J2.3 # THE 20-KM VERSION OF THE RUC

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1. INTRODUCTION

A new version of the Rapid Update Cycle (RUC) with 20-km resolution and significant changes in model and assimilation techniques is being implemented at NOAA's National Centers for Environmental Prediction (NCEP) in summer 2001. The RUC, a high-frequency mesoscale analysis and forecast model system, has become a widely used source for short-range weather forecasting guidance in the United States, especially for aviation, severe-storm, and public-forecasting applications.

This paper describes the primary components of the 20-km RUC and how it differs from the 40-km RUC (Benjamin et al. 1999) that has run at NCEP since April 1998. The overall goals for the 20-km RUC implementation have been the following:

- Take advantage of increased computer power at NCEP by using increased spatial resolution
- Improve RUC performance for quantative precipitation forecasting, especially in the warm season
- Improve RUC initial conditions, which are especially important given its niche for short-range forecasts.

These goals are realized in the 20-km RUC by incorporating improved modeling and data assimilation techniques, assimilating new observation data, and eliminating bugs. The primary model changes in the 20-km RUC model concern its treatment of convection, explicit clouds using mixed-phase microphysics, and land-surface processes. The key assimilation changes are the introduction of a three-dimensional variational (3dVAR) analysis in the RUC native hybrid isentropic-sigma vertical coordinate and assimilation of GOES cloud-top data to modify RUC hydrometeor fields.

In the following sections, we give more detail on resolution, assimilation, and model changes, and then present some recent results.

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2. HORIZONTAL AND VERTICAL RESOLUTION CHANGES

In this new version of the RUC, the horizontal grid spacing decreases from 40 to 20 km, and the number of vertical levels increases from 40 to 50. The increase in horizontal resolution to 20 km provides considerable improvement in accounting for the effects of topography and land-surface variations on wind and precipitation. In addition to much improved orographic precipitation, the smaller grid volumes in the 20-km RUC allow improved depiction of cloud and more representation of mesoscale convective cloud/precipitation systems at the resolved grid scale. These smaller grid volumes also improve the ability of the RUC to resolve clouds and areas with supercooled liquid water with potential for icing. The 20-km resolution also allows the RUC to better delineate areas with potential for turbulence, whether of clear-air, mountain-wave, or convective origin.

Improved terrain representation is apparent in the comparison of RUC 40-km and 20-km topography fields for the western United States presented in Figs. 1a-b. The size of the domain remains the same as that for the 40-km RUC.

The 20-km RUC uses 50 vertical levels, with 7 levels added in the upper troposphere and 3 in the lower troposphere (Fig. 2a, compared to 40 levels/40-km RUC in Fig. 2b). It continues to use the same hybrid isentropic/terrain-following coordinate used successfully in the previous versions of the RUC. In the 20-km version, the isentropic spacing is 2-3 K for reference potential temperatures from 270-352 K. The top level is now at 500 K (approximately 40-60 hPa). The spacing near the surface is 2, 5, 8, and 10 hPa in the first 4 layers, with an explicit model calculation level at 5 m above the surface. The definition of the RUC hybrid coordinate is explained in more detail in Devenyi et al. (2001).

(a) (b)

