Development of a new Ensemble Variational Assimilation System in Meteorological Research Institute

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1. Introduction

The Japan Meteorological Agency (JMA) and the Meteorological Research Institute have already developed the data assimilation system based on an ensemble Kalman filter (EnKF; Fujita 2011). The system adopts the local ensemble transform Kalman filter (LETKF; Hunt et al. 2007) implemented with the JMA non-hydrostatic model (JMANHM; Saito et al. 2006). In the present study, the ensemble-based variational scheme (EnVar; Zupanski 2005, Zupanski et al. 2008, Liu et al. 2008) is newly additionally developed for an analysis step, which will facilitate the comparison between the EnKF and EnVar. Here, the newly developed EnVar is applied to the case of Typhoon Talas in 2011, and its performance is evaluated by single observation assimilation experiment. Although the system is based on the three-dimentional (3D) variational data assimilation, realistic analysis increments are produced through its flow-dependent background error estimates from ensemble forecasting. As an extension of the present configuration, a four-dimentional (4D) EnVar is currently being implemented, and it is currently being tested.

2. System of the developed EnVar

The cost function of the EnVar is written by the following formula, and the optimal analysis is derived from the minimization of the cost function.

$$J(\overline{\mathbf{x}}^a) = \frac{1}{2}[\overline{\mathbf{x}}^a - \overline{\mathbf{x}}^f]^T \mathbf{P}_f^{-1}[\overline{\mathbf{x}}^a - \overline{\mathbf{x}}^f] + \frac{1}{2}[H(\overline{\mathbf{x}}^a) - \mathbf{y}]^T \mathbf{R}^{-1}[H(\overline{\mathbf{x}}^a) - \mathbf{y}]$$

$$\begin{cases} \overline{\mathbf{x}}^a - \overline{\mathbf{x}}^f = \mathbf{P}_f^{1/2} \cdot \overline{\mathbf{w}}^a \qquad \overline{\mathbf{w}}^a = \left[\overline{w}_1^a, \overline{w}_2^a, \cdots, \overline{w}_N^a\right]^T \\ \mathbf{P}_f^{1/2} = \left[\mathbf{p}_1^f, \mathbf{p}_2^f, \cdots, \mathbf{p}_N^f\right] = \frac{1}{\sqrt{N-1}}\left[\mathbf{x}_1^f - \overline{\mathbf{x}}^f, \mathbf{x}_2^f - \overline{\mathbf{x}}^f, \cdots, \mathbf{x}_N^f - \overline{\mathbf{x}}^f\right] \end{cases}$$

$\mathbf{x}_i^f$	; Ensemble forecast (i; member)	$\overline{\mathbf{x}}^f$	; Ensemble mean
$\overline{\mathbf{x}}^a$	; Analysis	$\overline{\mathbf{w}}^a$	; Control variable
$\mathbf{P}_f$	; Background error covariance	$\mathbf{R}$	; Observation error covariance

Algorithm of the developed EnVar is shown in Fig. 1. The optimal analysis is estimated with the LBFGS method using the cost function and its gradient in ensemble space. Since the gradient vector and the Hessian matrix are calculated using the ensemble perturbation. Hence, the tangent linear and the its adjoint codes are not required in the EnVar. The square root of the background error covariance matrix with the flow-dependency is constructed by the ensemble perturbation.

