6.2 IMPLEMENTATION OF THE RADAR-ENHANCED RUC

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1. Introduction

A significant RUC upgrade bundle is planned at NCEP for spring 2008, of which the most important change is the hourly assimilation of 3-d radar reflectivity, followed closely by TAMDAR aircraft data and improved radiation and convective parameterizations. These upgrades will result in discernible improvements to aviation guidance using RUC grids, especially for improvements in short-range convection forecasts (Weygandt et al. 2008a), winter storm forecasts, and surface forecasts in all seasons and at all times of day.

Assimilation of 3-d radar reflectivity in the RUC is achieved primarily by specification of 3-d radar-based latent heating during a pre-forecast diabatic digital filter initialization (DFI). This change has been in testing at NOAA/ESRL/GSD in real-time RUC cycles since February 2007. A number of revisions have been developed during the testing since then, including more careful QC procedures for the radar reflectivity data, and in the specification of latent heating. A convection suppression technique has also been developed as part of the RUC radar assimilation to suppress erroneous convection in the RUC background forecast in echo-free regions. A secondary contribution of the RUC radar reflectivity assimilation is to complement satellite cloud-top and METAR ceiling/visibility so as to modify the background, 1-h RUC, 3-d hydrometeor/water vapor forecast (Benjamin et al. 2004c). Proxy reflectivity, calculated using lightning stroke density, supplements the radar reflectivity data in areas of no-radar coverage.

2. Motivation for improved high-frequency data assimilation

By 2025, the number of aircraft flying globally is expected to increase by a factor of 2-3x. Crowded airspace will necessitate much higher accuracy for aviation forecast accuracy than even now. With the anticipated proliferation of decision-support tools for aviation and other situational awareness user groups, the requirement for accuracy and spatial coverage of very-high-frequency updating of numerical weather prediction (NWP) models using latest observations will increase.

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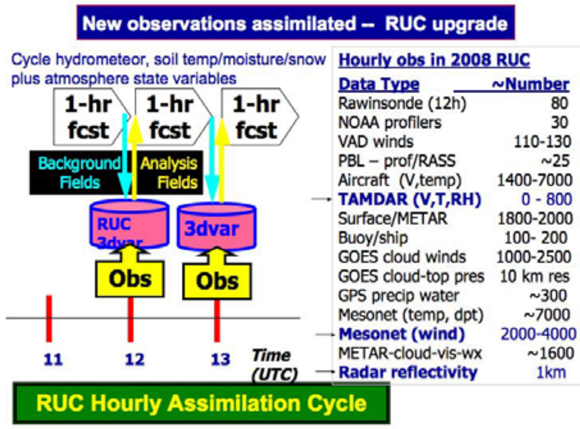

Figure 1. Observations assimilated into RUC as of 2008 after upgrade, new observations in bold and with leading arrows.

The Rapid Update Cycle (RUC, Benjamin et al. 2004a,b), covering 2/3 of North America, continues to be the only 1-h (hourly updating) assimilation and mesoscale forecast cycle in the world running as part of an operational numerical prediction center (US National Centers for Environmental Prediction - NCEP). RUC prediction grids are used heavily as mesoscale guidance for short-range forecasts, especially for aviation, severe-weather, and situational awareness forecast users.

The current improvements to the RUC and future transition to the Rapid Refresh reflects the need for hourly (at least) NWP updating over a larger area with improved accuracy via, in part, improved data assimilation of radar, satellite, aircraft, profiler, GPS moisture, surface, and other observation types. The Rapid Refresh hourly-updating cycle will play a key role in the planned Next Generation Air Transportation System (NextGen), under design by a consortium of government agencies.

