Growing typhoon influence on east Asia

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[1] Numerical model studies have suggested that the ongoing global climate change will likely affect tropical cyclone activity. Since the global warming has been underway, it is meaningful to ask: Are there evidences of observed changes in tropical cyclone activity? Using best-track data from 1965 to 2003, we show for the first time that over the past four decades the two prevailing typhoon tracks in the western North Pacific (WNP) have shifted westward significantly; thus the subtropical East Asia has experienced increasing typhoon influence; but the typhoon influence over the South China Sea has considerably decreased. Our trajectory model simulation indicates that the long-term shifts in the typhoon tracks result primarily from the changes in the mean translation velocity of typhoons or the large-scale steering flow, which is associated with the westward expansion and strengthening of the WNP subtropical high. **Citation:** Wu, L., B. Wang, and S. Geng (2005), Growing typhoon influence on east Asia, *Geophys. Res. Lett.*, *32*, L18703, doi:10.1029/2005GL022937.

1. Introduction

[2] The typhoon tracks in 2004 were unusual. An unprecedented number (10) of typhoons hit Japan whereas South China was ravaged by the worst drought since 1951 due to lack of landfalling typhoons (National Climatic Data Center/National Oceanic and Atmospheric Administration, Climate of 2004 preliminary annual review: Significant U.S. and global events, 2004, available at http://www.ncdc.noaa.gov/oa/climate/research/2004/ann/events.html). Does this track shift reflect a long-term change in the prevailing typhoon tracks? So far, many studies, mostly based on numerical model results of global warming experiments, have suggested that ongoing global climate change will likely change typhoon intensity [*Knutson et al.*, 1998; *Knutson and Tuleya*, 2004] and frequency of occurrence [*Bengtsson et al.*, 1996; *Henderson-Sellers et al.*, 1998], and shift prevailing tracks [*Walsh and Katzfey*, 2000; *Wu and Wang*, 2004]. However, little observed evidence has been shown to support these projected changes [*Knutson and Tuleya*, 2004; *Chan and Liu*, 2004].

[3] TC tracks are essentially controlled by large-scale atmospheric circulation patterns. Previous studies have demonstrated that the variability of seasonal typhoon activity is related to the El Nino Southern Oscillation (ENSO) [*Chan*, 1985, 2000; *Lander*, 1994; *Chen et al.*, 1998; *Wang and Chan*, 2002], the stratospheric quasi-biennial oscillation [*Chan*, 1995] and interdecadal variations [*Chan and Shi*, 1996; *Ho et al.*, 2004]. The tropical sea surface temperatures (SSTs) have changed abruptly around 1976 [*Nitta and Yamada*, 1989; *Kumar et al.*, 2004], and the atmospheric circulation over the Pacific and the properties of El Nino have also shown concurrent changes in response to the interdecadal SST change [e.g., *Trenberth and Hurrell*, 1994; *Wang*, 1995]. Can these changes in large-scale atmospheric circulation lead to changes in the prevailing typhoon tracks? The present study is aimed to address a heated issue: Is there any evidence of long-term changes in typhoon activity in the WNP and East Asia? While many previous studies that examined the possible changes in tropical cyclone frequency and intensity on the basin average, this study examines the possible tropical cyclone track shift within a specific basin.

2. Data

[4] The best track data from the Joint Typhoon Warning Center (JTWC) were used to calculate two critical parameters that measure the seasonal mean TC motion [*Wu and Wang*, 2004]. The first, the frequency of TC occurrence, indicates how many TCs enter a specific grid box of 2.5° latitudes by 2.5° longitudes. The higher the frequency in a given box, the more TCs have gone through it. The other is the mean translation velocity of the TCs. Both of the parameters are calculated annually from 1965 to 2003 for each box. The year of 1965 was chosen as the starting year because the satellite monitoring of weather events first became routine so that no TC would be missed.

