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A METHOD OF INITIAL VORTEX RELOCATION AND NUMERICAL SIMULATION EXPERIMENTS ON TROPICAL CYCLONE TRACK

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Abstract: Using the technique of smooth filtering and cylindrical filtering, the initial vortex circulation and large-scale environmental field were separated from the background field. Then the separated initial vortex circulation was translated and reinserted in the location where it was observed. This led to the determination of a method of initial vortex relocation. For seven tropical cyclones at 23 points of measurement time in the years of 2006 and 2007, two schemes, either directly adding a tropical cyclone bogus model in the background or adding it after the relocation of the initial vortex in the background field, were employed. Simulation experiments were compared. The results showed that the mean errors of the simulated tropical cyclone tracks at 24 and 48 hours were both smaller with the scheme of adding tropical cyclone bogus model after the relocation of the initial vortex in the background field. The relocation method of the initial vortex decreases the error caused by the deviation of the initial tropical cyclone location in tropical cyclone models. The relocation method is conducive to improving the track forecast of tropical cyclone models and has a good perspective for operational application.

Key words: relocation of initial vortex; filter and translation; tropical cyclone track; numerical simulation

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1 INTRODUCTION

To a large extent, the technique of processing the initial values of tropical cyclones (TCs) is affecting the performance of numerical prediction of TCs. As a result, the technique has become an issue that draws much attention across the world. In the actual background field of numerical prediction of TCs, the location of the initial vortex usually deviates for some distance from the observation. According to the Lorenz theory[1, 2], the atmosphere is a chaotic system for it is highly non-linear; the system sensitively relies on initial conditions such that any minute differences in the initial field could be sufficient enough to cause significant discrepancies in the state of the dynamic system. In other words, small initial differences in the initial position of the vortex could result in relatively large errors in the numerical prediction of TCs. Therefore, the issue of deviated location of the initial vortex cannot be neglected. In some of the TC models, the initial vortex is usually removed in the initialization scheme and a TC bogus is then incorporated[3-6], which produces no deviation from the observed position. As the initial vortex in the background field retains some valuable information while the bogus is made up of artificial factors, inconsistency may be caused between the bogus and the environmental field and forecast results will be eventually affected if the initial vortex is completely eliminated. Besides, the initial vortex—available with assimilation—may differ substantially from the observation in location[9]. It is therefore necessary to relocate the position of the initial vortex to minimize the model errors resulting from its inaccurate position. In recent years, American meteorologists discovered the capabilities of relocation techniques in improving the track and intensity forecast of hurricanes[10, 11] and applied a relocation technique developed by GFDL (Geophysical Fluid Dynamics Laboratory) in a hurricane numerical prediction system of NCEP (U.S. National Centers for Environmental Prediction). Later

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on, the National Meteorological Center in Beijing and Shanghai Regional Meteorological Center introduced the GFDL relocation technique in their numerical TC prediction systems. Because of need, the authors have made some trials with this technique. Based on the methods of filtering, translation and reinserting, a procedure was developed to relocate the initial vortex, the feasibility of relocation was assessed, numerical experiments were conducted with the GRAPES (Global and Regional Assimilation and Prediction System) model, and numerical model results of TC track forecast were compared with and without the relocation technique.

2 METHOD OF RELOCATING INITIAL VORTEX

To relocate the initial vortex in the background (analysis) field, the horizontal interpolation method was used to determine the background at 1°×1° resolution. Then, the position and radius of the initial vortex in the background was identified; the position of the initial vortex could be known by the 850-hPa geopotential height or vorticity field. For the sake of convenience, the position of the initial vortex was determined through the geopotential height at 850 hPa. The covering radius of the initial vortex was set as the radial distance r_0 when the angular mean wind was smaller for the first time than a preset value (taken to be 3 m/s in this study) after monotonous decreasing from the maximum. Then, large-scale environmental field h_E and vortex circulation h_V are separated from the background field h (e.g. surface pressure, temperature, humidity, wind field etc.) as in

$$h = h_E + h_V . \tag{1}$$

In separating the vortex circulation, the twice-smoothing filter technique (Kuribara et al.[12, 13]) was used; the background field was first put through longitudinal and zonal filtering for a perturbation field, which was then applied with column filtering for vortex circulation. The three-point smoothing equation was used in the longitudinal and zonal filtering with a smoothing coefficient of

$$a = \frac{1}{2}(1-\cos\frac{2\pi}{m})^{-1} . \tag{2}$$

First longitudinally and then zonally, smoothing filter was performed by taking m=2, 3, 4, 2, 5, 6, 7, 2, 8, 9, 2 to obtain a post-filtering perturbation field h_D.

