Assimilation of Multi-Sensor Rainfall Observations for Improved Quantitative Precipitation Forecasts

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1 Introduction

Compared to other meteorological fields, improvement in the forecast skill of quantitative precipitation forecasts (QPFs) has been slow, especially for the summer season (Olson et al., 1995). This could be attributed to uncertainties in model physical parameterizations and initial conditions. With a rapid increase in the amount of observations and the advanced techniques of data assimilation (e.g., 4D-Var), the forecast skill of QPFs is expected to improve by making use of these data.

Some initial efforts have been made for the assimilation of precipitation observations by Zou and Kuo (1996), Zupanski, D. and Mesinger (1995), and Xiao et al. (2000). In their studies, the 3-hr or 12-hr accumulated rainfall were incorporated into a numerical model via 4D-Var. It was shown that improvement in QPFs can been expected from rainfall assimilation. Studies on the assimilation of rainfall and the impact on rainfall observations using adjoint techniques are, however, limited to a few cases.

In this study, hourly multi-sensor rainfall data from the National Centers for Environmental Prediction/Climate Prediction Center (NCEP/CPC) will be used for both data assimilation and evaluation of the model physics over an ensemble of Spring and Summer precipitation cases. The NCEP/CPC rainfall observations are available at 4-km resolution and are generated by combining approximately 3000 automated hourly raingage observations available over the contiguous 48 states with the radar precipitation estimates from the Next Generation Weather Radar (NEXRAD) network. These are probably the best rainfall data set available for studying problems associated with the use of precipitation observations for numerical weather prediction over the United States.

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2 The first experiment

The numerical forecasting model used here is the Penn State/NCAR MM5. It is a limited-area, nonhydrostatic primitive equation model with multiple options of physical parameterization schemes (Dudhia 1993). The version used for this study includes high resolution planetary boundary layer parameterization, surface friction, the grid-resolvable scale precipitation, and Kuo-cumulus parameterization scheme. The MM5 adjoint model was developed by Zou et al. (1997). The same set of model physics was used in the forward MM5 model and the adjoint model.

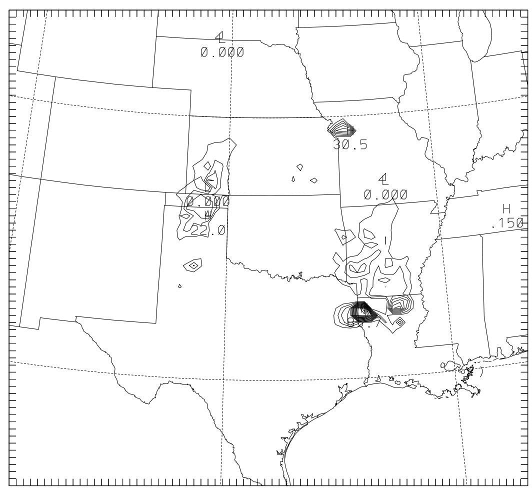

Figure 1: The 6-hr accumulated observed precipitation (unit: mm) from NCEP/CPC from 00 to 06 UTC 5 April 1999.

The case chosen for the first experiment is the squall line case that occurred over Oklahoman and Texas from 00 UTC 5 April 1999 to 00 UTC 7 April 1999. The center of the model domain is (35N, 98W). The grid dimensions are 68X74X27, with a horizontal resolution of 30 km.

The initial condition from the standard MM5 analysis based on the NCEP analysis at 00 UTC

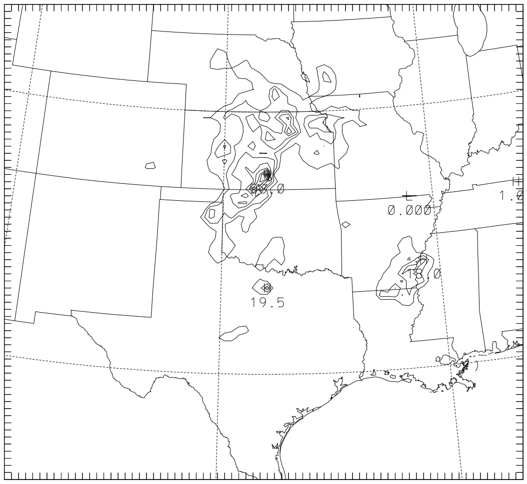

Figure 2: Same as Fig. 1 except from 06 to 12 UTC 5 April 1999.

