

Influence of Different Historical Best Track Databases on the Assessed Typhoon Wind Hazard for the Coastal Region of Mainland China

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ABSTRACT: Historical best track databases (HBTDs) are used as the basis for developing the tropical cyclone (TC) track model. Different HBTDs may not be consistent and may report different TC parameters. The impact of such inconsistency on the developed TC track model and the estimated TC wind hazard is not entirely clear. In the present study, we developed TC track models for TC events originating from the western North Pacific (WNP) basin by using each of the three HBTDs from the China Meteorological Administration, the Joint Typhoon Warning Center, and International Best Track Archive for Climate Stewardship. The model developed is based on the beta-advection modelling approach. The developed TC track models are then employed to assess the TC wind hazard for sites in the coastal regions in mainland China. A quantitative comparison of the estimated T -year return period value of the annual maximum TC wind speed, v_{A-T} , is presented using the developed track models. It is shown that v_{A-T} obtained based on the TC model developed based on different HBTDs can differ as much as 6% for T equal to 50 and 100 years. This translates to a difference of about 12% in wind load for engineered structures and infrastructure systems subjected to TC wind loading.

1. INTRODUCTION

Tropical cyclones (TCs) (also known as typhoons in China) are characterized by strong winds, heavy waves, and severe storm surges. TC has caused thousands of lives and tremendous economic loss for coastal regions in mainland China (Liu et al. 2009; Peng et al. 2019). Several studies were focused on the development of TC tracks and wind field models and the evaluation of TC wind hazards. The studies that were focused on mapping TC wind hazards for mainland China include those given by Ou et al. (2002), Xiao et al. (2011), Li and Hong (2016), and Hong et al. (2016). In earlier studies, Ou et al. (2002), Xiao et al. (2011), and Hong et al. (2016) used segments of TC tracks (i.e., circular subregion method (CSM)) to assess the TC wind hazard. Such an approach requires sufficient historical samples

near the site of interest to develop the site-dependent model. Unfortunately, historical TC track samples near a site of interest may be scarce. Consequently, the full-track approach was employed by Vickery et al. (2000a) for assessing the hurricane hazard in the United States. Such an approach was considered by several studies, including Li and Hong (2016), for assessing TC wind hazards of mainland China.

There are at least two approaches to developing the TC track models: the autoregressive (AR) type of model and a physical-based model - beta-advection model (β A-model). For example, by considering the TC events affecting mainland China, Li and Hong (2016) and Shen and Wei (2021) developed AR type of model, and Chen and Duan (2018), Hong and Li (2021), and Sheng and Hong (2022) developed

β A-model. In all cases, the model development relies on and was verified using a historical best track database (HBTD).

There are several HBTDs available for TCs originating from the western North Pacific (WNP) basin. The available HBTDs include those from the China Meteorological Administration (CMA), the Joint Typhoon Warning Center (JTWC), the Japan Meteorological Agency (JMA), Hong Kong Observatory (HKO), and the International Best Track Archive for Climate Stewardship (IBTrACS). There are differences between the HBTDs (Song et al. 2010). Sheng and Hong (2022) investigated the influence of using two HBTDs (one from CMA and the other from JTWC) on the estimated wind hazards.

The main purpose of this study is to extend the study given by Sheng and Hong (2022) by considering an additional HBTD, namely, the HBTD from IBTrACS, for developing the TC track model and by evaluating the influence of using different HBTDs on the typhoon wind hazard for the coastal region of mainland China.

2. DESCRIPTION OF CONSIDERED HBTDs AND COMPARISON

2.1. Considered HBTDs

Two HBTDs considered by Sheng and Hong (2022) for the TC track modelling for TC affecting mainland China are the HBTDs from CMA and JTWC. The first one can be accessed at <http://tcdata.typhoon.org.cn/tcsize.html> (Ying et al. 2014) and the second one can be accessed at <https://www.metoc.navy.mil/jtwc/jtwc.html> (Chu et al. 2002). These databases provide TC center coordinate (i.e., latitude and longitude), maximum sustained wind speed (MSWS), and minimum central pressure with a sampling interval of six hours. Another HBTD, IBTrACS, which is given by NOAA/National Climatic Data Center, can be accessed at <https://www.ncei.noaa.gov/products/international-best-track-archive> (Knapp et al. 2010). According to the authors, this HBTD combined existing HBTDs given by various agencies around the world, indicating that HBTD from IBTrACS is not independent of that

