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INVESTIGATION ON EFFECTS OF INITIAL SCHEMES FOR BINARY TYPHOONS ROKE AND SONCA IN 2011

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Abstract: Based on the Tropical Region Atmospheric Modeling System for South China Sea (TRAMS), Typhoon Roke (1115) and Sonca (1116) in 2011 which have large forecast errors in numerical operation prediction, have been selected for research focusing on the initial scheme and its influence on forecast. The purpose is to find a clue for model improvement and enhance the performance of the typhoon model. Several initialization schemes have been designed and the corresponding experiments have been done for Typhoon Roke and Sonca. The results show that the forecast error of both typhoons' track and intensity are less using the initial scheme of relocation and bogus just for the weak Typhoon Sonca, compared with using the scheme for both typhoons. By analysis the influence of the scheme on weak typhoon vortex circulation may be the reason that leads to the improvement. All weak typhoons in 2011 to 2012 are selected for tests. It comes to the conclusion that the initial scheme of relocation and bogus can reduce the error of track and intensity forecast. Besides, the height of cloud top in typhoon vortex constructed by bogus is too high according to weak typhoon. It is feasible to develop a bogus which is suitable for weak typhoon.

Key words: binary typhoons; typhoon model for South China Sea; numerical simulation; initial scheme
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1 INTRODUCTION

In recent years, the research personnel of Guangzhou Institute of Tropical and Marine Meteorology have discovered that as the performance of the tropical regional atmosphere model for South China Sea (TRAMS) improves, the track forecast for some certain typhoons are still in urgent need of improvement, as their track errors are far greater than the average errors of overall typhoons in the operational forecast. For instance, in 2011, the average track errors in the 24-h, 48-h and 72-h operational forecast were 103km, 178km and 277km, respectively. At 12:00 on September 15 and 00:00 on September 16, the 72-h track error of No. 16 Typhoon Sonca was about 600km, with the initial sea level pressure of about 1 002hPa. However, the No. 15 Typhoon Roke co-existing with the No. 16 Typhoon, with the initial sea level pressure center of about 990hPa, the 72-h track error was about 315km, comparable to that of the annual average. For No. 19 Typhoon Nalgae, the initial sea level pressure was about 995hPa, and its 48-h track error was 450km. In 2012, the average track errors in the 24-h, 48-h, 72-h forecast were 96km, 173km and 231km, respectively. For the No. 13 Typhoon Kai-Tak, its initial sea level pressure was about 998hPa, and its 24-h and 48-h track errors were in excess of 300km and 500km, respectively. In 2013, the average track errors in the 24-h, 48-h, 72-h forecast were 79km, 132km and 205km. For the No. 1 Typhoon Sonamu, its initial sea level pressure was about 998hPa, and its 48-h and 72-h track errors were in excess of 300km and 400km, respectively. Therefore, it is necessary to study and make experiments on these cases which have large forecast errors, so as to seek clues for better forecast. It shall be very important and instructive to further improvement on the TRAMS model.

The initialization, boundary condition and physical processes are the important factors which

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affect the numerical forecast results. According to the studies of Ma and Qu[1], typhoons without recurvature tracks are more sensitive to the initial condition than those with recurvature tracks. Typhoon Sonca (2011) moved northwestwards, belonging to non-recurvate typhoons, Typhoon Roke (2011) moved along a complicated annular track, belonging to recurvate typhoons. Considering the characteristics of typhoon's movement and keeping the schemes in the TRAMS model relatively stable, the initialization scheme was studied in this paper.

The typhoon intensity and position in large-scale analysis field (for instance, the NCEP analysis data) used as initial condition are usually not accurate. Moreover, the lack of observation in ocean and the limitation of the objective analysis schemes make model initial field unable to reflect the dynamic and thermodynamic features of typhoon (Qu and Ma [2]). Satellite observation has already become an important data source, but its observational resolution and error characteristics produce results far away from expectations when applying the data (Wang et al.[3]). For the problem, the basic solution to be adopted at home and abroad is to eliminate the inaccurate disturbance vortex field, create three-dimensional circulation of vortices according to the observation and the empirical equations, and then implant it in the background field. This is known as the bogus method (He and Wang[4]; Wang et al.[5]; Yuan et al.[6]). Many works have shown that the bogus scheme improves typhoon's track forecast effectively (Iwasaki et al.[7]; Mathur[8]; Kurihara et al.[9]). However, the bogus method has its limitations (Yan et al.[10]). For example, the original information of typhoon structure in the background may be omitted or the physical quantities in the constructed field may not be fully coordinated. Therefore, many studies have tried to coordinate these variables by combining assimilation and model processing. For instance, the bogus model was combined with the data assimilation (BDA scheme) (Ding and Wan[11]; Huang et al.[12]; Huang and Liang et al.[13]) and numerical model was run to obtain the initial vortex (Cha and Wang[14]). These methods have obtained sound results in studies, but have not yet been widely applied in operational departments. Currently, it is difficult to completely abandon the bogus method. Mostly, the construction of the initial vortex is combined with the vortex relocation method to correct the inaccurate information of typhoon position in the backgrounds.

Since Fujiwara proposed the "Fujiwara effect" of binary typhoons in 1921, the interaction of binary typhoons has aroused great interest of scientists (Fujiwhara[15]). Studies on binary typhoons at home and abroad are gradually increasing. These include studies on the track and influencing factors of interaction in dynamics (Wu[16]; Khandeker[17]), studies on mutual rotation and attraction when binary vortices approach each other in numerical simulation (Tan and Zhu[18]; Demaria and Chan[19]; Wang and Zhu[20]; Wang and Zhu[21]; Ritchie and Holland[22]; Yan et al.[23]), and studies on characteristics of binary typhoons' interaction in weather or climate perspective (Chen et al.[24]; Wang and Fu[25]; Bao et al.[26]), such as distances, intensity, track and motion speed of binary typhoons and regions and seasons when the interaction turns up. There are still rare studies on initial schemes of binary typhoons' forecasting, the bogus and BDA scheme were also rarely used to study binary typhoons.

On the basis of the large-scale analysis field, Typhoons Roke & Sonca in 2011 were selected as the examples and the vortex relocation method and bogus scheme were combined in this paper. The initial schemes of binary typhoons and their effects on track forecast were investigated through numerical simulation, so as to seek clues for forecast improvements.

In the paper, Section 1 is the Preface, Section 2 introduces the TRAMS model, Section 3 describes the vortex relocation method, the bogus scheme and the corresponding adjustment, Section 4 narrates the design of experiments and gives the analysis on results, and Section 5 provides the conclusion and discussion.

2 INTRODUCTION OF THE TRAMS MODEL

TRAMS is a non-hydrostatic model developed on the basis of GRAPES mesoscale model. It adopts the semi-implicit, semi-Lagrangian scheme for the integration of time. The Arakawa-C grid and Charney-Philips vertical layer setup are used in the horizontal and vertical directions. The vertical coordinate is terrain-following. The model covers the area within 81.6°E-160.8°E and 0.8°N -50.5°N, and its horizontal grid interval is 0.36°. It is divided into 55 layers in the vertical direction and its time integration step is 200 seconds. The TRAMS model adopts the Medium-Range Forecast (MRF) boundary layer scheme, Simplified Arakawa-Schubert (SAS) cumulus parameterization scheme, WRF Single-Moment 6-class (WSM6) microphysics scheme, Specified constants and Layers for soil land surface processes (SLAB), Short Wave Radiation (SWRAD) scheme and Rapid Radiative Transfer Model (RRTM) long wave radiation scheme. TRAMS has been in operational used by the China Meteorological Administration since 2011. It provides 120 hours forecasts twice daily for typhoon track, intensity, wind, rain and isobaric surface field. In this paper, only the 72 hours forecasts are analyzed.

