res Lett, 2005, 32, L24705, doi:10.1029/2005GL024562

18 Fan K, Wang H J. Interannual variability of Antarctic Oscillation and its influence on East Asian climate during boreal winter and spring. Sci China Ser D-Earth Sci, 2006, 49(5): 554—560, doi: 19.1007/s11430-006-0554-7[DOI]

19 Wang H J, Fan K. Southern Hemisphere mean zonal wind in upper troposphere and East Asian summer monsoon circulation. Chin Sci Bull, 2006, 51(12): 1508-1514, doi: 10.1007/s11434-006-2009-0

20 Wang H J, Fan K. Relationship between the Antarctic oscillation and the western North Pacific typhoon frequency. Chin Sci Bull, 2007, 52(4): 561—565 [DOI]

21 Gray W M. Atlantic seasonal hurricane frequency, Part I: El Niño and 30 mb quasi-biennial oscillation influences. Mon Wea Rev, 1984, 112: 1649—1668. [DOI]

22 Chan J C L. tropical cyclone activity in the western North Pacific in relation to the stratospheric quisa-biennial oscillation. Mon Wea Rev, 1995, 123: 2567—2571. [DOI]

23 He M, Song W L, Xu L. Impact of large-scale circulation on the tropic cyclones in 2000. Meteorology (in Chinese), 2002, 28(4): 15—20

24 Zhao B, Duan Y H, Yu H, et al, A statistical analysis on the effect of vertical wind shear on tropical cyclone development. Acta Meteorol Sin, 2006, 20(3): 383—388

25 Chan J C L, Shi J E, Lam C M. Seasonal forecasting of tropical cyclone activity over Western North Pacific and the South China Sea. Weather Forecasting, 1998, 13: 997—1003, doi: 10.1175/1520-0434(1998)013<0997[DOI]

26 Chan J C L, Shi J E, Liu K S. Improvements in the seasonal forecasting of tropical cyclone activity over the Western North Pacific. Weather Forecasting, 2001, 16: 491—497, doi: 10.1175/1520-0434(2001)016<0491[DOI]

27 Wang H J, Sun J Q, Fan K. Relationships between the North Pacific Oscillation and typhoon and hurricane frequencies. Sci China Ser D-Earth Sci, 2007, 50(9): 1409—1416

28 Fan K. North Pacific sea ice cover, a predictor for the Western North Pacific typhoon frequency? Sci China Ser D-Earth Sci, 2007, 50(8): 1251—1257

29 Wang H J, Lang X M, Fan K et al. The climate prediction experiment on the western North Pacific typhoon frequency for 2006. Clim Environ Res (in Chinese), 2006, 11: 133—137

30 Li C Y , Mu M Q. Relationship between East Asian winter monsoon, warm pool situation, and ENSO cycle. Chin Sci Bull, 2000, 45(6): 1448—1455