Article ID: 1006-8775(2017) 03-0281-11

COMPARISONS OF THE CHARACTERISTICS OF TROPICAL CYCLONES EXPERIENCING EXTRATROPICAL TRANSITION IN THE WESTERN NORTH PACIFIC BASED ON DIFFERENT DATASETS

SUN Hong-mei (**孙红梅**)[1], LEI Xiao-tu (**雷小途**)[2], TANG Jie (**汤 杰**)[2], YAO Cai (**姚 才**)[3],
LUO Xiao-li (**罗小莉**)[4]
(1. Guangxi Meteorological Observatory, Nanning 530022 China; 2. Shanghai Typhoon Institute of CMA, Shanghai 200030 China; 3. Guangxi Institute of Meteorology and Disaster-Mitigation Research, Nanning 530022 China;
4. Guangxi Weather Service Center, Nanning 530022 China)

Abstract: The differences in the climatology of extratropical transition (ET) of western North Pacific tropical cyclones (TCs) were investigated in this study using the TCs best-track datasets of China Meteorological Administration (CMA), Japan Meteorological Agency (JMA) and the Joint Typhoon Warning Center (JTWC). The results show that the ET identification, ET completion time, and post-ET duration reported in the JTWC dataset are greatly different from those in CMA and JMA datasets during 2004–2010. However, the key differences between the CMA and JMA datasets from 1951 to 2010 are the ET identification and the post-ET duration, because of inconsistent objective ET criteria used in the centers. Further analysis indicates that annual ET percentage of CMA was lower than that of JMA, and exhibited an interannual decreasing trend, while that of JMA was an unchanged trend. The western North Pacific ET events occurred mainly during the period June to November. The latitude of ET occurrence shifted northward from February to August, followed by a southward shift. Most of ET events were observed between 35°N and 45°N. From a regional perspective, TCs tended to undergo ET in Japan and the ocean east to it. It is found that TCs which experienced the ET process at higher latitudes were generally more intense at the ET completion time. TCs completing the ET overland or offshore were weaker than those finishing the ET over the ocean. Most of the TCs weakened 24 h before the completion of ET. In contrast, 21% (27%) of the TCs showed an intensification process based on the CMA (JMA) dataset during the post-ET period. The results presented in this study indicate that consistent ET determination criteria are needed to reduce the uncertainty involved in ET identification among the centers.

Key words: Western North Pacific; different datasets; tropical cyclone; extratropical transition; climatic differences; comparative analysis

CLC number: P444 **Document code:** A

doi: 10.16555/j.1006-8775.2017.03.005

1 INTRODUCTION

Extratropical transition of a tropical cyclone occurs in nearly every ocean basin that experiences tropical cyclones, e.g. North Atlantic, Western North Pacific, Southwest Pacific and southeast Indian Ocean. As tropical cyclones re-curve poleward and move into the midlatitude, they often interact with baroclinic systems and transform into extratropical cyclones. The process of ET has a significant impact on middle and high-latitude countries and poses a serious threat to people's life and property[1,2]. In recent years, the identification, physical understanding and impacts of ET have become hot topics and draw International Typhoon Committee's attention[3]. Although some objective indicators of ET determination, such as cyclone phase space (CPS) were proposed[4-7], consistent ET determination criteria and a universal definition of ET are still needed. In contrast, ET information in TC best track datasets among centers is still widely accepted and currently being considered "the best data".

Kitabatake[8] found that 49% of Western North Pacific tropical cyclones transitioned to extratropical phase in the JMA best track data during the period 1979–2004. Most ET events occurred with central pressure greater than 970hPa. However, sometimes more intense TCs completed ET, particularly in autumn. The latitude of ET completion was 35.4°N on average, varying from the south of 30°N in cold season to the north of 40°N in August. Both air-sea thermal contrast and the tropospheric vertical shear contributed to the season fluctuations in transition location. Using the JTWC best track data, Zhong et al.[9] found that 35% of

---

Received 2015-11-05; **Revised** 2017-07-11; **Accepted** 2017-08-15

Foundation item: National Natural Science Foundation of China (41465003), National Natural Science Foundation of China (41665006), China National Special Funding Project for Meteorology (GYHY201406010; GYHY201306071)

Biography: SUN Hong-mei, M.S., Research Associate, primarily undertaking research on tropical cyclones and forecasting.

Corresponding author: SUN Hong-mei, e-mail: 18707712799@163.com

all Western North Pacific TCs underwent ET during 1979–2008 with the method of CPS. In warm-season (June through September), 64% of all ET events occurred with the most occurrence in September. The most favorable region for ET onsets is the area 120°E – 150°E and 20°N–40°N in western North Pacific. The TCs experiencing ET at latitudes 30°N–40°N have greater intensity than those of at other latitudes. Using CMA best track data, Zhong et al.[10] also presented detailed statistics of Western North Pacific ET TCs. In contrast, only 23% of TCs underwent ET during 1961–2010 in CMA best track data. About 25% to 30% of ET events finally underwent intensification. Yuan et al.[11] found that only 17% of ET events re-intensified. Klein et al.[12] also found the phenomena.

At present, for TC forming in the western North Pacific, four sets of TC best track dataset from the China meteorological administration (CMA), Japan meteorological agency (JMA), the joint typhoon warning center (JTWC) of U.S. and the Hong Kong Observatory (HKO) (HKO dataset have no detailed information of TC extratropical transition) can be used. However, because of the different estimating techniques and different algorithms used to estimate TC intensity, the differences in TC frequency track and intensity of the four data sets still existed [13-17]. Song et al.[16] found that TCs in the JTWC data set are stronger than that of JMA and CMA and have an upward trend in the annual frequency of category 4–5, but downward trends are apparent in the JMA and CMA data sets. They also found that the different algorithms used in determining TC intensity may cause such trend discrepancies. Ren et al.[17] found that 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. In term of TC tracks, significant discrepancies exist in the two periods of 1951–early 1960s and 1988–1990s. This may have a great relationship to whether both aircraft reconnaissance data and the Dvorak technique were available or not. In fact, Ren et al.[17] also indicated that the CMA dataset has obvious advantages such as more complete and more accurate information, especially for TCs that affect China.

Admittedly, the discrepancies of TCs extratropical transition information among the three datasets also exist. Therefore, it is important and necessary to conduct a comparative analysis of TC extratropical transition data and climatology of the three datasets. After presenting a brief introduction to the data sets and methods used in this analysis in section 2, results are given in sections 3–4, a summary and conclusions are given in section 5.

2 DATA AND METHODOLOGY

As mentioned above, TC extratropical transition data used in this study are obtained from CMA, JMA and JTWC TC best track dataset at 6-hourly intervals, which include the time, location, and intensity of ET completion of CMA dataset from 1949, JMA from 1951, and JTWC from 2004. Since tropical depressions (VMAX < 17.2ms^{-1}) are not included in the JMA dataset, we only examine those TCs with a VMAX larger than 17.2ms^{-1}.

