Responses to *Dr. He*

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Title of Paper: Estimation of Tropical Cyclone Wind Hazards in Coastal Regions of China

Journal: Natural Hazards and Earth System Sciences (NHESS)

Dear Dr. He,

We would like to thank you for your careful and thorough reading of our manuscript and for the thoughtful comments and constructive suggestions. We are already crafting a revised version of the paper. Please, find below the referees' comments repeated in italics and our responses inserted after each comment.

1. Comment: *This article presents a detailed study on the estimation of TC-wind hazards in southeast coast of China. Values of key parameters of TCs, i.e., RMW and Holland-B, are firstly estimated by fitting TC best-track records from JMA via a TC wind field model. These results are then utilized to generate a number of recursive models for corresponding parameters of TC activities and TC wind field. The proposed recursive models are further exploited in conjunction of the TC wind field model to estimate TC extreme winds associated with different return periods at several selected coastal cities. Finally, results of TC wind hazards obtained from this study are compared with those stipulated in codes or the ones documented by peers. Overall, this work is well written and the analysis process is scrupulous, which makes the findings convincing. It is expected that the findings can provide further insights to better understand the design speeds at coastal areas of China. This reviewer actually has few specific comments for the improvement of this article, but there are still some issues that should be clarified.*

Response: We really appreciate your positive feedback and your valuable suggestions. We agree with all your comments and we have revised the manuscript accordingly.

2. Comment: RMW and Holland-B are two key parameters whose values can influence the simulation results of TC wind field severely. Actually, some researchers pointed out that the majority of uncertainty for assessing TC wind hazards should be attributed to the estimation of these parameters. In this regard, great efforts are encouraged to pay to accurate estimation of their values. Basically, there are two kinds of methods which are driven by wind speed records and pressure records, respectively. According to the pioneering work by Holland (1980), RMW and Holland-B are defined under the context of TC pressure field, which potentially indicates that the pressure-data driven method is more straightforward, and possibly more effective. As stated in my general comments, the authors choose the speed-data driven method. Besides the above consideration, there are also several uncertainty sources: (1) even though the authors explain much for choosing TC records from JMA, the basic records herein still belong to the "best-track" data, which means they may differ from the real noticeably. (2) TC wind field possesses asymmetric features, while according to the statements in this study, the best-track information for estimating these two parameters may practically account for symmetric TC wind field. If this is the case, the estimation accuracy could be degraded. (3) The authors use a height-resolving model to depict TC wind field, while the best-track TC information is given at a fixed level. Please detail in the context how to deal with the inconsistency in terms of height level between model and dataset (including what altitude should the best-track data best account for). It is also suggested that the obtained values of RMW and Holland-B be statistically compared with their counterparts in previous studies.

Response: Thanks for your comment. Indeed, as you mentioned, R_{max} and B have significant effects on the estimation of TC wind hazards. As replied to Anonymous Referee #1 and Dr. Huang, Table 1 lists the fitting methods for R_{max} and B. The pressure and wind speed data sources were commonly employed to extract the R_{max} and B using different fitting models.

Table 1 Use of data source and fitting model for R_{max} and B

Data source	Fitting model	Reference
Surface pressure	Holland pressure model	Holland, 1980; Zhao et al., 2013; Fang et al., 2018b
Surface wind speed	Gradient and boundary layer wind models	Vickery et al., 2008; Fang et al., 2019; Zhao et al., 2020
Upper level pressure	Convert to surface pressure	Vickery et al., 2000, 2008
Upper level wind speed	Gradient wind model	Vickery et al., 2000

Holland pressure model:

$$P_{rs} = P_{cs} + \Delta P_s \cdot \exp\left[-\left(\frac{R_{max,s}}{r}\right)^{B_s}\right] \quad (1)$$

in which subscripts s and r denote surface values at the radius of r, P_{rs}= surface air pressure at radius of r from the typhoon's axis (hPa), P_{cs} = central pressure (hPa), $\Delta P_s = P_{ns} - P_{cs}$ is the central pressure difference (hPa).

Gradient wind model:

$$V_g = \frac{V_{T\theta} - fr}{2} + \sqrt{\left(\frac{V_{T\theta} - fr}{2}\right)^2 + \frac{r}{\rho_g}\frac{\partial P_g}{\partial r}} \quad (2)$$

in which $V_{T\theta} = -V_T \cdot sin(\theta - \theta_T)$, V_T is the translation speed (m/s), θ_T and θ are the translation direction and the direction of interest (counterclockwise positive from the east, °), f is the Coriolis force, ρ_g (kg/m^3) and P_g (hPa) are the air density and pressure at gradient layer.

