Development of Unified 3DVAR for Global and Regional Application in KMA

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1. Introduction

Unified 3DVAR (hereafter U3VR) has been developed in collaboration with MMM division of NCAR. Although primarily designed for use with WRF (Weather and Research Forecasting Model), unified 3DVAR is being used in operational applications with KMA(Korea Meteorological Administration) global and regional model. The major motivation of the development is to share the common codes from global to regional data assimilation system in terms of observations, preconditioning, background error statistics, minimization algorithm etc. This paper shows the cycling experiment results estimated by KMA global and WRF model without satellite radiance assimilation.

2. Main characteristics

Unified 3DVAR is built within the WRF Advanced Software Framework (Michalakes *et al.,* 2005) in order to make use of advanced IO and distributed memory parallelism software. U3VR (based on the WRF 3DVAR described in Barker *et al*., 2005) has been continuously upgraded since first version was released in the early 2005. Among several versions of U3VR, the one developed in August 2005 was used in this study.

Major differences between KMA operational global/regional 3DVAR and unified 3DVAR are shown in Table 1. The most important difference is the control variable. U3VR uses the stream function(ψ), unbalanced velocity potential(χ_u), unbalanced temperature(T_u), unbalanced surface pressure(Ps_u), and pseudo relative humidity(*RH*) as the control variables, while KMA global 3DVAR(G3VR) introduces the vorticity(ζ), unbalanced divergence(D_u), unbalanced temperature, unbalanced surface pressure, and logarithmic specific humidity(lnq), and KMA regional 3DVAR (R3VR) introduces the stream function, velocity potential, unbalanced pressure, and specific humidity.

U3VR is more generalized and flexible approach when it is compared with G3VR and R3VR. It has more various options to select. Background error statistics based on ensembles can be used to describe the forecast errors (Lee *et al.,* 2005), even if NMC method is being used currently. FGAT (Lee *et al*., 2004) and selective minimization method (Quasi-Newtonian or Conjugate Gradient) can be also optional in U3VR.

Table 1. The comparison of major differences among regional (R3VR), global (G3VR), and Unified 3DVAR (U3VR).

	R3VR	G3VR	U3VR
Control variables (v)	ψ, χ, P_u, q	$\xi, D_u, T_u, Ps_u, \ln q$	$\psi, \chi_u, T_u, Ps_u, RH$
Background E (B)	NMC	NMC	NMC and ENS
Adaptive QC	No	No	Yes
FGAT	No	Late 2005	Yes
Satellite Radiance	No	Radiance	End of 2005
Analysis Grid	Grid (LC)	Wave	Grid (LL/LC)
U transformation $B = UU^T$ $x' = U_p U_v U_h v$	EOF Recursive Filter	No vertical Transform Wave to Grid	EOF Spectral Power or Recursive Filter
IO	Binary	Binary	NETCDF
Code	f90	f77	F90 / MPI
Minimization	QN	QN	QN and CG

The basic goal of U3VR is to seek an optimal estimate of the true atmospheric state at analysis time through iterative solution of a prescribed cost-function:

$$\boldsymbol{J}(\boldsymbol{x})=0.5(\boldsymbol{x}-\boldsymbol{x}_b)^T\boldsymbol{B}^{-1}(\boldsymbol{x}-\boldsymbol{x}_b)+0.5(\boldsymbol{y}-\boldsymbol{y}_o)^T\boldsymbol{O}^{-1}(\boldsymbol{y}-\boldsymbol{y}_o) \quad (1)$$

All notations in Eq.(1) are same as Barker *et al.* (2003).

This solution represents the estimate of the true atmospheric state given by two sources of a priori data, the background x_b and observations y_o. One practical solution to (1) is to perform a preconditioning via a control variable(v) transform defined by $\delta x = Uv$, where $\delta x = x - x_b$. The transform U is chosen to approximately satisfy the relationship $B = UU^T$. Using the incremental formulation and the control variable transform Eq. (1) can be rewritten as

$$J(\boldsymbol{v}) = 0.5\boldsymbol{v}^T\boldsymbol{v} + 0.5(\boldsymbol{d} - \boldsymbol{H}'\boldsymbol{U}\boldsymbol{v})^T\boldsymbol{O}^{-1}(\boldsymbol{d} - \boldsymbol{H}'\boldsymbol{U}\boldsymbol{v}) \quad (2)$$

where $d = y_o - H(x_b)$ is the innovation vector and H' is the linearization of the potentially nonlinear observation operator.

