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DIFFERENCES AMONG DIFFERENT DATABASES IN THE NUMBER OF TROPICAL CYCLONES FORMING OVER THE WESTERN NORTH PACIFIC

WU Sheng-an (吴胜安)[1, 2], KONG Hai-jiang (孔海江)[1], WU hui (吴 慧)[2]

(1. Institute of Atmospheric Physics of CAS, Beijing 100080 China; 2. South China Sea Meteorological Disasters Mitigation Research Key Laboratory/Hainan Climate Center, Haikou 570203 China)

Abstract: As shown in comparisons of the characteristics of inter-annual and inter-decadal variability and periodical changes in the number of tropical cyclones forming over the western North Pacific by three major forecast centers, i.e. China Meteorological Administration (CMA), Regional Specialized Meteorological Center of Tokyo (JMA) and Joint Typhoon Warning Center (JTWC) of Guam, there are the following important points. (1) Climatology of tropical cyclone (TC) or typhoon (TC on the intensity of TS or stronger) shows some difference in tropical cyclone frequency among the centers, which is more notable with TC than with typhoon. Both of them are more at the database of CMA than at those of the other two centers. (2) The difference is too significant to ignore in the inter-annual variability of tropical cyclone frequency between CMA and JTWC, which mainly results from the obvious difference in the inter-annual variability of the number of generated tropical depression (TD) between the two databases. The difference is small in the inter-annual variability of TS formations among all the three databases, and consistence is good between JMA and CMA or JTWC. (3) Though differences are not significant in the periodical variation of TC formations between CMA and JTWC, they are markedly apart in the inter-decadal variability, which is mainly shown by an anti-phase during the 1990s. (4) Non-homogeneity may exist around the late stage of the 1960s in the data of tropical cyclone frequency.

Key words: statistical characters; difference comparison; tropical cyclone frequency; non-homogeneity

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1 INTRODUCTION

There are differences in frequency, strength and path of tropical cyclones over the western North Pacific (WNP) among databases of China Meteorological Administration (CMA), Regional Specialized Meteorological Center of Tokyo (JMA) and Joint Typhoon Warning Center (JTWC) of Guam. Yu et al.[1] compared the tropical cyclone (TC) intensity expressed by the three databases and found that the strength is more or less different and even opposite in a specific moment or interval although the general trend is consistent among the databases. After detailed analysis of the TC intensity in the three data sets for 1988–2003, Yu et al.[2] showed that the difference of the mean strength is significant at the 1% level. Though there are many studies on the homogeneity and method related to climate data[3, 4], the research on the typhoon data encounters great difficulty because of the lack of reference series. As pointed out by Yu et al.[2], there are still few systematic works on the homogeneity of typhoon data, despite that attention has been paid to the discrepancy of the TC intensity data, including a special seminar held in 2001 in order to conduct research for a unified best track (including the strength) database of the WNP typhoons.

However, the objectivity of data directly affects the reliability of researches, as shown in the study on the relationship between the WNP tropical cyclone activity and sea surface temperature (SST). There exists obvious difference among those researches. Yang et al.[5] showed that higher SST leads to more tropical cyclones and tropical cyclones over the WNP increase with global warming. Tian et al.[6, 7] indicated that cold air from

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Biography: WU Sheng-an, Ph.D. candidate, primarily undertaking research on tropical meteorology and climate change.
E-mail for corresponding author: wsa01@sohu.com

the Southern Hemisphere to the WNP weakens with global warming, which leads to fewer tropical cyclones over the WNP. Chu et al.[8] suggested that the correlation between SST and TC frequency is not significant. Research by Chen et al.[9] showed that the subsurface temperature of the WNP warm pool affects the typhoon genesis significantly. Warmer temperature there leads to more typhoons and cooler temperature results in fewer typhoons. However, investigation by Wu et al.[10] showed that the TC number over the WNP tends to increase if the subsurface (100–200 m deep) temperature anomaly of the warm pool is in the positive phase during the summer half year, and vice versa. Obviously, there are differences among those investigations, which is caused by the differences in the stage or area of research on the one hand, and by the typhoon data discrepancy on the other.

