Article ID: 1006-8775(2006) 02-0150-09

# STATISTICAL CHARACTERISTICS ON TROPICAL CYCLONES LANDFALL IN CHINA

LI Ying (李　英)[1], CHEN Lian-shou (陈联寿)[1], ZHANG Sheng-jun (张胜军)[1], LEI Xiao-tu (雷小途)[2]

(1. Chinese Academy of Meteorological Sciences/LaSW, Beijing 100081 China; 2.Shanghai Typhoon Institute, Shanghai 200030 China)

**ABSTRACT:** With the data from the Tropical Cyclone Yearbooks between 1970 and 2001, statistical analyses were performed to study the climatic features of landfall TCs (noted as TCs hereafter) in China with particular attention focused on landfall frequency, locations, sustaining, decaying, transition, intensification and dissipation etc. The results indicate that the sustaining periods of TC over land are quite different for different landfall spots, and increased from Guangxi to Zhejiang. The most obvious decreasing of TC intensity occurs mainly within 12 hours after landfall. The stronger a TC is，the more it decays. The areas over which TCs are dissipated can be in Heilongjiang, the northernmost, and Yunnan, the westernmost. Besides, Guangxi is an area with high dissipating rate and subject to TC dissipation as compared with the other coastal regions.

**Key words:** tropical cyclones; landfall; Statistics

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

## 1 INTRODUCTION

The TCs bring about major disasters during their landfall processes. To mitigate the storm disasters, landfall processes of TCs have been drawing great attention from the research community. China is a country with the highest frequency of TCs landfalls in the globe. The decaying of TCs after landfall is a key issue in the study of TCs landfalls. The study shows that the sustaining of TCs over land depends on the season, land surface effect, environmental circulation, and structure/intensity of the cyclone itself (Chen [1]). Zhu and Chen [2] analyzed the interannual and monthly variations of TCs activities over the period from 1949 to 1996. Lei and Chen [3] investigated and compared in details different characteristics of TCs activities under the environments of tropical and middle latitude circulations. Initial analysis by Zhang [4] on the decaying characteristics of landfall TCs showed that 65.7% of landfall TCs dissipated within 24 hours in the mountainous and plateau regions, while only 10% in plain areas. Yu [5] studied the climatological characteristics of intensity changes after TC landfall. Liu [6] applied wavelet analysis on the climatological characters of annual frequency and the initial TC landfall date of landfall TCs that severely affected Guangdong. In spite of the above studies, no research has been published on statistical study on characteristics of activities of TCs landfall in China, such as their destination, sustaining period, decaying, transition and dissipation after their landfall.

Using the data from *Typhoon Yearbooks* and *Tropical Cyclone Yearbooks*[7-8], which are compiled by the China Meteorological Administration, statistical analyses were carried out on the characteristics of landfall TCs originating from the western North Pacific (including the South China Sea, same below) over the period from 1970 to 2001.

## 2 LANDFALL

### 2.1 Temporal distribution of landfall TCs

From 1970 to 2001, a total of 863 TCs (including tropical storms, severe tropical storms and typhoons) were generated in the western North Pacific, with an average of 27 TCs per year. Among them, 256 TCs (in 341 times) made landfall, with annual mean of 8 TCs (11 times), about 30% (40%) of the total.

---

**Received date:** 2005-08-26; **revised date:** 2006-08-22

**Foundation item:** National Natural Science Foundation of China (40575018); Shanghai Typhoon Research Foundation (2003ST015)

**Biography:** LI Ying (1968-), female, native from Yunnan Province, senior engineer, Ph.D., mainly undertaking the study on tropical cyclones and their forecast.

E-mail: liying@cams.cma.gov.cn

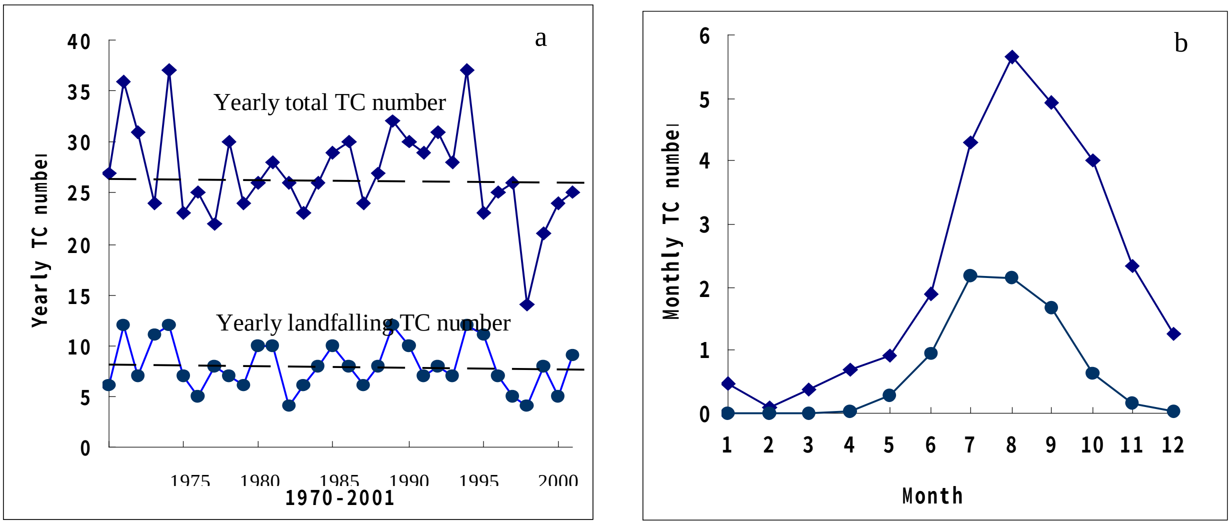



Fig.1 The interannual (a) and monthly (b) variation of the total number of TC occurrences (lines with squares) and the number of landfall TCs (lines with circles) over the western North Pacific from 1970 to 2001.

