RESEARCH WORK ON TORRENTIAL RAIN AND TYPHOONS

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ABSTRACT

Heavy rains and typhoons cause major disasters, including great economic losses and casualties, in China. Therefore, it is very important to research these torrential rains and typhoons in order to improve forecasting accuracy to mitigate their consequences. The Center of Disaster Reduction of the Chinese Academy of Sciences has cooperated with the Department of Atmospheric and Oceanic Science at the University of Maryland in the US in studying heavy rains and typhoons for over 7 years. Some of the findings from the study of heavy rains and typhoons are introduced in this paper.

Keywords: Heavy rains, Typhoons, Numerical modeling, Adjoint method, Coriolis force

1 INTRODUCTION

China is such a vast nation that it contains a great variety of the climates. Thus heavy rains have different intensities and frequencies in different climatic zones. According to statistics (Zheng, et al., 1995), flooding caused by heavy rains frequently occurs in China. From 1949 to 1966, on average, the north of China was the most stricken area, but since 1966, the most heavily impacted areas have been the mid and lower valley of the Yangtze River and Northeast China (in particular the Songhuajiang River and Heilongjiang River Valleys). The rains and flooding vary by season, moving from South China to Middle China and then to the north part of China during April to September (Feng, Li, and Wang, 1996). Typhoons, on the other hand, usually impact the coastal areas of China although sometimes tropical cyclones move inland and join the subtropical weather systems bringing severe heavy rains, which result in great damage and casualties from the flooding. Every year, there are seven to nine typhoons on average that make landfall in China. In 2005 for the first time, damage brought by tropical cyclones became the most expensive of all natural disasters, costing up to 80 billion Yuan RMB. Before 2005, flooding caused by heavy rains was the worst disaster in China (Wang, et al, 2006).

As mentioned above, heavy rains and typhoons always cause great economic losses and a large number of casualties in China. It is very important to research torrential rains and typhoons in order to improve forecasting accuracy and to mitigate the disaster. The Center of Disaster Reduction has cooperated with the Department of Atmospheric and Oceanic Science at the University of Maryland (US) in studying heavy rains and typhoons for over 7 years. Some findings from the study of heavy rains and typhoons are introduced in this paper.

2 NUMERICAL MODELING OF HEAVY RAINS

Weather systems with intense precipitation are the dominant meteorological phenomena in summer in China. Mesoscale systems play very important roles in these heavy rains, which produce long duration and violent rain, resulting in inundation of the countryside. So far, researchers have not been able to explain the mechanisms and dynamic processes of the heavy rains. Thus our ability to forecast these heavy rains is greatly hindered.

Heavy rains are produced by the interaction among various scales of weather systems, especially significant mesoscale systems of strong convection. The mesoscale system has an apparent interaction with large-scale weather systems. For instance, the Meiyu in the Changjiang River and Huaihe River Valleys in China is a large-scale weather system with a synoptic and climatological view. Usually it is a cloud belt in space or a rainband on the ground, but it is not a symmetrical band. It is made up of several α mesoscale systems, and in every α mesoscale system, there are many β mesoscale convective agglomerates in action.

In recent decades, with the development of numerical models and the great progress in computer technology, numerical simulations for typhoons and heavy rains have been heavily researched. This makes it much easier to study the convective system and its physics process in detail by means of high space-time resolution models. The mesoscale models from Penn State University and NCAR (in the US), such as MM4, MM5, WRF, are very familiar to meteorologists in China. Two cases of numerical modeling of heavy rains in China are illustrated here.

The first case is the study of the Meiyu that occurred in July 1991 in the middle and lower valley of the Yangtze River (Feng et al., 1999, 2004). This case study reveals that large-scale humidity distribution has a great influence on the intensity of heavy rains, and the mesoscale terrain has obvious impact on precipitation (intensity and area) of the rain. The mesoscale terrain's effect on heavy rains has been illustrated in another published paper (Feng et al., 1999, 2004), so here we will summarize the large-scale humidity distribution's significant influence on heavy rains.

