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Hourly data assimilation with the Gridpoint Statistical Interpolation for the Rapid Refresh

Dezso Devenyi*[1], Stephen S. Weygandt, Thomas W. Schlatter[1], Stanley G. Benjamin, Ming Hu[2]

NOAA Earth Systems Research Laboratory, Boulder, CO
[1] Collaboration with the Cooperative Institute for Research in Environmental Sciences (CIRES), Boulder, CO
[2] Center for Analysis and Prediction of Storms (CAPS), University of Oklahoma, Norman, OK

1. Introduction

The Rapid Refresh (RR) model and analysis system, currently under development at the Earth System Research Laboratory (ESRL), will replace the Rapid Update Cycle (RUC) in 2009. The RUC has been operational at the National Centers for Environmental Prediction (NCEP) since 1994. It is a high-frequency (hourly) data assimilation and prediction system designed to provide meso-scale weather guidance for aviation, severe weather, and public forecasting needs. The RR will occupy the same niche as the RUC in the NCEP operational model suite, but will be based on one of the two dynamical cores of the Weather Research and Forecasting (WRF) model and utilize the Gridpoint Statistical Interpolation (GSI), under development at NCEP and other agencies, for the hourly data assimilation cycle. In addition, as seen in Fig. 1., the RR will run over a domain that is 2.6 times larger than the present RUC domain, including Alaska, Puerto Rico and the Caribbean. For further information about the general design of RR, see Benjamin et al. (2007). Experiments relating to the selection of a WRF dynamical core for the RR are described in Brown et al. (2007).

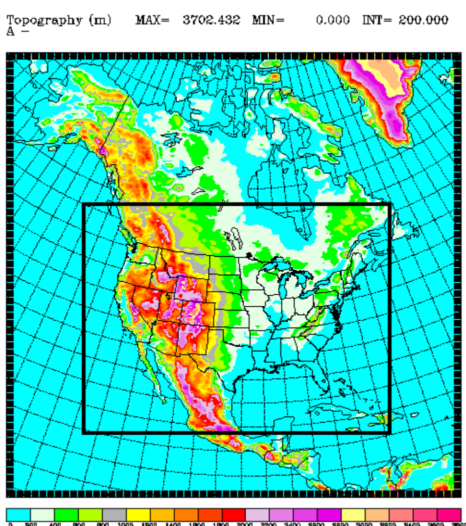

Fig. 1. Topography within the analysis and forecast domain planned for Rapid Refresh. Inner frame represents current RUC domain.

*Corresponding author address: Dezso Devenyi, NOAA/ESRL/GSD, 325 Broadway, Boulder, CO 80305, dezso.devenyi@noaa.gov

This paper describes new developments related to the data assimilation aspects of RR. In the present RUC system, a three-dimensional variational (3-DVAR) scheme is used in RUC's hourly update cycle for analysis of data from diverse sources. In the new RR, following a design decision in June 2005, the Gridpoint Statistical Interpolation (GSI) scheme will be used for data assimilation instead of the current RUC 3DVAR scheme.

For more details about GSI and its latest version see web site

http://www.emc.ncep.noaa.gov/gmb/treadon/gsi/

For the first conference report about installation of GSI at ESRL, see Devenyi et al. (2005).

2. Features of the present RUC 3-DVAR important for Rapid Refresh application

The operational RUC system performs well in a 1-h data assimilation cycle as a result of the specific features listed below. It is mandatory that the RR retain or even improve on these features.

- Assimilation of surface data within full 3-DVAR: analysis of METAR data (and other surface mesonet observations) is an integral part of RUC 3-DVAR. The contribution of these observations to the analyses is especially important at non-synoptic times.

- Cloud/hydrometeor analysis using background three-dimensional hydrometeor fields, derived from GOES cloud-top pressure/temperature, METAR cloud/visibility and radar data.

- Revised balance and background error covariances (standard errors and scales) appropriate for 1-h rapid updating.

- Calculation and application of innovations for METAR/buoy data, including application of similarity theory in the observation operator for 2-m temperature and mixing ratio, and 10-m wind. Use of pseudo-innovations from surface observations through the estimated depth of the planetary boundary layer (PBL).