provided by JTWC and CMA. The essential characteristics of the mentioned HBTDs are summarized in Table 1. The table shows that the HBTD from IBTrACS covers the longest period of the historical TC catalog. The time used to evaluate the temporal-averaged wind speed in these three HBTDs ranges from 1 to 10 minutes. The position-related TC data in the HBTD from IBTrACS is obtained by interpolating from the original 6-h data. In the present study, the TC tracks identified as “main” in the HBTD from IBTrACS for the period from 1949 to 2018, and TC records with a sampling time interval of 6 -h (i.e., 0000, 0600, 1200, and 1800 at the standard UTC), are used for the TC track modelling.

The TC tracks according to the three considered HBTDs are shown in Figure 1. It is shown that they have a similar spatial pattern. However, there are differences. The most noticeable differences from the plots are the patterns of the tracks with a latitude greater than 45°N. Through visual inspection, the similarity between the tracks reported in the HBTDs from IBTrACS and from CMA is more apparent than that between the tracks reported in the HBTDs from IBTrACS and JTWC.

Table 1: Summary of TC characteristics from various HBTDs for WNP.

HBTDs	Averaging period for MSWS	Minimum Central Pressure	Temporal resolution	Data span
CMA	2-min (m/s)	After 1949	6-h	1949 now
JTWC	1-min (knots)	After 2000	6-h	1945 now
IBTrACS	10-min (knots)	After 1951	3-h*	1884 now

* The storm center was reported with a sampling interval of 3 hours based on interpolated results; however, MSWS and central pressure were not interpolated as IBTrACS uses the official information from the World Meteorological Organization (WMO).

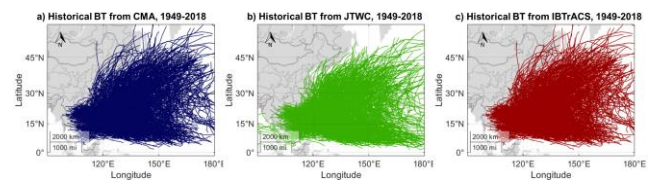


Figure 1: TC tracks from three HBTDs over 1949-2018: a) CMA, b) JTWC, c) IBTrACS.

2.2. Comparison of statistics of the HBTDs

2.2.1. Genesis location, occurrence rate modelling, and translation velocity

The genesis of the TC events is extracted from each HBTD and shown in Figure 2a, indicating that the locations of the TC genesis differ for different HBTDs. Figure 2b presents the number of TC events per year according to each HBTD, indicating that in most years, the number of TCs reported in the HBTDs from IBTrCS and from CMA is greater than that from JTWC. This is especially the case for years before the 1980s. However, in a few years, the number of TC events reported in the HBTD from CMA is much less than that from the remaining two. The statistical characterization (i.e., Mean and Standard deviation (STD)) of the number of TC events per year is given in Table 2. The average number of events per year is about 30.1 by using the HBTD from JTWC, 32.2 by using the HBTD from CMA, and 35.1 by using the HBTD from IBTrACS.

