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COMPARISON OF SOME TROPICAL CYCLONE DATASETS AND CORRECTION OF YEARBOOK DATA

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Abstract: This is a study to compare three selected tropical cyclone datasets separately compiled by CMA Shanghai Typhoon Institute (CMA_SHI), the Joint Typhoon Warning Center (JTWC), and the Japan Meteorological Agency (JMA). The annual frequencies, observation times and destructive power index as the characteristic quantities are investigated of the tropical cyclones over the western North Pacific. The comparative study has resulted in the following findings: 1) Statistical gaps between the datasets compared are narrowing down as the intensity of tropical cyclones increases. 2) In the context of interdecadal distribution, there is for the 1950s a relatively large gap between the datasets, as compared with a narrowed gap for the period from the mid 1970s to the 1980s, and a recurring widened gap for the mid and late 1990s. Additionally, an approach is proposed in the paper to correct the wind speed data in the TC Yearbook.

Key words: tropical cyclones; datasets comparison; comparative study

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1 INTRODUCTION

Previous studies showed that statistics derived from different datasets could result in different conclusions, sometimes simply opposite conclusions. Such gap also found its expression in the studies of tropical cyclone (abbreviated as TC) of all levels of intensity.

During the period of 1940s to 1970s, when satellite cloud images did not come into operation, the surveillance of TC over the western North Pacific depended mainly on the data jointly collected by the United States air force and navy at an air force base on the Island of Guam, leading definitely to missing reports [1, 2]. The shortage of regular ground observation data over the same region thrusts into doubt the stability and reliability of TC data collected during the period of 1950s to 1960s. In this context, one has to correct the exaggerated wind speed data collected by JTWC prior to the mid 1970s [3-8]. The reliability of the data from the Typhoon Yearbook of CMA_SHI for earlier years were also put into doubt[9-14].

The United States launched its first geosynchronous weather satellite in 1974, a substantive technological advancement for TC watch and warning. In the late 1970s, satellite imagery based TC positioning and intensity analyzing techniques developed by Dvorak found extensive applications and development. Unfortunately, the limited resolution of satellite images and the incomplete nature of remote sensing data analysis failed to keep Dvorak's TC intensity and feature analyzing techniques from having systematic and artificial biases. One has become increasingly dependent on weather satellites since 1987 when aircraft based sounding activities over the northwest Pacific Ocean ceased. As a result, a number of institutions started to offer TC datasets that may have some discrepancies against one another. Additionally, radar echo data, a reference for data correction, showed its limits on both observation times and accuracy, implying that one could not completely get rid of TC data errors, even with extensive applications of satellite and radar data.

As indicated in the work of Yu et al.[15], who analyzed the typhoons stronger than tropical storms in 1977 to 1986 and 1988 to 2003 from the aforementioned tropical cyclones datasets, there exist significant differences in the determined typhoon

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strength but the discrepancy in annual frequency is not high, resulting in a statement that the difference became smaller and smaller after the cessation of flight reconnaissance.

In view of the absence of generally accepted standards of data reliability, only their differences are explored here in yearly frequencies and TC observation times between these datasets in their comparison. Subsequently, quality control and correction are proposed for CMA_SHI data.

2 DATASETS COMPARISON

The data to be compared are split into two periods in line with technological advancements of TC observation, namely 1950 to 1979 and 1980 to 2005. JMA datasets do not include wind speed data until 1977. As a result, the data compared before the 1980s do not include the one from JMA. To obtain a relatively complete picture of TC data, we work on the maximum sustained winds near the typhoon center at three levels: tropical depression or above (TC), tropical storm or above (TS), and typhoon or above (TY). As far as the maximum sustained winds are concerned, CMA_SHI data present 2-minute, JTWC 1-minute, and JMA 10-minute, averages. The wind speeds employed have to be converted into the one that can be compared. Therefore, 1-minute and 10-minute averaged wind speeds are converted in line with the Dvorak approach, using 0.88 as a coefficient. 2-minute and 10-minute mean are converted based on the following formula: $Y = 0.88X+0.80$ (to be referred to at https://metoc.npmoc.navy.mil/jtwc/jma-dvorak.htm), in which Y and X are, respectively, the 10- and 2-min mean maximum sustained winds[16]. Considering together the time for averaging maximum wind, speed unit system and minimal time interval, the following statistical standards are proposed for different-strength TC.

For CMA_SHI data, we propose TC of $V \geq 10.8$ m/s, TS of $V \geq 17.2$ m/s and TY of $V \geq 32.7$ m/s.

