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NUMERICAL SIMULATION STUDY OF THE INNER-CORE STRUCTURES AND THE MECHANISM FOR INSHORE STRENGTHENING OF SOUTH CHINA SEA TYPHOON VONGFONG (0214) DURING LANDFALL

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Abstract: An explicit simulation with a fine mesh at intervals of 6 km is used to explore the inner-core structures of Vongfong (0214). The dynamic mechanism for the inshore strengthening of Vongfong is examined. It is found as follows. (1) The radius of maximum wind of the axisymmetric structures of the typhoon decreased with height during its mature stage. When Vongfong was inshore, the strongest low-layer inflow located in front of it and the outflow was to the rear of it, which was just reversed from the Atlantic hurricanes and other Pacific typhoons. (2) The dynamic and thermodynamic fields were highly asymmetric in structure. Convection was stronger in the northwest quadrant of the typhoon than in the southeast; the strongest convective cloud bands were consistent with the maximum wind region. During its strengthening stage, it was cold west of and warm east of the eye in the lower layer but warm in the west and cold in the east of the mid-upper layer. During its mature stage, a warm-core structure was evident in the lower and middle-upper layer. (3) The interactions between a mid-latitude cold low in the middle-upper troposphere and the typhoon were responsible for the latter to strengthen inshore. Firstly, the outer circulation of the cold low entered the typhoon from the middle troposphere when an outer cold airflow from the cold low flowed into the northwest quadrant of the typhoon so that geopotentially instable energy increased and convection developed. Secondly, the downdraft in the cold low was just the corresponding branch of the secondary circulation of the typhoon system; when the cold low weakened while moving south, the typhoon strengthened inshore. Due to the CISK mechanism, these two phenomena might be realized.

Key words: dynamic meteorology; typhoons; numerical simulation; structure

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1 INTRODUCTION

Typhoon structure and its variation are the most basic fields in typhoon research, which have been well studied at home and abroad [1 - 4]. In general, much of the work deals with the structure of mature hurricanes in the Atlantic, while little focuses on the structure of typhoon in the west Pacific, especially the South China Sea (SCS) [2, 5]. Due to the lack of data, composite techniques are mainly the tools in earlier research while large discrepancies exist between the results of these composite analyses and real cases as a result of the highly asymmetric structure and rapid transformation often existing in typhoons. With the perfection of numerical models in recent years, however, results from numerical simulations have been used by quite a number of meteorologists to study the inner core of the typhoon [6, 7]. Subject to the land effect, most of the typhoons were weakening when they approached the continent while some of them intensified abruptly. The abruptness of the intensity increase just before landfall usually turns the forecast into a failure. For this reason, the inshore intensification of typhoons is also one of the essential

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issues in typhoon research.

For Typhoon Vongfong (coded No.0214 in China), a storm mainly developing in the SCS and therefore dubbed a SCS typhoon, characteristics of its track, moving speed, intensity change, distribution of rainstorm and reflectivity have been well simulated using the MM5, especially with regard to the abnormal features of its inshore intensification and the location of severe rainfall center on the west side of the typhoon [8]. The results can then be used to advantage here to study more intensively the inner core of Vongfong and the reasons for its intensification near the shore. Before landfall, Vongfong was at its primary stage of activity as it enhanced from a tropical storm to a severe tropical storm. After landfall, it began to dissipate as it weakened from a severe tropical storm to a thermal low pressure. Taking the activity at 04:00, August 19, 2002 to represent the stage of intensification stage and 08:00 to stand for that of full intensity, this study undertakes the task of (i) analyzing the inner core structure of Vongfong around landfall using the explicit simulations at a 6-km resolution and comparing them with the general features of the Atlantic hurricanes, West Pacific and SCS typhoons, and (ii) investigating into the reasons for the inshore intensification of Vongfong.

