Article ID: 1006-8775(2007) 02-0185-04

FACTORS AFFECTING THE TRACK OF TROPICAL CYCLONES AFTER LANDFALL IN EASTERN CHINA

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Abstract: The correlation and composite analysis are carried out in this paper to study major factors affecting the track of tropical cyclones (TCs) after their landfall in the east of China. The mid-tropospheric environmental steering flow is found to dominate the movement of a TC even after landfall, with the inertia and Coriolis force two other subordinates. A key region is discovered covering the east of China and Yellow Sea, in which the environmental flow significantly affects the movement of TCs making landfall in this part of China. When the subtropical high in this region strengthens and extends westward, accompanied by northward shrink of the westerly trough, the TC tends to move westward after landfall and disappear inland. However, when the subtropical high in this region weakens and shrinks eastward, accompanied by southward push of the westerly trough, the TC tends to recurve after landfall and re-enter the sea at a location to the north of the site of landfall. The environment before the landfall of a TC has little impact on its post-landfall track, which is sensitive to the environmental change 12 – 24 hours after landfall. A 6-hour lag is found between the environmental change and the movement of a TC after landfall.

Key words: tropical cyclone; post-landfall track; moving tendency; effect factors

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

1 INTRODUCTION

Over the past few years, there has been some research on the track taken by tropical cyclones which make landfall. For instance, a statistical study has been done on tropical cyclones making landfall in China from the northwest Pacific over the past 32 years in terms of the frequency, location, maintenance, decaying, transformation, strengthening and dissipation[1]. The landfall tropical cyclone tends to accelerate towards the intense convection area ahead in the northwest direction[2]. The environmental field plays a role in the duration for which the landfall tropical cyclone persists over land[3]. There have been predictions of landfall probability and diagnostic analysis of landfall processes. All of the above studies have deepened the understanding of the post-landfall pattern of the tropical cyclone movement and governing mechanism, but none of them has touched upon the issue of track tendency after landfall. There are two main tendencies of track for post-landfall tropical cyclones on the eastern coast of China. One is moving westward with intensity decreasing till dissipation inland and the other is moving northward before recurving to the northeast and leaving the land for the sea again. What causes the two erratic tracks and what are the main factors? Few attempts have been made to discuss the issues. It is the purpose of this paper to, via analyses, have deeper understanding of the track tendency after landfall and its governing mechanisms and provide guidance for the prediction.

2 SAMPLES, DATA AND METHODS FOR THE ANALYSIS

In the 50 years from 1951 to 2000, there are 118 tropical cyclones making landfall over the coast from southern Fujian to the estuary of Yangtze River (23.5°N – 32°N), or an average of 2.3 per year. The data of track and intensity are from the *Typhoons*

Received date: 2006-09-26; **revised date:** 2007-09-25

Foundation item: Social Welfare Research Fund for the Research Institutes of Ministry of Science and Technology (2005DIB3J104); Open Fund for Meteorological Research of Zhejiang Province (KF2006008)

Biography: WANG Dong-fa (1962-), male, native from Zhejiang province, senior engineer, M.S., mainly undertaking the forecast and study on tropical cyclones.

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Yearbook and *Tropical Cyclones Yearbook* by China Meteorological Administration. The data of environmental field are from NCEP / NCAR, U.S.A., which are reanalysis gridpoint data available every 6 hours.

The method of climatological statistics is used to study the climatological summary of track tendency for TCs after landfall. The methods of correlation and composite analysis are used to study the effect of the environmental field on the post-landfall track of the TCs.

During the composite analysis, ten cases of TCs were selected for either dissipation inland or turning to move out to sea again after landfall in northern Fujian.

3 CLIMATOLOGICAL SUMMARY OF TRACK TENDENCY AFTER LANDFALL

Of the 118 TCs making landfall in the coast of East China Sea, 75 cases headed westward and dissipated inland and 43 cases turned to move out to sea again. In other words, of all the TCs making landfall from the sea, only about 1/3 of the cases turned to move to sea again and 2/3 dissipated inland.

For the post-landfall track tendency of the TCs, Tab.1 and Tab.2 give the distribution of frequency – landfall time and frequency – landfall site, respectively.

Tab.1 Monthly frequency and percentage of two patterns of post-landfall track tendency of the TCs

Month of landfall	May	June	July	Aug.	Sept.	Oct.	Sum
turning to sea / times	1	2	11	15	13	1	43
dissipating inland / times	0	1	19	36	17	2	75
sum of landfall / times	1	3	30	51	30	3	118
percentage of monthly turning in monthly landfall / %	100	67	37	29	43	33	36
percentage of monthly turning in total turning /%	2	5	26	35	30	2	100
percentage of monthly dissipation in dissipation total /%	0	1	25	48	23	3	100

Tab.2 Frequency and percentage of two patterns of track tendency of the TCs in different regions

Site of landfall	Southern Fujian	Central Fujian	Northern Fujian	Zhejiang	Shanghai -Jiangsu	sum
Frequency of turning to sea / times	1	8	13	18	3	43
Frequency of dissipating inland / times	19	20	21	12	3	75
Sum of landfall / times	20	28	34	30	6	118
Percentage of turning after landfall in the regions / %	5	29	38	60	50	36
Percentage of turning after landfall in the regions in turning total / %	2	19	30	42	7	100
Percentage of dissipating after landfall in the regions in dissipating total / %	25	27	28	16	4	100

The temporal change of track tendency has shown that the post-landfall track is still steered and constrained by the basic airflow. It is known that the track tendency of interest is closely linked with the site of landfall, with probability of turning after landfall increasing towards the north. This characteristic reflects on the effect of the steering flow at the outer edge of the subtropical high on TCs.