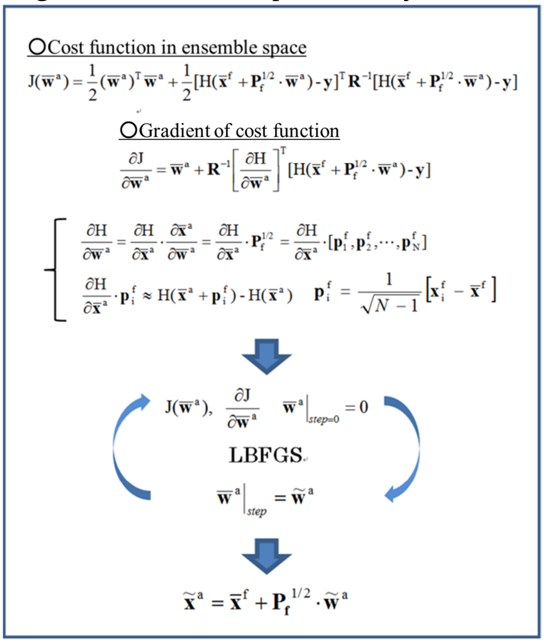


Fig. 1 Algorithm of the EnVar

3. Single observation assimilation experiment

First, the performance of the 3DEnVar is evaluated by a single observation assimilation experiment for the case of Typhoon Talas. The wind velocity of pseudo observation is set to be two times larger than that of the first guess (U= -35.54 ms^{-1}, V=45.68 ms^{-1}, Z=5 km) at the northeast side of typhoon's central position. The observation error is set very small to emphasize the analysis increment (R_{err}=0.5 m/s). As a result, positive increment is appeared along typhoon's circulation, and flow-dependent pattern is shown with a circulation enhancement (Fig. 2), suggesting that the wind data are assimilated appropriately.

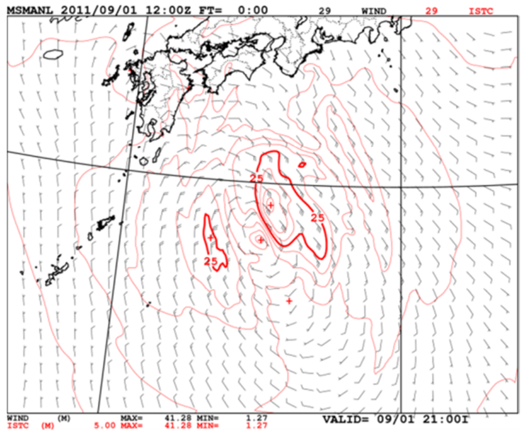
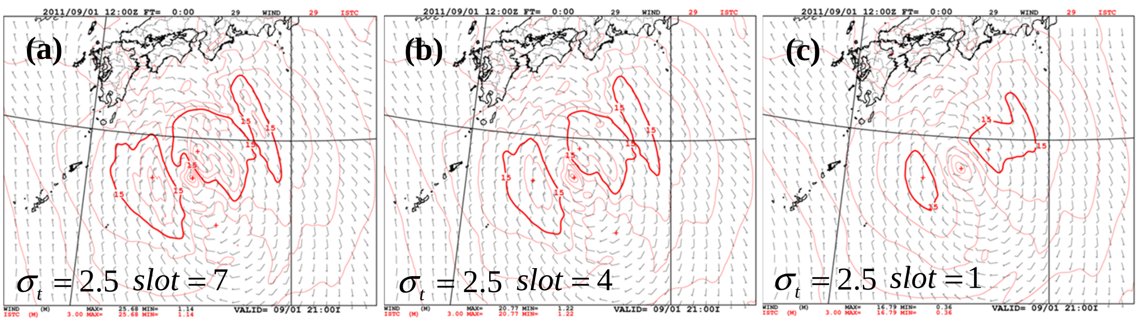


Fig. 2. Analysis increment (Wind, Height 5 km)

Next, temporal localization is implemented by the observation error by multiplying the reciprocal of the localization function. To see the effect of the temporal localization, sensitivity experiments are carried out in which a single observation is assimilated with different time intervals from the analysis. Figures 3a, 3b and 3c show the analyzed increments in which the pseudo observations were given at 0, 3 and 6 hours before the analysis time (corresponding slots are 7, 4 and 1, respectively). The increments became smaller with the increasing of the distance between observation and analysis times. These distributions indicate that the temporal localization worked effectively.



Figs. 3(a)-(c) Analysis increment (Wind, Height 5 km)
Assimilation window of 6 hours is divided into 7 slots. Analysis slot is 7.

The performance of the 4DEnVar which is implemented as an extension of the control variable is currently being tested for the same typhoon.

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