Applying column filtering to the perturbation field yields vortex circulation as in

$$h_V(r,\theta) = [1-E(r)][h_D(r,\theta) - \bar{h}_D(r_0)] \tag{3}$$

where $\bar{h}_D(r_0)$ is the angular mean of h_D at the point of r_0 with the column filter function as

$$E(r) = \frac{\exp[-(r_0-r)^2/l^2] - \exp[-(r_0)^2/l^2]}{1-\exp[-(r_0)^2/l^2]} \tag{4}$$

where l is the governing parameter of the shape $E(r)$, which takes $l=r_0/5$ in this work.

With vortex circulation derived, large-scale circulation field can be attained based on Eq. (1) as

$$h_E = h - h_V . \tag{5}$$

Finally, the vortex circulation obtained by filtering is added to the aforementioned large-scale environmental field where the TC is observed to have a background field in which the vortex has been relocated. The whole frame of work is presented in Fig. 1.

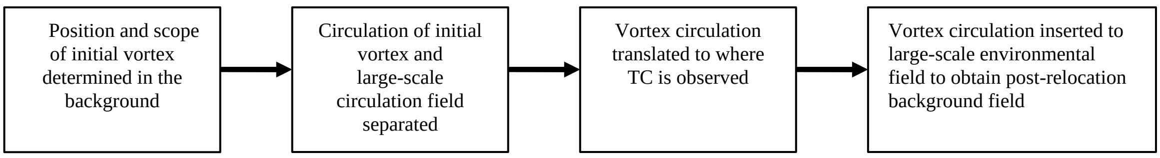


Fig. 1. Flowchart of work in relocating the initial vortex

The relocation method introduced above is useful in relocating the vortex in the background field not only prior to but also after data assimilation. As the initial vortex is relatively weak in the general background field, the TC bogus is still needed at this stage. The structure of the bogus used in this work is an asymmetric TC model that is statistic equilibrium, quasi-thermodynamic equilibrium, and conforming to the environmental field. It follows the idea of the Japanese MNG[14, 15], i.e., it is built by four criteria based on observation, namely, the location of the TC eye, intensity of TC, radius of Force eight wind (on the Beaufort scale), and initial movement of TC. The method of weighting coefficients will be used to incorporate the TC bogus, i.e., the weight of the large-scale environmental field takes 1 at r_0 and then gradually decreases to 0 near the eye of the TC. The relocation procedure introduced above differs from the GFDL method mainly in that the former separates the vortex circulation before obtaining the background field while the latter separates the environmental field before determining the vortex circulation, i.e., they differ in the way of filtering. Additionally, the former method does not deal with azimuths individually during horizontal filtering while the latter method divides 24 horizontal azimuths in filtering.

3 BRIEF INTRODUCTION TO MODEL

Taking as its core component the GRAPES-TMM (Global/ Regional Assimilation an Prediction System-Tropical Monsoon Model), the numerical model used in this study is a non-hydrostatic atmospheric model; its integration follows the semi-implicit Lagrangian scheme with the Arakawa C-grid in the horizontal and terrain-following height coordinates in the vertical that follows the Charney-Phillips grid staggering. The model is resolved at 0.36° horizontally and tops at an altitude of 35 km, with 31 vertical layers and 221×139×31 model grids, which correspond to a horizontal model coverage from 81.6°E–160.8°E and from 0.8°N–50.5°N. The model uses the Simplified Arakawa-Schubert(SAS) scheme for cumulus convection, the NCEP 3-CLASS simple ice-phase scheme for microphysics, the RRTM scheme for longwave radiation physics, the Swrad scheme for shortwave radiation physics, the Monin-Obukhov scheme for the surface processes, a thermal diffusion scheme for land surfaces, and the MRF scheme for the boundary layer. The integration is run for 48 hours.

