12.3 Cloud/Hydrometeor Initialization in the 20-km RUC Using Radar and GOES Data

Dongsoo Kim*, Stanley G. Benjamin and John M. Brown

NOAA Research – Forecast Systems Laboratory and
*Also affiliated with Cooperative Institute for Environmental Sciences
Boulder, CO 80305 USA
* (email – dkim@fsl.noaa.gov)

1. INTRODUCTION

Toward the goal of improved short-range forecasts of cloud/hydrometeors, icing, and precipitation, an advanced version of the Rapid Update Cycle (RUC) cloud-top pressure assimilation technique has been developed and tested. This improved technique, using GOES single field-of-view cloud-top pressure data provided by NESDIS, was implemented into operations at the National Centers for Environmental Prediction (NCEP) along with a major upgrade to the RUC including 20-km horizontal resolution on 17 April 2002 (RUC20, Benjamin et al. 2002)

In this paper, we present more recent modifications to the RUC cloud/hydrometeor analysis technique using GOES cloud-top data (Kim and Benjamin 2001) as well as initial experiments toward assimilation of radar reflectivity.

2. BACKGROUND FOR CLOUD INITIALIZATION WITH GOES DATA

The RUC20 uses a bulk mixed-phase cloud microphysics scheme from the NCAR/Penn State MM5 model, with 5 hydrometeor types explicitly forecast (Brown et al. 2000). The prognostic variables in this scheme are mixing ratios of water vapor, cloud water, rain water, ice, snow, and graupel, and number concentration of ice particles. Each of these variables is explicitly forecast at each 3-D grid point in the RUC model.

An improved version of the RUC/MM5 mixed-phase cloud microphysics scheme was implemented with the rest of the RUC20 at NCEP. This improved version provides more realistic forecasts of supercooled liquid water and reduces unrealistically large amounts of graupel.

Previously in the 40-km RUC (called RUC2), the initial conditions for the hydrometeor fields were simply those carried over from the previous 1-h RUC forecast. In the RUC20 which includes assimilation of GOES cloud-top data, these fields are modified each hour as part of the cloud clearing and cloud building process.

The RUC20 cloud/hydrometeor technique is an advanced version of the technique previously described by Kim and Benjamin (2001). GOES cloud-top pressure gives information about where clouds are present or are not present, but no information on cloud depth. Also, unless there is at least broken cloud coverage, it cannot provide information on multiple cloud layers. The RUC cloud/hydrometeor assimilation technique is designed to use this partial information. When GOES data indicate that no clouds are present, the technique removes any hydrometeors and reduces the water vapor mixing ratio to a subsaturation value. When GOES data indicate that clouds are present that are not in the RUC 1-h forecast at the correct level, cloud water and/or ice is added in a layer of not more than 50 hPa depth. This layer is also saturated with respect to water or ice with a linear variation between these two saturation vapor pressure values in the 248-263 K range.

3. RECENT MODIFICATIONS FOR ASSIMILATION OF GOES CLOUD-TOP PRESSURE

Recent changes to the RUC cloud/hydrometeor analysis technique include the following (Benjamin et al. 2002):

- Rederivation of cloud-top pressure from GOES cloud-top temperature if the original retrieval of cloud-top pressure is greater than 620 hPa. This rederivation of the cloud-top pressure uses the RUC 1-h temperature/moisture profile at the nearest grid point.
- Use of single field-of-view GOES data (~10-km resolution) instead of the previous 3x3 retrievals (~40-km resolution). The median values from the fields-of-view around each RUC box are used. Cloud fraction is calculated with this sampling into RUC grid volumes.
- Use of stability check to identify possible sub-field-of-view variations from small convective clouds that result in inaccurate cloud-top temperature and pressure determination.
- Remove cloud indicators if they only occur at isolated (noncontiguous) RUC grid points, again on the presumption that GOES may be observing sub-field-of-view clouds.
- Special handling for marine stratus situations to force cloud-top at a consistent level with top of marine inversion in RUC background profile.

