Application of WRFVar (3DVar) to a High Resolution (3-km) Model over Beijing Area

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Abstract

Assimilation of mesoscale observations, such as AWS, GPSPW, etc., and initialization of the high resolution (3-km or less) model with the 3DVar approach are still challenge problems. To improve the weather forecast over the Beijing area for the 2008 Olympic game, a 3 nests (27/9/3-km) WRFVar/WRF system with 3-h update cycle is established.

The background error statistics (BES) files for each nested domain were derived based on the differences between 24-h and 12-h WRF model forecasts valid at the same time. The BES for the fine domain (3-km) obtained by interpolation from its parent domain (9-km) was tested as well. This was shown to work well. User can now save much work related to the derivation of the fine mesh BES from the forecast over a period of time. To keep the dynamic balance existed in the first guess as much as possible for the high resolution frequent cycling run, the experiments with the tuned background error variance using different factors in the 3-km resolution WRFVar analysis are conducted. The adaptive tuning of observation error parameters (Desroziers and Ivanov 2001) was also tested.

For a convective event occurred on August 1, 2006, the results showed that the background and observation error statistics tuning in WRFVar improved the skill of the precipitation forecast.

1. Introduction

A fine scale numerical weather prediction (NWP) system is needed in support of the 2008 Olympic game in Beijing, China. Moreover, several types of observations with higher temporal and spatial resolution are available locally over Beijing area. To improve the performance of the NWP system, a three nests (27/9/3km) Rapid-Update (3h) Cycling (RUC) modeling system with WRFVar(3DVar)/WRF has been developed (Barker *et al.* 2004, Skamarock *et al.* 2005). with the capability of assimilating the mesoscale observations, AWS (Automatic Weather Station) and GPS (Global Positioning System) PW (Precipitable Water) data, etc..

One of the challenges to apply the WRFVar (3DVar) system to a high resolution (3km) model is how to derive and tune the background and observation error statistics to improve the performance of the NWP RUC system. A squall line case occurred over Beijing area on 1 August 2006 is chosen for this study. A series of experiments are conducted for the 1-h and 3-h cycling runs started at 0000 UTC 1 August 2006. The subjective evaluation and Threat Scores (TS) are used to assess the performance of the experiments.

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2. Squall line case ob 1 August 2006

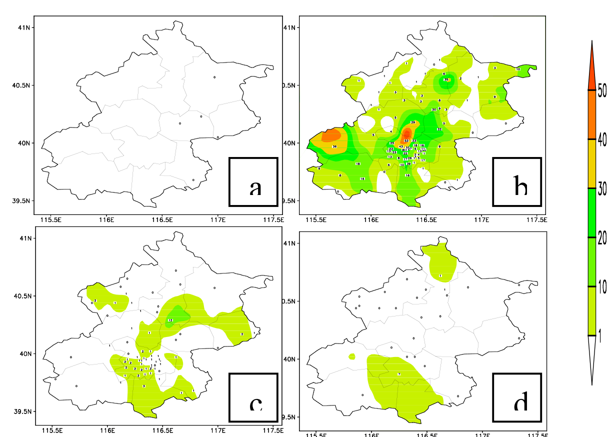

Fig. 1. 6-h accumulated precipitation ending at a) 0060, b) 1200, c) 1800 UTC 1, and 0000 UTC 2 August 2006. There are total 105 rain gauges over Beijing area.

In the afternoon of 1 August 2006, a strong convective event occurred over the Beijing area with the heavy rainfall of 43.8 mm observed at Haidian station. The hourly rainfall amount from 0090 to 1000 UTC was 32.4 mm. From the radar map, this heavy rain was caused by a squall line moving southeastward from northwest of Hebei province. Figure 1 showed the 6-h accumulated precipitation ending at 0060, 1200, 1800 UTC 1 and 0000 UTC 2 August 2006.