For JTWC data, we have TC of $V \geq 25$ knots, TS of $V \geq 34$ knots and TY of $V \geq 64$ knots.

For JMA data, we have TS of $V \geq 30$ knots and TY of $V \geq 60$ knots.

In addition to annual frequency data, the total observation times (every 6 hours) are also used to indicate the activity of TC in the comparison.

2.1 *Climatological comparison of northwest Pacific TC activities before the 1980s*

A statistical comparison is made between CMA_SHI and JTWC datasets to understand the possible discrepancies in annual frequency (TC) and observation times (TC, TS) (Figs. 1, 2, 3).

CMA_SHI data reveal 37 occurrences of TC activities, and JTWC 26 occurrences, with an annual gap at 10.8 occurrences (Fig. 1). The discrepancy in average passes the t-test at a significance level of 0.001, while the variance fails to reach 0.05 in the significance test. Statistical comparison also shows that CMA_SHI datasets have more incomplete data for weaker TC activities, with an averaged 16% for the missing data before the 1980s. JTWC data is in a better position for having much less incomplete data. Even with the years with incomplete data removed (Fig.2), CMA_SHI offers noticeably more TC observation times, compared with JTWC, though there is a noticeably narrowing gap in the mid and late 1970s.

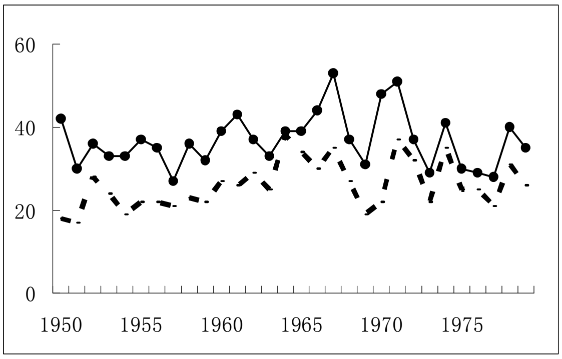

Fig.1 Comparison in TC yearly frequency between CMA_SHI and JTWC data denoted by solid and dashed lines, respectively.

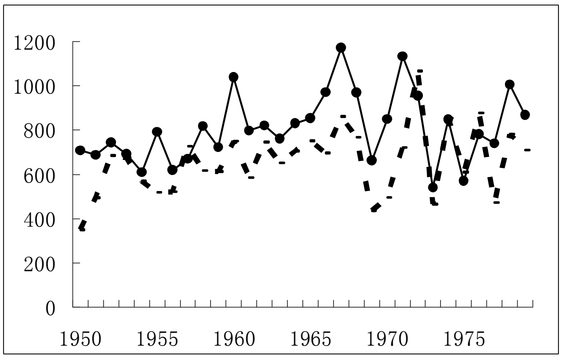

Fig.2 Same as in Fig.1 except for TC observation times.

In the context of TS observation times (Fig. 3), a noticeably reduced gap is seen between the CMA_SHI and JTWC datasets, compared with Fig. 2. Apart from a relatively large gap registered in the 1950s, the two datasets are close one another in TS observation times for the period of 1960s to 1970s. The t-test fails to pass a significance level of 0.10, suggesting an insignificant gap between the two. Both datasets pass a significance test at 0.05, indicating a slightly large gap in annual frequency.

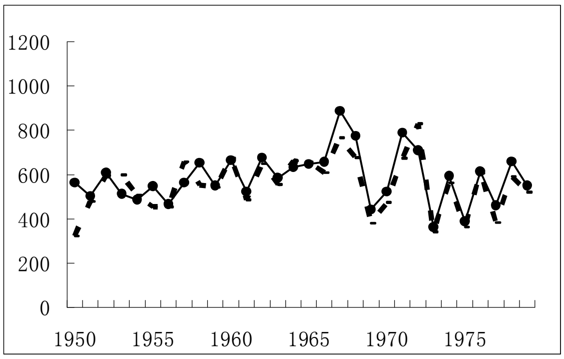

Fig.3 Same as Fig.1 but for TS observation times.

2.2 *Climatological comparison of northwest Pacific TC activities after the 1980s*

The JMA data join the comparison after the 1980s. Both Figs. 4 and 5 show the statistical results of CMA_SHI and JTWC (JMA has data only for storms stronger than TS).

