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Aviation Forecasts From the RUC-2

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1. INTRODUCTION

A number of significant weather forecasting problems exist in the 0-12 hour range, including hazards to aviation (clear air turbulence, icing, downbursts) and severe weather in all seasons (tornadoes, severe thunderstorms, crippling snow and ice storms). Accurate, frequently updated analyses and short-term numerical predictions are clearly indispensable for improving forecasts of these hazards, as well as for providing the best possible forecasts of ongoing conditions at the surface and aloft, for instance, for wind forecasts used by air traffic management and for efficient flight routing.

The Rapid Update Cycle (RUC) was designed to provide frequently updated, accurate numerical forecast guidance for weather-sensitive users for the next 12-h period. The RUC runs at the highest frequency of any forecast model at the National Centers for Environmental Prediction (NCEP), assimilating recent observations aloft and at the surface to provide high frequency updates of current conditions and short-range forecasts using a sophisticated mesoscale model.

A new version of the RUC (RUC-2) was implemented at NCEP in April 1998. The RUC-2 produces new 3-d analyses and short-range forecasts every hour, compared to the 3-h updating in RUC-1. The original RUC was implemented in September 1994 at NCEP. The RUC-2 is a significant advance over RUC-1 in assimilation frequency, resolution, types of data assimilated, and model physics. These changes allow the RUC-2 to more accurately represent significant weather systems across the United States in all seasons.

In this paper, we summarize the key differences between the new and old RUC, provide some verification data for the new RUC, and describe some upcoming changes in RUC-2.

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2. HIGHER FREQUENCY

The RUC-2 runs on a *1-h assimilation frequency* compared to the 3-h frequency of RUC-1. This increase has been made possible by the continued increase in asynoptic data over the United States and surrounding areas. For datasets available hourly such as profilers and surface data, this represents a 3-fold increase in data being assimilated. Aircraft data are assimilated in a 1-h window, often much closer to their actual valid time, in RUC-2 compared to the 3-h window in RUC-1. Twelve-hour forecasts are run every 3 h in RUC-2, with 3-h forecasts at other times.

The data cut-off time in the 1-h cycle is 20 min after valid time, compared to 1 h 20 min for the RUC-1. This constitutes a full 1-h speed-up in the availability of output from RUC-2 versus RUC-1, an important improvement considering the high-frequency, perishable nature of RUC data. As described by Benjamin and Schwartz (1999), the 1-h cycle in RUC-2 allows use of 1-2 h forecasts for air traffic management compared to 3-5 h forecasts with less frequently updated RUC-1 data. This increased availability adds significantly to the accuracy improvement from RUC-2 for air traffic management.

3. HIGHER RESOLUTION

Horizontal resolution in RUC-2 is *40 km* compared to 60 km for RUC-1. The higher resolution allows considerable improvement in terrain influence on local circulations and orographic precipitation patterns. The domain covered by RUC-2 is about 50% larger than that covered by RUC-1. More ocean area is also covered in the new RUC-2 domain (Fig. 1).

The RUC-2 has *40 vertical levels* compared to 25 levels in RUC-1. The RUC-2 continues to use a generalized vertical coordinate configured as a hybrid isentropic-sigma coordinate in both the analysis and model. This coordinate has proven to be very advantageous in RUC-1 in providing sharper resolution and improved data assimilation near fronts and the tropopause, and improved moisture transport. A sample cross section of RUC-2 native levels is displayed in Fig. 2. The typical RUC-2 resolution near fronts is apparent in this figure, as well as the tendency for more terrain-following levels to “pile up” in warmer regions. The minimum potential temperature spacing (through much of the troposphere) is 2 K instead of 4 K as in RUC-1. The top level in RUC-2 is at 450 K (at about 50 mb, not shown in Fig. 2) as opposed to 410 K in RUC-1. Overall, the vertical resolution is somewhat higher both in the boundary layer and free atmosphere, and the domain extends farther into the stratosphere.

Fig.1. Domain and terrain for the 40-km RUC-2. Topography is shown with 200 m contours.