3 DESCRIPTION OF THE INITIAL SCHEME FOR TYPHOON

The initial scheme for typhoon adopts the relocation method proposed by Yuan et al.[27]. It first separates the background field into the vortex circulation and the large-scale environmental field, removes the vortex circulation from the background and transfers the vortex circulation to the observation location, and then obtain the relocated background field.

After relocation, the bogus model can be inserted into the background. The construction of the bogus model following the approach raised by Anthes[28] and Ueno and Ok[29], namely it uses four conditions, *i.e.*: the observed typhoon center position, typhoon intensity (central pressure), radius of 8 grade wind and the typhoon's initial motion, to construct an asymmetrical typhoon model satisfying the static equilibrium, gradient wind equilibrium, quasi-thermodynamic equilibrium, and consistent with the environmental field and convection parameterization scheme. The weighting coefficients are used to insert the bogus model. The coefficients of the background and the bogus model are determined by the distance from typhoon center.

In the bogus model, the convection parameterization scheme is used to calculate the bottom and top height of the convection cloud. It is usually determined in accordance with the humidity profile and temperature profile of the air parcel in typhoon center. The bottom (top) altitude of the cloud is set as the height of the standard isobaric surface, where the temperature of the air parcel (T_b) in the lowest (highest) layer is higher than the temperature in the ambient air (T_e). The temperature of the ambient atmosphere in each layer is the average of the air around typhoon in the background field. The air parcel temperature (T_b) can be calculated through the wet static energy conservation formula when above the condensation level, and it is related to the typhoon center temperature and humidity on the 1 000 hPa isobaric surface. In the current model, the air parcel temperature (T_b) of the bottom in typhoon center is set as the temperature of the ambient atmosphere (and given the threshold as $308K > T_b > 300K$). The relative humidity (RH_b) is set as 95%. However it can be found that the air parcel temperature at the bottom of the typhoon center can be lower than 300K. As the temperature threshold and the relative humidity are set manually, we have tried tuning them in this paper and certain experiments have been designed to survey their influences.

4 DESIGN OF EXPERIMENTS AND ANALYSIS OF RESULTS

In this section, several initial schemes were adopted to carry out numerical experiments, their influences on the forecast for Typhoons Roke and Sonca in 2011 were analyzed.

4.1 *Experiments and case analysis*

Typhoon Roke was initially numbered on September 13. Its intensity gradually increased, on September 15 it was tropical storm and on Sep. 19 it strengthened to typhoon. It developed to strong typhoon on September 20. Typhoon Sonca was formed in the South China Sea on September 13 and numbered on September 15. It was initially a tropical storm, later severe tropical storm and strengthened to typhoon on September 18. It was weakened and dissipated on September 20. During its lifetime Sonca and Roke formed binary typhoons.

Numerical simulation was initiated at 12:00 of September 15, 2011 and 00:00 of September 16, 2011, hereinafter referred to as the former case and the latter case. Since the track forecast deviation of Sonca was on a high level, experiments on the initial scheme (Table 1) were designed, and the corresponding effects on the forecast was analyzed.

Table 1. Design of experiments for typhoon's initial scheme.

Experiment	Description of the initial scheme	Typhoon
CTR	No processing for initial vortex	Roke and Sonca
S1	Relocation	Roke and Sonca
S2	Relocation, bogus (threshold of the bottom air parcel temperature T_b＞300K)	Roke and Sonca
S3	Relocation，bogus (no threshold value was set for the bottom air parcel temperature)	Roke and Sonca
S4	Relocation，bogus (no threshold value was set for the bottom air parcel temperature, the relative humidity reduced to 85%)	Roke and Sonca
S5	Relocation，bogus (no threshold value was set for the bottom air parcel temperature, the relative humidity reduced to 90%)	Roke and Sonca
S6	Same as S5	Sonca
S7	Same as S2	Sonca

4.1.1 DATA AND DESIGN OF EXPERIMENTS

The TRAMS model was used to perform the numerical experiments, with the analysis data of the

National Center for Environmental Prediction (NCEP) as the background fields. The NCEP forecast data was used as the lateral boundary with the resolution of 0.5°×0.5°. The control experiment used the operational scheme without any processing for the initial vortex. The model integration was run for 72 hours. Table 1 shows the design for all experiments in detail. If not specified, the relative humidity of the bottom air parcel of the bogus model is 95%. In order to simplify the expression, the experiment initiated at 12:00 of September 15, 2011 is known as the former case, and the experiment initiated at 00:00 of September 16, 2011 is known as the latter case.

4.1.2 IMPACTS OF TYPHOON'S INITIAL SCHEME

As shown by Table 2, if the relocation and bogus method were adopted as the S2 Experiment, the cloud top height of the two typhoons was 150hPa in the former case. When reducing the relative humidity of the bottom layer of typhoon center in the bogus model (Experiment S4 and S5), the cloud top height of Typhoon Sonca changed from 150hPa to 200hPa, but that height of Typhoon Roke remained. In the latter case, the cloud top height of the two typhoons was fixed at 150hPa.

Table 2. Cloud top height of typhoons in experiments.

Experiment	Height in the former case		Height in the latter case	
	Sonca	Roke	Sonca	Roke
S2	150hPa	150hPa	150hPa	150hPa
S3	150hPa	150hPa	150hPa	150hPa
S4	200hPa	150hPa	150hPa	150hPa
S5	200hPa	150hPa	150hPa	150hPa

Figure1 shows the difference of the track forecast error between Experiments S1~S5 and Experiment CTR in the former and latter cases. The positive and negative values in the figure indicate the error increased and decreased relative to Experiment CTR, respectively. Obviously, the scheme used relocation only (as used in Experiment S1) could not reduce the subsequent track forecast error. We can see the track error for Typhoon Sonca in Experiment S1 was increased relative to Experiment CTR, but for Typhoon Roke it was reduced slightly, as the former case is involved. For the latter case, the track error for Typhoon Sonca was increased, and the track error for Typhoon Roke was increased during 54~60 hour forecast, otherwise it was reduced. Additionally, the track forecast was almost unchanged if no temperature threshold was set. Comparing the track forecast of Experiment S2 (with the temperature threshold) and S3 (without the temperature threshold) with Experiment CTR, the track error for Typhoon Sonca and Roke in the former case was reduced slightly, but in the latter case there was no difference, for the air temperature at the bottom layer of the two typhoons was not exceed the threshold. Comparing the track forecast of the experiments using the scheme of relocation and the bogus model with Experiment CTR, as the former case was involved, the track error for Typhoon Sonca in Experiment S2 and S3 was increased in the early stage and reduced in the later stage, but the error for Typhoon Roke was reduced in the early stage and increased in the later stage. In Experiments S4 and S5, the track error for Typhoon Sonca and Roke was increased, especially for Typhoon Roke, which was increased by up to 300km (the maximum error of the CTR experiment was only 200km). As for the latter case, in Experiment S2, S3, S4 and S5, the track forecast error for Typhoon Sonca was basically reduced, but it was increased at 72-h forecast (except for Experiment S5). The track forecast errors for Typhoon Roke were all reduced in the early and later stages, but were increased during 36~48 hour forecast). Additionally, comparing Experiment S4 and S5 with Experiment CTR, if adjusting the relative humidity, the track forecast error of the two typhoons was significantly increased in the former case, and the track forecast error of the two typhoons was reduced in the latter case. The error of Experiment S4 and S5 (with the relative humidity of 85% and 90%) was almost in the same level.