Therefore, the research attitude regardless of the data uncertainty is not rigorous and the reliability of results carried out in this manner is also questionable. Though it is difficult to determine the authority of relevant data, we can learn more about the objectivity of the typhoon data and get to understand their difference after comparisons and analysis of different databases and historical consistency of the data themselves. This would help us to choose proper data and assess relative research results cautiously.

The rest of this paper is organized as follows. Section 2 introduces the data and methods. Differences in the climate value of the TC number are given in section 3 and differences in the interannual, interdecadal and periodical change of the tropical cyclones are presented in section 4. Section 5 provides homogeneous analysis on typhoon data and section 6 summarizes the main findings.

2 DATA AND METHODS

The three TC datasets used in this study are respectively from the Tropical Cyclone Year Book published by CMA, Tokyo-Typhoon Center of JMA (http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/best track.html) and JTWC (http://metocph.nmci.navy.mil/jtwc/best_tracks/wpindex.html). All of the datasets have definite calibration for the intensity rank of TC. The rank of tropical storm or stronger cyclones are identified (referred to as TS hereafter) from tropical depressions (referred to as TD hereafter).

Since most researches concerning the TC number were based on its interannual or interdecadal change[11-14], the current study focuses on the differences of those changes among the three datasets. The analysis methods include correlation analysis, wavelet analysis and slide-t detecting method[15].

3 DIFFERENCE IN CLIMATE VALUE OF THE TROPICAL CYCLONE NUMBER

First, the climate value of TC over the WNP was compared. Since JMA TC data do not include TD, comparisons were made only between JTWC and CMA datasets here. No TD data are included in the JTWC dataset before 1961. Table 1 shows the comparison of seasonal and annual TC frequency over the WNP in 1961–2006 between the CMA and JTWC. Except that the minimum values are the same, the mean and maximum values of annual and seasonal TCs are different. There are about 10% more TCs in the CMA dataset than in the JTWC dataset, with three more annual TCs (34 versus 31) and two more in July–September (19 versus 17) when the TC is the most active. The difference is the smallest in October–December.

Differences in the climate value of TS among the three datasets are also compared (see Table 2). TS mean value from 1951 to 2006 in different datasets is 1.1 in January–March, 3.4 to 3.6 in April–June, 14.5 to 15.0 in July–September, and 7.5 to 7.7 in October–December. Compared with Table 1, the differences in TS number between CMA and JTWC datasets are much smaller than those of TC. Difference in TS between JMA and the other two datasets is smaller than that between CMA and JTWC datasets.

Table 1. Comparison of seasonal and annual TC frequency over the WNP in 1961–2006 between the CMA and JTWC datasets

	Mean		Minimum		Maximum		Total		
	CMA	JTWC	CMA	JTWC	CMA	JTWC	CMA	JTWC	DIF/%
Jan.–Mar.	1.5	1.4	0	0	7	5	70	63	**11.1**
Apr.–Jun.	4.8	4.3	0	0	13	10	220	197	**11.6**
Jul.–Sept.	18.7	16.7	10	10	34	26	859	769	**11.7**
Oct.–Dec.	8.9	8.6	4	4	16	15	407	397	2.5
Yearly	33.8	31	21	21	53	44	1556	1426	**9.1**

Table 2. Comparison of seasonal and annual TS frequency over the WNP in 1951–2006 among the CMA, JTWC and JMA datasets

	Minimum			Maximum			Mean		
	CMA	JTWC	JMA	CMA	JTWC	JMA	CMA	JTWC	JMA
Jan.–Mar.	0	0	0	4	5	4	1.1	**1.1**	**1.1**
Apr.–Jun.	0	0	0	9	9	9	3.6	**3.4**	**3.5**
Jul.–Sept.	7	5	8	26	22	25	15.0	**14.5**	**14.5**
Oct.–Dec.	4	4	3	14	13	13	7.7	**7.5**	**7.5**
Yearly	14	17	16	40	39	39	27.4	**26.6**	**26.6**

Summing up, the minimum, maximum and mean (or total) values of TC or TS frequency over the WNP in different season or the whole year show differences among the CMA, JMA and JTWC datasets. The difference of TC number is remarkable, and that of TS number is relatively small, especially between JMA and JTWC datasets. TC and TS frequency in the CMA dataset are relatively large than those in the other two datasets.

