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CORRECTION OF ASYMMETRIC STRENGTHENING OF QUIKSCAT WIND FIELD AND ASSIMILATION APPLICATION IN TYPHOON SIMULATION

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Abstract: As an approach to the technological problem that the wind data of QuikSCAT scatterometer cannot accurately describe the zone of typhoon-level strong wind speed, some objective factors such as the typhoon moving speed, direction and friction are introduced in this study to construct the asymmetric strengthening of the QuikSCAT wind field. Then by adopting a technology of four-dimensional data assimilation, an experiment that includes both the assimilation and forecasting phases is designed to simulate Typhoon Rananim numerically. The results show that with model constraints and adjustment, this technology can incorporate the QuikSCAT wind data to the entire column of the model atmosphere, improve greatly the simulating effects of the whole-column wind, pressure field and the track as well as the simulated typhoon intensity covered by the forecast phase, and work positively for the forecasting of landfall locations.

Key words: Numerical simulation; typhoon forecast; data assimilation; QuikSCAT wind field, asymmetric bogus model

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1 INTRODUCTION

Because of the coarse horizontal resolution of observing networks and sparse distribution of meteorological data over the ocean, it is difficult for the circulation structure of typhoons to be realistically described using conventional observational data. With continuous improvement of satellite detection technology, a series of observational data of characteristic atmospheric characteristics, such as the global high-resolution sea surface temperature, sea surface wind speed and direction, tropical precipitation, and vertical profiles of temperature, can now be obtained by satellites, of which QuikSCAT satellite microwave Scatterometer data can not only provide sea surface wind speed data but also surface wind direction data. So with this type of data, the circulation of tropical cyclone can be well tracked and monitored. Therefore its application has drawn extensive attention.

The scatterometer [1] works by transmitting microwave pulses to the earth surface to gauge the global roughness by backward scattering. Over the ocean that covers 3/4 of the earth surface, the backward scattering waves are mainly composed of shortwave from the sea surface. Remote sensing of sea surface wind is an idea that is based on the argument that minor perturbation of sea surface is in equilibrium state with local wind stress so that 10-m sea surface wind can be retrieved by acquiring the backward scattering from the surface. The polar satellite QuikSCAT was lifted into space by NASA in the U.S. in June 1999. Compared with other satellite-aboard scatterometers, the sensor of Seawinds, which was made on the Ku band with a “pencil-cluster” antenna cone, has a larger swath of scanning (1800 km), converging 93% of the global ocean daily and capturing almost all cyclones in the global ocean.

Because the scatterometer data can well describe wind speeds between 3 m/s and 20 m/s, it has been widely applied abroad in various aspects from analysis

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of data performance to weather analysis and forecasting [2-5]. It has been already assimilated into operational numerical prediction models at the European Centre for Medium-Range Weather Forecasts (ECMWF) and the U.S. National Centers for Environmental Prediction (NCEP). Statistical characteristics of QuikSCAT wind speed were studied and the assimilation of the scatterometer data in numerical prediction models was explored (Liu [6]).

Carswell et al. [7] and Bourassa et al. [8] studied the Ku-band and C-band in great detail, which are used generally in spaceborne scatterometers. It was found that, when maximum high wind speed is measured by different angles of incidence, saturation of wind speed sensitivity always happens. When the wind speed is between 20 m/s and 30 m / s, the error is 10%; but when it is over 30 m/s, the result is basically implausible, while the actual standard for the maximum wind speed of typhoons is actually over 32.7 m/s. Therefore, although this type of data can describe the characteristics of external wind speed of typhoons, it cannot depict those of typhoon wind fields in the strong wind zone. In this paper, firstly, the QuikSCAT satellite wind field product is corrected by asymmetrical strengthening before it is introduced to numerical models with the four-dimensional data assimilation technique, and the experiment scheme consisting of two phases, i.e., assimilation and forecasting, is designed. Then, through comparisons with the observed data, the effect of these data on the simulation of Typhoon Rananim is analyzed.