[5] The wind data reanalyzed by the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) are used to calculate the climatological mean steering flow. The large-scale steering flow is defined in this study as the pressure-weighted mean flow from 850 to 300 hPa [*Holland*, 1993]. In order to quantify the changes in the WNP subtropical high, two subtropical-high indices defined by the Chinese National Forecast Center were used in this study. The intensity index is defined as the sum of the geopotential height points on all 5°-latitude by 5°-longitude grid boxes covered by contour 5880 m between 110°E and 180°. For a specific grid box, the point increases by one when the maximum height on the grid increases by each 10 m from 5880 m. For example, the point is 2 if the height on a grid is between 5890 to 5899 m. The second index defined by the westernmost longitude of the 5880 m

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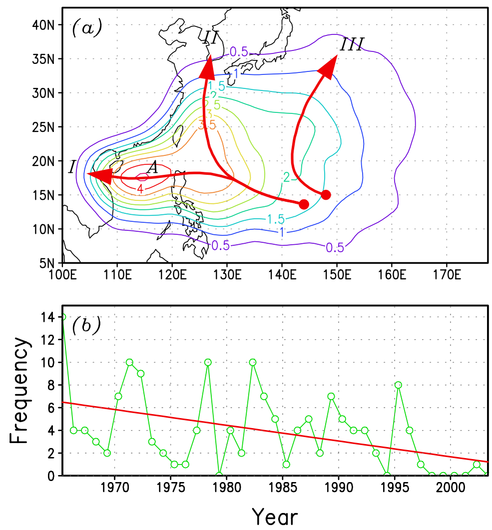

Figure 1. (a) June-October mean frequency of TC occurrence (unit per year^{-1}) derived from the JTWC best-track data from 1965 to 2003 and (b) the time series of the seasonal mean frequency of TC occurrence at the most active center A (17.5°N, 115°E) with a linear fit indicated by the straight line. The thick solid lines with arrows highlight schematically three prevailing typhoon tracks.

contour measures the westward extension of the WNP subtropical high.

3. Shifts in the Prevailing Tracks

[6] Figure 1a displays the spatial distribution of the 39-year mean frequency of TC occurrence for the typhoon season (June-October). TCs occur most frequently over northern South China Sea (SCS) and an adjacent region to the waters southeast of Taiwan, indicating a prevailing track of westward-moving typhoons (Track I). The high frequency of occurrence also extends from the Philippine Sea to Korea and Japan, suggesting another prevailing track that influences the coastal region of East Asia (Track II). In addition, some typhoons tend to recurve northeastward east of 130°E (Track III) often during WNP subtropical ridge splits. As shown in Figure 1b, the temporal evolution of the seasonal mean frequency of TC occurrence in the activity center (the grid box centered at 17.5°N, 115°E) is characterized by interannual variations and a significant downward trend, indicating that the TC activity over the central South China Sea has persistently decreased since 1965, in particular in the last seven years.

[7] Two approaches were used to detect the trends in the frequency of TC occurrence and the mean translation velocity. First, we fit the frequency and mean velocity on each grid box by linear regression: $f_i = a_i + b_i t$, where t is time and f_i is the frequency or velocity components on the ith grid. The first term (a_i) represents the base state at $t = 0$ (1965) and the second term ($b_i t$) represents the changes associated with linear trends. The significance of the linear trend on each grid box was tested with the Mann-Kendall method [*Kundzewicz and Robson*, 2000]. Second, since the linear trend of the frequency of occurrence is suggested in Figure 1b, we simply divide the 39-year data into two epochs (1965–1983 and 1984–2003) and contrast their means. The significance of the epoch mean differences was tested with the Student t-test.

[8] The patterns of significant linear trend and epochal change detected by the above two approaches resemble each other in both of the TC occurrence frequency and the mean translation velocity (Figures 2a and 2b), suggesting that the identified trend is largely linear. The robust spatial consistency among individual grids adds confidence to the results. Figures 2a and 2b indicate systematic shifts in the prevailing tracks during the past 39 years. The negative anomalies over the central South China Sea mean a sharp decrease in the number of the TCs that follow track I, while the positive anomalies extending from the Philippine Sea to the eastern coast of China and in the eastern part of the basin indicate westward shifts of prevailing tracks II and III, respectively.

[9] The shifts in the prevailing tracks can be seen clearly by comparing linear regression parts of the frequency of TC occurrence in the beginning (1965) and the end (2003) of the period examined (Figure 3). In 1965 three TC active centers between 110–120°E (South China Sea), between 120–130°E (east of Taiwan), and between 140–145°E can be identified. By 2003 the most active region over the SCS shifted northeastward and merged with the center to the east of Taiwan. The resulting new center is located in the northern Philippines. Meanwhile, the third active center, originally between 140–145°E shifted westward by about

