Reliability Analysis of Climate Change of Tropical Cyclone Activity over the Western North Pacific

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ABSTRACT

Data homogeneity has become a significant issue in the study of tropical cyclones (TCs) and climate change. In this study, three historical datasets for the western North Pacific TCs from the Joint Typhoon Warning Center (JTWC), Japan Meteorological Agency (JMA), and China Meteorological Administration (CMA) are compared with a focus on TC intensity. Over the past 55 years (1951–2005), significant discrepancies are found among the three datasets, especially between the CMA and JTWC datasets.

The TC intensity in the CMA dataset was evidently overestimated in the 1950s and from the late 1960s to the early 1970s, while it was overestimated after 1988 in the JTWC dataset, especially during 1993–2003. Large discrepancies in TC tracks exist in two periods of 1951–early 1960s and 1988–1990s. Further analysis reveals that the discrepancies are obviously related to the TC observational techniques. Before the era of meteorological satellites (1951–the early 1960s), and after the termination of aircraft reconnaissance (since 1988), large discrepancies exist in both TC intensity and track. That the intensity discrepancy was smallest during the period (1973–87) when aircraft reconnaissance data and the Dvorak technique were both available suggests that availability of the aircraft reconnaissance and the Dvorak method helps in reducing the TC intensity discrepancy. For those TCs that were included in all the three datasets, no significant increasing or decreasing trend was found over the past 50 years. Each of the three TC datasets has individual characteristics that make it difficult to tell which one is the best. For TCs that affect China, the CMA dataset has obvious advantages such as more complete and more accurate information.

1. Introduction

The homogeneity of historical observations is important in the study of tropical cyclones (TCs) and climate change. As pointed out in the summary statement from the WMO Sixth International Workshop on Tropical Cyclones (IWTC-VI) held in San Jose, Costa Rica, in November 2006, a large hurdle for climate change detection is the quality of TC historical databases. The TC databases were populated over time without a focus on maintaining data homogeneity, which is a key requirement for databases that are used to assess possible

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climate-related trends. Thus, the reliability of historical observations has become a ''bottleneck'' in tropical cyclone and climate change studies.

Although it is becoming more widely accepted that there has not been a significant increasing or decreasing trend in global TC frequency during the past half a century, intense disagreement exist as to the climate change in TC intensity, especially since 2005. Regarding the western North Pacific (WNP) basin, three positions can be summarized.

First, TC intensity has been increasing significantly. Using the Joint Typhoon Warning Center (JTWC) dataset, Webster et al. (2005) found that, globally in the six TC basins including the western North Pacific, the numbers of category 4 and 5 hurricanes/typhoons have almost doubled during the past 30 years. The TC Power Dissipation Index (PDI), defined by Emanuel (2005), over the western North Pacific region was increased nearly twofold from the late 1970s to 2003. Moreover, Kamahori et al. (2006) also indicated that the numbers of days with category 4 and 5 typhoons had significantly increased during 1977–2004.

Second, TC intensity has not had a significant increasing or decreasing trend. Also based on the JTWC dataset, Klotzbach (2006) found that no evident trend existed in the frequency of category 4 and 5 TCs in the western North Pacific during 1986–2005. Chan (2006) extended the analysis of Webster et al. (2005) for the western North Pacific basin to earlier years and argued that their trend in that 30-yr period was part of a large interdecadal variation. Landsea et al. (2006) and Knaff and Sampson (2006) have suggested that missing observations and data inhomogeneity issues are so serious in the JTWC dataset, owing to changes in observational techniques, that the TC intensity trends cited by Webster et al. (2005) and Emanuel (2005) are insignificant.

The third view is that TC intensity has been decreasing. This view is based on TC datasets other than the JTWC. Kamahori et al. (2006) showed that the number of days with strong typhoons during 1977–2004 had decreased in the JMA TC dataset. Wu et al. (2006) noted that the datasets from the JMA and Hong Kong Observatory (HKO), Hong Kong, China, indicate a decreasing trend in the numbers of category 4–5 typhoons since the 1970s. Utilizing the China Meteorological Administration (CMA) dataset, Ren et al. (2006) found a decreasing trend in both frequency and intensity of the typhoons affecting China during 1957–2004. Wang et al. (2008) also found a decrease in TC frequency and intensity in the western North Pacific during 1951–2004.

Two factors may be responsible for this controversy regarding climate change trends in TC intensity. The first is the lack of an in-depth comparison of the different historical datasets. The western North Pacific is peculiar for two reasons: (i) it is the only TC basin that has TC activity in all months of the year and (ii) multiple TC datasets exist in this region, which provides an opportunity for comparative analyses. The first and third arguments above are based on different datasets, which may account for the opposite conclusions as to the intensity trends. Therefore, it is important and necessary to conduct a comparative analysis of the different datasets. Kamahori et al. (2006) and Wu et al. (2006) have compared three datasets from JTWC, JMA, and HKO, with an emphasis on TC frequency. Yu et al. (2006) compared the CMA dataset with the JTWC and JMA datasets during 1988–2003 and found some significant intensity differences, but the differences in the frequency of different TC intensity categories were not so significant among these datasets. Lei (2001) compared the TC tracks in the CMA dataset with the JTWC dataset during 1949–90 and found significant differences between the two datasets. Whereas these studies indicate different climate trends in TC activity, the time spans covered in these studies are different, and a more comprehensive analysis is needed.

A second requirement is to assess the reliability of TC datasets. Even though the first and second intensity trend viewpoints were both from the JTWC dataset, two reasons may explain the different conclusions. One reason is possible differences in addressing data quality issues, and the other is differences in research approach, for example, selection of different time periods. The TC data quality issue is closely associated with the evolution in TC observational techniques, and the data homogeneity issue is unavoidable.

This study attempts an in-depth comparison analysis between the three datasets on WNP TCs in terms of TC intensities and tracks and addresses the reliability of the datasets for assessing climate change.