4 DIFFERENCE IN INTERANNUAL/INTERDECADAL/ PERIODICAL VARIATION OF TCS

4.1 *Difference in interannual variation*

Figure 1 shows the interannual variation of the TC number in CMA and JTWC datasets from 1961–2006. Obvious difference appears in every year between CMA and JTWC datasets, with the maximum value being 20 in 1970, comparable to the amplitude of the annual variation. However, their discrepancy becomes smaller after the 1970s, which decreases in amplitude to less than 10. According to the principle of correlation analysis, a correlation coefficient is equal to the result of covariance of two series divided by their respective standard deviation. Since the covariance value reflects the synchronic change of two series, the correlation coefficient can represent their synchronic change, i.e. the similarity of the series. The correlation coefficient of the TC number between CMA and JTWC is only 0.586 for 1961–2006 and reduces to 0.411 for 1971–2006, indicative of the obviously inharmonious in the annual variation of the two series. For example, corresponding to the 7 years in the CMA dataset when TCs are above the normal number (greater than standard deviation, $>\delta$), only 5 years with more TCs than normal appear in the JTWC dataset and 1 year with a little more than normal ($>0.5\ \delta$) as well as 1 year with a little less than the normal ($<-0.5\ \delta$). On the other hand, in the 5 years when TCs in the CMA dataset are below normal ($<-\delta$), only 2 years with fewer TCs than normal emerge in the JTWC dataset, and 2 years and 1 year correspond to a little less TCs than normal ($<-0.5\ \delta$) and a little more TCs than normal, respectively.

Figure 2 shows the interannual variation of TSs in the CMA, JMA and JTWC datasets from 1951–2006 as well as their annual difference. As compared to the TC difference, the TS difference significantly decreases between the CMA and JTWC datasets, especially after the late 1960s. Hence, the homogeneity of TS data provided by the three centers is much better than that of TC data, especially after 1968.

Table 3 lists correlation coefficients of the third and fourth seasonal and annual TS number between each two of the three datasets for 1951–2006 or 1968–2006. The correlation coefficients are between 0.83 and 0.97, obviously greater than those of TCs between the CMA and JMA datasets, further confirming the better consistency of TS data relative to TC data among the three datasets. Furthermore, the correlation coefficient of the TS number is relatively high between the CMA and JMA datasets and relatively low between the CMA and JTWC datasets, indicating that the consistency between the JMA dataset and the other two datasets is better than that between the CMA and JTWC datasets.

The aforementioned comparison suggests that the difference of TC between the CMA and JTWC datasets mainly comes from TD. In order to explain it clearly, the authors analyzed the difference of the interannual change of the TD frequency between the two datasets. Figure 3 shows the variation of the TD frequency in the CMA and JTWC datasets and their difference in 1961–2006. Generally, the TD frequency in the CMA dataset is more than that in the JTWC dataset. However, after the 1990s, the TD frequency in the CMA dataset is less with respect to the JTWC dataset. It implies that TDs in the CMA and JTWC datasets experience obviously inconsistent changes. In addition, the amplitude of the difference generally matches that of TD series, suggesting that the difference cannot be ignored. Their correlation coefficient is an insignificant

0.135 for 1961–2006. Therefore, it sufficiently explains that the TC difference between the CMA and JTWC datasets originates from the large difference in TD number.

Briefly, the difference of TCs between the CMA and JTWC datasets, which mainly comes from the great difference in TDs, is too significant to be ignored. The consistency of the TS data among the three datasets is much better. Difference of TS between the JMA dataset and the other two datasets is relatively small.