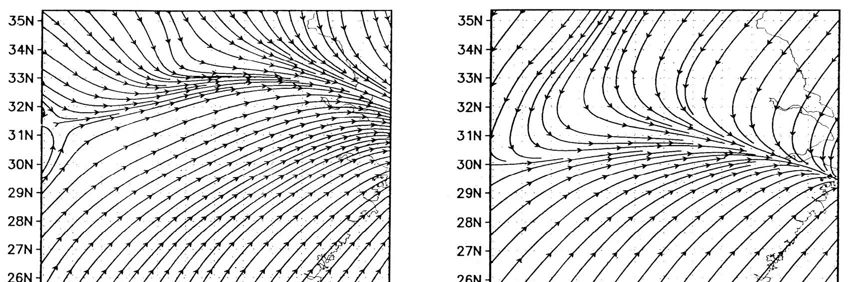
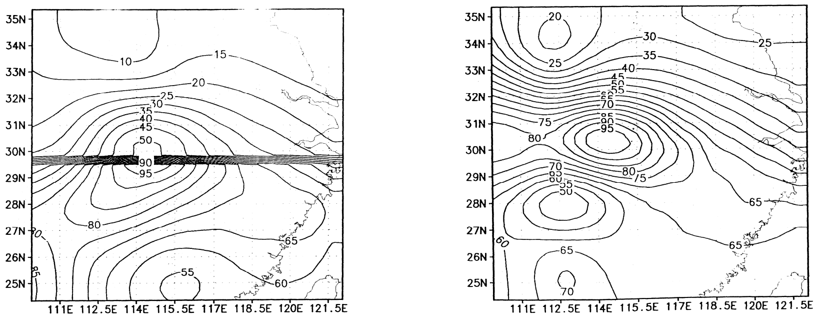


Figure 1. The streamline analysis at 850hpa and 700hpa at 00:00UTC on 2 July 1991(observed)

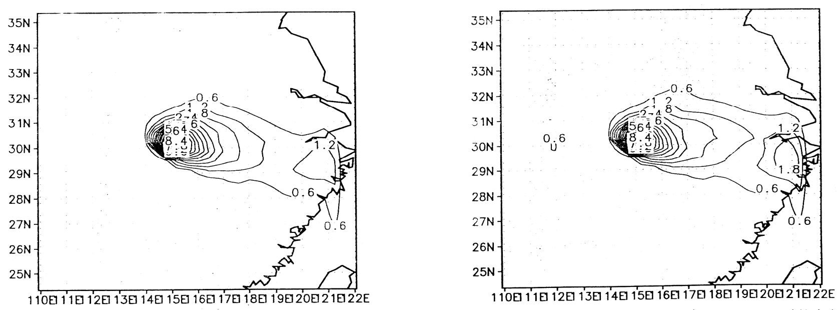
Figure 1 shows us the observed streamline analysis results at 850hpa and 700hpa at 00:00UTC, respectively. There is a convergence line in the Changjiang River and Huaihe River Valleys, and the convergence zone vertically tilts southward, which hints that the warm airflow is much stronger in the lower layer than that in the upper layer, while cool airflow is much stronger in the upper layer than that in the lower layer.

Because of the successful control experiments of MM4 (the fourth generation mesoscale model developed by Penn State University and NCAR) (Feng et al., 2004), we were able do a sensitivity test based on artificial change for the large-scale humidity distribution with no change of other parameters. We reduced the air moisture below 500hpa in the north side of 29.8˚N to 50 percent of its original value and kept the humidity in the south part of 29.8˚N. The humidity in the upper layers from 500hpa is not changed. Then we run MM4 to check the variation in the precipitation. Figure 2 is the humidity distribution after the air moisture of lower layers (<500hpa) is reduced by 50% in the north side of 29.8˚N, making it equal to that in the lower layers. Relatively, the north part is drier, and the south part is much wetter. Figure 3 is the precipitation of the control experiment (before humidity change), and figure 4 is the rainfall of the sensitivity test after the lower air moisture change.



700hpa 500hpa

Figure 2. The relative humidity distribution after the air moisture of lower layers (<500hpa) is reduced by 50% in the north side of 29.8˚N at 00:00UTC on 2 July 1991.