2. Data and analysis methods

a. Data

The three TC datasets used in this study are from CMA, JTWC, and JMA. The CMA dataset (which can be downloaded from the Web site http://www.typhoon.gov.cn/en/data/detail.php?id=38&type=11&style=) includes 6-hourly track and intensity [maximum sustained wind speed (MSWS) and minimum sea level pressure (MSLP)] of western North Pacific TCs since 1949. The TC data for the period 1949–71 were compiled during the period 1970–73. Three principles were followed in this compilation (Y. Fan and Y. Zhu 2007, personal communication): (i) give more attention to the U.S. Air Force aircraft reconnaissance record; (ii) combine all information from different centers; and (iii) emphasize TCs close to China. Since 1972, the TC data have been regularly compiled in the form of a yearbook. A key element of the CMA dataset is that the MSWS is 2-min mean wind speed when a CMA station observation is available.

The JTWC dataset, provided by E. Fukada, includes 6-hourly track and intensity (only MSWS) of every TC case during its life cycle since 1945. A special characteristic of the JTWC dataset is a 1-min mean wind speed.

The JMA dataset (which can be downloaded from the Web site http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/trackarchives.html) also includes 6-hourly track and intensity (MSWS and MSLP) of every TC case during its life cycle since 1951. Note that the MSWS is a 10-min mean wind speed.

The author mainly consulted with C. Guard, former director of the JTWC, K. Takahashi, JMA, and Y. Xu, CMA, on historical changes in observational techniques for TC intensity and position in the western North Pacific. The three main observational techniques in the western North Pacific have been the U.S. Air Force aircraft reconnaissance, which started in 1944 and ended in 1987; meteorological satellites, first launched in 1960 and then widely applied for TC tracking around 1970; and the Dvorak intensity technique, which was first developed in the early 1970s (Dvorak 1975) and quickly became widely used.

b. *Analysis methods*

A preliminary quality control was first conducted with the JTWC, JMA, and CMA datasets that (i) corrected some obvious errors in times, TC numbers, and omitted duplicate records; (ii) checked time consistency in UTC (i.e., 0000, 0600, 1200, and 1800 UTC); and (iii) selected the same period (i.e., 1951–2005) for the three datasets. At each time, two datasets were selected for comparitive analysis for each TC case (Fig. 1). Step one was to determine whether two TCs are "the same TC." If an overlap was found in two TC datasets and at least one such record exists during the overlap period in which the distance between the two TC centers was less than 200 km, then the two TCs are treated as the same TC. The distance less than 200 km was chosen to ensure the maximum number of the same TCs. For the two datasets, all of the same TCs were referred to as the "common TCs," and those unmatched TCs were referred to as the "independent TCs" for a specific dataset.

Step 2 was to carry out a statistical analysis of the differences in the same TCs by calculating the following statistical variables:

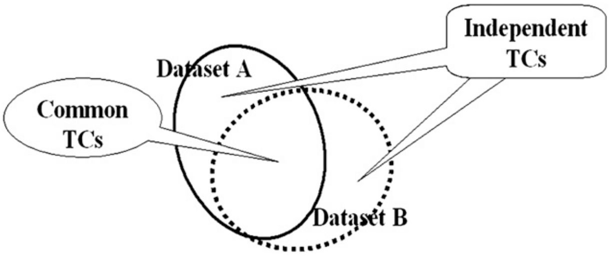

FIG. 1. Sketch of the comparative analysis among the three datasets to determine the common TC, with nonmatched TCs labeled as Independent TCs.

1) Difference in TC location

$$\Delta P = \frac{\pi r}{180}\sqrt{(y_1 - y_2)^2 \cos^2\left[\frac{\pi(x_1 + x_2)}{360}\right] + (x_1 - x_2)^2},$$

where (x_1, y_1) and (x_2, y_2) are the latitudes and longitudes of the centers of the same TC at the same time from the two datasets, r is the earth's radius in kilometers, and ΔP is distance in kilometers.

2) Difference in TC intensity

$$\Delta I = I_1 - I_2,$$

where I_1 and I_2 are the original intensities (MSWS) of the same TC at the same moment from the two datasets in meters per second.

Additional statistics include: (i) absolute intensity difference $|\Delta I|$, (ii) accumulated in time absolute intensity difference, and (iii) accumulated in time location difference. Then the least squares method was used to calculate the linear trend of time series, and the significance of the trend was tested for the significance of its correlation coefficient (r). For TC category statistics, the Saffir–Simpson scale was applied.

3. Basic characteristics of TC frequencies and intensities in the three datasets

During 1951–2005, the total numbers of TCs in the CMA, JTWC, and JMA datasets were 1868, 1648, and 1468 TCs, respectively. The annual TC frequency in the three datasets is given in Fig. 2. The correlation coefficients of every two datasets between CMA and JMA, CMA and JTWC, and JMA and JTWC were 0.77, 0.43, and 0.67, respectively. Although these correlations passed the significance test, some differences between the datasets were quite evident. From the perspective of time evolution, the CMA dataset showed an obvious long-term decreasing trend in TC frequency during 1951–2005, with the most active period from the late 1960s to the

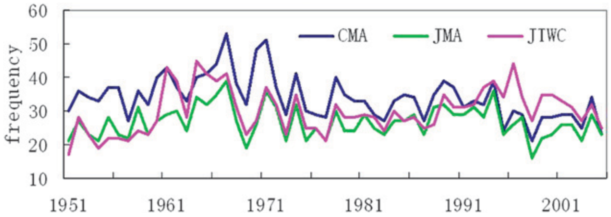

FIG. 2. Variations of annual total western North Pacific TC frequency in the CMA, JTWC, and JMA datasets.

early 1970s. The JTWC dataset has an interdecadal variation with two active periods in the early 1960s and the 1990s. The JMA dataset has a weaker interdecadal fluctuation with an active period in the mid-1960s. The TC frequency was higher in the CMA dataset than in the other two datasets before the 1990s, especially during the 1950s and from the late 1960s to the early 1970s, while the TC frequency was obviously higher in the JTWC dataset from the mid and late 1990s to the early 2000s, and was generally the lowest in the JMA dataset during these periods.

