

ASSIMILATION OF LIGHTNING DATA INTO RUC MODEL FORECASTING

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1. MOTIVATION

Accurate prediction of convective storms remains as a significant outstanding challenge in numerical weather prediction. Despite significant advances in computer power, numerical models, and especially in storm-scale data assimilation systems, skill in accurately predicting the location and evolution of thunderstorms has been slow to improve. Much research attention has rightfully focused on use of radar data to provide model initial fields that capture ongoing convection. Less common has been the use of lightning data to aid the depiction of ongoing convection within model assimilation schemes.

Within the NOAA Rapid-Update Cycle (RUC) model assimilation system (Benjamin et al. 2004a,b), lightning data have been used experimentally to improve the initialization of clouds, hydrometeors, and convection. Lightning data can be used to supplement other sources of information about the existence of convection (radar and satellite data, short-range model background forecasts). Lightning data is especially important in regions where radar reflectivity data are generally not available (oceans and terrain-blocked areas).

It is important to note that Lightning data provide conditional convection information: existence of strokes implies that convective clouds are present, but absence of strokes does not imply that convective clouds are not present. This conditional lightning information has been used within the RUC analysis to force convection to become active in the subsequent RUC model forecast. Lightning data have also been used within the RUC cloud/hydrometeor analysis, which blends GOES and METAR cloud data, with radar

reflectivity and lightning data, and a previous 1-h RUC forecast RUC fields. Within the cloud analysis, inter-comparisons between the respective data inputs ensure consistency between these data types, consistent with possible error modes.

Lightning data can contribute toward important problems for short-range numerical prediction, initialization of cloud/hydrometeor fields and convection. Forecasts of cloud, fog, ceiling/visibility, stable and convective precipitation are dependent on accurately initializing these fields. Aviation and other transportation activities require considerable improvement from current skill level for these fields and model-based predictions are the main source of guidance beyond a few hours.

2. RUC ANALYSIS CYCLE

The RUC provides high-frequency mesoscale analyses and short-range forecasts for a variety of forecasts applications including aviation/transportation, severe weather, and general forecasting. A particular emphasis has been aviation applications and RUC model output is used in the generation of a number of specialized aviation products. These products focus on specific aviation hazards, such as convection, icing, turbulence, and ceiling and visibility. A unique aspect of the RUC is its hourly analysis cycle, which brings in new observations each hour to provide the freshest initial fields for the new model forecasts, which are also made hourly. This setup has proven to be very beneficial for rapidly evolving weather situations (such as convection), where errors in longer-range forecasts can be quite large.

A key aspect to the hourly RUC update is the cycling of all model variables, including cloud, hydrometeor, and land surface fields. The result of this process is an evolving mesoscale analysis that reflects the temporal sequence of observations, while allowing the model to propagate information forward in time.

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Table 1. Summary of observations used in RUC cloud/hydrometeor analysis.

Observation Type	~ Number	Frequency
<u>NCEP Operational</u>		
GOES cloud top pressure	~ 10 km res.	/1h
METAR clouds/weather	1500 - 1700	/1h
<u>GSD Experimental</u>		
Radar reflectivity	~ 1 km res.	/1h
NLDN lightning	~ 4 km res.	/1h
NASA cloud top products	--- later in 2006 ---	

Within the RUC cloud analysis, 5 species of hydrometeors are cycled (cloud water, cloud ice, rainwater, snow, and graupel), with hourly updates to these fields from the observations listed in Table 1. In the operational RUC run at NCEP, GOES cloud-top data and surface cloud, visibility and current weather information are used to update these fields to improve RUC cloud initial conditions (Benjamin et al. 2004a). In the developmental RUC run at GSD, these data sources are complemented by 2D radar reflectivity and lightning data. Updating of the cycled hydrometeor fields is accomplished as follows. Two 3D logical arrays are used to characterize information about clouds and precipitation. Recognizing the “one-way look” nature of many cloud observations, the logical array can possess values of YES, NO, or UNKNOWN to

characterize the state of knowledge about clouds and precipitation. Satellite data, for example, can indicate the existence of cloud top (the logical array would be set to YES in this region), but cannot provide information below an estimated cloud depth (the logical array values would remain UNKNOWN below). When the satellite data indicate no clouds in the column, the entire column can be set to NO. For surface-based cloud observations, assumptions about the horizontal representative must be made before the logical arrays can be modified. Priority is given to satellite indications of no clouds in a column over METAR indications of cloudiness.

Once the cloud and precipitation arrays are specified, clearing and building (modifications of cloud/hydrometeor fields) are then accomplished using the logical arrays. Building of clouds is done by adding cloud water or ice (depending on the background temperature), and raising the water vapor to saturation. Clearing of clouds is done by removing cloud water and ice and reducing the water vapor to sub-saturate the grid volume. Within this process, checks are made for known difficult situations, including convective clouds and maritime stratus. Precipitation building/clearing is done in a similar manner using standard Z-Qr and Z-Qs relationship. Fig. 1 provides a schematic, depicting how the various observations are used to modify the various hydrometeor fields and additional details are given in Benjamin et al. (2002, 2004a).

