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ANALYSIS OF TYPHOON MATSA (NO.0509) AFFECTING SHANDONG PROVINCE

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Abstract: The characteristics of the moving course of Typhoon Matsa (No.0509), associated heavy rain and physical quantities fields have been analyzed, with the focus on the reason of the typhoon's abrupt northeastward turn in Anhui Province and heavy rain concentrating in the northeast of typhoon center instead of near it. Meaningful conclusions are as follows. The reasons for typhoon abrupt turning are that the subtropical high pressure was moving southward and divergence fields of 200 hPa were to the right of the typhoon center; there was no obvious cold air invading Shandong after the typhoon entered the westerly belt; the southeasterly jet of typhoon and shear brought heavy rainfall to the Shandong peninsula before the typhoon entered Shandong. But after the typhoon's movement into Shandong, the typhoon's inverted trough brought the rainfall to the northern and central Shandong.

Key words: Typhoons; affecting Shangdong; track of movement; distribution of severe rainfall

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1 INTRODUCTION

China is one of the countries that are severely affected by typhoons. Detailed study has been done on typhoons in the west Pacific with the conclusion that the change of landfall typhoon tracks are subject to the subtropical high, polar fronts and systems of positive vorticity in the vicinity of the typhoons[1]. Extensive study has been done in the aspect of typhoon activity and abnormal track and associated extreme heavy rain[2-7] and a number of research achievements have been made lately. The 500 hPa vorticity field around the time influenced by Typhoon No.9711 (Winnie) was diagnostically analyzed[8].

With a track rarely seen in recent years, Matsa made landfall and headed north to affect Shangdong. After moving over land in Zhejiang, it moved northwest into Anhui and then Bohai Sea after taking passage over Jiangsu and Shangdong. It made two turns inside Anhui and Shangdong to form a complicated zig-zag track (Fig.1).

Matsa was the largest typhoon for Shangdong after Winnie. The strong wind and heavy rain it brought about inflicted serious damage to the coastal area of the province. Areas with rainfall more than 100 mm were mainly over the peninsula and northern part and the time of heavy rain did not coincide with the eye of the storm.

2 DATA AND SCHEME OF NUMERICAL SIMULATION

Conventional weather data and simulations with the MM5v3.5 were used. Weather maps for 500 and 850 hPa were also used, which give the elements of geopotential height and wind field.

MM5v3.5 has a good simulation of the process, particularly with the rainfall center. For physical quantities, the vorticity, diversity, vertical velocity and divergence of water vapor flux as simulated by the model in fine mesh were used, which were at the interval of 18 km. The selected domain for the model is shown in Fig.2.

3 ANALYSIS OF TYPHOON TRACK

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The post-landfall track of Matsa was complicated, which moved northwest before turning northward. It is especially noted that quite a number of NWP predictions pointed to a westward track when it was still over Anhui in the morning of Aug.7. The eye became more difficult to determine as Matsa weakened rapidly and its central circulation expanded after it moved inland. Opinions differ among forecasters at various levels as to where it might be going when it suddenly turned to the northeast into Jiangsu.

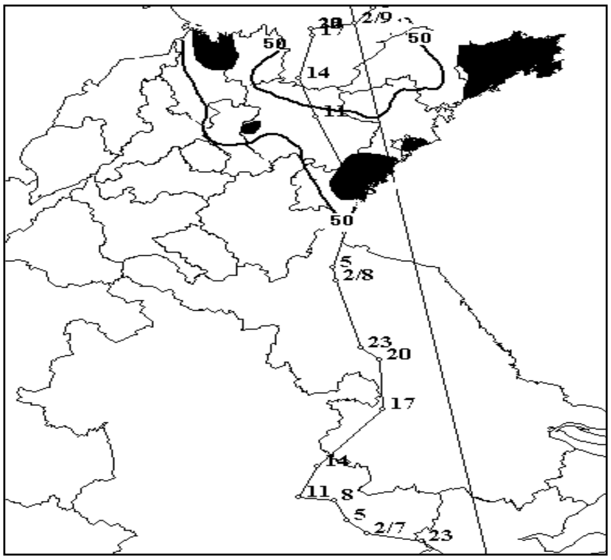

Fig.1 Track of Matsa and rainfall at 06:00 from Aug. 7 to 9. The solid line is for the contour of 50 mm and the shaded area is where rainfall is greater than 100 mm.

