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THE APPLICATION OF ASSIMILATED AIRCRAFT DATA IN SIMULATING A HEAVY RAIN OVER SOUTH CHINA IN JUNE 2005

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Abstract: Regular and irregular observational data are used to analyze and simulate a torrential rain over the south of China on 18 – 24 June 2005. Since the regular data cannot depict the rainfall system fully, GRAPES model is used to simulate this process. Different data are assimilated for 12 hours by its simulating system and different analysis data are obtained. In order to analyze how well the model forecast has been improved with the addition of assimilated aircraft data, these different analysis data are used as the first-guess data to conduct two control numerical simulation tests. From these tests, it is proved that the model that adds aircraft assimilation data can simulate the main region of precipitation, which is more consistent with the observed precipitation than the model that does not, and that the accuracy rate is also improved. These numerical simulation tests not only show that it is necessary and capable to improve the modeling of this torrential rain process by using aircraft data, but also lays the foundation for forecasting heavy rains in the south of China based on aircraft data.

Key words: heavy rain over South of China; aircraft data; data assimilation; model simulation

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1 INTRODUCTION

The south of China is a domestic region that has the longest raining season and most heavy rains[1]. With the development of various mesoscale models in recent years, research on mesoscale systems of heavy rain has become a focal point. Simulation studies have been conducted at home and abroad using various NWP models[5-11]. On the other hand, misses and false alarms remain at a relatively high level if conventional data are the only data in the forecasting of mesoscale heavy rain area. It is still quite hard to predict mesoscale heavy rain systems if only the conventional data are used[12].

At present, with the development of science and technology, there have been more unconventional data than before to increase the coverage and spatial-temporal resolution of the meteorological elements observed. It also makes it possible to have comprehensive analysis of mesoscale heavy rain systems and improve the capabilities of numerical prediction. It is, therefore, one of the key points in the attempt to improve the current NWP to apply unconventional data to provide accurate initial objective analysis. The Chinese assimilation system of GRAPES 3D-Var and NWP model of GRAPES have been used successfully in the numerical simulation of various weather, especially severe weather[13-15]. In the current work, aircraft data are used in the above assimilation systems to look into the role of the former in the improvement of initial objective field of the model and the possibility of expanding their use.

On Jun. 18 – 24, 2005, a severe rain appeared in the south of China that moved from north to south. There were a group of mesoscale convective cloud clusters on the cloud zone of a stationary front, which

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immediately caused the heavy rain. In view of the fact that conventional data have limitations in analyzing and simulating the structure and evolution of mesoscale heavy rain systems on small scales, surface and upper-level data are used in this work to analyze the rain and associated weather for the heavy rain before simulating the process with an analysis field incorporated with aircraft data. Then, the results are compared with those without the aircraft data in the assimilation analysis. The aim is to discuss the usefulness of aircraft data in the assimilation of numerical models and the feasibility of them in the improvement of the capabilities of describing precipitating systems in the south of China.

2 AIRCRAFT DATA AND SCHEMES FOR EXPERIMENTS

2.1 *Characteristics of aircraft data*

Aircraft data are the meteorological data measured during the flight of commercial airliners. At present, aircraft data are already part of routine weather records and it is part of our current study to improve the accuracy of routine weather forecasting.

Mainly four variables can be retrieved from aircraft data, air pressure, wind direction and speed and temperature. A representative section of time (of Jun. 18 – 20, 2005) is selected to analyze the distribution. It is found that the aircraft data follow certain spatial and temporal patterns. First, as the height of flights is mostly between 400 hPa and 200 hPa and low-level data are mostly available during take-off and landing, the time and location of the latter are few and concentrated. Then, due to the time in which the commercial flights actually take place, there are more aircraft data during the day (00:00 – 12:00, UTC) than during the night (13:00 – 00:00). As a result, rather than in linear, homogeneous distribution with time, aircraft data are mostly available during the day. In addition, aircraft data are more about the land than the sea and concentrate on a few main routes.

Aircraft data are much more during the day than the night, which will have different assimilation results for different periods of time and regions. To evaluate the assimilation results of the aircraft data and different effects on different regions, the current work decomposes the data by the hour for the time 01:00 – 23:00 June 18 and then introduces them into the model for assimilation. Then, the results are compared with those without the aircraft data during the assimilation.

