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AN IMPACT STUDY OF A NEW TYPE OF DATA OF ADAPTIVE OR TARGETING OBSERVATION ON TYPHOON FORECAST

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ABSTRACT: There was a new concept of 'adaptive or targeting observation' in recent years, which is an additional and targeting observation based on the existing and fixed observing network for the atmosphere on the impacted region. Dropsonde is one of the important observing instruments in the adaptive or targeting observation. In this paper, GRAPES, the next generation of numerical weather prediction system of China has been used. The impacts on the typhoon Dujuan (No.200315) forecast in experiments with dropsonde have been studied and experiments on sensitivity have also been done. It was found that the forecasts of the elements have been improved obviously with the use of dropsonde, such as the path, the center location, and the intensity of typhoon. It was also found in the sensitivity studies that the setting of deviation structure also has obvious impacts on the forecast for typhoons. It is not true that the simulation is better when the proportion of the data of dropsonde is larger in the course to modify the background.

Key words: adaptive or targeting observation; dropsonde; typhoon; numerical weather prediction

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1 INTRODUCTION

Typhoon (also called tropical storm, tropical hurricane or cyclone, etc.) occurring in the tropic ocean every year threatens severely the safety of inshore residents' lives and their properties and even results in a great loss. Thus a good forecast of typhoon is significant. The accuracy of typhoon forecasts, especially of the path, influences directly the whole predict effect of typhoons. The forecast of typhoon path has been studied in depth at home and abroad and the forecast accuracy of the normal moving typhoon has been better, but the forecast accuracy of typhoon with a complicated path has not been perfect. There are many factors which will change the path of typhoons, such as steering effects from the environment around the typhoon, changes of structure and intensity of the typhoon, and interactions of the atmosphere with the typhoon[1]. However, most routine observations are located in the land and observations over ocean are very limited though the area of ocean occupies 70% of the earth surface. Therefore, typhoon forecasting is a very difficult job.

Satellite observation is one of important means to obtain atmospheric information over the ocean and to improve the accuracy of numerical weather prediction (NWP), including that of typhoon forecasting, being especially critical for the improvement of global medium-range weather forecast accuracy. To accelerate improvements in the accuracy of 1- to 14-day numerical forecasts of high-impact weather events including typhoons, Word Meteorological Organization (WMO) approved a 10-year global atmospheric research program – The Observation Research and Predictability Experiment (THORPEX) [2]. Adaptive (or targeting) observation is one of the important contents in this program and a new concept proposed recently in the atmosphere science. It is an extra special aiming observation based on sensitive regions of NWP and present fixed atmospheric observation network. Dropsonde with good flexibility and reliability is an important adaptive observation instrument. Dropsondes can be thrown at a given position and time and observe the atmosphere during its descent. Dropsondes have been used for middle- and high-latitude adaptive

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observation experiments by Europe and north America since 1999[3,4]. For one or two years dropsondes have been used for tropical cyclones adaptive observations.

Since the 1997 purchase of a Gulfstream-4 jet aircraft by the United States government, special missions have been made to implement synoptic surveillance collection. On 2-8 September 2002, consecutive tropical storms formed near the Atlantic coast and attacked the eastern coast of the United States and the coast of Mexico gulf. During these days National Oceanographic and Atmospheric Administration/Atlantic Oceanic and Meteorological Laboratory/Hurricane Research Division (HRD) used the aeroplane (Gulfstream-4, also called G4) to throw dropsondes to collect synoptic surveillance data continually when the hurricanes was moving over ocean. Since September 2002, with the funding support of Science Committee, Taiwan University has continually implemented observation experiments of aircraft throwing dropsondes over the west Pacific Ocean to obtain the cross-section data of the atmospheric near the typhoon. [5] From 18UTC on 4 June to 6UTC on 11 June 2004, Typhoon No.200404 (Nida) moving over the ocean south to Taiwan rushed straight to the islands of Japan. During this event, Japan Meteorological Agency (JMA) threw 12 dropsondes around the center of the typhoon south of Taiwan Island (near 120°E, 20°N) to implement synoptic surveillance collection. And the data from this experiment were used to study the impact of dropsonde observation on typhoon forecasts in NWP. The simulation with dropsonde data indicates that the typhoon was moving all along over the ocean, which is close to the real situation. On the other hand, the two simulations without dropsonde data indicate that the typhoon landed on the southern part of Taiwan and even went through the whole island[6].