Since the track error of Sonca in the two control experiments was much greater than that of Roke, and the scheme with relocation and the bogus method was effective in improving track forecast for Sonca, the numerical experiments (S6 and S7) were conducted additionally, with the initial scheme only for Sonca.

To have a better idea, the difference of track forecast error for Typhoon Roke and Sonca between Experiment S2, S6 and S7 (relative to CTR) is shown in Fig. 2. In Experiment S7, the track forecast error for typhoon Sonca and Roke was basically reduced in both the former and the latter cases, compared with Experiment CTR. It leads to the conclusion that the initial scheme for Typhoon Sonca have improved the track forecast for Typhoon Sonca and Roke. Comparing Experiment S6 and S7, their track forecast errors were close, showing that the effects of the two initial schemes (with relative humidity 90% and 95% respectively) matched. The possible reason was that the cloud top height in Experiment S6 was not reduced effectively (in Experiment S6 and S7, the cloud top height of Sonca was the same as in Experiment S5 and S2 respectively in Table 2). Besides, the difference between Experiment S7 and S2 was whether the initial scheme was used for

Typhoon Roke. Comparing the forecasts of Experiment S7 and S2, the track errors of Roke and Sonca in Experiment S7 were less than those in Experiment S2, as both cases were involved.

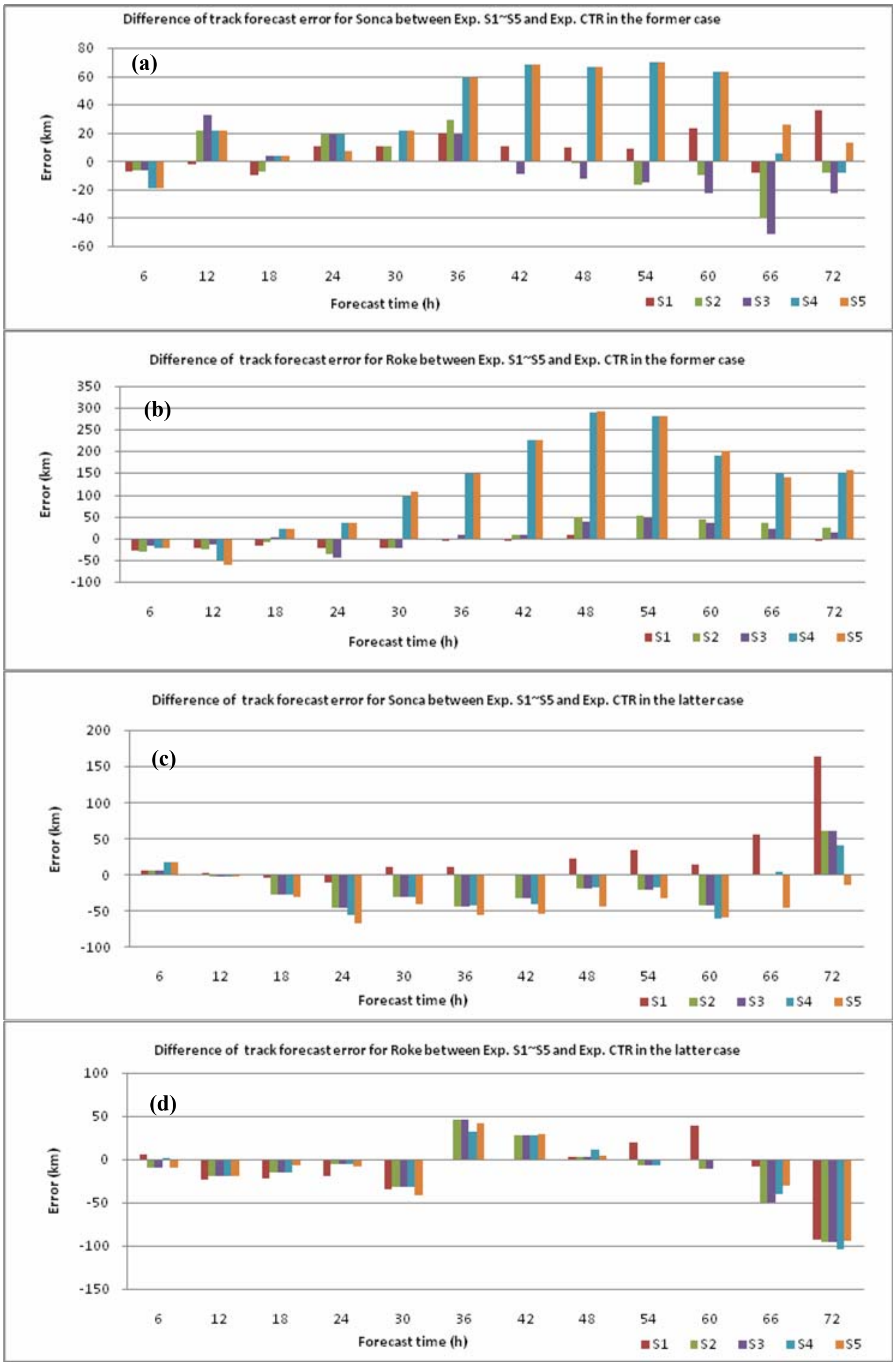

Figure 1. Difference of track forecast error for Typhoon Roke and Sonca between Experiment S1~S5 and CTR (Exp. S1~S5 minus Exp. CTR) (Unit: Km).

For the latter case, the track error in 72-h forecast for Typhoon Sonca was more than 700km in Experiment S2, but in Experiment S7 it was approximately 600km. For the former case, the track error in 72-h forecast for Typhoon Roke was more than 200km in Experiment S2, but in Experiment S7 it was less than 150km. Obviously, it was not beneficial or even detrimental for its track forecast to use the initial scheme for Roke, simultaneously it reduced the accuracy in track forecast for the other typhoon (Sonca). The main reason why the sensitive experiment made improvements was that adopting different initial schemes for different typhoons was the more than the control experiment.

Following, the differences of initial circulation and forecast field between Experiment CTR, S2 and S7 were compared, so as to further discuss the possible physical mechanism that leads to improvements on track forecast in Experiment S7. Herein only the former case was analyzed.

