JP4.3

IMPACT OF RADAR DATA ASSIMILATION ON THE NUMERICAL PREDICTION OF HEAVY RAINFALL IN KOREA

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1. INTRODUCTION

Heavy rainfall occurs frequently over the Korean Peninsula during the summer season, especially in association with the Changma (East Asian summer monsoon). In light of the fact that Korea suffers significant loss from flooding nearly every year, considerable research has been conducted on heavy rainfall forecasting, especially via numerical simulation. Whereas many studies of heavy rainfall forecasting have been performed successfully, it is difficult to produce operational heavy rainfall forecasts because the most intense convective elements within MCSs (i.e., elements that produce extremely heavy rainfall locally) are relatively small and short-lived. Additionally, the complex topography in Korea makes heavy rainfall prediction an even greater challenge.

Despite the importance of radar data for use in warning and numerical simulations, there remains no effort to include analyzed radar data in the data assimilation cycle of operational weather prediction models in Korea. There are a number of reasons for this, including various limitations in the quality of Korea Meteorological Administration (KMA) radar data and the lack of suitable assimilation techniques. *The first step in bringing Korean radar data into a numerical model for heavy rainfall forecasting has been undertaken within this study. The purpose is to assess the impact of Doppler radar data in the numerical forecast of a heavy rainfall event in Korea*.

In this study, a comprehensive 3-D non-hydrostatic prediction system, the Advanced Regional Prediction System (ARPS) Version 4.5.1, in combination with NEXRAD Level II data gathered by the US Air Force in Pyungtaek, Korea, is applied to the Chorwon-Yonchon heavy rainfall event. The ARPS Data Analysis System (ADAS) incremental analysis updating (IAU) scheme (Brewster 1996, 2001) based on the IAU technique by Bloom et al. (1996), is employed for radar data assimilation.

2. BACKGROUND

a. Overview of IAU

Incremental analysis updating (IAU), which is a type of nudging technique, is designed to gradually incorporate analysis increments into a model integration by using these increments as constant forcings in the prognostic equations over an assimilation period centered on an analysis time (Bloom et al. 1996). Through linear analysis, Bloom et al. showed that IAU has the advantage of serving as a low-pass time filter. They also find that IAU has a particular effect on the response of the model where analysis increments exist, and it leaves the model state unaffected where no data were available to assimilate. Figure 1 shows a simple schematic of the IAU technique.

Although the response functions for conventional nudging are very similar to those for IAU, the relaxation time scale in nudging is more important for damping the overall amplitude and shifting the eigenvalues to larger growth-decay rates than in IAU. Consequently, the IAU scheme adds the analysis increments to the model as a state-independent forcing term to perform the actual filtering only in response to the analysis increments, whereas the entire model state is relaxed toward an analysis in classic nudging (Bloom et al. 1996).

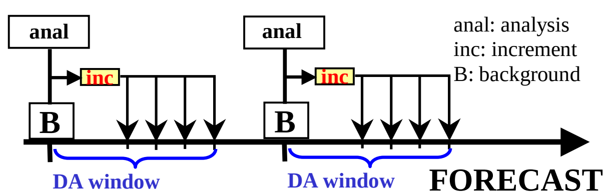

Fig. 1. *Schematic of IAU technique.*

b. The heavy rainfall event in Korea

A heavy rainfall event occurred over the middle part of the Korean peninsula from 26 - 28 July 1996. During this period, total rainfall accumulation exceeded 650 mm in many regions, including the Chorwon-Yonchon area. The storm claimed 29 lives, and property damage exceeded 380 million US dollars. KMA recounts that several mesoscale and synoptic features contributed to the flooding, including: the north boundary of a stationary North Pacific high (NP high) located at the middle of the Korean peninsula; continued strong moisture flux into the middle part of

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the Korean peninsula; and the passage of two upper-air troughs over the Korean peninsula. One feature that also contributed to heavy rainfall was the strong upper level jet that extended from the north part of China to the middle part of the Korean peninsula via the Shantung peninsula, as well as the strong moisture flux at low levels into middle part of the Korean peninsula from the west region of the East China Sea. The most severe flooding occurred in the Chorwon-Yonchon region, and thus the storm is appropriately named the Chorwon-Yonchon heavy rainfall event.