- Quality control: checking like observations against each other in the same neighborhood, checking for consistency between RAOB moisture profiles and estimates of total column water vapor from Global Positioning Satellites, platform flagging, and limiting the size of innovations.

- Adjustment of background soil temperature/moisture based on surface temperature/moisture analysis increment, depending on the environmental conditions (daytime, no cloud/precipitation, etc.)

- Land-use dependency near the surface.

In the present paper we restrict ourselves to basic issues: the use of data at the surface and in the boundary layer, assimilation of satellite radiance data and first experiences with a real time cycle.

Work related to the assimilation of radar reflectivity data in the RUC and its future application in RR is treated in detail by Weygandt et al. (2007). Hu et al. (2007) give information about a generalized cloud scheme for RR using radar, satellite, and METAR observations of clouds.

3. Surface and PBL analysis

One of the RUC strengths is the handling of surface data during the analysis period. The influence of surface data is restricted to the PBL using pseudo-observations. For the time being, a different approach is taken in the GSI, using anisotropic background covariance information in an adaptive way. The premise is to apply the PBL depth as computed in the present RUC (for details see http://ruc.fsl.noaa.gov/vartxt.html#PBL) and use this to constrain the scale of vertical correlation in the background error. This approach is combined with a model for anisotropic background error developed and implemented in GSI by NCEP (Pondeca et al., 2005). The present code employs the background virtual potential temperature when computing the vertical correlation of background error.

To illustrate how this idea works, we consider the case of 0000 UTC 15 July 2006. The height of the boundary layer is defined as the first level above the surface for which the virtual potential temperature (θ_v) is at least 0.6K greater than at the surface. Figure 2 shows the θ_v difference between level 1 (the surface) and level 5, about 600 m above the surface.

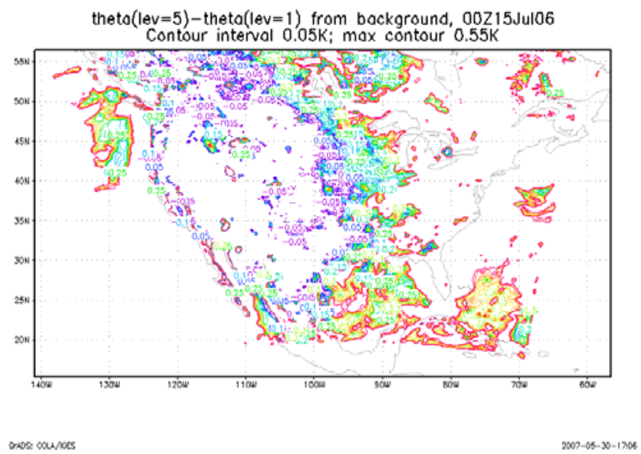

Fig. 2. The virtual potential temperature difference between level 5 and level 1 (the surface). Contours drawn at .05K intervals from -0.05K to 0.55K only, not outside this range. The purple contour is for 0.05K; the red contour is for 0.55K.

The top of the PBL is above level 5 over most land areas except in the eastern U.S. and Canada. At these longitudes, the hottest part of the day is past, and the sun is lower in the sky. The deepest PBL is evidently over the high elevations of the West, where θ_v is nearly constant between levels 1 and 5.

Figure 3 illustrates the θ_v difference between levels 1 and 9 (about 1500 m above the surface). Nowhere over water does the PBL extend to level 9 and, over land boundary layers this deep become spotty over high terrain, mostly in the West.

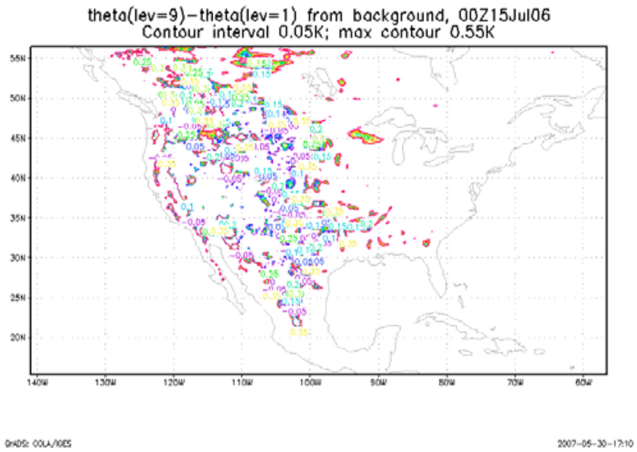

Fig. 3. The virtual potential temperature difference between levels 1 and 9. Contouring same as in Fig. 2.