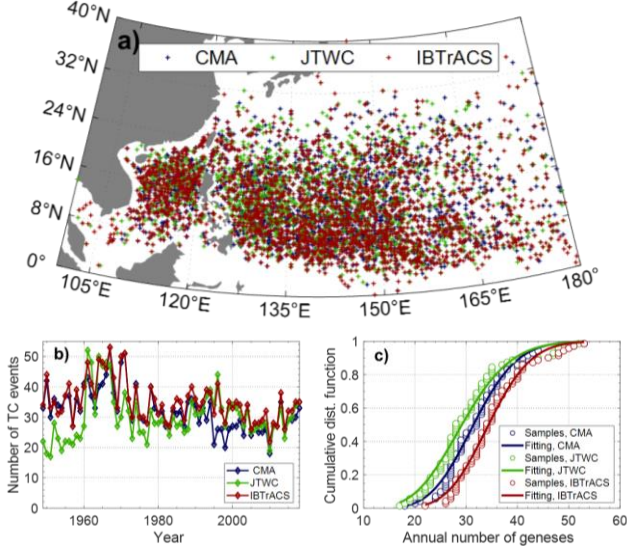


Figure 2: Locations of the TC geneses, number of TCs per year, and distribution of the number of events per year for three considered HBTDs: a) locations of the TC geneses; b) comparison of the number of TC events per year; c) probability distribution of the number of TC events per year.

The empirical cumulative distribution function (CDF) of the annual number of TC events is presented in Figure 2c, and could be

modelled using the negative binomial distribution, $p_X(x)$,

$$p_X(x) = \binom{x+r-1}{x} (1-p)^x p^r \quad (1)$$

where x is the value of X representing the number of events per year, and (r, p) are the model parameters that can be obtained through the distribution fitting. The obtained values of (r, p) are shown in Table 2. Figure 2c indicates that the fitted negative binomial distribution mimics well the empirical CDF.

Table 2: Statistics and model parameters of the number of TC events per year for the considered HBTDs.

HBTDs	Mean	STD	(r, p) (see Eq. (1))
CMA	32.2	6.76	(75.70, 0.70)
JTWC	30.1	5.72	(35.02, 0.54)
IBTrACS	35.1	9.13	(169.41, 0.83)

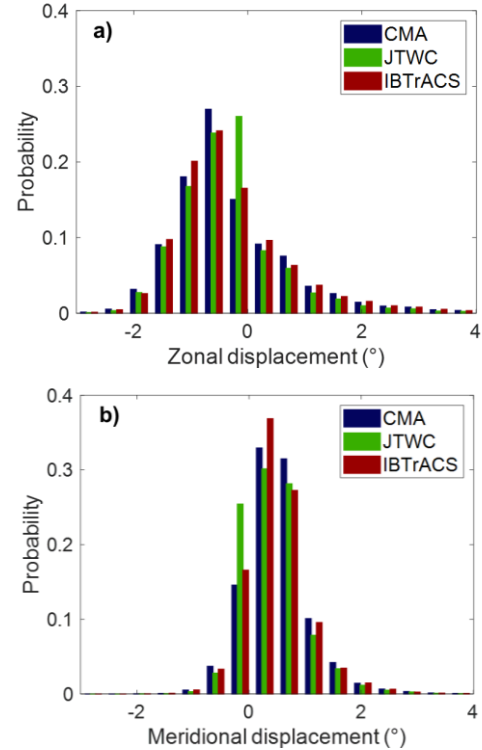


Figure 3: Histogram of the displacement of TC center per 6-h for tracks from the considered HBTDs: a) zonal displacement and b) meridional displacement.

The TC displacement for every six hours is extracted from the databases for the track segments within (5°- 40°)N – (110°-170°)E. The

histograms of displacement in two directions are shown in Figures 3a and 3b, respectively. It shows that the displacements in both directions by using the HBTDs from CMA and IBTrACS are relatively consistent. This is not the case when compared to those using the HBTD from JTWC.

2.2.2. Statistics of parameters of the TC tracks along the coastline of mainland China

To facilitate the presentation of the results, the kilometer posts (KPs) defined along the coastline of mainland China shown in Figure 4a are adopted. The TC parameters are extracted from the considered HBTD for tracks within a 250 km radius centered at the KP of interest. The statistics of the annual occurrence rate of TC events that make landfall within 250 km of the KP of interest, TC translation direction, and TC translation velocity are shown in Figures 4b to 4d.