However, the THORPEX program for China is still being instituted and sensitive observations (including areas in mid- and high-latitude regions in winter and tropics in summer) have not been carried out and the application of dropsonde is a blank for landing typhoon forecasts in the country. Therefore the main jobs of this paper include the followings. Typhoon cases with dropsonde data and GRAPES system are to be simulated and the forecast results are to be compared with numerical simulations without dropsonde data and actual typhoon observations. At the same time, with changed deviation structure parameters of dropsonde observation in the 3DVAR of GRAPES, typhoons are simulated, sensitivity is studied and the result is compared with previous outcome and the observation about the path, center location, the intensity of typhoon and other factors. We hope that this paper could offer some help in improving NWP accuracy with dropsonde data. In section 2, the GRAPES model and data used in this paper are introduced briefly. In section 3, the typhoon case selected and the experiment design are introduced. In section 4, results of the simulations and actual situation are compared with each other, the impact of dropsonde data on typhoon is analyzed and sensitivity analysis is done of the deviation structure of dropsonde in 3DVAR. Summary and discussion follow in section 5.

2 THE MODEL AND THE DATA INTRODUCTIONS

2.1 Model introduction

Global/Regional Assimilation and PrEdiction System (GRAPES) is a new generation data assimilation and prediction model with regional and global configurations in China. The spatial resolution of GRAPES can change from 1km to 100km. 3DVAR is used in data assimilation. A primitive full compressible equation set is used in the new GRAPES dynamic core. In addition, the new GRAPES dynamic core consists of many main characteristics, such as a semi-implicit and semi-Lagrangian scheme, a latitude-longitude grid point design, regionally and globally unified areas, an optional hydrostatic/non-hydrostatic approximation, and so on.

2.2 Data introduction

The dropsonde observation data used in this paper are provided by Prof. Guo Yinghua in NCAR, which were collected in an observation experiment in Taiwan in 2003. Ten dropsondes were thrown around the center of the typhoon from aircraft and at the same time the real data were obtained by them (Fig.1).

Direct information obtainable from Dropsonde observation include the latitude and longitude of the observation sites, observing time, sea-lever pressure, and geopotential height, temperature, temperature and dew-point temperature difference, wind direction and

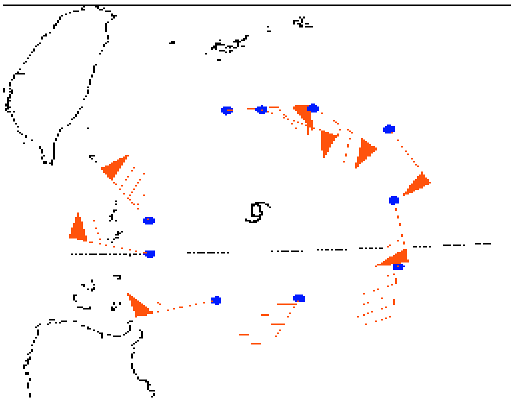


Fig.1 The locations of the thrown dropsondes used in this study.

velocity at different levels.

The dropsonde data used in this study are on 06UTC 1 September 2004, 126.7°E, 22.5°N and 56 levels for the first dropsonde thrown, 123.9°E, 23.0°N and 52 levels for the second one, 124.5°E, 23.0°N and 50 levels for the third one, 125.4°E, 23.0°N and 48 levels for the fourth one, 123.6°E, 19.0°N and 32 levels for the fifth one, 125.0°E, 19.0°N and 34 levels for the sixth one, 126.7°E, 19.6°N and 32 levels for the seventh one, 126.7°E, 21.0°N and 50 levels for the eighth one, 122.5°E, 20.0°N and 33 levels for the ninth one, and 122.5°E, 20.7°N and 36 levels for the tenth one. And the levels observed include both the standard and other levels.

The background data used in this study is 6-h T213 forecast data and the boundary is T213 analysis data instead of its forecast data. The region of interest in this study is between 100°-140°E and 10°-30°N.