It is desirable for the surface data to influence the analysis within the well-mixed boundary layer, but not beyond. Evidence that this is occurring may be found in the next two figures.

Figure 4 presents a vertical cross section along 44°N. The analysis increment of the u-component of the wind (colored contours) is shown along with the background virtual potential temperature (black contours). This case corresponds to an isotropic analysis, in which the horizontal correlation of background error shows no directional preference.

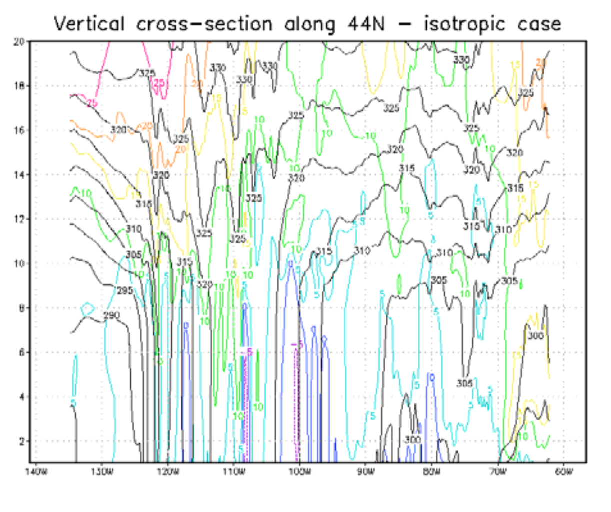

Fig. 4. Cross section along 44°N. Color contours depict analysis increment for the u-component of the wind; black contours depict the background θ_v. Isotropic analysis.

Figure 5 shows the corresponding result for the anisotropic case, in which the flow field imparts directional dependence to the horizontal correlation of background error.

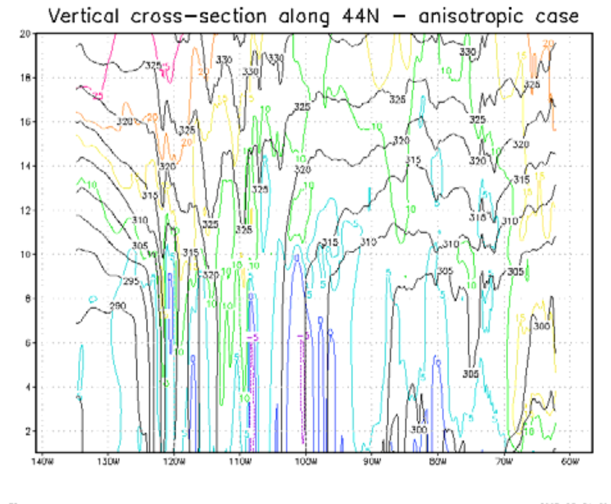

Fig. 5. As in Fig. 4, except for anisotropic analysis.

The difference between the two analyses is shown in Fig. 6. Close to 120°W, there is a difference of at least 5 m s^{-1} between u-component analyses. In this case, the reason is that the u-component analysis increments conform more closely to the θ_v contours in the anisotropic case.

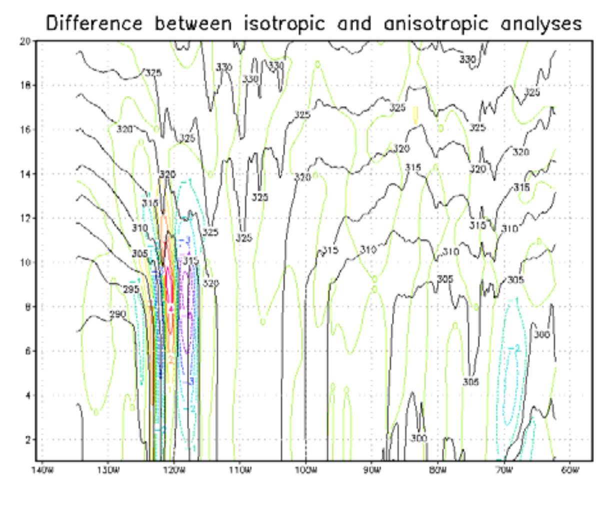

Fig. 6. Difference between isotropic and anisotropic analyses.

