Introduction of a New Hybrid Data Assimilation System for the JMA Global Spectral Model

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1. Introduction

A four-dimensional variational (4D-Var) data assimilation system has been employed in the analysis of atmospheric conditions for the JMA Global Spectral Model (GSM) since February 2005. An evolution of initial background error covariances for the assimilation window is calculated in 4D-Var, but initial background error covariances are climatological and do not represent day-to-day weather conditions. Daily forecast uncertainties can be represented via ensemble forecasting, and various operational global numerical weather prediction centers use such forecasting data for related covariances. In this context, JMA has applied its own hybrid method composed of a Local Ensemble Transform Kalman Filter (LETKF; Hunt et al. 2007) and 4D-Var within its operational system since December 2019.

This report gives an overview of the hybrid system and its impacts on tropical cyclone (TC) track forecasting and other areas. Section 2 outlines the system's specifications, Section 3 details its impacts on TC forecasting, and Section 4 provides a summary.

2. Specifications of the Hybrid Data Assimilation System for the GSM

JMA (2019) outlines the Agency's Global Ensemble Prediction System (GEPS) and the 4D-Var global data assimilation system. The LETKF used to make initial perturbations in the GEPS was imported into the 4D-Var global data assimilation system to construct the hybrid LETKF/4D-Var system. Three-hour ensemble forecasting initialized with the LETKF is used in 4D-Var with the extended control variable method of Lorenc (2003) to create flow-dependent background error covariances, which are blended with climatological background error covariances. Analysis from 4D-

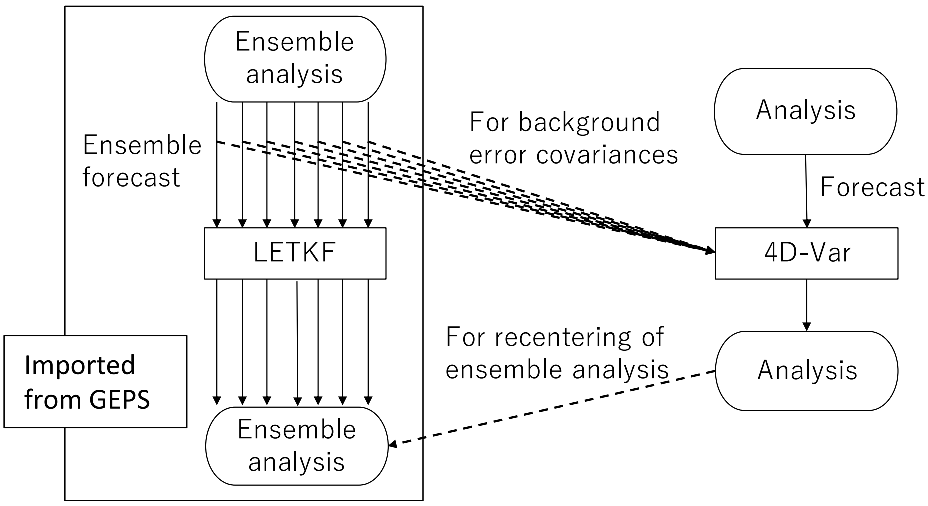


Figure 1. The hybrid LETKF/4D-Var system

Var is used to re-center LETKF ensemble analysis. Figure 1 outlines the hybrid LETKF/4D-Var system, and Tables 1 and 2 list related specifications.

Table 1. Specifications of 4D-Var in the hybrid LETKF/4D-Var system

Data cut-off	2 hours and 20 minutes for early-run analysis at 00, 06, 12 and 18 UTC 11 hours and 50 minutes for cycle-run analysis at 00 and 12 UTC 7 hours and 50 minutes for cycle-run analysis at 06 and 18 UTC
First guess	6-hour forecast by the GSM
Grid form, resolution, number of grids	Outer loop: Reduced Gaussian grid, roughly equivalent to 0.1875° [1,920 (tropic) – 60 (polar)] x 960 Inner loop: Reduced Gaussian grid, roughly equivalent to 0.5625° [640 (tropic) – 60 (polar)] x 320
Vertical levels	100 forecast model levels up to 0.01 hPa + surface for outer and inner loop
Outer-loop iterations	Once
Inner-loop iterations	About 70 times
Control variables for climatological background error covariance	Relative vorticity, unbalanced divergence, unbalanced temperature, unbalanced surface pressure and natural logarithm of specific humidity
Covariance inflation for ensemble covariance	Adaptive multiplicative covariance inflation (as per LETKF application). Additional covariance inflation is applied to create vertical profiles for the horizontal global mean of standard deviation from ensemble covariances consistent with those from climatological background error covariances.
Localization for ensemble covariance	Gaussian function. The localization scale for which the localization function is $1/\sqrt{e}$ is set to 800 km in the horizontal domain, and a 0.8 scale height in the vertical domain.
Weighting for hybrid covariance	0.85 for climatological covariance and 0.15 for ensemble covariance under 50 hPa. They are approaching to 1 and 0 above that, respectively.
Analysis variables	Wind, surface pressure, specific humidity and temperature
Assimilation window	6 hours