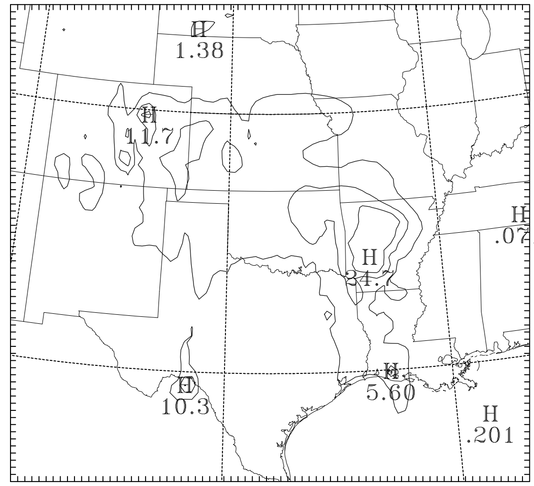

Figure 3: The 6-hr accumulated precipitation (unit: mm) from 00 to 06 UTC 5 April 1999 from the control experiment.

5 April 1999 was used to carry out a control experiment. Figures 1-4 show the observed and predicted 6-h precipitation. After the initial 6-h, a line-pattern of precipitation is observed over Texas, Oklahoma, and Kansas (Fig. 1). The model didn't catch this rainfall pattern (Fig. 3). It produced rain over the north Colorado and south Texas instead. The subsequent 6-h precipitation pattern produced by the control experiment (Fig. 4) is also very different from the observed one (Fig. 2). The model precipitation covered a much larger region. The model produced rain maxima over eastern Colorado and southern Texas where there was no observed precipitation. The simulated rain maximum over northern Arkansas is larger than observations located in southern Arkansas.

The hourly multi-sensor rainfall data during the 3-hr assimilation window from 00 UTC to 03 UTC 5 April 1999 (Fig. 5) were incorporated into the model. The model produced 3-h accumulated rainfall obtained before and after the 3-h precipitation assimilation are shown in Figs. 6 and 7. The initial 3-h rainfall amount associated with the squall line over the west-northern Oklahoma is only half of the observed amount. The rainfall assimilation is able to increase the rainfall amount to that of observations. What will be the impact of this change of the amount of the initial rainfall to the QPFs?

The 6-h accumulated rainfall with and without data assimilation are shown in Fig. 8 and 9. Compared with observations (Figs. 1 and 2) and control experiment (Figs. 3 and 4), improvement in the precipitation forecast is observed, with an increased amount of rainfall over north-east Kansas

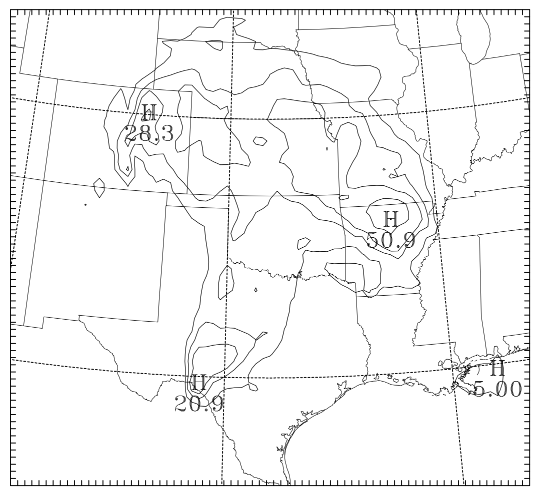

Figure 4: Same as Fig. 3 except from 06 to 12 UTC 5 April 1999.

and a reduced amount of rainfall over northern Arkansas. The predicted precipitation over northeastern Kansas is closer to the observations, and the unrealistically heavy precipitation over northern Arkansas is reduced. The false precipitation over eastern Colorado and southern Texas remains in the model prediction since no-rain information is not incorporated in this experiment.

