Improving ensemble-based background error covariances of the hybrid 4DVar in JMA's global analysis

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1. Introduction

The four-dimensional variational (4DVar) data assimilation system used to determine atmospheric analysis fields for JMA's operational global model (JMA 2019) was updated in December 2019 to a hybrid version with weighted averages for climatological and ensemble-based background error covariances (B_c and B_e, respectively) as initial background error covariances (Kadowaki et al. 2020). The initial ensemble forecast conditions for B_e are determined using a Local Ensemble Transform Kalman Filter (LETKF; Hunt et al. 2007), producing values to represent flow-dependent non-uniform uncertainties not represented by B_c. However, improvement based on B_e is limited due to insufficient ensemble size and hybrid covariance weight. This report outlines more effective use of B_e in hybrid 4DVar with increased ensemble size and hybrid covariance weight, and effects on forecasting.

2. Update Overview

B_e in JMA's 4DVar global analysis is created from three-hour ensemble forecasting initialized using the LETKF with 50 ensemble members (Kadowaki et al 2020). B_c and B_e are blended via the extended control variable method (Lorenc 2003). The weight for hybrid covariance is 0.85 for B_c and 0.15 for B_e below 50 hPa, with values approaching 1 and 0 above 50 hPa, respectively. Localization for B_e involves a Gaussian function application with scales of $1/\sqrt{e}$ set to 800 km (horizontally) and 0.8 scale height (vertically) in 4DVar, and 400 km (horizontally) and 0.4 scale height (vertically) in LETKF. Analysis from 4DVar is used to re-center LETKF analysis. This report details the settings updated as below.

(a) Ensemble size for B_e production is increased from 50 to 100 to suppress sampling errors.
(b) Hybrid covariance weights below 50 hPa are changed from 0.85 for B_c and 0.15 for B_e to 0.50 and 0.50, respectively, to reflect B_e values improved as a result of (a).
(c) Additional revisions:
1) Horizontal and vertical weights for addition of divergence in initialization of LETKF analysis (Hamrud et al. 2015) are modified for global uniformity based on the global average of horizontal wind ensemble spread.
2) The vertical localization scale for LETKF is expanded from 0.4 scale height to 0.6 scale height to reduce negative impacts in assimilating observation with vertical integrals (e.g., brightness temperature).
3) The horizontal localization scale for specific humidity in 4DVar is reduced from 800 to 400 km to suppress specific humidity sampling errors in B_e. As a result, the horizontal scale of B_e between specific humidity and other variables, along with related peak values, is also smaller.

3. Update Effects

To verify the effects of updates (a) − (c), several sensitivity experiments on ensemble size, weights of hybrid covariances and additional revisions were conducted based on the configuration of JMA's operational global NWP system as of December 2019 for the period July 21 – September 11 2018. Figure 1 shows initial cost functions in 4DVar divided by the number of assimilated observations (profiles for brightness temperature), indicating the standard deviation of first-guess departure to assimilated observations normalized by the observation error standard deviation in 4DVar. This indicator was the smallest in the experiment with weight 0.30 for 50 ensemble members and 0.50 for 100 ensemble members. Revisions of (c) also produced slightly smaller values. Such improvements were additionally observed in the boreal winter experiment (not shown).

Comparison between the experiments without (CNTL) and with (TEST) (a) − (c) updates showed larger ensemble spreads in the latter, especially for the stratosphere. Root mean square errors in forecasts of geopotential height, temperature, zonal wind and specific humidity were also smaller, especially in the winter hemisphere (not shown). Position errors for tropical cyclone forecasts were smaller in the eastern North Pacific and the Atlantic where tropical cyclone bogus data were not assimilated (Figure 2). These improvements were also observed in the boreal winter experiment (not shown).

4. Summary

The updates involving (a) increasing ensemble size from 50 to 100, (b) increasing the weight of hybrid covariances for B_e from 0.15 to 0.50 below 50 hPa, and (c) revising initialization and localization improved JMA's global analysis. These updates were applied in March 2021 (Ujiie et al. 2021).

References

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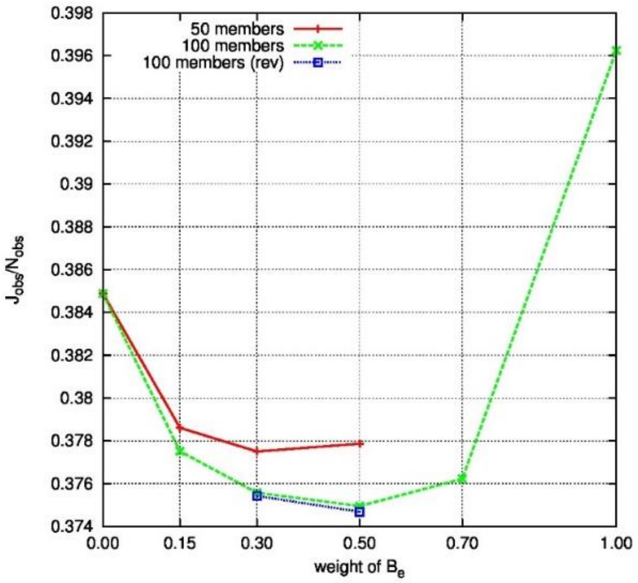

Figure 1. Initial cost functions in 4DVar divided by the number of assimilated observations (profiles for brightness temperature) averaged for August 1 − 31. The horizontal axis represents the weight of hybrid covariances for B_e below 50 hPa (and above 50 hPa for weight 1.00). The red and green lines show results with ensemble sizes of 50 and 100, respectively, without the additional revisions of (c). The blue line shows results with all revisions of (c) for 100 ensemble members. The weight points of 0.15 in the red line and 0.50 in blue line are CNTL and TEST, respectively.

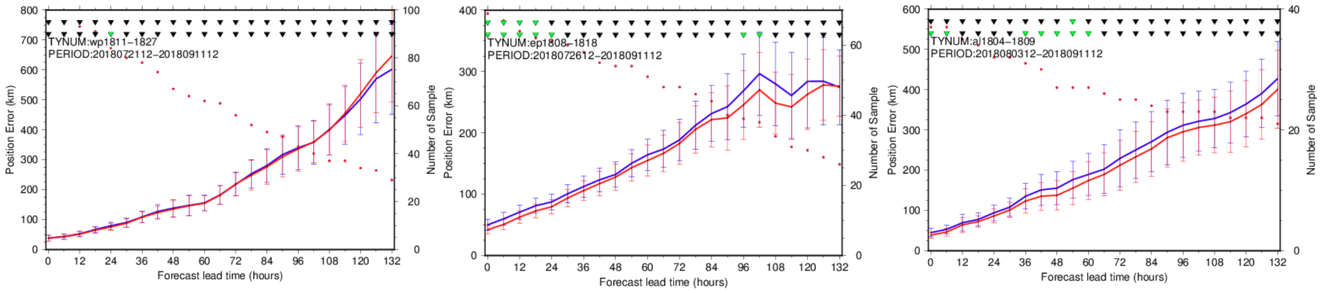

Figure 2. Average position errors (km) for tropical cyclones from July 21 to September 11 2018 in the western North Pacific (left), the eastern North Pacific (center) and the Atlantic (right). The blue and red lines show results from CNTL and TEST, respectively, and the red points are sample numbers. Error bars represent 95% confidence intervals.