

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

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## 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, now using GOES single field-of-view cloud-top pressure data provided by NESDIS, is being implemented into operations at the National Centers for Environmental Prediction (NCEP) along with a major upgrade to the RUC in April 2002. The new version of the RUC, called RUC20 (Benjamin et al. 2002), also includes a change in horizontal resolution from 40 km to 20 km and significant changes to the analysis and model forecast components.

Previous versions of the RUC technique for assimilation of GOES cloud-top pressure have been reported on by Kim and Benjamin (2001, 2000). In this paper, we present more recent modifications to the RUC cloud/hydrometeor analysis technique using GOES cloud-top data as well as initial experiments toward assimilation of radar reflectivity.

## 2. RUC MIXED-PHASE CLOUD MICROPHYSICS AND CYCLING OF CLOUD/HYDROMETEOR FIELDS

The 20-km RUC uses a bulk mixed-phase cloud microphysics scheme from the NCAR/Penn State MM5 model, with five 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 three-dimensional grid point in the RUC model. This approach is different (and more complicated) than diagnostic mixed-phase schemes in which total condensate is the only prognostic variable, such as the schemes used in the NCEP Eta model.

An improved version of the RUC/MM5 mixed-phase cloud microphysics scheme is being 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 (see Fig. 3, Benjamin et al. 2001).

Previously in the 40-km RUC-2 (RUC40), the initial conditions for the hydrometeor fields were simply those carried over from the previous 1-h RUC forecast. Since the RUC20 includes assimilation of GOES cloud-top data, these fields are modified each hour as part of the cloud clearing and cloud building.

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

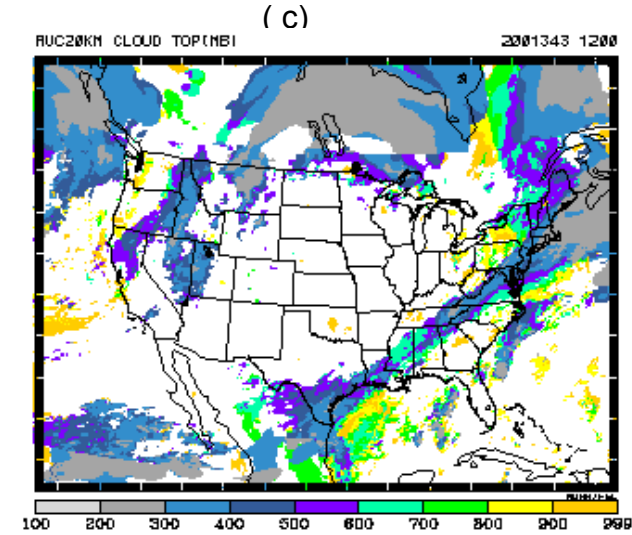
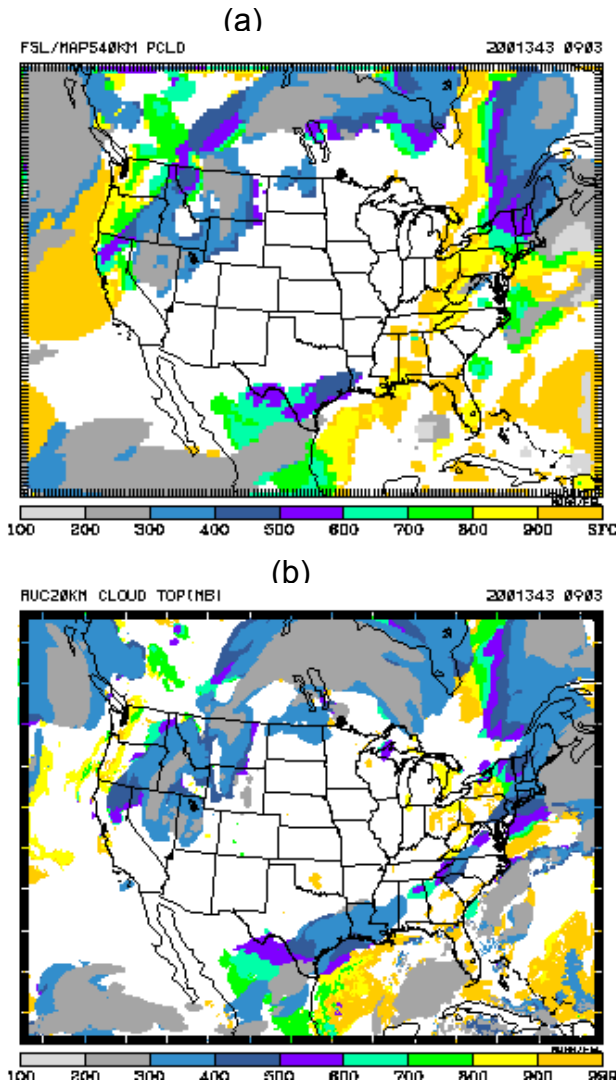
The RUC20 cloud/hydrometeor technique is an advanced version of the techniques previously described by Kim and Benjamin (2001, 2000). GOES cloud-top pressure gives information on where clouds are or are not, but not on cloud depth. Also, unless there are broken layers, it cannot provide information on multiple cloud layers. Thus, the RUC cloud/hydrometeor assimilation technique is designed to use this incomplete information. When GOES data indicate that no clouds are present, the technique removes any hydrometeors and reduces water vapor mixing ratio to a subsaturation value. When GOES data indicate that cloud is present that is not in the RUC 1-h forecast at the correct level, cloud water and/or ice is added in a layer not exceeding 50 hPa depth. The water vapor mixing ratio in this layer is saturated. A linear variation of the saturation vapor pressure over water and ice is employed when the temperature is 248-263 K, with ice saturation at temperatures below this range and water saturation at temperatures above.