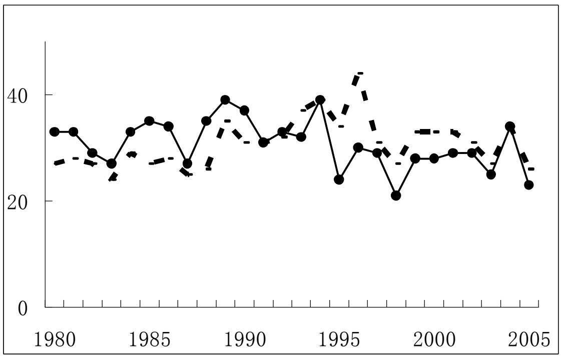

Fig.4 Comparison of TC annual frequency between CMA_SHI (full line) and JTWC (dashed) datasets.

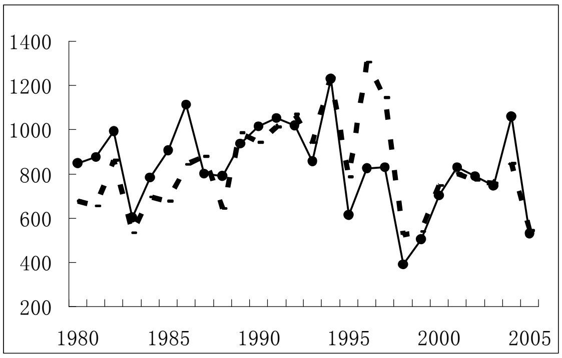

Fig.5 Same as Fig.4 except for TC observation times.

As it is shown in Figs. 4 and 5, CMA_SHI and JTWC datasets are different in annual TC frequency and observation times, though not significantly. Both discrepancies in average and variance fail to pass the *t*-test at 0.10 and *F*-test at 0.05 respectively. The gaps go along with interdecadal variations. For example, CMA_SHI has more TC occurrences in the 1980s, with JTWC only being in the same position after the 1990s. The general picture does not show a significant gap in terms of TC frequency, though the two datasets could be significantly different in individual years, with JTWC having 44 TC occurrences and CMA_SHI 30 occurrences in 1996. In the context of TS frequency, JTWC indicates a further reduced gap against CMA_SHI and JMA at 1.8 and 1.6 respectively (Fig. 6). CMA_SHI has a further narrowed gap compared with JMA at ≤ 1 for averaged yearly TS occurrences. The three datasets show a TS observation time gap that is larger in the 1990s, compared with the 1980s (Fig. 7).

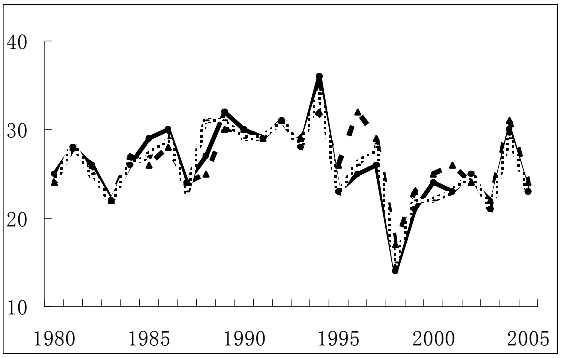

Fig.6 Comparison in TS annual frequency among data of CMA-SHI (solid), JTWC (dashed) and JMA (bold dashed) datasets in 1980 to 2005.

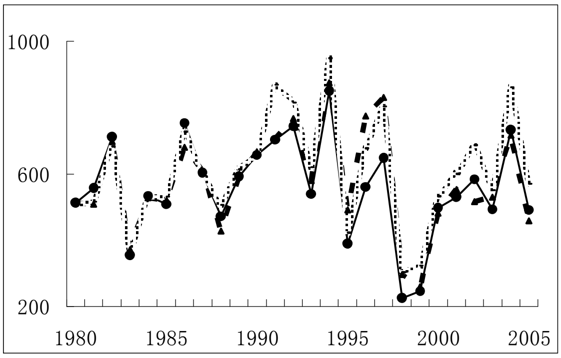

Fig.7 Same as in Fig.6 but for TS observation times.

Figure 8 shows the destructive power indexes of northwest Pacific TC derived from the three datasets. JTWC data show an overall enhanced destructive power over the recent 20 years, with CMA_SHI pointing a weakened trend. JMA data indicate a tendency close to JTWC, though insignificant for an ascending trend. Moreover, their differences increase in the 1990s.

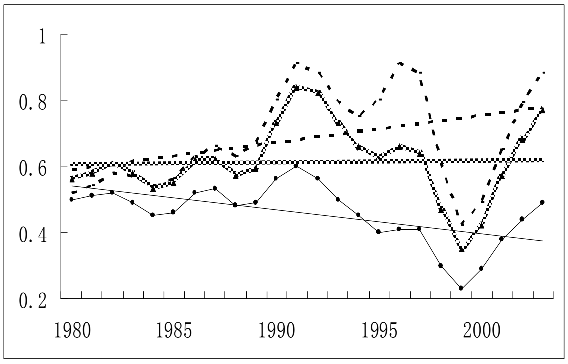

Fig.8 The destructive power index (×10^{13}/(8.3$(m/s)^3$)) of TS in the studied waters between these data of CMA-SHI (solid), JTWC (dashed) and JMA (thick line).