Due to the errors in observations and the inconsistency between the model and observations, some high frequency gravity-wave oscillations can be introduced by the assimilation of the rainfall observations. In order to remove these undesired gravity-wave oscillations, a digital filter (Lynch and

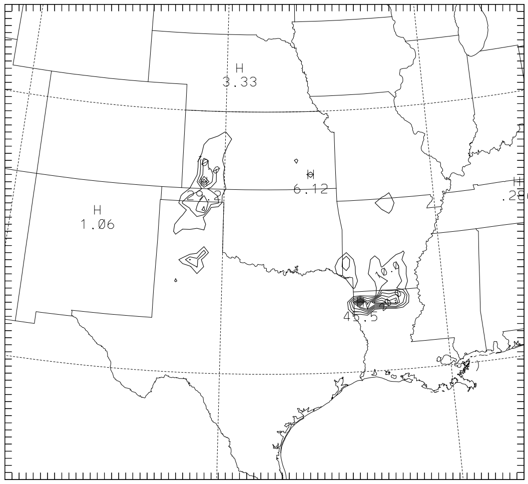

Figure 5: The 3-hr accumulated precipitation (unit: mm) from NCEP/CPC (upper panel) ending at 03 UTC 5 April 1999 from the control experiment.

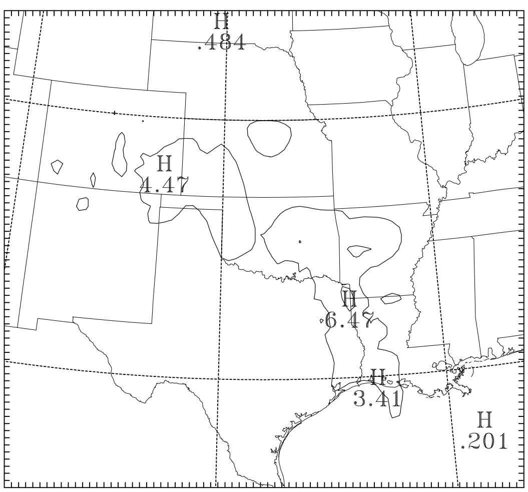

Figure 6: Same as Fig. 5 except for model prediction without data assimilation.

Huang 1992) is applied to the "optimal" initial condition after data assimilation. Figure 10 shows the averaged (absolute) surface pressure tendency for the control run and the data assimilation experiment with and without digital filter. It can be seen that the assimilation of rainfall observations did introduce high frequency gravity-wave oscillations, which were removed after the digital filter had been applied.

3 Summary

The case study conducted above shows that (i) improvement in QPF can be obtained through assim-

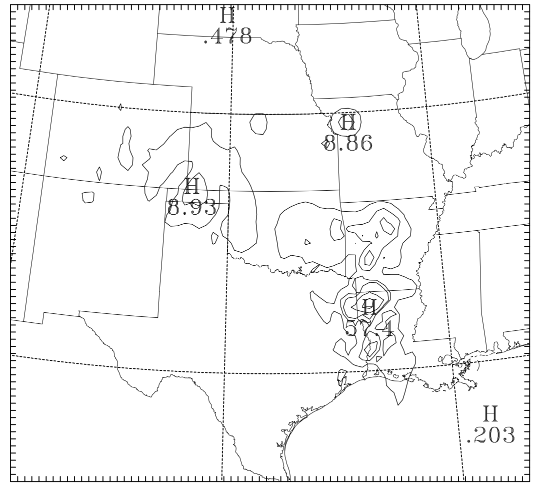

Figure 7: Same as Fig. 5 except for model prediction with data assimilation.