2 THE AXISYMMETRIC STRUCTURE

To study the structural characteristics of Vongfong better, the method as introduced in Liu et al.[6] is followed in principle by taking the width of a ring at $\Delta\gamma =$ 6 km and separating the axisymmetric component from the asymmetric one in the model output over a range of 300-km radius from the eye.

The tangential flow is the principle circulation of Vongfong. When it was at full intensity (Fig.1b), the maximum tangential flow surpassed 26 m/s between 850 hPa and 600 hPa over a range of 120 – 240 km in radius; the radius of maximum wind (RMW) was 240 – 270 km in the near-surface layer. By contrast, the tangential flow of Hurricane Andrew (1992, figure omitted) had a maximum of more than 65 m/s between the altitudes of 0.8 km and 1.2 km, with a radius between 35 and 50 km; its RMW was only 20 – 25 km in the near-surface layer. Compared to Andrew, Vongfong was marked with weaker circulation, higher altitude at which severe tangential flow appeared and larger radius of activity; the RMW was about 3 – 4 times larger throughout the troposphere. Compared to the Pacific typhoon, Vongfong was weaker but similar in the location and altitude for which severe tangential flow appeared; the RMW differed little throughout the troposphere. The comparison also reveals sharp differences in tropical cyclones between SCS and Atlantic / Pacific in that the RMW was decreasing with

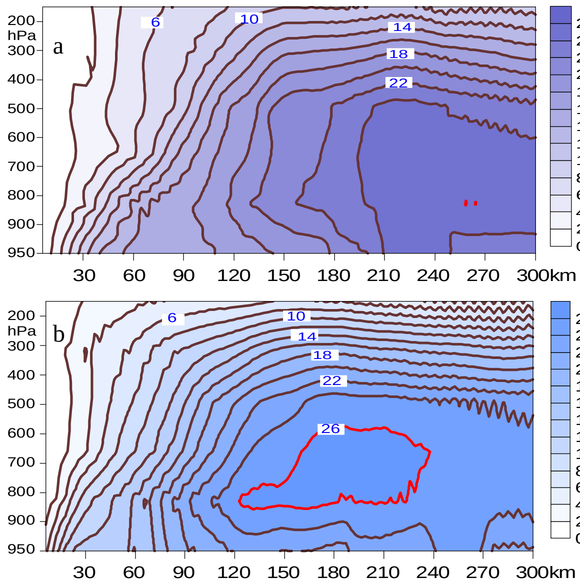

Fig.1 Radial direction – altitude cross section of Vongfong with regard to the axisymmetric component of tangential wind during the stage of intensification (a) and full intensity (b). The isolines are at intervals of 2 m/s.

altitude for Vongfong but increasing with altitude for Andrew and Pacific typhoons.

The RMW reduced substantially, wind speed increased and its radial gradient grew significantly within the radius of maximum wind as Vongfong shifted from the stage of intensification (Fig.1a) to that of full intensity. Compared with the vertical motion (Fig.2), ascending motion was around the eyewall tilting outward and became even greater as Vongfong was at full intensity at the middle and upper layers of the ring within the radii between 150 and 210 km around the eyewall and inclined towards the eye with altitude, which was similar to the structure of the circle of maximum wind. It shows that Vongfong had weak eyewall convection, poorly-defined wall cloud, and its zone of maximum wind did not coincide with the eyewall; its convection was relatively strong within the spiral rain belt outside of the eyewall and the zone of severe updraft was consistent with that of maximum wind.