4. Assimilation of satellite radiance

Satellite radiance assimilation will be a new feature of the planned RR, and GSI provides this capability. Preliminary experiments have been performed over the Continental U.S. (CONUS) domain using satellite data and bias files from the NAM (North American Model) of NCEP during a limited period. Two analyses were generated, both relying on observations stored in NCEP's prepBUFR files, but one of them incorporated, in addition, radiance observations from polar orbiting satellites, specifically from these instruments: MSU, MHS, HIRS4, HIRS3, HIRS2, and AMU. The radiance data were stored in separate BUFR files.

Here the 1200 UTC 11 April 2006 case is presented. Figure 7 shows the difference between the two analyses of potential temperature at level 10, roughly 2000 m above the surface. Figure 8 shows the difference between specific humidity analyses for the same level. As expected, the incorporation of satellite radiance data in the initial state leads to significant modifications only over open water, where there is little competition from other observing systems.

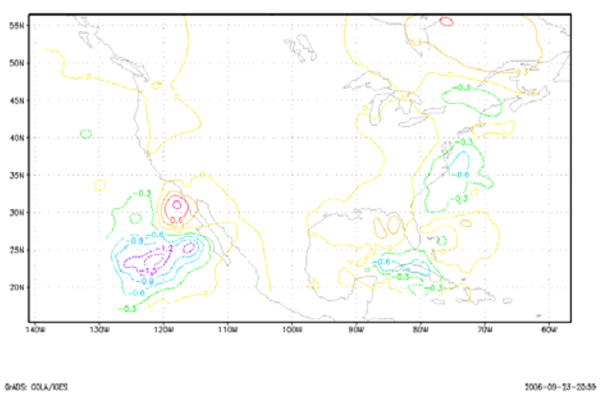

Fig. 7. Difference between satellite and no-satellite potential temperature analyses at model level 10. 1200 UTC 11 April 2007.

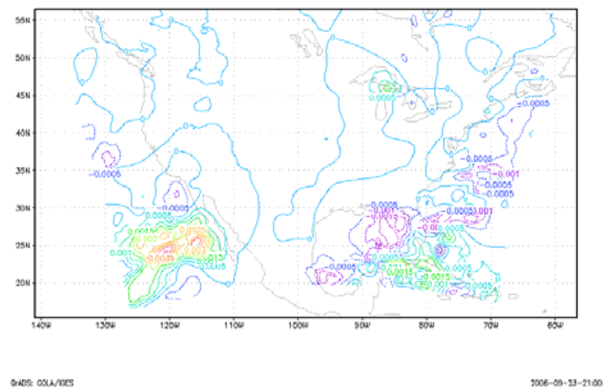

Fig. 8. Difference between satellite and no-satellite specific humidity analyses at model level 10. 1200 UTC 11 April 2007.

5. Information about present real time cycle

Because of computer resource limitations, the current RR real-time runs are restricted to a 12-hour cycle. This suffices to test basic stability and viability of the new set-up. We use the WRF-ARW model for the forecast, with lateral boundary conditions supplied by NCEP's Global Forecast System (GFS), and GSI assimilation. Here we present an example from 29 May 2007 1200 UTC, including an analysis and a 3-h forecast. Figure 9 presents the wind analysis at model level 15 colored by the potential temperature.

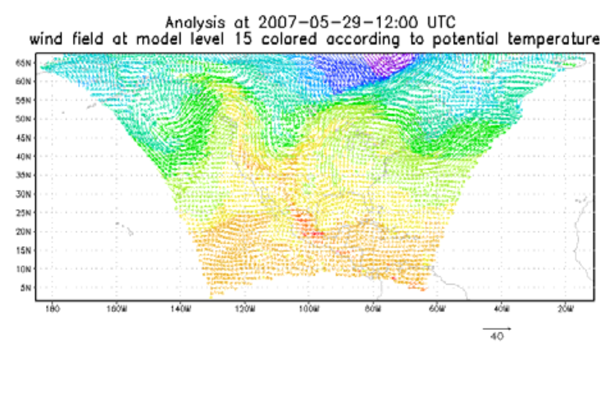

Fig. 9. Analysis at 1200 UTC 29 May 2007 over RR domain. Wind field at model level 15 colored according to potential temperature. Each color represents a 5-K interval of potential temperature, with purple representing from 285-290K (north) and red representing 330-335K (south).