Intensity–time distributions of TC cases in the three datasets are shown in Fig. 3. All three datasets have decreasing trends in annual extreme MSWS, with the most significant decreasing trend in the CMA dataset and a relatively flat trend in the JTWC dataset. Although a significant decreasing trend is found in the JMA dataset, the JMA wind speed data were available only after 1977. The historical extremes in the CMA, JMA, and JTWC datasets were 110, 72, and 95.2 m s^{-1} in the cases of TC Ida (24 September 1958), TC Tip (12 October 1979), and TC Nancy (12 September 1961), respectively. The intensities of these extreme TCs from the three datasets are given in Table 1. Notice that the extreme MSWSs above 85 m s^{-1} occurred only before 1970 in both the CMA and JTWC datasets, and these extreme values particularly occurred in the CMA dataset. Since 1988, the extreme MSWSs in the CMA and JMA datasets have been very close, with only a few exceeding 60 m s^{-1}. However, the extreme MSWSs were close to 80 m s^{-1} in the JTWC dataset, with a large number of wind speeds exceeding 60 m s^{-1}. Finally, the MSWSs were above 18 m s^{-1} for all TCs in the JMA dataset since 1977 and the JTWC dataset before 1971 (i.e., tropical depressions were not included in these datasets), but were contained in the CMA dataset during all of the period and the JTWC dataset after 1971.

4. Comparison of the common TCs

a. Tracks

Differences in track positions for the common TCs for each pair of the datasets are shown in Fig. 4. The

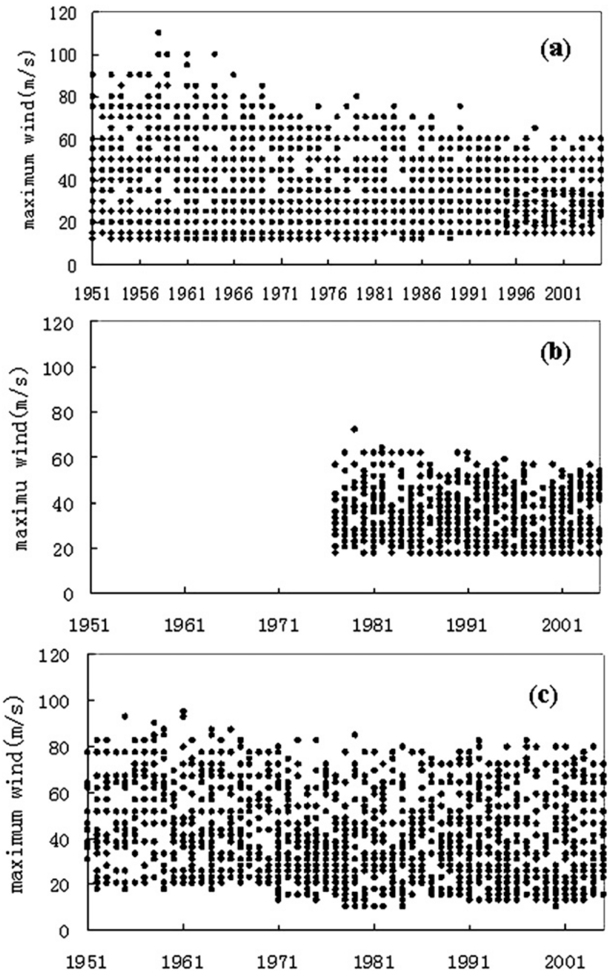

FIG. 3. Intensity–time distribution of TC cases in the (a) CMA, (b) JMA, and (c) JTWC datasets.

decreasing trend (i.e., the tracks are becoming more consistent) during 1951–2005 is above the significance level 0.01. The annual mean difference between the CMA and JMA datasets was smallest with a downward trend, especially after 1988. The minimum CMA − JMA difference is 14.9 km, which occurred in 2004. The evolution of the annual mean differences between the JTWC and the other two datasets was associated with an interdecadal fluctuation during 1988–2000. For example, the mean differences between the JTWC and both CMA and JMA datasets had maxima of 71.6 and 71.0 km, respectively, in 1994. In contrast, the mean differences among the three datasets during 1972–87 were relatively stable, with values of 45–50 km. Significant interannual differences existed prior to 1972, while differences between the JTWC and the CMA and JMA datasets reached maxima of 154 and 162 km, respectively, in 1952, and the difference between the CMA and JMA datasets reached a maximum of 103.5 km in 1953.

TABLE 1. Tropical cyclone intensity in terms of maximum surface wind speed (m s^{-1}) and minimum sea level pressure (hPa) of three extreme TCs in the three datasets.

Tropical cyclone	Occurrence time and dataset	Intensity information		
		Dataset	Maximum wind speed (m s^{-1})	Minimum pressure (hPa)
Ida	24 Sep 1958 CMA	CMA	110	878
		JMA		877
		JTWC	90	
Nancy	12 Sep 1961 JTWC	CMA	100	888
		JMA		890
		JTWC	95.2	
Tip	12 Oct 1979 JMA	CMA	80	870
		JMA	72	870
		JTWC	85	

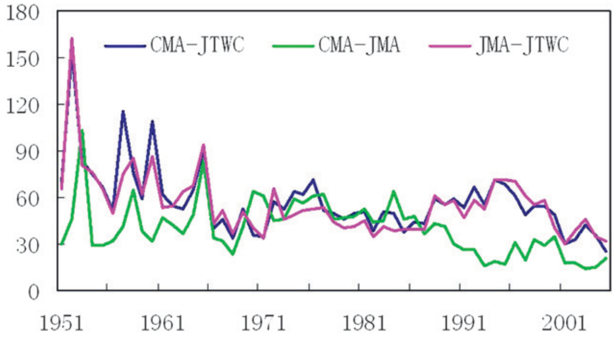

FIG. 4. Variations of annual mean differences in distance (km) for common TC locations between the three datasets.

Possible factors responsible for these differences in common TC tracks were examined by comparing the CMA and JTWC datasets (Fig. 5). Accumulated track differences for common TCs in these datasets are generally clustered with values less than 5000 km with the mean track differences less than 200 km. However, the largest accumulated location difference and the largest mean location difference were 36 650 km (case "a" in Fig. 5) and 909 km (case "f"), respectively.

Analysis was targeted to a group of extreme cases (a–h) in Fig. 5 with significant accumulated and mean track differences. The TC tracks from the CMA and JTWC datasets that correspond to the extreme cases, a and b, are illustrated in Fig. 6. Large location differences in case a are due to longitude errors since the tracks of JTWC5710 (TC 10 in year 1957) and CMA5716 early in their life cycles are antisymmetric with respect to the date line. Evidently the initial track of JTWC5710 was recorded as "longitude east" instead of "longitude west." In the lifetime of case b (Fig. 6b), the TC positions near the end of JTWC6003 imply a translation speed far beyond the normal range, which then leads to a mismatch with the translation speed in the CMA dataset for the same TC. Although the two tracks appear similar, an unexplained difference is that the end time of the JTWC track is 4.5 days earlier than for the CMA track.