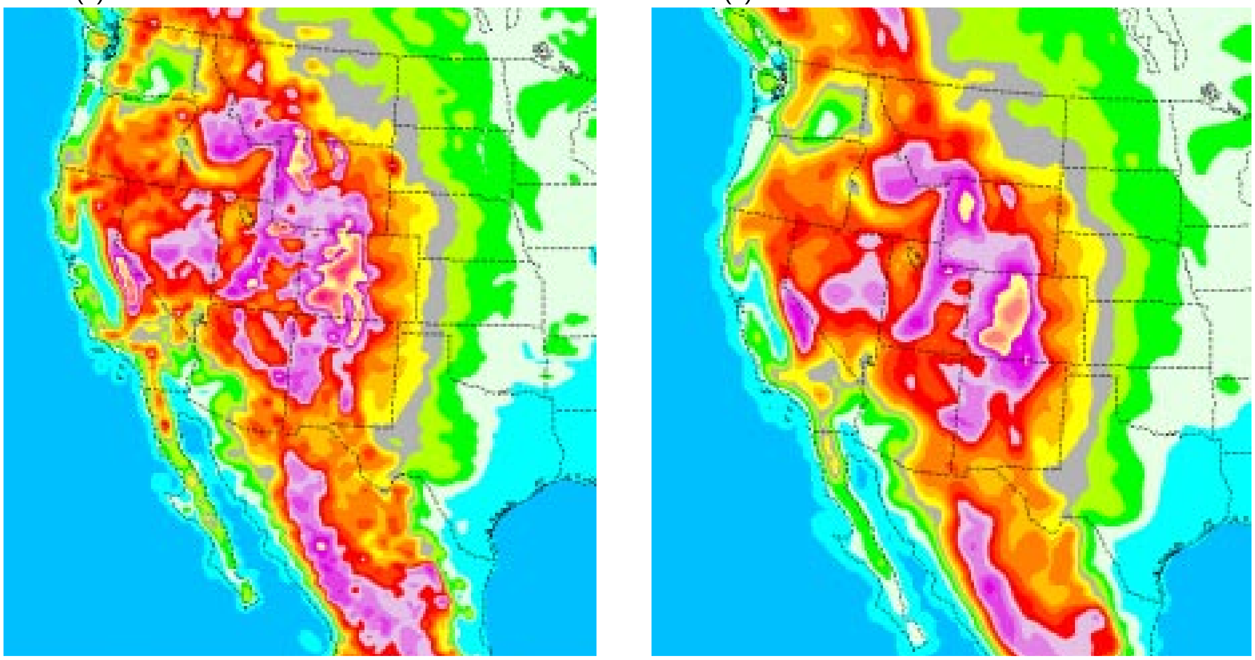

Figure 1. Topography in western United States for a) 20-km RUC, and b) 40-km RUC

(a) (b)