3 CMA_SHI WIND SPEED DATA CORRECTION

Previous studies show that the maximum sustained wind speed near the typhoon center went along with the lowest pressure in the center[3-10]. JTWC made a correction to its exaggerated wind speeds collected before 1973 using the traditional Atkinson-Holliday wind-pressure formula. In this paper, the same formula is employed to correct the wind speed data collected by CMA_SHI in the early years.

3.1 *Disposal of missing wind records in the CMA_SH data*

The Atkinson-Holliday formula is applicable to the TC cases with central pressures lower than 1010 hPa. Hence, the boundary value of the center pressures should be confined to 1010 hPa before the use of the relation formula.

The central pressure data at ≥ 1010 hPa are abundant in number before the 1980s, though with a lot of missing data for wind speed. After that period, the data with the same quality are reduced in number and with rare missing wind speed data. For the fact that the maximum central pressure of 1012 hPa was recorded with measured winds after 1980, the early data of > 1012 hPa are ignored and setting the 1012 hPa and 1010 hPa (2 hPa as the minimum pressure interval in observations) to be the boundary values of central pressure, the associated winds can be determined by the measurements in 19802005.

There were ten records showing a central pressure equal to 1012 hPa during the period of 1980–2005, with an averaged wind speed at 10 m/s. In this context, the wind speed for p = 1012 hPa shall be 10 m/s (table omitted). 42 observed results having a central pressure at 1010 hPa are made as reference (Table 1).

Table 1 Winds (denoted as V) in association with the cases of central pressure p = 1010 hPa in 1980 to 2005 CMA_SHI dataset.

year	cases of p = 1010 hPa	no V	V = 9 m/s	V = 10 m/s	V = 12 m/s	V = 15 m/s
1981	10	3			1	6
1982	8		3	5		
1984	2		2			
1986	1			1		
1987	5				2	3
1988	2			2		
1989	1			1		
1993	11			9	2	
2003	2			2		

It is seen from the table that 20 of the 42 cases show V = 10 m/s and the total mean is 11.3 m/s. In practice the use of 12 m/s is suitable.

Thus, in practical statistics, when for $p \geqslant 1010$ hPa, the A-H formula is unsuitable. We can make use of the following scheme: for $p > 1012$ hPa $V = 0$, for p = 1012 hPa, V = 10 m/s, for p = 1010 hPa, V = 12 m/s.

3.2 *CMA-SHI wind speed data quality control and associated correction*

For the maximum sustained wind data with a central pressure less than 1010 hPa, we substitute the pressure into the traditional Atkinson-Holliday formula to obtain the theoretical maximum wind speed. When the observed wind speeds show a noticeable gap against the theoretical one, with the relative error higher than 30%, correction is needed (Table 2).

Table 2 shows that the observed wind speeds collected before the 1980s departed far away from the theoretical value by 43.4%, with the portion of missing wind speed data reaching 16.4%. When the data without wind speed are removed, the observed wind speeds still have a noticeable departure from the theoretical value by 27%. The data collected after the

1980s see a quite different story, with only an 8.5% gap between the observed and the theoretical, suggesting that the stability and applicability of the Atkinson-Holliday formula makes a desirable tool for correcting the wind speed data collected in the early years.

The maximum sustained wind speeds before 1973 were corrected using CMA_SHI and JTWC data in line with the approach mentioned in Emnauel[8]. The destructive power indexes of northwest Pacific tropical cyclones (1950 to 1979) before and after the correction are given in Fig. 9.

Figure 9 indicates that the two corrected datasets present overall agreeable destructive power indexes, though some individual years can be an exception, which justifies the necessity of correcting the exaggerated wind speeds collected before early 1970s.

3.3 *Annual frequency correction*

The application of satellite images and Dvorak interpretation techniques in the late 1970s secured a substantive technological advance for tropical cyclone positioning and intensity analysis, though not yet to a point making the analysis completely objective. Before this, it is difficult for aircraft or ship based observation to make valid identification of the tropical cyclones, either close to one another or belonging to the same tropical depression system. That incurs the possibility of overlapped counting.