3. Summary of Spring 2008 Changes to RUC

The final major change upgrade to the operational RUC includes the following key characteristics, in testing at NCEP since November 2007. Real-time comparisons between the operational RUC and the parallel RUC with the following new features are available at **http://www.emc.ncep.noaa.gov/mmb/ruc2/para**:

- Assimilate 3-d radar reflectivity – components in both analysis and model (Weygandt and Benjamin 2007)
- Assimilate TAMDAR aircraft observations (Moninger et al. 2007, 2008, Benjamin et al. 2007a)
- Assimilate mesonet winds per mesonet wind station uselist (Benjamin et al. 2007c)
- Change of longwave radiation scheme from current Dudhia (1989) to Rapid Radiative Transfer Model (RRTM – Mlawer et al. 1997) – primary effect - less warm bias in warm season, less cold bias in cold season
- Modification to Grell-Devenyi convective scheme introducing nonlocal subsidence warming to improve more realistically coherent convective systems, decrease excessive areal coverage
- Modification to snow component of RUC land-surface model (Smirnova et al. 2000) for snow density to decrease the incidence of excessively low, 2-m air temperatures over fresh snow cover at night
- Add reflectivity output grids similar to those for the NCEP North American Mesoscale (NAM) model, based on 3-d hydrometeor fields Thompson microphysics and Grell/Devenyi convective precipitation

4. More details on radar reflectivity / lightning assimilation in the RUC

The most important component of the RUC assimilation of radar reflectivity is the specification of 3-d, radar-based, latent heating during a pre-forecast diabatic digital filter initialization (DFI, Benjamin et al. 2004a, section 2a)). Additional information is available in Weygandt et al. (2008b).

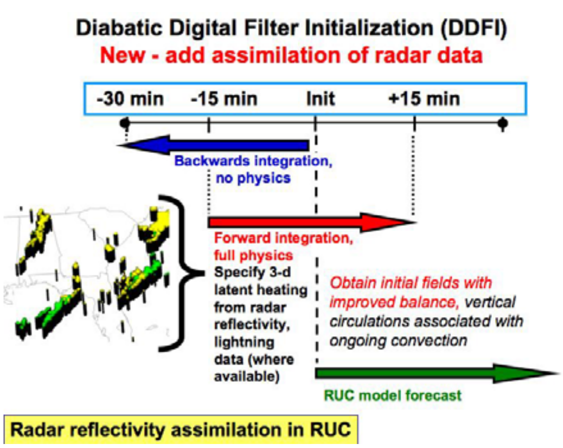

Figure 2. Flowchart for radar-enhanced RUC diabatic digital filter initialization.

Radar/lightning-proxy reflectivity in RUC model initialization is assimilated in the diabatic DFI as follows and shown in Fig. 2. To accomplish this:

- Read in 3-d latent heating field with 3-d mask (e.g., Fig. 3) . Also, read in 2-d "no-echo" field (Fig. 4b).
- Replace model-forecast 3-d latent heating rate at 3-d grid points where reflectivity is available in forward full-physics step of RUC diabatic digital filter initialization (DFI). Thus, model-forecast latent heating from both explicit (resolved) and parameterized precipitation processes is replaced where observed estimates of latent heating are available.
- Force convection inhibition at "no echo" grid points, also during the diabatic DFI period. This avoids any latent heat release even from parameterized convection in the RUC model during initialization where radar reflectivity shows an absence of convection.

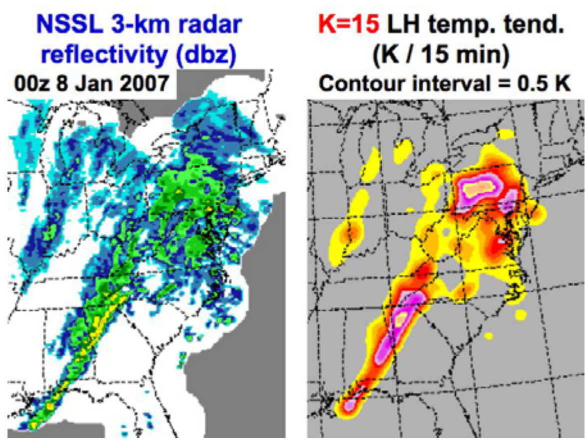

Figure 3. Radar reflectivity at 3-km for 00UTC 8 Jan 2007 (left) and corresponding latent heating temperature tendency (K/15min) at RUC vertical level 15.