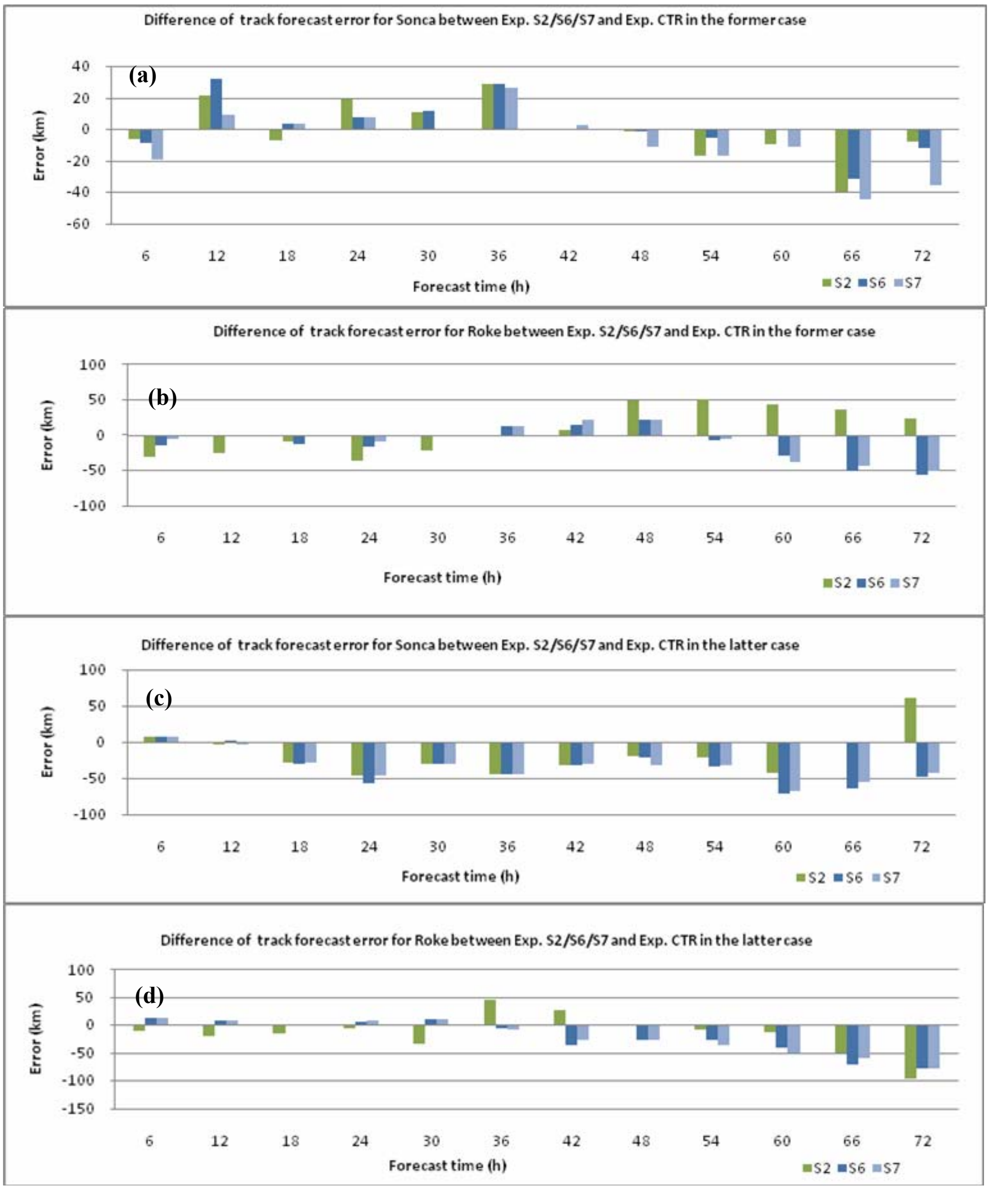

Figure 2. Difference of track forecast error for Typhoon Roke and Sonca between Experiment S2, S6, S7 and CTR (Exp. S2/S6/S7 minus Exp. CTR) (Unit: Km).

As shown in Fig.3(a), there was cyclone A around (152°E，22°N) in the initial field of Experiment CTR, the circulation center corresponding to a cold center. In Experiment S2 and S7 [Fig. 3(b), (c)], there was a cyclone circulation B in the east of cyclone A. The location of cyclone B was corresponding to the lower layer of typhoon center (155°E，22°N) and its temperature field was corresponding to a warm center. Furthermore, from the vertical vorticity of the background field [see Fig. 3(d)], the vortex center located at 155°E corresponding to cyclone B, *i.e.*: the circulation of Typhoon Sonca. Between 1 000hPa and 200hPa there was positive vorticity, with a maximum value beneath 500hPa. It was basically barotropic below 500hPa. West to cyclone B there was a vortex, which corresponded to cyclone A, namely the cyclone circulation located at 152°E and 22°N in the Fig. 3 (a), (b) and (c). It was an upper cold vortex independent from Typhoon Sonca. In Experiment CTR, the circulation and warm center in the middle-upper layer of Typhoon Sonca was rather weak, which was not beneficial to sustaining typhoon development, but even made it prone to being affected by the cold vortex westward (the cyclone A). In Experiment S2, at 400hPa the distribution of geopotential height and temperature within the region of Sonca and the cold vortex in the initial field [see Fig. 3(b)] was similar to that of Experiment S7. However, the structure of Typhoon Roke in Experiment S2 was more symmetrical and the warm center associated with Roke was even stronger than in Experiment S7.

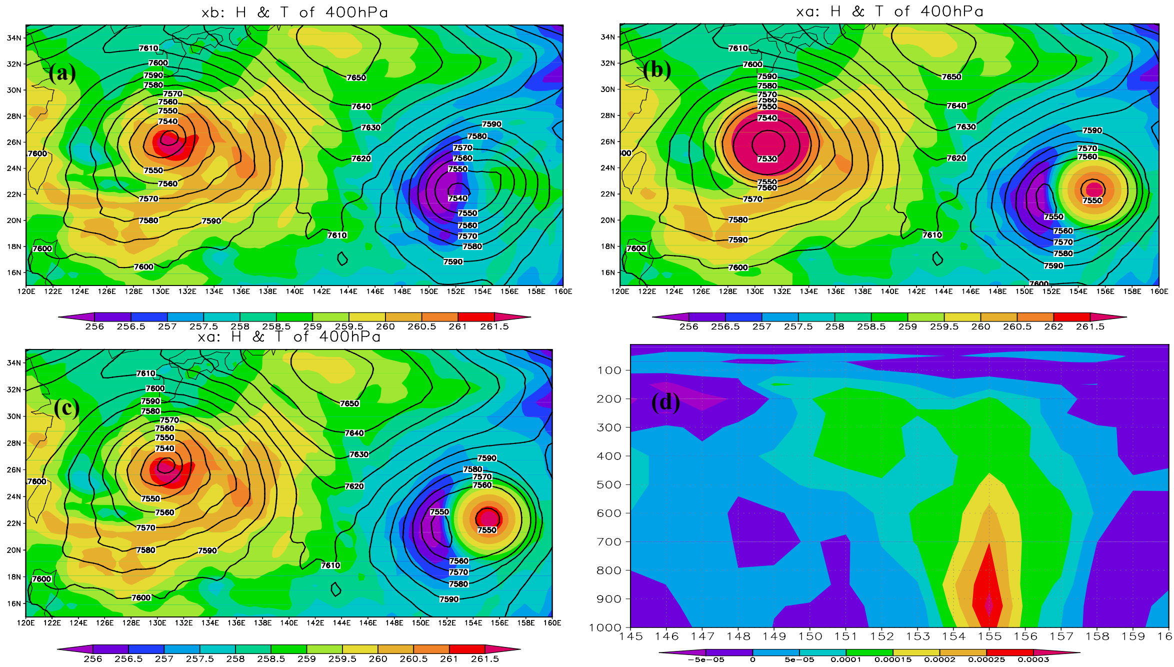

Figure 3. Temperature (shadow, unit: k) and geopotential height (contour, unit: gpm) in the initial field at 400hPa in Experiment CTR (a), S2 (b), S7 (c) and the vertical vorticity of the background field (d, unit: s^{-1}) along the height-longitude section through the center of Typhoon Sonca in the former case.