Recent changes to the RUC cloud/hydrometeor analysis technique include the following:

- Rederivation of cloud-top pressure from GOES cloud-top temperature and RUC 1-h temperature profile at nearest grid point if the original retrieval of cloud-top pressure is greater than 620 hPa.
- 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 grid box are used. Cloud fraction is calculated with this sampling into RUC grid volumes for later use in cloud building/clearing criteria.

- Use of stability check to identify possible sub-field-of-view variations from convective clouds that result in inaccurate cloud-top temperature and pressure determination.
- Removal of cloud indicators if they only occur at isolated (non-contiguous) RUC grid points, again on the presumption that GOES may be observing sub-field-of-view clouds (e.g., convective clouds).
- Special handling for marine stratus situations to force cloud top to be consistent with top of marine inversion in RUC background profile.

An example of improvement in RUC cloud-top pressure forecast is presented in Fig. 1. The RUC40 3-h cloud-top forecast (Fig. 1a) shows some skill compared to the NESDIS verification product (Fig. 1c). However, the 3-h forecast from the RUC20, including hourly GOES cloud-top assimilation, shows much more accuracy overall, including removal of cloud off the US West Coast and over the eastern US, and a more coherent structure of the frontal cloud band extending from Texas through New Jersey.



**Figure 1. Cloud-top pressure (hPa) valid at 1200 UTC 9 Dec 2001. a) RUC40 3-h forecast, b) RUC20 3-h forecast, c) analysis using NESDIS data at 1200 UTC.**

FSL routinely computes statistics of differences between GOES cloud-top pressure and the RUC40 and RUC20 forecasts (1,3,6,9,12 h) every 3 hours. The predicted cloud-top from RUC is estimated by the combined hydrometeor mixing ratio threshold value of  $10^{-6}$  g/g. Contingency tables (not shown here) of cloud vs. clear and the RUC forecast vs. GOES are routinely examined. For each category of the 2x2 contingency table, we compute bias, standard deviation, correlation coefficients, and lagged autocorrelation coefficients. The most useful summary verification product has been the correlation coefficient between RUC forecasts and GOES values. Display of correlation coefficients in time-series has been very useful to understand temporal variations in cloud forecast accuracy.

Figures 2a,b show the correlation coefficient between the NESDIS GOES cloud-top pressure product and cloud-top pressure forecasts from the RUC40 and RUC20. The RUC20 shows higher cloud-top forecast accuracy at all forecast projections from 1 h to 12 h. This forecast improvement in the RUC20 is attributed to both the GOES cloud-top assimilation and model improvements.