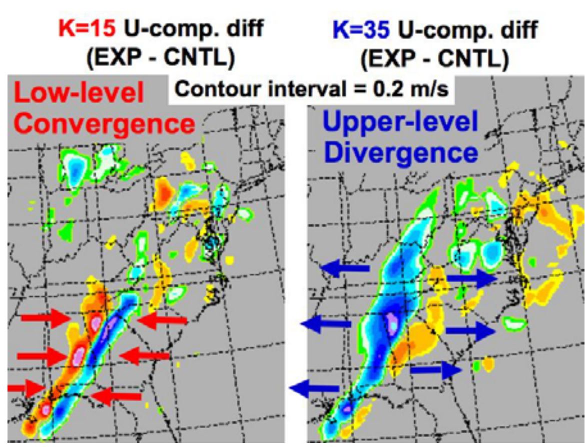

Figure 4. Difference in u-wind component at lower (left) and upper (right) levels after application of RUC DFI with (EXP) and without

(CNTL) 3-d specification of latent heating from 3-d radar reflectivity.

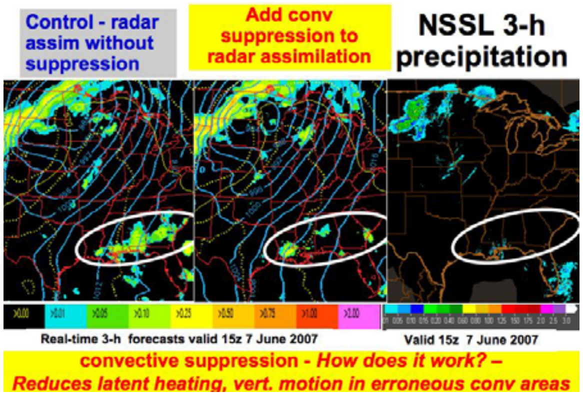

Figure 5. Case study (1200-1500UTC 7 June 2007) for which convective suppression is applied (at 12z). NSSL Q2 3-h precipitation shown on right, RUC 3-h precipitation forecasts without (left) and with (center) convection suppression also shown.

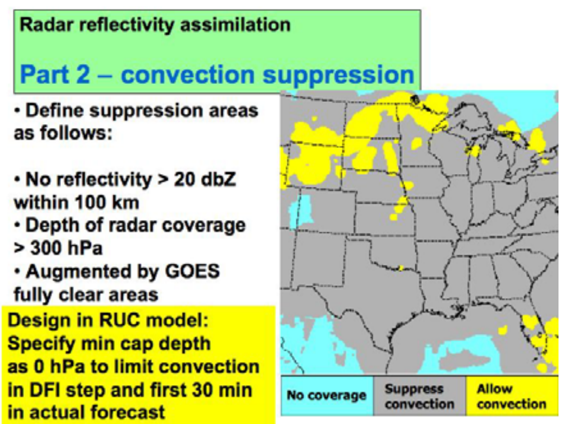

Figure 6. Convective suppression mask for case shown in Fig. 5.

A secondary contribution of the RUC radar reflectivity assimilation is to complement satellite cloud-top and METAR ceiling/visibility so as to modify the background1-h RUC 3-d hydrometeor/water vapor forecast (Benjamin et al. 2004c, Hu et al. 2008). Proxy reflectivity, calculated using lightning stroke density, supplements the radar reflectivity data. Other aspects of using the radar/lightning-proxy reflectivity in the RUC cloud analysis include the following:

- Use a Yes/No/Unknown 3-d array that specifies at each 3-d grid volume whether the foregoing observations support clouds / no clouds / are indeterminate (Benjamin et al. 2004c, Weygandt et al. 2006)
- Apply conditions for radar reflectivity usage based on 3-d temperature, solar zenith angle, and reflectivity, all designed to avoid susceptibility to ground clutter contamination.
- Add cloud water where reflectivity > 5 dBZ but only in temperature-indicated winter conditions where snow hydrometeors are likely.
- Add water vapor, moistening volume toward saturation, where reflectivity exceeds limits between 5 dbZ and 28 dbZ under previous conditions for usage (second bullet).
- Determine 3-d latent heating fields, also subject to usage conditions, based on reflectivity, for subsequent use in RUC model diabatic initialization.
- Also determine horizontal "no-echo" area at least ~100 km from any existing echo to be used in subsequent RUC model initialization, specifically for "convection suppression."