The track observed and forecasted for Typhoon Roke in the former case is shown in Fig. 4. Since Typhoon Roke moved along a ring-shaped track, to avoid confusion the forecast track of every experiment is presented respectively, see Fig. 4(b), (c) and (d). The track of Roke in Experiment S7 [see Fig. 4(d)] was the most consistent to the track observed [see Fig. 4(a)], the track forecasted in Experiment S2 [see Fig. 4(c)] was the most different from observation, and the track in Experiment CTR [see Fig. 4(b)] fell between them. In all experiments (S1/S2/S7), Typhoon Roke moved at a quicker speed with a weaker intensity in its late stage, its 36-h location of Roke was approaching the 48-h position in observation. The difference between the experiments was in the period that Roke turned from moving southeast to northeast, and then further to the northwest. In Experiment CTR and S7, Roke turned from southeastward to northeastward at 42-h forecast (in observation at 54-h), and turned northwestward at 48-h forecast (in observation at 60-h). The two turns were 12 hours earlier in the forecast than in observation. In Experiments S2, Roke turned from moving southeast to northeast at 36-h and then to northwest soon (at 42-h). The two turns were much earlier than observation. After turning to moving northwest, in Experiment S2 and CTR the westward movement of Roke was more than in reality, and the moving speed was faster. In Fig. 4, the different color of the solid line indicates the intensity. It can be seen that in Experiment S7 Roke's intensity was stronger during 12~24 hours, but after 60-h the intensity forecasted in Experiment S2, S7 and CTR was weaker. All in all, Experiment S2 performed relocation and bogus model for Typhoon Roke, but its track forecast was inferior to that of Experiment CTR and S7. The original typhoon structure information of the background field might be omitted after being embedded into the typhoon model, and thence lead to the follow-up development and motion of the typhoon drifting away from the actual situation. It comes to the conclusion that an inappropriate initial scheme might reduce the accuracy of typhoon forecast, which is consistent with the conclusion above.

The actual and forecast track in experiments for Typhoon Sonca is shown in Fig. 5. It can be seen that there was deviation between the forecast track and the actual track, similar to Typhoon Roke, the moving speed of Sonca in its late stage was faster than observation, which caused increased track error in late stage. The track forecasted in Experiment S2 and S7 was very close, but that forecasted in Experiment S7 was a bit closer to the actual track, and the track error was slightly less [see Fig. 2(a)]. According to Fig. 4, Experiment S7, relative to the control experiment CTR, performed the initial scheme only for Typhoon Sonca, which improved not only the track forecast for Sonca, but also the one for Roke. Experiment S2 performed the initial scheme for both Sonca and Roke, which not only reduced the forecast accuracy of Roke but also that of Sonca. The track error increased (compared with Experiment S7), it was even more than that of Experiment CTR. Obviously in a binary typhoon situation, adopting the initial schem for either typhoon could influence the forecast for the other typhoon, and thence there is a possibility of "twin advantages" or "twin disadvantages". It needs more prudent evaluation and sufficient experiments performing initial scheme in the situation of binary typhoons.

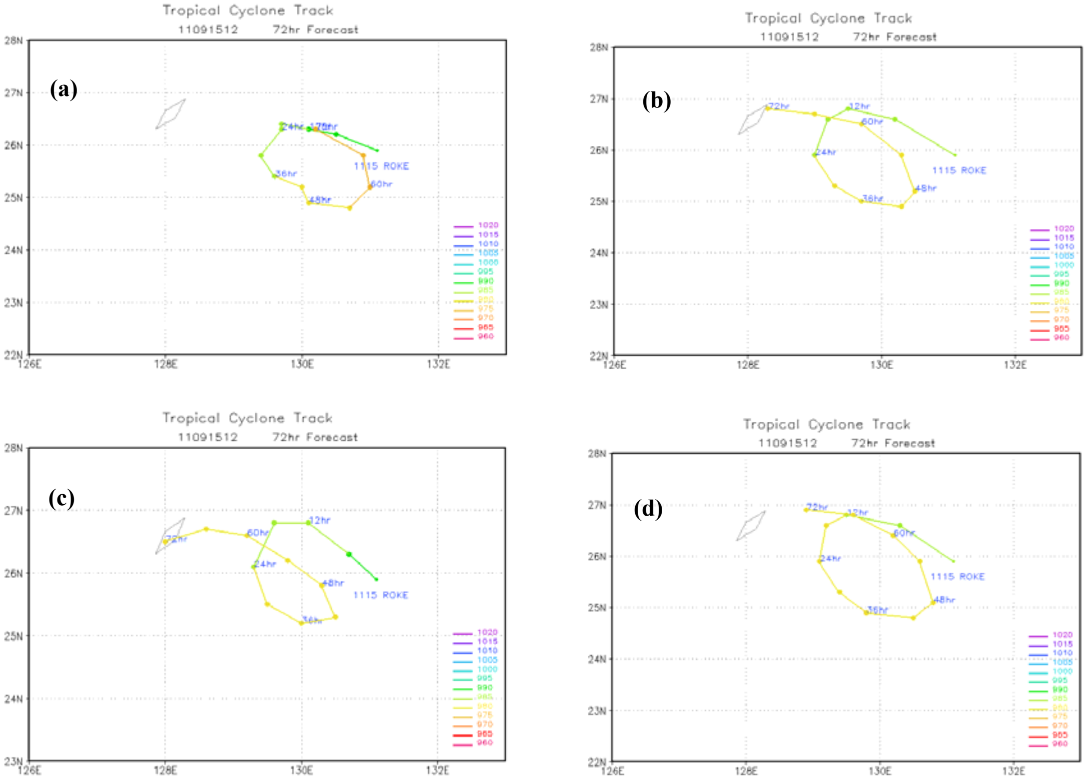

Figure 4. Actual motion track of Roke (a) and track forecasted in Experiment CTR (b), S2 (c) and S7 (d) for the former case.

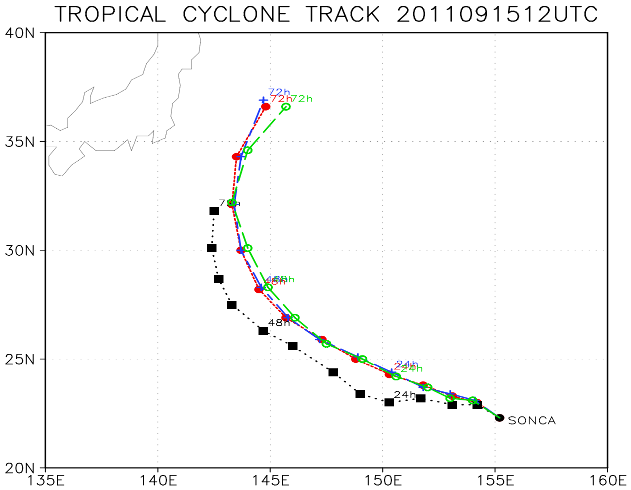

Figure 5. Actual track of Sonca and track forecast in Experiment CTR, S2 and S7 for the former case. (The time interval is 6 hours. "■" shows the actual track, "○" shows the track forecasted in Experiment CTR, "●" shows the track in Experiment S7, and "+" shows the track in Experiment S2).