3 THE ASYMMETRIC STRUCTURE

Significant asymmetry is shown in Fig.3 between the inflow, mainly at lower levels, and outflow; the strongest inflow was in front of Vongfong while the strongest outflow at the rear of it. As shown in some studies, the strongest inflow, which was at lower levels, was behind the typhoon, as in the case of Pacific typhoon [2] and Atlantic hurricane [4], while the outflow was ahead of it. It is a sign that the typhoon had

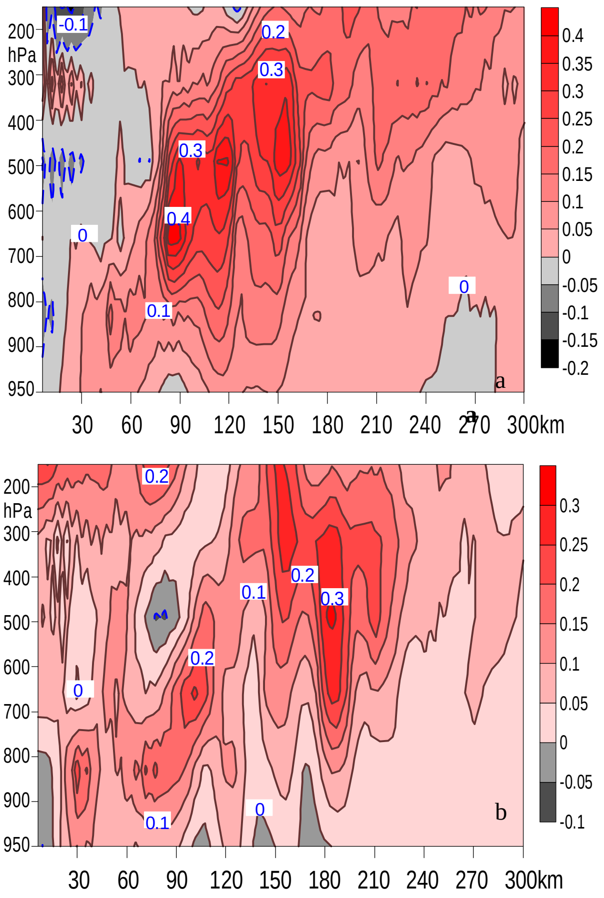

Fig.2 Same as Fig.1 except for the vertical velocity. The isolines are at intervals of 0.05 m/s.

evolved so that its structure became very complicated, especially so with its inner core, as it was about to make landfall. The environmental air was not necessarily passing right through the eye, as demonstrated in the distribution of low-level inflow and high-level outflow. As indicated from the two trajectories of particles (Figure omitted), the air did not go through the eye as it traveled from behind the typhoon, a conclusion that differs from some studies that hold that air flows through the storm [9]. At upper levels (150 hPa), outflow was the main feature and its strongest part occurred before the typhoon while there was weak inflow behind it.

4 DYNAMIC MECHANISMS FOR INSHORE INTENSIFICATION

For the inshore intensification, the secondary circulation was mainly on the north and west side (a bit stronger) of Vongfong, with significant ascending flow near the eyewall and descending flow inclining off it at the middle and lower layers. The center of the secondary circulation was at the level of 300 hPa, which was more than 200 km away from the center of the cyclonic circulation. At this point, there was not any descending branch of the upper-level secondary circulation in the inner core of Vongfong. Is there any system at the periphery of the typhoon, as it may be naturally anticipated, to go with the evolution of the secondary circulation?

As a result of the advancement of cold air from the middle level in association with warm and humid air at lower levels, unstable geopotential energy increased, convection further developed and the secondary circulation strengthened. The circulation of Vongfong also intensified via the CISK mechanism. Obviously, it resulted from the interactions between the cold, low pressure system at the middle and upper levels in the mid-latitudes and the typhoon, suggesting that the former has important contribution to the inshore intensification of Vongfong.

For analyses of the convection characteristics, streamflow and temperature fields of Vongfong, see the Chinese edition of the journal.