4 SIMULATION EXPERIMENTS OF TC CASES AND RESULT ANALYSIS

A total of seven TCs were simulated for 23 different time of measurement; they are Chanchu and Utor in 2006 and Man-yi, Usagi, Pabuk, Sepat and Fitow in 2007. The simulation was conducted in two different schemes; in Scheme 1, the TC bogus was directly added to the background field as the model initial field, and in Scheme 2, however, the initial vortex in the background was relocated before the TC bogus was incorporated as model initial field. The T_{213} analysis field from Beijing was used in the background field and the T_{213} forecast field from Beijing in the lateral boundary of the model.

At 0000 UTC (Coordinated Universal Time, same below) on May 14, 2006, TC Chanchu was observed to be at 117.6°E, 14.0°N while the initial vortex was centered on 117.9°E, 15.3°E in the corresponding background field, i.e., the error of position was more than 100 km between the center of the initial vortex in the background and that of the observed TC, making it necessary to relocate the initial vortex in the background.

Figure 2 presents the 1 000 hPa geopotential height and wind field for 0000 UTC on May 14, 2006, before and after the relocation of the initial vortex. It shows that the pattern of TC circulation generally remained unchanged after the relocation while the position of TC center was adjusted to where it was observed. Fig. 3 gives the 1 000 hPa temperature field for 0000 UTC on May 14, 2006 before and after the relocation of the initial vortex. It shows that after the relocation of the initial vortex there are some changes in the temperature field within the TC circulation in that the warm sector (enclosed by the 302 K isotherm) is better defined. Additionally, the TC circulation keeps coordinated and continuous linkage with the large-scale environmental field, as shown from the geopotential height field, wind field and temperature field in the post-relocation time, indicating that the method presented in this study is reasonable and feasible in relocating the initial vortex.

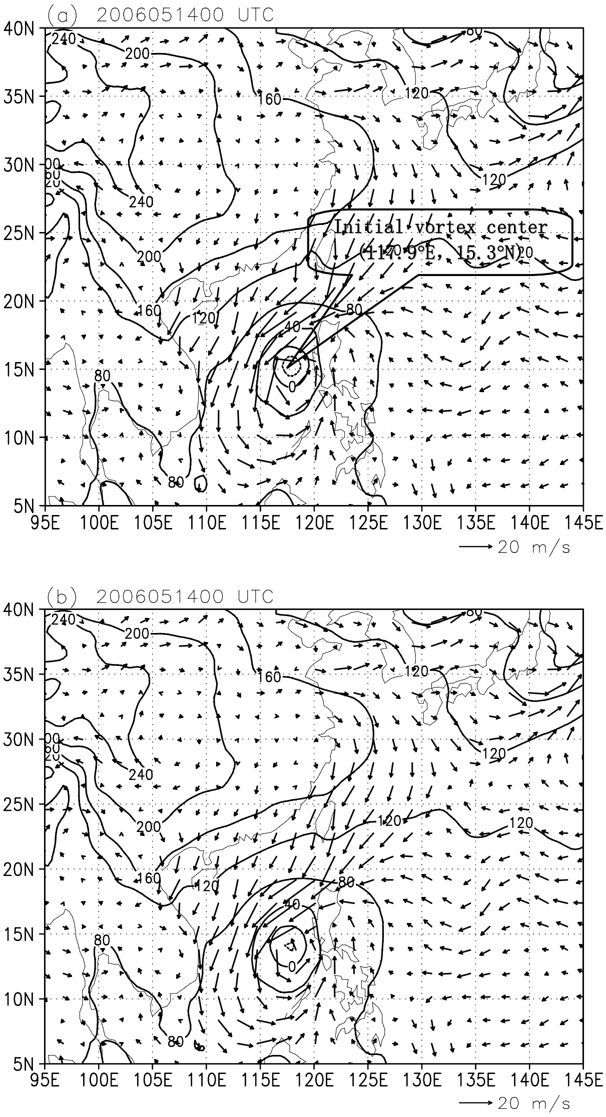


Fig. 2. 1 000 hPa geopotential height field (unit: gpm) and wind field (unit: m/s) of TC Chanchu for 0000 UTC May 14, 2006. a: original background field; b: background field with the relocation

It is also displayed that differences in the background field with the vortex relocated and without the vortex relocated exist only within the TC circulation rather than outside of it. In other words, the relocated initial vortex changes only the distribution of meteorological elements within the TC circulation while keeping all environmental elements unchanged at the periphery of the TC, a character that fully ensures the consistency of large-scale environmental field off the TC circulation (Fig. 4).