3. EXPERIMENT DESIGN

As shown in Figure 2, one-way nesting is employed with a horizontal resolution of 27-km for the coarse outer grid (99x103x37 points), 9-km for the middle grid (115x139x37 points), and 3-km for the inner fine grid (144x187x37 points). Nine experiments have been conducted, as shown in Table 1, to test the effect of model resolution, impact of radar data and difference between a cold start and data assimilation.

a. Experiment design for 27-km and 9-km resolution forecasts

Initial and lateral boundary conditions for the 27R simulation were provided by the KMA 40-km operational forecasts using the Regional Data Assimilation and Prediction System (RDAPS). The 18-

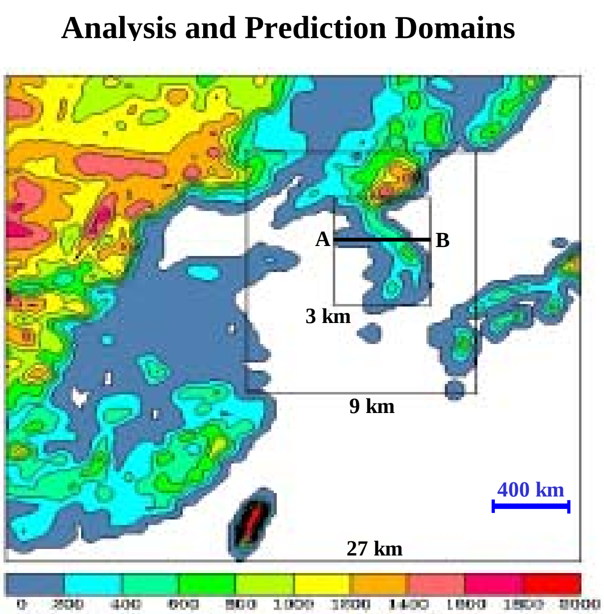

Fig. 2. *The analysis and prediction domains.*

hour forecast initialized at 12UTC July 25, 1996 is employed as a first guess field for the 27R simulation. The 27R run is advanced 21 hours (from 0600 UTC 26 to 0300 UTC 27) using GTS(sfc), AWS (Korea Mesonet), and satellite (both IR and VIS) data at the initial time. The 27R case is not capable of resolving individual convective cells, and the area covered by the one radar is very small compared to the forecast

Table 1. Summary of experiments.

Name	Resolu-tion	Radar	Convective parameterization
27R	27 km	none	Kain-Fritsch
09RNR	9 km	none	Kain-Fritsch
09RYR	9 km	initial field	Kain-Fritsch
09RAR	9 km	12hr assim.	Kain-Fritsch
03RNR	3 km	none	none
03RYR	3 km	initial field	none
03RAR	3 km	12hr assim	none
03RAR1T	Same as in 03RAR but for only one time assimilation		
03RAR20M	Same as in 03RAR but for 20 min. assimilation window		

domain; therefore, no attempt was made to utilize radar data in this case.

The 09RNR case used the 9-hour forecast results from the 27R run as a first guess field and was run for 12 hours from 1500UTC July 26 to 0300UTC July 27. This 12-hour time interval was chosen to coincide with the observed rainfall data. GTS and AWS data were used in ADAS to aid the initial condition for this run (09RNR). The 09RYR test is similar to the 09RNR initialization, with the addition of radar data at the initial time. Results from experiment 09RAR are similar to those from 09RYR, with the exception that radar data were assimilated at hourly intervals from 1500UTC to 1800UTC, July 26. The first guess field for this run is the initial field of 09RYR, in contrast to the 9-hour forecast from 27R, which has been employed in 09RNR and 09RYR. We can expect to learn how radar data assimilation can affect on the forecasts by comparing this result with the result for 09RYR.

