8.5 Impact of Assimilating Rainfall Derived from Radar and Satellites on Rainstorm Forecasts over the Southwestern United States

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1. Introduction

The major advantage of 4DVAR is the use of full model dynamics and physics to assimilate multiple-time-level observation data (instead of assimilating observation data only at the initial time). Rainfall assimilation via 4DVAR has been used in several studies to improve the moisture distributions in model ICs and have obtained encouraging forecasting results (Zupanski and Mesinger, 1995; Zou and Kuo, 1996. Using 4DVAR to generated model ICs, the precipitation intensity and patterns can be improved substantially over the mid-latitude plain regions (Alexander et al., 1999; Guo et al., 2000) as well as the tropical regions (Tsuyuki, 1997). However, it is a challenge to forecast rainfall over the mountainous southwestern United States.

In this paper, a typical strong convective rainfall event occurred in southern Arizona during 5-6 August 2002 was studied. A series of numerical experiments with alternative selections of assimilation time windows and assimilation rainfall data sources in the MM5-4DVAR system was conducted and their influences on weather forecasts were analyzed.

2. Experiment Design

Because the storms occurred largely during the period of 0000-0300 UTC 06 August 2002 over both Arizona and New Mexico (Figure 1), experiment NO4DVAR represented a standard 12-h model forecast run starting at 2100 UTC 5 August without data assimilation. This experiment was used as a benchmark to compare with other 4DVAR experiments. Six 4DVAR experiments were carried out with different combinations of assimilation windows (3-h or 6-h) and assimilation rainfall data sources (radar or satellite or radar-satellite). All the experiments were conducted at 20-km horizontal space resolution. The six 4DVAR experiments are as follows:

RAD3H: use radar-derived rainfall data and 3-hour assimilation window

SAT3H: use satellite-derived rainfall data and 3-hour assimilation window

BOTH3H: use combined radar-satellite rainfall data and 3-hour assimilation window

RAD6H: use radar-derived rainfall data and 6-hour assimilation window

SAT6H: use satellite-derived rainfall data and 6-hour assimilation window

BOTH6H: use combined radar-satellite rainfall data and 6-hour assimilation window

3. Data

***3*.1 Radar rainfall**: A prototype, real-time, hourly National Preciptation Analysis (NPA) has been developed at NCEP in cooperation with the NWS Office of Hydrology. The multi-sensor product was used in this study. This product is based on radar estimates but has a bias correction using rain-gauge data.

3.2 Satellite rainfall: The system, Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) provides hourly and 0.25° × 0.25° rainfall data (Sorooshian et al., 2000) which were also used for rainfall assimilation.

4. Performance of Rainfall Assimilation

4.1 Rainfall Forecast

In the study case, rainfall was concentrated in the Tucson area during the first 6 hours (from 2100 UTC 05 to 0300 UTC 06) then, the rain center shifted northeastward during the second 6 hours (from 0300 to 0900 UTC 06). In order to show the effectiveness of rainfall assimilation, the rainfall forecasts from the 4DVAR experiments are compared with the NO4DVAR forecasts in these two successive 6-hour periods. In Figure 1, the forecasts of accumulated rainfall for the first 6-h from experiment NO4DVAR, RAD3H, SAT3H, BOTH3H are compared. The results show that the forecast of NO4DVAR did not pick up the correct location of storm: the rainfall center was shifted northeastward to the area close to the Arizona–New Mexico border (Fig. 1). In contrast, all the three forecasts from the 4DVAR experiments improved the rainfall distribution over southeastern Arizona and reduced the substantial overestimation of rainfall amount in the NO4DVA forecast. The rainfall forecasts in the second 6-h period are not shown. The NO4DVAR experiment produced three rainfall centers in southeast Arizona in comparing with only one rainfall center in observations. The rainfall forecasts from the 4DVAR experiments possessed better patterns and reduced rainfall amounts than NO4DVAR did although they were still overestimated. In Figure 2, the curves for rainfall accumulations within the heavy rainfall area (109°-111.5°W, 31.5°-33°N) during the 12-hour forecast are plotted, which shows that all assimilation experiments predicted more precipitation than the observation, but the forecasts made by the 4DVAR runs except for the SAT6H, had smaller errors than the NO4DVAR prediction did.

