7.1 Rapid-refresh testing: examples of forecast performance

John M. Brown[1], T. G. Smirnova[1,2], S. G. Benjamin[1], B. Jamison[1,3], and S. S. Weygandt[1]

1. Introduction and background

The currently operational Rapid Update Cycle (RUC, Benjamin et al 2004a,b) occupies the "situational awareness" niche in the National Centers for Environmental Prediction (NCEP) forecast production suite. That is, forecasters use it extensively as an aid in monitoring the latest trends in fast-breaking weather situations for the purpose of updating very short-range forecasts. The primary users of the RUC are therefore forecasters concerned with severe local storms and with weather having a high impact on aviation, both from considerations of safety (e.g., turbulence) and operational efficiency (e.g., flight routing).

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

With this future in view, and toward a NOAA goal to accelerate transition of development from the research community into operational environmental models, NOAA/NCEP and NOAA Earth System Research Laboratory (ESRL) Global Systems Division (GSD) (formerly NOAA FSL) agreed in 2002 to use a version of the Weather Research and Forecast (WRF) model to eventually replace the current hydrostatic RUC model. A year later, in response to a request from the National Weather Service (NWS) to make forecasts for Alaska part of the RUC, it was decided to expand the current RUC domain to include most of Alaska, as well as Puerto Rico and the US Virgin Islands, while keeping the rapid update function intact. It was also agreed to switch from the current RUC three-dimensional variational (3dVAR) analysis to the Gridpoint Statistical Interpolation (GSI, also based on three-dimensional variational principles) under development by NCEP and NASA and now used in both the North American Mesoscale (NAM) and Global Forecast System (GFS) operational configurations

[1] NOAA/Earth System Research Lab/Global Systems Division, Boulder CO
[2] Collaboration with the Cooperative Institute for Research in the Environmental Sciences (CIRES), Boulder CO
[3] Collaboration with the Cooperative Institute for Research in the Atmosphere (CIRA), Fort Collins CO

at NCEP. This new analysis and nonhydrostatic model forecast configuration was dubbed the *Rapid Refresh (RR)*.

Immediately after the decision was made in 2002 to go with a version of WRF, GSD began experimentation with WRF on a CONUS domain. Since that time, our efforts toward the RR have gradually gained momentum in parallel with continued development of the RUC. Our goal in this talk is to give the current state of development of the RR, and show examples of RR performance in test cycles running at GSD.

During the summer of 2007 a further agreement between GSD and NCEP/EMC was reached to implement the RR in two stages. In the first stage, scheduled for implementation in September 2009, the RR will be run, as the current RUC, in an hourly assimilation cycle, but over the larger domain noted above (Fig. 1 is the domain we are currently testing at GSD), using GSI and WRF. The second stage of the RR implementation (in the year 2012) is currently planned as a 4-member ensemble configuration within the new National Environmental Modeling System (NEMS), now in the early stage of development at NCEP. [For more on NEMS, see Lord (2007).] Both the ARW and NMM (Nonhydrostatic Mesoscale Model, Janjic et al 2001) may be used, along with updated versions of "RUC-like" physics (defined below) and the physics used in the NAM. It is the development of the first-stage implementation in 2009 that is the subject of this talk.