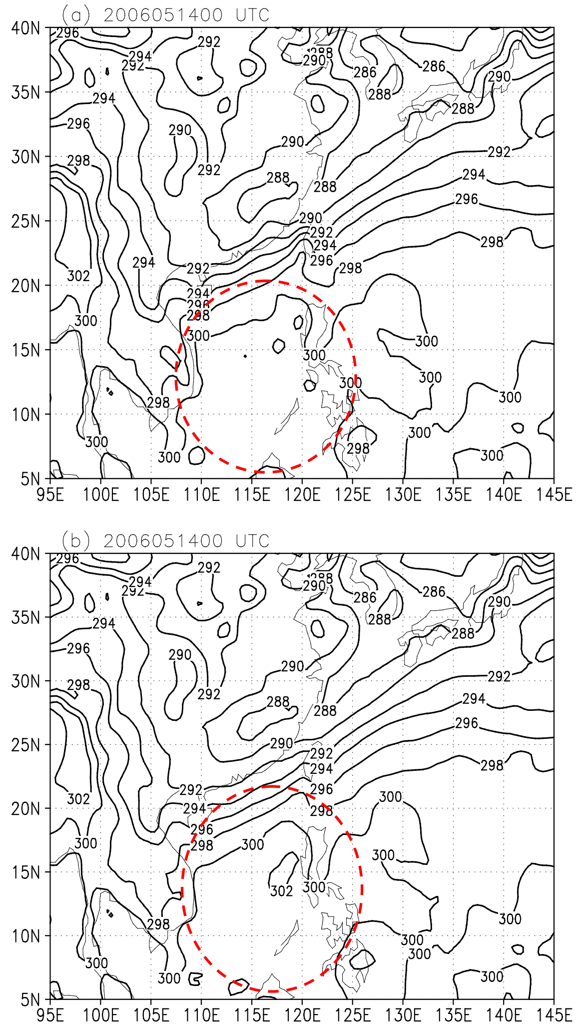
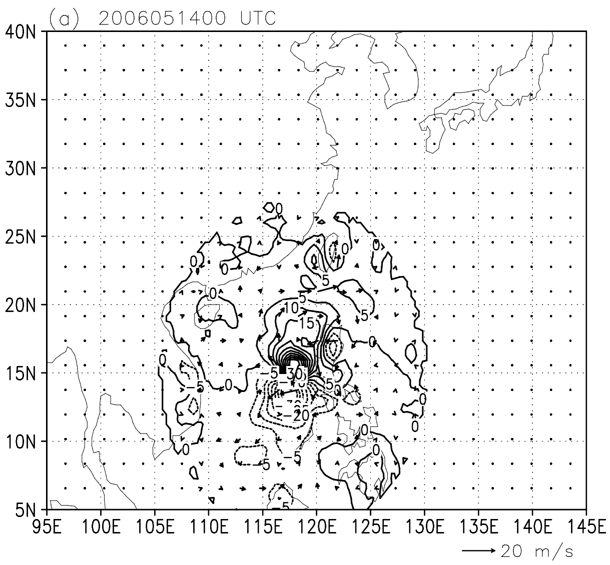


Fig. 3. Same as Fig. 2 but for the temperature field (unit: K, the circle enclosed by the bold, dashed line indicates roughly where the vortex is.)



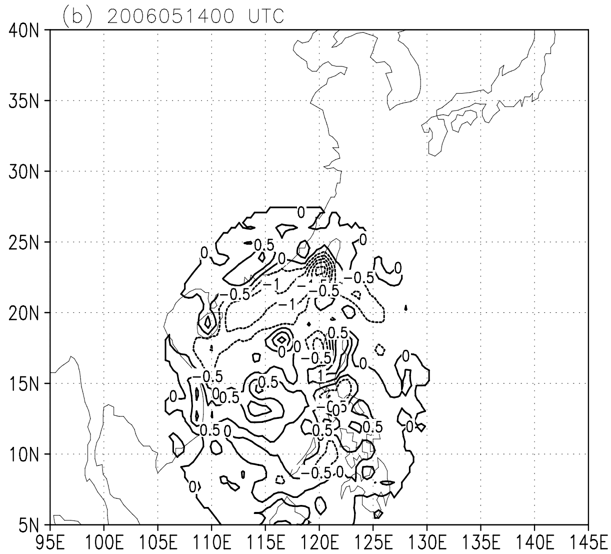


Fig. 4. 1 000 hPa differences of the background field before and after the relocation of Chanchu initial vortex for 0000 UTC May 14, 2006 a: geopotential height field (unit: gpm) and wind field (unit: m/s); b: temperature field (unit: K)

Figure 5 gives the 1 000 hPa geopotential height field, wind field and temperature field of Chanchu with the inclusion of the TC bogus following the relocation of the initial vortex in the background field. It shows that the inclusion of the TC bogus has strengthened the TC circulation and obtained closer-to-observation TC intensity.