2 CORRECTION OF ASYMMETRIC STRENGTHENING OF QUIKSCAT WIND FIELD

2.1 *Construction of the model of asymmetric wind field*

In this study, an asymmetric model is constructed according to the basic ideas of Hu [9] and Huang [10]. The horizontal kinetic equations [11] in the plane polar coordinate (taking the typhoon center as the pole point) of any air particle in a stationary typhoon area are

$$\begin{cases} \dfrac{dv}{dt} + fu + \dfrac{uv}{r} = -\dfrac{1}{r}\dfrac{1}{r}\dfrac{\partial p}{\partial q} + \mathrm{F}_q \\ \dfrac{du}{dt} - fv - \dfrac{v^2}{r} = -\dfrac{1}{r}\dfrac{\partial p}{\partial r} + \mathrm{F}_\mathrm{r} \end{cases} \qquad (1)$$

where u is the radial velocity, v the tangential velocity, and F_q and F_r are the frictions in the direction of q and r.

The air density r is replaced by the one in the state equation $p = rk_cT$, and we set

$$A = \frac{2\cdot 3^{-3/2} k_c T\left(p_\infty - p_0\right)}{p_\infty - 3^{-1/2}\left(p_\infty - p_0\right)} \qquad (2)$$

where P_0 is the typhoon central pressure, P_∞ the typhoon external pressure, k_c the atmospheric constant, and T the sea surface temperature.

Considering V_s as the moving speed of the typhoon, set

$$\begin{aligned} a &= A^2(k\sin f_1 + f) + k^2\cos^2 f_1 (A - V_{\max}{}^2)^2 \\ b &= 2kAV_{\max}V_s\cos a\cos f_1(k\sin f_1 + f) \\ c &= k^2V_{\max}{}^2V_s^2\cos^2 a\cos^2 f_1 - k^2\cos^2 f_1(A - V_{\max}{}^2)^2 \end{aligned} \qquad (3)$$

where a is the azimuth angle, k the friction coefficient and f_1 the angle of the friction deviating from the opposite direction of wind, which is set as 38° in this paper [12].

Owing to the surface friction, the actual wind would be deflected towards the inside of isobaric lines (in the direction of the gradient wind) by an angle of b , which is called the inner declination angle of wind direction.

Substituting Eq.2 and Eq.3 into Eq.1 leads to the formulas of b and wind speed, respectively, i.e.,

$$b = \arcsin\left(-\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a}\right) \qquad (4)$$

$$V = \frac{kr\cos(f_1 + b) - V_s\cos a\sin b - fr\sin b}{\sin b\cos b} \qquad (5)$$

From the distribution of the model of asymmetric wind speed (not shown), which is designed according to Eq.(5), it is known that the maxima wind speed appears to be in the right rear portion relative to the typhoon moving direction, which is consistent with observed facts and classical theories [12] about typhoons. Owing to the use of the observed center location, maximum wind speed of the observed typhoon, the typhoon moving direction and speed in the typhoon warnings, and minimal consideration of surface friction factors, the model can well describe part of the specific characteristics of the real typhoon.

2.2 *Removal of poorly analyzed vortex and synthesis of asymmetric wind model and QuikSCAT wind field*

The removing scheme of NCAR-AFWA Typhoon bogussing scheme [13] is adopted to remove a vortex that has been poorly analyzed, in which the searching radius is 400 km and the scope of the removed typhoon analyzed is the circle determined by the wind speed radius of 50KTS (25.7m/s). Using the method of additive weighting, the above asymmetric typhoon wind field is added to the mixed wind field product of the QuikSCAT and NCEP after the removal of the analyzed vortex. The specific scheme is as follows:

$$V_{\mathrm{new}} = \begin{cases} V_1 + V_2 & r \le R_{50} \\ V_1 + w * V_2 & r > R_{50} \end{cases} \tag{6}$$

where V_1 is the removed QuikSCAT wind field, and V_2 is the asymmetric typhoon wind field. The weighting coefficient is calculated with an empirical equation as put forward by Barnes [14], which guarantees the smooth transition of the two wind fields, i.e.

$$w = \exp\left(\frac{-d^2}{2R_{50}^{\;2}}\right) \tag{7}$$

where R_{50} is the radius of 50-knot wind speed and d is the distance between the calculated point and the 50-knot wind speed radius of the typhoon.

