Developments of a Local Ensemble Transform Kalman Filter at JMA

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INTRODUCTION

The ensemble Kalman filter (EnKF) takes an advantage of the ensemble prediction technique to estimate the background error covariance in a flow-dependent manner, which enables advanced data assimilation. This feature allows automatic adjustment of the background error covariance, which in general needs to be specified manually within the three- and four-dimensional variational data assimilation (3D/4D-Var) methods as well as optimum interpolation (OI). Since the observing network varies much in history, using an appropriate background error covariance in each era would be important in a long-term reanalysis. The adaptive estimation of the background error covariance in EnKF would be favorable in this context. Moreover, we have developed a novel method of adaptive bias correction for satellite radiances just like the variational bias correction, which would also be favorable for reanalysis. Another important advantage of EnKF is that it automatically produces analysis ensemble which contains information of the analysis errors. It is hard in general to obtain quantitative information of the analysis errors with other data assimilation methods including variational methods. However, the analysis accuracy would vary much in temporal scales from days to years; the quantitative information of analysis uncertainty would be useful. We could investigate dynamical aspects of the analysis errors, which may lead to a new approach of the atmospheric dynamics.

Before proposing an EnKF method for a next generation reanalysis project, it is important to prove the stable performance with a solid career in an operational NWP. For a possible future operational choice, JMA is now developing an EnKF method known as the local ensemble transform Kalman filter (LETKF, Hunt et al. 2007), which Szunyogh et al. (2008) and Whitaker et al. (2008) applied to the National Centers for Environmental Prediction (NCEP) global forecasting system (GFS) at a reduced resolution and obtained better performance than the benchmark 3D-Var system. LETKF is based on the idea of the local ensemble Kalman filter (LEKF, Ott et al. 2004), which Szunyogh et al. (2005) applied to the NCEP GFS at a reduced resolution. At JMA, FORTRAN90 codes of LETKF have been developed independently and applied to three realistic models: AFES (AGCM for the Earth Simulator, Ohfuchi et al. 2004), NHM (JMA nonhydrostatic mesoscale model, Saito et al. 2006), and GSM (JMA global model, JMA 2007). Using the AFES-LETKF system (Miyoshi and Yamane 2007), real observations over 1.5 years are assimilated to generate the AFES-LETKF experimental ensemble reanalysis (ALERA, Miyoshi et al. 2007a). In the first part of this presentation, dynamical aspects of the analysis errors estimated by ALERA are presented. Then, this presentation overviews recent developments with GSM-LETKF, including the comparison with the operational 4D-Var system.

DYNAMICS of the ANALYSIS ERRORS of ALERA

ALERA, the AFES-LETKF experimental ensemble reanalysis (Miyoshi et al. 2007a), is freely available for research purposes online at the following Internet address: http://www3.es.jamstec.go.jp/. It performed stably for more than 1.5 years. Ensemble spread represents the analysis errors well. In fact, ALERA ensemble spread correlates the RMS difference between ALERA and NCEP/NCAR reanalysis (Kalnay et al. 1996) for sea-level pressure (Fig. 1). Moreover, large spread areas seem to correspond with disturbance indicated by cloudy areas in a geostationary satellite image (Fig. 2). Large spread seems to propagate downward from upper levels, which coincides with QBO (Quasi Biannual Oscillation) phase change (Fig. 3). Furthermore, the peak of ensemble spread occurs just a few days before the peak of stratospheric sudden warming event in January 2006 (Fig. 4). Thus, ensemble spread would be related to atmospheric dynamics.