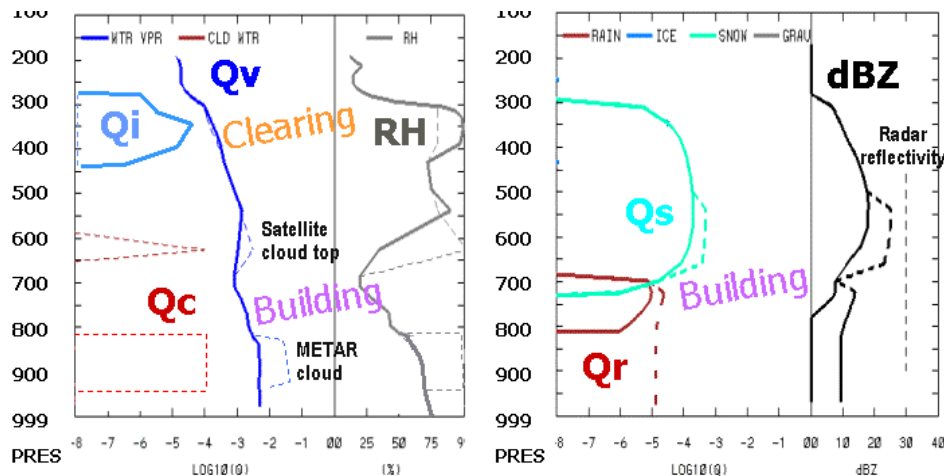


Figure 1. Schematic diagram illustrating the RUC cloud/hydrometeor analysis procedure. Left panel shows modification from cloud observations (satellite cloud top pressure, METAR clouds/weather) to cloud ice (Qi), cloud water (Qc), and water vapor (Qv), and resultant change in relative humidity (RH). Right panel shows modification from radar/lightning data to rainwater (Qr) and snow (Qs). Solid lines indicate fields before the analysis and dashed lines indicate changes due to the analysis.

Table 2. Summary of observations that indicate the presence of convection.

Observation Type	Comments
Radar reflectivity	2D, Testing NSSL 3D mosaic
GOES Effective Cloud Cloud Amount (ECA)	> 0.96, cloudtop > 450 mb
NLDN lightning	> 2 stokes per 40 min. window in a RUC 13-km grid box

3. ASSIMILATION OF LIGHTNING DATA

Lightning strokes indicate the presence of convective activity, but how to best use lightning data to improve model initial conditions is not clear. For models that explicitly resolve convection (typically grid lengths smaller than ~ 5 km), lightning (and other convection information) can be used to modify wind and hydrometeor fields within the resolved convective elements. Here lightning data can be used in combination with radar and other data to deduce important sub-storm scale details that may be resolved by the numerical model. For models that utilize a cumulus parameterization to represent convection, there is a need to project the observational information about convection onto the cumulus parameterization. Accordingly, specifying sub-storm scale details becomes less important than depicting the location and overall characteristics of the convection.

Recognizing this distinction, for the 13-km RUC, lightning data is grouped with other “convection indicators” as shown in Table 2. Note the fields in Table 2 represent a smaller subset of the cloud analysis variables listed in Table 1. Among the variables in Table 2 are radar reflectivity (above a certain threshold), GOES effective cloud amount (ECA), and lightning data. Within the RUC cloud analysis, lightning data are considered a proxy for radar reflectivity. As such, a simple relationship is used to augment reflectivity information with lightning data. First, lightning strokes are summed over a 40 min. window around the given analysis hour (-30 min. to + 10 min.) for each RUC 13-km grid box. The resultant lightning stroke densities are used to set minimum values of radar reflectivity, which are

used in subsequent assimilation steps. A minimum of two lightning strokes per grid box is required to reset the reflectivity value, resulting in a value of 20 dBZ. For greater stroke densities, corresponding reflectivities are increased linearly up to a maximum of 40 dBZ for 10 lightning strokes per grid box.

Once the lightning data have been used to augment the reflectivity data, the reflectivity field is used in two ways: 1) modification of the model rainwater and snow hydrometeor fields through the cloud analysis, and 2) modification of the cumulus parameterization “trigger” constraints. This modification occurs by removing the convective inhibition constraint within the cumulus parameterization scheme. The result is that in regions with observed convection (and model-predicted CAPE), the cumulus scheme will activate, regardless of the strength of the model convective inhibition.