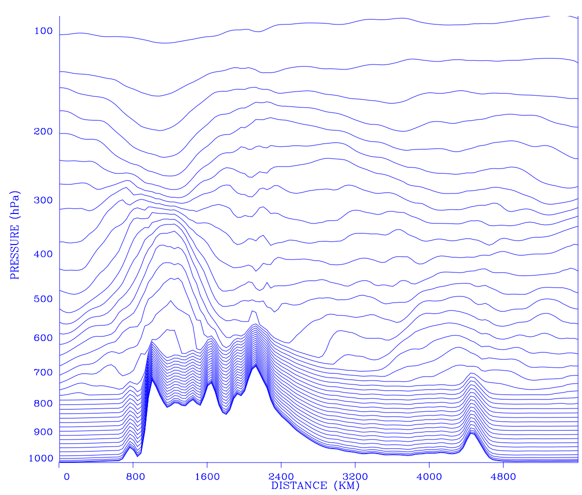

Figure 2. RUC-2 native hybrid isentropic-sigma coordinate levels in a W-E cross section at about 39^{o}N valid at 0000 UTC 1 October 1998 through central California, Washington, DC, and into the Atlantic. The primary mountain ranges shown are the Sierra Nevadas, the Wasatch (Utah), Rockies (CO) and Appalachians (WV/VA).

4. NEW DATA SETS

The RUC-2 uses several new types of observational data not incorporated into RUC-1, including

- VAD (Velocity Azimuth Display) wind profiles from WSR-88D radars,
- total precipitable water values from GOES and polar orbiter satellites,
- GOES cloud-drift winds, and
- reconnaissance data for tropical storms.

New, more accurate specifications of the land and water surface have also been incorporated into RUC-2. These include daily 50-km resolution sea-surface temperatures, daily 14-km resolution lake-surface temperatures for the Great Lakes, and monthly 0.14^{o} latitude vegetation fraction data.

5. IMPROVED ANALYSIS

The optimal interpolation multivariate analysis used in RUC-1 has been substantially modified for the initial RUC-2, providing, among other things, closer fit to observations, better use of aircraft ascent/descent winds and temperatures, and greater efficiency. Levels at and near the surface are subjected to both multivariate and subsequent univariate wind analyses. In the RUC-2, hourly surface analyses are produced directly out of the hourly 3-d cycle rather than in a stand-alone system as in RUC-1. The hourly surface analyses from RUC-2 are considerably improved over those from the RUC-1 surface cycle due to quality control using a forecast model rather than persistence, consistency with mesoscale terrain effects from a model forecast background, and weak geostrophic coupling. The RUC-2 surface analyses fit surface observations of wind and temperature more closely than the RUC-1 surface cycle. Modifications to the RUC-2 analysis were made in October 1998 to improve the use of cloud-drift winds aloft and the influence of surface observations near the surface.

The RUC-2 analysis provides *de facto* analyses of cloud variables and soil variables by using the previous 1-h forecast of these variables as initial conditions for the next run. Although use of observations will later provide improved fields for these variables, as described in Section 8, this “cycling” provides substantial improvement over fields for all cloud variables in initial conditions and climatology for soil variables.

6. IMPROVED MODEL PHYSICS

To provide improved short-range forecasts of icing, turbulence, cloud, precipitation, and surface conditions, the RUC-2 has incorporated state-of-the-art physics parameterizations in the following four areas:

Cloud microphysics. The level 5 microphysics scheme (Reisner et al. 1998) from the NCAR/PSU MM5 model has been incorporated into the RUC-2, providing explicit forecasts of mixing ratios for cloud water, rain water, snow, ice, and graupel. An additional prognostic variable is the number concentration for ice particles. The incorporation of this scheme into RUC-2 is described in detail by Brown et al. (1998).

Turbulence. The Mellor-Yamada level-3.0 scheme of Burk and Thompson (1989) has also been incorporated into the RUC-2. This scheme provides explicit forecasts of turbulence kinetic energy, which show considerable potential for improved forecasts of clear-air turbulence (Marroquin et al. 1998).