The corresponding 3-hour forecast is presented in Fig. 10. Subjective analysis indicates that these fields are realistic.

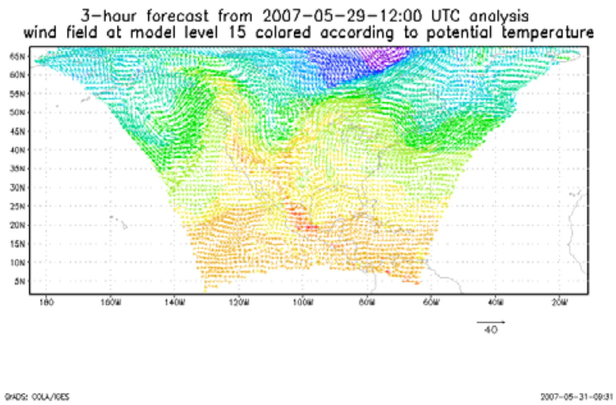

Fig. 10. 3-hour forecast from 1200 UTC analysis. Wind field at model level 15 colored according to potential temperature. Color scale as in previous figure.

6. Future work

All GSI tests reported above were performed using the September 2006 version of GSI. In the real-time application, the May 2006 version of GSI was used. We intend to follow new releases of GSI as closely as possible.

The most important work in the near future is the installation of a high-frequency RR cycle on the new supercomputer of ESRL. This will enable controlled experiments with a 1-h cycle and the introduction of individually tested components into the system. The deadline for establishing this cycle is September 2007.

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REFERENCES

Benjamin, S.G., S.S. Weygandt, J.M. Brown, T.G. Smirnova, D. Devenyi, K.J. Brundage, G.A. Grell, S.E. Peckham, T.W. Schlatter, T.L. Smith, and G.S. Manikin, 2007: From radar-enhanced RUC to the WRF-based Rapid Refresh. *18th Conference on Numerical Weather Prediction*, 24-29 June, Park City, UT, Amer. Meteor. Soc., Paper J3.4.

Brown, J.M., S.G. Benjamin, T.G. Smirnova, G.A. Grell, L.R. Bernardet, L.B. Nance, R.S. Collander, and C.W. Harrop, 2007: Rapid-Refresh core test: aspects of WRF-NMM and WRF-ARW forecast performance relevant to the Rapid-Refresh application. *18th Conference on Numerical Weather Prediction*, 24-29 June, Park City, UT, Amer. Meteor. Soc., Paper 4A.1

Devenyi, D., S.G. Benjamin, J.M. Middlecoff, T.W. Schlatter, and S.S. Weygandt, 2005: Gridpoint statistical interpolation for Rapid Refresh. *17th Conf. on Numerical Weather Prediction*, 1-5 August, Washington, D.C., Amer. Meteor. Soc., Paper P1.56

Hu, M., S.S. Weygandt, M. Xue, and S.G. Benjamin, 2007: Development and testing of a new cloud analysis package using radar, satellite, and surface cloud observation within GSI for initializing Rapid Refresh. *18th Conference on Numerical Weather Prediction*, 24-29 June, Park City, UT, Amer. Meteor. Soc., Paper P2.5.

Pondeca, Manuel S.F.V. de, R.J. Purser, D.F. Parrish, and J.C. Derber, 2005: Comparison of strategies of anisotropies in the covariances of a three-dimensional atmospheric data assimilation. *4th WMO International Symposium on Assimilation of Observation in Meteorology and Oceanography*, 18-22 April 2005, Prague, Czech Republic. Proceedings on CD.

Weygandt, S.S., S.G. Benjamin, and J.M. Brown, 2007: Radar reflectivity-based initialization of precipitation systems using a diabatic digital filter within the Rapid Update Cycle. *18th Conference on Numerical Weather Prediction*, 24-29 June, Park City, UT, Amer. Meteor. Soc., Paper 1B.7.