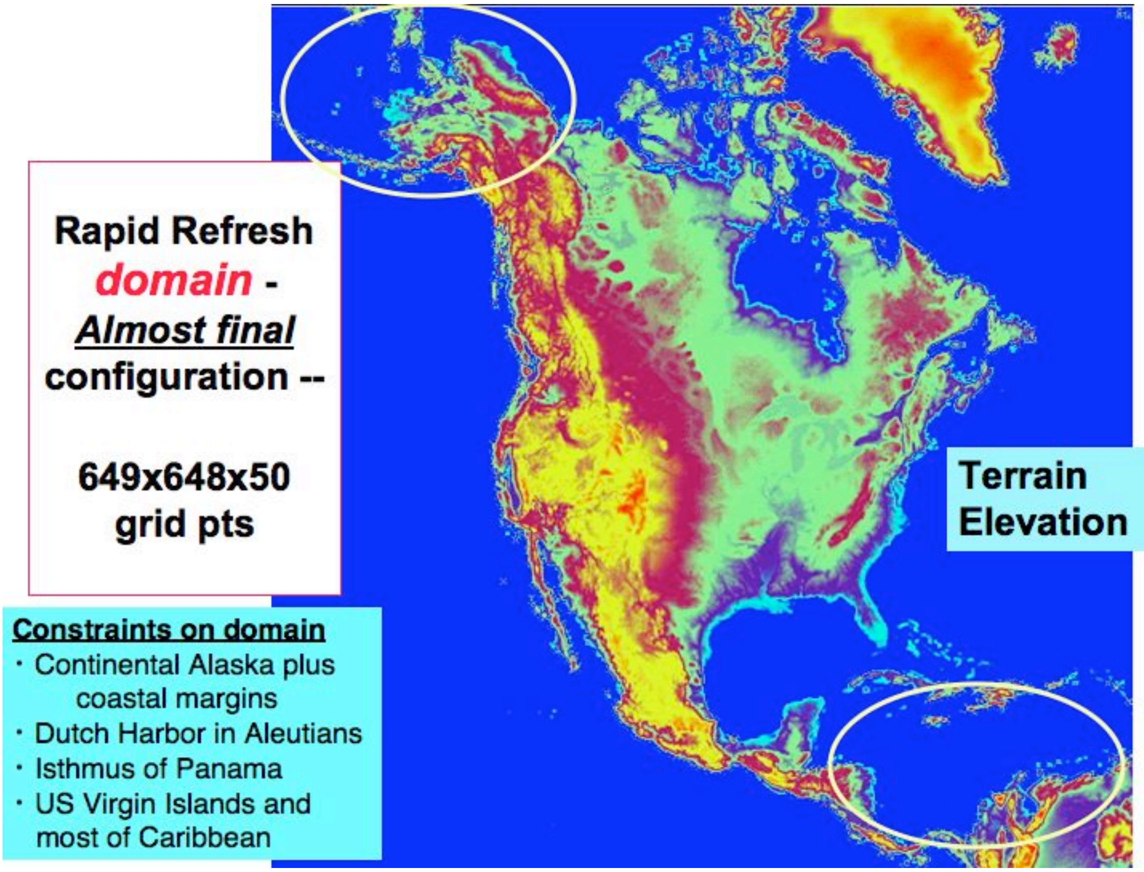

Figure 1. "Almost final Rapid Refresh domain. This is the domain currently used for testing at GSD.

2. Some recent RR developments

Here are some highlights of RR development during the 2 years since the last Aviation, Range and Aerospace Meteorology conference in Atlanta. More details can be found in the papers referenced in the individual subsections to follow.

a. DTC-GSD RR Core Test

The ESRL/GSD and the NCAR-NOAA Developmental Testbed Center (DTC) conducted a rigorous comparison of the forecast performance of the two dynamical-core options in WRF, the ARW and the NMM. The purpose of this was to provide a basis for the GSD recommendation to NCEP concerning which of the WRF cores to use in the initial 2009 RR implementation. The design, execution and detailed results of this core test are described in detail in Benjamin and Brown (2006) and Brown et al (2007). The outcome was to "recommend, by a slight margin, the ARW core over the NMM core for the initial operational Rapid Refresh Implementation."

b. GSI development for RR

The GSI has been developed by NCEP, and both NASA and GSD have been working together with NCEP to extend and improve GSI. GSI has contributed to various aspects of GSI analysis code development and software improvements over the past few years. For example, the GSI has not previously been exercised in an hourly updating environment, and GSD has been working toward incorporating some features of the RUC 3dVAR that are regarded as essential to the RUC into the GSI code. Of particular importance, because of their hourly availability and (over land) their number, is full use of good-quality surface data, including winds, temperature, humidity, and pressure, and, where available, ceiling, visibility and present weather. [Because the quality of surface data varies widely due to siting issues, maintenance, quality and non-uniformity of instrumentation, etc., a procedure has also been developed to examine each station's (or each mesonet provider's) recent history of observed minus 1-h forecast background for wind and other quantities, and exclude data from those stations that show systematic and unacceptable bias. In this way, a dynamic station or provider reject list can be maintained. This is described in Benjamin et al (2007).] In the RUC 3dVAR, a procedure for spreading the influence of the surface wind, temperature and humidity was developed for use in situations where a well-defined mixed layer is present in the 1-h forecast background field (Benjamin et al 2004). In GSI, this same effect is desired by using anisotropic and non-homogeneous error covariance, whereby the vertical influence of the observational innovations from the surface data is spread upward depending on the low-level static stability in the background field. This and some other aspects of GSI development are described more fully in Devenyi et al 2007.

