Climate trends in tropical cyclone-induced wind and precipitation over mainland China

Ming Ying,1,2,3 Baode Chen,2 and Guoxiong Wu1

Received 4 October 2010; revised 23 November 2010; accepted 30 November 2010; published 11 January 2011.

[1] The trends in tropical cyclone (TC) induced wind and precipitation are estimated by applying a quantile regression to station data collected from mainland China. Results indicate that stations located close to the southeast coast show significant decreasing trends in annual windy days, maximum sustained wind and wind gusts, while positive trends in precipitation per TC and maximum 1-hr precipitation dominate over the south of the Yangtze River. The TC frequency is generally decreased over China, especially over south China. The location of significant trends in precipitation seems to be related to the mountains and coastline in southeast China. The influence of local conditions, such as topography and urbanization, on circulation may contribute to the spatial pattern of trends in influence of TC activity. The different behaviors of trends in wind and precipitation also necessitate a more thorough metrics for assessing the impacts of TCs. Citation: Ying, M., B. Chen, and G. Wu (2011), Climate trends in tropical cyclone-induced wind and precipitation over mainland China, Geophys. Res. Lett., 38, L01702, doi:10.1029/2010GL045729.

1. Introduction

[2] With the ongoing development of coastal areas worldwide, the risks posed by TCs in a warming climate are one of the most important factors related to the security of society and economy. Temporal trends in TC activity and their potential influence on society have been extensively examined in previous studies, but with conflicting results. For example, it has been predicted that the destructiveness of TCs will increase because TC intensity shows an increasing trend in the North Atlantic [Emanuel, 2005; Kossin et al., 2007; Webster et al., 2005]; however, the actual financial losses resulting from TCs in the United States show no upward trend [Pielke, 2005]. Based on gauged precipitation for the past century, Groisman et al. [2004] reported no trend in TC precipitation over the coastal area of the southeastern United States. Over the western North Pacific (WNP), Joint Typhoon Warning Center best track data suggest an increasing trend in TC potential destructiveness [L. Wu et al., 2008], whereas best track data from the Regional Specialized Meteorological Center Tokyo and the Hong Kong Observatory show no significant trend [Wu et al., 2006], which is consistent with results based on relatively homogeneous satellite-derived data [Kossin et al., 2007]. These apparent discrepancies may be attributed to many factors, including differences among ocean basins, different data sources, the gap between synoptic and social aspects of TC influences, and the metrics of TC activity.

[3] Severe wind and torrential rain are two main factors by which TCs influence human society as they commonly produce storm surges, floods, and debris flows. Moreover, wind and precipitation are fundamental variables of the climate system and are available as higher-quality data than TC intensity from best track data; consequently, these variables have an advantage in representing the influence of TCs. In assessing the risk of TCs in a warming climate, it is necessary to investigate the nature of temporal trends in wind and precipitation.

[4] In China, the area affected by TC-related wind and precipitation comprises almost all of the second and third level topographic regions (Figure 1) [cf. Xu, 2007]. Storm winds associated with TCs are most intense in coastal regions [Xu, 2007; Yang and Lei, 2004], whereas heavy rains can affect a much larger area [Xu, 2007]. Some studies have suggested that annual TC precipitation in southeast China accounts for more than 10% of the total annual precipitation [Ren et al., 2006; Rodgers et al., 2000; Xu, 2007]. Previous analyses of observed TC rainfall in China suggest decreasing trends in both total precipitation and frequency of torrential rains [Cheng et al., 2007; Ren et al., 2002, 2006]. These results are inconsistent with predictions of an increasing trend in global storm precipitation under a warming climate [Gualdi et al., 2008; Trenberth, 1999, 2008; Yoshimura et al., 2006], thereby suggesting a complex regional-scale relationship between inland precipitation and warming climate.

[5] To perform an assessment of the TC-related climate trends in mainland China, we analyzed a dataset of TC-induced wind and precipitation, with an emphasis on maximum wind and precipitation intensity. The remainder of this paper is organized as follows. In Section 2, the data and methodology are briefly introduced. The results are presented in Section 3, and concluding remarks are provided in Section 4.