4. ASSIMILATION OF RADAR REFLECTIVITY DATA

The hourly GOES cloud-top data assimilation described in sections 2 and 3 improves the 3-D hydrometeor distribution in the RUC analyses, but for cloud building, its impact is limited to adjusting the top layer of hydrometeors. Therefore, we have extended the hydrometeor assimilation in a test version of the RUC which also assimilates real-time NEXRAD reflectivity data (Kim and Benjamin 2001). FSL is testing assimilation of data from real-time reflectivity mosaics from Weather Services International (WSI) and NWS (Fig.1). The WSI reflectivity data, called NOWRAD®, are manually edited 2-km resolution maximum reflectivity data. The NWS radar-coded messages (RCM) are 10-km resolution data with an automatic QC procedure applied. As seen in Figure 1a, WSI reflectivity has improved the dynamic range but no distinction between no-echo and no-coverage,

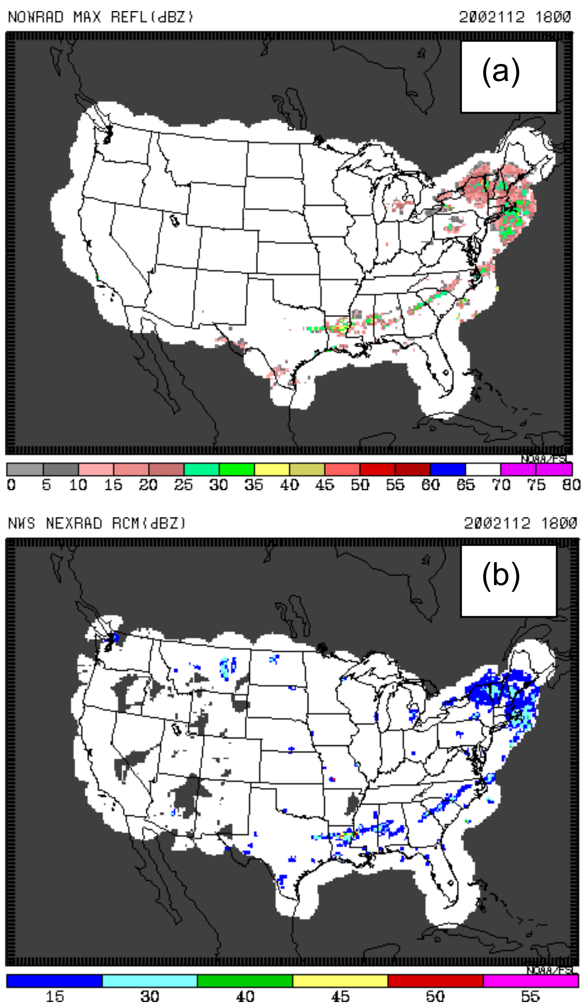

Fig.1 Reflectivity data from WSR-88D radars. a) Processed by WSI with manual editing, b) Provided by NWS with automatic QC. NWS RCM show beam shadows due to topography.

while RCM (Fig. 1b) shows no-coverage area.

Within the area of reflectivity data coverage by NWS RCM, the initial RUC radar assimilation technique adjusts mixing ratios of rainwater, ice, snow, and graupel such that maximum reflectivity (dBZ) of the column is close to the WSI maximum reflectivity. This process critically depends on the predicted hydrometeor distribution and the forward model. Since the vertical level of observed reflectivity is not known, the predicted level, if one is available at this grid point, is used. If the observed reflectivity is greater than 20 dBZ, then precipitation is assumed reaching the ground. If the model has failed to predict any hydrometeors at this grid point, rain or snow mixing ratios, depending on temperature, are set consistent with observed reflectivity in the lowest 200 hPa above the ground. If the model predicts any hydrometeors, then the model predicted maximum reflectivity level is used to add hydrometeors down to the surface. In the case of mixed species, the reflectivity for each species is calculated from the predicted profiles, and then the mixing ratios of each species are adjusted according to relative contributions among four species. The forward model for reflectivity data is based on Rogers and Yau (1989):

