J3.4 FROM THE RADAR-ENHANCED RUC TO THE WRF-BASED RAPID REFRESH

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1. Introduction

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.

In this report, we summarize both significant changes planned for a RUC upgrade at NCEP later in 2007 and testing and development toward the 2009-planned implementation of the Rapid Refresh (RR), an hourly update analysis/forecast cycle succeeding the RUC. The RR differs from the RUC in using a version of the Weather Research and Forecast (WRF) model and a version of the Gridpoint Statistical Interpolation (GSI) analysis (used at NCEP), both including RUC-unique enhancements, over an extended North American domain. These modifications and subsequent testing for both RUC changes and RR development are described in this paper.

2. Motivation

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. The improvement to the RUC and 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.

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3. 2007 Changes for the RUC

The final major change upgrade will be made to the operational RUC later in 2007. Below, we summarize its key characteristics:

- Assimilate radar reflectivity – components in both analysis and model (Weygandt and Benjamin 2007)
- Assimilate mesonet winds from accepted provider uselist
- Change of longwave radiation scheme from current Dudhia (1989) to Rapid Radiative Transfer Model (RRTM – Mlawer et al 1997) – primary effect - less nighttime warm bias
- Modification to Grell-Devenyi convective scheme to reduce excessive areal coverage for light precipitation.
- 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 products similar to those for the NCEP North American Mesoscale (NAM) model.

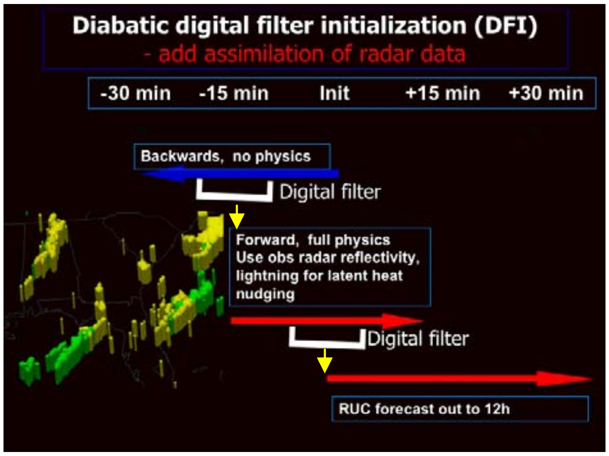


Figure 1. Flowchart for radar-enhanced RUC diabatic digital filter initialization.

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

The most important component (Fig. 1) of the RUC assimilation of radar reflectivity is specification of 3-d radar-based latent heating during a pre-forecast diabatic digital filter initialization (DFI, Benjamin et al. 2004a, section 2a)).

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.

Other aspects of use of the radar/lightning-proxy reflectivity in the overall RUC cloud/hydrometeor analysis module include the following:

- Use 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"

Radar/lightning-proxy reflectivity in RUC model initialization is assimilated in the diabatic DFI as follows and shown in Fig. 1:

- Read in 3-d latent heating field with 3-d mask. Also, read in 2-d "no echo" field.
- 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 absence of convection.

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

- Forces dynamic (3-d wind fields, especially in divergence wind) 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 – information available at (http://ruc.fsl.noaa.gov/ruc13_docs/RUC-testing-Jun06.htm

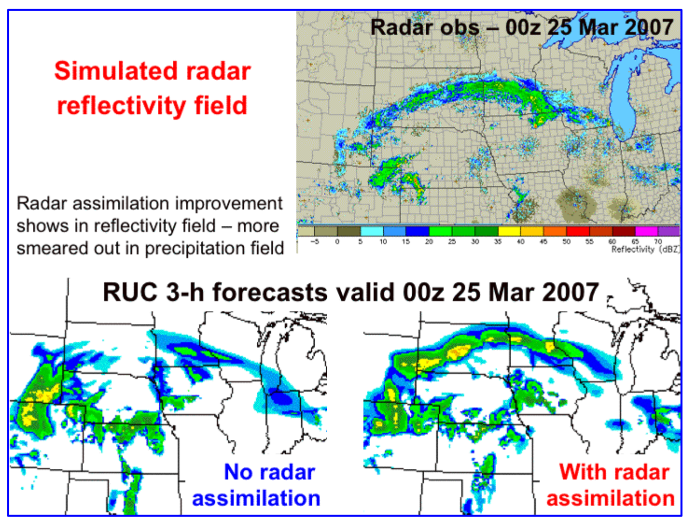


Figure 2. 3-h reflectivity forecasts with (lower right) and without (lower left) radar reflectivity assimilation compared to observed reflectivity (upper right), all valid at 00z 25 March 2007.