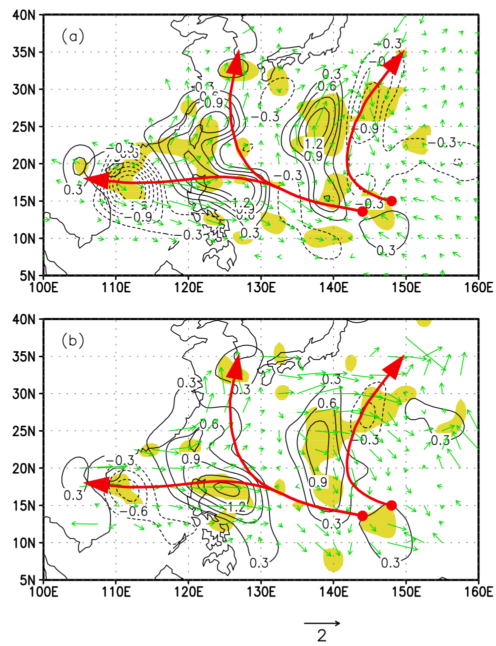

Figure 2. (a) Changes of the June-October mean frequency of TC occurrence and the motion vectors based on the derived linear trend change and (b) the difference in TC occurrence frequency between the periods 1965–1983 and 1984–2003. The areas with confidence level exceeding 95% for the identified changes are shaded. The contour interval is 0.3 year^{-1} and the unit of the vectors is ms^{-1}. The thick solid lines with arrows denote the prevailing typhoon tracks.

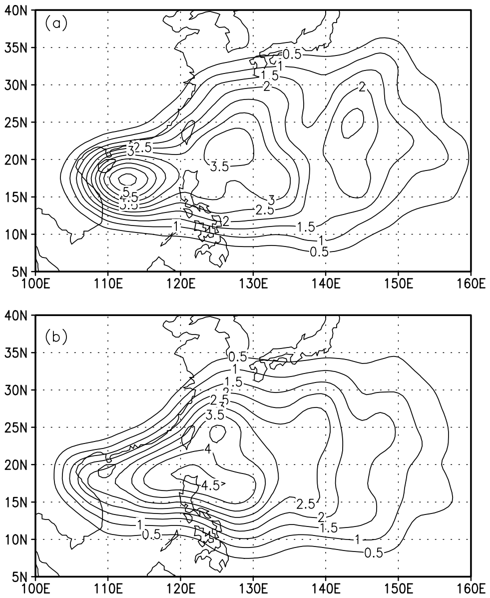

Figure 3. (a) The June-October mean frequency of TC occurrence in 1965 and (b) the same as in (a) except that a linear trend has been added so that the plot can be viewed as June-October mean frequency of TC occurrence in 2003 obtained by linear regression. The contour intervals are 0.5.

10 degrees of longitude. As a result, East Asia tends to experience growing typhoon influence.

4. Cause of the Prevailing Track Shift

[10] For a given TC, its track depends on its formation location and subsequent movement. The TC movement is primarily determined by large-scale steering plus a minor propagation component. The steering component is advection of TC potential vorticity by large-scale environmental flows. The propagation component arises from nonlinear interactions among the environmental flow, planetary vorticity gradient, and TC circulation [*Holland*, 1983; *Carr and Elsberry*, 1990; *Wang and Li*, 1992] and from diabatic heating [*Wu and Wang*, 2001]. Recently *Wu and Wang* [2004] put forward a trajectory model with which the spatial distribution of TC occurrence frequency can be determined given the TC formation locations and the climatological mean TC translation velocity at each grid box. The latter is also composed of the mean large-scale environmental steering and propagation.

[11] It is hypothesized that the track changes are mainly due to changes in the large-scale mean flow field whereas the propagation component does not change. Climatologically, the propagation is dominated by the beta effect and the effects of environmental flow and diabatic heating are largely averaged out. Two numerical simulations using the trajectory model were performed, in which all TCs that formed during the period of June-October are assumed to move with the mean translation velocity fields deduced from the epoch means of 1965–1983 and 1984–2003, respectively. The trajectory model simulations capture faithfully the observed frequency changes west of 140°E (Figure 4), suggesting that the changes in the mean steering flows (translation velocity) are a dominant factor responsible for the prevailing track shift. We also evaluated the influence of the changes in the formation locations on the prevailing track shift. Using the same mean TC translation velocity averaged over the period of 1965–2003 the trajectory model is run with the formation location data over the periods of 1965–1983 and 1984–2003, respectively. We find that the changes in the formation locations play a minor role in terms of the magnitudes (figure not shown).