According to the intensity forecast, the initial scheme used above did not provide an obvious improvement. In Fig. 6(a) and (b), the actual intensity of Typhoon Roke and Sonca gradually increased with the time, the intensity of Sonca was basically maintained within 30 hours and the intensity of Roke slowly increased. According to the intensity for Roke, all the experiments was able to simulate its intensity increasing in the early stage, but in Experiment CTR and S7 it increased more quickly, in Experiment S2 it was close to the actual situation. However the intensifying in the late stage was not simulated by any experiment. As for Sonca, the sustaining of the intensity in the early stage was simulated by all experiments, but the strengthening after 30-h was failed to simulated. Relatively, the intensity forecast error of Experiment CTR for Sonca was less than that of other experiments, and the intensity forecast error of Experiment S2 for Roke was slightly less than those of the other experiments, but the track forecast error for Roke was larger. In general, the initial scheme did not provide obvious improvement for the late intensity forecast, and the influence of the initial scheme decreased with the lapse of time.

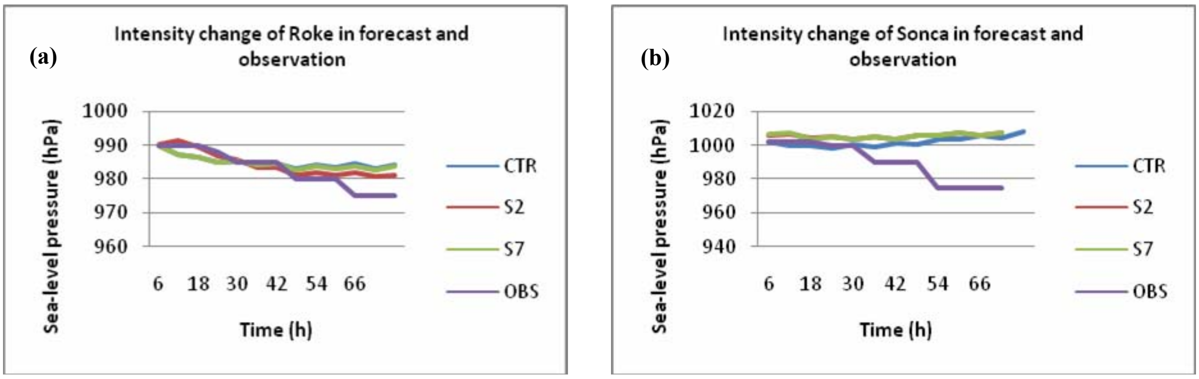

Figure 6. Intensity change observed and forecasted of Typhoon Roke (a) and Sonca (b) for the former case.

4.1.3 DISCUSSION OF THE MECHANISM OF DIFFERENT FORECASTS

According to the above analysis, the improvement of the forecast of Experiment S7 was mainly reflected by the Typhoon Roke track forecast, including the recurvature and motion after recurvature. In order to display the difference and facilitate the analysis, the track forecasted between 36~48 hour in Experiments S2 and S7 and the actual track between 36~60 hour (Fig.7) are provided. The time interval was 3 hours. The reason the actual track given from 36-h to 60-h is that the movement in Experiment S2 and S7 was faster than observation, thus the 48-h position of Roke forecasted reached the 60-h position of the actual track. According to Fig.7, in Experiment S7 Roke moved quicker than the actual situation, but its track and direction were close to observation. However, the track of Roke in S2 was obviously located to the north of the actual location. Furthermore, since the time resolution is on a higher level, it can be seen that Typhoon Roke moved northwards during 42~45 hour, and turned northwest at 45-h. Fig. 8 shows the 850 hPa wind field at turning stage in experiments. In Fig. 8, the typhoon exhibited a basically asymmetrical structure, the wind in the east or southeast of the typhoon center was more intense, but the wind speed in the west was less. According to the 500hPa situation of geopotential height (the figure is omitted), because of the existence of the other typhoon (Sonca), the influence of the subtropical high was cut off. Roke was not steered by the flow southside of the subtropical high, but became in the environment of non-advantageous steering. The motion of Roke was hugely affected by the high-wind speed region. According to the 42-h forecast of Experiment S2 in Fig. 8(a), region with the maximum wind speed was located to the east of the center of Typhoon Roke, southern wind prevailing in the region. Thus the typhoon moved northward. The wind with larger speed located east to Roke, changed from south wind to southeast wind at 45-h, Roke turned to moving northwestward. At 48-hr east wind intensified (the figure is omitted), and Roke increased westward motion [see Fig. 4(c)]. According to Experiment S7, at 42-h the maximum wind of Roke was on the southeast side, and it was a southwest wind, so the typhoon moved northeastwards. Afterwards, the region with maximum wind moved eastwards slowly, at 48-h the prevailing wind shifted to the southeast, the typhoon turned to moving northwestwards. Typhoon Sonca was located in the southwest of the subtropical high and was steered by the southeast flow of the subtropical high , so it moved in the northwest direction (see Fig. 5).

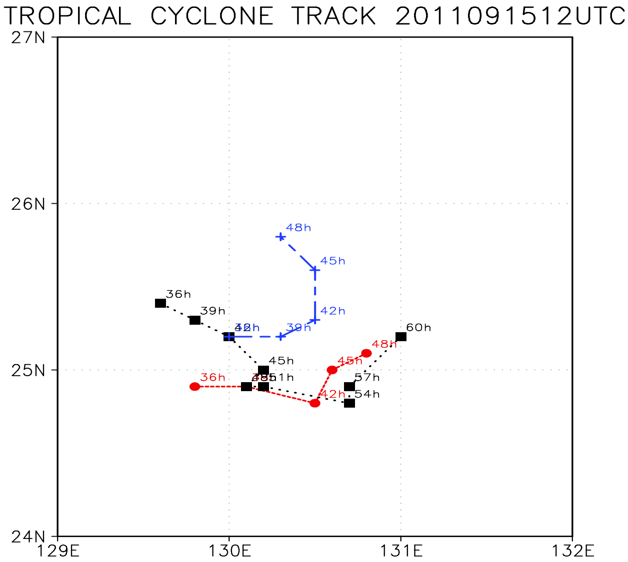

Figure 7. The 36~48 hour track forecasted in Experiments S2 and S7 for Typhoon Roke and the actual track between 36~60 hour in the former case. (The time interval is 3 hours. "■" shows the actual track, "●" shows the track in Experiment S7, and "+" shows the track in Experiment S2).