It is worth noting that the criterion used to indicate the end of the ET process in CMA TC best track dataset is whether a midlatitude frontal system has merged into the inner core of the TC circulation. The midlatitude front system is usually defined using either upper-level synoptic charts or satellite imagery, while the TC circulation is usually based on either surface level or low-level synoptic charts. After the ET process, an analysis of the central location is usually conducted according to upper-level synoptic charts, such as the 850-hPa charts. The procedure is similar to that for midlatitude cyclones, including the occlusion stage. The extratropical cyclone intensity is determined from surface station observations or is estimated from synoptic charts and satellite imagery when observations are not available [18]. In CMA TC best track dataset, the ET process is defined according to satellite imagery. When satellite imagery is not available, an analysis of the central location is usually conducted according to synoptic charts. Completion of the transformation is judged from "dissipation of a central dense overcast in satellite imagery" or "surface frontogenesis at the cyclone center in the surface analysis"[19-20]. JTWC is based on Klein's ET conceptual model[12] and CPS [5-6].

3 COMPARISON OF ET DATA AMONG CMA, JMA, AND JTWC TC BEST TRACK DATASET

Figure 1 indicates that CMA, JMA and JTWC all have ET data in 2004–2010. CMA and JMA are in 1951–2010. Statistics show that there are 69 ET TCs in JTWC's TC best track dataset during the period 2004–2010. CMA and JMA are 68 and 76 ET TCs,

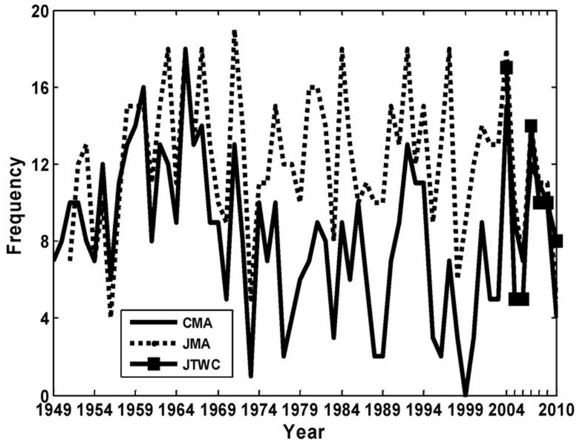

Figure 1. The annual numbers of ET TCs in the CMA, JMA, and JTWC datasets.

respectively. 53 ET TCs are identified by three agencies, consistently. The CMA dataset ranging from 1951 to 2010 have 496 ET TCs while the JMA dataset covering the period 1951 –2010 has 735 ET TCs, respectively. 464 ET TCs are consistent both in the CMA and JMA datasets. Consequently, our objective in this study is to examine the differences in ET data only for those ET TCs that were recorded simultaneously in the CMA, JMA, and JTWC TC best track datasets from 1951 to 2010 and from 2004 to 2010.

3.1 *Analysis of three agencies ET data in 2004–2010*

3.1.1 ET TCs RECORDED UN-SIMULTANEOUSLY BY THREE AGENCIES

There are two types of ET TCs that were not recorded simultaneously by the three agencies. One is that ET data were recorded only by one agency, e.g. only CMA, JMA, or JTWC; the other is that it is recorded by any two of the agencies. As we examined, ET TCs recorded only by CMA were none, those only by JMA were TC Kulap (0501) and Pabuk (0706), while those only by JTWC were 10. As mentioned in section 2, this discrepancy can be attributed to different criterion of ET judgment among the three agencies.

Table 1 indicates that ET TCs were recorded by any two of the agencies. As shown in Table 1, ET identification by JTWC is much different from that of CMA and JMA, while CMA and JMA get closed to each other. Moreover, ET TCs recorded by CMA were also recorded by JMA.

Table 1. ET TCs as recorded by any of the two agencies during 2004-2010.

Years	CMA&JMA		CMA&JMA		CMA&JMA	
	Only CMA	Only JMA	Only CMA	Only JMA	Only CMA	Only JMA
2004		Namtheun(0410) Meari(0421) Nanmadol(0427)	Sudal(0401) Meranti(0412) Haima(0420)	Namtheun(0410) Malou(0411) Malakas(0414) Meari(0421) Nanmadol(0427)	Sudal(0401) Meranti(0412) Haima(0420)	Malou(0411) Malakas(0414)
2005		Kulap(0501)	Sonca(0503) Nalgae(0506) Matsa(0509) Guchol(0512) Khanun(0515)	Bolaven(0523)	Kulap(0501) Sonca(0503) Nalgae(0506) Matsa(0509) Guchol(0512) Khanun(0515)	Bolaven(0523)
2006			Ewiniar(0603) Ioke(0612) Shanshan(0613)	Bebinca(0616)	Ewiniar(0603) Ioke(0612) Shangshan(0613)	Bebinca(0616)
2007		Pabuk(0706) Lingling(0718)	Podul(0717)	Lingling(0718) Tapah(0722) Mitag(0723)	Pabuk(0706) Podul(0717)	Tapah(0722) Mitag(0723)
2008			Phanfone(0810) Dolphin(0822)	Matmo(0803)	Phanfone(0810) Dolphin(0822)	Matmo(0803)
2009		Vamco(0910)	Linfa(0903)	Vamco(0910)	Linfa(0903)	
2010		Kompasu(1007)		Omais(1001) Kompasu(1007) Malou(1009) Megi(1013)		Omais(1001) Megi(1013) Malou(1009)

What caused the discrepancy of ET TCs identification among the three agencies? How is the geographic and temporal distribution of these 33 inconsistent ET TCs shown in Table 1? Close examination reveals that the discrepancy occurs in August to November, which peaks in August to September. The season of discrepancy correlates fairly well with the TC season. As shown in Fig.2, during the warm season (July–September), ET discrepancy occurs at high latitudes. Conversely, during the cold season (December-March), ET discrepancy occurs at low latitudes. Eastern China, Sea of Japan, ocean south of 30° N, and ocean east of Japan are the areas that are conducive to ET discrepancy.

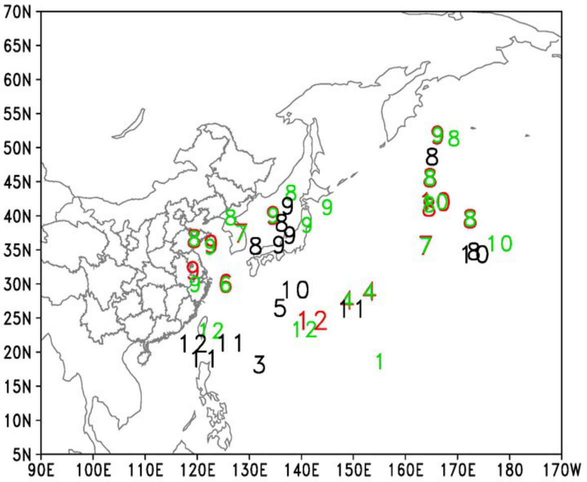

Figure 2. Geographical distribution of inconsistent ET TCs of the three datasets from 2004 to 2010. Digits in the figure represent ET months, with the red ones identified only by CMA, green ones only by JMA, and black ones only by JTWC.

