Recent Progress on Tropical Cyclone Research in China[①]

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ABSTRACT

This paper summarizes main progresses made in tropical cyclone research field in China in the past few years after the 8th five year program of China. New achievements have been made on tropical cyclone (hereafter referred as TC) structure, numerical prediction, evaluation of operational numerical model, TC-caused heavy rain, TC climate features and disasters, etc.

Key words: Recent research progress, Tropical cyclone

1. Introduction

As one of the most serious natural disasters, tropical cyclone (TC) has always been paid lots of attention by scientists. Especially during the 8th five-year program of China, researches on TC have been carried out widely and deeply. Lots of valuable results have been achieved (Chen and Meng, 2001). Since then, even though there is not large national project supporting TC research, study in the TC field is still being continued. This paper will summarize briefly the main new findings obtained in the TC field in the past few years.

2. TC structure

Because of lack of observational data over open sea, studies on TC inner structure develop rather slowly. However, the distribution of TC inner wind field is very important for operational forecast. To solve this problem, with the introduction of Fujita pressure mode, the radius of maximum wind and inner deflection angle of wind direction into the primitive equation, a formula was obtained to calculate wind distribution inside a TC over sea (Hu et al., 1999). The result of this method is mainly consistent with the real wind field for strong, weak, westward moving or recurving TCs, especially for those significantly affected by subtropical high.

Other study shows that the brightness temperature of GMS infrared imagery can be used to define gale distribution of TC (Yang and Li, 1999). The accuracy of the established mode can reach 85%.

As we know, TC is a kind of weather system that has great spiral characteristics. Spiral degree is closely related to the formation, development and structure of TC. Study shows that the development of TC is the increasing process of spiral degree (Chen and Tan, 1999). Thus, spiral degree can be regarded as a measure to evaluate TC intensity. The long duration of TC has close relationship with the inhibition of spiraling flow to energy diffusion and dispersion.

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Under weak environmental steering condition, the asymmetric structure of TC circulation may have significant impact on its motion. With a four-layer-quasi-geostrophic baroclinic model, the correlation between the moving speed of a TC and its asymmetric degree at different quadrants, different radius and different levels are investigated without the environmental flow (Yu, 1999). Result shows that a TC moving speed in the west-east direction is negatively correlated with its asymmetry in the west-east and southwest-northeast directions at a distance of 100 km to 300 km away from the TC center. Meanwhile, the moving speed in the north-south direction of the TC has a strong positive correlation with the asymmetry in the northwest-southeast direction at a distance of 200 km to 500 km away from the TC center. Besides, the asymmetry of the lowest level circulation has the highest correlation with TC moving speed.

3. Impact of large-scale circulation on TC motion

Observational study (Ma et al., 2000) is carried out on the relation between TC activities and the variations of large-scale circulation such as the location and intensity of polar low in the Northern Hemisphere, the westerly index in East Asia and the general circulation of the Southern Hemisphere. Useful references for the prediction of TC genesis have been put forward. Other study (Xu et al., 1999) shows that there is a close relation between the variation of middle troposphere synoptic system over the Qinghai-Xizang Plateau and movement of TC over the western Pacific. Statistic result shows that when the low-pressure system on 500 hPa isobaric surface occupies the middle troposphere over the plateau, TC in the western Pacific tends to move to the west. On the contrary, the high-pressure system on 500 hPa isobaric surface is always beneficial to TC recurvature to the northeast. The result of dynamical diagnosis shows that it is the transport of disturbance kinetic energy over the upstream plateau that makes the downstream trough develop and then affect the steering flow of TC. The southerly wind in front of the trough over the plateau together with the southerly wind at the east part of TC transports low potential vorticity of low latitudes into subtropical high, which would be beneficial to the development of subtropical high, and thus have effect on TC's movement.

With the IOP data of TCM-90 field experiment, the motion characteristics of target typhoons FLO and ED are investigated from the aspect of kinetic energy (Xu et al., 1998a). The diagnostic analysis and numerical experiment results show that TC can be regarded as a source of dynamic and thermal forcing to its environmental atmosphere, and the interaction between a TC and its environment may lead to the dispersion of kinetic energy and excite a horizontal Rossby-wave like train. The correlation analysis with the diagnostic results shows that the motion of target typhoon agrees with this wave train, and so the diagnosis of TC perturbation energy dispersion is meaningful for the forecasting of TC motion.