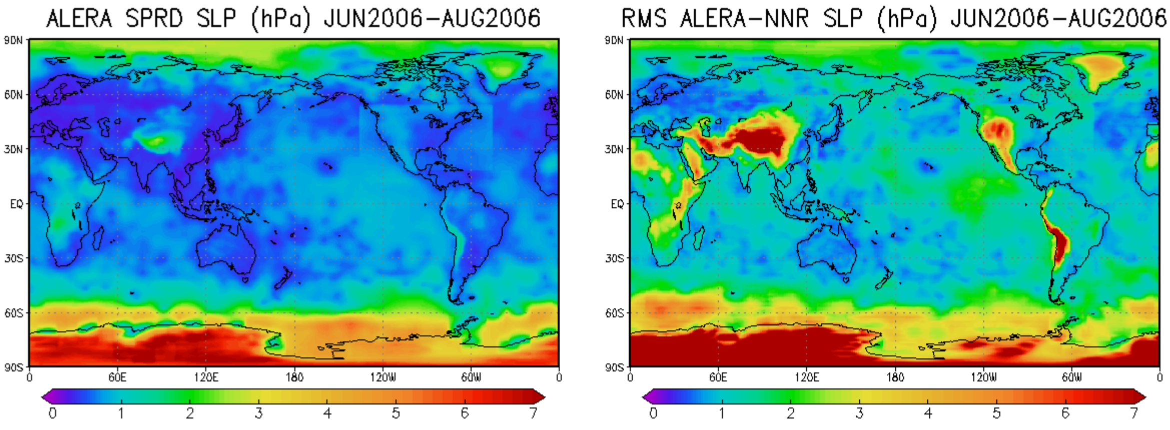

Figure 1 ALERA ensemble spread (left) and the RMS difference between ALERA and NCEP/NCAR reanalysis (right) for sea-level pressure (hPa).

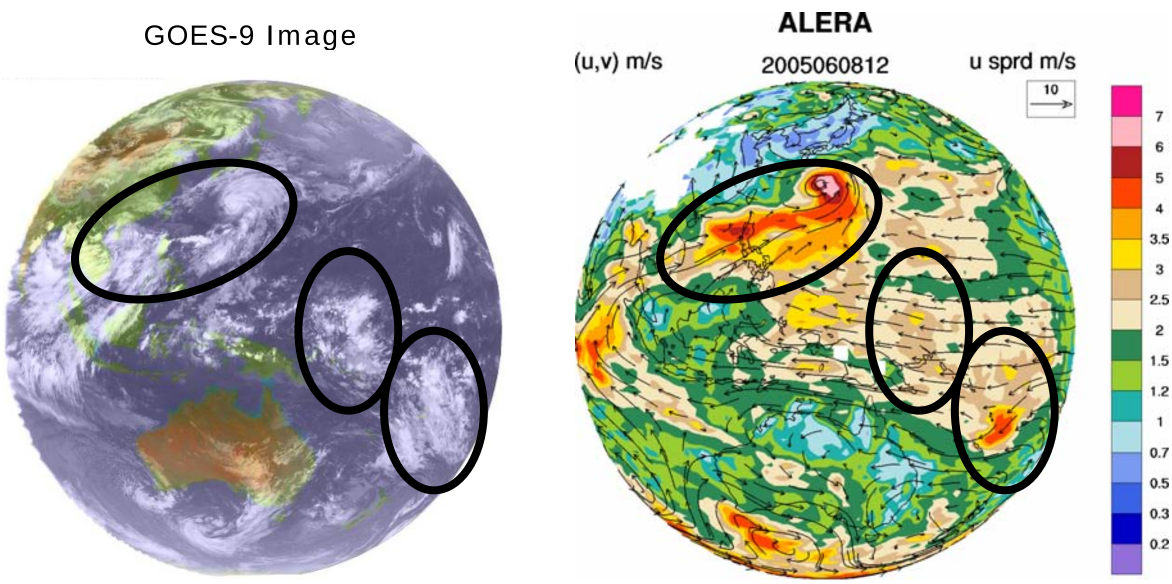

Figure 2 GOES-9 geostationary satellite infrared image (left) and ALERA ensemble spread of zonal winds (right, m s^{-1}) on 12 UTC, 8 June 2005.