2. Data and Methodology

[6] The WNP TC best track data (available from http://www.typhoon.gov.cn/en/data) and TC-induced wind and precipitation in China were used in this study. The TC wind and precipitation dataset is based on observations at more than 1600 stations, which has been archived in Shanghai Typhoon Institute, China Meteorological Administration since 1970s. The regions affected by individual TC that formed over the WNP, with the precipitation heavier than
10 mm per storm or sustained wind great than Beaufort Scale 6, were subjectively identified by inspecting weather maps and observation data. The subjective approach has advantages over objective methods [e.g., Chen et al., 2010; Kubota and Wang, 2009; Ren et al., 2001] under complex interaction of TCs and other weather systems [Ren et al., 2001]. That the expert team has been kept stable for several decades minimizes possible spurious signals due to personnel factors [Ying et al., 2011]. Both datasets go back to 1949 and are updated annually. The sustained winds in both datasets are about 2–3 min mean. To ensure temporal homogeneity of data, only stations with more than 50 years of data are selected for analysis. The resultant dataset extends from 1955 to 2007 and is based on 676 stations (Figure 2), covering almost the entire region in China affected by TCs [Xu, 2007].

Trends are estimated for TC wind in terms of both the maximum 2-min sustained wind speed and maximum wind gusts. For TC precipitation, we consider the trends in precipitation per TC, and maximum 1-hr precipitation. In addition, we will also show that due to changes in TC frequency, the trend in annual total TC-related precipitation is different from the trend in precipitation per TC.

Quantile regression (QR), based on order statistics, is a method for estimating functional relations between variables at various portions of the probability distribution [Barbosa, 2008; Koenker, 2005; Koenker and Basset, 1978]. We applied QR to data at each station to estimate the trends of median, that is, the slope of conditional median function, which are obtained by solving

\[
\min \sum f(y_i - (a_0 + a_1 t_i)),
\]

where \(f(y - q) = \begin{cases} 
\tau (y - q) & y \geq q \\
(1 - \tau) (q - y) & y < q 
\end{cases} \) is the response variable on \(t_i\), \(a_0\) and \(a_1\) are intercept and slope, \(\tau = 0.5\), and \(q\) is the \(\tau\)-th quantile, here is median. The approach was used because the median has an advantage over the mean in describing the average status of a variable with non-normal distribution and because assumption about the probability distribution is not necessary for QR. In addition, a bootstrap method [Xu, 2006] with 5000 re-sampling iterations was used to determine the significance levels of the trends, as it also does not require a priori assumption of probability distribution.

3. Results

[9] Figures 2a–2b shows trends in maximum sustained wind speed, and maximum wind gusts, respectively. Both show significant trends in the coastal areas of southeast China, whereas no trend is seen inland. This is consistent with the fact that TC-related winds dissipate rapidly toward inland from the coast [e.g., Kaplan and DeMaria, 1995; Yang and Lei, 2004] and hence may largely kill the temporal trends, with either positive or negative sign, in wind away from the coastline. At the stations that show significant trends, most of them have decreasing trends in the maximum sustained wind speed (Figure 2a) or in wind gusts (Figure 2b), with rare exceptions in the Yangtze Delta and

![Figure 1. Topographic map of China.](image1.png)

![Figure 2. Significant climatic trends (dots) for the median of (a) maximum 2-min sustained winds, and (b) maximum wind gusts.](image2.png)
along the coastline of south China. Overall, the trends indicate that the intensity of TC-induced severe coastal winds has declined in southeast China. Figure 2a also shows no or rare decreasing trend in maximum sustained wind over the marginal sea within 300 km away from the coast of southeast China. This implies that the negative trend in wind at the coast may be not due to the weakening of incoming TCs, but more possibly due to the change in local conditions at the coast. We suggest that the intense urbanization since the late 1980s and associated increase in surface roughness may contribute to the decreasing trends in TC-related wind, though some other unknown local or larger-scale conditions may also contribute to the observed trends.