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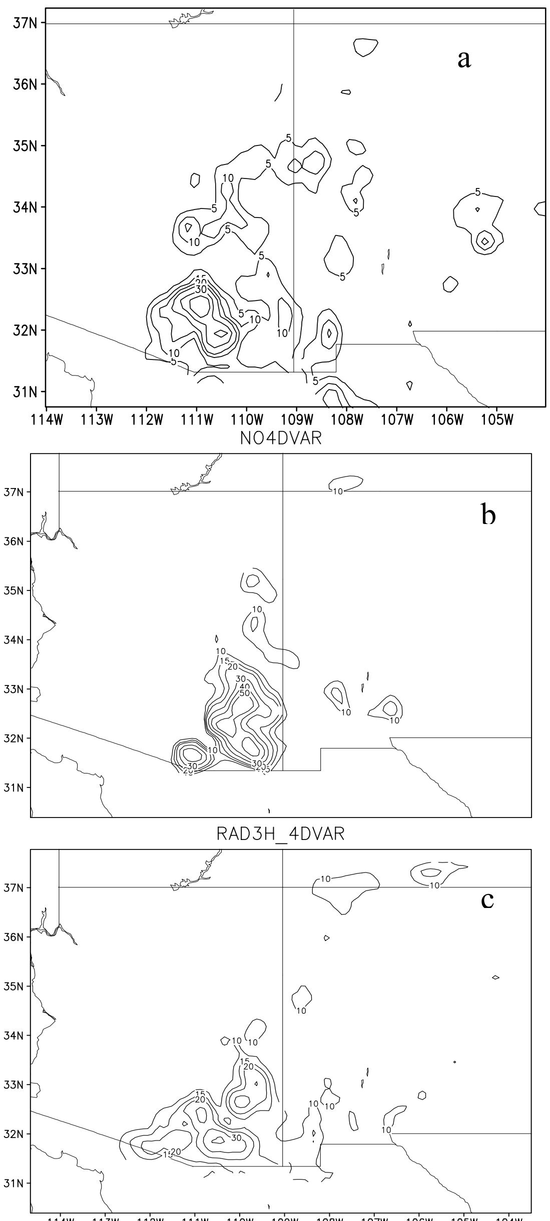

Fig. 1 Six-hour accumulated precipitation of observation and model simulation during the first 6-hour rainfall (from 2100 UTC 05 to 0300 UTC 06 2002) (a) Radar rainfall, (b) NO4DVAR, and (c) RAD3H_4DVAR

4*.2 Sensitivity to assimilation time window*

The statistics showed that for 6-hour rainfall forecasts, using 3-h assimilation window resulted in higher correlation coefficient and lower *RMSE* than using 6-h assimilation window unanimously; however, for 12-h forecasts, an opposite conclusions was displayed: using 6-h assimilation window provided better rainfall forecasts. The results suggest that the 3-h assimilation window worked well for 6-h forecast duration using the MM5-4DVAR system in this study case, while for 12-h or longer forecasts, 6-h assimilation window should be used.

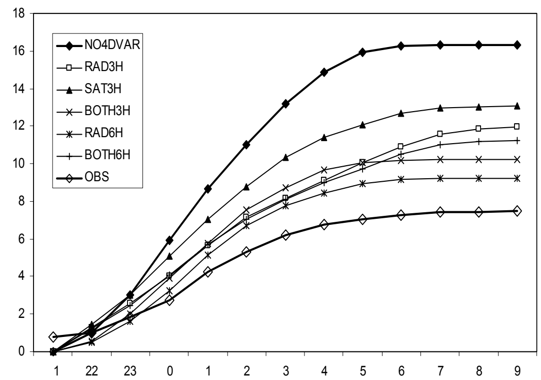

Fig. 2 Time series of accumulated rainfall averaged over the rainstorm center (111.5°-109°W, 31.5°-33°N).