[12] The changes in the mean TC translation velocity are closely associated with the large-scale steering flow. Following *Holland* [1993], the large-scale steering flow is defined in this study as the mean flow from 850 to 300 hPa. Figure 4a shows the large-scale steering flow changes between the periods of 1965–1983 and 1984–2003. The change in large-scale steering flows is characterized by a cyclonic circulation centered over eastern China. Comparisons of Figures 2a and 2b with Figure 4a indicate that the changes in the large-scale steering flows can well explain the changes in the mean translation velocity of TCs over the western part of the basin. Further examination

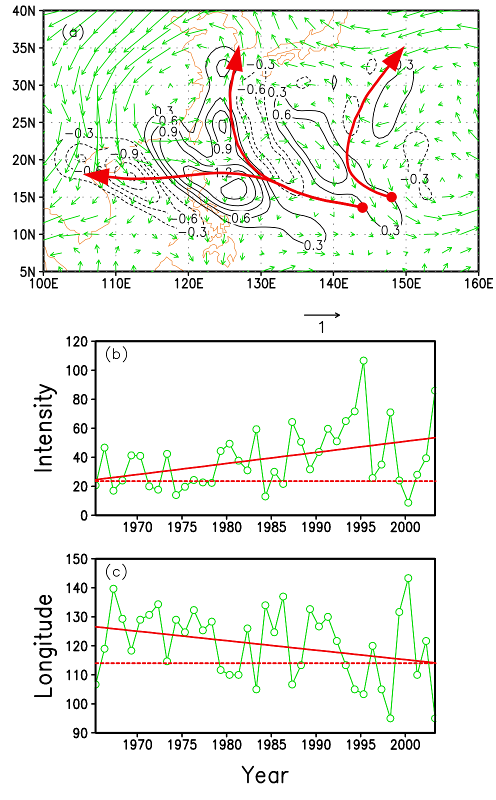

Figure 4. (a) The changes of the June-October mean frequency of TC occurrence derived from the changes in the mean translation velocity using the trajectory model. Superimposed are the climatological prevailing typhoon tracks (thick solid lines with arrows). The vectors are the differences of the large-scale steering flows between the periods of 1965–1983 and 1984–2003 derived from the NCEP/NCAR reanalysis data. The contour intervals are 0.3 year^{-1} and the unit of the vectors is m s^{-1}. (b) and (c) Time series of the intensity and west-most longitude of the July-September mean WNP subtropical high, respectively. The horizontal dashed lines in (b) and (c) indicate the minima of the linear fits.

reveals that the enhanced cyclonic steering flow in the last two decades results mainly from the upper-level circulation change (500 hPa and above) (figure not shown). What causes the inconsistency between the changes in the large-scale steering flow and the changes in the mean translation TC velocity over the eastern part of the basin needs further investigation.

5. Discussion

[13] The 39-year typhoon data are relatively short for full determination of the climatic trend in typhoon tracks. However, the identified prevailing track shift shows physically meaningful consistency between the changes in the mean translation velocity and the changes in the large-scale circulation at least in the western part of the basin. That is, the prevailing typhoon track shift occurred over the past four decades is a primary result of changes in the large-scale steering flow. Since the track shift is intermingled with strong interannual variations, one feels more evident track shift in some extreme years like 2004. Regardless of whether it is a consequence of anthropogenic impacts or is due to a long-term natural variability, the demonstrated shift in the prevailing typhoon tracks has a profound influence on the countries of East Asia.

[14] The changes in the atmospheric circulation over East Asia have been documented recently. In an observational analysis, *Yu et al.* [2004] found that in contrast to the global warming trend over the past 50 years, a distinctive tropospheric cooling trend is found in the middle latitude East Asia. Accompanying this cooling, the upper-level westerly jet stream shifts southward. *Ho et al.* [2004] documented the westward expansion and intensification of the subtropical high over the WNP as shown in Figures 4b and 4c. They attributed these changes in the subtropical high to the interdecadal shift of the tropical SSTs. As a result of these changes, the Yangtze River Valley tends to have more frequent flooding [*Gong and Ho*, 2002; *Yu et al.*, 2004]. We suggest that this tropospheric cooling in the last two decades may be responsible for the large-scale circulation change shown by Figure 4a. The East Asian tropospheric cooling is associated with the lowering of the upper tropospheric geopotential height and the enhancement of the anomalous surface anticyclone, which is associated with the westward expansion of the strengthening subtropical high over the WNP (Figures 4b and 4c). However, what causes the enhanced cyclonic steering flows in the East Asia during the last two decades (Figure 4a) is an important issue that deserves further investigation.

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