3. Background error statistics

The control variable transform is in practice composed of a series of operation $\delta x = U_p U_v U_h v$ (Lorenc *et al.* 2000) ensuring the relationship $B = U_p U_v U_h v U_h^T U_v^T U_h^T$. Generally the NMC method (Parrish and Derber, 1992) provides a climatological estimate of background error covariance, assuming the background error is closely related with the averaged forecast difference (e.g., month-long series of 24h-12h in regional, 48h-24h in global). U_p and U_v are same in global and regional part in terms of control variables and EOF decomposition representing the vertical correlation. U_h should be different for global part of power spectrum and regional part of recursive filter.

Fig. 1 shows the correlation between balanced and full component of velocity potential (left) and temperature (right) error fields as estimated from KMA T213 48 minus 24 hour forecast differences. (c) and (d) are same as (a) and (b) except for WRF 10km forecasts with 24 minus 12 hour forecast differences. Results show that up to 40% of the global velocity potential error can be estimated from the stream function in the mid-latitude boundary layer(Fig. 1(b)). Larger values are appeared in the boundary layer of KMA WRF 10km domain (Fig. 1(c)) too. For temperature, up to 90% of error in global (Fig. 1(b)) and 40% in regional (Fig. 1(d)) can be estimated from the stream function. These significant correlations show the importance of using the unbalanced (rather than full) components of velocity potential and temperature as control variable – with the full fields, these multivariate error correlations would be ignored, resulting in a potentially much poorer analysis.

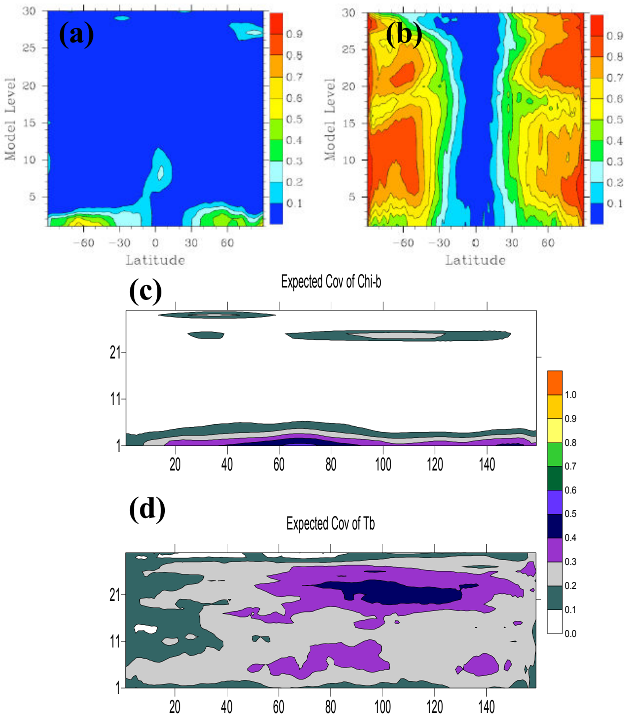

Fig. 1. (a) and (b) shows the correlation between balanced and full component of velocity potential (left) and temperature (right) error fields by KMA T213 global model. (c) and (d) are same as (a) and (b) except for KMA WRF-10km forecasts.

Unified 3DVAR has three unbalanced control variables, χ_u, T_u, Ps_u, and the balanced components of these variables are modeled via a regression analysis of the field using specified predictor field, stream function. The resulting regression coefficients are for use in U_p transform in 3DVAR (Wu *et al*.,2003).

4. Forecast performance

4.1 Global forecasts

U3VR was coupled with KMA global model and its result was compared with that of G3VR. One-month cycles from January and July 2005 were implemented to investigate the winter and summer season performance, respectively. T213 global model system has a suite with 6 hour cycling period.

To make exact comparison, we used almost same observation data sets in both operational G3VR and U3VR. Because 2005 U3VR version did not include the satellite radiance assimilation part and typhoon bogussing part, we eliminated these parts from the operational G3VR. Fig. 2 shows 20 days verification results against analysis in July 2005 in terms of 500hPa geopotential height RMS error over the northern hemisphere. U3VR showed the improved result than G3VR after 2 days, though it had larger error before that time. U3VR was definitely improved in the southern hemisphere for all forecast time steps and showed also the much better result in the tropic region after 1 day forecast (not shown here).

But, when we compared U3VR with the operational G3VR with satellite radiance assimilation and typhoon bogussing process, U3VR showed poorer score than G3VR over the whole forecast period with 1 – 5 m of RMS differences(not shown here).