The same TC sometimes does not match in one-to-one TCs (cases d ~ h, figure not shown) owing to the fact that in a dataset two real TCs may be merged or they are both very close to a TC in another TC dataset at a given moment or different moments. Existing in both datasets, this situation leads to such matches as "two-to-two TCs," "one-to-two TCs," or "two-to-one TCs" when the same TCs were being distinguished, which eventually enlarged the TC location differences. Seasonal variations of mean differences between common TC locations between the three datasets were also analyzed (not shown). However, these differences were stable without obvious seasonal variations.

b. Intensity

MSWS was chosen for comparison of TC intensities. Variations of annual mean absolute TC intensity differences among the three datasets are given in Fig. 7. The annual mean absolute intensity difference between the CMA and JTWC datasets during 1951–2005 has multidecadal variations with maximum intensity differences during the early 1950s and middle 1990s. The period from 1973 to 1987 had relatively low intensity differences, with the minimum value (2.9 m s^{-1}) recorded in 1978. The differences increased rapidly after 1987, with an extremely significant value of 8.8 m s^{-1} in 1997. Afterward, despite a decline, the intensity differences between CMA and JTWC remained high in the 2000s. The mean absolute intensity differences between JMA dataset and the other two showed quite opposite trends

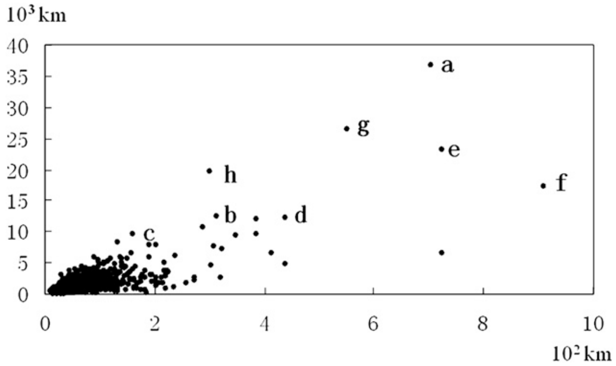

FIG. 5. Mean accumulated location differences (ordinate, unit 10^3 km) for common TC cases between the CMA and JTWC datasets plotted relative to the mean location difference (abscissa, unit 10^2 km).

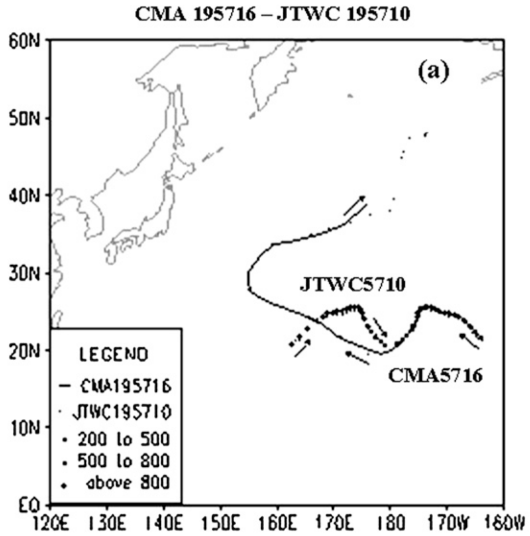

FIG. 6. Tracks of common TC cases with extreme location differences in terms of the CMA and JTWC datasets. (Note JTWC5710 indicates the 10th TC case in the JTWC dataset for 1957, and so on.)

during 1977–2005; that is, these between the JMA and JTWC datasets are similar to the differences between the CMA and JTWC datasets for the same period, with an extreme value of 9.9 m s^{-1} in 1997, while the JMA and CMA datasets suggested a steady decline in the mean absolute TC intensity difference, dropping approximately from the initial 3.5 to about 2 m s^{-1} over 29 years.

Further insights on these intensity differences can be gained by examining the percentages of positive and negative TC intensity differences, ignoring the small proportion of "0." During 1951–78, the frequencies of positive (CMA > JWTC) and negative (CMA < JWTC) intensity differences were around 50%, with some significant interannual variations such as in 1968 when ~80% of the CMA intensities were greater than the JTWC intensities (Fig. 8a). During 1979 to 2005, the percentage of the CMA intensities greater than the JTWC intensities declined rapidly, while the percentage of larger JTWC intensities increased rapidly and reached 90% in the middle 1990s. By contrast, the percentages of positive and negative CMA and JMA intensity differences (Fig. 8b) were around 50%, especially during 1977–95. Overall, the JMA intensities have been slightly larger than the CMA intensities, especially during 1995–2005. Because of the similarity of the JMA and CMA intensities, the intensity differences between JMA and JTWC (Fig. 8c) are similar to the CMA and JTWC intensity differences in Fig. 8a. During the most recent 29-yr period, the percentage of positive (JMA > JTWC) intensity differences has a significant downward trend, with values around 12% since 2000.

The mean absolute values of the negative intensity differences between the CMA and JTWC (i.e., CMA < JTWC, Fig. 9a) have the same trends as the annual mean absolute intensity differences in Fig. 7 with maximum values early and late in the period and minimum values in the middle period. While the positive intensity differences have similar mean absolute values as the negative intensity differences from 1951–81, the mean absolute value for the positive differences are consistently about 3 m s^{-1} after 1981.

Recall from Fig. 8b that the CMA and JMA datasets had about 50% frequencies of positive and negative intensity differences. The mean absolute values of these differences are both about 3 m s^{-1} with a tendency for a little larger magnitude when the CMA intensity is larger than the JMA value (Fig. 9b). Because of the similarity in the JMA and CMA intensities, the mean

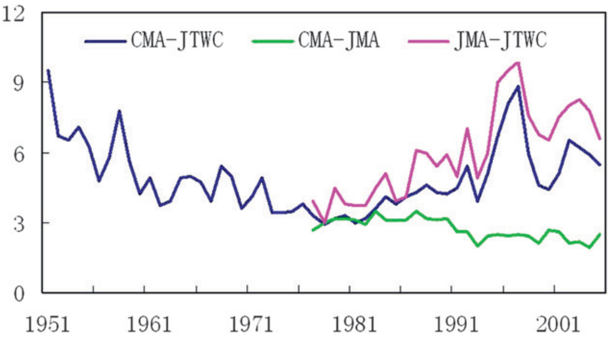

FIG. 7. Variations of annual-mean absolute TC intensity differences (m s^{-1}) between the three datasets.