Fig.1a showed the interannual variation of the number of TC generation and landfall, respectively, in western North Pacific during the 32 years. It illustrated that positive correlation existed between the number of TCs landfalls in China and the total number of TCs generated over the western North Pacific every year, of which the tendency of variation was basically the same, with a period of about 4-6 years. This is consistent with the analysis results by Zhu and Chen [2]. It may be seen through the tendency that the number of TCs generated from 1995 to 2001 was less than 27, which is the annual mean number of TCs averaged over the 32 years (as shown by the dashed line). Specifically, the TC number in 1998 is the lowest over the 32 years (ever since 1949), with only 14 TCs generated. Moreover, the highest number of TCs landfalls in China is 12, while the lowest is only 4. Similarly, the number of TCs landfalls in China is lower than the average after 1995, except 2001. Therefore, it may be considered that the period from 1995 to 2001 is climatologically in a phase with less-than-average numbers of TCs generated in western North Pacific and landfalls in China, respectively. The study by He and Song[9] also showed that the year 2000 was the 6$^{th}$ consecutive year after 1995 with less-than-average number of TC occurrences as a result of abnormally large scale atmospheric circulation.

From the monthly variation of TC number averaged over the 32 years as shown in Fig.1b (the line with squares), it may be known that there existed TC genesis round the year, with less than one a month in January through April, and the least in February. Then the number of TC genesis increased until August when it reaches the maximum, followed by a decrease by the month in September to December. The TC genesis mainly occurred in July – October. The number of landfall TCs (the line with circles) had a similar trend of monthly variation as that of TC genesis, and is zero from January to March, reaches maximum in July, is slightly less in August, and is in downgrade sequence as in September, June, October, May, November, April and December. During the 32-year period, there was only one TC landfalling in China in April and December, respectively, i.e. the severe tropical storm 9103 (Vanessa) and the strong typhoon 7427 (Irma). The period from July to September is the most active season for TCs landfalling in China, about 75% of the total number of the landfall TCs.

### 2.2 Spatial distribution of landfall TCs

During the period from 1970 to 2001, there were 341 times of TC landfalls (including multiple landfalls of a TC) in China, about 11 times on average per year. Fig.2 explained the annual mean number of landfall TCs in coastal provinces in China during the 32 years, from Guangxi to Liaoning Province. Guangdong is the province with the highest rate of landfall TCs, about 35.2%, or over 1/3 of the total number of TCs landfalling in China, followed by Hainan, Taiwan and Fujian with 17.9%, 15.8% and 14.4%, respectively, and then by Zhejiang, Guangxi, Shandong, Liaoning, Jiangsu, Shanghai and Tianjin.

## 3 TC SUSTENTION OVER LAND

### 3.1 General description

The duration of TCs sustaining over land is variable. Some TCs dissipated soon after they landed while others disappeared or moved into sea again after they sustained over land for a certain period of time. According to the TCs Yearbooks, there were 256 landfall TCs from 1970 to 2001. The activities of these typhoons may be categorized into the following: dissipating over land after landfall, re-entering into sea after a long trip inland, passing over islands, landing again outside China (destination no known) after passing over an island, and moving into sea again in less than 24 hours after landfall. Neglecting the latter three categories of landfall TCs which were mainly under the influence of sea, the study is focused on sustaining and dissipation of TCs over land, i.e. the first two categories. The duration of a TC sustaining over land may be defined as the time interval between landfall and disappearance of a TC over land or moving into sea again; or the sum of time periods over land if the TC has multiple landfalls.

During the 32 years, 92 landfall TCs which were in the latter three categories as described above were neglected in the study. Statistical results (Table not shown) for the rest 164 landfall TCs investigated indicated that 142 TCs landed in China and dissipated over land, and 22 TCs moved deep inland for over 24 hours and reentered the sea. Among the 164 landfall TCs, those sustaining over land for periods ≤ 6, 6 – 12, 12 – 24, 24 – 48 and ≥ 48 hours were about 7%, 17%, 21%, 34% and 21%, respectively, of the total landfall TCs. In other words, the landfall TCs maintained over land for half a day to two days after landfall were about 3/5, while those which either disappeared within 12 hours or remained active for more than 2 days after landfall were about 1/5.

### 3.2 Interannual and monthly variation of TC maintenance over land

The mean duration for the 164 TCs to sustain over land is 31 hours. From the Fig.3a, it may be seen that the interannual variation of the duration varied quite significantly. For some years, the mean duration can be as long as 57 hours after TC landfall, e.g. 1975. Contrarily, it can be as short as 12 hours in 1998, as an example. Examining the general trend, it may be understood that the landfall TCs sustained over land longer from the 1970's to the mid-1980's than from the 1980's to 2001. It was also indicated that the annual mean durations were mostly lower than the total mean value (as shown by the dashed line).