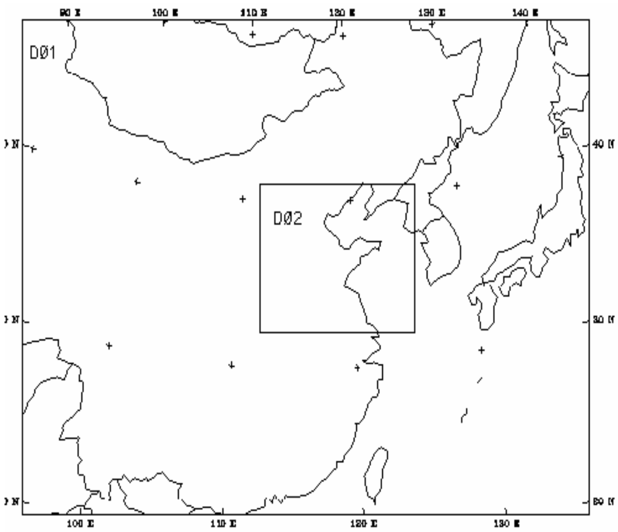

Fig.2 Simulated domain for dual nested meshes.

On Aug.5, Matsa was about to land in a pattern that looked like it would be going north after landfall. The ridge line of the subtropical high at 120°E was north of 36°N, indicating that it would continue its northwest path off the southern rim of the subtropical high, with the turning point north of 36°N. In fact, Matsa suddenly turned toward Jiangsu on Aug.7 for two main reasons.

The key to determine whether the typhoon keep moving westward or turn north is to know whether there is a well-defined ITCZ south of the subtropical high, which is to the east of the typhoon that has made landfall[1]. If yes, the subtropical high will be stationary; otherwise it will weaken suddenly and move southward. In the case of Matsa, no clear ITCZ was present after it landed in Zhejiang and moved northwest to Anhui. The subtropical high did move southward to expose Matsa on the northern side of the subtropical high, which caused it to shift to Jiangsu from Anhui.

One of the important reasons for the typhoon to persist is upper-level divergence. It is known from a comparison of 200 hPa divergence that the storm tended to move with it, which clearly moved toward the northeast of the eye to cause it to turn northeast into Jiangsu.

On Aug.7, a high ridge formerly over eastern Siberia moved to northeast China before forming a NW-SE-oriented high ridge. When Matsa was in Shangdong, it was steered by a southeasterly airflow on the southern side of the ridge to move westward again and entered the Bohai Sea.

4 ANALYSIS OF MATSA-INFLICTED PRECIPITATION

After landfall, heavy precipitation did not coincide with the path of the eye. Before entering Shangdong, the area of heavy rain was to the northeast of Matsa. A N-S inverse trough appeared to its north after it entered the province. A secondary rainfall center appeared in the north of the province, which was in the front of the trough.

One of the key points about Matsa was that there were always at the levels below 500 hPa a shear and a cyclonic curvature between the southwesterly and southeasterly to the east of its eye. According to [1], the convergence of wind speed and direction at the circulation center of typhoon, shears in different portions of its lower levels and cyclonically curved streamlines within the inflow layer all contribute to the generation and strengthening of conditions under which convergence occurs and the rainfall center of the typhoon often coincides with these characteristics. The shear and cyclonic curvature east of the storm dislocated the center of heavy rain to the east.

Matsa shows asymmetric structure. It is known from the visible cloud imagery and 500 hPa pattern after landfall that it had an extensive, trailing cloud system, which was associated with the presence of the shear.

Usually, the strong wind around the typhoon is evenly distributed around the eye. The interaction between the subtropical high and westerly system will change it into asymmetric distribution, which then leads to asymmetric distribution of vorticity.

As shown in the pattern of 500 hPa for Aug.7, winds stronger than 12 m/s around the eye was evenly distributed across all quadrants of the typhoon circulation. The 500 hPa vorticity was centered around the typhoon and so was the center of positive vorticity. Late on that day, a southeasterly jet stream occurred between the area east of the storm and the subtropical high when wind speed became smaller southwest of the typhoon to increase the positive vorticity north of it. From the night of Aug.7 to the early morning of Aug.8, heavy rain occurred in the southeastern part of the province. In the morning of Aug.8, Matsa was around Linyi when the positive 500 hPa vorticity was over the northern part of Shangdong Peninsula and there was a center of positive vorticity over the Straight of Bohai Sea. The 6-h rainfall was more than 50 mm from 02:00 to 08:00 on Aug.8 in northeastern Shangdong Peninsula, with the maximum at 99 mm. In the afternoon, positive vorticity covered northern Shangdong so that heavy rain, even unusually heavy rain, occurred during the day in this part of the province, which concentrated at 08:00 through 20:00.