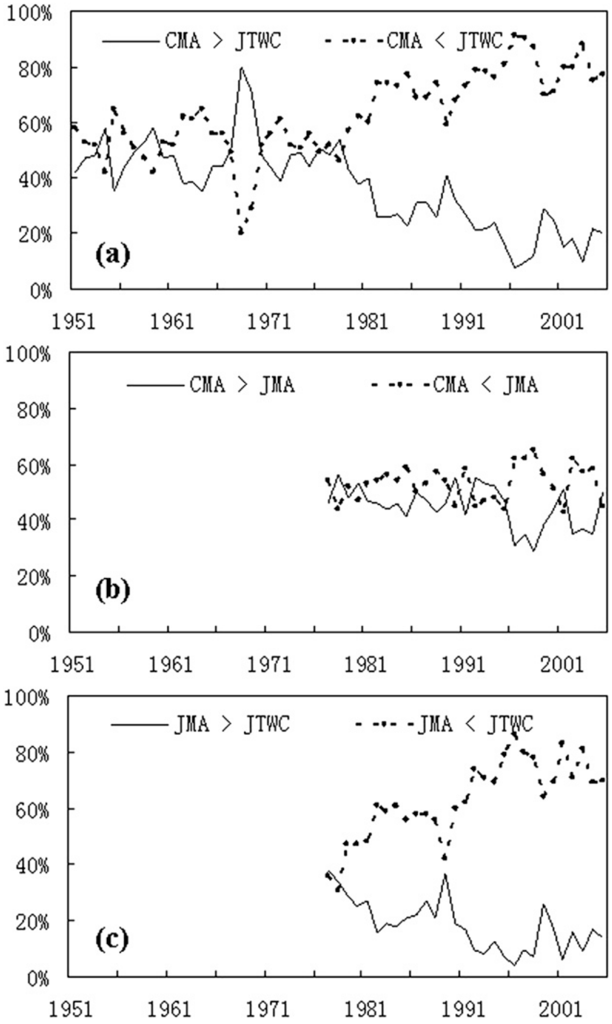

FIG. 8. Variations in percentages of positive and negative TC intensity differences between the three datasets: (a) CMA and JTWC, (b) CMA and JMA, and (c) JMA and JTWC.

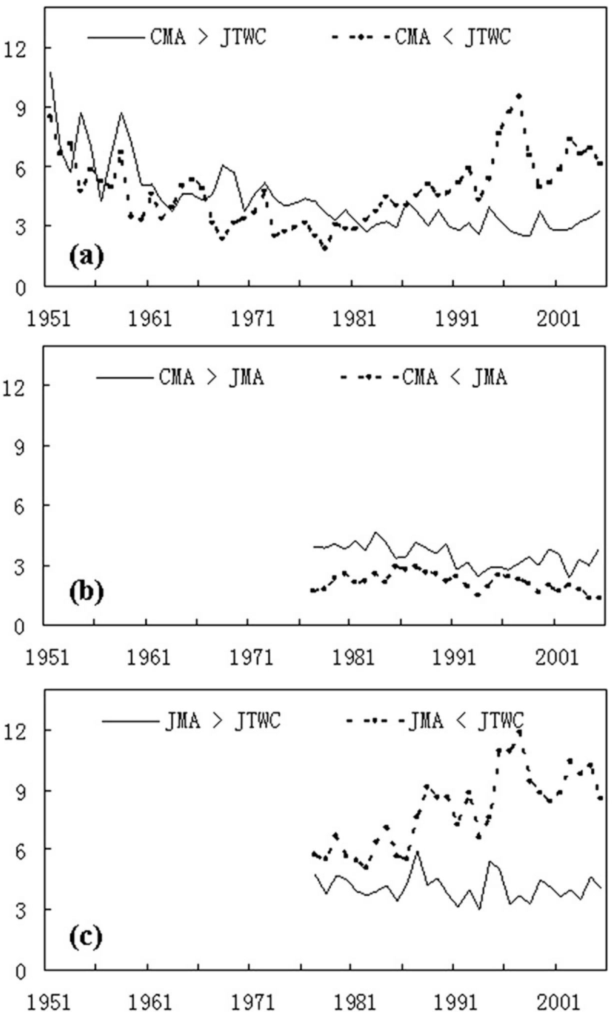

FIG. 9. Variations in the annual absolute values of positive vs the negative TC intensity differences between the three datasets: (a) CMA and JTWC, (b) CMA and JMA, and (c) JMA and JTWC.

absolute values of positive and negative intensity differences between JMA and JTWC (Fig. 9c) have similar characteristics as for the CMA and JTWC intensity differences in Fig. 9a after 1977.

Keeping the different averaging times (2, 10, and 1 min) in defining TC intensity for the three TC datasets in mind, it is easy to understand that, if the three datasets do strictly follow this principle, the inequality "$\mathrm{MSWS}_{\mathrm{JTWC}} > \mathrm{MSWS}_{\mathrm{CMA}} > \mathrm{MSWS}_{\mathrm{JMA}}$" is always set up. However, the above analysis reveals that the result is not always that situation. Historically, this means that all the three datasets did not strictly follow the traditional practice in CMA, JMA, and JTWC, respectively, in identifying TC MSWS with 2-, 10-, and 1-min averages.