The duration of TC sustaining over land is also associated with seasons of TC occurrences. Fig.3b shows the monthly variation of sustaining period of TC over land. It is known that TCs sustain the longest over land in August and July, reaching 39 and 32 hours, respectively, followed by June and September for about 25 hours. The TC sustaining period over land was relatively short in October, November and May, varying between 16 and 20 hours.

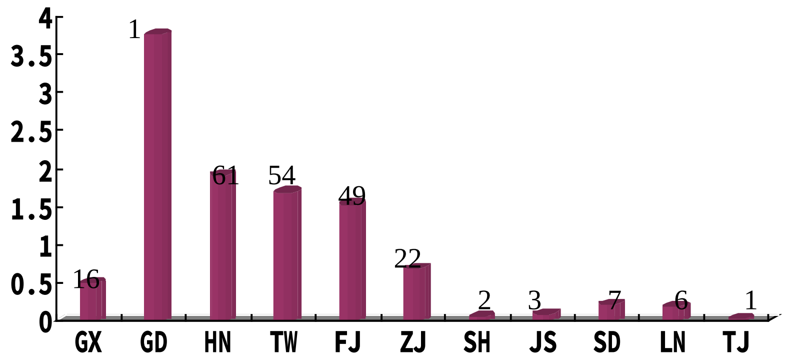
### 3.3 Spatial distribution of TC maintenance over land

The duration of TC sustaining after landfalling was significantly different depending on the coastal areas where landfalls occurred (Figure not shown). The TC sustaining period was the longest, more than two days on average (53 hours), if TCs landed in Zhejiang, evidently longer than other provinces and 16 hours more than the second longest province of Fujian (37 hours on average). There were only three cases that landed in Jiangsu (plus Shanghai), with averaged sustaining duration of 32 hours after landfall. It was the least duration (16 hours) of TC sustaining if TCs landed in Guangxi. Coming after Guangxi is Guangdong, 26 hours on average. It might be different for TCs making landfalls Liaoning. The TC sustaining duration over there was about 27 hours on average, slightly longer than that in Guangdong. However, since Liaoning was geographically located in the northernmost relative to other provinces on the coast of China, the TC sustaining period over land was closely related to possible invasion of cold air.

### 3.4 TC sustaining over land in relation to its intensity at landfall

The duration of TC sustaining over land was also related to TC intensity. By minimizing the effects of seasonal changes, geographical differences and land surface diversity, for more straightforward illustration of the relationship between TC sustaining duration and TC intensity, scattered plotting diagrams (see Fig.4) for the correlation between TC sustaining duration and TC intensity (by the minimum sea level pressure of TC centre and maximum wind speeds) were made for TCs making landfalls in Fujian from July to August. It may be seen from the diagrams that there existed evident correlation (See the solid lines in Fig.4) between TC sustaining duration over land and TC intensity. The TC sustaining duration was proportional to the maximum wind speed of TCs at landfall, but inversely proportional to TC center pressure. The weaker a TC is, the shorter the TC sustaining duration will be. It is also the case for the longer TC sustaining duration with stronger TC intensity at landfall.

However, there were samples in Fig.4 indicating that strong TCs can dissipate shortly after landfall. For instance, Typhoon Wayne (8304) sustained for only 16 hours after it landed in Fujian with wind speed of 40 m/s and center pressure of 950 hPa at the time of landfall. Moreover, some TCs were not strong in intensity, but can sustain for quite a long time over land. Taking TC 8407 (Ed) as an example. Its intensity was merely 25 m/s in wind speed and 988 hPa in center




Fraction(%): 5.7 35.2 17.9 15.8 14.4 6.5 0.6 0.9 2.1 1.8 0.3

Fig.2 The annual mean number of TCs landfalling in the coastal areas of China from 1971 to 2001. The vertical coordinate is the mean number of landfall TCs, the numerals above the columns are the number of landfall TCs over the 32 years and the numerals underneath the names of provinces are the percentages of regional landfall TCs in the totals. GX, GD, HN, TW, FJ, ZJ, SH, JS, SD, LN and TJ stand for Guangxi, Guangdong, Hainan, Taiwan, Fujian, Zhejiang, Shanghai, Jiangsu, Shandong, Liaoning and Tianjin, respectively.