c. *Combined ARPS-GSD cloud/hydrometeor analysis*

To provide for the initialization of cloud and precipitation systems in RR, CAPS (Center for the Analysis and Prediction of Storms, ARPS = Advanced Regional Prediction System) and GSD have collaborated to develop a generalized cloud analysis procedure (Hu et al. 2008) This combines the strengths of both RUC (for stable clouds) and ARPS (for explicit deep convection) cloud-analysis packages to improve the analysis of both stratiform and convective cloud and precipitation systems over a large domain. In addition to satellite cloud-top pressure and Estimated Cloud Amount, ceiling, present weather and visibility from METAR observations are used, along with mosaic 3-dimensional radar reflectivity data (from the National Severe Storms Lab of NOAA) and lightning data (from the National Lightning Detection Network for the CONUS and Alaska) empirically converted to reflectivity are used. To improve the efficiency of this procedure and to make it amenable to application within the RR, it has been parallelized and put within the latest version of GSI. It is, however, outside the variational solver within GSI.

d. Diabatic digital filter initialization.

Another crucial ingredient of frequent cycling, as gleaned from our experience with the RUC since we started 1-h cycling in 1998, is a means to reduce spurious features in the 1-h forecast background, which arise from dynamical imbalance in the initial conditions for that previous forecast. Our experience with RUC has shown that the Digital Filter Initialization (DFI, Huang and Lynch 1993), applied to the initial conditions of every forecast, is adequate for this task. In concept, the DFI is simple: it is a low-pass time filter applied to the dynamical variables plus water vapor at each grid point during a short backwards (adiabatic), then forwards (diabatic) integration. Recently, Tanya Smirnova and Steven Peckham of GSD successfully introduced this procedure into WRF. The manner in which it is applied in RR is shown in Fig. 2. Although that portion of the code that does the actual time filtering of the dependent variables (dynamical variables plus water vapor) has to be specific to the WRF-ARW, an effort was made to keep other changes to ARW-specific code to a minimum. This should facilitate implementation in the WRF-NMM in the future.

