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IMPROVEMENT OF NUMERICAL SIMULATION OF TYPHOON RANANIM (0414) BY USING DOPPLER RADAR DATA

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Abstract: Typhoon Rananim (0414) has been simulated by using the non-hydrostatic Advanced Regional Prediction System (ARPS) from Center of Analysis and Prediction of Storms (CAPS). The prediction of Rananim has generally been improved with ARPS using the new generation CINRAD Doppler radar data. Numerical experiments with or without using the radar data have shown that model initial fields with the assimilated radar radial velocity data in ARPS can change the wind field at the middle and high levels of the troposphere; fine characteristics of the tropical cyclone (TC) are introduced into the initial wind, the *x* component of wind speed south of the TC is increased and so is the *y* component west of it. They lead to improved forecasting of TC tracks for the time after landfall. The field of water vapor mixing ratio, temperature, cloud water mixing ratio and rainwater mixing ratio have also been improved by using radar reflectivity data. The model's initial response to the introduction of hydrometeors has been increased. It is shown that horizontal model resolution has a significant impact on intensity forecasts, by greatly improving the forecasting of TC rainfall, and heavy rainstorm of the TC specially, as well as its distribution and variation with time.

Key words: radar data; ARPS; numerical simulation; typhoons; heavy rain

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1 INTRODUCTION

Being the most intense of the typhoons that have ever landed in Zhejiang since 1956, Typhoon Rananim (0414) is marked by strong wind, large area of impact, concentrated rainfall and complicated track after landfall. It caused immediate economic loss of 18.128 billion yuan.

Numerical forecasting of tropical cyclones has been well attended to by numerous researchers. The accuracy of numerical forecast depends largely on that of model initial values, the importance of which has been pointed out in the early 1970s [1]. Addressing the relatively low resolution of conventional observations in both time and space, many scientists have attempted, with much success, to improve the forecast by assimilating models with non-conventional data with high temporal and spatial resolution [2 - 9]. With the gradually operational use of the next generation weather radar network and rapid increase of Doppler-based measurements, how to apply radar data with high temporal and spatial resolution to numerical models has become a necessary and urgent issue for the scientific community. In this paper, radar data will be assimilated into the ARPS model for a numerical experiment with Typhoon Rananim in attempts to probe into the effect of radar data on the numerical forecast of the typhoon.

2 ADJUSTMENT OF MODEL INITIAL FIELD BY RADAR DATA

The ARPS model is a regional forecast system developed at Center for Analysis and Prediction of Storms (CAPS), University of Oklahoma, USA, which is non-hydrostatic and with high resolution [10]. The model is very suitable for numerical modeling of weather systems on the meso- and fine- scales and storm scale [10, 11]. Details of radar data pre-processing,

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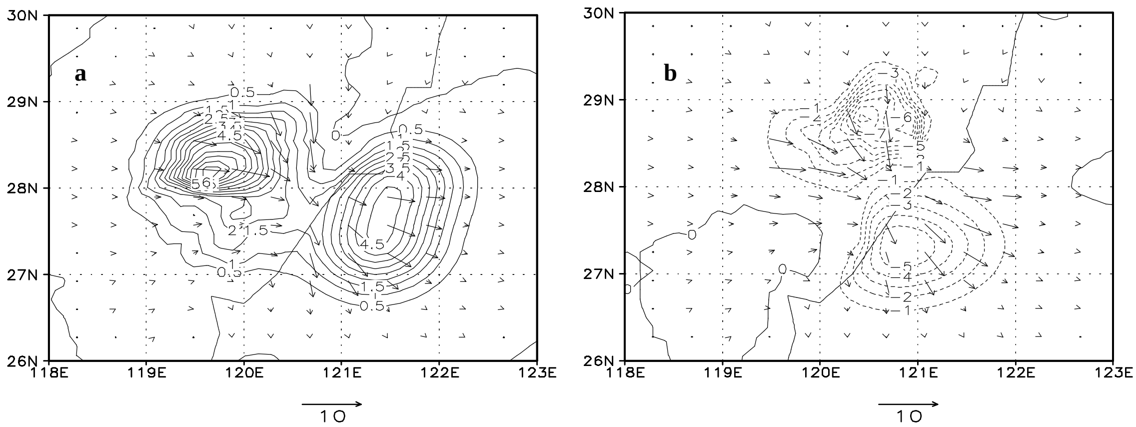

Fig.1 Difference vectors and horizontal wind increments at the altitude of 6 km for initial fields with and without radar data. a. Difference vectors and *u* increment of the horizontal wind; b. Difference vectors and *u* increment of the horizontal wind. Unit: m/s.

radial velocity processing and wet variables adjustment based on base reflectivity can be seen in Brewster[11] and Xue and Wang [12]. An experiment designed in this work, RT, forms a high-quality and dynamically coordinated initial field by integrating the base reflectivity and radial wind speed from the new generation Doppler data in Wenzhou into the model via the ADAS analysis, and compares with another experiment, NT, which is without radar data in the model.

Fig.1 gives the difference field between the initial fields with and without the radar data, i.e. increments of a large-scale analyzed wind field. It is shown from the radial wind speed by radar (Fig.1) that the NW and SE quadrants are the sections where large radial wind speed is detected by radar. Analyzing the radar data in the initial field discovers significant adjustment of the wind field in northwestern and southeastern Wenzhou; the mesoscale features as revealed in the radar data are then applied to the initial field to improve the description of fine structure of the typhoon. It is consistent with the finding by Lin et al [7]. It is shown from the figure that the northerly component west of the eye and the westerly component south of it are increasing.