3. Experiment design

First, we conducted the 1-h and 3-h cycling experiments, called Exps. A1h and A3h, from 0000 to 0900 UTC 1 August to see if more frequent cycling improves the results. The WSM6 microphysics scheme was used in these experiments. With the same physics, Exp. O1h, which included the observation error tuning factors (Desroziers and Ivanov 2001), was carried out. To tune the background error statistics (BES), Exps. B3h, B3hvs, and B3hin were conducted, which were corresponding to the variance tuning factors = 1.0, 0.5, and the 3km BES interpolated from 9km BES. The table below provides a brief summary of the experiments conducted in this study.

CTL	NO DA, Thomp.
A1h	1h cycle, WSM6, var_scal.=1.0
A3h	3h cycle, WSM6, var_scal.=1.0
O1h	1h cycle, WSM6, var_scal.=1.0, ob_error tune
B3h	3h cycle, Thomp., var_scal.=1.0
B3hvs	3h cycle, Thomp., var_scal=0.5
B3hin	3h cycle, Thomp., var_scal=0.5, 3km Intp-BE

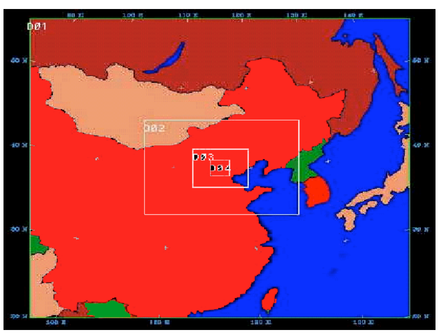

Fig. 2. Nested domains for BMB operational run with resolution of 27-, 9-, 3- and 1-km.

All experiments were performed with WRFVar v2.1 and WRF v2.2 in cycling mode over the 27/9/3km domains (Fig. 2). The BES for 3 domains were derived from the differences of 24h and 12h forecast valid at the same times over a period of 18 days with NMC-approach. The NCEP GFS analysis and forecasts were used to generate the initial condition at 0000 UTC 1 August and the boundary conditions. In the cycling experiments, the first guesses were obtained from the previous cycle's WRF model forecast. In addition to the conventional observations, the AWS and GPS PW data over Beijing area were also assimilated with 1h (for 1h cycling run) or 3h (for 3h cycling run) time windows. Because the heavy rain occurred during the period of 0800 to 1000 UTC, only 12h forecasts were made after data assimilation in each of the cycles (see Fig.3).

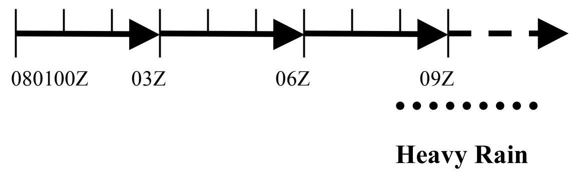

Fig.3. Schematic of WRFVar/WRF experiments in cycling mode.

4. Results

a) CTL and 3h cycling run (B3hvs)

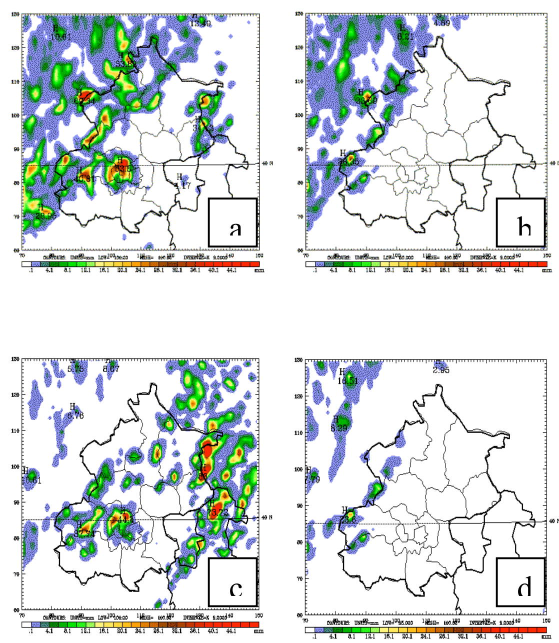

Fig.4. a) 0-6h accumulated precipitation forecast from 3h cycling (B3hvs) at initial time 0300 UTC, b) 3-9h accumulated precipitation forecast from CTL initiated at 0000 UTC, c) same as a) but initiated at 0600 UTC, and d) same as b) but 6-12h accumulated precipitation. The 3h cycling (B3hvs) run with the background error variance tuning factor=0.5.