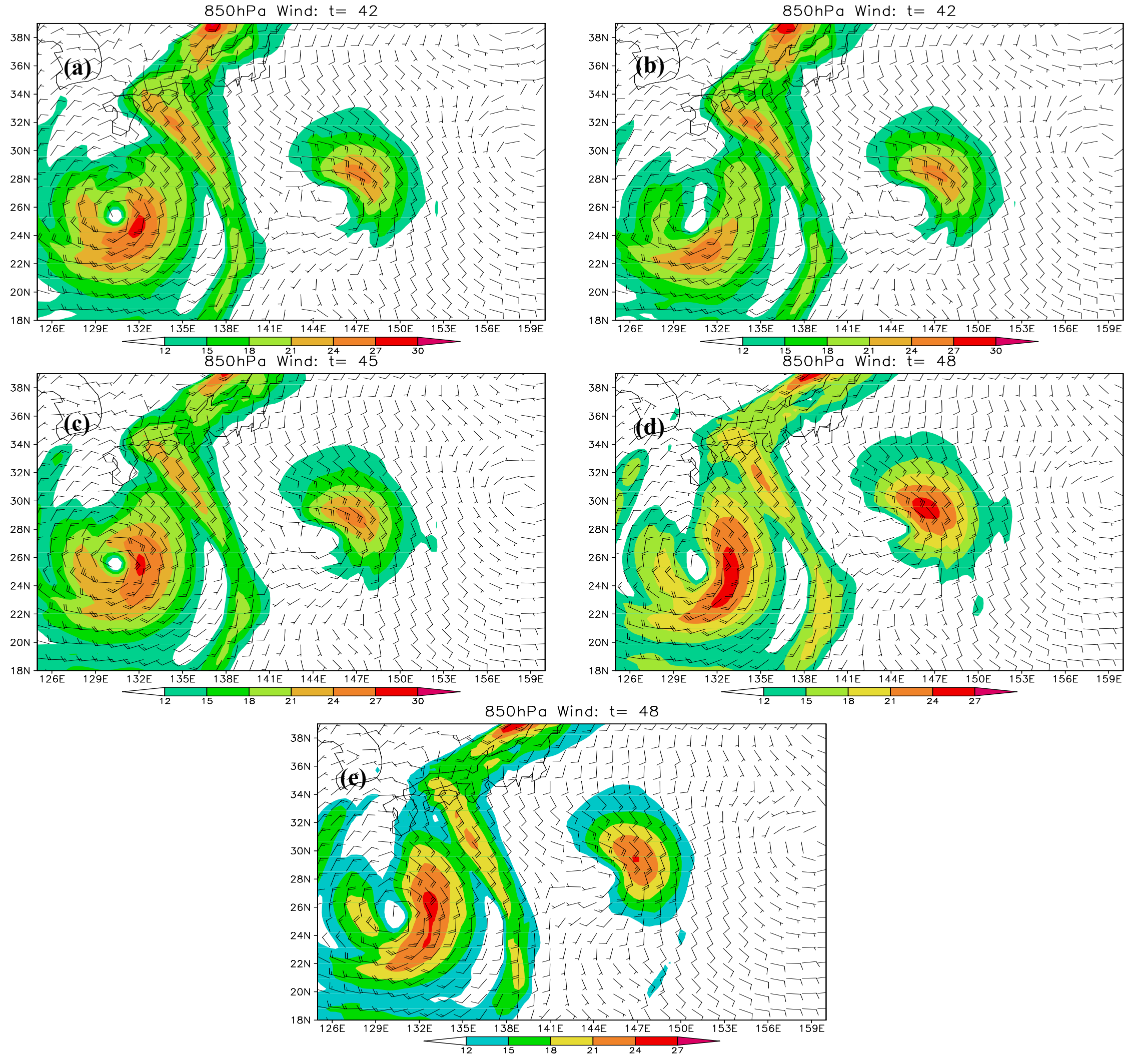

Figure 8. 850hPa wind vector and wind speed (shadow) forecasted by Experiment S2 and S7 for Typhoon Roke. (a) 42-h forecast by Experiment S2; (b) 45-h forecast by Experiment S2; (c) 42-h forecast by Experiment S7; (d) 48-h forecast by Experiment S7; (e) 48-h forecast by the CTR Experiment.

From the initial field and forecasts obtained with two initial schemes, Experiment S2 performing the relocation and bogus model for Roke, the center of geopotential height and warm center of temperature field coincided with each other, making the typhoon symmetrical at initial time. But in background [see Fig. 3 (a)], the upper warm center at 400hPa was located southward to Roke. This was different from the normal coincident distribution of the circulation center and warm center in typhoon, and it might result in the unbalanced development of typhoon circulation. In Experiment S2, the initial structure of Roke might cause a uniform development of Roke deviating from its own conditions and the actual situation. For instance, its typhoon center was round [see in Fig. 8 (a, c)], and the high wind region (with the speed more than 21m/s) was ring-shaped. Experiment S7 did not apply the initial scheme for Roke, thus reserved the original structure information of Roke in the background field. It was not symmetrical at the beginning, and the subsequent development was asymmetrical. For instance the typhoon center was an elliptical shape and its high wind region (with the speed more than 21m/s) was located on one side of the typhoon. The possible reason is Sonca blocked the influence of the subtropical high making its own structure and development dominant in its motion. In Experiment S7, the structure of Roke was more coherent with the actual situation, so the track was closer to the observation.

The intensity of Sonca was weaker than Roke, with the subtropical high in the east and Typhoon Roke in the west. Its motion was affected by three factors, *i.e.*: the steering airflow of the subtropical high, the binary typhoon Fujiwara effect and its own circulation. The Fujiwara effect was related to typhoon intensity, scale and the distance between two typhoons. Typhoon Sonca was weak (its initial pressure was 1 000hPa), with a smaller scale and it was far away from Typhoon Roke. So the gravitation from Roke was small and the effect of its self-circulation was weak too. Its motion was chiefly led by the airflow of subtropical high. Thus the difference of track deviation between the experiments was not obvious as Typhoon Roke (see Fig. 5). Before 48-h the tracks were almost coincident, after that the track of Experiment CTR was located to the east of that of Experiment S7, deviating further from the actual tracks. By comparing Fig. 8(d) and (e), the development of Roke in Experiment CTR and S7 was similar, furthermore the high wind region was both located to the east of Sonca. In the region the southwest wind of Experiment S7 was stronger than that of CTR and had a higher speed. Therefore the track of Sonca in Experiment S7 was west to the track in Experiment and was closer to the actual situation. Additionally, the intensity of the vortex forecasted in Experiment S7 was stronger (nevertheless there was no lower center pressure) and the typhoon circulation was more compact than that in Experiment CTR (the figure is omitted here). The reason why Experiment S7 improved the forecast might be that the bogus model inserted made the dynamic and thermodynamic structure more coincident with typhoon features, which supplemented or highlighted structure characteristics lacked in background due to its low intensity.

For Summary, performing the initial scheme for weak typhoon can help to establish the typhoon circulation, moreover the low intensity make less interference to the background field and easy for coordination. Strong typhoon has more obvious circulation, adding a bogus model will make the dynamic and thermodynamic structure closer to the ideal model. However it might obliterate or weaken the information related to other feature of typhoon in the original background, which is more important for the follow-up forecast. The bogus model may work well in the initialization of weak typhoon.

The following conclusions can be obtained by summarizing the above numerical experiments, *i.e.*:

(1) Adopting the initial scheme of relocation and the bogus model for the weak typhoon (Sonca) could improve the track forecast for both Sonca and Roke. Adopting the initial scheme for weak typhoon could possibly improve its track forecast, however it needs more experiments for further verification.