3 THE CASE AND EXPERIMENTAL SETUP

3.1 The typhoon case introduction

The typhoon case selected in this study is Typhoon Dujuan in 2003, also called TY No.200313. Dujuan was at the ocean about 420km southeast off Eluanbi, Taiwan, i.e. 125.2°E, 20.7°N. At 08:00 L.T. 1 September, the wind was at Force 12 (on the Beaufort scale) around its center. After reaching Gangkou, Huidong, Guangdong at 19:50 on 2 September, Dujuan was moving west steadily through the Daya Bay and landed again at the coastal region of Shenzhen at 20:50. Then it went across the Pearl River Mouth and landed for the third time with a Force-12 wind force around the eye at the coastal region of Zhongshan east to the estuary at 23:15. After the third landing, its center moved through two cities of Jiangmen and Yunfu, then became a severe tropical storm at 01:00 on 3 September, weakened to a tropical storm at 02:00 and became a tropical depression at 08:00 on 3 September. From the evening on 2 to 3 September, there was widespread of heavy rain in the east, middle part and southwest of Guangdong Province and usually heavy rain in some parts. More than ten towns and countries recorded precipitation more than 100 mm, such as Puning, Fengshun, Chaoyang, Jieyang, Haifeng, Gaoyao, Huidong, Dongguan, Fanyu, Jiexi, Zhongshan and Wuhuan. Guangzhou got a record of 82 mm precipitation and gusts from Force 9 to 11. There were moderate showers in other regions. Dujuan has been the strongest one impacting on Pearl River Delta since Typhoon No.197908 in 1979 because of its great intensity and swath and rapid movement.

3.2 Experiment design

Four different experiments are designed. Exp.1(control experiment) used T213 data at 00UTC 1 September 2003 forecasting for six hours as background and only routine observation was used in 3DVAR. Exp.2 is similar to Exp.1 but adding extra dropsonde observation data with a same deviation structure to TEMP in 3DVAR. Exp.3 differs from Exp.2 by using a different deviation structure for dropsonde data in 3DVAR, in which geopotential height, temperature parameter, horizontal winds and humidity parameter at each standard level are set 1.2 times of those in Exp.2. Exp.4 differs from Exp.2 by using a different deviation structure for dropsonde data in 3DVAR, in which geopotential height, temperature parameter, horizontal winds and humidity parameter at each standard level are set 1.4 times of those in Exp.2.

4 ANALYES

Because there are no bogus in T213 data, the location of tropic cyclones differs largely with the reality [7,8]. T213 data were used as background for analysis and boundary for forecasting in this study so that the forecast locations and intensities of the tropic cyclone have a larger error with respect to the observation. The deviations of distance, sea level pressure, upper geopotential height and winds of each experiment from the reality are given to study the impact of dropsonde data on typhoon forecasting in NWP model. Considering that the typhoon can be influenced by other factors after it lands, our main analysis aims at the process before the typhoon landed. In other words, the first 36 hours of forecasting are analyzed in the following.

4.1 Impact on typhoon path

Fig.2 shows the typhoon paths from four different experiments and the true path in 36 hours (from 06UTC 1 September to 12UTC 2 September). According to the true path, we can see that Dujuan located in the sea southeast of Taiwan Island at 06UTC 1, then moved to west-northwest steadily, and landed in Guangdong about 12UTC 2 September. The simulated paths of Exp.2, Exp.3, and Exp.4 (with dropsonde data) are much better than that of Exp.1 (without dropsonde data). The path of Exp.1 shows that Dujuan moved to the west along the latitude in the first 12 hours and then its center location shifted considerably during the westward movement in the 12 hours before landing. As shown in the other three experiments, in the whole, Dujuan tended to move northwest in the first 6 hours and westward along the latitude after 24 hours. But Exp.1 gave a better velocity forecast than the others. In the results of Exp.2, Exp.3, and Exp.4, the typhoon moved faster than reality in the first 24 hours so that the center locations were forecast faster than the real