$$Y = c\log_{10}[b\sum_{j} a_j Q_j], \qquad (1)$$

where c is 17.8, b is 264083.11 and a_j are coefficients assigned to species of rain water, ice, snow and graupel (1, 0.2, 0.2, 2.0 respectively), Q_j is the mixing ratio in g/g for i^{th} species, and *Y* is reflectivity (in dBZ).

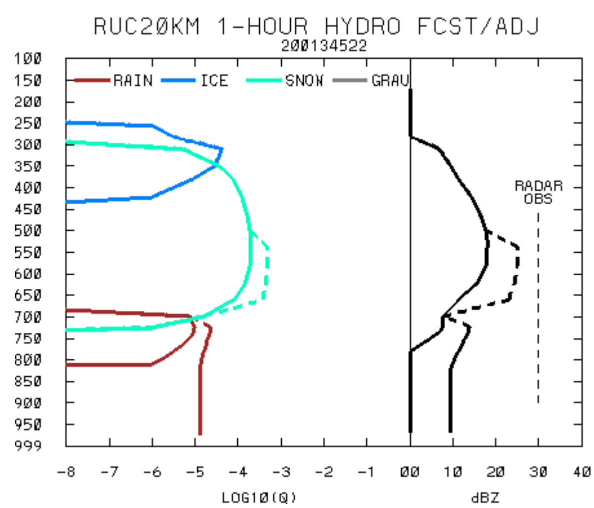

Fig.2 An example of adjustments of species of rain, ice and snow mixing ratios given reflectivity data (OBS) and vertical distribution of total reflectivity. Solid lines - first guess, and dashed - adjusted. This example shows only snow and rain mixing ratios are modified in order to fit the first guess reflectivity(18 dBZ) to 30 dBZ of observed reflectivity. The y-axis is height in hPa, x-axis in the left is mixing ratio in log(g/g), and x-axis in the right is reflectivity in dBZ.