Fig. 1a – 1b respectively present the QuikSCAT wind fields before and after the asymmetric strengthening. After the strengthening, the maximum wind speed reaches 32.69 m/ s, which is close to the observation (33 m/s), while the one before it is only 21.4 m/s. From the centers of wind speed which are located in the south of Guangdong and north-west of Taiwan Island, it can be seen that the post-strengthening wind field maintains the inhomogeneity of the original QuikSCAT external wind field and the objectivity of satellite-measured data.

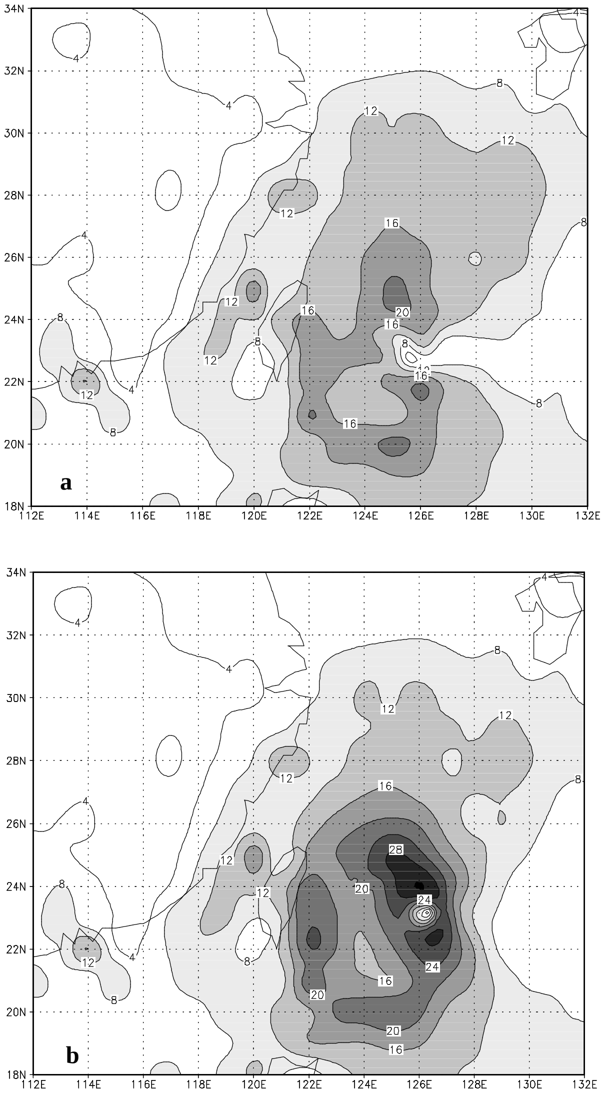

Fig.1 Distribution of sea surface wind speed of Typhoon Rananim at 08 BST August 11th, 2004 with (a) representing the QuikSCAT wind field and (b) the asymmetrically strengthened QuikSCAT wind field.

3 THE SCHEME OF ASSIMILATING AND FORECASTING EXPERIMENTS

The four-dimensional data assimilation, i.e. the nudging assimilation [15] technique, is used, which aims at applying the observed data of different times to a unified system of analysis and prediction to make the various elements satisfy the required corresponding conditions. Typhoon Rananim is selected for case study, and the simulation time is from 08:00 BST 11 August 2004 to 20:00 BST 12 August 2004.

The scheme of numerical experiments is designed as follows:

Test 1: Control experiment, in which no assimilation scheme is adopted;

Test 2: Assimilating and forecasting experiments, which assimilate the asymmetrically strengthened QuikSCAT wind field during the first 12 hours (of the assimilating phase, denoted as Phase A), and in order to make the study relevant in forecasting, a forecast experiment is carried out in contrast with the switch of assimilation turned off during the last 24 hours (of the forecasting phase, denoted as Phase B). The specific flow chart is shown in Fig.2.