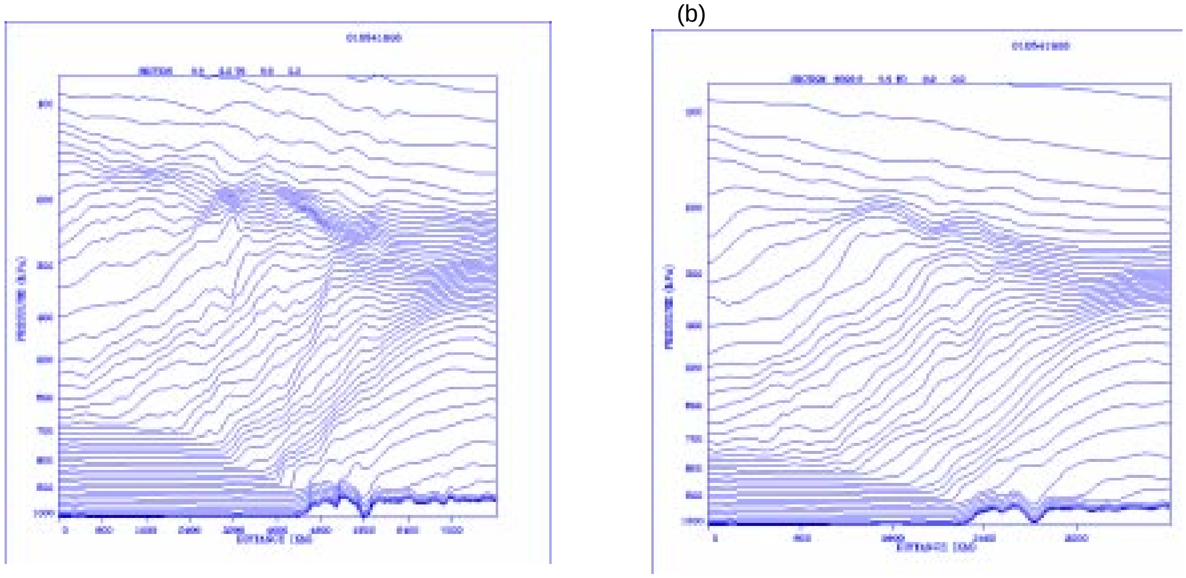

Figure 2. Native analysis/model levels in hybrid isentropic/sigma coordinate for east/west cross-section from 6-h forecast valid 0000 UTC 24 February 2001 for a) 20-km 50-level RUC, b) 40-km 40-level RUC.

3. DATA ASSIMILATION CHANGES IN THE 20-KM RUC

There are two major changes in data assimilation for the 20-km RUC: replacement of the optimal interpolation (OI) analysis procedure by a 3dVAR procedure, and introduction of an initial cloud analysis using GOES cloud-top pressure to modify RUC 1-h hydrometeor forecasts.

3.1 *3dVAR analysis*

The 3dVAR analysis for the RUC (Devenyi et al. 2001) continues to use a native isentropic-sigma hybrid coordinate, and so preserves the advantage of confining the influence of in-situ observations to within the air mass with similar isentropic properties. The 3dVAR analysis improves over the OI analysis in providing smoother analysis increments (differences from background), improved wind/mass balance relationships, and a much better framework for assimilation of observations of non-prognostic variables such as satellite radiances, radial wind speed, etc. The RUC 3dVAR analysis has been designed to maintain horizontal and vertical structures represented in observations, a characteristic important for the RUC's nowcast application.

3.2 *Assimilation of GOES cloud-top pressure*

The 20-km RUC includes a cloud analysis in which GOES cloud-top pressure data are used to clear and build clouds/hydrometeors using the previous 1-h RUC 3-dimensional hydrometeor forecast as a background (Kim and Benjamin 2001, 2000). This technique has been shown to improve short-range cloud forecasts, even out to 12-h duration. Forecasts of heavier precipitation events show a slight statistical improvement from the cloud assimilation, as do those of relative humidity forecasts at 500-400 hPa.

An explicit mixed-phase cloud microphysics scheme (Reisner et al. 1998) was introduced into operations with the 40-km RUC in 1998. This scheme includes explicit prediction of mixing ratios for 5 hydrometeors, cloud water, cloud ice, rain, snow, and graupel. For each hourly cycle in the 40-km RUC, the initial fields for these variables are taken from the previous 1-h forecast without modification. The introduction of the GOES cloud assimilation is new to the 20-km RUC.

In cloud-cleared areas, water vapor mixing ratio is also decreased to 50% of saturation along with setting hydrometeor mixing ratios to zero. For cloud-building, cloud mixing ratio is set to a fraction of the autoconversion threshold for rain formation (Brown et al. 2000), but due to intermittent difficulty with identification of low-level cloud when the skin temperature of the earth's surface is similar to lower-tropospheric air temperatures, no clouds are built below 700 hPa.

4. FORECAST MODEL CHANGES IN THE 20-KM RUC

The 20-km RUC forecast model has incorporated a number of improvements that, even without the change in horizontal resolution, result in better RUC forecasts. The key areas of improvement are:

1) Improved convective (sub-grid-scale) precipitation from an ensemble closure/feedback convective parameterization by Grell and Devenyi (2001), including effects of shallow convection, and fixes to problems with the model interface to the convective scheme. The Grell/Devenyi scheme currently uses 8 closure assumptions and 9 feedback assumptions, as currently implemented in the 20-km RUC model. It provides significant improvement in convective precipitation forecasting over the 40-km RUC, as shown in section 5 below. The Grell/Devenyi scheme also detrains cloud water and ice directly to the RUC microphysics, a feedback absent in the 40-km RUC.

2) Improved vertical advection of moisture and stable precipitation (vertical advection of all moisture/cloud variables changed to be conservative).