In this study, ADAS was run at 1500UTC without IAU. Increments then were calculated at 15:50 using the 1600UTC data, and the ARPS forecast was initialized at 1500UTC. For experiment 09RAR (and 03RAR in 3-km resolution), the increments were introduced in a window from 15:50 to 16:00. Similarly, data at 1700 and 1800UTC were assimilated during the period 16:50 to 17:00 and 17:50 to 18:00UTC, respectively.

b. Experiment design for 3-km resolution forecasts

In the 3-km resolution forecasts, the methodology for runs 03RNR, 03RYR, and 03RAR is exactly same as for 09RNR, 09RYR, and 09RAR, respectively. In all cases, experiment 09RYR provides the first guess field.

In order to determine the impact on forecast quality of the length of the assimilation window and the number of increments used, we conducted other two experiments, 03RAR20M and 03RAR1t, respectively (see Figure 3).

4. RESULTS

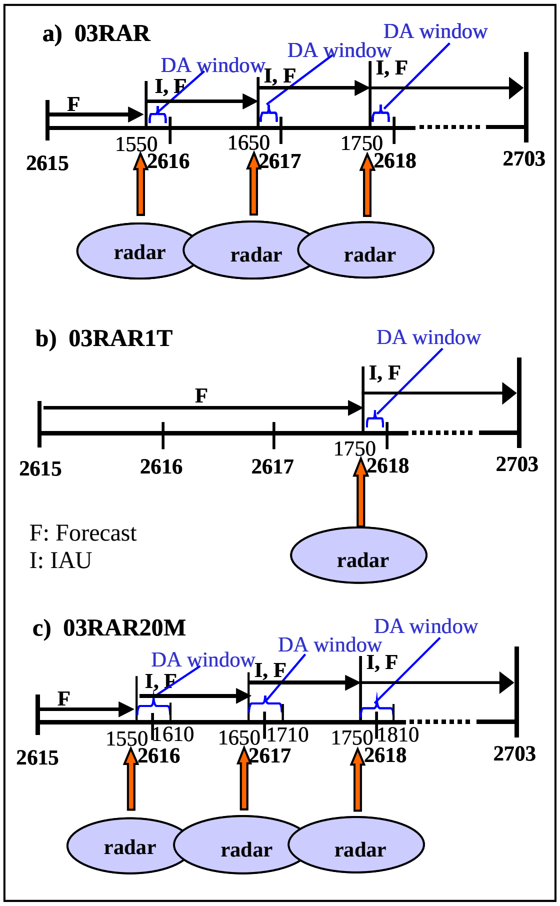

Fig. 3. *Experiment design for radar data assimilation on 3-km resolution forecasts a) 03RAR (3 times and 10 minute assimilation window), b) 03RAR1T (1 time and 10 minute assimilation window), and c) 03RAR20M (3 times and 20 minute assimilation window).*

As shown in the previous study of Yoo et al. (2002), the maximum predicted rainfall in the 9-km experiments is much improved over that in 27-km run. The 27-km performance is typical because such a coarse grid cannot capture intense precipitation events. And, 9-km resolution is still quite coarse to represent deep and strong convection.

The 12-hour accumulated rainfall valid at 03 UTC July 27 for experiments 03RNR, 03RYR, 03RAR, 03RAR1T, and 03RAR20M compared with observations is shown in Fig. 4. The asterisk shows the position of Chorwon, and the position of the maximum rainfall for each experiment is indicated by north end of the bold line. Experiment 03RAR (e) shows the greatest agreement with observations. The distances between Chorwon and the position of the maximum accumulated rainfall for each experiment are calculated and presented in table. *We find significant improvement when radar data assimilation ,especially the experiment using 3 volume scans and a 10 minute assimilation window (03RAR), is applied using 3-km resolution*.