3.1.2 ET TCs RECORDED SIMULTANEOUSLY BY THE THREE AGENCIES

Fifty-three ET TCs were recorded simultaneously by three agencies from 2004-2010. Annual average is 7.6 cases. The most ET TCs are 12 cases in 2004. The least are 4 cases in 2005 and 2006, respectively. These ET TCs can undergo ET at any month from April to December, with a higher ET probability from August to October, a peak in September and a secondary peak in October.

Based on 53 ET TCs, Fig.3 indicates the ET timing difference of the three agencies. 8% of ET TCs recorded simultaneously by the three agencies were determined to be without difference in ET timing. Approximately 90% of simultaneously recorded ET TCs in the JTWC best track dataset were identified to have completed ET process earlier than those of CMA and JMA, as early as about 12 h on average. Only one case was 6h later than that of CMA and JMA. The smallest ET timing difference occurs between CMA and JMA. Nearly 91% of simultaneously recorded ET TCs have no difference in ET timing identification.

To further explore ET data differences among the three datasets during the period 2004–2010, Table 2 shows the sustaining timing of a TC from ET process completion to lifecycle dissipation reports by agencies (called sustaining timing), indicating that ET TCs sustaining timing, on average, 8h at JTWC, about 20h at CMA and 55h at JMA.

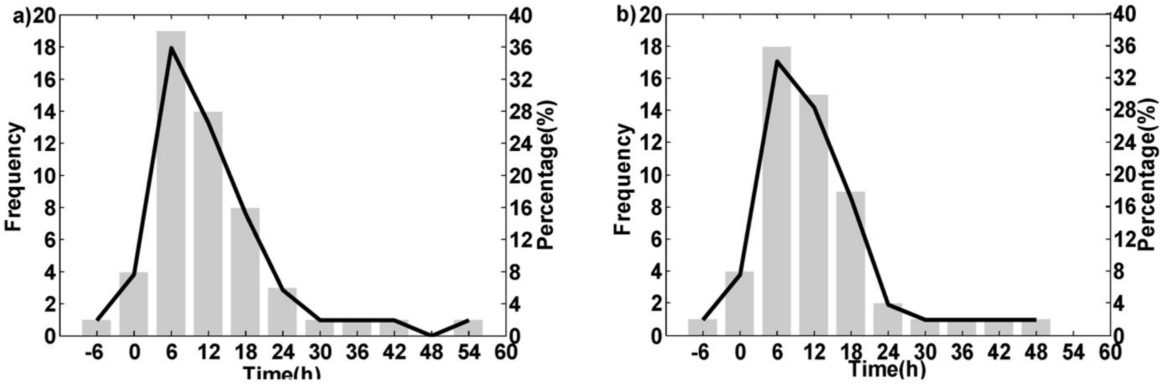

Figure 3. ET timing difference of ET TCs recorded simultaneously by the three agencies. a. ET timing difference of CMA and JMA; b. ET timing difference of JMA and JTWC. Left and right ordinate represent the frequency and percentage of ET TCs, respectively.

Table 2. Post-transition sustaining timing, standard deviation, and median of ET TCs recorded simultaneously by three agencies during 2004–2010.

2004-2010	ET TCs samples	Sustaining timing/h	standard deviation/h	median/h
CMA	53	20	21.5	12
JMA	53	54.9	46.4	42
JTWC	53	8.3	8.6	6

3.2 *Comparison of ET data among CMA and JMA TC best track dataset in* 1951–2010

As mentioned above, JTWC records ET data just from 2004. Most of ET TCs dissipate at the transition point or soon after. Consequently, ET data in JTWC dataset are greatly different from those of CMA and JMA in ET timing identification and post-ET sustaining timing. Therefore, our comparison is mainly focused on the differences between CMA and JMA in the ET TCs datasets.

3.2.1 COMPARISON OF ET TCs RECORDED SIMULTANEOUSLY BY CMA and JMA

Statistics show that 464 ET TCs were recorded simultaneously by CMA and JMA during the period 1951-2010. 32 and 271 cases were recorded by CMA and JMA, respectively. ET timing difference between CMA and JMA was on average about half an hour, which means the ET timing of CMA was earlier than that of JMA. Fig. 4a illustrates that 53.7% (249/464) of ET cases were without ET timing difference, 77.8% (361/464) of the cases from CMA were as early or late as 6h, and 84.9% (394/464) of the cases were 12 h.

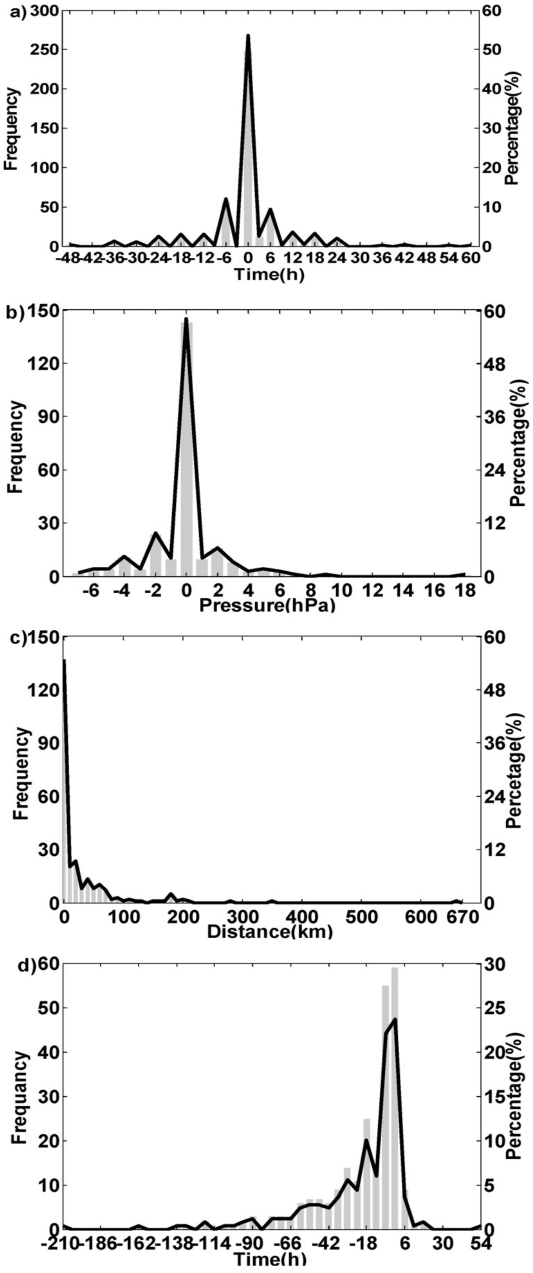

Figure 4. Differences of ET TCs recorded by CMA and JMA during 1951–2010. a. ET timing difference (CMA–JMA); b. centre pressure difference of ET TCs with the same ET timing; d. post-transition sustaining timing difference of ET TCs with the same ET timing. Bars represent the frequency and black curve is the percentage.