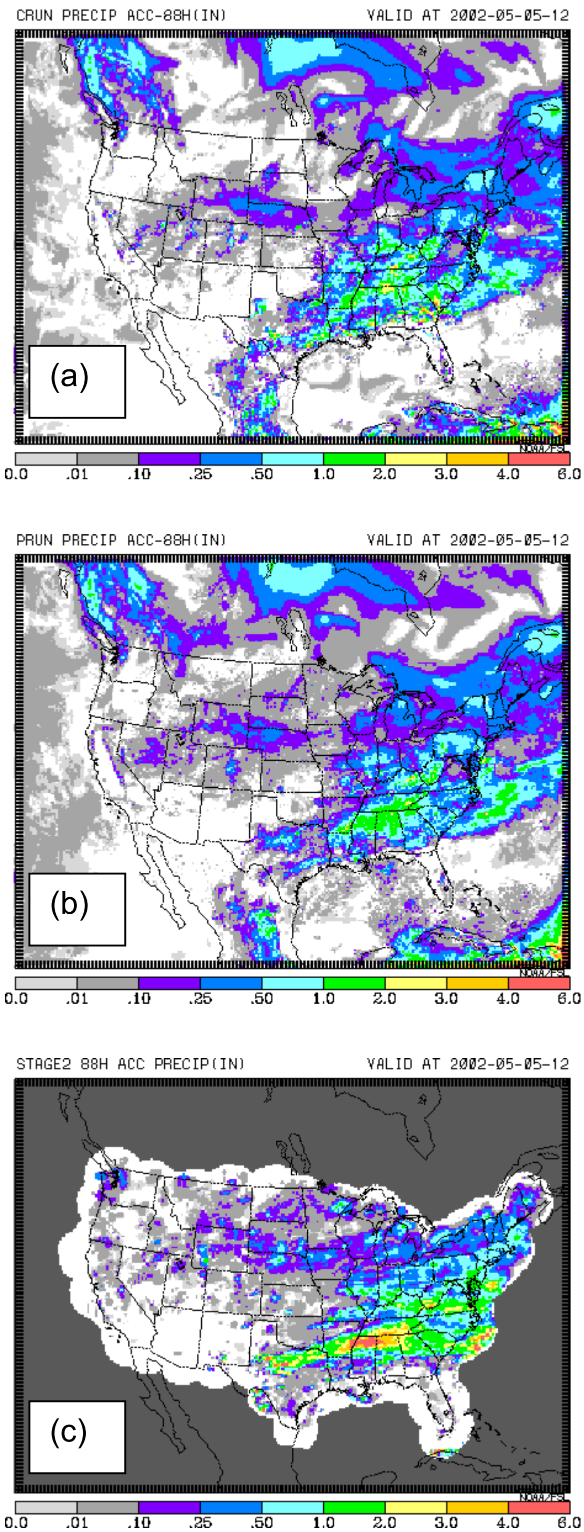

Fig.3 An 88-h accumulation of precipitation for the period ending 0600 UTC 28 April 2002 from (a) control run, without radar reflectivity assimilation, (b) from parallel run with radar reflectivity, and (c) Stage II precipitation amounts. Forecast amounts are for 88 consecutive 1-h forecasts from RUC cycles.