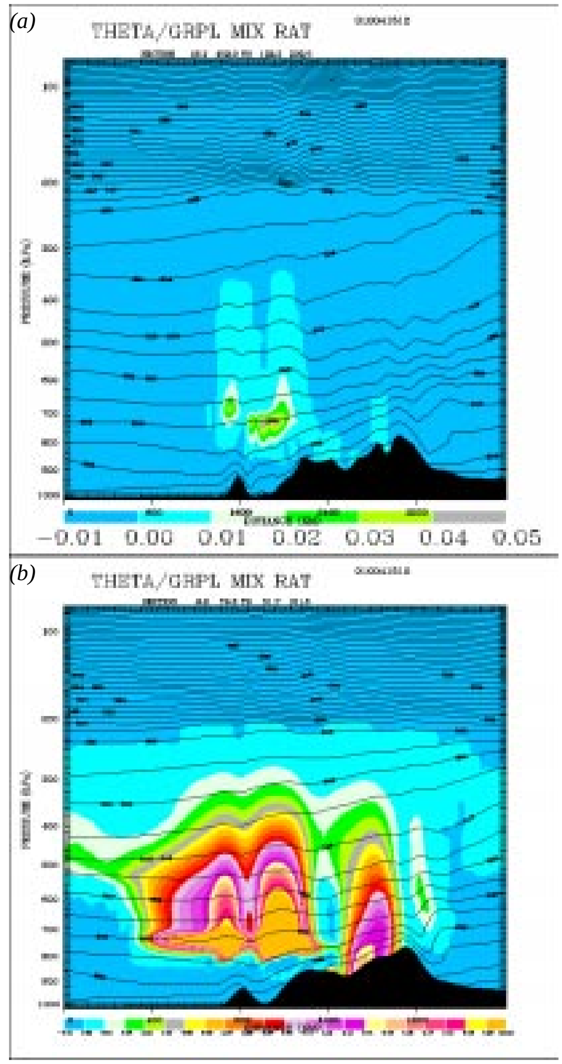

Figure 3. Graupel mixing ratio and isentropes in vertical cross-section for 12-h forecasts valid 0300 UTC 5 Jan 2001. Cross-section is oriented from southwest to northeast from the Pacific Ocean across Washington/Olympic Peninsula into British Columbia and Alberta. a) 20-km RUC, b) 40-km RUC

3) Revised version of explicit mixed-phase microphysics used in RUC and MM5 in collaboration with NCAR/RAP (Brown et al. 2000). The key aspects to this change in the MM5/RUC microphysics are to improve the representation of supercooled liquid water and reduce the exaggerated amounts of ice/graupel. A comparison showing the effects of this change on 12-h RUC forecasts for the same time from the 20-km and 40-km versions is presented in Fig. 3. Another consequence of this change is that precipitation type at the surface is improved. The RUC precipitation type algorithm is calculated directly from hydrometeor output at the surface as opposed to a sounding diagnostic. The 40-km precipitation type showed fairly good rain/snow distinction, but tended to indicate sleet too often due to the problem now fixed in the 20-km version. Also, the scheme is now called with a

much smaller time step, reducing truncation errors that are apparent under close inspection in the current 40-km RUC.

4) Improvements to land-surface/vegetation/snow model, including provision for frozen soil and a 2-layer representation of snow (Smirnova et al. 2000), and more detailed land-surface data. The previous land-use and soil data sets used in the 40-km RUC were from 1-degree resolution data, whereas the 20-km data sets are aggregated from 1-km data sets. The RUC land-surface model has been tested extensively in long-term 1-dimensional simulations, which show that the frozen soil and snow model changes will decrease surface temperature biases in transition seasons. The prescribed values for thermal conductivity are also changed, leading to a more accurate diurnal cycle for soil temperature.

5) More accurate diurnal cycle of temperature also from more frequent call of short-wave radiation (30 min instead of 60 min) and corrected centering within time interval.