4. Numerical prediction

With the improvement of computer and observational tools, great progress has been achieved on numerical weather prediction. Study shows that the model with the consideration of sophisticated physical process is able to better describe the thermal structure around TC center than that without (Liu et al., 1998). The strongest ascending motion area at 850 hPa can be a rather good indication of the future 6-12h TC moving direction. Analyses on the three-dimensional thermal and flow structure around TC center show that the positive

feedback mechanism, namely strong upward motion → condensation of warm and humid air → release of latent heat → increase of air temperature → upper air divergent outflow → dropping down of surface pressure → lower level convergence → upward motion, might be the dynamic reason for TC movement towards the convergent ascending area.

Furthermore, satellite data is being introduced into the numerical model. Study shows that TC track and rainfall prediction can be apparently improved with the use of modified diabatic heating scheme based on the distribution of satellite brightness temperature (Zhou and Zhu, 1999). The effect would be better if the asymmetric moisture field of the TC is adopted simultaneously. With respect to operational application, several kinds of typical spiral structures of diabatic heating scheme were constructed as well. Different spiral structures would have different impacts on TC motion. Choosing the pattern that is mostly close to real cloud distribution would significantly improve the accuracy of TC track prediction.

Besides, preliminary study has been carried out on the employment of satellite cloud-derived wind in the numerical weather prediction system of typhoon tracks at National Meteorological Center (NMC) of China (Zhang and Wang, 1999). Result shows that cloud-derived wind data may improve the wind analysis field and consequently significantly improve TC track prediction. On the other hand, cloud-derived wind data can be used as the asymmetric wind component in TC-bogussing process, which can also contribute to improvement of TC track prediction.

Based on the cloud-derived wind and the upper sounding winds, computations are carried out on different terms of vorticity equation (Feng, 1999). Result shows that the local vorticity variation rate has special significance in indicating TC movement. TCs move generally towards the direction of the maximum local vorticity variation rate. In addition, just as the steering current, there is an effective radius of interaction in the vorticity variation rate field, within which changes of vorticity may have a direct influence on TC motion.

On the other hand, the performance of Shanghai Typhoon Model (STM, an operational typhoon model for TCs affecting the East China Sea) in 1996, 1997 and 1998 was evaluated statistically (Gu et al., 2000). Based on the comparison results between STM and subjective forecast as well as Typhoon Model of Japan, experiments were made concerning the impact of PBL physical process, TC bogussing technique, objective analysis and data assimilation on TC movement. It is found that the varying drag coefficient instead of the former constant one, two times of TC bogussing method before and after objective analysis instead of one-time after the objective analysis, three dimensional optimum interpolation objective analysis instead of two-dimensional one and the introduction of intermitted data assimilation can significantly improve the accuracy of TC track prediction of STM.

5. TC climate features

In the past few years, new findings are also obtained in the climate analyses on TC activities in the western North Pacific basin. The climate features of about 50 years' TCs during 1949–1996 were investigated statistically (Chen et al.,1999). The interannual variation and seasonal distribution of TC frequency, intensity distribution, track categories, seasonal variation of TC origins and the relationship between TC intensity and its origins are obtained.

With the statistic correlation technique, the relation between the western North Pacific TC activities and El Niño—La Niña events was analyzed (He et al., 1999). It was put forward that there would be less TC in the El Niño year, and more in the La Niña year. TC activities are closely related to the starting and ending times and the intensity of the two abnormal

events. This correlation turns to be useful information for the TC frequency forecast. Besides, the mechanism for the difference between TC activities in the two different event years is also analyzed. The result shows that the influence of air–sea coupling function on the atmospheric circulation plays an important role in TC activities.

Besides, the relation between landing TC numbers and the Pacific SST field from 1951 to 1997 is studied (Deng et al., 1999). The eastern Pacific SST field (or ENSO event) can be correlated with landing TC numbers in China. Besides, the landing TC numbers are negatively correlated with the equatorial Pacific SST and positively correlated with the central Pacific and the western North Pacific SST.