As mentioned above, for ET TCs recorded simultaneously by CMA and JMA during the period 1951–2010, 249 (249/464) cases were without ET timing difference. To further explore the 249 ET cases with difference, Fig. 4b shows their central pressure difference at the end of transition, which is between –7 and 18 hPa, with the mean difference being –0.1 hPa. 58.1% (143/249) of ET TCs had no central pressure difference and 81.3% (204/249) of ET TCs were ± 2 hPa. In terms of ET location difference (Fig.4c), the location difference was in the range of 0 to 669 km. The average was 32 km. 54.8% (135/249) of ET TCs had no location difference, 79.9% (199/249) of ET TCs were less than 50 km, and 91.9% less than 100 km. Only one case was 669 km. After careful analysis of the reasons for the location differences in CMA and JMA best track datasets, agencies [18] are the key factor for the ET TCs location difference to be greater than 300 km. The difference of sustaining timing (Fig.4d) is up to 210 h with an average of 21 h. 23.7% (59/249) of ET TCs had no sustaining timing difference, 71% of ET TCs in CMA datasets were shorter than those of JMA, and 49.4% (123/249) of ET TCs were ± 6 h.

It should be noted that there is no evident central pressure and location difference for the 249 ET cases without ET timing difference, but the sustaining timing difference was significant in 1951–2010.

3.2.2 POSSIBLE REASONS FOR ET IDENTIFICATION DIFFERENCE

In 1951-2010, for the 464 cases of ET TCs recorded simultaneously by CMA and JMA, the mean sustaining timing of the CMA dataset is 34h, while that of the JMA dataset is 54h, which means ET sustain timing of the JMA dataset is 20h longer than that of the CMA dataset. In fact, many storms in the CMA best-track dataset were stopped reporting when the TC crossed 55° N, while the JMA dataset still continued. Therefore, it is possible that the inconsistent TC dissipating time of CMA and JMA can result in ET identification differences.

In addition, the agencies are another important reason resulting in ET identification differences between CMA and JMA datasets. Consequently, we compare the ET timing of the 271 ET TCs recorded only by JMA with last reported time of corresponding TCs in the CMA dataset, finding that six TCs were identified by agencies and one TC (Tess (6102)) was not recorded by the CMA dataset.

To further determine the possible reasons for ET identification difference between CMA and JMA, we continue to compare ET timing of the remaining 264 ET TCs recorded only by JMA with the last reported time of corresponding TCs in CMA dataset. T_{CMA} represents the last reported time of corresponding 264 TCs in the CMA dataset, and T_{JMA} represents the ET timing of the remaining 264 ET TCs recorded only by JMA. If T_{CMA}–T_{JMA} is less than zero, it means that these

264 ET TCs have stopped reporting by CMA while JMA continues to report their track information. If $T_{CMA}-T_{JMA}$ is greater or equal to zero, it means that these TCs continued to be reported but were not determined to be transitioned TCs. As shown in Table 3, 35.6% (94/264) of ET TCs were earlier stopped reporting by CMA, 64.4% (170/264) of ET TCs were caused by inconsistent ET identification methods.

Table 3. Frequencies and percentages of controversial ET TCs caused by inconsistent TC stopped reporting time and subjective ET determination method of CMA and JMA.

	TC frequencies	percentages
CMA-JMA<0	94	35.6%(94/264)
CMA-JMA=0	57	21.6%(57/264)
CMA-JMA>0	113	42.8%(113/264)

Besides, for the 32 ET TCs recorded only by CMA, one case (Irma (6020)) was not recorded by JMA, 16 % (5/31) of ET TCs were earlier stopped reporting by JMA, and 84% (26/31) were caused by inconsistent ET identification methods by the two agencies.

In fact, there are yet no consistent objective ET determination criteria in current operational centers; the determination of ET is mainly based on synoptic charts and satellite imagery, making ET determination vary subjectively. As mentioned in section 2, the ET determination in CMA best-track dataset is more rigorous than that of JMA, which may also cause greater ET data differences between CMA and JMA. Thus, it is desirable to develop and apply consistent objective ET determination criterion to operational forecasts and warnings.

4 CLIMATOLOGICAL DIFFERENCES OF ET TCS BASED ON CMA AND JMA DATASETS

To further understand the climatological differences of ET TCs in CMA and JMA datasets, a comprehensive climatology of extratropical transition in the Western North Pacific based on CMA and JMA datasets is presented here. During the period 1951–2010, although there are no significant differences in the recorded total of TCs frequency in CMA and JMA datasets, the frequency of ET TCs in the JMA dataset is 239 cases more than that of the CMA, and the percentage of ET TCs in the JMA dataset is 49.3% while that of the CMA dataset is 32.8% (Table 4). The percentage of ET TCs in the JMA dataset is the highest. According to the results of other meteorologists, Zhong et al.[9], who used the JTWC best track data, found that 35% of all Western North Pacific TCs underwent ET during 1979–2008 with the method of CPS, and Zhong et al. [10], using CMA best track data, found that only 23% of TCs underwent ET during 1961–2010. Note that tropical depressions are included.

Table 4. Frequency of TCs and ET TCs in CMA and JMA datasets during 1951–2010.

	TCs	ET TCs	annual average TCs	annual average ET TCs	ET percentage
CMA	1,512	496	25	8	32.8%
JMA	1,490	735	25	12	49.3%
CMA-JMA	22	–239	0	–4	–16.5%

4.1 *Differences in decadal changes of ET TCs frequency*

Figure 5a shows the annual numbers of ET TCs in CMA and JMA datasets. The annual numbers of ET TCs in CMA dataset have a decreasing trend, while those in JMA dataset have no significant change. Except for a few years (1951, 1955, 1956, 1957 to 1960), the annual numbers of JMA ET TCs are more than those of CMA, with the most being 11 cases, e.g. in 1996 and 1997. Fig. 5b illustrates the subtraction of JMA and CMA annual numbers of ET TCs and 5–year running mean of the subtraction (the black curve). As shown in Fig. 5b, the subtraction is small during 1951–1960, the difference from 1961 to 1981 increased year by year, which showed a decreasing trend in 1981–1995 before beginning to increase until 2000, but after 2000 the difference decreased year by year, especially in the five years of 2005–2010 with the difference reaching a minimum, and the maximum was with no more than three cases. Thus, it should be noted that the period 1961–2000 are mainly the years creating ET identification discrepancy between CMA and JMA, while the differences in the past 10 years have significant reduction.