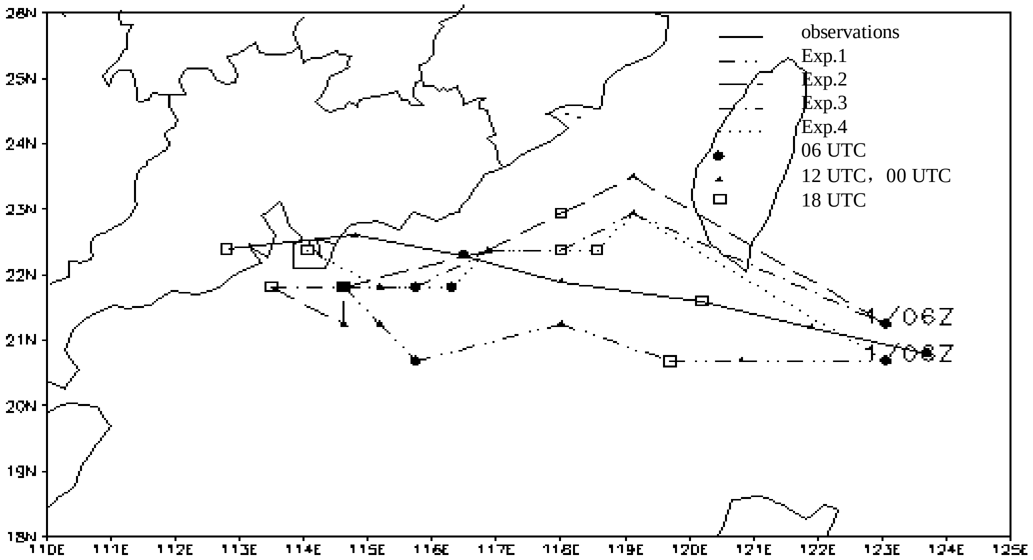


Fig.2 The forecasting typhoon paths from four different experiments (Exp.1,Exp.2,Exp.3, and Exp.4) and the real typhoon path observed in 36 hours.

ones, which leads a larger error, and a litter slower than the reality after 24 hours so that the center locations were forecast behind the real locations a little.

It is obvious from Tab. 1 that, in the forecast from the 18th hour to the moment of landfall, the deviations from true typhoon center in Exp.2 and Exp.3 are remarkably smaller than the one in Exp.1. For example, in the 24-h forecast the center location error in Exp.1 is 195 km but only 94 km in Exp.3. We noticed that larger center location errors compared with that in Exp.1 appear in the prophase forecast with dropsonde. This is because there are almost not any routine TEMP data at 06UTC so that the initial field of Exp.1 is effectively the forecasting field of T213, which harmonizes with the assimilated process in the background of 3DVAR, leading to less forecast errors. After all, forecast errors increase over time in any models! However, in Exp.2, Exp.3 and Exp.4, data form ten dropsondes near the typhoon center were assimilated so that false increments may be produced in wide regions of data scarcity outside regions with dense data concentration, according to the design characteristics of GRAPES_3DVAR. At the same time, if the scale factors of GRAPES_3DVAR selected improperly or geostrophic balance was used as restriction between winds and pressure, it maybe result in an unreasonable typhoon structure to some extent. All of these may be a cause leading to larger errors in prophase forecasting of Exp.2, Exp.3 and Exp.4.

Summing up from all of the above discussion, the forecasting path in Exp.1 is more southward than reality, and the moving velocity forecasts follow well with the reality in the first 24 hours, but is incorrect in the six hours before landfall. The trend of forecast typhoon movement cannot exhibit the characteristics of Dujun in reality either and is especially far away from the observation in the distance of typhoon center from the land as well as the moving trend during the process from landing to disappearance after 06UTC 2 September when the typhoon was landing. However, Exp.2, Exp.3 and Exp.4 gave better trend forecasts of typhoon movement but faster forecast moving velocity in the first 24 hours. Therefore, a new issue needed to face with is how to improve NWP system to improve the forecasting of typhoon moving velocity with dropsondes.

Tab.1 Deviation of distance between the forecast and observed center of Dujian (Unit: km)

time	forecasts	without_ dropsondes Exp.1	With_ dropsondes Exp.2	With 1.2×Dropsondes Exp.3
t=90106	1	67.51343	83.00815	83.00815
t=90112	2	126.5372	383.1902	345.0931
t=90118	3	114.5126	270.8601	242.6502
t=90200	4	72.28978	127.3377	127.3377
t=90206	5	195.3724	200.6876	94.40858
t=90212	6	155.3591	151.1916	89.40694
t=90218	7	199.0411	97.31108	97.31108
t=90300	8	228.8124	148.2505	116.1697
t=90306 Disappear	9	276.2127	61.78782	61.78782

4.2 Impact on typhoon intensity

From Tab. 2, it is known that all of the four experiments in this study present a trend that the sea level pressure in the typhoon center increases first and then decreases but the typhoon intensity is weaker than reality. However, the experiments with dropsondes (Exp.2, Exp.3 and Exp.4) simulated much more intense typhoon center forecasts with varying extent than the experiment without dropsondes (Exp.1). It implies that the using of dropsonde data can improve typhoon intensity forecasting.