4.3 Sensitivity to the Data Source

Three rainfall data derived from radar, satellite, and combined radar-satellite rainfall estimates are assimilated into the analyses separately. The assimilation experiments with satellite data for 6-h forecast using 3-h assimilation window (Figure 1) and 12-h forecast using 6-h window produced more rainfall than the assimilation experiments with radar data. The results show that the correlation coefficients of 6-h forecast of satellite rainfall assimilation is higher than these of radar rainfall assimilation which indicated that satellite rainfall assimilation can capture better rainfall patterns. However, the higher RMSEs in the forecasts of satellite rainfall assimilation indicated that the satellite rainfall data did not get the right rainfall intensity. In order to avoid the error from different data sources, combined radar and satellite rainfall data were used in the BOTH3H and BOTH6H experiments. Compared to single satellite rainfall assimilation, RMSEs in both experiments were reduced, but it still higher than the radar rainfall assimilation. It indicates that rainfall assimilation can improve rainfall forecast in both amount and pattern; however, the qualification of the assimilation rainfall data has a significant impact on the forecast results.

5. *Optimal Initial Condition*

The 4DVAR system seeks the optimal ICs for numerical weather forecasts by tuning the model ICs to make the prediction match the observed (hourly) data during the assimilation window. In the BOTH3H experiment, three times (2200, 2300, and 0000 UTC) of observed rainfall information were to be matched through the model dynamics and physics from the adjusted physical fields at the initial time (2100 UTC). The differences between the optimal ICs and original ICs are showed in Figure 3.

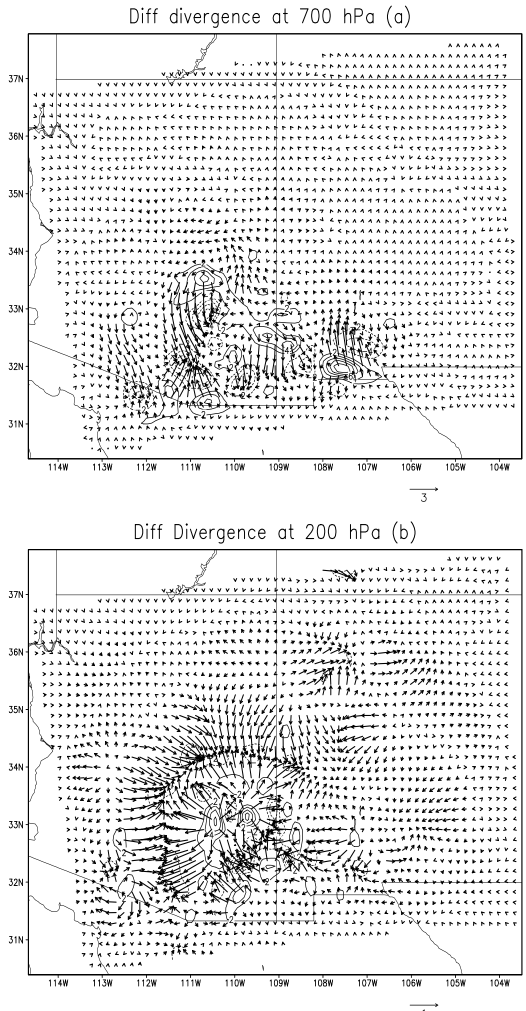

Fig. 3 Difference of initial field between the BOTH3H_4DVAR results and original analysis (NO4DVAR): (a) divergence field (shaded, unit:$10^{-5}s^{-1}$), moisture transport vector (u*q; v*q) (unit: kg/kg*m/s) at 700 hPa, (b) 200 hPa.

The data assimilation resulted in an low-level (700 hPa) divergence (Figure 3a) and an upper-level (200 hPa) convergence (Figure 3b) over eastern Tucson where storms were observed, which indicates that the convergence of moisture flow at the lower level in ICs was reduced and the overestimated rainfall in the NO4DVAR experiment could be corrected.

6. Summary

The minimization procedure of the MM5-4DVAR system worked well in the rainstorm event over a mountainous area of the southwest United States. The effective forecast duration is sensitive to the length of the window. A 3-h assimilation window works for 6-h forecasts at 20-km model resolution. When 12-hour or longer forecasts were made, a 6-h assimilation window was needed. The 4DVAR rainfall assimilation is sensitive to the assimilation data source, which indicates that the quality of observed rainfall data used for assimilation has significant impacts on the improvement of the initial conditions and thereby the forecasts.

7. Acknowledgements

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