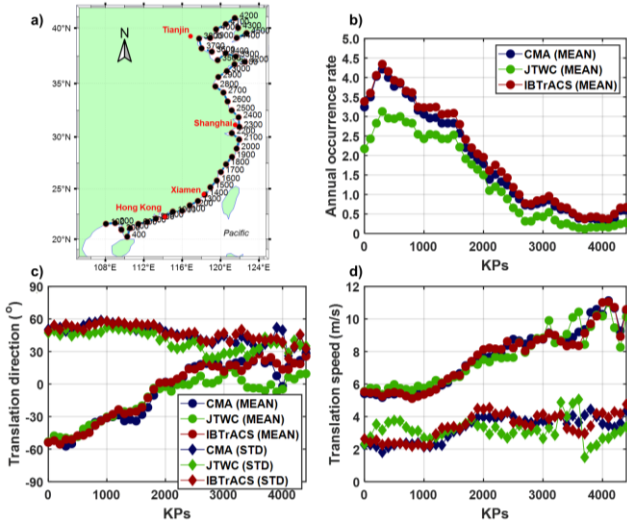


Figure 4: Definition of kilometer posts (KPs) along the coastline of mainland China and the statistics of the TC track parameters for the landfalling TC events: a) defined KPs, b) annual occurrence rate within a 250 km radius, c) Mean and STD of TC translation direction, and d) Mean and STD of TC translation velocity.

In general, the statistics obtained based on the information in the considered HBTDs are comparable, especially for TC translation direction and speed. The results of using the HBTD from CMA agree well with those of using the HBTD from IBTrACS. The calculated annual

occurrence rate of landfalling TC events within a 250 km radius by using the HBTD from CMA agrees well with that by using the HBTD from IBTrACS; the estimated rate by using the HBTD from CMA and by using the HBTD from IBTrACS is consistently larger than that estimated by using the HBTD from JTWC. The most apparent difference occurs at KP 400 with a discrepancy of about 40%. The translation direction and speed from three HBTDs are more comparable for KPs located in a latitude less than 30°N as compared to those for a latitude greater than about 30°N. This may be attributed to that the sample size of TC tracks is relatively small in high-latitude regions.

3. CHARACTERISTICS OF BA-MODEL USING VARIOUS HBTDs

The characteristics of the β A-model developed based on the HBTD from IBTrACS are presented in this section. The use of the β A-model could be advantageous in some applications because it can be used to simulate TC tracks using large-scale environmental wind data, which can be obtained for historical events from the reanalysis data as well as for future climate scenarios from the projected climate data. For the development, the procedure employed by Sheng and Hong (2022) to develop such a model based on the HBTD from CMA and the HBTD from JTWC is followed. In developing the model, the vector of the displacement of the TC center, \mathbf{V}_{TC} , is considered to be represented by the summation of two velocity components,

$$\mathbf{V}_{TC} = \mathbf{V}_{steering} + \mathbf{V}_{\beta} \quad (2)$$

where $\mathbf{V}_{steering}$ represents the steering velocity and \mathbf{V}_{β} is a correction term known as the beta drift (Marks 1992), which is primarily affected by the advection of the storm circulation with the large-scale environmental flows.

$\mathbf{V}_{steering}$ is estimated using the pressure-weighted vertically-averaged wind speed on a circle with a radius of 5° centered at the storm center, which is given by (Carr and Elsberry

1990),

$$\mathbf{V}_{steering} = \frac{1}{P_u - P_l} \int_{P_l}^{P_u} \mathbf{v}_{GW} dp \quad (3)$$

where \mathbf{v}_{GW} is the global wind field, and p_u and p_l are the considered upper and lower pressure layers. p_u and p_l are taken equal to 850 and 300 hPa, respectively. \mathbf{v}_{GW} at various pressure layers are obtained from the re-analysis data provided by the National Centers for Environmental Prediction (NCEP)-National Center for Atmospheric Research (NCAR) with a resolution of $2.5^\circ \times 2.5^\circ$ (<https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.derived.pressure.html>) (Kalnay et al. 1996).