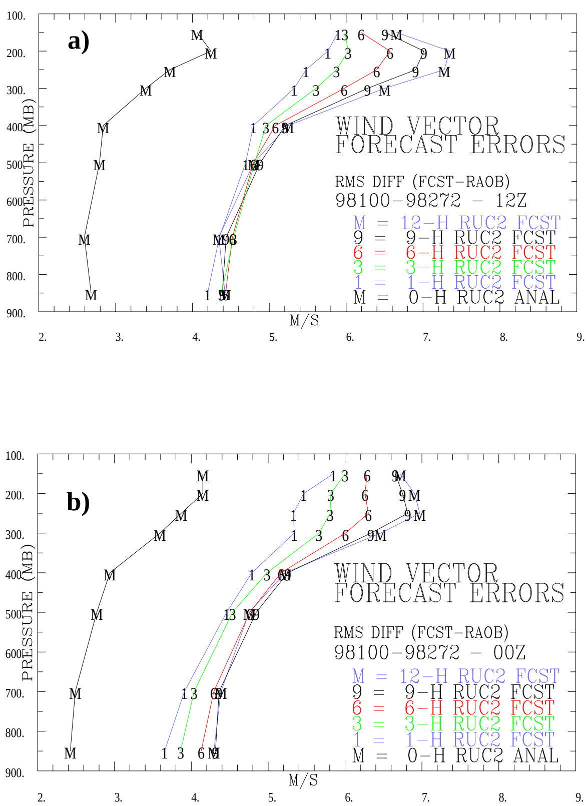

Figure 3. RUC-2 wind forecast verification statistics (RMS vector difference) for analyses and 1-h, 3-h, 6-h, 9-h, and 12-h forecasts valid at the same time against rawinsonde observations. Period is for 10 April - 30 September 1998. a) forecasts valid at 1200 UTC, b) forecasts valid at 0000 UTC.

Radiation. The RUC-2 uses the atmospheric longwave and short-wave component also from the MM5 model (Dudhia 1989). This scheme includes effects of hydrometeor mixing ratios. A fix to a significant problem in the RUC-2 version of this radiation scheme was implemented in October 1998. This fix substantially improves surface temperature forecasts in RUC-2.

Surface physics. A multi-level soil/vegetation/snow module (Smirnova et al. 1997, 1999) runs in the RUC-2, giving much improved forecasts of surface and lower tropospheric conditions. A 1-d soil model with variable soil characteristics, vegetation fraction, and seasonally varying albedo runs at each land grid point with six levels down to 3 m below the surface. A treatment of frozen soil physics was added in October 1998 to improve surface temperature forecasts in spring and fall in northern parts of the RUC-2 domain.

Soil moisture and temperature have been cycled since April 1996 in RUC-2 (in a test version before April 1998), producing, after many months, very reasonable estimates of these fields (Smirnova et al. 1999). For aviation purposes, the use of the soil model and associated cycling has proven to be important, since realistic regional anomalies of soil moisture provided by this model have been shown to improve short-range forecasts of surface temperature, clouds, and related fields in the RUC-2.

7. SHORT-RANGE FORECAST SKILL

The 40-km RUC-2 provides somewhat more accurate forecasts of upper-air variables than the 60-km RUC-1 (Benjamin et al. 1997). Verification against commercial aircraft reports in the central U.S. indicate an improvement in RMS vector error of 0.5-1.0 ms^{-1} between RUC-1 and RUC-2 short-range forecasts (Benjamin and Schwartz 1999).

Verification against rawinsonde observations shows a steady improvement in skill as forecast duration decreases for both wind (Fig. 3) and temperature (Fig. 4) due to the use of more recent asynoptic data. The fit of RUC-2 analyses to rawinsonde data is also shown in Figs. 3 and 4, indicating the approximate score for a "perfect" forecast, accounting for rawinsonde observation error. The fit to the rawinsonde observations (indicated by the left-most line labeled 'M') is set by the specified observational error in the analysis. Thus, a substantial portion of the difference between forecast and analysis fit to rawinsondes is removed when going from a 12-h to a 1-h RUC-2 wind forecast at upper levels. For users able to use frequent short-range wind forecasts from the RUC-2 such as air traffic management, this increased skill is significant. It also shows that the hourly assimilation in RUC-2 is resulting in better analysis quality through the accuracy of the 1-h forecast background.

7.1 Daytime versus nighttime forecasts

The degree of improvement from use of asynoptic data in RUC-2 is larger at 0000 UTC than at 1200 UTC, a curious result. This difference is apparent for both wind (Fig. 3) and temperature forecasts (Fig. 4). For wind forecasts, the 1-h and 3-h forecasts show more improvement over longer duration forecasts at 0000 UTC (Fig. 3b) than at 1200 UTC (Fig. 3a). This difference for wind forecasts is most apparent in the lower troposphere (500-850 mb) and is smaller at higher levels (150-400 mb).