The abundance of water vapor and its continuous supply to the typhoon system are two basic conditions for the typhoon-induced heavy rain to persist. Low-level jet stream is the key to moisture transportation. From the analysis of the 850 hPa situation, it is known that a low-level jet stream stronger than 16 m/s was extending from northern Jiangsu to the peninsula part of Shangdong, in front of which laid a well-defined S to SE shear. Corresponding to it, water vapor converged over the northeastern part of the peninsula and northern Shangdong, with the center over Yantai and Weihai. The divergence of water vapor was also large in northwestern Shangdong, contributing to another center of heavy rain. Water vapor was in divergence in southern and southeastern parts of the province, resulting in less rainfall in these regions.

Water vapor and ascending motion are the two most basic conditions for typhoon-induced precipitation. From the 500 hPa vertical velocity from the night of Aug.7 to the morning of Aug.8, it is known that the maximum ascending velocity gained the order of magnitude for mesoscale ascending velocity[9], which was much higher than the index for regional heavy rain in Shangdong[10].

Upper-level divergence maintains the ascending motion in the middle and lower levels of the troposphere, which is one of the important conditions for the generation of heavy rain. The 200 hPa divergence had two centers in both the northern and southern parts of the peninsula, corresponding to two centers of heavy rain in Yantai / Weihai and Qingdao.

A main 200 hPa divergence area moved to the Yellow Sea and Bohai Sea in the morning of Aug.8, there were two divergence centers in the central and northern Yellow Sea and divergence was clearly seen in northeastern peninsula and northern Shangdong. In the latter area, precipitation began to intensify in the morning of Aug.8 and heavy rain occurred in the afternoon. It is then seen that upper-level divergence was always on the northern side of the eye, which was one of the reasons why the heavy rain area was on the northern side of the eye.

It is known from the vertical, zonal distribution of divergence around the eye for the night of Aug.7 that airflow converged beneath 600 hPa and quite strongly between 900 hPa and 650 hPa, suggesting that the latter be the maximum inflow layer of warm and humid airflow in lower levels. Airflow diverged above 600 hPa, with the maximum between 500 hPa and 400 hPa. Divergence was quite intense at 200 hPa. The inflow of low-level mass was in equilibrium with the outflow of upper-level mass. Compared to a previous statistical work[10], the upper-level outflow was very strong in this case.

With Matsa in Shangdong, the easterly north of the typhoon climbed over hills and low-lying mountains in Jiaodong and central and southern parts of the province before descending and expanding over the plain in the northwestern part. Consequently, positive vorticity increased, strong northeasterly wind appeared in northern Shangdong and the inverse trough north of Matsa strengthened. At the time, the 500 hPa inverse trough of the typhoon was more westward than the 850 hPa one, i.e., the trough line slanted westward with altitude in the troposphere. It made it possible for warm and humid air stream to be transported by the southeasterly from the rear of the trough to the front of it and significant convergence of water vapor flux occurred in both the front and rear of the inverse trough. As a result, heavy rain also took place in northern Shangdong, even though it was in front of it.

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

5 SUMMARY

(1) Changes in the subtropical high and high pressure within the westerly zone are vital for the typhoon track and special attention should be paid to the possibility that the subtropical high may suddenly retreat eastward and southward after landfall.

(2) The 200 hPa divergence field is indicative of

the direction in which the typhoon moves and the area over which heavy, or unusually heavy, rain occur.

(3) The asymmetric structure of the typhoon itself, shears and converging lines in low-level circulation have significant effect on the location of rainfall center, displacing it some distance from the eye.

(4) When the typhoon was inland, asymmetric distribution of strong winds resulted in that of vorticity and the area of heavy rain coincided with the positive vorticity at 500 hPa.

(5) When the typhoon inverse trough slanted with altitude, i.e. the axis slanted westward with altitude, a deep layer of warm and humid air stream was transported by the southeasterly from the rear of the trough to the front of it and significant convergence of water vapor flux occurred in both the front and rear of the inverse trough, giving rise to heavy rain in the front of the inverse trough.

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