Based on the classification of cold and hot summer year in the middle and lower reaches of the Yangtze River, statistic analysis was conducted on the abnormal activities of offshore TC in China (Chen et al., 2000). Result shows that large differences on the genesis frequency, strength, drifting speed and tracks of offshore TC to the east of China exist between the cold and hot summer years of this area. Statistics show that the TCs in hot–summer years are more, stronger and faster while entering China offshore than those in cold–summer years. The track patterns in hot summer years are also different from that in cold summer years. In cold summer years, most TCs turn to the northeast without making landfall with the affecting extent to the east of 117°E. While in the hot summer years, the TCs usually move to the west and make landfall with the affecting area extending westward to about 112°E. The recurving points in hot summer years are usually to the west and north of those in cold summer years.

Furthermore, the interannual variation and tendency prediction of TCs in Hainan Province of China are performed (Li et al., 1998). Methods of accumulative anomaly and smoothing T–test etc. are used to conduct tendency analysis and detection for abrupt changes. Result shows that 1946 is the abrupt change point at which a period of few typhoon ends and a fresh period of more typhoons begins. It is predicted that Hainan is within a period of fewer typhoons by 2004 and may step into a period in which the typhoon becomes active from 2005 on.

During the past few years, great efforts have been made on the climatic features of TCs affecting East China. For example, the mechanism of factors that affect TC annual frequency of Shanghai is investigated (Li et al., 1998). Result shows that the anomalous frequency of TC has relationship with the large–scale atmospheric and oceanic background. Features of general circulation and SST are analyzed for the years with more and less TCs that affect East China (Jiang and Deng, 1998). Through analyzing the frequency of TCs affecting East China, the probable forecast zones of TC affecting frequency in the time scale of year, season and month are designed (Lei, 2001). EOF analyses on the frequency of TC affecting East China show that the frontal four characteristic vectors and their time coefficients are good representatives of space and time distribution of TCs in East China (Feng and Yang, 2000). The characteristics of the atmospheric circulation and TC tracks in the anomaly year of time coefficient could be precursor for short–term anomalous climate.

Besides, a wavelet transform method is applied to analyze the TCs which make landfall and affected Fujian in the passed one hundred years (Wu and Zhang, 1998). It is shown that those TCs that landed on and affected Fujian can be separated into 11 periods with different TC numbers by a time scale of 20 years. Wavelet variance analysis indicates that 25 or 10 years are the dominant oscillation periods for these TCs. The interannual frequency change of TCs over the East China Sea affecting Zhejiang are studied also (Zhong and Zhang, 1998).

On the other hand, climatic and general –circulation characteristics of the sudden intensity changes of offshore TCs are analyzed as well (Lin et al., 1999). It is shown that sudden intensity changes of offshore TCs are of significant seasonal fluctuations and appear in the relative concentrated regions. They have close relation with the variations of wind field around the TC and positions of TC's upper and lower level circulation.

6. TC–caused heavy rain

TC–caused heavy rain was another key point in the TC research field in the passed few years. Diagnostic study on the heavy rain caused by typhoon Tim (No.9406) was conducted and compared to North American cases (Sun and Zhao, 2000). It is found that both Tim and North American cases belong to lower latitude systems captured by the baroclinic zone when they move to the middle latitudes. The North American cases can be transferred into extra–tropical cyclones. But Tim still maintains somewhat TC features with the warm core not destroyed completely. Computations on the various terms of vorticity equation show that the twisting term has the same order as the advection and convergence term in the upper troposphere. However for the North American cases, the function of lower level convergence is more significant. Furthermore, the calculation of the energy equation shows that the kinetic energy is not completely transformed from the available potential energy. A considerable part of it comes from the horizontal transportation of the kinetic energy. The analysis on moisture source shows that moisture transportation from the South China Sea and the western Pacific plays important roles in the rainfall process in North and Northeast China.