The advantages of the RUC radar-enhanced diabatic DFI technique include the following:

- Forces dynamic (3-d wind fields, especially in divergence wind, example in Fig. 4) and thermal response consistent with convection-associated latent heating. This ensures some response over an approximate time scale of 1-3h, often longer in RUC-based experiments.
- Takes no additional computational time for RUC model, which already included diabatic DFI, implemented with June 2006 RUC change package.

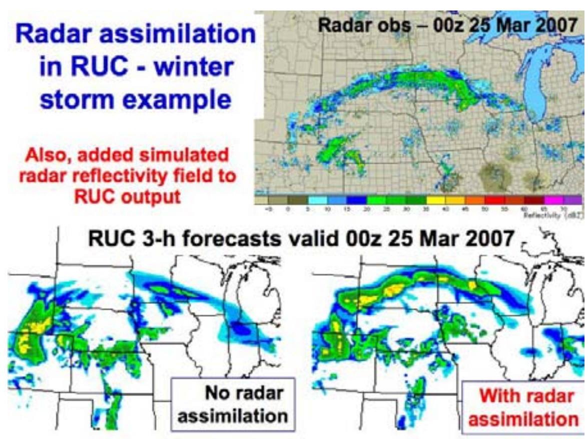

Figure 7. Case study showing effect of radar-enhanced diabatic DFI in RUC.

An example of the effectiveness of the radar-enhanced diabatic DFI in the RUC model is shown in Fig. 7 from a case from 25 March 2007. Reflectivity from a 3-h forecast *with* reflectivity assimilation (lower right) is a much better match with the observed reflectivity (upper right), especially in the warm-front regions from southwest South Dakota through Minnesota into Wisconsin.

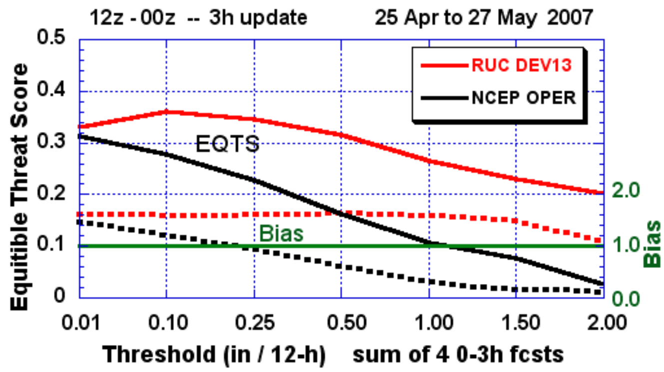

Figure 8. Effect of reflectivity assimilation on precipitation verification for 12-h periods from 1200UTC to 00UTC (daytime) for 25 Apr – 27 May 2007 (25 cases). *RUC-dev13* = 1-h RUC cycle with reflectivity assimilation. *NCEP-OPER* = no reflectivity assimilation - operational RUC. (See text)

Short-range (3-h) precipitation forecast accuracy over a month-long period (April-May 2007) shows a pronounced improvement (Fig. 8) in the RUC cycle with radar reflectivity assimilation (RUC DEV13). The equitable threat score (EQTS) remains above 0.2 out to a threshold of 2.0 inches per 12-h period, comparedwith much lower values for control without radar reflectivity assimilation. With reflectivity assimilation, the bias holds between 1.0-1.5 out to 2.0 inches per 12 h, compared with the desired value of 1.0, again much improved over the control run values without reflectivity assimilation.