Table 2. Specifications of the LETKF in the hybrid LETKF/4D-Var system

Data cut-off	As per 4D-Var
First guess	Own 6-hour forecast
Grid form, resolution, number of grids	As per 4D-Var inner loop
Vertical levels	As per 4D-Var inner loop
Ensemble size	50 members
Perturbations to model physics	Stochastic perturbation of physics tendency
Initialization	Horizontal divergence adjustment based on the analysis of surface pressure tendency (Hamrud et al. 2015)
Covariance inflation	Adaptive multiplicative covariance inflation
Localization	Gaussian function. The localization scale for which the localization function is $1/\sqrt{e}$ is set to 400 km in the horizontal domain (300 km for humidity-sensitive observations), a 0.4 scale height in the vertical domain (0.8 for surface pressure and ground-based GNSS zenith total-delay observations) and 3 hours in the temporal domain. For satellite radiance observation, the maximum of the weighting function divided by its peak value and the Gaussian function with a 0.8 scale height centered at the peak of the weighting function is used as the vertical localization function.

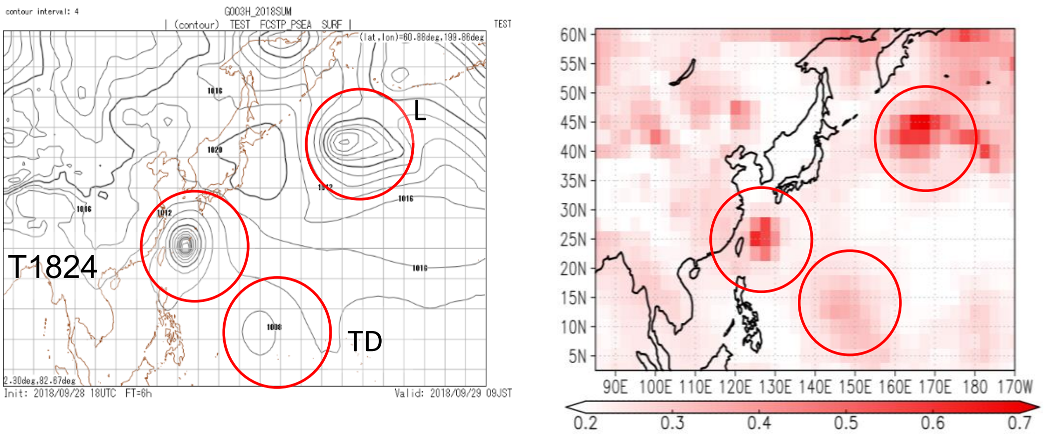
Re-centering	Ensemble analysis is re-centered so that the ensemble mean is consistent with 4D-Var.
Analysis variables	As per 4D-Var
Assimilation window	As per 4D-Var

3. Hybrid System Impacts on TC Forecasting

To verify the impacts of the hybrid LETKF/4D-Var system, a 4D-Var experiment with configuration identical to that of the operational JMA global NWP system as of October 2018 was conducted along with a hybrid LETKF/4D-Var experiment. Both covered the period from June 2 to October 11 2018, which included forecasting for TCs from T1804 to T1825 in the western North Pacific.

Ensemble forecasting initialized with the LETKF showed the capacity for background error covariance creation dependent on day-to-day weather conditions as exemplified in Figure 2 (a) (extratropical cyclone, tropical cyclone and tropical depression) and 2 (b) (indicating a larger ensemble spread around these phenomena than in other areas).

Figure 3 shows average TC position errors for the western North Pacific from both experiments. The results from the hybrid LETKF/4D-Var experiment are slightly better.



(a) (b)

Figure 2. (a) 6-hour forecast for sea-level pressure. (b) 6-hour forecast for sea-level pressure spread. Both forecasts are from the hybrid LETKF/4D-Var experiment initialized at 1800 UTC on 28 Sep. 2018.

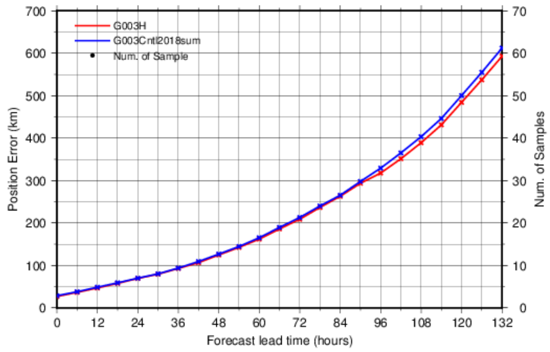


Figure 3. Average TC position errors for TCs from T1804 to T1825 in the western North Pacific. Blue and red represent the 4D-Var experiment and the hybrid LETKF/4D-Var experiment, respectively.

4. Summary

This study examined the import of the LETKF used in GEPS into the 4D-Var global data assimilation system to construct a hybrid LETKF/4D-Var system. Ensemble forecasts initialized with the LETKF showed the capacity for background error covariance creation dependent on day-to-day weather conditions. Average TC position errors from the hybrid LETKF/4D-Var system were slightly better than those from the 4D-Var system. The new system has been operated by JMA since December 2019.

References

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