Based on the information in the HBTD and reanalysis data, \mathbf{V}_β can be evaluated by subtracting $\mathbf{V}_{steering}$ from \mathbf{V}_{TC} (see Eq. (2)). That is, for each track point, \mathbf{V}_{TC} can be estimated from an HBTD and $\mathbf{V}_{steering}$ can be calculated by using Eq. (3) using the reanalysis data. The obtained samples of \mathbf{V}_β for easterly and westerly tracks are then binned into a grid system with $5^\circ \times 5^\circ$ cells covering the WNP. Figure 5 shows the mean of the \mathbf{V}_β values obtained using the HBTD from IBTrACS for cells with at least 30 samples. Compared to the spatial pattern of \mathbf{V}_β obtained using the HBTDs from CMA and JTWC (Sheng and Hong 2022), the results by using the HBTD from IBTrACS are more comparable to that obtained by using the HBTD from CMA. The mean of amplitude and direction are 3.0 m/s and 316.6° (clockwise from the true north is defined as positive), respectively, which are very close to that obtained using the HBTD from CMA (i.e., 2.99 m/s and 317.4° , respectively). In addition, a distribution fitting for the residuals of amplitude and direction of \mathbf{V}_β for cells with at least 30 samples is carried out. In such a case, the fitting exercise indicates that the Jonshon S_B distribution for the amplitude and the bimodal distribution (i.e., a mixture of two normal distributions) for the direction could be adequate. For cells without enough samples, TC track information from

neighboring cells is borrowed for assessing the probability distributions of the amplitude and direction.

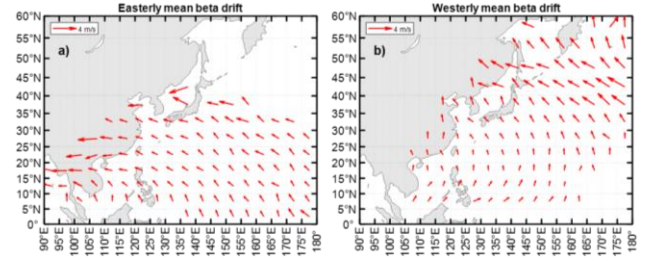


Figure 5: Variation of the mean of \mathbf{V}_β obtained by using the HBTD from IBTrACS: a) easterly and b) westerly tracks.

4. COMPARISON OF PERFORMANCE OF THE SIMULATED TRACKS AND THE ESTIMATED WIND HAZARDS

4.1. Comparison of statistics of simulated tracks

To validate the developed βA -model in the present study, tracks are simulated by using the developed model and the reanalysis dataset obtained from NCEP-NCAR. However, before using the reanalysis data, the effect of TC (vortex) on the global wind field needs to be removed with the resulting wind field known as the environmental wind field that will be used to calculate $\mathbf{V}_{steering}$ (see Kurihara et al. 1995; Sheng and Hong 2022). The simulation of the TC intensity which is required to define the TC central pressure is carried out using the equation shown in Vickery et al. (2000a) (see also Li and Hong 2016; Sheng and Hong 2022).

For a given number of years of TC activity to be considered, the steps utilized to simulate the TC tracks for each of the considered years are: 1) generate the number of TC events using negative binomial distribution for each year; 2) sample the genesis from HBTC for each TC event; 3) Sample the track with a sampling interval of 6 hours by using developed track model and sample the TC intensity (Li and Hong 2016); 4) if the TC event makes landfall, use the filling-rate model to obtain Δp until the lysis.

A total of 10000 years of TC activity is simulated. The obtained statistics of some of the

key TC parameters are shown in Figure 6. It can be observed that, in general, the statistics of the simulated tracks are in good agreement with those obtained by directly using the HBTd from BTrACS. Additionally, the statistics of TC parameters obtained by directly using the HBTds from CMA and JTWC are compared with those obtained from TC tracks that are simulated using the β A-models developed based on the corresponding HBTds (Sheng and Hong 2022). Results indicate that the statistics of the simulated track are in good agreement with those obtained by directly using the corresponding HBTd. In general, the difference between the statistics associated with the HBTds from CMA and IBTrACS is small. Note that in Figure 6d, as central pressure information in the HBTd from JTWC is relatively few, it is not shown.