4 COMPARISON AND ANALYSIS OF NUMERICAL RESULTS

4.1 *The impact upon typhoon wind field*

In Phase A, the sea-level maximum wind speed as simulated in Test 2 is very close to the observed one, being only 1.5 m/s in average deviation in contrast to the one of Test 1 (16.7 m/s). From an analysis of pressure-latitude cross section (along 23.5°N) of the horizontal speed difference between the two tests after 6 hours of integration, we can see that there is a center of high wind speed variation of more than 12 m/s at the 780 hPa near 124°E in the model atmosphere, while a change of 5 m/s also appears at the upper level between 300 hPa and 200 hPa near 115°E. Therefore, by adopting the technology of four-dimensional data assimilation, the impact of the strengthened QuikSCAT in the near-surface wind field can be introduced to the upper level of the model atmosphere, greatly improving

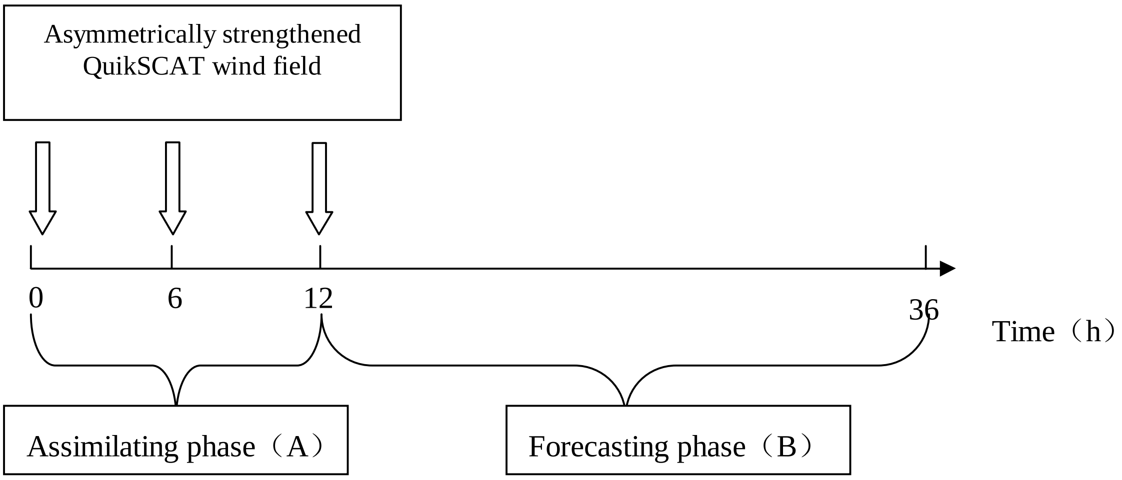

Fig.2 Flow chart of assimilating and forecasting phases in Test 2.

the wind field of the typhoon throughout the whole air column.

During the course of simulation in Phase B, the results of Test 2, whose average deviation is 3.7 m/s, are better than those of Test 1, whose average deviation is 17.8 m/s. It shows that the introduction of QuikSCAT wind field in Phase A well corrects the 12th-hour three-dimensional wind field, while the 12th hour is also the beginning of Phase B, such that the improving effects of QuikSCAT wind field continue to govern the model atmosphere.

4.2 *The impact upon the sea-level pressure and geopotential height fields*

Fig.3 presents spatio-temporal changes in the sea-level pressure (SLP) and geopotential height fields. In Phase A, the deviations of typhoon SLP in Test 2 are all less than 25 hPa (Fig.3a) and the average deviation in Test 2 is significantly reduced to 23.6 hPa, compared to the one of Test 1 (33.5 hPa). After six hours into the integration, moreover, the difference in geopotential height near 125.5°E extends from the bottom to the height of 400 hPa, and a positive potential difference of about 20-30 geopotential meters appears near 1.5°E at the upper level between 300 hPa and 200 hPa (Fig.3b). Therefore, through the assimilation of wind field data, with the dynamical constraint of the numerical model, the QuikSCAT wind field has also affected the geopotential height field of the whole column of the model atmosphere.