As there are inevitably errors in the process of observation and reporting, quality control is needed before the aircraft data are used. Then, the data are decomposed into hourly segments that are incorporated into the hourly assimilation system. Being different from the more usually seen dataset at 6-h intervals, those used in this work have shorter periods of cycling and more times of assimilation. It is then hoped that it is closer to the observation to have better results.

2.2 *Assimilation and scheme of simulation experiment*

In accordance with the aim of the experiment, a scheme is designed for comparative simulation. GRAPES is used to simulate the heavy rain. The model interval is 0.12°×0.12° with a total of 209×176 gridpoints over an area at 15°N – 36°N, 105°E – 130°E. The simulation validity is 24 hours, or, covers the time from 12:00 UTC June 18 to 12:00 UTC June 19, 2005. To compare the validity of the analysis field with the assimilated aircraft data, two sets of experiments are designed and both of them use as background the forecasts by a monsoon model at the Guangzhou Institute of Tropical and Oceanic Meteorology. For Exp.1, the initial field is based on the data obtained after a 12-h assimilation with ship and satellite data as well as conventional ones. For Exp.2, the initial field is determined using the assimilated and analyzed fielda made available with the same data with the addition of hourly aircraft data. With the results achieved with the same mesoscale regional model for Guangzhou as the lateral boundary, the experiments differ basically in whether the assimilated data contain the aircraft data and whether the procedure of hourly cycling is used in the assimilation.

3 COMPARISON OF THE RESULTS OF ASSIMILATION

3.1 *Comparison of assimilation results*

It is known from the results of assimilation that the two experiments are similar in simulating the general circulation that is close to the reality. The assimilation of aircraft data can be shown from the comparison of the wind fields determined from the assimilation analysis. It is known from the assimilation analysis for the 300-hPa level (Fig.1) that large-scale circulation is consistent in both experiments but with considerable difference in mesoscale circulation; Exp.2 is able to simulate disturbances on relatively small scales while Exp.1 does not work as well in simulating mesoscale circulation. Fig.1c shows the differences of horizontal wind field between the two experiments. It is seen that there is anti-cyclonic difference in northern Fujian, northern Jiangxi and southern Zhejiang, indicating a wind field for this area that is more convergent in Exp.2 than Exp.1. The region is also where precipitation is the most for the period from 00 UTC to 12 UTC Jun. 18. It is known from an analysis of 850-hPa assimilation that the aircraft data also have some effect on low-level wind field to cause significant differences in circulation in and around Guangdong. According to the difference between the two experiments, the aircraft data have more significant simulation of the southward-going cold air and northward-going warm and humid air — the two air currents converge just on the frontal zone, corresponding to the rain zone.

From the distribution of the wind field with the aircraft data, it is known that they distribute mostly around 200 hPa and 300 hPa, or from 250 hPa to 150 hPa, to be more exact. The wind field data around 300 hPa is mostly over the northern part of South China through the middle and lower reaches of the Yangtze River. It is just the area that has the largest difference in the wind field after the assimilation, which also shows the role of aircraft data in model assimilation.

In general, the difference is the largest in the wind field and temperature at upper levels for the two experiments, showing that the simulation has the best result as the aircraft data contain the data of wind and temperature. The difference is much larger at the upper than the lower levels, indicating that the aircraft data have a larger role to play in the upper-level field during the assimilation. Besides, the difference is also larger between the experiments in areas where there is dense data from aircraft. Due to relatively long periods of integration, the simulating effect of aircraft data will accumulate for the late stage of the integration and spread to cover the whole region. Both experiments are able to simulate the maximum center of the precipitation.

3.2 *Comparison of experimental results and sounding data*

Except for those at the boundary, there are all together 44 sounding sites within the simulated domain into which the results of assimilation are interpolated following the method of dual linear interpolation. Then, variance analysis is performed using the differences