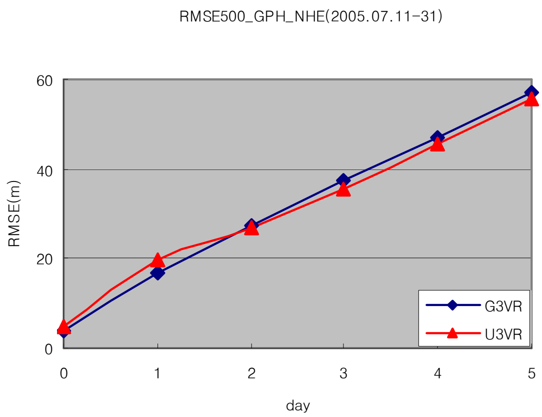

Fig. 2. RMS error of 500hPa geopotential height over the northern hemisphere. Used observations are almost same in both U3VR and G3VR.

4.2 WRF forecasts

The following cycle runs were implemented to verify the performance of U3VR coupled with WRF model.

o U3VR cycle

U3VR was connected with WRF model and its 3 hour and 6 hour cycle were performed. WRF background error statistics was used and any initialization process was not applied.

o SI cycle

KMA has used WRF for regional forecast system in semi-operational frame since June 2005. KMA WRF has used directly T426 global operational model data as the initial and boundary condition.

o RDAPS cycle

KMA regional cycle in operation is managed by RDAPS (Regional Data Assimilation and Prediction System) based on MM5 3dvar and MM5 model. RDAPS used IAU technique in 3 hour RUC (Lee *et al.,* 2006).

The results from U3VR 3 hour and 6 hour cycle run were compared with those of SI and RDAPS cycle.

Fig. 3 shows CSI (Critical Success Index) from four experiments, SI, RDAPS, U3VR 3 hour and 6 hour cycle. CSI is the index to see the accuracy of rain forecast and so heavy rainfall case, (September 2005), was selected for comparison: In September 2005, Korea peninsula experienced frequent (9 times) heavy rainfall situation with 1 or 2 days duration over the whole nation. SI showed the worst performance among four experiments. 3 hour cycling experiment (U3VR-3h) showed also poor score due to initialization and spin up problem. At this moment RDAPS and 6 hour cycle (U3VR-6h) show comparably good performance for whole threshold value. Every experiment showed the reduced forecast skill and lower CSI score in strong threshold values.

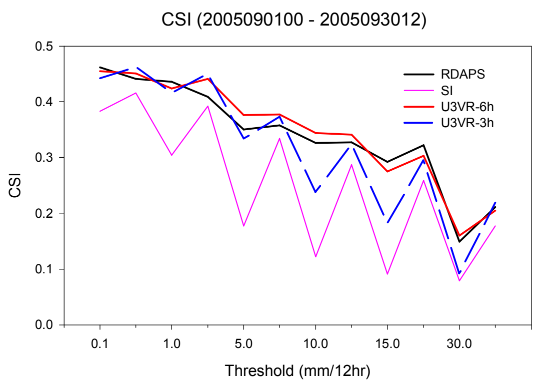

Fig. 3. CSI score with difference threshold value in 12hr threshold period for 4 experiments.

U3VR experiments in Fig. 3 did not assimilate the radar reflectivity and radial velocity, while operational RDAPS did assimilate them. U3VR-WRF 6 hour cycle showed the similar score to RDAPS, even without radar data.

5. Summary and plan

Unified 3DVAR system for both global and regional model has been developed under the collaboration with NCAR. In 2005, this system successfully has tested in cycling mode, even if satellite radiance part was not included. In two months test in global cycling system, we didn't find any severe systematic forecast bias in U3VR global mode. WRF 6hr cycling system coupled with U3VR has also shown the good performance in summer season when we compared with operational one based on MM5.

Fig. 4 shows flow diagram for the satellite radiance assimilation in both global and regional application at KMA in 2006. "Update Boundary Conditions" stage is only required in regional mode. New experiment with radiance assimilation part will be performed on the T426 operational model which was launched in 1 Dec 2005. According to Fig. 4, 1DVAR procedure outside 3DVAR is necessary for quality control of raw satellite radiance data.

In WRF experiment, we will start to develop the digital filter technique for initialization in 2006. Radar data assimilation in regional, typhoon bogussing in global will be tested too. Observation input data format will be changed from ASCII to BUFR format. Incorporation of inhomogeneous /anisotropic background error for global application will be also tested.

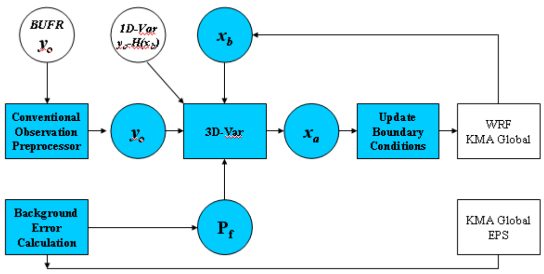

Fig. 4. Flow diagram of unified 3DVAR in both global and regional application at KMA in 2006.

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