Figure 5c shows the annual percentage of ET TCs in CMA and JMA datasets. Except for 1951, 1955 and 1957, the annual percentage of JMA ET TCs is higher than that of CMA. In the JMA dataset, the highest annual percentage is up to 76% (1953), the minimum is 21.7% (1956), while the highest in CMA is 63% (1977), the minimum is null (1999), and the decadal changes of annual ET percentage of CMA and JMA are similar to that of annual ET numbers.

4.2 *Differences in seasonal variations of ET TCs*

As shown in Fig.6 (a & b), the number of ET events following a distribution in time is similar to that of the total number of TC occurrences. Most of ET events occur in June to November, with the maximum in September and minimum in February. Fig.6 (a & b) also shows the monthly percentage of ET event of CMA and JMA datasets. February is the month of the lowest ET probability, and July is also the lowest with respect to active TC and ET seasons. In the CMA dataset, the highest is May, followed by September and October, while in JMA the highest is September, followed by May and October.

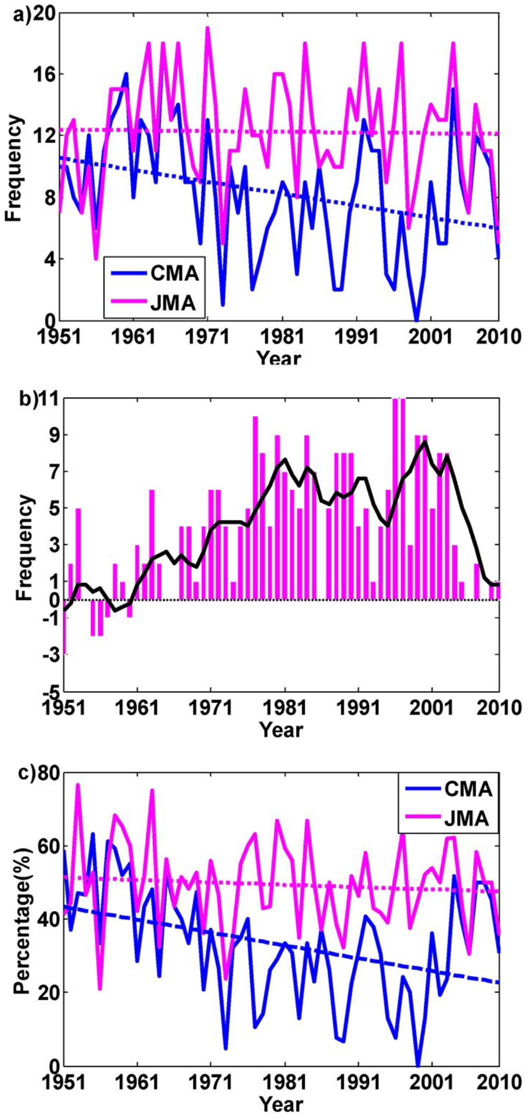

Figure 5. a. Annual numbers of ET TCs of CMA and JMA; b. Subtraction of ET TCs frequency between JMA and CMA (black curve is 5-year running mean of ET TCs frequency); c. Interannual variability of ET TCs percentage.

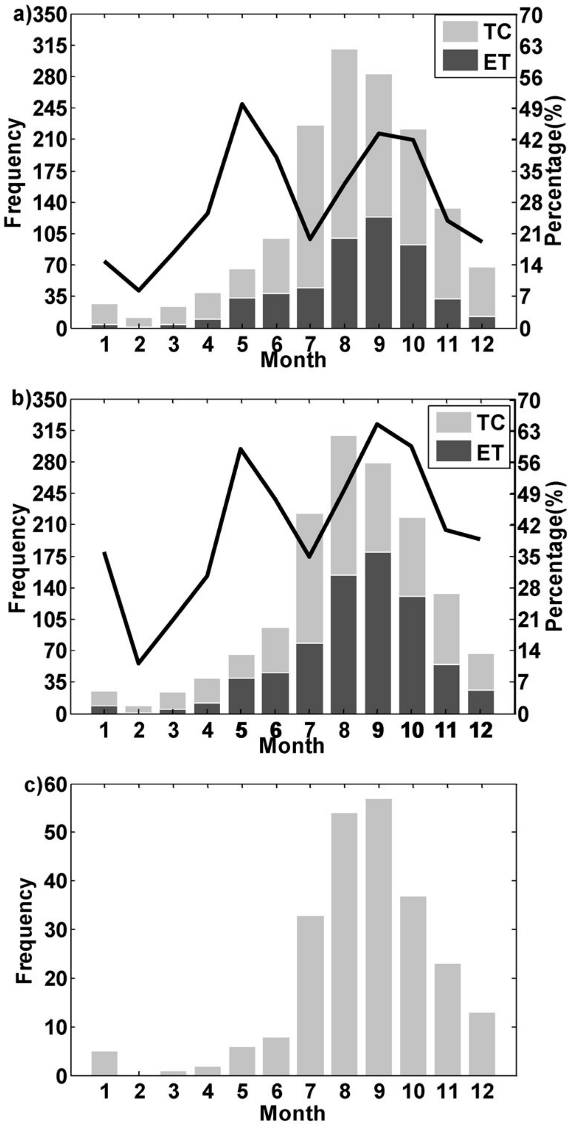

Figure 6. Seasonal variation of TCs and ET TCs frequency. a. CMA; b. JMA; c. Subtraction of monthly frequency of ET TCs between JMA and CMA.

Figure 6c illustrates the subtraction of monthly number of ET TCs in JMA and CMA datasets. In addition to February, the number of CMA ET TCs is lower than that of JMA. The months of significant difference range from July to October and peak in September with the maximum in 57 ET events. In contrast, January to June has relatively small difference with total numbers less than 10 cases. Clearly, it is the TC active season (July–October) that easily produces ET identification differences between CMA and JMA. It should be noted that cold air in the summer and early fall is not active. As mentioned in section 2, ET identification criterion at CMA is more stringent than that of JMA. In fact, only when cold air invades the central region or frontal cloud systems move into the central circulation area of TC did CMA determine that a TC has completed ET, while ET TCs in the JMA dataset are determined with relatively loose limitations. Usually, cold air in summer and early fall is weak, but the TC active season may make ET TCs of CMA less than those of JMA.

4.3 *Differences in geographical distribution of ET TCs*

During 1951–2010, latitudinal distribution of ET TCs frequency exhibits that most of ET TCs underwent ET at the latitude band of 25°N–45°N with the peak at 35°N–40°N both in CMA and JMA datasets (Fig.7a), while ET TCs at lower or higher latitudes are relatively small, which are consistent with the results of Atlantic[21]. In fact, TCs undergoing ET at lower latitudes usually generate in cold season (December-March), while in this season less TCs are generated and cold air is difficult to invade southward to lower latitudes, resulting in less ET events at lower latitudes. Besides, less TCs go through ET at higher latitudes as they move poleward, because of the changes in its environment, such as decreased sea surface temperature or increased baroclinity and vertical shear. For a TC, these factors are usually disadvantageous for it to retain its tropical characteristics, make it dissipate in most cases. Only a small part of the TCs can reach higher latitudes and complete ET process.