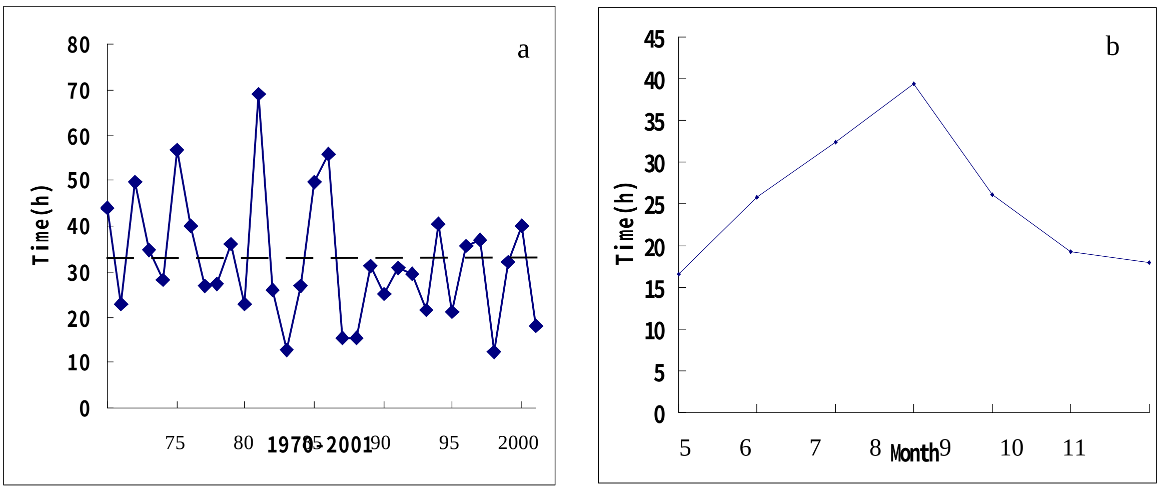



Fig.3 Interannual (a) and monthly (b) variation of duration of landfall TC Sustaining over land from 1971 to 2001.

pressure while it made landfall for the second time in Fujian. However, it sustained for more than 84 hours over land. Fig.4 also illustrated that the TC sustaining duration longer than 80 hours over land did not seem to correlate with the TC intensity at the time of landfall. Even for the same intensity of TCs, the TC sustaining period over land varied significantly. It explains that the TC sustaining duration over land is determined by many factors such as environmental atmospheric circulations, interaction between TC and mid-latitude circulation systems, etc. in addition to seasons, land surface diversity, geographic locations and the intensities of TCs themselves at the time of landfalling. It is similar for TCs landfalling in Guangdong and Fujian in July and August (Figure not shown), concerning the characteristics described in the section.

### 3.5 TC Tracks after landfall

The environmental atmospheric circulation influences both the TC tracks and sustaining over land. The TCs can sustain for a long time if sufficient supply of moisture and energy is continuously available during TC movements[1]. Fig.5 shows the distribution of tracks over land for 23 TCs in the 32 years, which sustained for more than 60 hours over land. It may be seen from Fig.5 that TCs that lasted long can reach as northward as 50°N and as westward as Yunnan (104°E). These long-lasting tracks over land were mostly northward for TCs that landed in Fujian and Zhejiang. Most of the TCs moved to the areas east of 110°E and near 35°N in the Chinese mainland. In some cases, TCs continue to move northward to Heilongjiang or further north. Transition occurred easily for TCs with such tracks. Furthermore, TCs making landfall in Guangdong and taking northeastward tracks normally moved into sea again from parts of Jiangsu and Shandong. TCs with westward and southward tracks can also sustain for

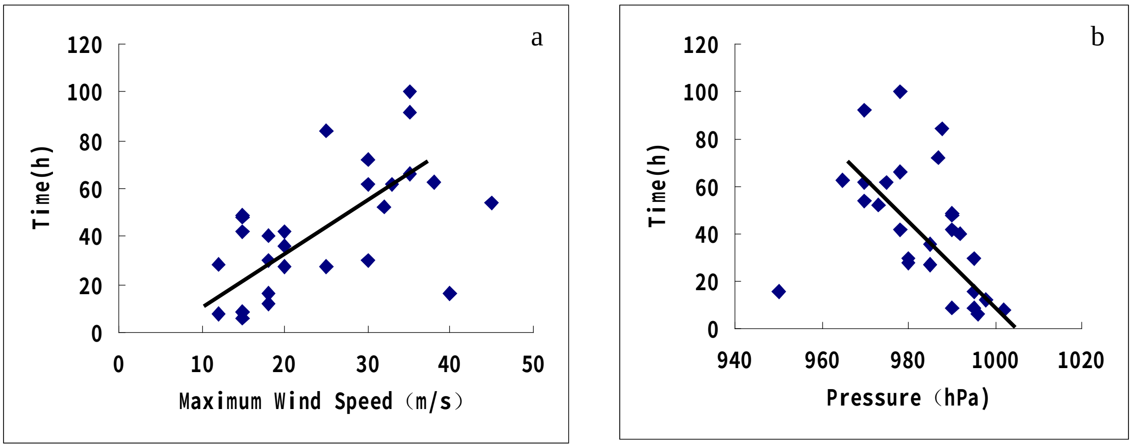



Fig.4 The scattered plotting diagrams of the correlation between TC intensity at landfall (center pressure and maximum wind speed) and TC sustaining duration over land in Fujian in July and August.

quite a long time. There were nevertheless only 7 cases of such tracks in the data. These TCs normally landed in Fujian and Guangdong and moved slowly and in short tracks, with few of them heading westward beyond 110°E. Among the southward-moving TCs, two cases entered the sea again from Guangxi. In particular, the peculiar typhoon 8107 (Maury) landed again soon after it entered the sea before moving northward. It sustained for 48 hours for its journey from Guangxi to Hunan. The total duration of Typhoon 8107 (Maury) sustaining over land with two landfalls was 120 hours.