An example of the effectiveness of the radar-enhanced diabatic DFI in the RUC model is shown in Fig. 2 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.

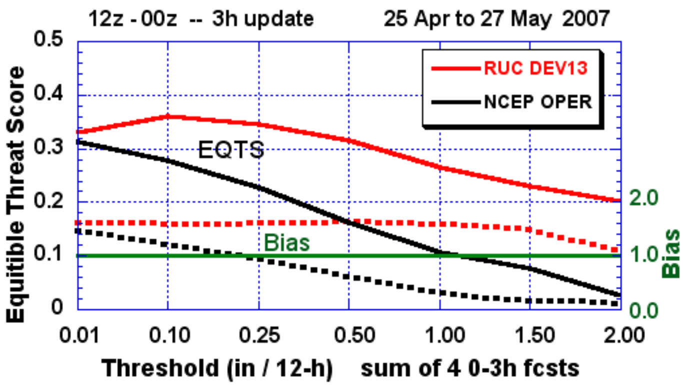


Figure 3. Effect of reflectivity assimilation on precipitation verification for 12-h periods from 12z to 00z (daytime) for 25 Apr – 27 May 2007 (25 cases). *RUC-dev13* = 1h RUC cycle with reflectivity assim. *NCEP-OPER* = no reflectivity assim. - Operational RUC. (See text)

Short-range (3-h) precipitation forecast accuracy over a month-long period (April-May 2007) shows a pronounced improvement (Fig. 3) in the RUC cycle *with* radar reflectivity assimilation (RUC DEV13). Scores were calculated over a daytime (12-00z) period summing four 0-3h forecasts, targeting this short-range period. The equitable threat score (EQTS) remains above 0.2 out to a threshold of 2.0 inches per 12-h period, compared to 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. Rapid Refresh development and testing

The Rapid Update Cycle (RUC) is planned to be replaced by the Rapid Refresh (RR) in 2009. The Rapid Refresh model will be a version of the WRF model (core still uncertain as of this writing) and a version of the GSI assimilation system.

The larger domain for the Rapid Refresh (Fig. 4) 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.

NOAA's Earth System Research Laboratory (ESRL) (which includes the former Forecast Systems Laboratory, now Global Systems Division (GSD)) has been testing and developing versions of the WRF model toward the Rapid Refresh since 2002, as summarized in January 2006 by Benjamin et al. (2006). As a contribution toward the Rapid Refresh design, an experiment to compare the two WRF dynamic cores by NOAA/ESRL/GSD and the Developmental Test Center (DTC) from November 2005 to September 2006. This study is summarized by Brown et al. (2007, this conference), and a more complete report (Benjamin and Brown 2006) is available at http://ruc.noaa.gov/coretest2/GSD-report.pdf . In this study, ESRL/GSD recommended the use of the ARW dynamic core of the WRF by a slight margin over the NMM dynamic core. ESRL/GSD has continued to test both ARW and NMM cores since that time while awaiting a NOAA/NCEP decision.