Table 2. Distances between Chorwon and the location of maximum forecasted rainfall position for each experiment.

Exp.	03-RNR	03-RYR	03-RAR1T	03-RAR20M	03-RAR
Dist.	64 km	57 km	51 km	45 km	36 km

As shown in Fig. 4, the observed total rainfall at 12 hours is 167.7 mm, while the results of all experiments show that rainfall is over-predicted despite not using any convective parameterization for the 3-km resolution forecasts. However, the amount of total rainfall in the 3-km run is more reasonable than the results from 9-km run. When we compare the result of 03RAR, which utilized 3 volume scans and a 10 minute assimilation window, with the other experiments, i.e., one volume scan (03RAR1T) and a 20 minute assimilation window (03RAR20M), 03RAR also produces better results. Overall, we find that the assimilation of radar data has a positive impact on the prediction of heavy rainfall at 3-km horizontal resolution, especially in forecasting the maximum rainfall location as compared to the observed maximum.

For the purpose of creating a quantitative verification of the impact of radar data assimilation, RMS errors are examined for the ARPS forecast every 3 hours. As shown in Fig. 5, the results of 03RAR (solid thick line in Fig. 5) are superior, from which we conclude that a 20 minute data assimilation window is too long when only a single volume scan is used. This may be related to the time scale of convective elements. While the RMS errors from the experiments that include radar data assimilation are quite good early in the forecast, those the last 3 hours are not. This suggests that radar data have impact over a finite time period, as would be expected, and this impact likely depends upon the length of the data assimilation window and the number of observations used.

5. FINAL REMARKS

The first step in bringing Korean radar data into a numerical model for heavy rain forecasting has been accomplished successfully. Although the results show some positive impact for radar data assimilation at high spatial resolution (3-km grid spacing), these results are preliminary and represent the most basic tools for radar data assimilation. In order to complete this study, radar data retrieval, assessing the relative value of reflectivity and radial velocity, and quantitative verification, will be conducted in the future.

ACKNOWLEDGEMENT

This study was supported by KMA, METRI, and by the National Science Foundation under Grant ATM99-81130. We thank Dr. Won-Tae Kwon for generously providing the WSR-88D data used in this study.