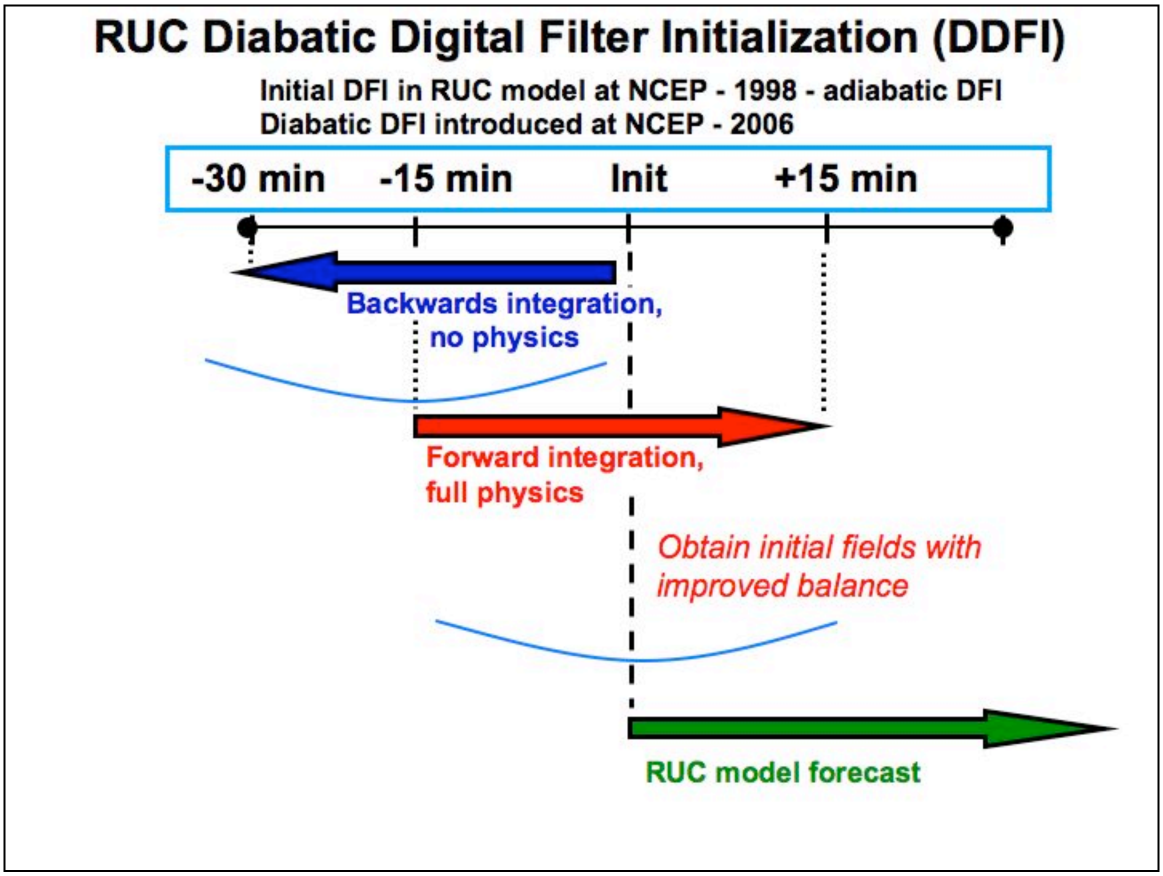

Figure 2. Schematic of the Digital Filter Initialization as used in both the RUC and Rapid Refresh. The backward integration is done first, using only the reversible, adiabatic processes. The forward integration starts from the low-pass filtered state results of the backward integration. The forecast starts from the filtered forward integration state.

e. Physics improvements

LSM
Convective scheme
Microphysics

f. Cycling

3. RR testing at ESRL/GSD

The RR development group at ESRL/GSD has been engaged in testing various versions and configurations of the WRF model since 2003. More recently, with the availability of GSI and sufficient computer resources to run on the much larger RR domain, we have initialized with the GFS (Global Forecast System) and DFI. We have been running a 6-h cycle on the RR domain since late October 2007, and at this writing are able to do 1-h cycling, but without the DFI. We expect to begin a full 1-h cycle with the DFI shortly. Results from cycled RR runs will be shown during our talk at the conference.

4. Planned 2009 operational RR configuration

Salient features of the RR as planned for implementation in 2009 are

- North American domain approximately 2.6 times larger than that of the present RUC (Fig. 1);
- Approximately 50 layers in the vertical, with smallest grid spacing near the ground in the standard sigma-p vertical coordinate, i.e., terrain following at the bottom level, uniformly transitioning to being isobaric at the top of the model (currently 50mb in testing at GSD, but will likely be raised to ~ 10mb);
- hourly updating using the GSD-enhanced version of GSI (Devenyi et al 2007);
- The Advanced Research WRF (ARW) forecast model;
- Hydrometeor assimilation (similar to the what is currently in parallel testing at NCEP for the RUC, see Weygandt et al 2008) based on radar and satellite observations and incorporated within the new diabatic Digital Filter Initialization (DFI) developed for the ARW at GSD (Section 2d);
- So-called “RUC-like” physics, including the Geophysical Fluid Dynamics Lab (GFDL) long- and short-wave radiation (also used in NAM), RUC LSM (land-surface model, Smirnova et al 2000), Mellor-Yamada-Janjic (MYJ, Janjic 2001) sub-grid scale vertical mixing (also used in NAM), a new version of the Grell-Devenyi (2002) convection parameterization, and the NCAR-Thompson microphysics scheme (Thompson et al 2007).