While the use of lightning data in this very preliminary manner can be extended further as described in the next section, it is consistent with the one-sided information from lightning data: it clearly shows presence of convection with a crude relationship to convective precipitation, but absence of lightning cannot confirm the absence of convective activity.

Because of the extensive WSR-88D radar coverage over the coterminous United States, one would expect to find fairly limited areas where lightning data reveals convection not observed by radars. Nevertheless, lightning data can be expected to an important source of convection information in certain situations (oceanic areas, locations with radar data coverage holes or beam blockage due to terrain). Fig. 2 shows one such case, 0500 UTC 23 March 2005. A band of strong convection extended from east of South Carolina, southwestward across Florida into the Gulf of Mexico. A standard radar mosaic captures much of the convection, but misses two key areas as indicated by the corresponding lightning coverage. The bottom panel shows that by augmenting the radar data with lightning data a more coherent depiction of the convective system is obtained.

Fig. 3 is a similar comparison for a different weather region, scattered summer convection, from 2300 UTC, 30 July 2005. For this case several areas of convection that the radar data misses are captured by the lightning data. These include convection over oceanic areas, Mexico, and a WSR-88D coverage hole over southwestern Wyoming.

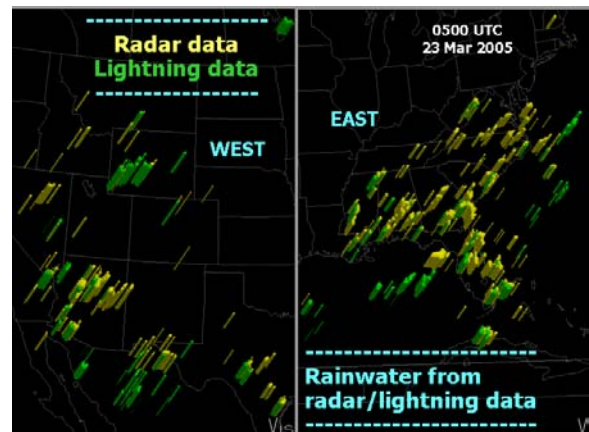
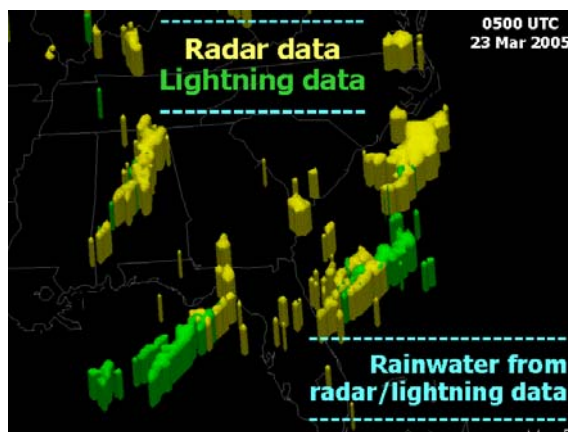
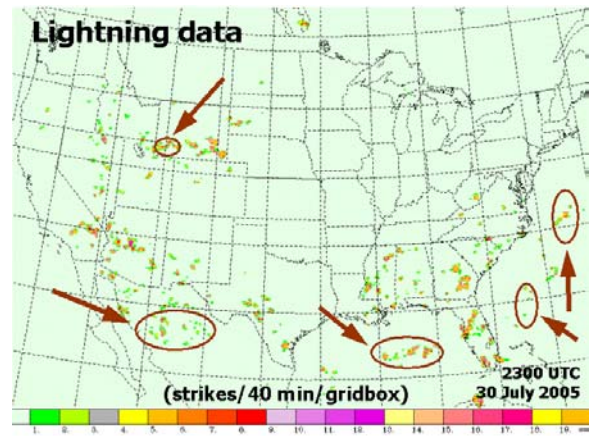
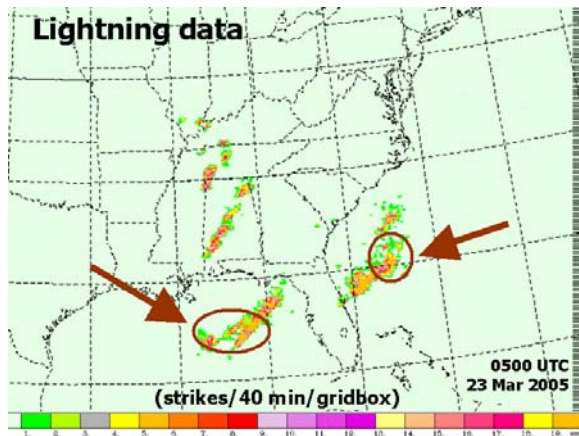
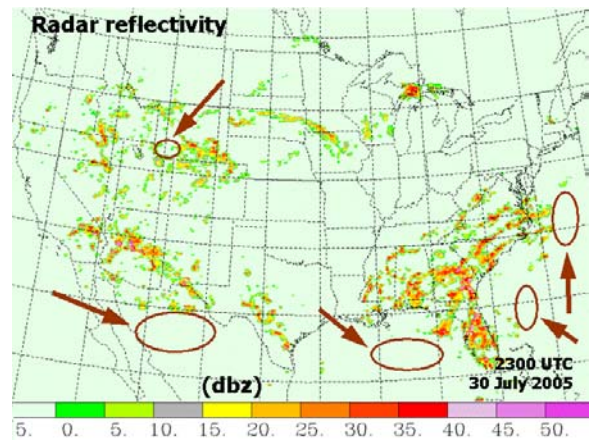
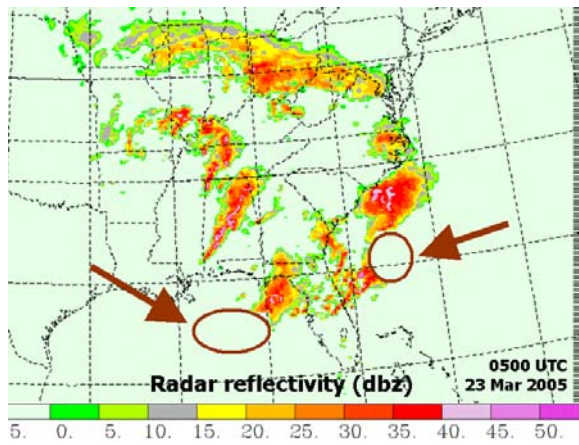