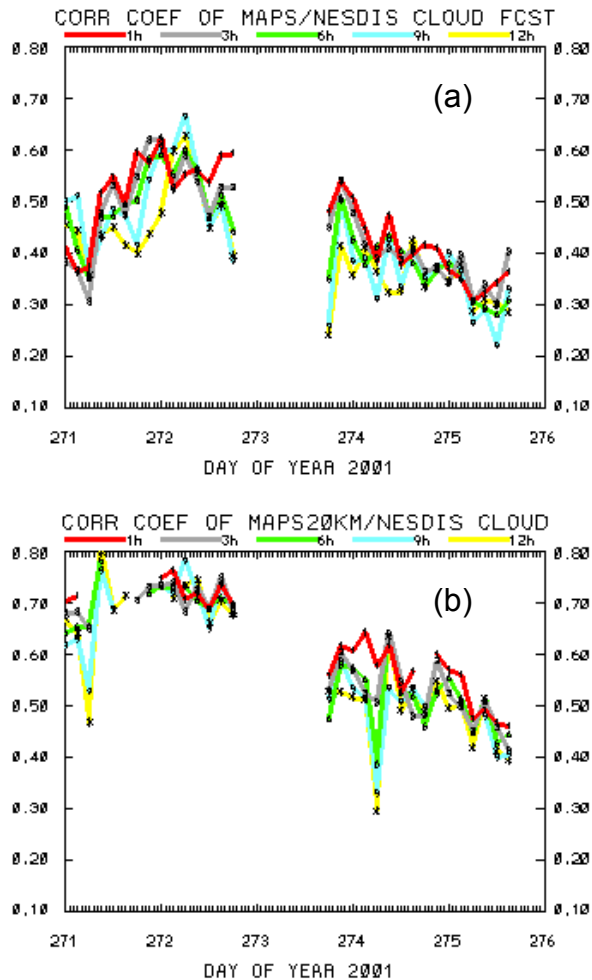


Figure 2. Cloud-top pressure forecast verification time series for 29 Sept – 2 Oct 2001. Correlation coefficient (y-axis) between forecast and NESDIS cloud-top pressure product for forecasts from 1-12 h for a) RUC40 and b) RUC20.

#### 4. ASSIMILATION OF RADAR REFLECTIVITY DATA

Testing has started at FSL toward assimilation of radar reflectivity into the RUC to augment the assimilation of GOES cloud-top pressure data. Data sets examined include a real-time 2-km resolution reflectivity mosaic from WSI (Weather Services International) and a 10-km resolution Radar Coded Message (RCM) from NWS. Both are processed for each 20-km RUC gridpoint. While the WSI reflectivity data provide higher resolution, the RCM data provide beam blockage area information that helps to differentiate “no echo” from “no coverage”.

Initial experiments with reflectivity data assimilation have been performed by adjusting the background (1-h forecast) mixing ratio profiles of rain water, ice, snow, and graupel, such that the maximum reflectivity

(dBZ) of the column is close to the WSI maximum reflectivity. The forward model for reflectivity data is based on Rogers and Yau (1989):

$$Y = c \log_{10} [b \sum_j a_j Q_j], \quad (1)$$

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 mixing ratio in g/g for  $i^{th}$  species, and  $Y$  is reflectivity (in dBZ). The procedure critically depends on the predicted hydrometeor distribution and the forward model. Since the level of maximum reflectivity is not known from these observational data sets, initial tests have used the predicted level. The reflectivity for each species from the predicted profiles is first calculated from the forward model, and then the mixing ratio of each species is adjusted according to the relative contributions among the four species.

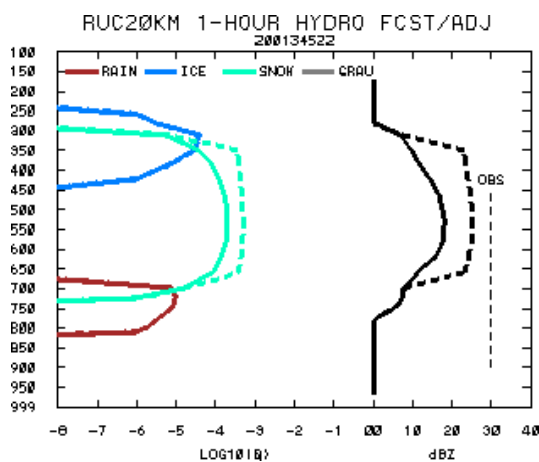


Figure 3. Adjustment of RUC hydrometeor profiles based on radar data at Lamont, OK at 2200 UTC 11 Dec 2001.