5. Other data assimilation improvements in spring 2008 RUC upgrade.

The other data assimilation additions in spring 2008 RUC upgrade package are:

1. TAMDAR aircraft observations from Mesaba-Northwest Saab-340 aircraft, including lower-middle troposphere observations of moisture, temperature, and wind. TAMDAR observations have been shown to improve short-range forecasts year-round in extensive impact studies with parallel RUC cycles since early 2005 (Moninger et al. 2007, 2008, , Benjamin et al. 2007, Szoke et al. 2008)
2. Mesonet wind observations from about 3000 stations passing the latest station uselist from a GSD-developed observation quality monitoring system as described in Benjamin et al. (2007c).

6. Changes to RUC forecast model in upgrade

The implementation of an RRTM longwave radiation package, replacing the previous Dudhia scheme, has been an effective solution to the long-term surface warm bias problem with the RUC model.

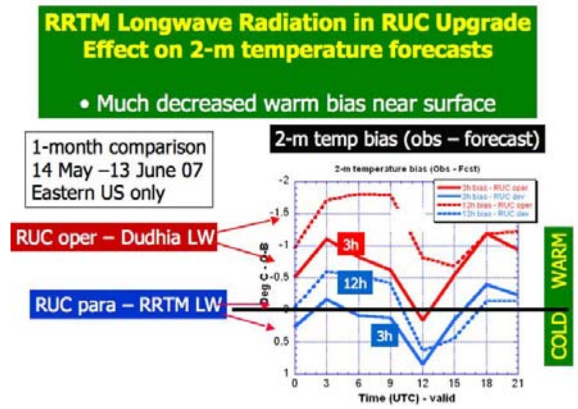

Figure 9. 2-m temperature forecast bias (ob-fcst) for RUC versions, red – operational RUC using the Dudhia LW scheme, blue – development RUC using the RRTM LW scheme.

The results in Fig. 9 show a reduction in 2-m temperature forecast bias, especially at nighttime (03-09UTC) but also in daytime at both 3-h and 12-h forecast durations.

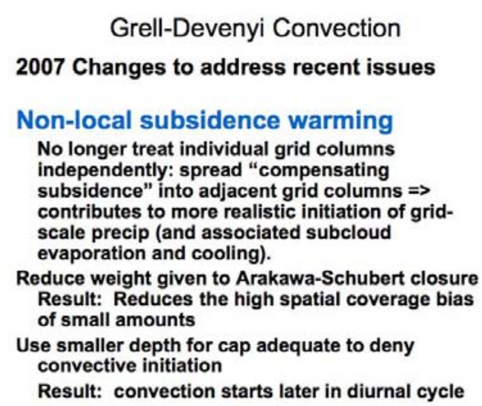

Figure 10. Summary of 2007 changes to the Grell-Devenyi convective parameterization.

A new version of the Grell-Devenyi convective parameterization has also been introduced into the 2008 RUC upgrade (Fig. 10). The primary change in the new scheme is the introduction of a nonlocal application of subsidence warming, instead of the previous column-only application. The closure schemes and associated weights have also been modified to reduce excessive areal coverage for light precipitation.

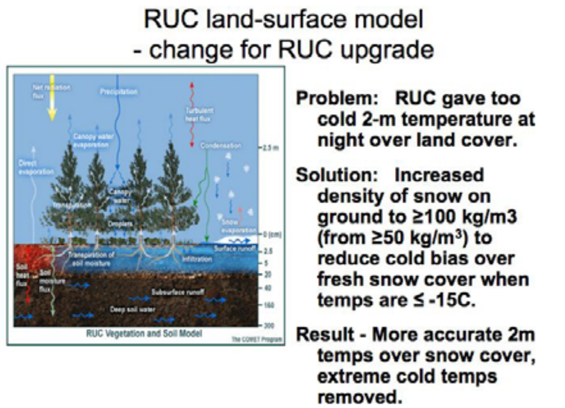

Figure 11. Summary of 2008 change in RUC land-surface model.

The RUC land-surface model (Smirnova et al. 2000) has also been revised to improve 2-m temperatures over fresh snow cover at night. (Fig.11).