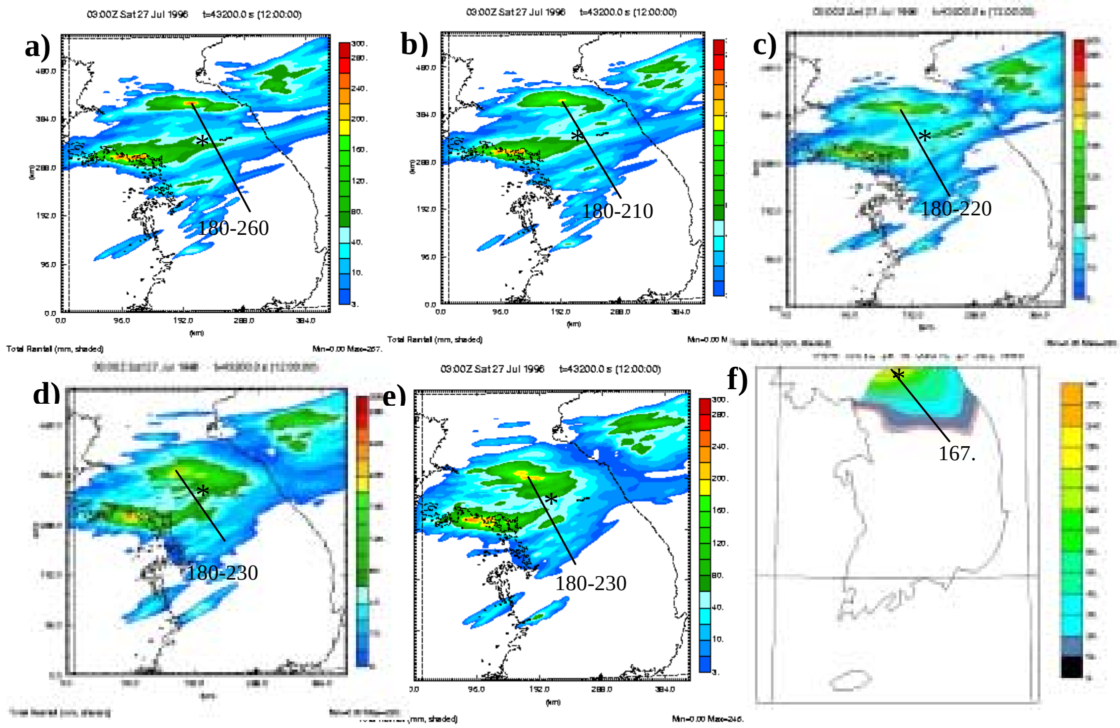

Fig. 4. *12-hour accumulated rainfall in mm for experiments a) 03RNR, b) 03RYR, c) 03RAR1T, d) 03RAR20M, e) 03RAR, and f) observed precipitation from 15UTC July 26 to 03 UTC July 27.*

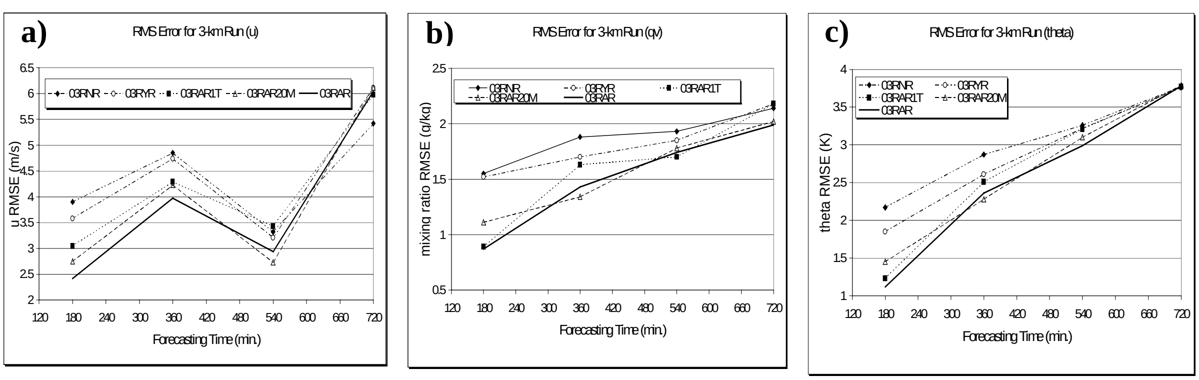

Fig. 5. *RMS Errors for verification for each experiment; ARPS forecasting versus GTS surface and AWS stations in domain a) RMSE for u, b) RMSE for mixing ratio, and c) RMSE for theta.*

REFERENCES

Bloom, S. C., L. L. Takacs, A. M. Da Silva, and D. Ledvina, 1996: Data assimilation using incremental analysis updates. *Mon. Wea. Rev*., **124**, 1256-1271.

Brewster, K., 1996: Application of a Bratseth analysis scheme including Doppler radar data. Preprints, *15th Conference on Weather Analysis and Forecasting*. Amer.Meteor. Soc., Norfolk, VA, 92-95.

_________, 2001: ADAS-ARPS data assimilation using incremental analysis updating. Available from author, CAPS/Univ. of Oklahoma, 4 pp.

Yoo, H.-D., K. K Droegemeier, K. Brewster, S.-Y. Lee, and C.-H. Cho, 2002: Impact of radar data assimilation on the Chorwon-Yonchon 1996 heavy rainfall event: Preliminary Results. *Preprints, The 3rd Korea-US Joint Workshop on Storm and Mesoscale Weather Analysis and Prediction*, Boulder, CO, 157-163.