## 4 TC DECAY

### 4.1 TC decay in intensity after landfall

To understand the characteristics of the variation of TC intensity after landfall, a diagram is plotted to describe the time evolution of center pressure ($p$) of the 23 TCs that sustained long (more than 60 hours) after landfall during the 32 years. As shown in Fig.6a, changes in TC intensity mainly occurred within 12 hours after landfall as indicated by substantial increase in pressure near the TC centers, but were not evident after 24 hours, with small fluctuation of pressure in TC centers. The TCs sustained and moved with intensity equivalent to that of tropical depressions, with the center pressure either decreasing or increasing within the limit of about 2 hPa every 6 hours.

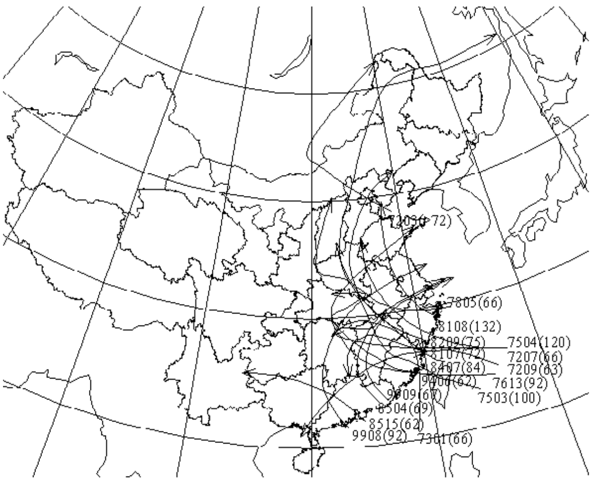



Fig.5 The codes and tracks of the 23 TCs during the 32 years that sustained for more than 60 hours over land (the numbers inside the brackets indicate the TC sustaining duration in hours).

The general scenarios for the attenuation of TC intensity may be understood by taking average of pressure differences between the center pressure at TC landfall and each of those center pressures at different times after TC landfall. The results showed that the center pressure increased by 8 hPa in 6 hours, 13 hPa in 12 hours, and 16 hPa in 24 hours after landfall, as compared with that at landfall.

Fig.6a also denoted that attenuation of TC intensity varied with the TC intensity at landfall. The stronger the TC intensity is at landfall, the faster the TC decay will be. Applying the difference between the maximum wind speed at landfall ($V_0$) and that 24 hours after landfall ($V_{24}$) to express the extent of TC attenuation, the variation of maximum wind speed after landfalling was examined. Fig.6b shows the scattered plots diagram on the correlation between $V_0$ and the degree of attenuation of TC intensity. It may also be found that stronger TCs at landfall may decay more rapidly. On average, the maximum wind speed attenuated by 20% – 30%, 50% and more than 50% 24 hours after landfall for tropical depressions, tropical storms and severe tropical storms, respectively.

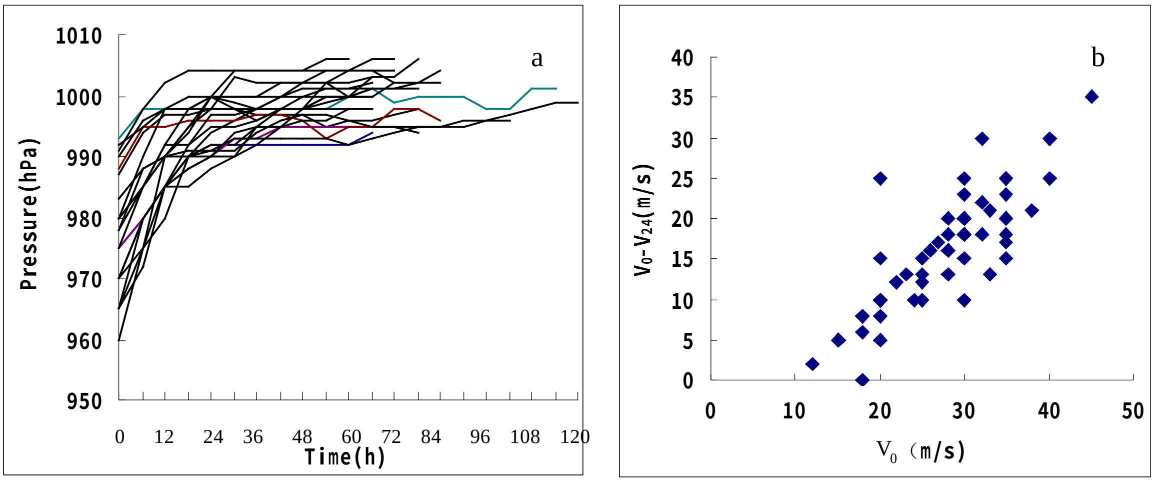



Fig.6 Time evolution of center pressure of the 23 TCs sustaining for long duration after landfall (a); the scattered plots diagram on the correlation between the maximum wind speed at landfall and the degree of decay (b). "0" stands for the time at TC landfall, while $V_0$ and $V_{24}$ denote the maximum wind speed at landfall and 24 hours after landfall, respectively.