Figure 6 gives the 1 000 hPa geopotential height field and wind field of Chanchu for 0000 UTC May 15, 2006 before and after the relocation of the initial vortex. In the original background field, the center of the initial vortex is at (115.0°E, 14.1°N) while the observed location of Chanchu is at (115.2 °E, 14.0 °N). With the relocation, the center of the initial vortex was adjusted to that of the observation.

Figure 7 presents the 1 000 hPa geopotential height field and wind field of Utor for 1200 UTC December 11, 2006 before and after the relocation of the initial vortex. In the original background field, the center of the initial vortex is at (117.0°E, 13.1°N) while the observed location of Utor is at (117.3°E, 13.7°N). As they deviate from each other by more than 50 km, it is necessary to correct the location of the initial vortex. It was corrected to where it was observed with the relocation technique. It was also noted that the post-relocation vortex circulation also linked with the large-scale environmental field in a coordinated and continuous way, indicating that the relocation technique used in this work is successful.

Table 1 gives the errors of 24-h and 48-h TC tracks simulated with Scheme 1 and Scheme 2 using the GRAPES model at 23 points of measurement time with regard to the seven TCs in 2006–2007. It shows that the mean errors of simulated 24-h and 48-h TC tracks are 147.6 km and 344.7 km, respectively, if the TC bogus is directly included in the original background field; they decrease to 128.5 km and 304.3 km, respectively, if the TC bogus is added to the initial vortex in the background field after the relocation. For some isolated time of measurement, the errors in the former case may be even smaller than the latter case, possibly due to imperfect model configurations, erroneous initial values and poor coordination of some relocated vortexes with the environmental field. Despite this, the simulated 24-h and 48-h TC tracks are generally smaller when the relocation of the initial vortex in the background filed is followed by the incorporation of the TC bogus. It is then clear that relocating the background initial vortex is necessary to minimize the error of TC models resulting from inaccurate position of the initial vortex, thus having good prospective and value in routine application.

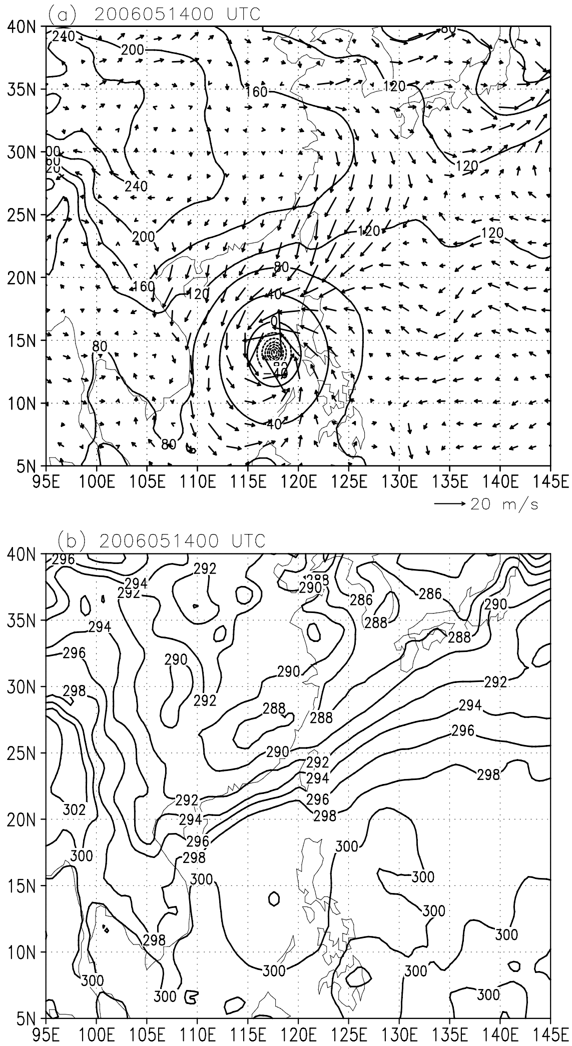


Fig. 5. 1 000 hPa field of elements of Chanchu for 0000 UTC May 14, 2006 with the inclusion of TC bogus following the relocation of the initial vortex (Captions are the same as those in Fig. 4.)