Tab.2 Sea level pressure of Dujuan (Unit: hPa)

	Exp.1	Exp 2	Exp 3	Exp 4	Observations
06 UTC Sep.1	1001.4	1002.1	1001.8	1001.4	960
12 UTC Sep.1	1000.6	1000.9	1000.9	1000.9	950
18 UTC Sep.1	998.3	998.0	997.9	997.7	950
00 UTC Sep.2	998.7	997.6	996.9	996.5	950
06 UTC Sep.2	998.3	996.5	995.5	995.3	960
12 UTC Sep.2	998.2	994.0	993.6	993.5	965
18 UTC Sep.2	998.2	991.8	992.3	993.0	988
00 UTC Sep.3	999.3	992.2	993.0	993.9	995
06 UTC Sep.3	1000.4	993.5	994.4	995.0	998

4.3 Impact on upper geopotential height, winds and precipitation

The detailed analysis above is about the impact on the path, center, and intensity of the typhoon with dropsonde data. Next is further analysis with the Dropsonde data of the impact on the upper geogeopotential height, winds and precipitation brought by Typhoon Dujuan.

Fig.3 shows the changes of initial geopotential height at 500hPa level and 850hPa level only caused by assimilating dropsonde data. After assimilating the dropsonde data, errors of initial geopotential height at the 500-hPa level change from -5 to 40 geopotential meters and errors of initial geopotential height at the 850-hPa level change from -4 to 14 geopotential meters. The deviation of geopotential height in 24-h forecast is drawn for Exp.1 and Exp.2 from the analysis field at the same moment without dropsonde (can be seen as the reality) at 500 hPa and 850 hPa (figure omitted). It can be seen that, at 500 hPa, the errors of Exp.2 are much smaller than that of Exp.1 both in range and value. It can also be seen that, at 850 hPa, the errors of Exp.2 are also much smaller than that of Exp.1 both in range and value.

Fig.4a shows the 24-h forecast winds at 1000 hPa of Exp.2 and Fig.4b shows the difference of 24-h forecast winds at 1000 hPa between Exp.2 and Exp.1. From Fig.4a, it is noted that a strong easterly flow from the northeast of the typhoon transports huge amount of vapor to the southern part of China. Low-pressure cyclonic systems of tropical storms can be seen obviously in this figure. From Fig.4b, we can see the forecast winds over the ocean around Dujuan greatly changed after assimilating the dropsonde data and even influenced winds over the coast where the typhoon made landfall.