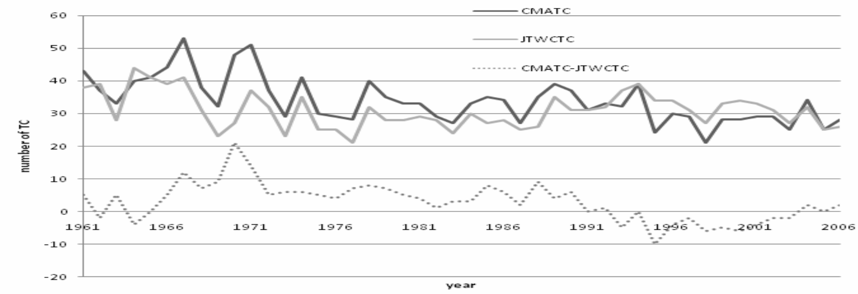

Fig. 1. Variation of the tropical cyclone frequency over the WNP based on the CMA and JTWC datasets and their difference in 1961–2006

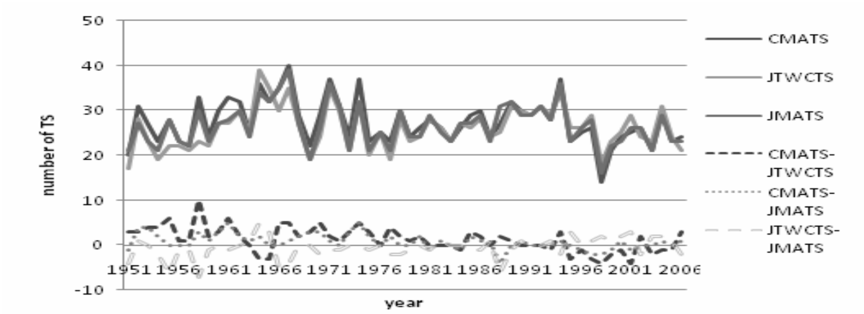

Fig. 2. Variation of the tropical storm and typhoon frequency over the WNP based on the CMA, JMA and JTWC datasets and their difference in 1951–2006

Table 3. Correlation coefficient of the third and fourth seasonal and annual TSs over the WNP between each two of the three datasets

	1951–2006			1968–2006		
	Jul. –Sept.	Oct. –Dec.	yearly	Jul. –Sept.	Oct. –Dec.	yearly
R(CMA, JMA)	**0.937**	**0.957**	**0.940**	0.899	**0.968**	**0.937**
R(CMA, JTWC)	0.887	0.828	0.839	0.878	0.833	0.870
R(JMA, JTWC)	0.896	0.870	0.885	**0.933**	0.860	0.925

The comparison before suggests that the difference of TC between the CMA and JTWC datasets mainly comes from TD. In order to explain it clearly, the difference of the yearly variation of TD frequency is analyzed between the two datasets. Figure 3 shows TD frequency variation with time based on the CMA and JTWC datasets and their difference over the WNP in 1961–2006. The TD frequency in the CMA dataset is generally more than that in the JTWC dataset, but less after 1990, indicating the TDs in CMA and in JTWC change much inconsistently. In addition, the amplitude of the difference generally matches that of TD series itself, suggesting that the difference is too large to ignore. Their correlation coefficient in 1961–2006 is insignificant (0.135). The analysis above explains sufficiently that the difference of TC between the CMA and JTWC datasets comes from the great difference of TD between them.

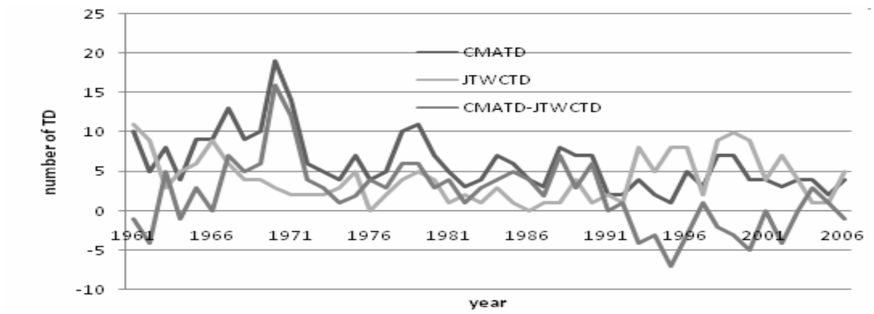

Fig. 3. Variation of the tropical depression frequency over the WNP based on the CMA and JTWC datasets and their difference in 1961–2006.