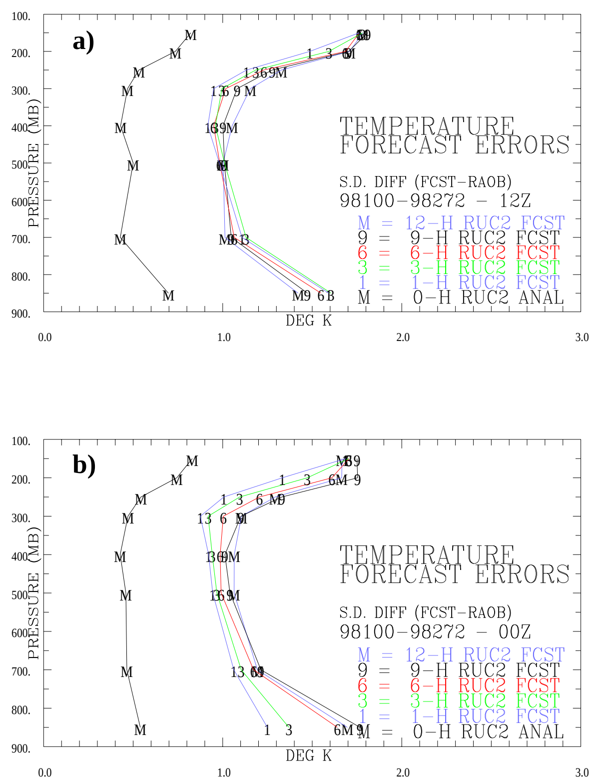

Figure 4. Same as Fig. 3 but for RUC-2 temperature forecasts. Again, a) is for forecasts valid at 1200 UTC and b) is for forecasts valid at 0000 UTC.

For temperature forecasts (Fig. 4), the short-range (1-3 h) forecasts again show more improvement over longer duration forecasts in the lower troposphere (500-850 mb). In fact, short-range temperature forecasts valid at 1200 UTC are actually slightly worse at 700 mb and 850 mb than longer-range forecasts. At higher levels (200-400 mb), short-range temperature forecasts are more accurate than longer-range forecasts valid at 0000 UTC or 1200 UTC, but the margin of improvement is again greater at 0000 UTC.

There are two possible reasons for this behavior: 1) larger error in daytime forecasts valid at 0000 UTC and, hence, more room for improvement from assimilation of asynoptic data, or 2) additional asynoptic data available in the daytime period ending at 0000 UTC versus the nighttime period ending at 1200 UTC.

It appears that there is a larger 12-h forecast error in lower tropospheric temperature forecasts valid at 0000 UTC, probably related to daytime boundary layer heating. However, for upper level temperatures and winds at all levels, it appears that the difference in daytime versus nighttime asynoptic data is probably responsible for the difference in short-range forecast improvement. All of the asynoptic data sources used in RUC-2 are available with about the same volume day or night with the key exception of commercial aircraft data. Thus, it is likely that diurnal variations in the volume of commercial aircraft data are at least partly responsible for the diurnal variation of short-range forecast skill. To the extent that this is true, short-range (1-3 h) forecast skill from the RUC-2 at night will increase as more nighttime aircraft data become available. It may also be that further improvements will occur in *daytime* RUC-2 forecasts with increased aircraft data, but no conclusions on that can be drawn from these results.

8. INITIAL WORK TOWARD THE RUC-2 CLOUD ANALYSIS

Considerable improvement in the RUC-2 cloud and moisture initial fields is expected in the next 2 years. This will occur through assimilation of satellite, radar, surface, and possibly lightning data.

The first step toward the RUC-2 cloud analysis has been development of a cloud-top pressure product combining GOES imager data and RUC-2 forecast fields. This product will be used to modify the explicit cloud fields from RUC-2 forecasts by pruning or adding clouds, with consistent changes in water vapor mixing ratio.

The use of the forecast cloud is an essential ingredient of the cloud analysis, since the 3-d cloud field is partially unobserved. Satellites provide cloud top information only, radar gives reflectivity information from precipitation only, and surface clouds provide cloud base only and with incomplete horizontal coverage. The cloud forecast from the previous 1-h forecast is the best estimate for clouds in unobserved regions, such as occurs with multiple cloud layers or with low-level clouds in mountainous regions.

A diagnosis of forecast cloud top from the RUC-2 is shown in Fig. 5, where a water cloud top has been estimated from the highest level where the cloud water mixing ratio exceeds 10^{-8} g g^{-1}. (A similar field, not shown, can be produced for forecast ice clouds.) The corresponding diagnosed cloud top from the GOES-8 imag-

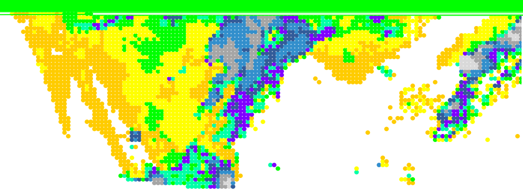

Figure 6. Cloud top pressure (mb) from GOES-8 imager channel 4 combined with RUC-2 temperature and pressure data, valid at 1145 UTC 2 Oct 1998. Predicted surface pressure is shown where there is data but no cloud. (white for > 1000 mb)..

9. SUMMARY AND THE FUTURE RUC

A new version of the Rapid Update Cycle, RUC-2, was implemented at NCEP in April 1998, culminating 2-3 years of development. Many aspects of the RUC-2

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