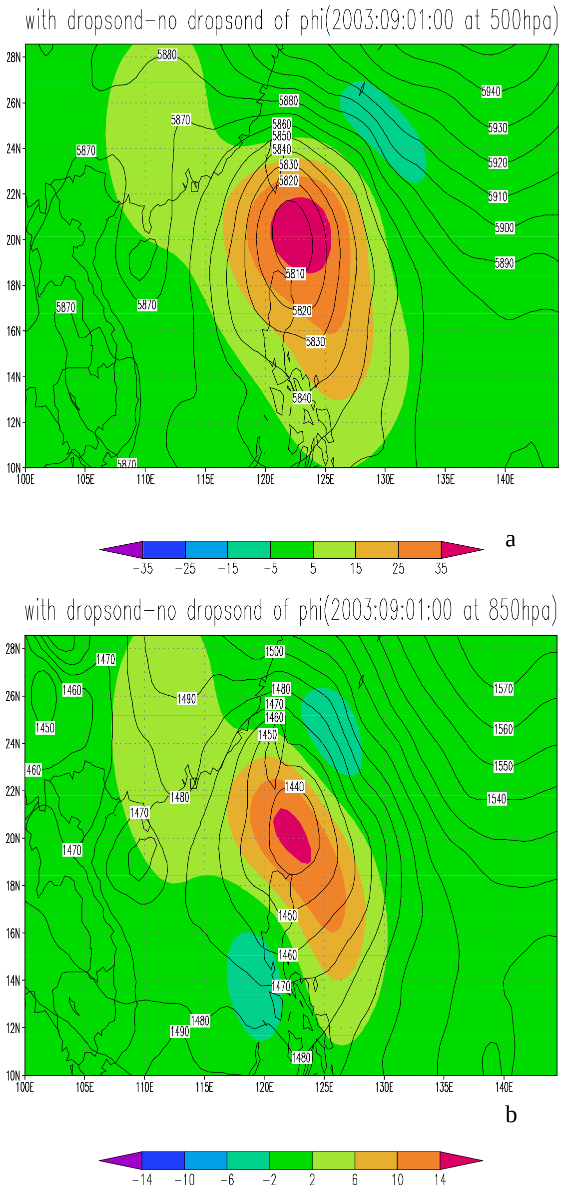


Fig.3 Difference of initial geopotential height between Exp.2 and Exp.1 at 500 hPa (a) and 850 hPa (b). The solid line in the background is the geopotential height of Exp.1.

Fig.5 shows the precipitation difference in 36-h forecast between Exp.3 and Exp.1 with a contouring interval of 30 mm and absence of contours between -30 mm and 30 mm. From Fig.5, we can see that using dropsonde data in NWP changes precipitation greatly both in range and value.

4.4 Sensitivity to different deviation structure for dropsonde data

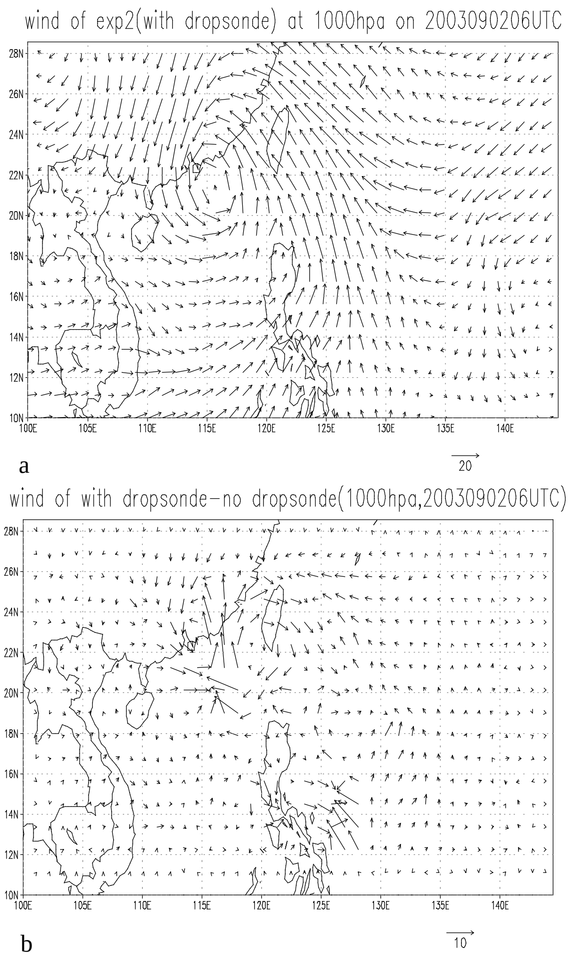


Fig.4 (a) 24 hours forecasting winds at 1000-hPa level of Exp.2 and (b) the difference of 24 hours forecasting winds at 1000-hPa level between Exp.2 and Exp.1. Unit: m/s

Up till now, lots of studies have proved that TEMP data is very significant in NWP. The experiments in this study have proved that data from synoptic surveillance around the center of typhoon collected by thrown dropsonde were efficient in improving the forecast accuracy of typhoons. But the percentage of dropsonde data should not be over that of TEMP data in the assimilation system in background modification. The weight of dropsonde cannot be too big or too small, otherwise the validity of typhoon forecasting would be influenced and could not have the best result.

Comparing typhoon movement forecasts of the three experiments with dropsonde data (Exp.2, Exp.3 and Exp.4) with each other, we can see that both the forecasting velocity and trend of typhoon movement of Exp.3 approach the reality more than that of Exp.2 or Exp.4 (see Fig.2 and Tab.2). It indicates that it is not true that more percentage (even being equal to that of TEMP) of dropsonde leads to better forecasting results.

Therefore, a very important job is to select a more reasonable deviation structure for dropsonde in the assimilation system. It needs further study in the future.