5. RESULTS

The two areas where improvement was most needed in 40-km RUC forecasts were quantitative precipitation forecasting, and a diurnal cycle of too small amplitude. Initial results presented by Schwartz and Benjamin (2001) show that the 20-km RUC is fairly successful in providing improvement in both of these areas. In Fig. 4, we present an additional recent case (24-h precipitation ending 1200 UTC 4 May 2001) also showing substantial improvement for a precipitation forecast from the 20-km RUC over that from the 40-km RUC. In this case, an analyzed precipitation maximum of over 3” in the north Texas panhandle was captured in the correct location by the 20-km RUC (> 2”), but with only ~0.8” by the 40-km RUC.

Verification of RUC 20-km and 40-km forecasts against rawinsonde observations show improvement at most levels for wind and height 12-h forecasts from the 20-km version (Fig. 5). Forecasts of temperature and relative humidity show less difference for standard deviation (Fig. 5), but the 20-km version clearly shows smaller bias for these variables (not shown).

6. SUMMARY

A new version of the Rapid Update Cycle will be implemented at NCEP in summer 2001, including 20-km horizontal resolution, 50 vertical levels (increased from 40), and significant improvements to its data assimilation and forecast model components. This new version of the RUC replaces the previous 40-km 40-level version. These changes will result in improvements to RUC performance in many areas, including forecasts of precipitation, near-surface fields of temperature, moisture, and winds, and clouds.