Figure 2. Observed radar data (top panel) and observed lightning data (middle panel) for 0500 UTC 23 March, 2005. Bottom panel shows 3D depiction of the rainwater from the RUC cloud analysis. Yellow indicates rainwater derived from radar data and green indicated rainwater derived from lightning data. All fields are shown on the RUC 13-km grid.

Figure 3. Observed radar data (top panel) and observed lightning data (middle panel) for 2300 UTC 30 July, 2005. Bottom panel shows 3D depiction of the rainwater from the RUC cloud analysis. Yellow indicates rainwater derived from radar data and green indicated rainwater derived from lightning data. All fields are shown on the RUC 13-km grid.

4. SUMMARY AND FUTURE PLANS

Lightning data have been used experimentally within the RUC assimilation cycle to improve the initialization of clouds, hydrometeors, and convection. Lightning data is used to supplement other sources of information about the existence of convection, including radar and satellite data and short-range model background forecasts. Lightning data is especially important over oceanic and terrain-blocked areas, regions where radar reflectivity data are generally not available.

It is important to note that lightning data provide conditional convection information: existence of strokes implies that convective clouds are present, but absence of strokes does not imply that convective clouds are not present. This conditional lightning information has been used within the RUC analysis to force convection to become active in the subsequent RUC model. Lightning data have also been used within the RUC cloud/hydrometeor analysis, which blends GOES and METAR cloud data, with radar.

Much stronger constraints from lightning data can be used for cloud/hydrometeor assimilation in the future to improve model initial conditions over oceans and other areas without radar data. We are presently exploring two methods: 1) forcing convection from radar and lightning data during a pre-forecast diabatic digital filter initialization, and 2) utilizing an adjoint of the cumulus parameterization scheme in a variational formulation to more optimally map convective information onto model fields, especially the wind field.

We expect the importance of lightning data to increase as the RUC is transitioned to the Rapid-Refresh (RR) model. The RR, which is scheduled for operational implementation at NCEP in 2008 using some version of the WRF model, will continue to utilize an hourly update cycle, but will have a much larger domain, covering all of North America and adjacent waters. Associated with this will be a substantial increase in the portion of the domain not covered by radar networks. For this new domain there will also be a much greater use of satellite data, allowing more

intercomparison between different data inputs, including lightning data.

5. REFERENCES

Benjamin, S.G., D. Devenyi, S.S. Weygandt, K.J. Brundage, J.M. Brown, G.A. Grell, D. Kim, B.E. Schwartz, T.G. Smirnova, T.L. Smith, and G.S. Manikin, 2004a: An hourly assimilation/forecast cycle: The RUC. *Mon. Wea. Rev.*, **132**, 495-518.

Benjamin, S.G., G.A. Grell, J.M. Brown, T.G. Smirnova, and R. Bleck, 2003b: Mesoscale weather prediction with the RUC hybrid isentropic / terrain-following coordinate model. *Mon. Wea. Rev.*, **132**, 473-494.

Benjamin, S.G., D. Kim, and J.M. Brown, 2002: Cloud/hydrometeor initialization in the 20-km RUC with GOES and radar data. Preprints, 10th Conf. on Aviation, Range, and Aerospace Meteorology, Portland, OR, Amer. Meteor. Soc., 232-235.