Furthermore, the divergence and rotational wind kinetic energy budget and conversion during a torrential rain process caused by typhoon trough are calculated using the complete equations of budget of divergent and rotational wind kinetic energy (Yu and Yao, 1999). The results show that the increment of the kinetic energy in the torrential rain area is one of the main contributors to the amplification of the torrential rain. Energy analysis also shows that the available potential energy is first transformed into the divergence wind kinetic energy through the baroclinic process, then the divergence wind energy is continuously transformed into rotational wind kinetic energy. This kind of energy transformation has the maximum in the lower troposphere and is an important condition for the enhancement of TC–caused torrential rain. It is also denoted that there exist enhancement of baroclinic instability and decrement of barotropic stability during the heavy rain process, which also plays an important role in the amplification of the torrential rain. The impacts of TC and westerly trough on the rainfall occurring in front of westerly trough far from the TC are analyzed with non–hydrostatic meso–scale model MM5 (Zhu et al., 2000). The results show that TC intensity can have influence on the water vapor transportation to mid–latitude by the southerly jet to the east of the TC. Low–level water vapor transport may result in strong water vapor convergence and unstable energy accumulation in the middle–latitudes rainfall area. Consequently, the rainfall intensity in front of the westerly trough has close relationship with the water vapor transport to the east of the TC. Additionally, westerly trough provides a large–scale background beneficial to the occurring of mid–latitude rainfall. The westerly trough can contribute to the development and maintaining of vertical motion and thus benefit the occurring and intensification of the heavy rain. Furthermore, the simulation results also show that the intensity of westerly trough can affect the intensity of the heavy rainfall of the mid–latitude area.

Other study is carried out on the formation and development of meso–scale cloud clus-

ters in the torrential rain happening around the tropical depression (Li et al., 2000). Result shows that these cloud clusters happen in high unstable energy and weak baroclinic condition. They were triggered by unsteady ageostrophic gravitational wave in the low-level jet from the southeast of the outskirts of the typhoon. Q-vector front-genesis function analysis indicated that a vertical circulation between the torrential rain and westerly trough to its northeast plays a role of energy transformation. On the other hand, the westerly trough may strengthen the divergence above the torrential rain and thus make the cloud cluster redevelop.

Besides, the mechanism of the interaction between TC and Meiyu circulation from the regional energy and water cycle point of view is also analyzed (Xu et al., 1998b; Cheng et al., 1999). Result shows that the influence of TC on Meiyu front comes from the forcing of TC to the change of large scale circulation such as subtropical high and the impact of TC on the transport of water vapor and energy to Meiyu region. The ending-up of Meiyu is closely related to the landfall of TC. The landing of TC cuts not only the transport of the water vapor to Meiyu area but also the conversion of the mean flow energy to the Meiyu circulation because of the TC forcing to the zonal circulation. These effects make the convection and perturbation existing in the Meiyu region lack the supply of the vapor and energy for their maintenance and lead to the end of Meiyu rainfall.

7. TC disaster analyses

New achievements are also obtained in studies on TC disaster. Statistic analyses were carried out on TC disaster that occurred from 1979 to 1996 in the area of Guangdong Province (Liang et al., 1999). Result shows that affected area of agriculture, death toll, collapsed houses and destroyed hydrology instruments are four main factors that are related to TC disaster degree. By the method of fuzzy subset theory, a TC disaster assessment model is set up. The composite disaster index for every landing TC was calculated and criteria of TC disasters with different degrees were established. It is found that the composite disaster index can basically reflect the direct economic loss.

According to the intensity of wind and rain as well as the position of TC approaching Shanghai and the Yangtze Delta, the criteria of TC affection and serious affection are designed (Feng et al., 1998).

8. Conclusion

The above research results show that TC research work in our country in the past few years have obtained certain achievement on TC structure, TC motion and TC-caused heavy rain as well as climatic features of TCs. These aspects are indeed important. Certain efforts are still necessary to carry out further investigation in these fields.

On the other hand, new research issue is drawing more and more attention of scientists in the international TC field, namely TC landfall problem. The USWRP and World Weather Research Program (WWRP) have identified landfall TCs as a key point of their research programs (Marks, 1998). It is the national interest to mitigate damage that occurs after a TC makes landfall. In fact, the landfall is what we really care. It is during landfall that TC causes most of the disasters. The emphasis of operational forecast is also the landfall point and intensity. However, the physical mechanism study on TC during landfall process is very few in China, which might be a problem that we should pay more attention to in the coming years.

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中国近几年热带气旋研究进展

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摘 要

总结了中国过去几年尤其是"八五"结束后热带气旋领域取得的研究成果。主要包括以下几个方面的内容:热带气旋的结构、数值预报研究、业务数值预报评估、热带气旋暴雨、热带气旋的气候特征以及热带气旋的灾害等等。

关键词: 最新进展,热带气旋