From Fig. 4, the 3h cycling run performed very well compared with the observed precipitation (Fig.1). The heavy rain located over the urban area of Beijing is well captured. The maximum rainfall amounts reached 54 mm (Fig. 4a) and 45 mm (Fig. 4c). Figs.4b and 4d showed that no rainfall was predicted over the urban area by Exp. CTL (no data assimilation, no cycling). During the period of 0000 to 0300 UTC, the data sources are mainly from the surface observations (SYNOP and AWS) and GPS PW. The mesoscale datasets from BMB (Beijing Meteorological Bureau) played a critical role in this case. Also a mesoscale data assimilation system with cycling is necessary for predicting the strong convection.

b) 1h (A1h) and 3h (A3h) cycling runs

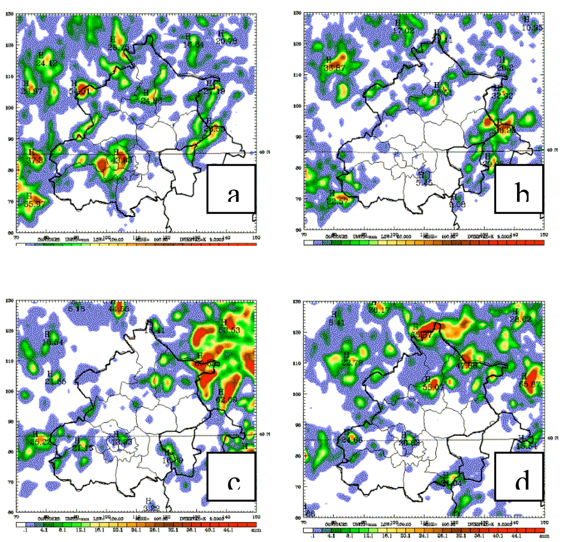

Fig. 5. The 0-6 accumulated precipitation forecast a) 3h cycling (A3h) , b) 1h cycling (A1h) at initial time 0300 UTC, and c) 3h cycling , d) 1h cycling at initial time 0600 UTC.

Can a more frequently cycling gain more for the convection forecast? To answer this question, Exp. A1h and A3h are conducted. The 6h accumulated rainfall forecasts from the initial times 0300 and 0600 UTC are shown in Fig. 5. In terms of the heavy rain occurred over Beijing urban area, 1h cycling run (A1h) did not perform better than the 3h cycling run (A3h). Rather, it degraded the forecast at the initial time 0300 UTC (Fig. 5a and 5b). It seems that with 27/9/3km domain configuration, and the current available datasets, the 3h cycling is a suitable choice for NWP in the Beijing area.

c) Observation error tuning (O1h)

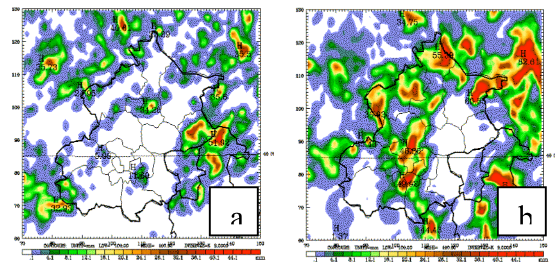

Fig. 6. The 0-6 accumulated precipitation forecast a) 1h cycling (O1h) at initial time 0300 UTC, and b) 1h cycling at initial time 0600 UTC.