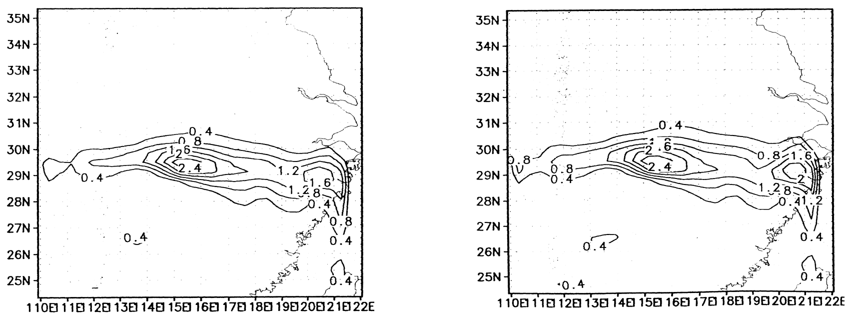


05:00UTC

06:00UTC

Figure 3. The precipitations of the control experiment of MM4 at 05:00 and 06:00UTC, respectively, on 2 July 1991(unit: ×10.0mm).

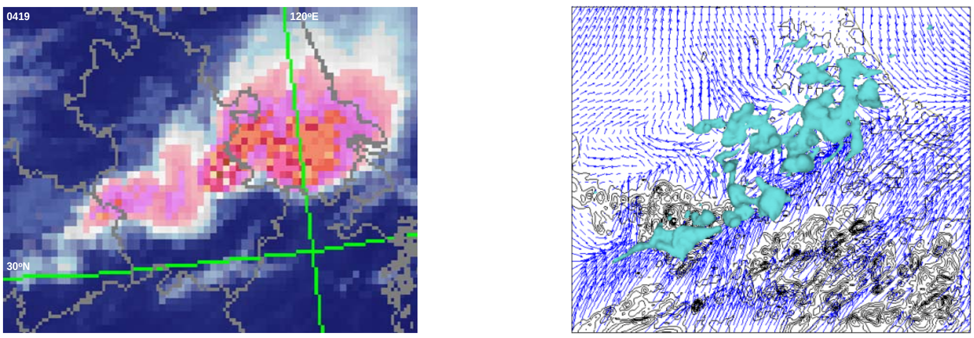
Comparing the precipitation in figure 3 with that in figure 4, we find that the rain band of heavy rains moves to the south side of 29.8˚N, and generally the rain intensity has been weaken because of the reduction of humidity in the lower layers. According to the results of the sensitivity experiment (the output is given by the model in half hour intervals), the rain zone gradually enlarges eastward and finally forms two precipitating centers respectively in the west and in the east. This phenomenon obviously tells us that (1) there many β mesoscales moving from west to the east in this heavy rains process, and (2) the mesoscale system moves to the moister area, which illustrates the interaction between the mesoscale system and the large-scale environment from which the mesoscale system gets its energy and moisture. In other words, we find that large-scale humidity distribution greatly influences the heavy rains' intensity and area.



05:00UTC 06:00UTC

Figure 4. The rainfall of the sensitivity experiment of MM4 at 05:00Z and 06:00Z GMT, respectively, on 2 July 1991(unit: ×10.0mm).

The second case study is the cloud-resolving model simulation of a mesoscale convective system (MCS) producing torrential rainfall. This is carried out with fine horizontal resolution of 444 m (Zhang, et al, 2006). The results appear to have important implications for the improvement of summertime quantitative precipitation forecasts and the understanding of vertical hot towers and midlevel mesoscale convective vortices for mid-latitude MCSs. In this case study, the heavy rains occurred from the 4th to the 5th of July 2003. The area from Nanjing to Chuzhou has been simulated using the mesoscale model MM5V3.6 (developed by PSU/NCAR USA). Figure 5 is an instance for comparison of the modeling products by MM5 with the infrared nephogram obtained from the satellite, which validates that the output from the high-resolution model can realistically simulate the convective cloud system, which is exhibited in the infrared nephogram from the meteorological satellite. It can also reproduce the sites, the scope, and approximate shape of the convective cloud cluster at a specified time.



(a) (b)

Figure 5. (a) The infrared nephogram at 19:00UTC (b) 3D display of the coagulated water (the light green mass) at 20:00UTC（clw+rnw+snow+ice＋graupel≥0.8g/kg）from simulation by MM5 - the arrowheads stand for wind fields and the solid black line for the topographical height.