It is shown from the vertical and radial distribution of cloud-water mixing rate field going through the eye (figure omitted) that the radius of the eye is more than 100 km when the radar data are not introduced into the initial model field but much reduced when they are. It is consistent with the imagery of the FY-1D weather satellite, which shows that the eye is small and compact with a dense and enclosed area of clouds at landfall. Convection is strong in the eye wall of an intensifying TC and shrinks towards the eye [13]. As shown in the observation, for a few hours prior to landfall, Typhoon Rananim has been intensifying and the convection has been developing near the eye wall to transport low-level warm and humid air to the top of the TC; as a result, temperature at the TC top is higher than in the surrounding air to form a warm cloud shield. The more vigorously the convection develops, the better-defined the cloud shield at the TC top, i.e. temperature of the latter is higher than that of the surrounding. It is concluded from the vertical distribution of the difference of potential temperature disturbance that it is higher with the radar data than the one without, which also agrees with the fact that Typhoon Rananim is still an intense storm with fully developed convection at the time of landfall. Besides, with the radar data introduced in the model, much improvement has been made to the rates of moisture mixing and, rainwater mixing especially, at the upper portion of the TC.

3 COMPARISON OF NUMERICAL EXPERIMENT RESULTS

3.1 *Impacts on the simulated track*

Fig.2 presents the tracks simulated with the ARPS and positioned at National Meteorological Center (NMC). Comparing the simulation with objective positioning, result reveals that the sites of landfall simulated in RT and NT are within the same region though being more southward than those located at NMC; the sites of landfall simulated by ARPS are also very close to the observation. It is shown from the statistics of positioning errors (figure omitted) that RT simulates track with smaller error than NT does and the former has a much smaller linear trend of error than the latter does, too. It is indicated in the wind velocity of the increments of the initial field with and without the radar data (figure omitted) that there are meso- and fine- scale features in the NW and SE quadrants near the typhoon center. The interaction between systems of different scales is an important factor affecting the structure and movement track of the TC [14] and the asymmetric structure accompanying the landfall of Typhoon Rananim is mainly responsible for a northwest movement after landfall, as shown in a numerical study by Yu et al [15]. It is then inferred that the data of radar radial wind velocity has improved the model initial field, which may be the main reason for the successful forecast of the westward journey taken by Rananim after landfall.

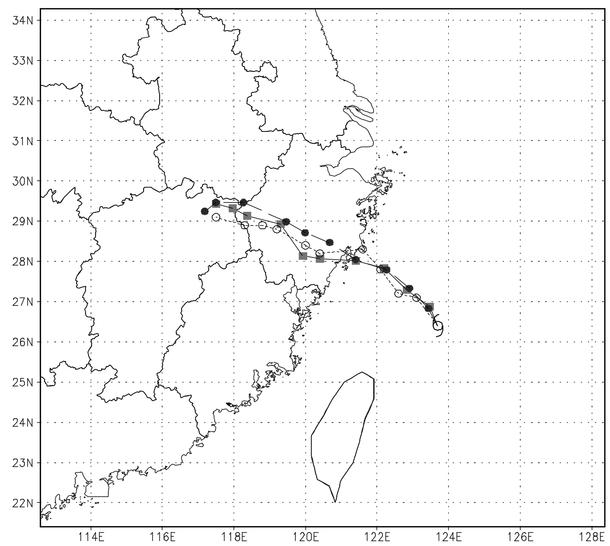

Fig.2 Typhoon Rananim's track of movement as simulated with the ARPS model (the square indicates the inclusion of radar data while the solid circle the exclusion of them) and that as located at National Meteorological Center using the method of objective analysis (the shallow circle).

3.2 *Impacts on the typhoon-related precipitation*

It is deduced from the simulation of the typhoon-related precipitation in the 12 hours just before landfall that while RT is able to reproduce the center of an intense precipitation area with the distribution of rain area and rainfall consistent with the observation (figure omitted), NT's predicted rain center is more northward than the observation though with comparable intensity. In comparison, RT's simulation of other secondary precipitation centers is closer to the observation than NT's. As shown in some other analyses, precipitation simulated by the RT experiment is more realistic than that by NT as far as the large-scale distribution of typhoon-related precipitation is concerned.

See the Chinese edition of the journal for more details.

4 CONCLUSIONS

In this paper, ARPS has been used to run a 30-h simulation experiment with the landfall process of Typhoon Rananim (0414) and compare the result with that without the inclusion of radar data. Results have been obtained as follows.

(1) The application of the data from the next generation weather radar to the ARPS model helps reproduce Rananim's track of movement, the rain rate and distribution of the typhoon-related torrential rain.

(2) With the typhoon within the radar-scanned range, the radial wind velocity based on the radar is introduced into the model to enable the adjustment of the wind field at the middle and high layers of the initial field of the model; the initial wind field of the typhoon is then made closer to the observation, fine-scale structural features are added to the typhoon and the westerly component south of the eye and the northerly component west of the eye are increased so that the forecast of Rananim's westward track after landfall is improved.

(3) With the typhoon within the range scanned by the radar, the introduction of radar base reflectivity into the model mainly improves the variables related with relative humidity and moisture in the initial field of the model to make the analyzed result of clouds more reasonable. Because the initial model field has been effectively improved due to model's adjustment of the disturbance temperature, rainwater and cloud water mixing rates and field of moisture mixing rate. As a result, much improvement has been achieved in the forecast of the heavy rain area, distribution of intense precipitation and variation of rain with time to effectively avoid unrealistic precipitation prediction over large-scale areas.

(4) While the introduction of the radar data in the model helps relieve the problem of spin-up efficiently, it also easily produces excessive precipitation in the few hours after the model starts. The cause will be studied separately.

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