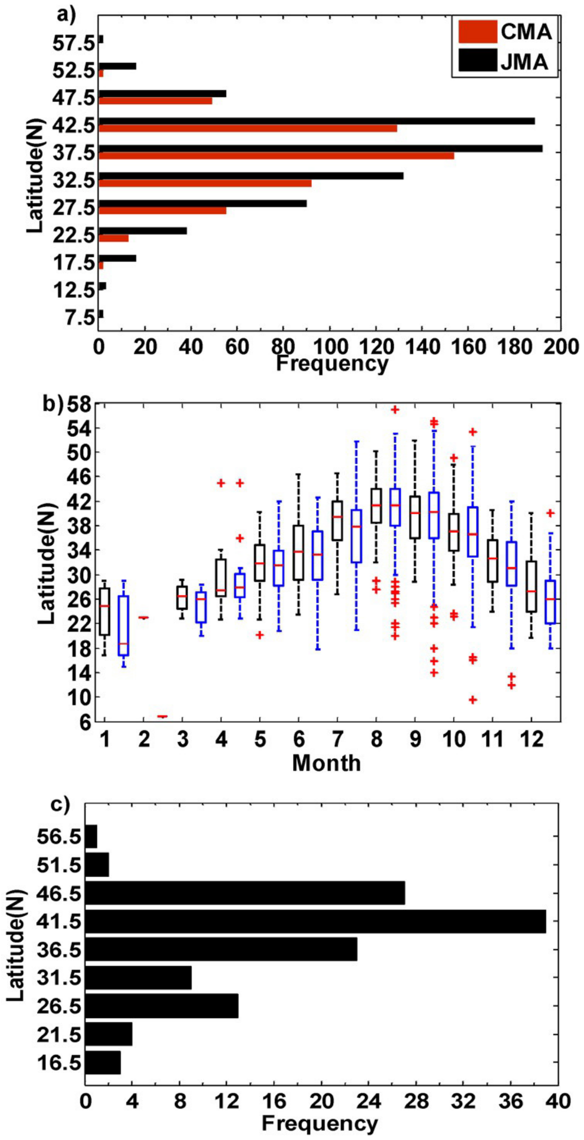

Figure 7. a. Frequency of ET TCs at different latitudes in CMA and JMA datasets during 1951–2010 (the values of the ordinate represent the latitude range of "value±2.5°"); b. Box plots of seasonal changes of ET latitudes (black boxes for CMA and blue boxes for JMA), "+" represents outliers. c. same as Fig.7a but for ET TCs recorded only by JMA.

Figure 7b illustrates seasonal changes of ET latitudes and monthly distribution of CMA and JMA ET TCs. The latitude of ET occurrence shifted northward from February to August, followed by a southward shift. Hart et al.[21] found that the seasonal cycle of transition location of Atlantic TCs is the result of competing factors. Late in the season, the delayed warming of ocean forces the location of transition northward while the climatologically favored region for baroclinic development expands southward. The relative position of the two regions finally determines seasonal changes of ET latitudes.

In addition, as shown in Fig.7b, the transition latitudes of CMA are between 17°N and 52°N from January to December, while the range of JMA is much larger than that of CMA, extending equatorward to 7°N (Ruby (6701)) and polarward to 57°N (Ellen (6711)). Moreover, during August to September, the monthly ET latitudes of JMA dataset have more outliers and a larger range than that of CMA. Fig.7c also illustrates the frequency distribution of ET TCs recorded only by JMA in different latitudes from 1951 to 2010. The latitudes 34 °N to 49 °N are most likely to result in ET identification difference between CMA and JMA, followed by 24°N–29°N, while the south of 24°N and north of 49°N are relatively small.

Figure 8 also shows the geographical distribution area of ET TCs frequency. The main distribution area of ET TCs in the CMA dataset is to the east of 110°E and north of 15°N with the most to the north to 55°N. The ET-prone area is the Sea of Japan, central Japanese islands, and ocean surface east of the Japanese islands (Fig.8a). While the ET distribution area of JMA is wider than that of JMA, westernmost to 100° E, the southern and northern boundary are as far as 10°N and 55°N, respectively. The ET-prone area is the Japanese islands and ocean surface to the east of the islands, which is five longitudes more to the east than that of CMA (Fig.8b), and with much larger frequency in South China, South China Sea, and Indochina Peninsula, especially in the Yunnan–Guizhou Plateau (see Fig.8c). It is also noted that, in Central China, East China, East China Sea, Bohai, and Liaoning, the ET frequency is also higher than that of CMA (Fig. 8c).

4.4 *Differences in complete ET intensity*

Figure 9 illustrates the time evolution of ET TCs central pressure. Two characteristics can be informed from Fig.9. Firstly, the intensity of ET TCs increases with latitudes, which indicates ET at higher latitudes with strong intensity but ET at lower latitudes with weak intensity. Secondly, for the same latitude band, TCs completing ET in the mainland of China or offshore are weaker than those in the ocean, maybe because the friction of land or offshore is greater than that of the ocean or other environmental factors.

The linear fitting of ET TCs central pressure by latitude and longitude indicates that the strength (pressure) of central pressure of complete ET with ET latitude (from south to north) and longitude (from west to east) increases (decreases). The fitting line slope of CMA is greater than that of JMA, while the fitting line of interception of CMA is smaller than that of JMA, which indicates that ET TCs intensity of CMA increasing with latitude or longitude is faster than that