4.2 *Decadal and periodic variation*

Since the TS data show good consistency in annual variation among the three datasets, their difference in decadal variation will be even smaller. Thus, only the decadal difference of the TCs between the CMA and JTWC datasets will be analyzed. High-frequency variations are removed from the original sequence and the results are shown in Fig. 4. There are prominent differences between the CMA and JTWC datasets on the decadal timescale, whether in July–September or in the whole year. Before the 1990s, although TCs in the two datasets show in-phase decadal variations, the negative phase of TCs in the JTWC dataset occurs earlier and persists longer than that in the CMA dataset. In the 1990s, the decadal variations of TC have opposite phases in the two datasets, with the positive phases in the JTWC dataset and the negative phases in the CMA dataset. Due to this reason, a significant decreasing tendency of the TCs over the WNP was detected in the CMA dataset[9] which cannot be observed in the JTWC dataset. The tendency ratio of TCs from 1961 to 2006 is -0.8/10a in the JTWC dataset, far less than that in the CMA dataset, where the tendency ratio is -3.1/10a. Furthermore, the tendency coefficient is -0.188 (not significant) in the JTWC dataset but -0.617 in the CMA dataset, significant at the 99% level. The differences in the decadal variation of TCs between the two datasets in July-September are similar to those of the whole year. Difference in other seasons such as April–June or October–December is also obvious (figures not shown). Differences in October–December mainly present opposite variations before 1970, in-phase variations during the 1970s and 1980s, and opposite variations again in the 1990s. Differences in April–June mainly occur from the mid 1960s to the late 1970s.

To compare the difference in the periodical variation of TCs between the CMA and JTWC datasets, a wavelet analysis of TC sequences was performed (Fig. 5). Figure 5 presents the real part of the TC frequency over the WNP from the wavelet analysis in July–September or the whole year for 1961–2006 in the CMA and JTWC datasets. The TC frequency during July–September or the whole year has a quasi 32-year period, and their phase and time position are the same. In addition, the quasi 20- and 15-year periods during July–September are also revealed by the two datasets. In short, the periodic variation of TCs has no notable difference between the CMA and JTWC datasets.

In conclusion, though the periodic variation of TCs has no obvious difference between the CMA and JTWC datasets, the difference in decadal variation is significant, mainly by having opposite phases in 1990.

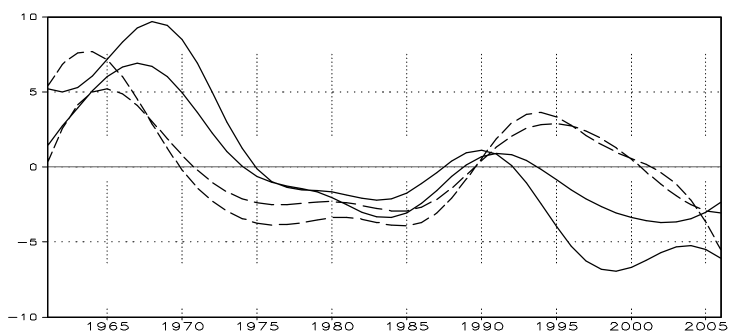

Fig. 4. Low-frequency variation of the TC frequency abnormities over the WNP during July to September or the whole year in 1961-2006 (bold line: CMA dataset, whole year; thick dotted line: JTWC dataset, whole year; thin solid line: CMA dataset , July-September, thin dot line: JTWC dataset, July-September.)

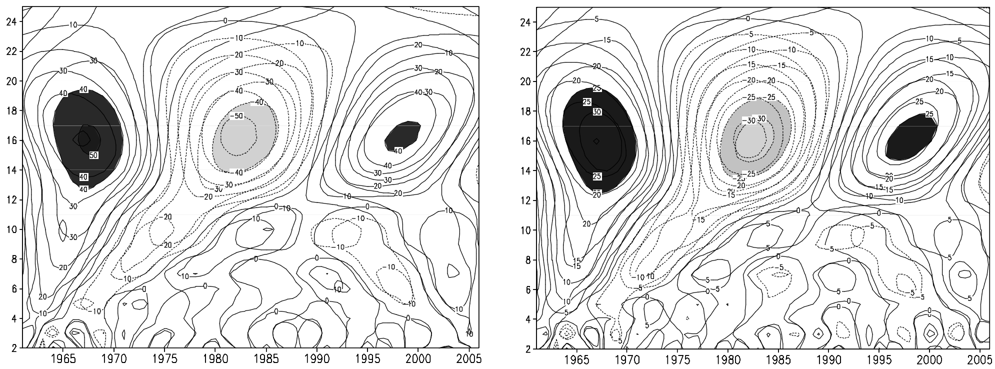

Fig. 5. Real part of wavelet analysis of TC frequency over the WNP in 1961-2006 in the CMA (with shading, thin line) and JTWC (without shading, thick line) datasets (left panel: July-September; right panel: year)