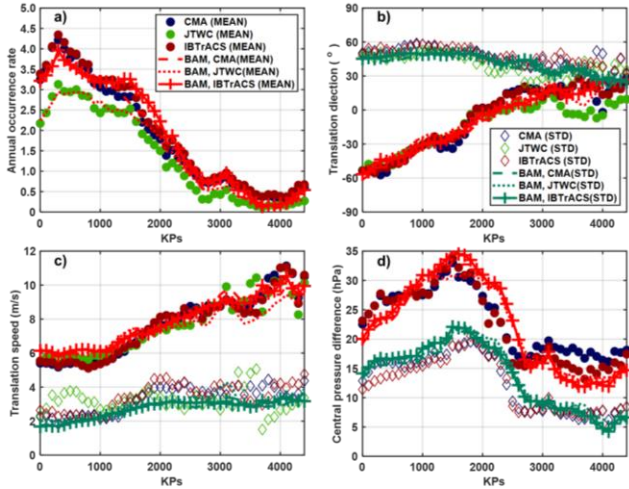


Figure 6: Comparison of statistics of the key TC parameters of landfalling TCs: a) annual occurrence rate, b) heading, c) translation velocity, and d) central pressure difference. Note that the data for simulated tracks using β A-model developed based on HBTds from CMA and JTWC are those given in Sheng and Hong (2022).

4.2. Comparison of the estimated wind hazards for nine coastal cities of mainland China

This section provides a comparison of the estimated typhoon wind hazard for a few selected sites. To evaluate the TC wind, the slab model given by Vickery et al. (2000b) (see also Li and Hong 2015) is employed. The wind hazard assessment is carried out following the same

procedure as that used in Li and Hong (2016) but with different track models, and the radius to maximum wind speed, R_{max} , and Holland B parameters, which are required for evaluating the wind field, are evaluated using the empirical equations developed by Vickery and Wadhera (2008) and Vickery et al. (2009)

The calculated mean and coefficient of variation (COV) of the annual maximum 10-min wind speed at 10-m height above the ground surface (for roughness with $z_0 = 0.05$ m), V_A , are presented in Table 3 for nine selected sites. To compare the estimated mean or COV of V_A by using different TC track models, the ratio of the mean (or COV) of V_A obtained by using the track developed based on the HBTd from IBTrACS to that obtained by using the track developed based on the HBTd from CMA, denoted as $R_{I/C}$, is calculated. Similarly, the ratio of the mean (or COV) of V_A obtained by using the track developed based on the HBTd from IBTrACS to that obtained by using the track developed based on the HBTd from JTWC, denoted as $R_{I/J}$, is calculated. The calculated $R_{I/C}$ and $R_{I/J}$ are also shown in Table 3, indicating that the maximum absolute difference of V_A is less than about 16% for the mean value and 15% for the COV.

Table 3: Mean and COV of V_A for selected sites along the southeast coastline of China using three HBTds.

Cities	β A-model based on IBTrACS		$R_{I/C}$		$R_{I/J}$	
	Mean	COV	Mean	COV	Mean	COV
Shanghai	12.8	0.74	1.09	0.92	1.10	0.87
Ningbo	14.3	0.64	1.04	0.98	1.06	0.86
Wenzhou	17.1	0.56	1.04	0.91	1.14	0.85
Fuzhou	17.4	0.53	1.12	0.91	1.16	0.83
Xiamen	18.3	0.53	1.08	0.97	1.13	0.87
Guangzhou	14.9	0.53	1.03	1.01	1.13	0.86
Shenzhen	18.6	0.51	1.03	1.01	1.14	0.87
Hong Kong	19.1	0.49	1.03	1.01	1.13	0.88
Zhanjiang	18.3	0.50	0.99	1.01	1.13	0.86

Figure 7 shows the comparison of the probability distribution of V_A . It shows that the results by using the track developed based on the HBTd from IBTrACS are in good agreement with

those by using the track models developed based on the HBTD from CMA or JTWC.