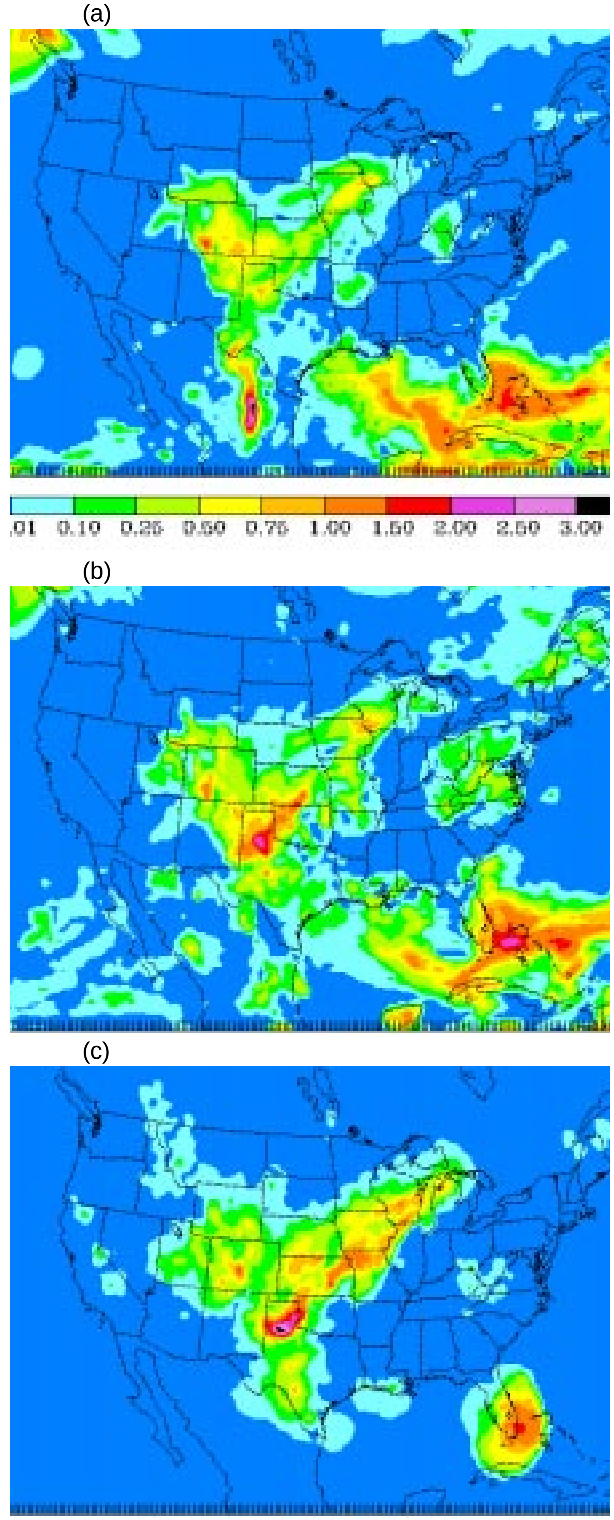

Figure 4. 24-h precipitation ending 1200 UTC 4 May 2001. a) 40-km RUC - two 12-h forecasts summed, b) same for 20-km RUC, c) gauge-based precipitation analysis from NOAA Climate Prediction Center

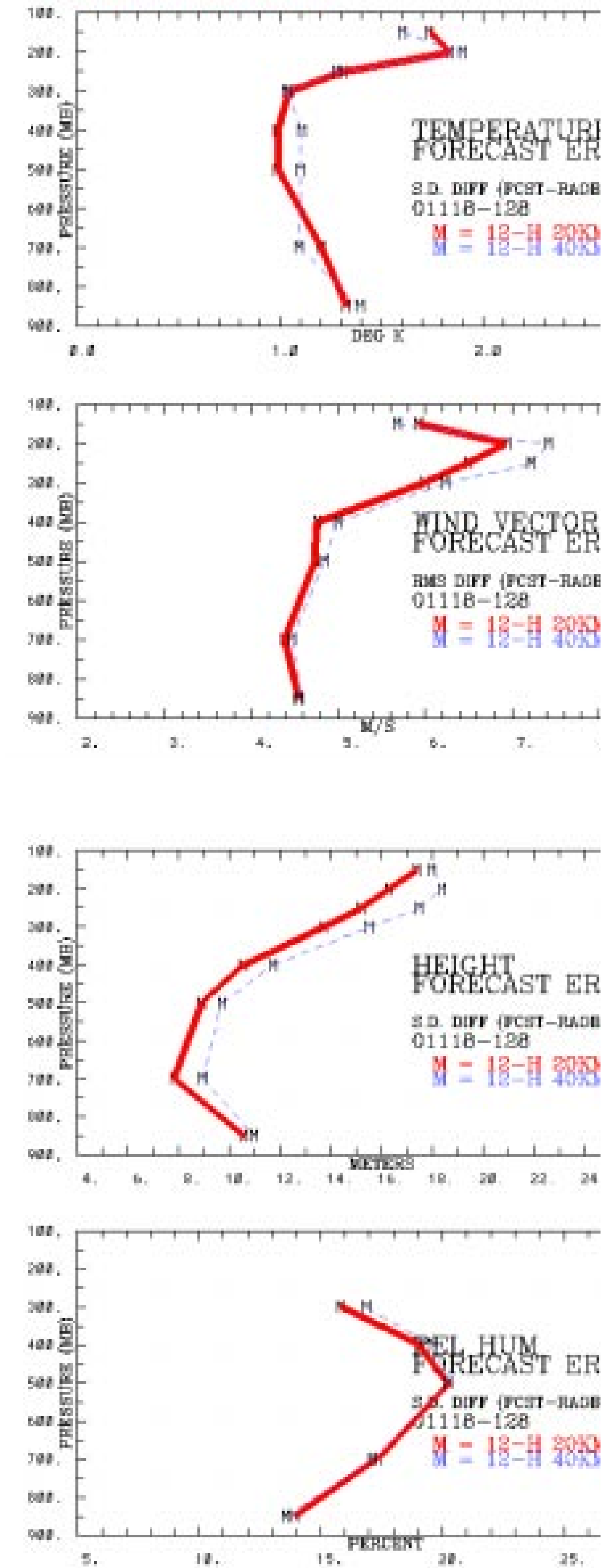

Figure 5. Verification of 12-h RUC forecasts against rawinsonde observations over U.S. for 28 April - 8 May 2001. Solid - 20-km version, dashed - 40-km version.

7. ACKNOWLEDGMENTS

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