3 NUMERICAL MODELING OF TYPHOONS

3.1 Simulation of typhoons at different stages

In researching typhoons, the typhoon's intensity and its track predictions are very important and very difficult issues. Three case studies of typhoons (Dan in 1999, Nari in 2001, and Durian in 2001) in the northwest Pacific

Ocean have been carried out respective by Deng (2006), Tian Liqing, and Zhang Wenlong (Wang, et al., 2006). These studies obtained many interesting results in numerical modeling of typhoons by using a two-way interactive, quadruple nested-grid, non-hydrostatic version of the Penn State University/National Center for Atmospheric Research model (MM5v3). The horizontal resolution of the model has been improved to 1.33km and the vertical resolution to 41 layers. These studies were supported by the World Bank project for basic research on natural disaster mitigation in China and conducted in the Center of Disaster Reduction, Chinese Academy of Sciences, which has cooperated for over 7 years with the Department of Atmospheric and Oceanic Science, University of Maryland. We have successfully simulated the typhoons that occurred in the northwest Pacific and in the South China Sea at different stages (genesis, development, and landfall) or throughout their lifetimes. Figures 6 and 7 are the simulated results of typhoons Nari (2001) (by Tian Liqing), and Figures 8 and 9 are the results of the simulation of typhoon Durian (2001), including its track and radar echo before landfall (by Zhang Wenlong). We are making a great effort in the numerical modeling of typhoons and heavy rains at the Center of Disaster Reduction in the Chinese Academy of Sciences, focusing on the scientific issues in large-scale organized convective systems. We are making steady progress in this area.

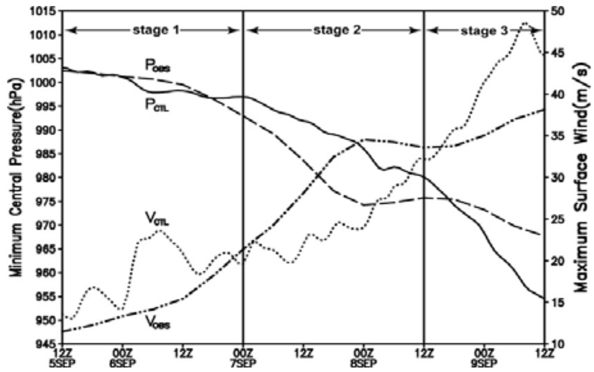


Figure 6. The simulated centric pressure (P_{ctl}: solid line) of typhoon Nari (Sept., 2001), the observed centric pressure(P_{obs}: dashed), the simulated maximum wind (V_{ctl}: dots), and the observed maximum wind (V_{obs}: dots and dashed).

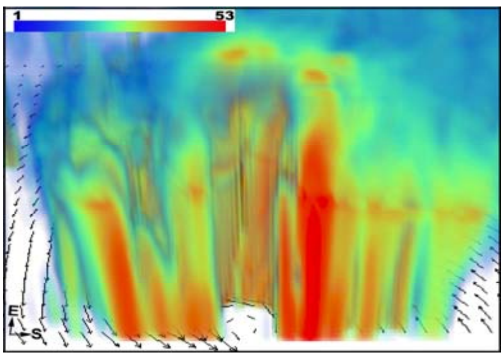


Figure 7. The simulated 3D radar echo of typhoon Nari (2001) at matured stage (made by Vis5D) at 12:00UTC, Sept. 9, 2001.

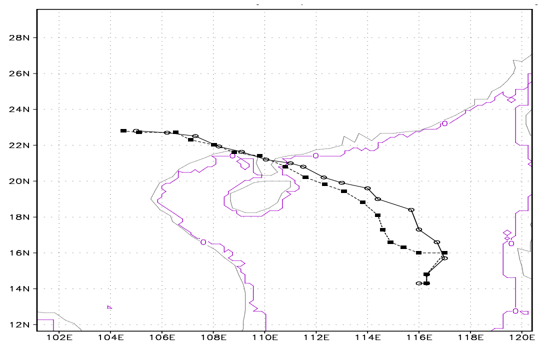


Figure 8. The simulated track (cycle and solid line) and the observed track (dots and dashed) of Durian (2001)

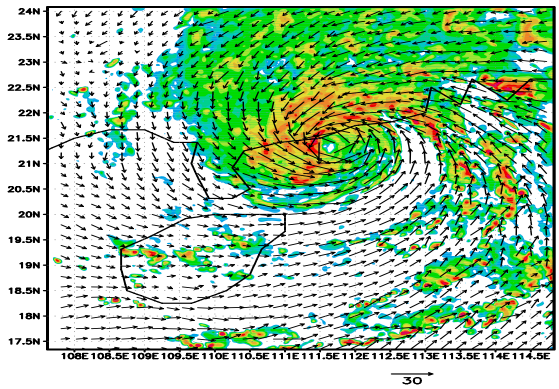


Figure 9. The simulated radar echo of typhoon Durian (18:00UTC, July 1, 2001) before its landfall - the arrowheads stand for wind fields.