A similar comparison as that shown in Table 3 is carried out but for the T -year return period value of V_A , v_{A-T} . The results for $T = 50$ and 100 are presented in Table 4. The table again shows that the TC wind hazard is geographically varying, which is consistent with that observed in Li and Hong (2016) and Sheng and Hong (2022). The calculated ratios $R_{I/C}$ and $R_{I/J}$ but based on v_{A-T} instead of based on mean or COV is also shown in Table 4. The value of $R_{I/C}$ ranges from 0.99 to 1.06 for $T = 50$ and from 1.00 to 1.05 for $T = 100$. The value of $R_{I/J}$ ranges from 0.99 to 1.05 for $T = 50$ and from 0.97 to 1.05 for $T = 100$. This indicates that the differences are within 6%.

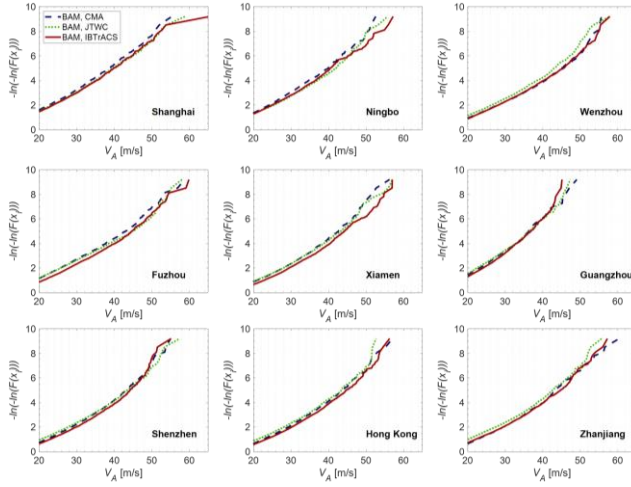


Figure 7: Comparison of probability distributions of V_A using TC track models developed based on three different HBTDs.

Table 4: Comparison of estimated v_{A-50} and v_{A-100} using track models developed based on different HBTDs.

Cities	V_{A-50}			V_{A-100}		
	IBTrACS	$R_{I/C-50}$	$R_{I/J-50}$	IBTrACS	$R_{I/C-100}$	$R_{I/J-100}$
Shanghai	34.7	1.05	1.01	37.9	1.04	1.00
Ningbo	36.1	1.05	0.99	39.1	1.03	0.97
Wenzhou	39.6	0.99	1.05	43.6	1.01	1.05
Fuzhou	39.4	1.06	1.03	43.2	1.05	1.01
Xiamen	40.0	1.06	1.05	42.5	1.04	1.03
Guangzhou	32.5	1.00	1.01	35.3	1.00	1.01
Shenzhen	40.0	1.03	1.03	43.0	1.04	1.03
Hong Kong	40.0	1.02	1.04	43.2	1.02	1.04
Zhanjiang	39.8	1.00	1.04	42.9	1.02	1.04

5. CONCLUSIONS

There are several historical best track databases (HBTDs) available for the western North Pacific (WNP) basin. These datasets have been extensively used for developing the TC track models and for typhoon wind hazard assessment. However, the TC track information from different HBTDs is not entirely consistent. The consequence of this discrepancy in the estimated wind hazards is investigated in the present study by comparing the results using the TC track models developed based on HBTDs from IBTrACS, CMA, and JTWC.

The analysis indicates that the TC annual occurrence rate estimated based on HBTDs from CMA, JTWC, and IBTrACS are on average 32.2, 30.1, and 35.1, respectively. The statistical characteristics of several important TC parameters for the landfalling TCs affecting mainland China obtained from three HBTDs are illustrated and compared. Results show that the statistics of TC tracks estimated based on the HBTDs from CMA and IBTrACS datasets agree well. Differences in the annual occurrence rate for the landfalling TC events are observed for locations near the coastline for some areas; the observed difference is as high as 40% by considering the HBTDs from IBTrACS and JTWC.

The beta advection models (β A-models) developed based on three HBTDs are used to simulate TC tracks. A comparison of the statistics of the simulated TC tracks and those estimated directly from the databases indicates that the model reflects well the corresponding database. The assessment of the TC wind hazard for nine major coastal cities of mainland China is carried out using the β A-models. The analysis results indicate that the difference between the estimated T -year return period values of the annual maximum TC wind speed can be up to 6% for $T = 50$ and 100 years (i.e., 12% in wind loading).

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