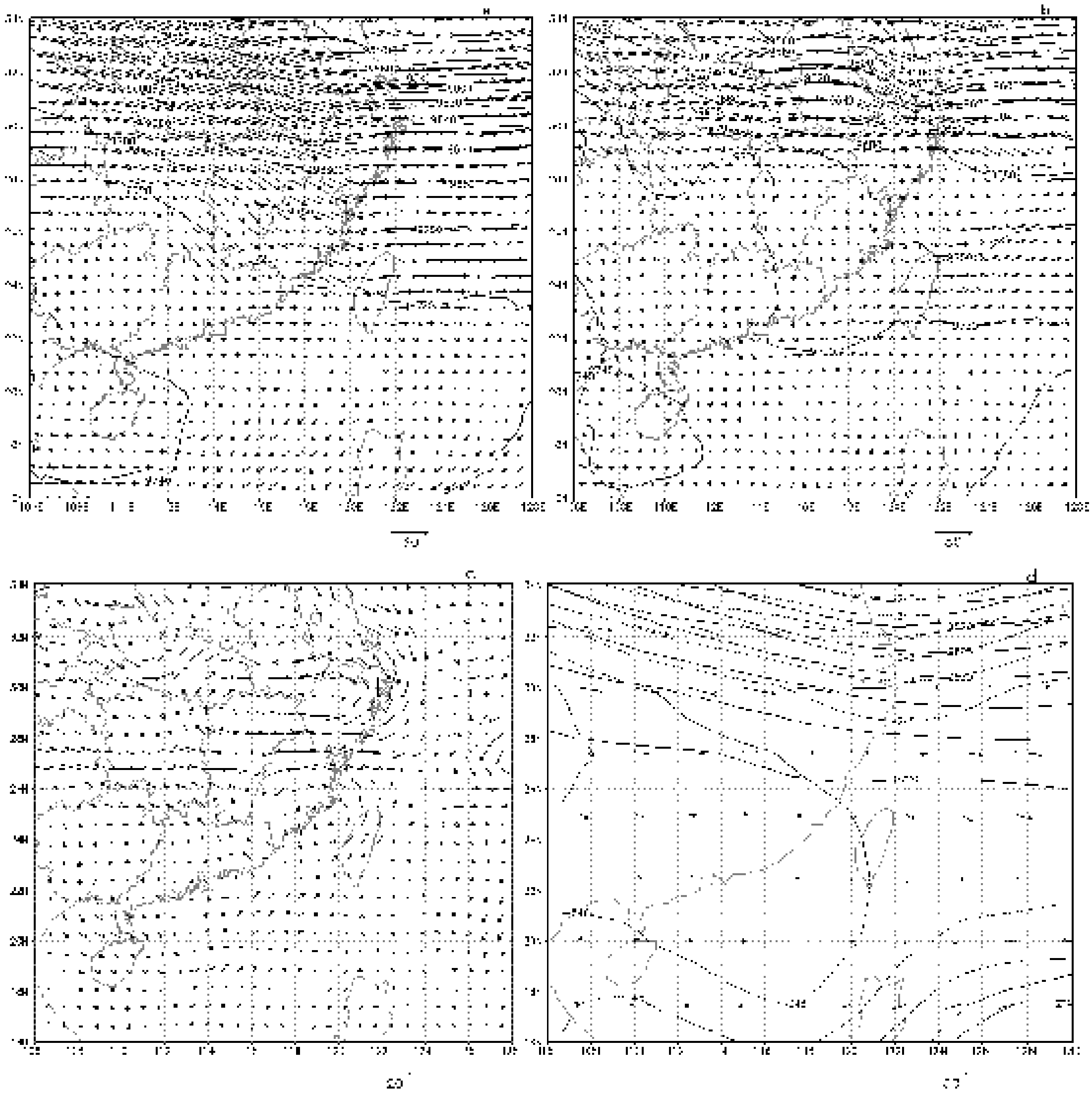

Fig.1 Assimilated wind and geopotential height fields at 300 hPa 12 UTC on Jun. 18. a. Exp.1; b. Exp.2; c. Difference of wind field (Exp.2 – Exp.1); d. Observations from NCEP.

determined by comparing the interpolation result and sounding data. The variance is determined with the formula of $s_x^2 = \frac{1}{n}\sum_{t=1}^{n}(x_t - \bar{x})^2$, in which n is the number of sounding sites, x_t the difference between the difference for a particular site and its sounding data, and $\bar{x}$ the mean of the differences.