The pressure data (direct surface observations or converted from upper-level observations) can be directly applied to Eq. (1) to obtain $R_{max,s}$ and B_s, which is considered as the most physically reasonable method. Vickery et al. (2000, 2008) utilized the surface pressures converted from flight-level reconnaissance data to optimally obtain a pair of $R_{max,s}$ and B_s for each traverse observation through the storm. Fang et al. (2018b) fitted the surface pressure data of landing typhoons observed by distributed meteorological stations in the mainland of China. However, when this equation is applied to model the wind speed field (assume $P_{rs} = P_g$) using Eq. (2) as used by most wind field models (Vickery et al., 2008), some inconsistencies could be introduced since the pressure distribution at free atmosphere is somewhat different from that at the surface. This can be approved from the results obtained by Willoughby et al (2004) and Vickery et al. (2000). Vickery et al. (2000) found that estimated B from upper-level wind speed data using Eqs. (1)~(2) were about 20%~30% higher than that estimated from surface pressures. That means if Eq. (1) is estimated from the surface pressures, it cannot be directly applied to Eq. (2) due to the height-resolving characteristics of air density and pressures. And Eq. (2) is actually an approximate formula by neglecting the radial and vertical wind components. Moreover, even the pressure observation-based $R_{max,s}$ and B_s were employed in the present wind field model, some inevitable errors on the estimations of wind speed would be introduced due to the simplification and linearization of the Navier-Stokes equations as discussed by Kepert and Wang (2001).

The other method is the use of wind speed observations. Vickery et al. (2008) used a boundary layer model to match the H* Wind surface wind field. The Holland pressure model, say Eq. (1) was also directly applied to Eq. (2) for calculating the gradient wind speed before converting to surface level. In fact, if Holland pressure model is considered to be valid at gradient level and substituted into Eq. (2), it is acceptable and self-consistent. That means R_{max} and B are estimated from gradient wind. And real wind field at gradient or surface level can be well captured although the real pressure field has a large deviation from Holland's model. The only problem is how to predetermine a gradient height since it is a variable and generally believed to increase from the storm center to peripheral area.

Comparatively, the wind field model adopted in present study uses the surface level say 10 m above the ground as a standard height. The surface pressure was converted to gradient layer using a height-resolving pressure model (Fang et al., 2018a):

$$P_{rz} = \left\{P_{cs} + \Delta P_s \cdot exp\left[-\left(\frac{R_{max,s}}{r}\right)^{B_s}\right]\right\} \cdot \left(1 - \frac{gkz}{R_d\theta_v}\right)^{\frac{1}{k}} \tag{3}$$

Then, an analytical boundary layer wind field model was utilized to calculate the surface wind speed (Fang et al., 2018a). The maximum gradient wind speed is considered to be positively correlated with the central pressure difference and B_s. To fit a specific real wind speed, a higher value of B_s is required due to the decrease of central pressure difference from the surface to gradient layer when compared to no consideration of height-resolving characteristics of pressure field. Moreover, the analytical boundary layer model disregards some nonlinear terms and neglects the non-axisymmetric effects (Fang et al., 2018a), a larger B_s is usually fitted to compensate for the deficiency of the model.

It is noteworthy that the surface pressures modeled by Eq. (1) using the fitting pair of $R_{max,s}$ and B_s in this study could have a remarkable difference from the real pressures, but the modeled wind field is forced to match the observations (wind speed information in best track dataset) as closely as possible to increase the accuracy of wind hazards estimation. More details regarding the extraction of $R_{max,s}$ and B_s used in this study have been discussed in another study and in review (Zhao et al., 2020).

As stated in Line 90, the surface wind speed information is provided, say at height of 10 m. The height-resolving TC boundary layer wind field model employed in this study allows to reproduce the wind field at any given height. So $R_{max,s}$ and B_s were all fitted at a height of 10 m.

Reference

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Willoughby H E , Rahn M E . Parametric Representation of the Primary Hurricane Vortex. Part Ⅰ: Observations and Evaluation of the Holland (1980) Model[J]. Monthly Weather Review, 2004, 132(12):p.3033-3048.