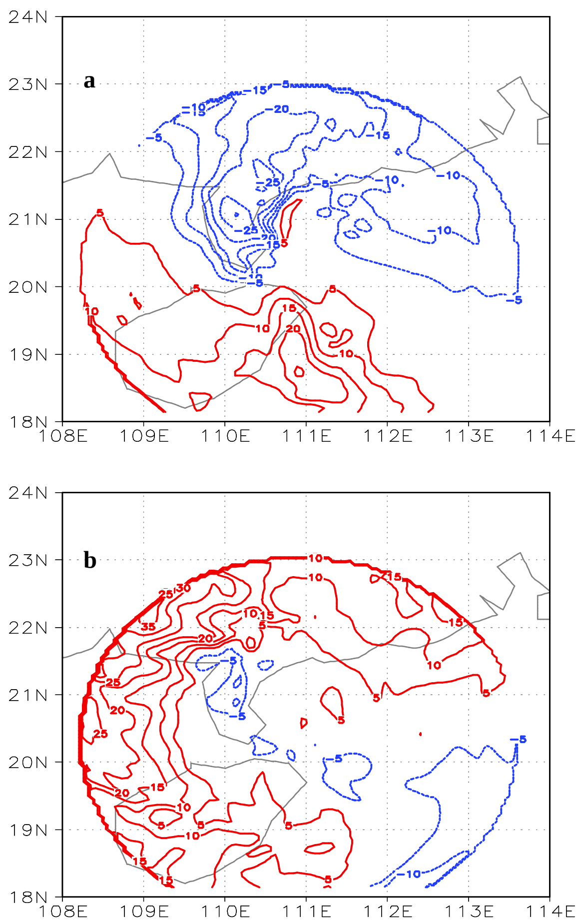

Fig.3 Distribution of inflow and outflow during Vongfong's intensification at 850 hPa (a) and 150 hPa (b). The isolines are at intervals of 5 m/s for the component of the radial wind speed; the positive values are for the inflow and the negative values for the outflow.

5 CONCLUSIONS

(1) As shown in the axisymmetric structure, the wall cloud of Vongfong was weak and inclined outwards with altitude, with the zone of severe convection corresponding to the circle of RMW; the radius of maximum wind decreased gradually with altitude. It is a feature in contrast to the hurricane in the Atlantic and the typhoon in the Pacific.

(2) Vongfong was highly asymmetric in both the dynamic and thermodynamic fields. During its time of full intensity, the storm was marked with more intense convection in the northwest than in the southeast quadrant and the belts of strong convective clouds were consistent with the zones of maximum wind. The axis going through the center of the typhoon flow field was inclining towards the northwest at all levels of the air column, which differed from the results of a composite analysis for typhoons in the central part of SCS. During its period of intensification, temperature was lower in the west than in the east of Vongfong at lower levels while being higher in the west than in the east at higher levels. When the storm was at full intensity, it was featured with well-defined warm-core structures at both low and high levels.

(3) The strongest low-level inflow appeared ahead of Vongfong and the outflow was behind it when it moved to the inshore waters. The strongest high-level outflow was before the typhoon and there was weak inflow to the rear of it. By contrast, the strongest inflow is behind the storm and the outflow is ahead of it as far as the Pacific typhoons and Atlantic hurricanes are concerned.

(4) The inshore intensification of Vongfong was mainly attributed to its interactions with an upper- and-lower cold, low pressure system in the mid-latitudes in the following two ways. (i) As the cold low was closely connected with the periphery circulation of Vongfong at the middle layer of the troposphere, cold air from outside of the system migrated into this layer from the northwest while there was warm and humid air at the lower layers of the storm, increasing the potentially unstable energy to further develop the convection. (ii) As the descending airflow from the center of the cold low was just the descending branch of the secondary circulation of Vongfong, the low moved south and filled up as the typhoon intensified inshore. Acting together, they intensified Vongfong via the CISK mechanism eventually. This is in great contrast with previous research on typhoon structure and physical factors for intensity change, which ignores cold, low systems at the middle and upper levels in mid-latitudes.

As shown in the study here, there are large differences in structure between the SCS typhoon Vongfong and typhoons in western Pacific, hurricanes in the Atlantic and typhoons in the central part of SCS, deserving much more research using more cases.

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