In WRFVar system, there is a utility program, based on Desroziers and Ivanov's (2001) adaptive tuning technique, to obtain the observation error parameters. In this study, we used this tool to tune the observation error statistics. We got a factor of about 1.32 for σ_o, and applied it to WRFVar. Figure 6 showed the results from 1h cycling run (Exp. O1h). Compared Fig. 6a and 6b with Fig .5b and 5d, the precipitation forecast skill at initial time 0600 UTC was improved. This is also confirmed by the objective evaluation with Threat Scores (TS) in Table 2. For the threshold of 0.1, 1.0, 5.0, and 10.0 mm, Exp. O1h gave TS = 0.62, 0.54, 0.34, and 0.27, but A1h only has 0.38, 0.24, 0.09, and 0.03. We suggest that BMB may consider using this technique in future operation.

d) Background error statistics tuning (B3hvs and B3h)

For the high resolution (3km) WRF model cycling run, to retain more fine scale features in the first guess, we subjectively reduced the background error variance by a factor of 0.5. This may allow the final analysis from WRFVar to be better balanced. Figure 4a and 4c and Fig. 7 showed the results from tuned BES and non-tune BES (var_scaling=1.0). Comparing Figs. 4a, 4c with Fig.7a, 7b, Exp.B3hvs with tuned BES gave heavier rainfall forecast, which is closer to the observation. The TS (Table 2) also confirmed the skill improvement with the tuned BES. For initial time 0300 UTC, TS scores with threshold of 0.1, 1.0, are 0.20, 0.13 from B3hvs, but 0.12, 0.09 by B3h. For initial time 0600 UTC, they are 0.36, 0.24, and 0.17, 0.12. Obviously, the BES tuning factor of 0.5 gave the positive impact on the heavy rain forecast. We also tested the factors of 0.75 and 0.25, the forecast skill were not improved (not shown). So selection of a suitable tuning factor is important.

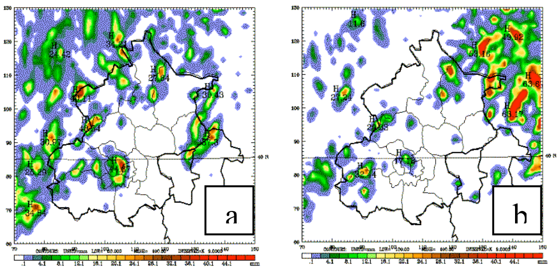

Fig.7. The 0-6 accumulated precipitation forecast a) 3h cycling (B3h) at initial time 0300 UTC, and b) 3h cycling at initial time 0600 UTC.

e) Using the interpolated BES (B3hib)

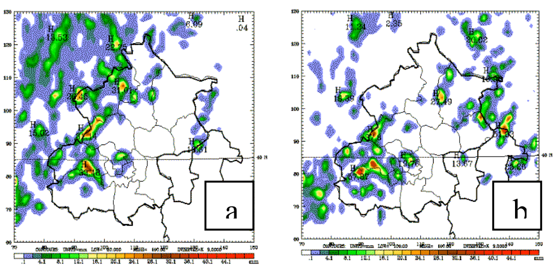

Fig. 8. The 0-6 accumulated precipitation forecast a) 3h cycling (B3hib) at initial time 0300 UTC, and b) 3h cycling at initial time 0600 UTC.

Derivation of the background error statistics for a high resolution model is a labor-consuming task. The capability of obtaining the interpolated BES from an existing coarse mesh BES files was developed in WRFVar v2.1. This interpolated BES could be used as the first approximation to run WRFVar. Here, the 3km BES, interpolated from existed 9km BES, was tested. To account for the resolution difference, a length scaling tuning factor of 1.732 (=sqrt(9km/3km)) is introduced.