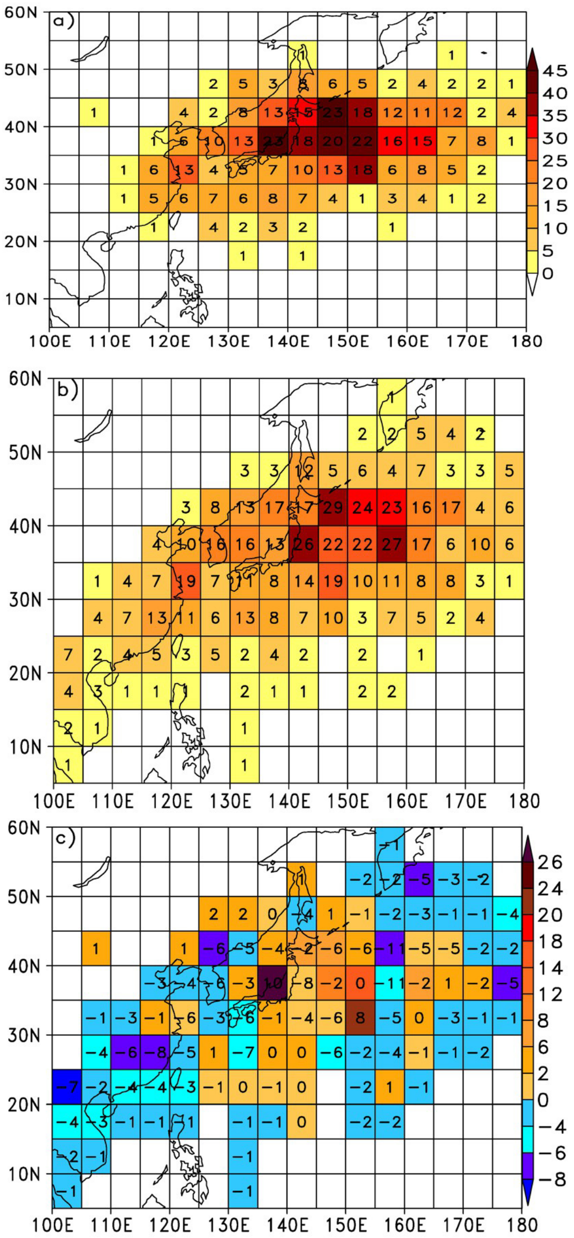

Figure 8. Geographical distribution of ET TCs in CMA and JMA datasets. a. CMA; b. JMA; c. subtraction of frequency of CMA and JMA. The values in the figures represent numbers of ET TCs in a 5°×5° grid box, the values of color code represent per mill of ET TCs in a 5°×5° grid box.

of JMA. At the same latitude or longitude, the intensity of CMA ET TCs is stronger than that of JMA. Further investigation shows that most of ET TCs in the CMA dataset are stronger than those of JMA.

Figure 10 indicates that the mean intensity of ET TCs gradually weakened 24h before the completion of ET. After ET, 21% (27%) of the TCs showed an intensification process based on the CMA (JMA) dataset during the post-ET period, while 79% (73%) weakened or remained unchanged. Mean intensity of post-transition still weakened.

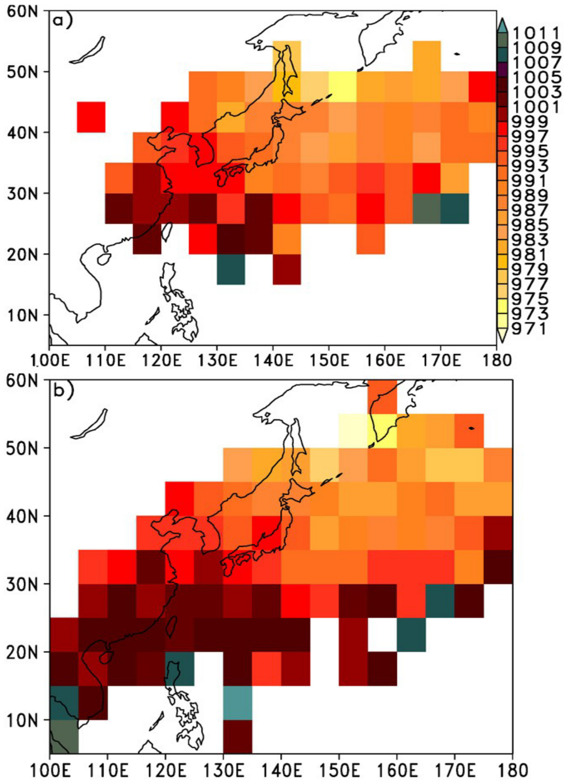

Figure 9. Geographical distribution of centre pressure of ET TCs at the time of ET completion during 1951–2010. a. CMA; b. JMA. The pressure in each box represents the mean of centre pressure in 5°×5° grid box.

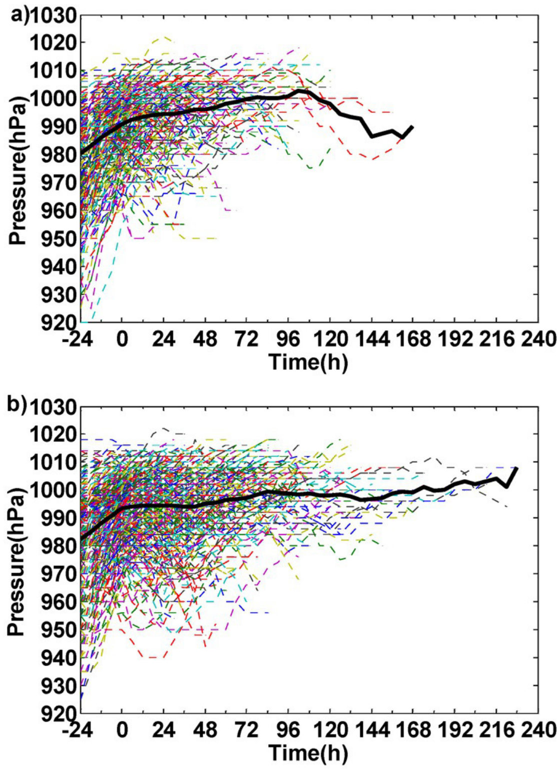

Figure 10. Central pressure evolution of ET TCs in CMA and JMA datasets during 1951 –2010. a. CMA; b. JMA. "0"represents the time of complete ET; black curve is the mean of central pressure.

In fact, most of ET TCs are stopped reporting 108h after the completion ET in the CMA dataset. Only fifteen ET cases were recorded. There are two cases (5307, 5613) with central pressure less than 995hPa and continuing to intensify 108h after the completion ET, which enhanced the mean intensity of CMA ET TCs significantly 108h after the completion ET (Fig.10a). In addition, as shown in Fig.10, the sustaining timing of CMA ET TCs is shorter than that of JMA. The statistics show that the mean sustaining timing of CMA (with samples of 496) is 34 h, with the maximum at 168 h, while JMA (with samples of 735) is 47 h, with the maximum at 228 h. For ET TCs recorded simultaneously by CMA and JMA (with samples of 464) during the period 1951–2010, there is a weak negative correlation between ET timing difference and sustaining timing difference, which indicates that the sooner of the completion ET, the longer of post-transition sustaining timing. Moreover, as mentioned in section 3.2.1, even for ET TCs without ET timing difference, the sustaining timing of CMA was significantly shorter than that of JMA.

5 CONCLUDING REMARKS

In this article, we have investigated the differences in the climatology of ET of western North Pacific TCs based on TCs best-track datasets of CMA, JMA, and JTWC. The findings can be summarized as follows:

(1) In the year 2004-2010, the discrepancy of ET TCs identification among the three agencies mainly occurs in the TC season, Eastern China, Sea of Japan, and the ocean east of Japan islands. ET discrepancy occurs at higher latitudes in the warm season, while it occurs at lower latitudes in he cold season. For ET TCs recorded simultaneously by three agencies, ET timing of JTWC is as early about 12h as that of CMA and JMA on average, while there is smallest ET timing difference between CMA and JMA. In terms of sustaining timing of post-transition, JTWC is shortest, followed by CMA and JMA. Consequently, in the recent seven years of 2004–2010, ET data of JTWC dataset are greatly different than those of CMA and JMA, while the data of CMA and JMA have no significant difference.