The average absolute TC intensity differences among the three datasets on a monthly basis (not shown) were stable without an obvious seasonal variation. The geographic distribution of the mean TC intensity difference (not shown) indicates larger TC intensity differences along the Asian coast, in the higher latitudes, and in the eastern TC genesis region. Larger TC intensity differences might be expected when a landfalling TC was about to dissipate or when a TC was just organizing since fewer in situ observations are available and satellite intensity interpretation is more variable.

c. Frequency

Besides the common TCs in a pair of datasets, the common TCs in all three datasets had also been identified. The annual frequency of common TCs in all three datasets has an interannual variability superposed on a multidecadal variability (Fig. 10a). No significant trend of either an increasing or decreasing number of common TCs is evident over the past 55 years. The total number

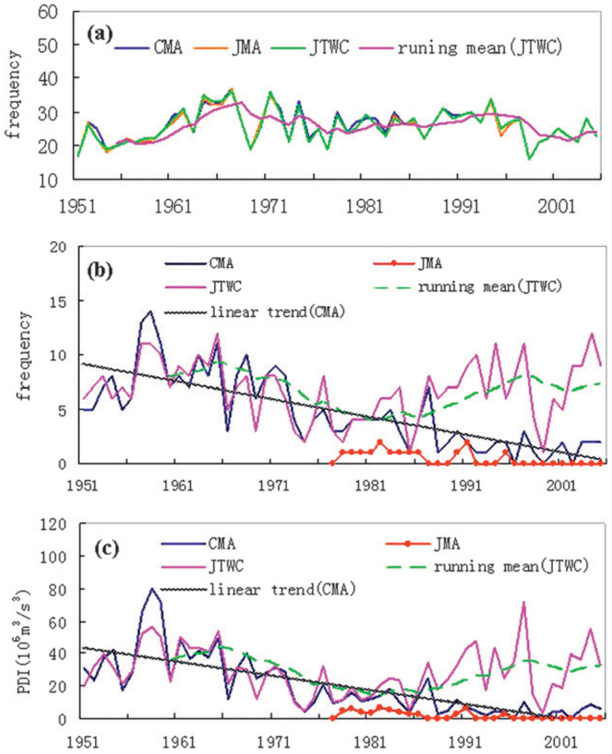

FIG. 10. Characteristics of the common TCs in the three datasets: (a) TC frequency, (b) TC frequency in category 4 and 5, and (c) power dissipation index (PDI) for TCs in category 4 and 5.

of common TCs from the CMA, JMA, and JTWC datasets over the past 55 years were 1424, 1407, and 1414, respectively. The correlation coefficients between CMA and JMA (JTWC) were 0.988 (0.982), and that between JMA and JTWC was 0.992. This close agreement in frequency is a result of the matching technique to define "common TCs," in which more attention was paid to the strong TCs with only a few unmatched. For this set of tropical storms, and those mentioned above, the frequencies of common TCs had no significant long-term trend during 1951–2005.

Altogether 262 supertyphoons with MSWS $\geq$ 58.6 m s^{-1}, equivalent to category 4 and 5 on the Saffir–Simpson hurricane scale, were registered in the CMA dataset over the 55-yr period, and the number of common supertyphoons with either JTWC or JMA totaled 261. The JTWC dataset had the largest number of supertyphoons with 377, of which 374 were common supertyphoons. However, only 14 supertyphoons were included in JMA dataset over the past 29 years, and all belong to the common TCs.

The supertyphoon frequency from 1951 to 1987 is similar in the CMA and JTWC datasets, but clearly different after 1987 (Fig. 10b). The correlation coefficients between the two series for the first 37 years and last 18 years between the two datasets were 0.86 and 0.41, respectively. After an active period of supertyphoons from the late 1950s to early 1960s, the CMA dataset has a significant downward trend of -0.16 yr^{-1} over the 1951–2005 period. After 1988, the annual frequency of supertyphoons in the CMA dataset was between 0 and 3. The frequency of supertyphoons in the JMA dataset since 1977 was significantly less than in the other two datasets, with no supertyphoons in 16 out of the 19 years after 1987 (Fig. 10b). The JTWC supertyphoons in the dataset have a multidecadal variation (Fig. 10b), with active phases from the late 1950s to early 1960s and after 1987 (except during 1998–2000).

Even though there is no significant long-term trend during 1951–2005 in the frequency of common TCs (Fig. 10a), the differences in their intensities among the three datasets in Fig. 10b leads to substantial differences in PDI (Fig. 10c). Considering only the period after 1970, the supertyphoons (category 4 and 5) in the JTWC dataset would be consistent with the conclusions of Webster et al. (2005) and Emanuel (2005), namely that strong typhoon activity had doubled. However, the frequency of these supertyphoons over a longer period in the JTWC dataset agree with the conclusion of Chan (2006) that the increasing trend after 1970 was only part of a multidecadal variability. Based on the CMA dataset, the supertyphoon activity has been small in the 35 years after 1970 and has significantly decreased in the 55 years after 1951.

5. Analysis of independent TCs

Analysis of the independent TCs (i.e., those TCs in one dataset that could not be matched with a TC in another dataset) provides some further insights into different operational practices at the CMA, JMA, and JTWC.

a. *Frequency*

First consider the percentages of the independent TCs in the CMA and JTWC (Fig. 11a) datasets during each year from 1951 to 2005. The CMA dataset has 342 independent TCs relative to the JTWC dataset accounting for about 18% of the total, which is much more than the number (119) of the independent TCs in the JTWC dataset relative to the CMA dataset accounting for about 7% of the total. During 1951–2005, the percentage of independent TCs in the CMA dataset shows not only a significant long-term downward trend (passing the significance of 0.01) but also an obvious interdecadal variation, while the percentage of independent TCs in the JTWC dataset increases significantly over the past 55 years (passing the significance of 0.05), with an