5. References

Benjamin, Stan, and John Brown, 2006: WRF Rapid Refresh Dynamic Core Evaluation and Recommendation. Memo to S. J. Lord and N. Seaman, 31 August 2006, 62pp. Available at http://ruc.noaa.gov/coretest2/WRF_Rapid_Refresh_dynamic_core_recommendation-31aug06.pdf

Benjamin, Stan, and W. R. Moninger, S. R. Sahm, and T. L. Smith, 2007: Mesonet wind quality monitoring allowing assimilation in the RUC and other NCEP models. 22nd Conf. Wea. Analysis Forecasting / 18th Conf. Num. Wea. Pred., Park City, Amer. Meteor. Soc., P1.33. http://ams.confex.com/ams/pdfpapers/124829.pdf

Benjamin, S.G., S. Weygandt, D. Devenyi, J.M. Brown, G. Manikin, T.L. Smith, and T. Smirnova, 2004: Improved moisture and PBL initialization in the RUC using METAR data. *11th Conf. on Aviation, Range, and Aerospace Meteorology* , Hyannis, MA, Amer. Meteor. Soc., CD-ROM, 17.3.

Brown, John M., Stan Benjamin, Tanya Smirnova, Georg Grell, Ligia Bernardet, Louisa B. Nance, Randall Collander, and Chrstopher W. Harrop, 2007: Rapid Refresh Core Test: Aspects of WRF-NMM and WRF-ARW Forecast Performance Relevant to the Rapid Refresh Application. 22nd Conf. on Weather Analysis and Forecasting/18th Conf. on Numerical Weather Prediction, Park City, Paper 4A.1. http://ams.confex.com/ams/pdfpapers/124822.pdf

Devenyi, Dezso, S. S. Weygandt, T. W. Schlatter, S. G. Benjamin and M. Hu, 2007: Hourly data assimilation with the Gridpoint Statistical Interpolation for the Rapid Refresh. 22nd Conf. on Weather Analysis and Forecasting/18th Conf. on Numerical Weather Prediction, Park City, Paper 4A.2. http://ams.confex.com/ams/pdfpapers/124535.pdf

Grell, G. A., and D. Devenyi, 2002: A generalized approach to parameterizing convection. *Geophys. Research Letters* **29**, 38-1-38-4.

Hu, Ming, S. S. Weygandt, S. Benjamin, and M. Xue, 2008: Ongoing development and testing of generalized cloud analysis package within GSI for initializing Rapid Refresh. 13th Conf. on Aviation, Range, and Aerospace Meteorology, New Orleans, Paper 7.4.

Huang, X.Y., and P. Lynch, 1993: Diabatic Digital-Filtering Initialization: Application to the HIRLAM Model. *Mon. Wea. Rev.*, **121**, 589–603.

Janjic, Z. I., 2001: Nonsingular Implementation of the Mellor-Yamada Level 2.5 Scheme in the NCEP Meso Model. National Centers for Environmental Prediction Office Note 437, 61 pp. Available at http://www.emc.ncep.noaa.gov/officenotes/FullTOC.html#2000

______, J.P. Gerrity, and S. Nickovic, 2001: An Alternative Approach to Nonhydrostatic Modeling. *Mon. Wea. Rev.*, **129**, 1164–1178.

Lord, S. J. and EMC Senior Staff, 2007: Progress on future NCEP production suite. Presentation at NCEP Production Suite Review. http://www.emc.ncep.noaa.gov/research/NCEP-EMCModelReview2007/Progress_on_Future_NCEP_Production_Suite.dec2007.pdf

Smirnova, T.G., J.M. Brown, and D. Kim, 2000: Parameterization of cold-season processes in the MAPS land-surface scheme. *J. Geophys. Res.* **105**, 4077-4086.

Thompson, Gregory, Paul R. Field, Roy M. Rasmussen, and William D. Hall, 2008: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part II: Implementatoin of a new snow parameterization. Mon. Wea. Rev., accepted with revisions.

Weygandt, Stephen S., and S. Benjamin, T. G. Smirnova, J. M. Brown, and K. J. Brundage, 2008: Hourly convective probability forecasts from an experimental RUC with radar data assimilation. 13th Conf. on Aviation, Range and Aerospace Meteorology, 7.5.