Zhao L , Lu A , Zhu L , et al. Radial pressure profile of typhoon field near ground surface observed by distributed meteorologic stations[J]. Journal of Wind Engineering and Industrial Aerodynamics, 2013, 122:105-112.

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3. Comment: Why do the authors choose a height-resolving TC wind field model rather than others, e.g., a slab model, in this study? To match it with the best-track data which account for a height beyond near ground range? Please clarify.

Response: Thanks for your comment. JMA best track dataset provides the surface wind speed information (at height of 10 m). To fit the $R_{max,s}$ and B_s, the TC boundary layer wind field model should be able to reproduce the surface wind field. The height-resolving boundary layer wind field model developed by Meng et al. (1995) and enhanced by Fang et al. (2018a) is adopted in this study. The slab model usually defines the gradient height as a constant value. The surface wind speed is estimated by an empirically based reduction relationship between the gradient and the near ground wind velocity. The accuracy of the slab model, especially for simulating the typhoon boundary layer, is not well-behaved because it relies heavily on modification from observation data and empirical analysis. Furthermore, the spatial velocity distribution in the typhoon boundary layer and the terrain effects are ignored to some extent. Comparatively, the height-resolving wind field model is an improved method for directly solving the Navier-Stokes equation and is based on several simplified semi-analytical algorithms. The features of the wind field can be described approximately and the terrain types, treated as roughness-related parameters, are included in the updated wind field model.

As stated in Line 183, $R_{max,s}$ and B_s were fitted at surface level.

"A height-resolving TC boundary layer model developed by Meng et al. (1995) and enhanced by Fang et al. (2018a) is adopted in this study. It is also used to extract two typical TC wind field parameters: radius to maximum wind speed ($R_{max,s}$) and radial pressure profile shape parameter (B_s) at surface level."

Reference

Meng, Y., Matsui, M., Hibi, K.: An analytical model for simulation of the wind field in a typhoon boundary layer, Journal of Wind Engineering and Industrial Aerodynamics, 56, 291-310, 1995.

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4. Comment: Another comment is about the gradient height. It is assumed in this study that the gradient height is equal to 500 m. However, observational results show that TC depth tends to deepen when TCs get close to coastal areas. Will the inaccuracy of TC depth influence the estimation results? If so, to what an extent?

Response: We really appreciate you for pointing out this. We assumed the gradient height of 500 m only when we roughly converted the design wind speed suggested by Hong Kong Code (2004) to the wind speed associated with the reference exposure used in this study (z_0 = 0.05) for comparison purpose. As mentioned, observations show that the gradient height tends to increase when TCs get close to coastal areas. The height resolving boundary layer wind field model can reproduce the inner boundary layer of a TC at a given surface roughness length. For example, as shown in Fig.1, the vertical wind speed profiles of a synthetic TC are compared with that observed by dropsonde data (Giammanco et al., 2013). It can be noted that the wind field model well reproduces the vertical profiles. To predict the wind hazard curves at a specific site, a reference surface roughness length, say z_0 = 0.05 is employed. This is consistent with Chinese code. Moreover, the TC surface wind field can also be reproduced if the location-specific surface roughnesses are applied as studied by Fang et al. (2019) and Zhao et al. (2020). Fig. 2 shows an example of reproduced surface wind field of typhoon Rammasun at 06:00 UTC, 07/18, 2014 studied by Zhao et al. (2020).