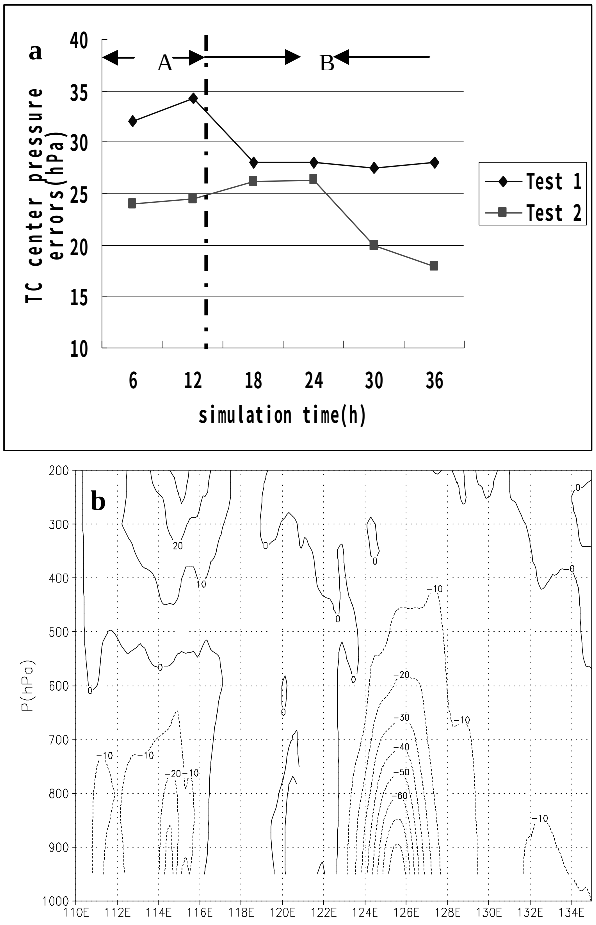

Fig.3 Temporal / spatial variation of the SLP and geopotential height fields (a: 6-hourly difference between simulated and observed values; b: longitude-altitude cross-section at 23.5°N after 6 hours into integration).

4.3 *The impact upon typhoon track*

From the comparison between the simulated typhoon tracks of the two tests and the observed best track (OBS), we can see that, in Phase A, the average deviation of Test 2 is only 20.3 km, far less than the one of Test 1 (87.3 km). Besides in Phase B, Test 2 can forecast more successfully the course of typhoon landing, whose deviation is only 46 km as compared to the one for Test 1 (131 km). Therefore, through the assimilation of asymmetrically strengthened QuikSCAT wind field, the distribution of the typhoon's internal physical field has been improved while the adoption of measured satellite data for the periphery makes the distribution of the environmental guiding airflow more reasonable.

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

5 CONCLUSIONS

QuikSCAT scatterometer wind field data can provide sea surface wind field at higher spatial and temporal resolutions and improve to a large extent the existing situation arisen due to the lack of data over the ocean surface. However, owing to the technical limitations of satellite observations, this dataset cannot accurately describe the zone of typhoon-level strong wind. In order to solve this problem, this paper introduces some objective factors, such as the typhoon moving speed, direction and friction, to construct the asymmetric strengthening of the QuikSCAT wind field to make it closer to the actual wind field. Then by adopting a four-dimensional data assimilation technology, the experiment that includes both assimilation and forecasting phases is designed; during the first 12 hours, the data is introduced into the MM5 model every 6 hours by the assimilation of dynamic analysis, and during the last 24 hours, contrasting experiments of forecast are carried out by switching off the assimilation.

Through the numerical experiment of Typhoon Rananim, it is shown that, by using the four-dimensional data assimilation technology, QuikSCAT wind data, which can be introduced to the whole column of the model atmosphere, improves greatly the simulating effects of the whole-column wind, pressure field and track, and the simulated typhoon intensity during the forecast with the constraints and adjustment of the model, and exerts a positive influence on the forecasting of landfall locations.

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