4.2 Change of TC numbers in different regions after landfall

To investigate how the TC will decay in different regions, it is necessary to analyze the change of TCs numbers making landfall in different areas. The attenuation rate at which the TCs decreased in number ($D_i$) may be defined as:

$$D_i = \frac{N_i}{N} \times 100\,\%$$

where $N$ and $N_i$ are the total number of TCs making landfalls in a region and the number of TCs that decreased within a specific period of time after landfall, respectively.

Fig.7 displays the variation of the number of TCs making landfalls in different coastal areas of China. The columns are the rates of decrease within 6, 12, 24, 48 hours, respectively, after TCs making landfalls in individual regions. The number of TCs making landfalls in Guangxi decreased dramatically, by 33% in 6 hours, more than 50% in 12 hours, 78% in 24 hours, and 100% in 48 hours after landfall, i.e. no TC was able to sustain for 48 hours in Guangxi. For TCs landing in Guangdong, the number of decrease was less than that in Guangxi, at the rate of 25% in 12 hours, 50% in 24 hours, and 90% in 48 hours after landfall. Alternatively speaking, half of the TCs landing in Guangdong dissipated within one day, and only 10% of them sustained for more than 48 hours over land. Similarly, TCs landing in Fujian decreased at rates smaller than that in Guangdong and Guangxi, by 37% in 24 hours and 67% in 48 hours after landfall. The number of TCs making landfalls in Zhejiang decreased the least, with no case found to dissipate in less than 12 hours, and about 13% and 50% of the TCs disappeared within 24 and 48 hours, respectively, after landfall. Or, about half of the TCs making landfalls in Zhejiang were able to sustain for more than two days. In general, over half of the TCs dissipated within 24 hours if they make landfalls in mountainous regions, while less than 1/5 disappeared if the landfall took place in the plain areas. This result is similar to that by Zhang[4]. There were much fewer cases of TCs making landfalls in Jiangsu (plus Shanghai) and Liaoning, only 3 and 6 respectively, the rates of TC dissipation within 48 hours after landfall in the two provinces were larger than that in Zhejiang.

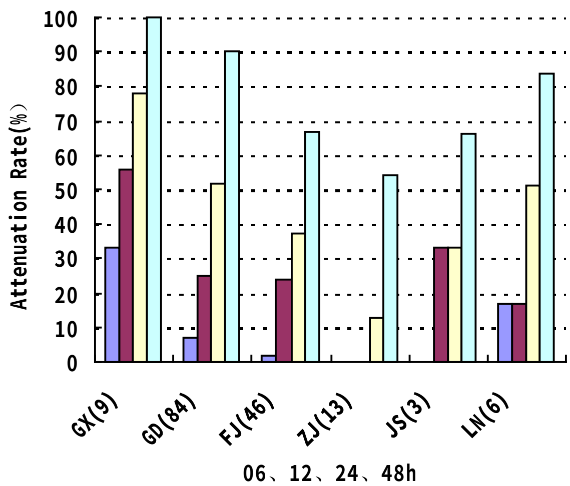



Fig.7 The variation of the number of landfall TCs in different coastal areas of China. The columns from the left to the right are the rates of decrease within 06, 12, 24, 48 hours, respectively, after TCs making landfalls in individual regions. The numbers inside the brackets indicate the number of samples.

## 5 TC TRANSITION AND INTENSIFICATION OVER LAND

### 5.1 Geographic distribution of TC transition

The transition of TCs is one of the important issues that reflect the effect of the ambient atmosphere on TCs. When they moved northward into middle-latitude areas, TCs will be re-energized and become active again due to the invasion of cold air. As a result, TCs were transformed into extratropical cyclones. This is called the extratropical transition of TCs (Chen [10]).

Among the 256 landfall TCs in the period from 1970 – 2001, 30 cases of transition occurred, with a transition rate about 12%. In the 164 samples of interest in this study, there were also 12% (20 cases) of the landfall TCs that transformed. Among these transitional TCs, the one that sustained for the least time of 18 hours over land was TC 8509 (Mamie) that landed in Liaoning, while the one for the longest time of 132 hours was TC 8108 (?) that landed in Zhejiang. The mean duration of the 20 TCs sustaining over land was more than 2 days, or about 53 hours. Therefore, it is obvious that the duration of TC sustaining over land is associated with transition of TCs. Among the above 23 cases that sustained over 60 hours over land, nine of them transformed, taking up about 39% of the total number of TCs.

Transitional TCs mostly landed on the coast of Guangdong and northward. In particular, most of these TCs landed in Fujian, totaling at nine cases. The distribution of transitional areas may be referred to Fig.8 (as denoted by Δ). It may be seen from Fig.8 that TCs could be transformed near 27°N. The transformation areas included the coastal areas north of 27°N and the areas of the Yellow Sea and Bo Hai Sea. In more details, one TC transition area was in Jiangsu (Shanghai), Anhui and Jiangxi and the other in Liaoning, Jilin, Heilongjiang and the Yellow Sea and Bo Hai Sea. The southernmost region of transformation was in Jiangxi in which four TCs transformed during the 32 years. It was unusual for Typhoon 7203 (Rita) that transformed in Mongolia (110°E, 43°N).