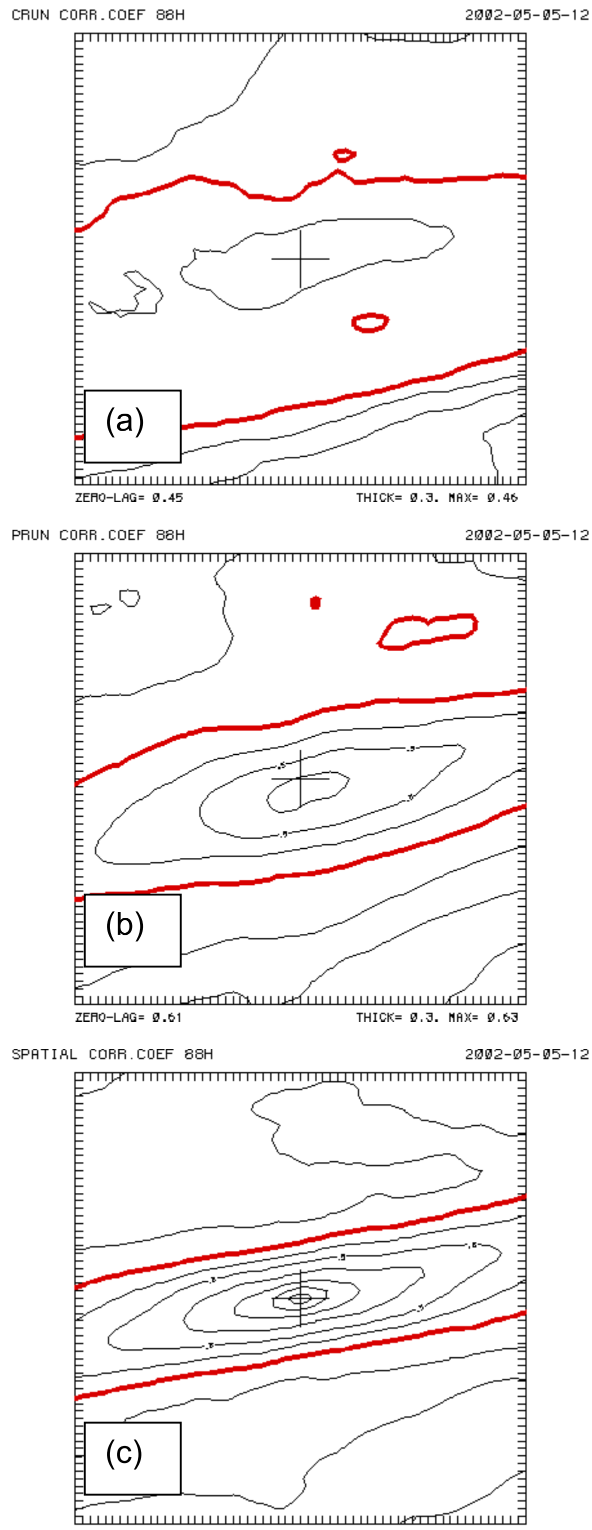

Fig.4 Spatial cross-correlation contours between Stage II QPE and forecast QPF for (a) 88-h parallel run, (b) 88-h control run, and (c) spatial auto-correlation of 88-h QPE. The maximum values are 0.63 for parallel run with radar reflectivity assimilation, and 0.46 for control. Thick contours are 0.3.

5. PARALLEL EXPERIMENT AND PRECIPITATION VERIFICATION

In April 2002, a parallel cycle of the RUC20 was started with hourly radar reflectivity assimilation. Since the cloud-top assimilation is already implemented in the operational RUC20 without radar reflectivity assimilation, it is used as the control experiment. The NCEP Stage II hourly quantitative precipitation estimation (QPE) (Baldwin and Mitchell 1997) is used to verify precipitation forecasts. The Stage II precipitation data are at 4-km resolution and are derived from both NEXRAD reflectivity and gauge observations. The original 4-km resolution Stage II precipitation data are remapped to the RUC20 grid by taking the maximum value in the grid box to represent the grid point. Figures 3a and b are examples of accumulated forecast precipitation from a sequence of 1-h forecasts in RUC20 assimilation cycles over an 88-h period. Figure 3a is from the control run (without radar reflectivity assimilation) and Fig. 3b is from the parallel run. These were compared with NCEP's Stage II precipitation data derived from WSR-88D reflectivity and rain gauge data over the same 88-h period (Fig. 3c). A spatial correlation field was computed as a measure of precipitation verification (Webster and Oliver 2001). The spatial cross-correlation is a function of x-y displacement between two fields, QPF and QPE within a predetermined evaluation window (60 x 60 grid points on a 20-km grid). Figures 4a and b are corresponding spatial cross correlation contours. The distance of maximum correlation to the center (zero displacement) is a measure of QPF phase error, and the maximum value of correlation coefficient provides an approximate measure of forecast accuracy modulated by spatial variability of rainfall amount. The shape of the contours gives information on the directional dependency of precipitation forecast accuracy.

The two contour fields were compared with the spatial auto correlation field (Fig. 4c), which is computed from QPE against itself. The preferred orientation of reflectivity during this period is evident, with strong anisotropy oriented from WSW to NNE. The spatial patterns also depend on the duration of accumulation. As an overall assessment, better QPF should result in a QPF-QPE correlation pattern similar to that of the spatial auto correlation. In the example shown in Fig 4, the maximum value of cross correlation coefficient of parallel run (with radar reflectivity assimilation) is 0.63, better than 0.46 for the control run (without radar reflectivity assimilation) indicating that the QPF error in the parallel run is reduced from that of the control run. Also, the contour lines of the parallel run result are better defined, suggesting that its spatial scales and directional orientations are more accurate than those of the control run in this case.

6. SUMMARY

We have discussed preliminary results of NEXRAD reflectivity data assimilation into a test version of the RUC20 model and assimilation system. Despite quality problems with radar reflectivity data, a RUC20 experiment with hourly assimilation of radar reflectivity shows improvement of the QPF over a control experiment without radar reflectivity data. This case suggests that there is very useful information content in the NEXRAD reflectivity data for improving short-range forecasting. It is planned to have routine assessment of QPF based on spatial correlation as well as threat scores.

7. ACKNOWLEDGMENTS

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