(2) By comparison of adopting the initial scheme of relocation and the bogus model for Roke and Sonca with for the weak typhoon of Sonca only, the former method increased the track forecast error. For binary typhoon circumstances, using a initial scheme for one typhoon might influence the forecast for the other typhoon and lead to the situation of “twin advantages” or “twin disadvantages”.

4.2 *Batch experiments and result analysis*

In order to further investigate the influence of the initial scheme of relocation and the bogus model on weak typhoon’s forecast, batch experiments were designed to verify whether the scheme could improve track forecast of weak typhoons. All weak typhoons during the period from 2010 to 2012 were selected. The typhoons with a center pressure greater than or equal to 1 000hPa or a near-center speed less than or equal to 18m/s were defined as weak typhoons. The initial scheme of relocation and the bogus model were adopted for the weak typhoons, and the track forecast error and intensity forecast error of the sensible experiment were compared with that of the control experiment so as to find if there was any improvement. The weak typhoon examples selected are shown in Table 3 as follows. The experiment applying the initial scheme for the 31 examples (in Table 3) was defined as the sensitive experiment (expressed as S-S), the experiment without the initial scheme for the typhoons was defined as the control experiment (expressed as C-S). The forecast period of every experiment was 72 hours. Finally the results of the sensitive experiment were compared with that of the control experiment.

According to the experiment results, the track error at different forecast time length in Experiment S-S was all less than that in Experiment C-S [Fig. 9(a)]. The intensity error was slightly higher than Experiment C-S within 24 hours and basically less within 30~72 hours [Fig. 9(b)]. Table 4 provides the statistical specimens of Experiment S-S and C-S. In Table 4, there were more than 31 specimens at 6-h forecast because some cases in Table 3 were binary typhoons. The specimens of some forecast time length in Experiment C-S and S-S were different, it was because at the corresponding time the typhoon was not included in the statistics due to the vanishing of typhoon or the unstable integration.

The batch experiments on the weak typhoons in 2010~2012 showed that the initial scheme of relocation and the bogus model could improve the forecast of track and intensity for weak typhoons. The track forecast error was decreased within 72 hours and the intensity error was also decreased.

5 CONCLUSIONS AND DISCUSSION

This paper adopted the TRAMS model to experiment and study the effects of the initial scheme on the No. 15th and 16th typhoon in 2011 (known as Roke and Sonca), and performed batch forecast experiments for weak typhoons with the initial scheme. It comes to the following conclusions:

(1) The case study showed that applying the initial scheme of relocation and the bogus model for the weak typhoon of binary typhoons could improve the typhoon track forecast. Applying the scheme for binary typhoons would increase the track forecast error. Adopting an initial scheme for binary typhoons needs more prudent evaluation and sufficient

experiments.

Table 3. Samples of weak typhoon in 2010~2012 for batch experiments.

Weak typhoon	No.	Forecast time	Center pressure (hPa)	Highest speed near center (m/s)
Chanthu	1003	10071912	1000	18
		10072000	1000	18
Tokage	1107	11071512	1000	18
Kulap	1114	11090900	1001	18
		11090912	1008	16
Sonca	1116	11091512 (binary typhoons)	1002	18
		11091600 (binary typhoons)	1002	18
		11091612 (binary typhoons)	1000	20
Nesat	1117	11092400	1000	18
Pakhar	1201	12032900	1006	18
		12032912	1002	18
		12040112	1000	18
Sanvu	1202	12052200	1004	18
Guchol	1204	12061212	1000	18
Doksuri	1206	12062612	1004	18
Saola	1209	12072800	1000	18
Damrey	1210	12072812 (binary typhoons)	1004	18
		12072900	1000	18
		12072912	1000	18
Haikui	1211	12080312	1002	18
Sanba	1216	12091100	1000	18
		12091112	1000	18
Prapiroon	1221	12100712	1000	18
Maria	1222	12101412	1002	18
Bopha	1224	12112700	1000	18
		12112712	1000	18
Wukong	1225	12122500	1000	18
		12122512	1000	18
		12122700	1004	18
		12122712	1002	18
		12122800	1002	18

Note: The data in the table above were obtained from the typhoon location report of Beijing. In some cases data of air pressure was slightly different from the data on China's Typhoon Network, which might be revised by the typhoon panel afterwards.

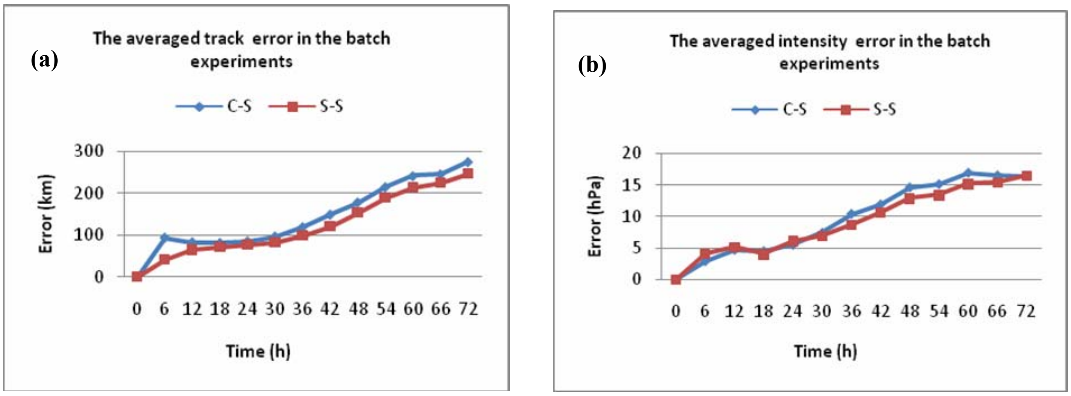

Figure 9. Track error (a) and intensity error (b) forecasted in Batch Experiments.

Table 4. Samples of Experiment S-S and C-S at different forecast time length.

Forecast time length	6	12	18	24	30	36	42	48	54	60	66	72
C-S	34	29	29	28	28	28	28	28	28	28	25	26
S-S	34	31	30	29	28	28	28	28	28	28	25	24

(2) According to the batch experiments on all weak typhoons from 2011 to 2013, applying the scheme of relocation and the bogus model for weak typhoons could improve the forecast of weak typhoons. The track error and intensity error was reduced. The rules on which the weak typhoons were selected for the batch experiments (such as the centre pressure of 1 000hPa) can be adjusted by further experiments.

(3) The cloud top height in bogus model for most typhoons was 150hPa. For weak typhoon with shallow convection, the cloud top height was high. By adjusting the parameters of relative humidity and temperature of the bogus model, the cloud top height of the weak typhoons could be reduced slightly, but it had no great impact on typhoon forecast. It is deserving for further research on a suitable bogus model for weak typhoons.

The preliminary discussions were made to investigate the reasons why the application of the initial scheme for Typhoon Roke did not produce a good result and the application of the scheme for Typhoon Sonca improved the forecast. The scheme with dynamical initialization was possibly a better option for strong typhoons. In the situation of binary typhoons or multiple typhoons, using different schemes according to the features of different typhoons might be beneficial to improve the forecast. Meanwhile, the cloud top height of typhoons in the bogus model was high, which differed from the characteristic of weak typhoons with lower convection. The bogus model should be re-designed or adjusted so as to be coincident with the structural characteristics of weak typhoons. These shall be studied and experimented on in the future.

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