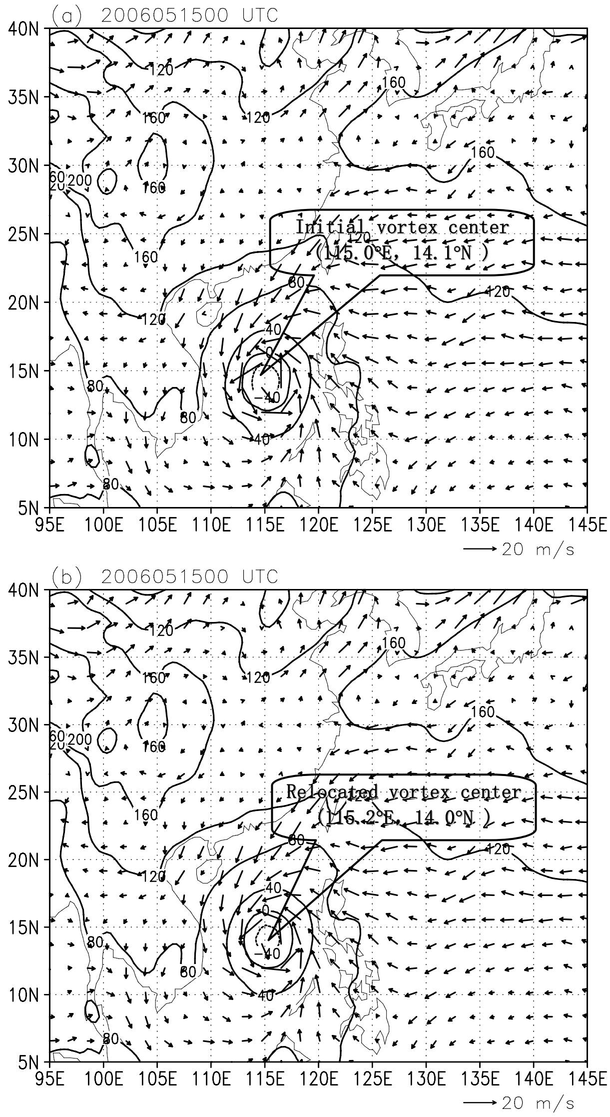
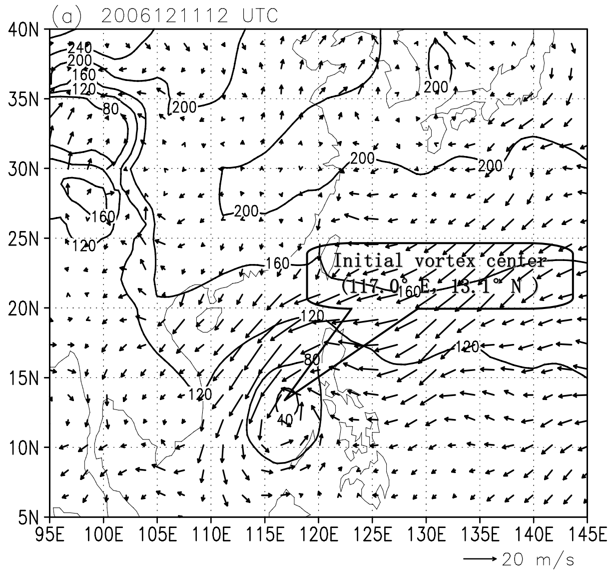


Fig. 6. 1 000 hPa geopotential height field (unit: gpm) and wind field (unit: m/s) of TC Chanchu for 0000 UTC May 15, 2006 (Captions are the same as those in Fig. 2.)