Table 2 Deviations of measured winds from theoretical values in 1949 to 2005 CMA_SHI dataset.

period	TR	VDT	%	CMDW	%	VU	%
1949-1979	33747	14633	43.4	9098	27.0	5535	16.4
1980-2005	22972	1957	8.5	1947	8.5	10	0.0

Notes: TR = total records; VDT = cases of wind (*V*) deviating greatly from the theoretical value; CMDW = cases of wind measurements significantly deviating from estimates without unmeasured winds; VU = wind unmeasured.

To address the problem, the following are defined as overlapped counting: when there is ≥ 1 observed record 1) made at the same time with a longitude or latitude that is less than 2 degrees between the two events, or 2) made in the following day with a longitude or latitude that is less than 3 degrees between the two events. The TC data, when meeting either of the conditions mentioned above, would be viewed as an overlapped observation of the same tropical cyclone. Figure 10 shows the annual frequency of northwest Pacific tropical cyclones (1950 to 1979) before and after the correction.

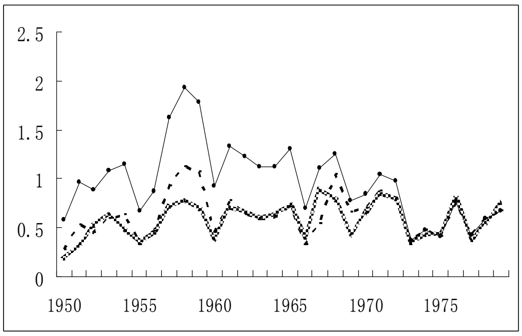

Fig.9 The western North Pacific TS devastation index ($\times10^{12}/(8.3(m/s)^3)$) before correction for CMA_SHI (solid) and for JTWC data (dashed line) in 1950 to 1979, and after correction (thick line), where the JTWC data underwent wind correction according to Emanuel[8].

Figure 10 indicates that CMA_SHI registered more TC occurrences than JTWC in most of the years investigated, with a gap of more than 10 occurrences between the two, in 16 of the these years (1950 to 1979), and an extreme year (1970) showing the gap up to 24 occurrences. Although the two datasets have shown a much smaller gap in TS occurrences, their averages still pass the *t*-test at 0.05 (figure not shown). After removing the repeated counting the years with TS yearly frequency difference less than 2 increase from 50% to 67%, but the mean and variance are unable to pass significance test, indicating there to be no noticeable discrepancy for the reduced TS occurrences (Fig. 10). Statistics indicate that CMA_SHI has noticeably more overlapped observations, compared with JTWC, at 2.2 and 0.7 events respectively. The discrepancey in average passes the *t*-test at 0.001, while the variance fails the *F*-test at 0.05.

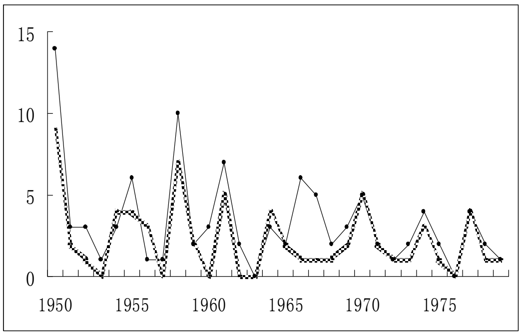

Fig.10 The TS differences in annual frequency between CMA-SHI and JTWC data in 1950 to 1979, with solid (dashed) line denoting the difference before (after) correction.

4 CONCLUSION

(1) The statistical gap between the three selected datasets becomes narrowed down along with an increased TC intensity. Operational practices applied at different TC forecast centers, and the poor understanding of the physical properties of a relatively weak depression system explains the phenomenon. Statistics show that CMA_SHI and JTWC datasets have a noticeable gap between the two in averaged TC numbers, observation times, and variances during 1950 to 1979, though with a much narrowed gap for those tropical systems stronger than tropical storms.

(2) Gaps in different years are different, with the largest gap appearing in the 1950s when aircraft and ship based observation just started. TC data become more consistent over the period from the late 1970s to the 1980s, thanks to the improved precision of aircraft based observation and satellite capability. Unfortunately, the gap becomes larger again in the period from the mid and late 1990s to the following century, which could be associated with the uneven application of new and advanced sounding technologies at TC forecast centers.

(3) The correction of exaggerated wind speeds collected during the period of 1950s to 1960s, based on the relationship between the maximum sustained wind speeds near the typhoon center and the lowest central pressure, has been proved rational and valid.

(4) Overlapped observation was frequently made before satellite technology was introduced. For the period of 1950s to 1970s, CMA_SHI has more overlapped observation events, compared with JTWC, and the gap in annual TS occurrences is noticeably reduced after the overlapped observations were removed.

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