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A NEW VERSION OF RUC 3DVAR

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1. INTRODUCTION

A new version of the Rapid Update Cycle (RUC) was implemented operationally at the National Centers for Environmental Prediction (NCEP) in April 2002 (Benjamin et al. 2002a). This new version features a doubling of the horizontal resolution (40-km 20-km) and an increase on the number of vertical levels (40 to 50), as well as improvemnets to the model physical parameterizations. In this 20-km version of RUC (or RUC20), the objective analysis is performed by the optimal interpolation (OI) method. To improve the data assimilation and to facilitate the introduction of new data types into the analysis, a 3DVAR analysis method has been under development for several years.

Because the RUC20 is a very high-frequency mesoscale data assimilation and short-range prediction system, it utilizes an hourly data analysis cycle, with the previous 1-h forecast providing the background field. The analysis is performed over the RUC domain, which includes the lower 48 United States and adjacent areas of Canada and Mexico. The RUC20 assimilates many different types of data, including rawinsonde and surface observations, wind profiler observations, aircraft observations, cloud-drift winds, and observations of integrated precipitable water (IPW) from both geostationary and polar-orbiting satellites. All observations are preprocessed and are the subject of a hierarchy of quality control checks.

In this paper, we describe the formulation of the RUC three-dimensional variational (3DVAR) analysis procedure and present the latest results from its development and testing.

2. BASIC FEATURES OF RUC 3DVAR

A key issue in the design of RUC 3DVAR is the introduction of a *unified framework* which allows us to use the same data processing and quality control procedures for both the OI and 3DVAR methods. Using this framework, we can easily switch from one analysis method to the other and perform comparisons between the schemes.

The basic version of RUC 3DVAR is described in Devenyi et al. (2001). Here we summarize the most important features. In the RUC 3DVAR, we minimize the standard form of the incremental cost function. The control variables are streamfunction, velocity potential, unbalanced height, virtual potential temperature, and the natural logarithm of water vapor mixing ratio. The analysis is performed on hybrid sigma-isentropic model levels. The use of this hybrid grid space introduces some adaptivity in 3-D model space according to the baroclinic structure of the background field.

During the preprocessing phase of 3DVAR, all observations are converted into differences from background (innovations) and subjected to buddy checks. The buddy check procedure is the same as that used in the OI analysis, and it provides appropriately flagged data for further processing.

The 3DVAR analysis includes three main steps, which closely follows the design of the OI method (Benjamin ,1989):

1. First, a multivariate wind/mass analysis is performed using streamfunction, velocity potential and unbalanced height as control variables (each scaled by grid distance). Balancing is accomplished by using a pre-computed linear regression relationship

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between balanced height and streamfunction. At present, no cross-correlation between streamfunction and velocity potential is employed.

2. Second, the new height analysis increment is used to update the virtual potential temperature background field. New innovations are then computed from this updated field and a univariate virtual potential temperature analysis is performed.

3. Third, the moisture field is analyzed in a univariate framework. Several iterations are performed with updated moisture background fields and recomputed moisture innovations. Two other moisture analysis procedures are included within this outer moisture loop, assimilation of GOES cloud-top pressure (Benjamin et al. 2002b, Kim et al. 2002) and assimilation of integrated precipitable water (IPW) observations, currently using an OI technique (see section 4).

For all analysis variables, increment fields obtained from the minimization are used to update the background fields. Then, all analyzed fields are mapped to the hybrid isentropic-sigma coordinate by vertical interpolation.

For most observation types, the observation (forward) operators are simply linear interpolation operators. The observation and representativeness standard deviations are represented by diagonal matrices. The matrix values are obtained from corresponding values in the optimal interpolation method.

The first-guess error correlations are approximated by convex linear combinations of digital Gaussian filters with different filter scales. A filter package developed by R. James Purser of NCEP is used (for details see Purser et al. 2001). Using the filter package, approximate convolutions of a Second Order Autoregressive (SOAR) function and increment fields are computed. Approximation to a SOAR function is provided as follows. We define elementary Gaussian correlation functions as:

$$G_k(r) = \exp\left[-\frac{1}{2}\left(\frac{r}{L_k}\right)^2\right].$$

The SOAR function is given by

$$C(r) = \left(1+\frac{r}{L_S}\right)\exp\left(-\frac{r}{L_S}\right).$$

Therefore, to get an appropriate mixture of Gaussian correlations, we minimize the following distance:

$$\left(C_S - \sum_{k=1}^{K} w_k G_k\right)^2.$$

Real-time application restrictions limit our scheme to two Gaussian filter applications (K=2). We performed different numerical experiments to obtain the optimal combination of weights.

3. SPECTRAL VERSION OF RUC 3DVAR

Spectral versions of the 3DVAR method make use of the fact that the convolution between fields in physical space can be performed in wave number space by multiplication between transformed fields. Fast Fourier Transformation (FFT) is a convenient tool to communicate between the two spaces.

In order to better understand the properties of our filter-based approximate SOAR correlations and to introduce a reference scheme, a spectral version of RUC 3DVAR was developed with direct spectral representation of the homogeneous and isotropic 2-D SOAR functions. This representation follows the one given by Daley (1991, p.78, Eq. (3.3.27)), and it has the form

$$\widehat{C}(k,l) \propto (1+L^2(k^2+l^2))^{-5/2}$$

where k and l are wave numbers and L is the scale in the SOAR function. For application with the streamfunction as a control variable, a zero Dirichlet boundary condition is applied. This results in a *sine* transformation for streamfunction fields. Similarly, for velocity potential, a zero Neumann boundary condition results in a *cosine* transformation. FFTPACK Version 4 is applied to compute sine and cosine transformations.

4. ASSIMILATION OF IPW DATA

Appropriately assimilated IPW data can play an important role in prediction of severe weather through improved analysis and forecasting of precipitation and stability. Results from a number of GPS impact studies using different versions of the RUC model are presented in Smith et al. (2002).

Direct assimilation of IPW data in the RUC 3DVAR framework has proven to be a difficult problem. IPW assimilation tests using the RUC 3DVAR scheme have shown a bad fit to the observations and unrealistic moisture fields. The probable cause of these difficulties may lie in differences between characteristic scales of integrated precipitable water and moisture fields and large representativeness errors of forward models. In order to lessen the effect of these problems, we developed a suboptimal approach to IPW data assimilation in RUC 3DVAR. Our method is similar to the one applied by Joiner and Dee (2000) in satellite radiance data assimilation. In the suboptimal approach, the first step of the analysis is a 1-D retrieval of vertical moisture profile. A 1DVAR method was developed for this purpose using specific humidity as the control variable. Retrieved moisture profiles can be assimilated in several ways. In the simplest approach we just neglect the unknown nonzero retrieval-background error covariances. This results in suboptimal gain but the scheme still performs better than the ones using incorrect retrieval error covariances.

5. RESULTS

Extensive real-time and retrospective tests have been conducted with the RUC 3DVAR analysis procedure. Performance results from these trial runs will be presented at the conference.

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