### 5.2 TC Intensification over land

The TC re-intensification may be indicated by some characteristics such as the fall of surface pressure in the TC center, increase of wind speed and precipitation, and strengthening of cloud systems etc. Due to the limitation of available data, TC intensification over land may be examined only by variations of center pressure and maximum wind speed in 6-hour intervals. A TC was considered to intensify over land when the centre pressure of the TC over land was lower than that 6 hours earlier, or remained unchanged while the maximum wind speed increased. Based on such criteria, it was noted that 25 out of the 164 samples, about 15%, satisfied the requirements. The intensification of TCs over land may be categorized as the strengthening of the split sub-centers (7 times), strengthening during transition (6 times), strengthening during landfall (6 times), and strengthening in other circumstances (10 times). The strengthening of a TC may occur with a few categories. Taking Typhoon 9403 (Russ) for example. The TC intensified while making landfall and intensified once again for the split sub-centre during transition. TCs intensifying over land usually sustained for long duration, posed serious threats to human community, and thus are worth of further investigation into the mechanism.

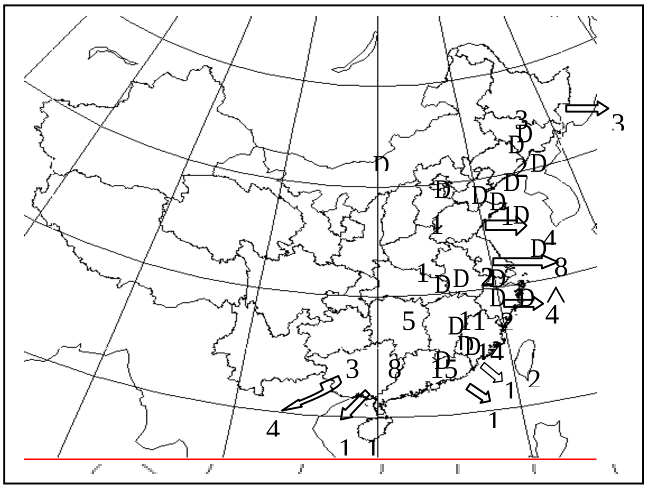


Fig.8 The locations and corresponding numbers of landfalling TCs dissipated over land, and those re-entering sea after moving deep inland (arrows and numbers marked over sea areas) and of TCs transition locations denoted by triangles.

## 6 TC DISSIPATION

### 6.1 Geographic distribution

In addition to the 22 cases that re-entered the sea after long stay over land, 142 out of the 164 landfall TCs dissipated over land, including four that dissipated outside the territory of China. Fig.8 showed the locations and corresponding numbers (marked over land) of landfall TCs that dissipated over land. It indicated that landfall TCs dissipated the northernmost in Heilongjiang, westernmost in east Yunnan. Guangxi is the area that as many as 36 landfall TCs dissipated. In fact, the number of landfall TCs is not high. However, the landfall TCs that dissipated there were mostly those that landed in Guangdong and moved westward. The number of landfall TCs that dissipated in Guangdong was second only to Guangxi, 28 cases in total. Adding up the two regions, the number of landfall TCs that dissipated in Guangdong and Guangxi was 46% of the total in the study. There were also many landfall TCs that dissipated in Jiangxi, Fujian and Anhui, about 11%, 10% and 8% of the total, respectively; they are then followed by Hunan and Hebei, 6% and 4%, respectively; and yet again followed by Yunnan, Heilongjiang, Guizhou, Jilin, Zhejiang and Liaoning, from 3 to 1 case during the 32 years. Though there were many landfall TCs in Taiwan and Hainan, only 2 and 1 cases, respectively, dissipated over land, as the others dissipated outside the territory after passing over the islands.

There were 22 cases of the landfall TCs that re-entered sea after having moved deep inland. The areas that TCs finally re-entered sea were marked by arrows in Fig.8 with the corresponding numbers annotated over sea areas. Although there were only 2 TCs that dissipated there, Jiangsu is the province with the largest number (8 cases) of the TCs re-entering the sea after having moved deep inland, about 33% of such cases, followed by Shandong (4 cases), Heilongjiang (3 cases), Zhejiang and Shanghai (2 cases each). There was also one case of TCs re-entering the sea in Fujian, Guangxi and Guangdong, respectively.

### 6.2 Destinations of TCs making landfalls in different areas

To understand where the TCs terminated after landfall in different areas of coastal China, a schematic diagram indicating the geographic distribution of TC making landfalls, moving and dissipating over the 32 years (Figure not shown) was made. For those TCs making landfall in Guangdong, 30% of them dissipated locally, while 44% moved westward and mostly dissipated in Guangxi with a few moving further westward into Yunnan or outside the country via Guangxi, and the remaining 26% moved northward and dissipated mostly in Jiangxi, Hunan and Anhui, with some entering the sea again from Zhejiang, Fujian, Jiangsu and Shangdong. The TC traveling the northernmost is Typhoon 9908 (Sam) that entered the sea again from Jiangsu. Only a few TCs make landfalls in Guangxi, with most of them dissipating locally while the rest moved into the neighboring Guizhou and Hunan or migrated out of the country in the southwest. The TCs landing in Fujian had a widespread distribution of locations where TCs terminated. In addition to the 28% of locally dissipating TCs, the rest moved into the neighboring provinces, mainly in Jiangxi, followed by Hunan, Hebei and Anhuin and the westernmost being in Guizhou while the northernmost in Heilongjiang before moving into sea again. The TCs making landfall in areas north of Fujian were able to move northward or westward, with few of them dissipating locally. As for those TCs making landfalls in Zhejiang, many of them (27%) moved to Anhui and dissipated there with only one case of local dissipation. Some of them were able to move westward to Hubei or northward to Jiangsu and Shangdong where they moved further into sea again or made landfall again and moved further northward, like Typhoon 9711 (Winnie). The TCs landing in Liaoning and Tianjin were mostly after their second time landfalls, which all moved northeastward after landfalls, dissipated in Jilin and Heilongjiang, or moved further to enter the sea again.