5 HOMOGENEOUTY ANALYSIS

Non-homogeneity in observation data is generated by variations in observation methods. It is the same for the TC data. Though the first satellite was launched in 1960, the satellite could only distinguish large scale cloud clusters, and technologies capable of distinguishing mesoscale structures were not improved until the late 1960s. Thus, there may be difference in typhoon data between the time prior to and that after the late 1960s.

From section 3, the homogeneity of TS is known to be relatively good among the three datasets in 1951–2006. However, the difference is great in the TS frequency among the three datasets before and after 1968. The difference is relatively large before 1968, and is greatly reduced after that. Slide-*t* detecting was applied to the sequences of the annual TS frequency in the CMA, JTWC and JMA datasets, as well as the disparity between each two of them. The same analysis was done for the TS frequency during July–September. Results (Table 4) show that the difference of the TS frequency over the WNP in the whole year or during July–September between the CMA and JTWC datasets is significant at the 95% level. Such difference between the JMA and JTWC datasets is also significant but at the 90% level. The difference of the annual TS frequency between the JMA and CMA datasets is significant at the 95% level, but the counterpart during July–September is not significant at the 90% level. Hence, this may explain that there may exist non-homogeneity in the observed typhoon data with the turning point around 1968. It conforms to the result of Nicholls et al.[16] and Chu et al.[8], which suggested that credible typhoon data begins in 1969/1970. This paper regards 1968 as the turning point just because TS frequency difference is the smallest compared to that in the five adjacent years. Because of the improvements of satellite meteorology year by year, the monitoring of typhoons is getting more and more objective at the typhoon centers, leading to smaller and smaller difference of typhoon data between them. However, before the late 1960s, there were errors in typhoon observations in every typhoon monitoring center and thus the disparity was present. It is worth explaining that there is no significant disparity in the TS frequency sequence in every center.

Summing up, because of the progress of techniques and methods for typhoon monitoring, there is non-homogeneity in TS frequency with the turning point in the late 1960s, and the objectivity of typhoon data is better after 1968.

Table 4. Slide-*t* detecting of TS frequency over the WNP in the CMA, JTWC and JMA datasets between 1951–1967 and 1968–2006

t value	CMA	JTWC	JMA
year	1.6	0.73	1.03
JAS	0.99	-0.22	0.57
t value	CMA-JTWC	CMA-JMA	JTWC-JMA
year	2.96**	2.01**	1.99*
JAS	2.72**	1.2	1.79*

"**" means significant at the 95% level, and "*" means significant at the 90% level. JAS: July, August, September

6 CONCLUSION

By comparing the characteristics of interannual, interdecadal and periodical variations of the TC number over the western North Pacific monitored by three major forecast centers (CMA, JTWC and JMA), the difference of TC data are analyzed in detail, and results are shown as follows:

(1) The minimum, maximum and mean value (or total) value of TC or TS frequency over the WNP in different season or the whole year are different among the CMA, JMA and JTWC datasets. The TC difference is remarkable and TS difference is relatively small, especially between the JMA and

JTWC datasets. The TC and TS frequency in the CMA dataset are more than those in the other two datasets.

(2) The TC difference between the CMA and JTWC datasets is too significant to be ignored. It mainly comes from the great difference of TDs among them. The consistency of TS data among the three datasets is much better. The difference of TSs between the JMA dataset and the other datasets is relatively less.

(3) Though the periodic variation of TCs is not obviously different between the CMA and JTWC datasets, the difference in decadal variation is significant, which is mainly caused by the opposite phases occurring in the 1990s.

(4) There is non-homogeneity in the TS frequency with the turning point in the late 1960s, and the objectivity of typhoon data is better after 1968.

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