5 SUMMARY AND DISCUSSION

This paper studies primarily the impact of the use of dropsonde, a new adaptive observation data, on typhoon forecast, using the case of typhoon Dujuan landing in Guangdong on 2 September 2003 and making use of the GRAPES assimilation / forecast system. The main conclusions are as follows.

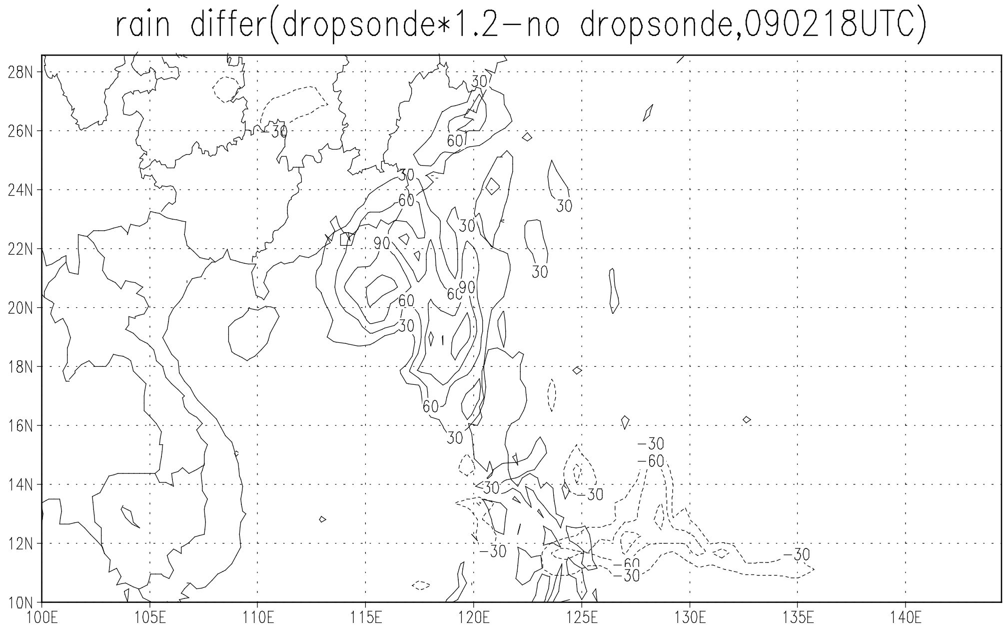
First, after adding dropsonde data in 3DVAR, the typhoon forecasting has been improved for the path, center location, and geopotential height at all levels. After assimilating the dropsonde data, forecasts of the typhoon show that the forecasting trend of typhoon movement agrees well with the reality, the deviation of forecast typhoon center locations are small from that of the observation in 24 hours, the forecast geopotential heights at the 500-hPa and 850-hPa levels are closer to those in the analysis field for that time than the forecast without the dropsonde data, and the forecast sea level pressure is quite similar. In addition, assimilating dropsonde data greatly changes the forecast winds and precipitation of typhoon.

Second, the forecasting of typhoon moving velocity without dropsonde was preferable in the first 24 hours in this case, but it has become worse after using dropsonde data.

Third, the forecast typhoon center intensity is weaker than that of the reality, though it has been improved. Fortunately, the trend that typhoon center intensity increases first and then decreases has been presented.

Fourth, the deviation structure of dropsonde data in 3DVA impacts greatly on the forecast. Different deviation structure of dropsonde data lead to different forecast effect. The percentage of dropsonde must be a little less than that of TEMP because TEMP data is still important for typhoon forecast, and too large or too small percentage of dropsonde will decrease the forecast accuracy. Therefore, a reasonable deviation structure of dropsonde data is needed to improve typhoon forecast.

This paper only primarily studied the use of dropsonde data in NWP system to forecast typhoons. In this study, it has been found that some issues need further study though the using of dropsonde data did bring some improvements for typhoon forecasting. Existing issues include the constructing of background deviation covariance for new adaptive observation systems, studying of impact of atmospheric nonlinear behavior on adaptive observations, confirming of sensitive regions for adaptive observations in a typhoon situation with vortex structure, and so on. All of these



rain differ(dropsonde*1.2−no dropsonde,090218UTC)

Fig.5 The forecasting precipitation difference in 36 hours between Exp.3 and Exp.1. Unites, mm, contouring interval, 30 mm. Positive values, solid line; negative values, dashed line.

issues of analysis, assimilation and application need further study in the future.

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