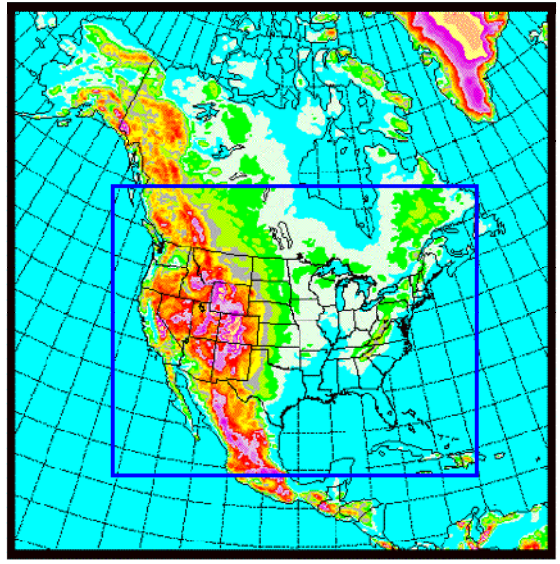


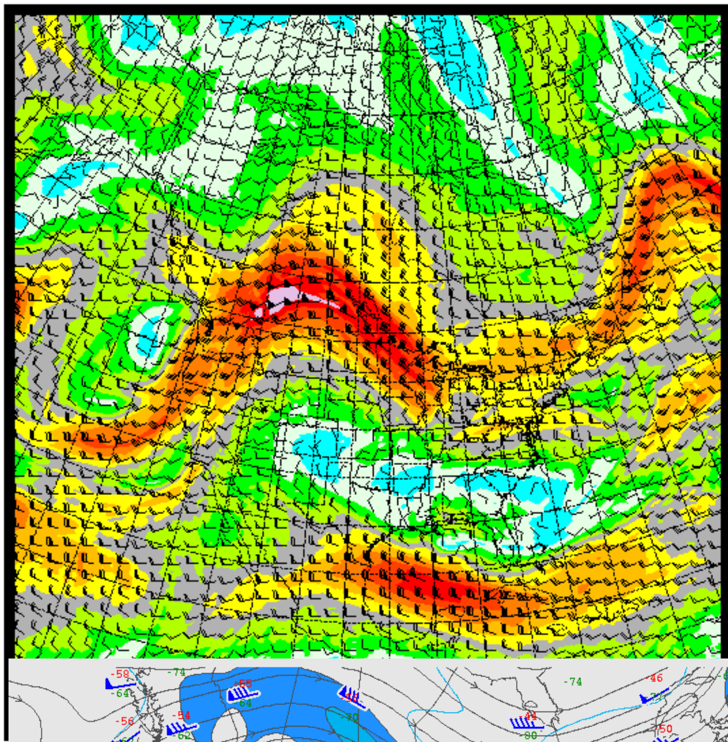
Figure 4. Approximate Rapid Refresh domain (outer region). Blue rectangle is the current RUC domain.

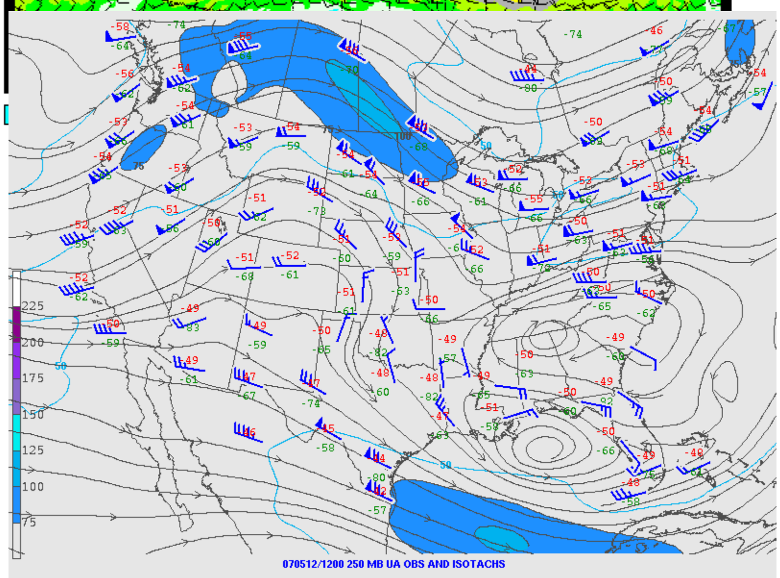
Current WRF-RR testing has used a suite of physical parameterizations, many consistent with those used in the RUC model:

- Thompson (2006, personal communication) cloud microphysics
- Grell-Devenyi (2002) convective parameterization
- Eta Mellor-Yamada-Janjic vertical turbulent mixing
- Dudhia (1989) short-wave radiation
- RRTM long-wave radiation (Mlawer et al. 1997)
- RUC land-surface model (Smirnova et al. 2000)

In fall 2006, Rapid Refresh cycle testing began with WRF-ARW v.2.1.2 using GSI over the Rapid Refresh domain, with only RUC observational data available at that point. This summer, cycling will begin using a new version of GSI and WRFv2.2 and NCEP observation files. By fall/winter, we hope to install

Figure 5. 250-hPa winds – 12 May 2007 12z, a) 12-h RR forecast (units – 5 m/s), b) 250 hPa wind analysis – from NOAA Storm Prediction Center (speed in kts).





the diabatic DFI capability into the WRF model core chosen for the Rapid Refresh. A more detailed examination will take place, especially for surface aspects in the cold season. Refinement of the Rapid Refresh components during this period into 2008 is expected to bring the Rapid Refresh toward operational-level skill (at least equal to that of the current RUC).

The GSI for the Rapid Refresh will use the GSI satellite radiance assimilation (a first for hourly updating and not used in RUC), and will also introduce RUC-like components including:

- Pre-forecast diabatic DFI
- Cloud/hydrometeor analysis (based on satellite, METAR, radar, lightning, *using* a 1-h forecast background for 3-d cloud/hydrometeor fields). (current work by GSD and CAPS, Hu et al. 2007)
- Accounting for boundary layer depth in surface observation assimilation (Benjamin et al. 2004d) through GSI anisotropic error covariance option.
- Forcing of latent heating (in WRF model) using radar/lightning-specified reflectivity.