4 ANALYSIS OF CORRELATION BETWEEN PRE-LANDFALL QUANTITATIVE STATES AND POST-LANDFALL TRACK TENDENCY

Initial parameters for the location determined just prior to landfall are used to define the pre-landfall quantitative states of the TC for the

(1) variability of the geostationary parameter, $\beta_0=\partial f_0/\partial \Phi = (2\Omega/R)\cos j_0$,

(2) moving direction in 6 and 12 h, $q_t = \arccos[\sin j_0 \sin j_{-t} + \cos j_0 \cos j_{-t} \cos(l_0 - l_{-t})]$,

(3) moving speed in 6 and 12 h, $V_t = (R/t)q_t$, and

(4) Change of parameter X in 6 and 12 h,

$$\Delta_t X = X_0 - X_{-t} \quad \begin{pmatrix} t = 6,12 \\ X = p,v,b \end{pmatrix}.$$

whereas Ω is the geostationary angular velocity, R the radius of Earth, t the time, and $-t$ the moment prior to the initial time ($t = 0$).

The coefficients of the correlation between the 15 quantitative quantities of the pre-landfall state and the post-landfall track tendency have been determined. Those that pass the 0.999 confidence test (with the correlation coefficient |*r*|>0.32) are listed in Tab.3.

5 CORRELATION BETWEEN THE ENVIRONMENTAL FIELD AND POST-LANDFALL TRACK TENDENCY

To look into the effect of the environmental field on the post-landfall, 20 environmental elements in 118 samples and their 12-h variance factors within 10°N – 50°N, 90°E – 150°E at a resolution of 2.5° lat. × 2.5° long. have been analyzed for correlation with the post-landfall track on 11 time levels. As shown in the analysis, the environmental mid-level airflow steers not only the moving track of TCs over the ocean[7, 8], but also that over land.

Tab.3 The coefficients (*r*) of the correlation between the 15 quantitative quantities of the pre-landfall state and the post-landfall track tendency

Initial longitude	6-h Moving direction	6-h difference of *b* -effect	12-h moving direction	12-h difference of *b* -effect
0.34	−0.38	0.36	−0.37	0.36

6 SPATIAL DISTRIBUTION OF ENVIRONMENTAL FIELD FACTORS IN HIGH CORRELATION WITH POST-LANDFALL TCS TRACK

It is known from the analysis above that most of the high correlation areas of the environmental field factors with the post-landfall track are in northern Jiangsu, southern Shangdong and the Yellow Sea. Tab.4 gives statistical description of the areas where there are the maximum correlation coefficients of 40 environmental field factors.

Tab.4 Number of factors with the appearance of maximum correlation coefficients in the high correlation areas of the environmental field

	Environmental field factors	Factors of 12-h variables
Region I（30 – 35 °N，120 – 125 °E）	12	10
Region II（30 – 40 °N，115 – 130 °E）	18	15

7 TEMPORAL DISTRIBUTION OF ENVIRONMENTAL FIELD FACTORS IN HIGH CORRELATION WITH POST-LANDFALL TCS TRACK

The correlation-time distribution of the factors on the zonal and meridional profiles (figure omitted) and frequency of 12-h variables factors with maximum correlation coefficients at different time (Tab.5). As shown in the analysis, the pre-landfall environmental field is much less than the post-landfall in the effect on the post-landfall track tendency. The time from 12 to 24 hours after landfall is sensitive to the post-landfall track when the variation of the environmental field affects the post-landfall track tendency 6 hours earlier than the current environmental field.

For analyses of other aspects, refer to the Chinese edition of the journal.

8 CONCLUSIONS

(1) Of the TCs coming from the East China Sea, 2/3 move westward before dissipating inland while the remaining 1/3 turn to move out to the sea again. The probability of the former pattern is the maximum in August but that of the latter one is relatively large in May, June and September. It increases from south to north for the latter pattern. The TCs make the least landfall in southern Fujian but the most landfall in Zhejiang. As shown by the distribution of the variation of post-landfall track with landfall time and site, the post-landfall track are basically steered and constrained by basic airflows.

(2) The characteristic quantities of the TC state at the time of landfall has the least effect on the post-landfall track while the moving direction at landfall and the variation of β-effect are well correlated with the post-landfall track. It shows that the variation of the inertia and geostationary force have some effect on the post-landfall track tendency.

(3) The environmental field and its variation are well correlated with the post-landfall track tendency, indicating that the former has large effect on the post-landfall track and the middle tropospheric flow field has significant steering effect on the movement of post-landfall TCs.

(4) The region from eastern China to the Yellow Sea at 30°N – 40°N, 115°E – 130°E is the key region in which the environmental field affects the post-landfall track. When the subtropical high inside strengthens and extends westward and the westerly trough retreats northward, the landfall TC will be steered by an easterly flow south of the subtropical

high to go westward till dissipation. When the subtropical high weakens and retreats eastward and the westerly trough moves southward, the landfall TC will be steered by a southerly flow west of the subtropical high and a southwesterly flow in the front of the westerly trough to turn to move out to the sea.

(5) The environmental field prior to the landfall has little effect on the post-landfall track tendency. The time from 12 to 24 hours after landfall is sensitive to the post-landfall track when the variation of the environmental field affects the post-landfall track tendency 6 hours earlier than the current environmental field.

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