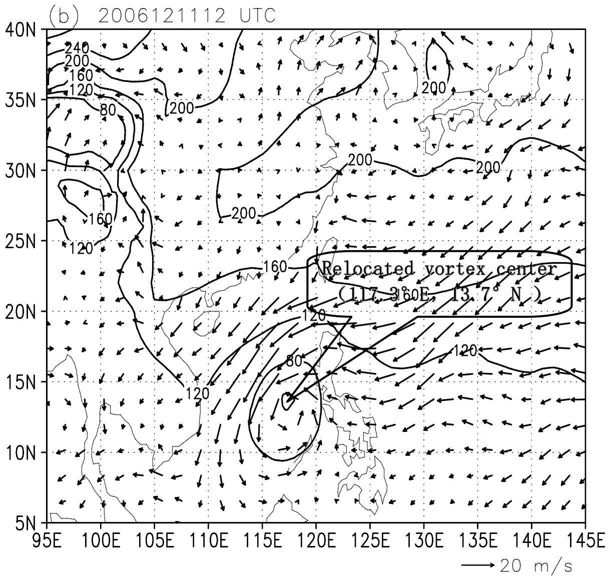


Fig. 7. 1 000 hPa geopotential height field (unit: gpm) and wind field (unit: m/s) of TC Utor for 1200 UTC December 11, 2006 (Captions are the same as those in Fig. 2.)

Table 1. Errors of 24-h and 48-h TC tracks simulated with Scheme 1 and Scheme 2 using the GRAPES model (0.36°)

TC cases	Time of initial forecast /UTC	Scheme 1		Scheme 2	
		24-h err. /km	48-h err. /km	24-h err. /km	48-h err. /km
Chanchu	2006051400	113.4	229.2	84.7	214.7
	2006051500	124.3	368.1	114.5	358.0
Utor	2006121112	120.3	353.4	116.1	378.1
Man-yi	2007071000	149.6	240.0	149.6	240.0
	2007071012	198.0	102.5	205.0	111.8
	2007071100	70.3	212.4	70.3	212.4
	2007071112	78.6	189.0	86.8	179.3
	2007071200	15.8	148.3	15.8	157.3
	2007071212	55.6	324.7	55.6	309.1
	2007071300	183.4	560.0	161.9	541.1
	2007071312	344.9	834.0	333.8	800.6
	2007071400	209.8	323.2	213.9	330.6
	2007071412	284.1	652.7	284.1	644.7
	2007071500	184.1	537.8	185.1	562.2
Usagi	2007073012	89.0	91.7	89.0	91.7
	2007073112	49.7	130.2	49.7	137.5
	2007080200	142.4	400.9	149.6	431.7
	2007080212	394.8	646.5	190.0	243.9
Pabuk	2007080700	64.8	173.7	64.8	181.0
Sepat	2007081600	95.7	149.2	104.9	144.6
	2007081612	67.6	114.5	67.6	114.5
Fitow	2007083100	267.8	796.8	71.2	274.6
	2007083112	91.7	349.0	91.7	338.7
Mean errors		147.6	344.7	128.5	304.3

Notes: In Scheme 1, the TC bogus is directly incorporated to the background field while in Scheme 2, the relocation of the initial vortex in the background field is followed by the incorporation of the TC bogus.

5 CONCLUSIONS

A method of relocating the initial vortex has been developed using a filtering technique to separate the initial vortex circulation and the large-scale environmental field from the background field before applying the methods of translation and reinserting. This method can be used to correct the position of the initial vortex in the background field. For seven TCs in 2006–2007 measured at 23 different points of time, two schemes were used, which are characterized by either direct inclusion of a TC bogus in the background field or relocation of the background initial vortex before incorporating the TC bogus. Then, contrast numerical experiments were carried out using the GRAPES-TMM model. Main results are obtained as follows.

(1) The method of relocating the initial vortex presented in this work changes only the distribution of meteorological elements within the TC circulation while keeping unchanged the surrounding large-scale environmental field of meteorological elements. After the relocation of the initial vortex, the vortex circulation maintains coordinated and continuous interaction with the ambient large-scale environmental field. It can be seen that the method in question can not only be applied in the background field prior to data assimilation but also the analysis field after data assimilation.

(2) The contrast experiment has also shown that the inclusion of a TC bogus in the background after the relocation of the initial vortex yields smaller mean errors of 24-h and 48-h TC tracks than the direct inclusion of TC bogus in the background, showing that the correction of the position of the initial vortex center minimizes the errors brought about by deviations of the initial location of the TC and helps improve the track forecast of TC models, and thus having good prospective and value in operational application.

At present, the method of relocating the initial vortex described in this work is being used in operational numerical prediction models for TCs in Guangzhou and will be improved toward perfection in future application.

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