3.2 Statistical-dynamic modeling of tropical cyclone (TC) tracks

If we expect to reduce the property damage and the loss of life caused by tropical cyclones (TCs) or typhoons, we must be able to predict the track of TCs as precisely as possible in advance. However, this has been a difficult issue for scientists for years. In the recent 20 to 30 years, with the progress of typhoon dynamics research, the improvement of unconventional detecting instruments, the great increase of various data (satellite and radar data), and the application of up-to-date methodology and technology (such as 4-D variation and ensemble prediction, etc.) in numerical weather forecasting, the forecasting level for a typhoon's path has obviously been enhanced. Besides the dynamic mesoscale models, the adjoint method is also used to imitate the tracks of the typhoon's motion within China. In this section we summarize our primarily work in this area.

A variational data assimilation by the adjoint method (Feng, et al., 2006; Xiang, et al., 2006) is carried out for real tropical cyclone (TC) tracks. The model used is the statistical-dynamical prediction model SD–90 developed by the Shanghai Institute of Typhoons. The results indicate that, although the TC motions are very complicated, the TC tracks can be fitted well; for a given TC, the distribution of the resultant retrieved force and Coriolis force matches well to the corresponding TC track. That is, when a TC turns, the resultant retrieved force and Coriolis force act as a centripetal force, which means that TCs behave like particles, which also verifies the validity of the point-vortex viewpoint.

Some TCs occurring in the Northwest Pacific Ocean with abnormal tracks have been studied according to the adjoint algorithm (Xiang, et al., 2006), and the variational data assimilation and reversion were conducted in each case. Figures 10 and 11 illustrate the experimental consequences of TC No.6110.

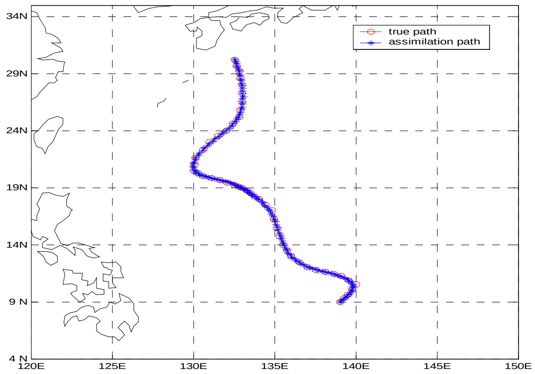


Figure 10. The fitted track by assimilation and the true track of TC No.6110

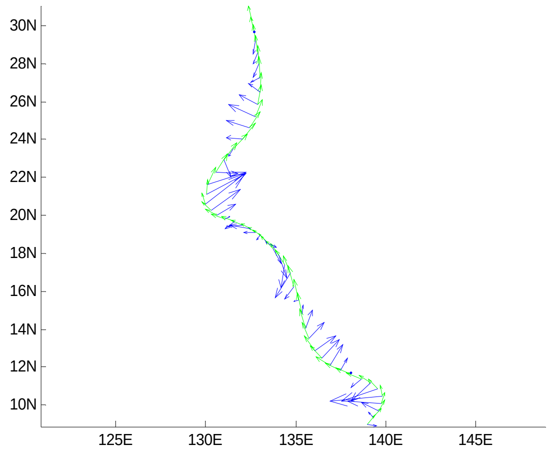


Figure 11. The retrieved velocity vector (green, unit: (°) h^{-1}) and the resultant of the retrieved force and Coriolis force (blue, unit: ×116.8N)

4 CONCLUSION

In the past seven years, we have done several studies about heavy rains and typhoons using numerical simulation. We did these studies not only because heavy rains and typhoons are frequent natural phenomena that result in flooding, other damage, and loss of life but also because there are many complex scientific issues concerning heavy rains and typhoons, such as their developmental mechanisms, the causes of the zigzag tracking of typhoons, quantitative precipitation forecasting, multi-scales interactions, interaction between tropical and subtropical systems, their uncertainty and predictability, etc. What we have done in the Centre of Disaster Reduction, Chinese Academy of Sciences has taken much initiative. The ongoing research will link the fundamental research and the basic application research with the view toward disaster mitigation. In fact, we still face a great challenge; there is still a long way to go.

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