To access the property of the interpolated BES, another experiment, B3hib, was performed. Figure 8 shows the results from Exp. B3hib. Comparing this figure with Fig.4a and 4c (B3hvs), Exp. B3hib gave little bit weaker rain forecasts. The TS in Table 2 also showed the degraded forecast skill. But the heavy rain is still predicted over the Beijing urban area. This shows that the interpolated BES could be used as a reasonable approximation to the high-resolution BES.

f) Objective assessment of the precipitation forecast skill

Table 2. Threat score for the different experiments

Exp	Init. Time	0.1 mm	1.0 mm	5.0 mm	10.0 mm
CTL	0300	0.08	0.14	0.0	0.0
	0600	0.04	0.02	0.0	0.0
A1h	0300	0.28	0.17	0.0	0.0
	0600	0.38	0.24	0.09	0.03
A3h	0300	0.26	0.24	0.0	0.0
	0600	0.26	0.15	0.09	0.0
O1h	0300	0.24	0.14	0.0	0.0
	0600	0.62	0.54	0.34	0.27
B3h	0300	0.12	0.09	0.0	0.0
	0600	0.17	0.12	0.09	0.03
B3hvs	0300	0.20	0.13	0.0	0.0
	0600	0.36	0.24	0.11	0.19
B3hib	0300	0.18	0.03	0.0	0.0
	0600	0.28	0.22	0.17	0.0

The threat scores are computed only over 105 rain gauge stations over the Beijing area (Fig.1). In general, the TS values from the initial time 0600 TUC are higher than those from the initial time 0300 UTC for the cycling experiments. This is to be expected because of the initial time 0600 UTC has a shorter forecast leading time.

With a threshold of 5 mm or larger, the TS values are rather low except for Exp.O1h. This means the heavier rain is harder to be correctly predicted in both location and timing. The higher TS for O1h is coming from the correct timing of the rainfall forecast although the location and amount forecast are not as good as other experiments. After carefully checking the hourly precipitation forecasts, we found that all cycling experiments except O1h predicted the heavy rain occurred about two hours early although the location and amount of rainfall forecasts are close to the observed one. For the mesoscale convection forecast, like this case, the correct prediction of the location and intensity of precipitation may be more important than the one or two hours difference. So sometime the TS values may be not suitable to assess the skill of the strong convection forecast, but only be used as a reference. The observation error tuning is worthwhile to be further tested.

5. **Summary and conclusions**

In support of the 2008 Olympic game in Beijing, China, a high resolution numerical weather prediction system with three nests (27/9/3km) has been developed with WRFVar v2.1 and WRF v2.2 in cycling mode. To improve the performance of the NWP system and to properly assimilate the data from the local observation network in Beijing area, such as AWS and GPS PW data, several experiments were conducted in this study, which include i) cycling frequency, 1h or 3h; ii) observation and background error statistic tuning; and iii) using an interpolated 3km background error statistic file, A squall line case, which produced heavy rain in the Beijing urban area on 1 August 2006, is chosen for this study. To assess the performance of this system, the precipitation forecasts are verified against the data from 105 rain gauge stations over the Beijing area. We checked the location, intensity, and timing of the heavy rain forecasts subjectively, and the threat scores are computed for all the experiments.

The main conclusions drawn from this study are:

1) This 3 nests WRFVar/WRF configuration works well and can successfully predict heavy rain occurred over Beijing urban area on 1 August 2006.

2) The system with 3h assimilation/forecast cycle is satisfactory, shorter time cycling does not lead to further improvement.

3) The adaptive observation error tuning technique gave encouraging results, especially in improving the timing of the heavy rain forecast for this case.

4) An appropriate reduction of the background error variance, var_scaling=0.5, for 3km BES improved the skill of the heavy rainfall forecasts.

5) The interpolated 3km BES from the 9km BES could be used as a reasonable approximation to the 3km BES in WRFVar.

In this study, we only focused on the WRFVar component of the NWP system. As it turned out, the parameter tuning in WRF model component is also very important. For example, the differences between Fig.4a, 4c (A3h) and Fig.7a, 7b (B3h) could be caused by the different microphysics schemes, WSM6 in A3h and Thompson in B3h. Also in another study, we found that the old and new Kain-fritch parameterization scheme gave significantly different forecasts. Based on these results, we suggest that the current system design, B3hvs, could be used as the primary operational NWP system at the Beijing Meteorological Bureau, China.

Acknowledgements

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