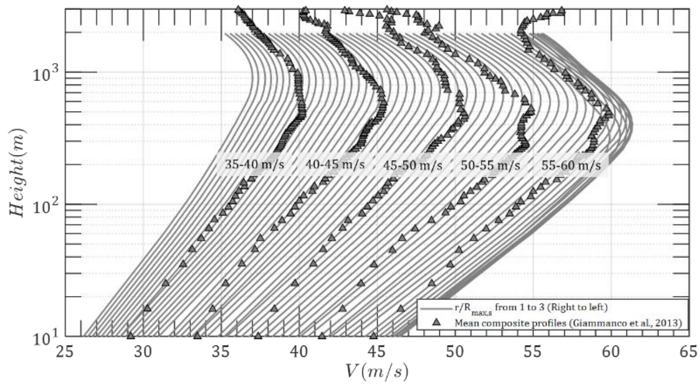

Fig. 1 Comparison of vertical profiles between a synthetic TC and observations

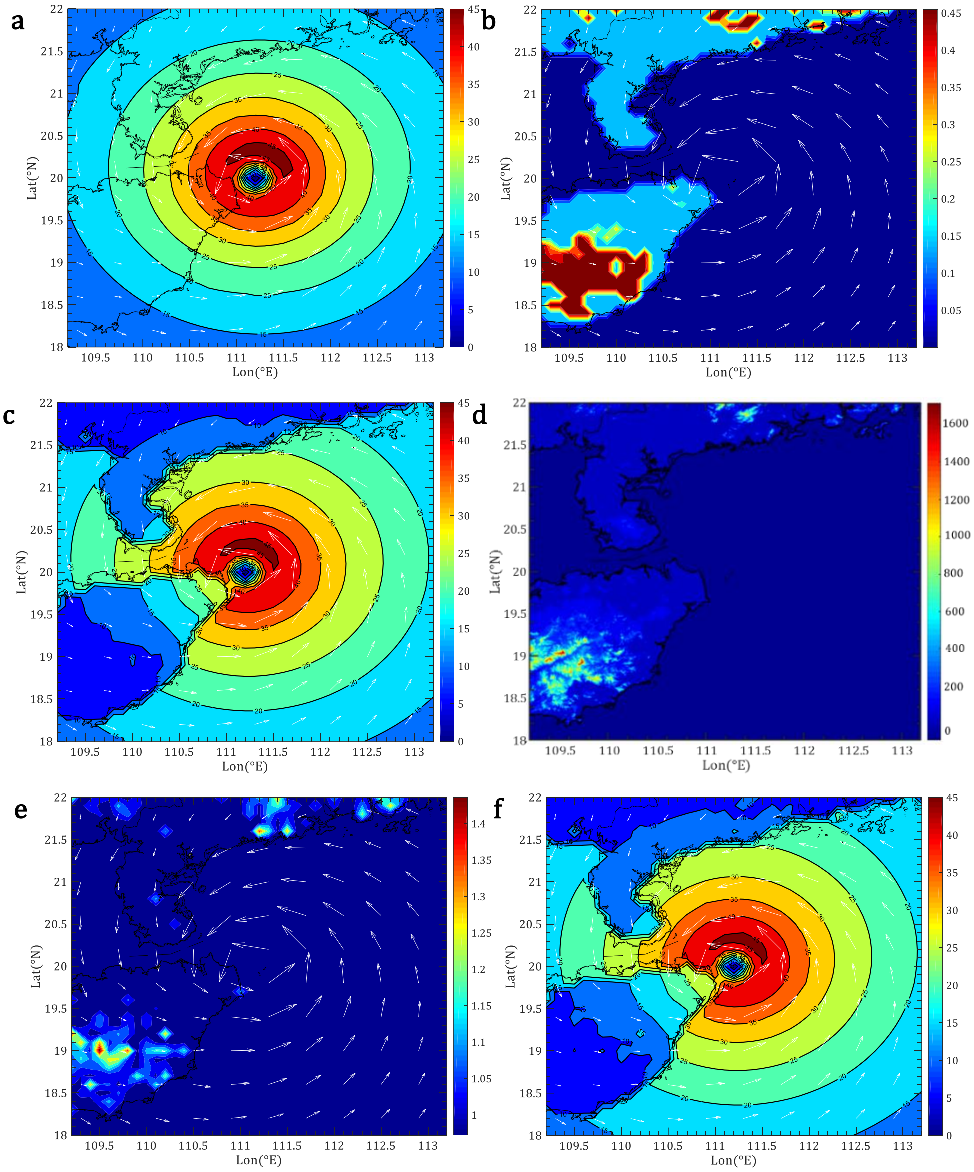

Fig. 2 Wind field of strong typhoon Rammasun at 06:00 UTC, 07/18, 2014 (10 m): a) Wind field with a uniform z_0 (m/s); b) Directional z_0 (m); c) Wind field with directional z_0 (m/s); d) Elevation map (m); e) Directional K_t; f) Wind field with directional z_0 and K_t (m/s);

Reference

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5. Comment: Some minor comments: 1) Line 21: under TC climates climate; 2) Lines 225-226: The critical value of K-S test (n = 161) is 0.1059 at a 5% significance level larger than the test statistics…

Response: Thanks for your careful reading and comments. The correction has been made. And similar typos have been carefully checked and revised.