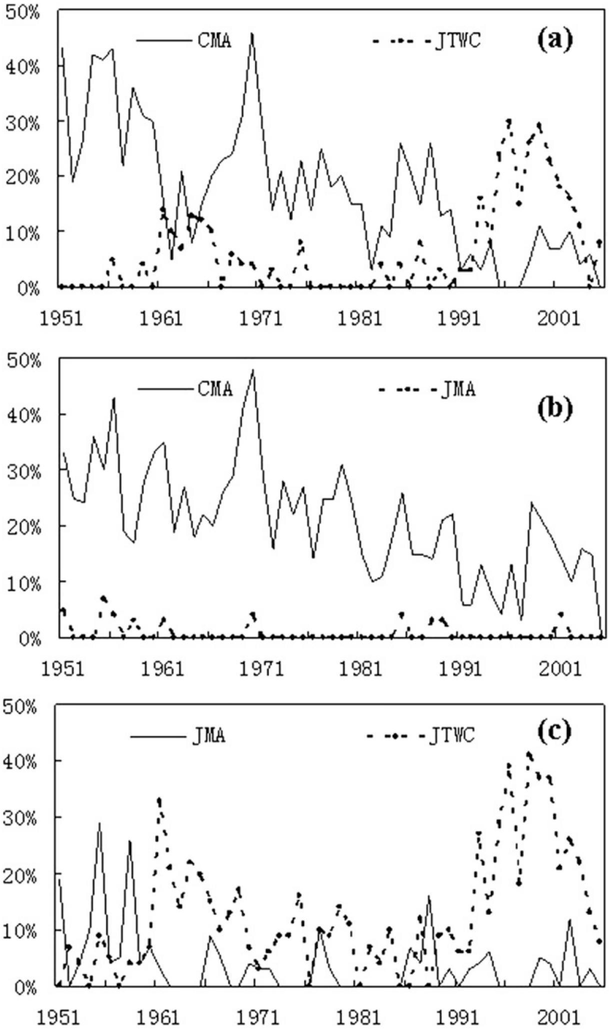

FIG. 11. Evolution of independent TC ratios between the three datasets: (a) CMA and JTWC, (b) CMA and JMA, and (c) JMA and JTWC.

obvious interdecadal variation. Except during 1961–65, the CMA dataset has about 20%–40% independent TCs during the period 1951–71 (peak ratio of 46% in 1970), about 20% in the mid-1980s, and about 10% around 2000. The JTWC dataset has about 20% during 1993 to 2003 (with the maximum reaching 30% in 1996), which was the only period in history with the average ratio obviously higher than that of CMA dataset. The above analysis revealed that, when the annual TC frequency was higher in one dataset than in another one, the independent TC ratio in the dataset was generally higher than in the other. The independent TCs always existed in the two datasets in every year over the past 55 years, indicating that there were more or less differences in techniques for TC fixing between the two datasets in every year.

Figure 11b shows the results of the CMA and the JMA datasets. The CMA dataset has 407 independent TCs relative to the JMA dataset accounting for about 22% of the total, which is much more than the number (11) of the independent TCs in the JMA dataset relative to the CMA dataset accounting for about 1% of the total. During 1951–2005, the percentage of the independent TCs in the CMA dataset shows a clear downward trend, with the average value being about 20% and the maximum up to 48%. The independent TC ratio in JMA dataset was unexpectedly zero in 45 out of 55 years, with the largest ratio being 7% in 1955. The year 2005 is the only one in which the two datasets do not have any independent TC: the reason is that the intensities of the 23 TCs in 2005 were all in the category of tropical storm or above.

Figure 11c shows the results in comparison of the JMA dataset against the JTWC dataset. On the whole, the independent TC ratio in the JTWC dataset was greater than that in the JMA dataset, especially in the 1960s and after the 1990s, of which the maximum ratio was up to 41% in 1998. The independent TC ratio in the JMA data in 1951, 1955, 1958, and 1988 was relatively larger with the maximum reaching 26% in 1955.

b. Tracks and others

Now consider the tracks of the independent TCs in the CMA (Fig. 12a) and JTWC (Fig. 12b) datasets from 1951–2005. Notice that most of the independent TCs in the CMA dataset were for TCs that either made landfall or were near offshore of China. Indeed, the number of these independent TCs affecting China was 154, accounting for 45% of the total number of independent TCs in the CMA dataset.[1] The sea areas dominated by TC tracks covered the South China Sea, waters to the east of Philippines, East China Sea, and areas southeast to Japan—especially over the South China Sea and its adjacent areas. The independent TC tracks in the JTWC dataset relative to the CMA dataset were found mostly within the domain from 103°E to 180°, with fewer landfall TCs and, in particular, no TC landing China, and even a few TCs entering China's coastal waters. A few TCs went beyond the area (100°E–180°), out of which only one TC from the central Pacific and six TCs from the aforementioned area crossed the date line into the western North Pacific, and three TCs in the domain moved westward into the Indian Ocean from the oceanic region east of 100°E.

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[1] The TCs affecting China refers to all tropical cyclones originating from the western North Pacific Ocean (including the South China Sea) bringing precipitation to mainland China and any of the two biggest islands (i.e., Taiwan and Hainan).

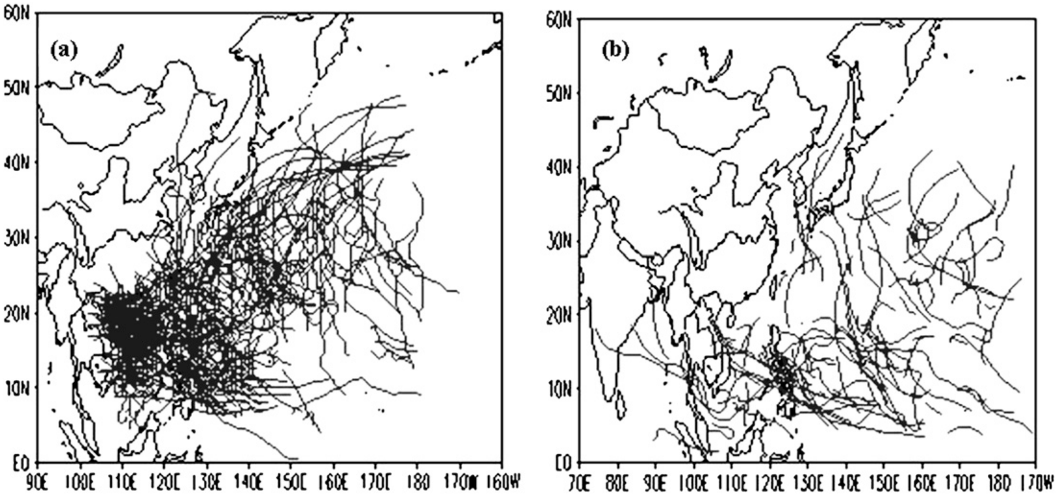

FIG. 12. Independent TC tracks for the (a) CMA and (b) JTWC datasets relative to each other.

Further analysis was made on the life cycle and intensity distribution of independent TCs (figure not shown). The independent TCs in the CMA dataset lived mainly for 2–6 days, with peak at 3–4 days. The life cycle of independent TCs in the JTWC dataset was mainly 1–6 days without any prominent peak. The intensity of the independent TCs in the CMA dataset fell into TD category (75.1%), next TS category (21.9%), and 10 TCs were in category 1 or above (less than 3%). The intensity of independent TCs in the JTWC dataset was broadly classified into three categories—TD, TS, and an undefined one—accounting for 49.6%, 22.7%, and 24.4% respectively, while 4 TCs were in category 1 or above, accounting for 3.4%.