## 7 CONCLUDING REMARKS

In this paper, statistical analyses on the characteristics of frequency, geographical distribution, sustaining over land, attenuation, transition and dissipation of TCs that originated from western North Pacific (including the South China Sea) and landed in China from 1970 to 2001 have been carried out with the following results:

(1) There are 863 TCs that generated over the western North Pacific (including the South China Sea) during the 32 years, with average of 27 TCs per year. The number of TCs making landfalls in China during that period was 256, with an annual mean of 8 TCs. There were TCs making landfalls in any parts of coastal China. Guangdong is the area with maximum number of TC landfalls. The numbers of TC genesis and landfall cases were each less than the average for the period from 1995 to 2001.

(2) The statistics on duration of TC sustaining over land for the 164 landfall TCs that either dissipated over land or moved deep inland and re-entered the sea during the 32 years indicated that the mean duration of TC sustaining over land was 31 hours, and 55% of the landfall TCs can sustain over land for periods from half a day to two days. Investigation of the interannual and monthly variations revealed that the duration of TC sustaining over land was less than the average from late 1980's to 2001, with the longest being in August and July.

(3) The durations of TC sustaining over land were notably different in different areas of coastal China, and increased from Guangxi northward to Zhejiang.

(4) On average, the stronger a TC is at landfall, the longer it will sustain over land. Such a relationship is, however, not obvious for TCs sustaining over land for more than 80 hours.

(5) The landfall TCs might be transformed when they moved northward to 27°N. The durations of transformed TCs sustaining over land were 53 hours on average. Re-intensification of TCs over land was mainly manifested during transition, at landfall, and by

strengthened sub-centers after separating from main centers.

(6) Significant decrease of intensity of landfall TCs occurred mostly within 12 hours after landfall. The stronger the TC intensity is at landfall, the more it will attenuate.

(7) The dissipation rate is different for the number of TCs landfalling in different areas. About 78% of TCs that landed in Guangxi dissipated within 24 hours after landfall, while 52% in Guangdong, 37% in Fujinag and 13% in Zhejiang did so.

(8) The TCs making landfall in China can move as northward as 50°N and beyond, and as westward as around 104°E. The northernmost area for a TC to dissipate over land is Heilongjiang, and the westernmost is the east part of Yunnan. Guangxi is the region with the maximum number of TCs dissipating over land. It is also the case for Jiangxi as an inland province. Similarly, Jiangsu is the region with the maximum number of landfall TCs that re-entered sea after moving deep inland. The number of landfall TCs that dissipated at landfall areas decreased northward (not including Hainan and Taiwan).

**REFERENCES:**

[1] CHEN Lian-shou. A Summary on research on the movement of TCs [C]// Proceedings of the 11th National Workshop on TCs. Beijing: Meteorological Press, 2001: 1-9.

[2] ZHU Qian-gen, CHEN Min. Statistic characteristics of landfall TCs in western North Pacific [C]// Proceedings of the12th National Workshop on TCs. Beijing: Chinese Academy of Meteorological Sciences, 2002: 15-17.

[3] LEI Xiao-tu, CHEN Lian-shou. Characteristics of different activities of TCs under atmospheric environmental fields in middle and low latitudes [J]. Journal of Tropical Meteorology, 2002, 18 (4): 289-301.

[4] ZHANG Sheng-jun. Dynamic models of typhoon structure and associated numerical experiments [D]. Beijing: Ph.D. Thesis, Chinese Academy of Meteorological Sciences, 2002: 39-40.

[5] YU Hui. Analysis on climatological characteristics of intensity changes of TCs after landfalling: Disappearance of TCs after landfalling [C]// Proceedings of the 12th National Workshop on TCs. Beijing: Chinese Academy of Meteorological Sciences, 2002: 33-35.

[6] LIU Chun-xia. Wavelet analysis on interannual variation of TCs in Guangdong [J]. Journal of Tropical Meteorology, 2001, 17: 381-390.

[7] China Meteorological Administration. Typhoon Yearbooks (1970-1988) [Z]. Beijing: Meteorological Press. 1971-1989.

[8] China Meteorological Administration. Tropical Cyclone Yearbooks (1989-2001) [Z]. Beijing: Meteorological Press1990-2002.

[9] HE Min, SONG Wen-ling, XU Li. Analysis on the atmospheric environmental fields affecting tropical storm activities in 2000 [J]. Meteorological Monthly, 2000, 28(4): 15-20.

[10] CHEN Lian-shou, DING Yi-hui. An Introduction to Typhoons in West Pacific [M]. Beijing: Science Press, 1979: 423-428, 466-474.