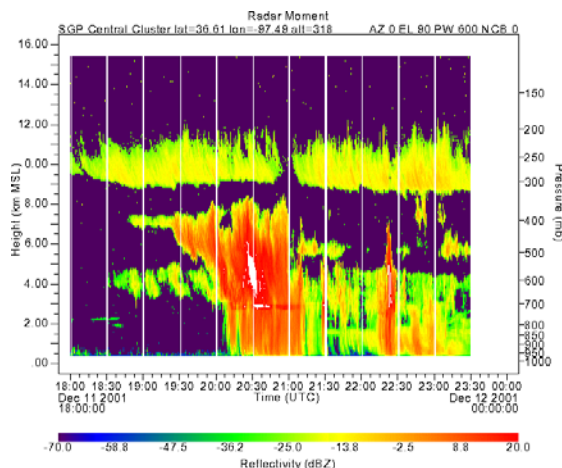
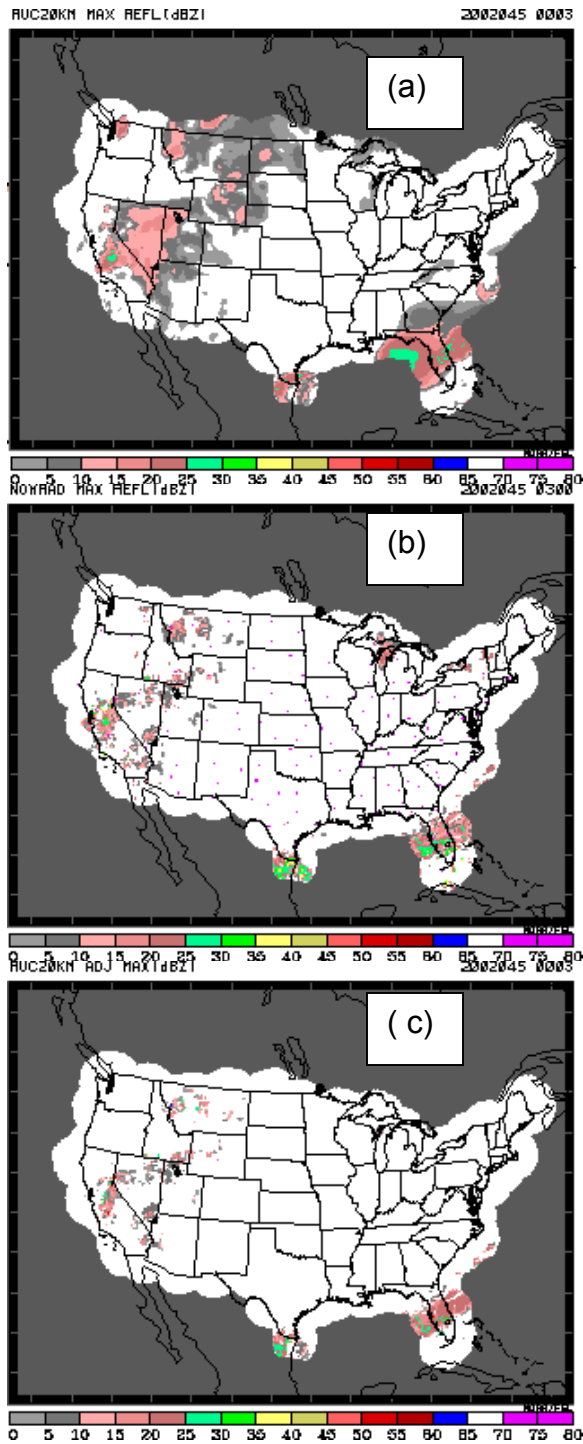


Figure 4. Cloud lidar observations from ARM/CART site at Lamont, OK, from a 6-h period starting 1800 UTC 11 Dec 2001.



**Figure 5. Radar reflectivity valid at 0300 UTC 14 Feb 2002 from a) RUC20 3-h forecast using reflectivity forward model, b) WSI/NOWRAD product, c) RUC20 field after hydrometeor adjustment using NOWRAD data.**

The adjustment of a RUC profile at the ARM/CART site at Lamont, OK is shown in Fig. 3. In this example, only the snow mixing ratio profile is adjusted

such that the model reflectivity using (1) corresponds to the WSI observed reflectivity at this point. A time-height section of vertically pointing cloud radar (Moran et al. 1998) data (Fig. 4), also from the ARM/CART site at this point, shows the complexity of the temporal and vertical variation of hydrometeors for this period (these data were not assimilated). A second example is shown in Fig. 5, a horizontal view of a 14 Feb 2002 case of RUC hydrometeor adjustment using reflectivity. Fig. 5a is the maximum reflectivity computed from the RUC 3-h forecast hydrometeors, Fig. 5b is the WSI maximum reflectivity valid at the same time, and Fig. 5c is the reflectivity computed from the adjusted hydrometeors. Much of the ground clutter present in Fig. 5b is removed in Fig. 5c.

## 5. CONCLUSIONS

Assimilation of GOES cloud-top pressure data will be implemented along with the 20-km RUC at NCEP in April 2002 to provide improvement in cloud and precipitation forecast. Promising initial experiments are being performed for further hydrometeor adjustment in the RUC using radar reflectivity.

## 6. ACKNOWLEDGMENTS

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