(2) In the year 1951–2010, most of ET TCs recorded simultaneously by CMA and JMA have an ET timing difference of 12 h. There are no significant differences in centre pressure and ET locations, but they are evident in sustaining timing for ET TCs with the same ET timing. Agencies, inconsistent TC stopped reporting time, and subjective ET determination method can result in ET identification difference between CMA and JMA.

(3) The results of climatological difference of ET TCs in CMA and JMA datasets show that the annual percentages of ET TCs in the CMA dataset have a decreasing trend, while those of JMA have no significant change. Most of ET events occur in June to November, with a peak in September and a valley in February. Most of ET TCs underwent the ET peak at the latitude band 35° N–40° N. The latitude of ET occurrence shifted northward from February to August, followed by a southward shift. The range of ET occurrence of JMA is much larger than that of CMA, and the ET-prone area is Japanese islands and east of them, which are five longitude bands as east as that of CMA. Intensity of ET TCs increases with latitudes, and for the same latitudes, TCs completing ET in the mainland of China or offshore are weaker than those in the ocean. Most of the TCs weakened 24 h before the completion of ET, while 21% (27%) of the TCs showed an intensification process based on the CMA (JMA) dataset during the post-ET period.

From what this article reveals, we present the following recommendations: (1) ET TCs data of JTWC is greatly different from that of CMA and JMA, caution should be exercised in research; (2) ET identification methods of CMA and JMA get close to each other since 2004. It is necessary to modify and replenish the ET data prior to 1979 using reanalysis data and the method of CPS, while ET data after 1979 can be revised to combine with satellite imagery. (3) ET identification method in present operation is too subjective, and it is desirable to strengthen the operational application of objective ET identification among the centers.

Acknowledgement: We are grateful to Ying Ming and Li Qing-qing for their helpful advice and help.

REFERENCES:

[1] MAO Hui-qin, SONG Li-li, HUANG Hao-hui, et al. Study on the wind energy resource division in Guangdong province [J]. J. Nat. Res., 2005, 20 (5): 679-683 (in Chinese).

[1] PALME′ N E. Vertical circulation and release of kinetic energy during the development of Hurricane Hazel into an extratropical storm [J]. Tellus, 1958, 10(1): 1-21.

[2] HILL H W. The precipitation in New Zealand associated with the cyclone of early April 1968 [J]. N Z J Sci, 1970, 13(4): 641-662.

[3] JONES S C, HARR P A, ABRAHAM J, et al. The extratropical transition of tropical cyclones: Forecast challenges, current understanding, and future directions [J]. Wea Forecast, 2003, 18(6): 1052-1092.

[4] HARR P A, ELSBERRY R L, HOGAN, T F. Extratropical transition of tropical cyclones over the western North Pacific. Part II: The impact of midlatitude circulation characteristics [J]. Mon Wea Rev, 2000, 128 (8): 2634-2653.

[5] EVANS J L, HART R E. Objective indicators of the life cycle evolution of extratropical transition for Atlantic tropical cyclones [J]. Mon Wea Rev, 2003, 131 (5): 909-925.

[6] HART R E. A cyclone phase space derived from thermal wind and thermal asymmetry [J]. Mon Wea Rev, 2003, 131(4): 585-616.

[7] GUO Rong, LEI Xiao-tu, GUO Pin-wen. A study on the criterion of extratropical transition of western north Pacific tropical cyclones [J]. J Trop Meteor, 2011, 27(2): 257-263 (in Chinese).

[8] KITABATAKE N. Climatology of extratropical transition of tropical cyclones in the western North Pacific defined by using cyclone phase space [J]. J Meteor Soc Japan, 2011, 89(4): 309-325.

[9] ZHONG Lin-hao, HUA Li-juan, FENG Shi-de. A climatology of extratropical transition of tropical cyclones in the western North Pacific [J]. J Trop Meteor, 2009, 15 (2): 130-147.

[10] ZHONG Ying-min, XU Ming, WANG Yuan. Spatio-temporal distributive characteristics of extratropically transitioning tropical cyclones over the Northwest Pacfic [J]. Acta Meteor Sincia, 2009, 67(5): 697-707 (in Chinese).

[11] YUAN Juan-juan, DING Zhi-ying, WANG Li. A statistical study and composite analysis on the characteristics of the extratropical transition of landfall typhoons during 1949-2007 [J]. J Trop Meteor, 2011, 27 (4): 529-541 (in Chinese).

[12] KLEIN P M, HARR P A, ELSBERRY R L. Extratropical transition of western North Pacific tropical cyclones: An overview and conceptual model of the transformation stage [J]. Wea Forecast, 2000, 15 (4): 373-395.

[13] LEI Xiao-tu. The precision analysis of the best positioning on WNP TC [J]. J Trop Meteor, 2001,17(1): 65-70 (in Chinese).

[14] YU Hui, HU Chun-mei, JIANG Le-yi. Comparison of three tropical cyclone strength datasets [J]. Acta Meteor Sin, 2006, 64(3): 357-363 (in Chinese).

[15] WU Shen-gan, KONG Hai-jiang, WU Hui. Differences among different databases in the number of tropical cyclones forming over the Western North Pacific [J]. J Trop Meteor, 2009, 25(6): 660-666 (in Chinese).

[16] SONG J J, WANG Y, Wu L. Trend discrepancies among three best track data sets of western North Pacific tropical cyclones [J]. J Geophys Res, 2010, 115 (D12): 1-9.

[17] REN F, LIANG J, WU G, et al. Reliability Analysis of Climate Change of Tropical Cyclone Activity over the Western North Pacific [J]. J Climate, 2011, 24 (22): 5887-5898.

[18] YING M, ZHANG W, YU H, et al. An overview of the China Meteorological Administration tropical cyclone database [J]. J Atmos Oceanic Technol, 2014, 31 (2): 287-301.

[19] KITABATAKE N. Extratropical transformation of Typhoon Vicki (9807): Structural change and the role of upper tropospheric disturbances [J]. J Meteor Soc Japan, 2002, 80(2): 229-247.

[20] KITABATAKE N. Extratropical Transition of Tropical Cyclones in the Western North Pacific: Their Frontal Evolution [J]. Mon Wea Rev, 2007, 136(6): 2066-2090.

[21] HART R E, EVANS J L. A climatology of the extratropical transition of Atlantic tropical cyclones [J]. J Climate, 2001, 14(4): 546-564.

Citation: SUN Hong-mei, LEI Xiao-tu, TANG Jie et al. Comparisons of the characteristics of tropical cyclones experiencing extratropical transition in the western North Pacific based on different datasets [J]. J Trop Meteor, 2017, 23(3): 281-291.