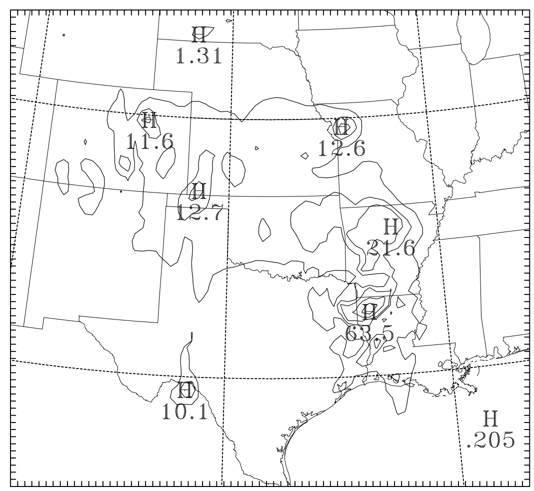

Figure 8: The 6-hr accumulated precipitation from 00 to 06 UTC 5 April 1999 after rainfall assimilation (unit:mm).

ilation of the multi-sensor rainfall observations over areas where there were observed precipitation; and (ii) the assimilation of rainfall observations could introduce high frequency gravity-wave oscillations. These oscillations can be removed by applying a digital filter.

Areas for further improvement of QPF include

1. Force the model to produce no rain over areas where there is no observed precipitation. This can be carried out by including $R^{obs} = 0$ in the cost function over all the grid points where the observations from the hourly multi-sensor rainfall data from NCEP/CPC indicate lack of precipitation.

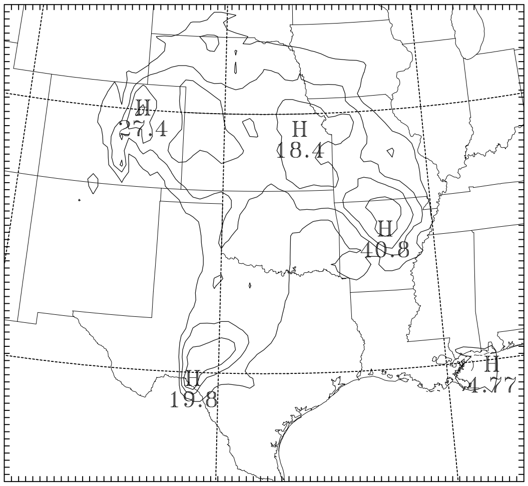

Figure 9: Same as Fig. 8 except from 06 to 12 UTC 5 April 1999 after rainfall assimilation (unit:mm).

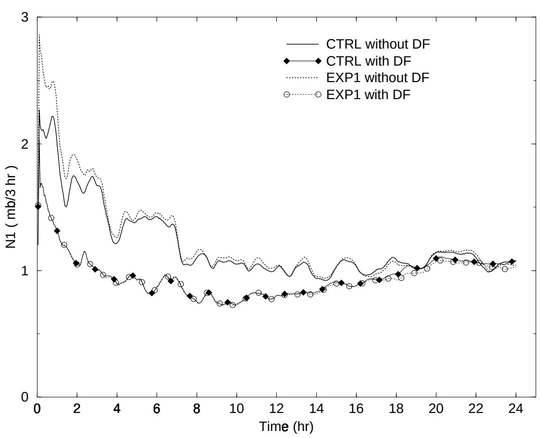

Figure 10: Averaged (absolute) surface pressure tendency with and without digital filter (DF, Lynch and Huang, 1992). CTRL: the MM5 standard analysis is used as initial condition. EXP1: the "optimal" initial condition obtained by rainfall assimilation (unit: mb/3 hr).

2. Introduce additional constraint, such as the amount of precipitable water, into the rainfall assimilation. This is important to reduce the uncertainty in adjusting 3-dimensional variables of temperature and moisture from 2-dimensional rainfall data.

3. Test a new scheme for assimilating the rainfall observation through 4D-Var. One proposal is to use the rainfall observations to adjust the vertical profile of moisture over areas where $R_{\rm model} > 0$, $R_{\rm obs} \geq 0$ and adjust the vertical velocity where $R_{\rm model} = 0$, $R_{\rm obs} > 0$ (where $R_{\rm model}$ and $R_{\rm obs}$ are simulated and observed precipitation). Another proposal is to use the rainfall observations to adjust model parameters involved in the formulation of moist physical parameterization schemes, instead of the initial condition.

4. Carry out the rainfall assimilation over an ensemble of Spring and Summer precipitation cases.

Results from these experiments will be presented at the conference.

Acknowledgment

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