The overall effects of the RUC data assimilation and model changes in the 2008 upgrade package for precipitation forecasts for a 2-month period in fall 2008 are shown in Fig. 12. The improvement for 3-h forecasts is particularly prominent at all precipitation thresholds even out to 2" (integrated over a 12-h period). But some improvement is also evident in 12-h RUC precipitation forecasts, slightly more so in the 0.25"-1.50" thresholds. These improvements are primarily attributable to the radar reflectivity assimilation and improvements in the Grell-Devenyi convective scheme.

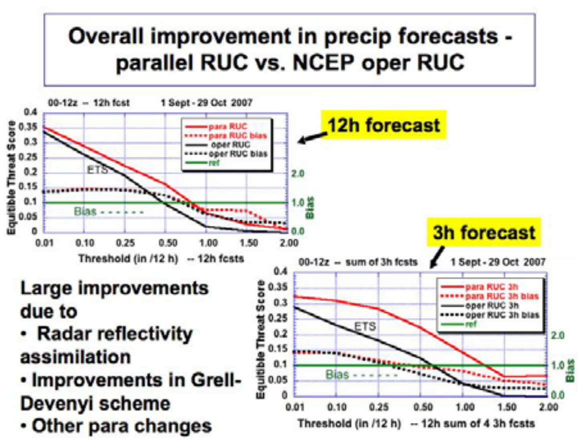

Figure 12. Precipitation verification for 3-h and 12-h forecasts from the NCEP operational RUC (black) and parallel RUC with upgrade changes (red) for equitable threat score (ETS) and bias.

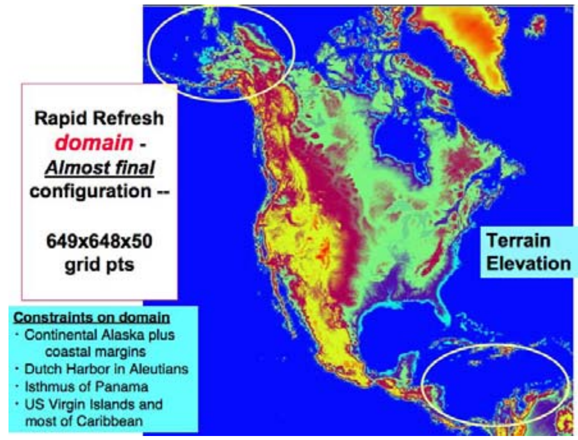

Figure 13. Domain for the Rapid Refresh, planned to replace the RUC for the NOAA hourly-updating NWP system.

7. Rapid Refresh development and testing

The Rapid Update Cycle (RUC) is planned to be replaced by the Rapid Refresh (RR) in late 2009. The Rapid Refresh model will be a version of the WRF model (ARW core, as selected in September 2007) and a version of the GSI assimilation system.

The domain for the Rapid Refresh (Fig. 13) is designed to meet aviation requirements for hourly updated numerical weather prediction (NWP) guidance for Alaska, Puerto Rico, and the Caribbean. It will also provide unified guidance for all of North America, including almost all of Canada.

More details on the Rapid Refresh are available in these papers by NOAA/ESRL/GSD scientists:

- Brown et al. (2008) – Rapid Refresh testing
- Hu et al. (2008) – Rapid Refresh cloud analysis.
- Benjamin et al. (2007b) – June 2007 status on RUC-Rapid Refresh transition

In addition, Weygandt et al. (2008a,b) also present information on improvement from radar-reflectivity assimilation to the RUC Convective Probabilistic Forecast (RCPF) and the experimental 3-km High-Resolution Rapid Refresh (HRRR).

8. Summary

The RUC change package, to be implemented in spring 2008, is arguably the most significant set of changes to the RUC for aviation applications since the 40-km RUC (RUC-2) implementation in 1998. The improvements include the addition of radar reflectivity and TAMDAR aircraft observations assimilation as well as changes to radiation and convection physics. This entire bundle will also be incorporated into the WRF- and GSI-based Rapid Refresh, which is under development to replace the RUC in late 2009.

9. Acknowledgments

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