According to comparisons of the results of 12-h assimilation (Tab.1), it is known that Exp.2 has much smaller standard deviation for upper levels than Exp.1 does, i.e. it is closer to the true value of sounding data. The result of Exp.2 is generally better than that of Exp.1, with the best in the assimilation of temperature. Comparing the results of 24-h assimilation (Table omitted), it is known that the results of both experiments do not differ much from the standard variance of the difference from observations. From the results of comparing the variance of the 12-h horizontal wind (*Vh*). It is seen that with the addition of the aircraft data, the variance of Exp.2 is stable with the change of altitude and improves much at upper levels and shows better overall performance than Exp.1 that does not include the aircraft data. It is then known that the errors of wind and temperature can be changed the most if the assimilation takes the aircraft data into account.

Tab.1 Standard deviation of the differences between experiment results and observations for 12 UTC Jun. 18.

	Pressure / hPa	925	850	700	500	400	300	200	mean
Exp.1	U/(m • s^{-1})	5.43	5.77	7.49	6.83	6.76	6.16	9.17	6.80
	V/(m • s^{-1})	6.44	4.80	4.31	3.17	3.79	5.45	7.47	5.06
	T/℃	2.89	2.00	1.11	1.02	1.03	1.25	1.11	1.49
	H / gpm	1.41	1.45	1.56	1.51	1.752	2.039	2.815	1.80
Exp.2	U/(m • s^{-1})	5.82	6.78	8.54	7.17	5.76	4.86	4.56	6.21
	V/(m • s^{-1})	6.6	5.13	4.78	3.42	4.32	4.40	5.30	4.85
	T/℃	2.73	1.79	1.03	1.06	0.98	1.19	0.95	1.39
	H / gpm	1.44	1.56	1.63	1.442	1.554	1.72	2.37	1.68

3.3 *Comparison of vorticity field*

Aircraft data have significant effect on the vorticity field. From the 200-hPa vorticity field that is assimilated in the experiments, it can be seen that there is a vast stretch of negative vorticity near the rain zone in Exp.2, which is just the northeastern part of the South Asian high at upper levels. The wind is from the west by north, showing that there is significant advection of negative vorticity at upper levels near the rain zone that strengthens the ascending air stream, which is closely linked with severe precipitation in relevant regions. It is attributed to the fact that the aircraft data included in the assimilation contain a large amount of upper-level wind field data and improve the vorticity field much more at upper levels than lower levels. Mild difference is found between the two experiments. It also shows that aircraft data contribute more to the improvement of upper levels than to the lower levels when they are included in the assimilation of models.

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

4 CONCLUSIONS AND DISCUSSIONS

With both conventional and unconventional data, the early stage of a disaster-inflicting heavy rain taking place in late June 2005 (June 18 – 19) was analyzed and model studied. As shown in the study, the rain zones during the process are discontinuous and contributed by different systems. The precipitation in the northern part of the zone is mainly resulted from a low vortex that has developed on the frontal zone due to the convergence of cold and warm air. The precipitation in the southern part is mainly of warm sector nature in which a warm shear plays a main role.

As analysis based on conventional data does not quite meet the need of accurately describing the generation and development of mesoscale systems responsible for heavy rains, simulation has been run to study the weather systems prior to this process using GRAPES. As there is need to explore more unconventional data to make up the insufficient distribution of conventional data on both temporal and spatial dimensions and aircraft data are just what need to be further explored and used, two experiments have been carried out in our study to examine the effect of aircraft data on simulation when they are included in the assimilation and the results are then compared with those without the use of aircraft data.

As shown in the assimilation results, the assimilation with aircraft data is better than the one without as far as the wind and temperature are concerned. The difference is the largest in the fields of wind and temperature and by much larger margin at the upper levels than at the lower ones. Additionally, the difference is also the largest in areas where there is densely distribution of aircraft data. It indicates a significant effect of the latter on the assimilation. The analysis field with the addition of hourly assimilated aircraft data is better than the one without. If no aircraft data are used, then after 24-h numerical simulation, false alarms and less realistic simulation of the areas of severe precipitation begin to appear, together with some inaccurately described mesoscale systems, owing to the lack of sufficient mesoscale information and in spite of some capability of the model in simulating the weather systems for the heavy rain and the distribution of the rain area. With the latter taken into account in the initial field, in contrast, the model improves substantially in the simulation of the temperature and wind fields, moderately in that of false alarms of precipitation and rain rates, and describes in more detail the generation and development of mesoscale systems. The above work has proved that aircraft data can be used to improve the simulation of heavy rains in the south of China, laying foundation for this type of data to be used in the forecasting of heavy rains during the annually first raining season in the region.

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