Additional information on development and testing of the Rapid Refresh version of the GSI is provided by Devenyi et al. (2007).

An example of a Rapid Refresh upper-level wind forecast is shown in Fig. 5 (250 hPa winds, valid 12 May 2007, 1200 UTC), with reasonable location and intensity for jets over western US and Canada and over the Gulf of Mexico. The RR cycling as of this date, using only NAM observations, was not expected to be precise, but shows reasonable accuracy over the lower 48 United States and surrounding areas (current RUC domain).

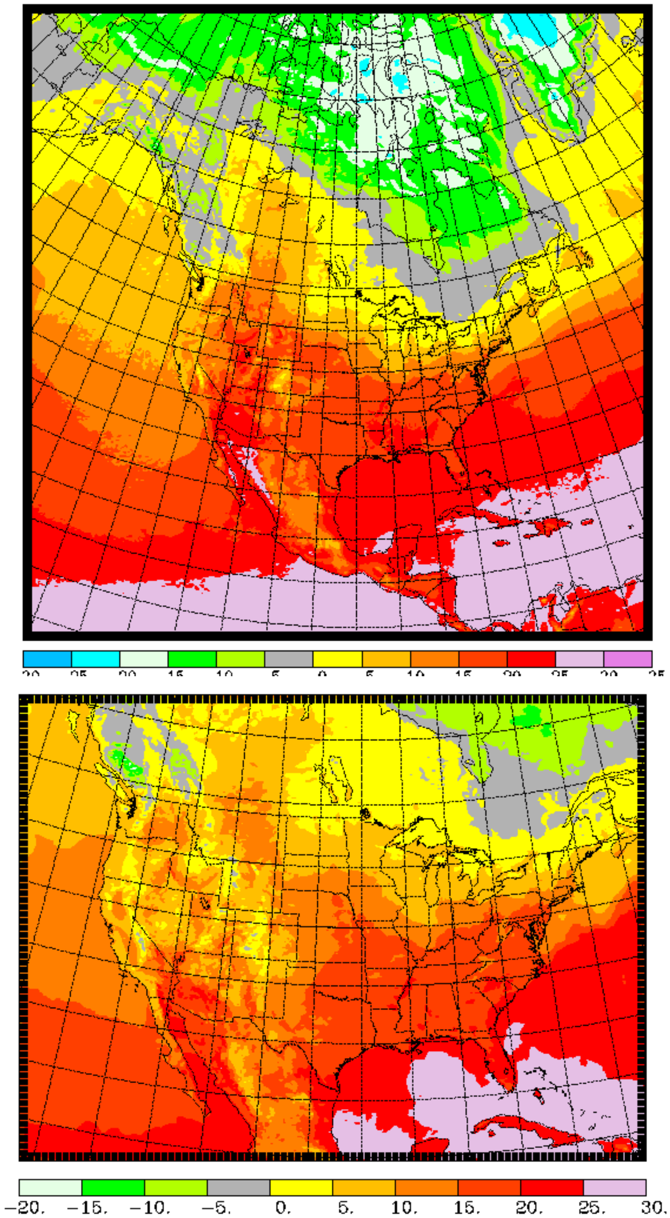


Figure 6. 2-m temperature (deg C) from 12h forecasts valid 12 May 2007 – 12z, from a) Rapid Refresh, and b) RUC.

A second example is shown in Fig. 6 for 12-h forecasts of 2-m temperature from the Rapid Refresh and the RUC. In this comparison, the general pattern is similar with colder temperatures (<0° C) over southeastern Canada and warmer conditions in south central Canada (Prairie provinces). Nevertheless, there were still many significant differences, including temperatures over ocean (colder in RR forecast, smaller area with temperature > 25° C) and over land (generally warmer over land in RR, larger area over lower 48 US with temperature > 15° C).

6. Rapid Refresh transition to operations

The Rapid Refresh must meet the same product delivery requirements currently met by the RUC, with the assimilation complete within 5-10 min after job initiation, and 12-h forecast complete within 20 min, all within the computer resource allocation for the Rapid Refresh at NCEP. While these goals appear realistic, full testing at NCEP is still a year off with a planned transfer to NCEP in summer 2008. Implementation of the operational Rapid Refresh at NCEP is currently planned for summer 2009.

7. Acknowledgment

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