Analysis of the independent TC tracks between the CMA and JMA datasets (figure omitted) reveals that the independent TC tracks in the CMA relative to the JMA dataset have similar characteristics as those independent TC tracks in the CMA relative to the JTWC dataset. For the JMA dataset, the independent TC tracks are located in the sea areas east of 140°E.

A similar comparison between JMA and JTWC datasets (figure omitted) shows that the independent TCs from JMA dataset mainly concentrated in three areas: (i) Japan and its eastern coast, (ii) the South China Sea, and (iii) around the date line. The independent TCs in the JTWC dataset are almost uniformly distributed across the entire western North Pacific basin, focusing on the sea areas east of Philippines and over the South China Sea.

6. Summary and discussion

This study has compared the historical tropical cyclone datasets in the western North Pacific from the CMA, JMA, and JTWC during the period 1951–2005 to understand different conclusions about climate change that have been drawn from these datasets. The special focus is on intensity differences, especially the maximum sustained wind speed (MSWS), between the CMA and the JTWC datasets. Different studies using these datasets have concluded that tropical cyclone intensities may have an increasing trend, no significant trend, or even a decreasing trend. The CMA dataset during 1951–71 had been compiled using Chinese observations along with the other datasets, including the U.S. Air Force aircraft reconnaissance records, with a special emphasis on tropical cyclones that made landfall or passed close to China.

The CMA dataset contains 1868 tropical cyclones, which is considerably more than the 1648 and 1468 tropical cyclones in the JTWC and JMA datasets. The comparisons have been made using two subsets of tropical cyclones. First, common tropical cyclones between two datasets (CMA and JTWC, CMA and JMA, and JMA and JTWC) by defining the ''same TC'' if the distance between the two centers was less than 200 km at a moment during the overlapping time period. Those tropical cyclones that could not be matched between the two datasets are then defined as independent tropical cyclones for a specific dataset relative to the other dataset. Differences in locations and differences in intensities were calculated for the common tropical cyclone sets.

Differences between the three datasets exist mainly in the following. 1) TC frequency of the CMA dataset was higher than those of the JMA and JTWC datasets before the 1990s, especially in the 1950s and from the late 1960s to the early 1970s, while that of the JTWC dataset was obviously higher than those of the CMA and JMA datasets from the middle 1990s to the early 2000s. 2) Historically, all datasets did not strictly follow the so-called traditional practice in CMA, JMA, and JTWC, respectively, in identifying the TC MSWS with 2-, 10-, and 1-min averages. 3) Intensities of common TCs differed substantially from one dataset to another. In the CMA dataset, the TC intensity was apparently overestimated in 1950s, while the JTWC dataset overestimated TC intensities from 1993–2003. 4) Annual mean differences in TC locations between the JTWC dataset and the other two datasets were higher in 1990s than in other periods when satellite data was applied. 5) Significant differences existed in terms of frequency and geographical distribution of independent TCs.

Future in-depth discussions may be necessary in the following issues. 1) Both TC number and intensity in the CMA dataset were seemingly overestimated before 1987, particularly in the 1950s and the 1960s, which may mainly be attributable to the first effort in TC data compilation during 1970–73, especially the three principles on the one hand, and persistent interests in TCs that affect China on the other. 2) The TC number and intensity in the JTWC dataset seemed to be overestimated since 1988, particularly from 1993 to 2003. The overestimations were possibly due to the following factors: (i) no TC intensity references with high accuracy for operational centers after aircraft reconnaissance terminated in 1987; (ii) obvious differences in applications of the Dvorak technique in different operational typhoon/hurricane Centers; and (iii) differences in time intervals for the MSWS at different centers, especially when in situ observation was available. From the comparative analyses of different datasets, it was noted that in the 1990s, when satellite observations were increasingly improved, the differences in TC frequency and intensity between the JTWC dataset and the CMA/JMA datasets were significantly higher than in the prior period from 1973 to 1987. So, further exploration and analysis might be needed for a more reasonable explanation. (3) Although the difference in annual-mean absolute TC intensities between the CMA and JTWC datasets showed neither an increasing nor decreasing trend, there existed a clear interdecadal variation in it: two periods from 1951 to 1972 and after 1987 featuring relatively larger differences and the period from 1973 to 1987 showing relatively smaller differences. Further analysis suggested that the period (1973–87) with smaller difference coincided with the timeframe when the aircraft reconnaissance data and the Dvorak technique were both available to the TC operational centers. Interestingly, it may be assumed that coexistence of aircraft reconnaissance with the Dvorak technique proved to be useful in reducing the TC intensity difference.

As stated above, the three TC datasets covering the western North Pacific basin had evident differences of which each was bearing its own characteristics. Currently, it is still difficult to judge which one is best. However, for the TC activity affecting China, the CMA dataset has obvious advantages such as more complete and more accurate information. Bearing in mind fewer missing intense TCs, it is reasonable that frequencies of the common TCs in all the three datasets show no obvious increasing or decreasing trend over the past 50 years but a weaker interdecadal variation, for example, more TCs from the mid-1960s to the mid-1970s and in the early 1990s.

Nevertheless, the intensities of the common TCs differed largely from one dataset to another, leading to quite opposite conclusions for TCs of category 4 and 5. For the period after 1970, the JTWC dataset shows an increasing trend that complies with those by Webster et al. (2005) and Emanuel et al. (2005). However, for a longer time scale, the result may be well consistent with that of Chan (2006). In other words, the so-called ‘‘trend’’ is a fragment of the longer interdecadal variation. For the CMA dataset, the activity of TCs in category 4 and 5 shows a weakening trend either in the 35-yr (after 1970) or the 55-yr cycle (after 1951). It seems that, although the JMA dataset covers a shorter period for maximum wind speed, it also gives a declining trend in TC activities over the recent 30 years.

In general, the three datasets present obviously different results for climate change of category 4 and 5 TC activities in the western North Pacific. Taking into account the differences and problems in techniques of defining TC intensity, more reasonable results may lie between the outcomes of the JTWC and the CMA datasets. In this respect, further studies and analyses are needed on TC data to better address the existing issues.

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