Figure 3 shows the trends in TC-induced rainfall, which saliently differ from the trends in wind: stations with significant trends are not restricted to coastal areas, and most of them show positive trends. The areas with increasing trend in precipitation per TC extend more westward into inland China, while the areas with increasing trend in maximum 1-hr precipitation are mainly located at the windward sides of Nanlin and Wuyishan Mountains as well as along the coast of southeast China. It also seems that the increasing trend in maximum 1-hr precipitation is more significant than the trend in total rainfall per TC. The overall increase in the intensity of TC-induced rainfall over South China is consistent with the increase in precipitable water and water vapor in the past decades, especially during summer over South China [Zhai and Eskridge, 1997], which provides a more suitable climate background of moisture supply for TC-induced rainfall. The increasing trend in rainfall is also consistent with the numerical simulations [e.g., Knutson and Tuleya, 2004; Gualdi et al., 2008].

That the locations with significant trend in rainfall intensity tend to occur at the windward of mountains and mountainous coastal south China deserves more careful explanation. Both the observations [e.g., Yu and Cheng, 2008] and numerical simulations [e.g., Li et al., 2007] suggest a topographical enhancement of TC rainfall. It is plausible that the windward side of the topography may be more favorable for convection to be enhanced through the joint effects of the topography-induced lifting of the flow [e.g., Wu, 1984] and warming-induced increase in water supply. As well, the local contrast of land–sea can also help to enhance convections over the coastal area [e.g., G. Wu et al., 2008]. Further investigation is needed to clarify detailed physical processes.

It is interesting to note that the trends in annual total TC-induced precipitation (Figure 4a) do not show dominant increasing trend as in Figure 3a. The difference between Figures 4a and 3a results from the changes in TC-frequency (Figure 4b), which show a decreasing trend over most part of China except at some locations such as the low reach of the Yangtze River. The decreasing trend is especially significant in south China where the averaged number of TCs over the last 25 years in the data decreased about 1–2 per year relative to the first 25 years (Figure 4b). The decrease in the TC frequency is consistent with the trend in TC frequency under global warming [Gualdi et al., 2008]. The decrease in TC frequency also lead to the difference between the trend of annual total rainy days (Figure 4c) and that of the rainy days per TC (Figure 4d). The longer rainy days associated with each TC (Figure 4d) may increase the risk of TCs to the society.

4. Concluding Remarks

In this study, we assessed the trends in TC-induced wind and precipitation over mainland China. The decreasing trends in TC wind over the southeast coastal area of China suggest a weakened influence of TCs; however, the increasing trends in the rainy days per storm, total precipitation per storm and maximum 1-hr precipitation indicate an enhanced influence of TCs in this area. This apparent contrast demonstrates that the conclusions regarding the trends of TC influences based solely on best track data, wind observations, or precipitation should be taken with cautions. A more thorough metrics for assessing the influence of TCs on society is necessary.

In addition, the different behaviors of trends in wind and precipitation suggest that the coupled dynamic–hydrologic aspects of TCs may be affected by complex factors. The decreasing trend in TC-induced wind intensity at the coast may contain contributions of the increase in the surface roughness related to the rapid urbanization in the past decades. The spatial pattern of the increasing trend in the rainfall intensity suggests the importance of local con-
ditions, such as topography and land-sea contrast, in localizing the significant trends at the windward side of mountains and at the coast.

The TC frequency is generally decreased over China, especially in south China. Due to the changes in TC frequency, the spatially noisy trends in annual amount of rainy days and rainfall may cover up the more consistent trends in intensities per storm. This again reinforces the importance of a suitable statistical metrics.

Acknowledgments. This research was sponsored by the Specialized Climate Change Project CCSF-09-10 of the China Meteorological Administration, projects 40821092 and 40810059005 supported by the National Natural Science Foundation of China, and the Specialized Fund of the Shanghai Meteorological Bureau (YJ200801) for the Climate Change Research Team.

References


B. Chen and M. Ying, Laboratory of Typhoon Forecast Technique, Shanghai Typhoon Institute, China Meteorological Administration, 166 Puxi Rd., Xuhui District, Shanghai 200030, China. (baode@mail.typhoon.gov.cn; yingm@mail.typhoon.gov.cn)

G. Wu, State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China. (gxwu@lasg.las.ac.cn)