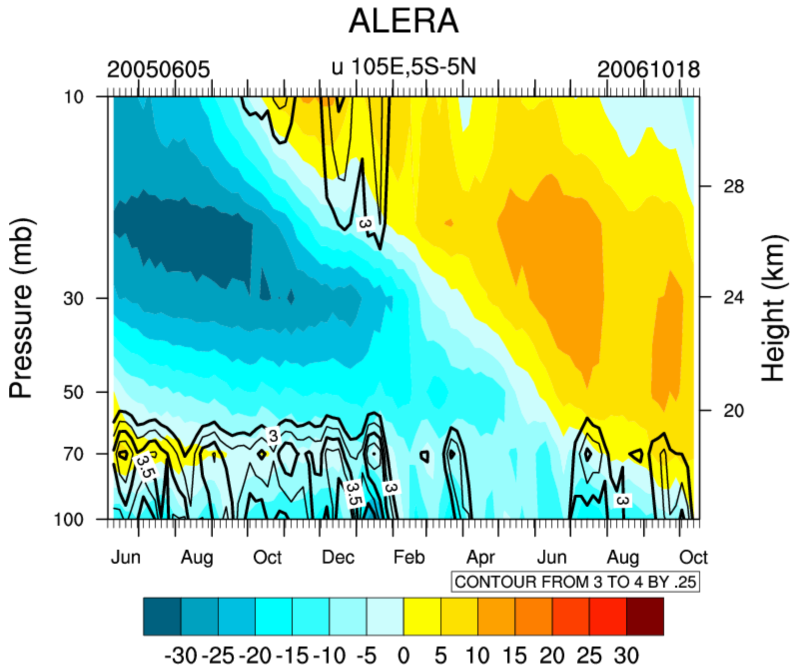

Figure 3 Time series from 5 June 2005 to 18 October 2006 of vertical distribution of tropical zonal wind (shade, m s^{-1}) and its ensemble spread (contour, m s^{-1}) averaged over 5S to 5N at 105E.

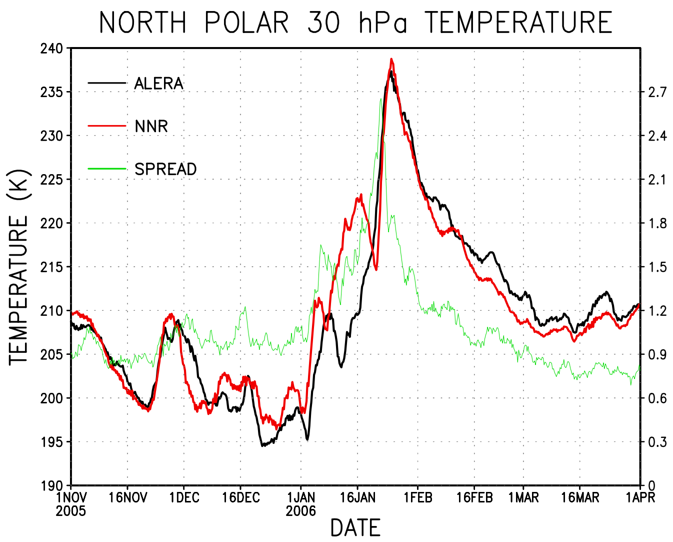

Figure 4 Time series of temperature (K) at 30 hPa averaged over north of 80N for ALERA (black), NCEP/NCAR reanalysis (red), and ALERA ensemble spread (green).

LETKF and 4D-Var INTER-COMPARISON with JMA GLOBAL MODEL

Although ALERA is considered to be a successful trial of LETKF ensemble data assimilation with real observations, it has two major limitations, that is, 1) AFES is not an operational model, and 2) satellite radiances or their retrievals are not assimilated. In order to use LETKF in an operational reanalysis, it is important to develop with an operational environment. Therefore, LETKF has been applied to JMA global model (GSM); the GSM-LETKF system has been embedded into the JMA operational experimental system. Recent developments of the GSM-LETKF include the following:

1. Removing local patches as in Miyoshi et al. (2007b)
2. An additive covariance inflation method as in Whitaker et al. (2008), but using JRA-25 (Onogi et al. 2007)

instead of NCEP/NCAR reanalysis (Kalnay et al. 1996)

3. Efficient parallel algorithm
4. Adaptive bias correction for satellite radiance observations to simulate the operational variational bias correction (Derber and Wu 1998; Dee 2004; 2005; Sato 2007)

The detailed description of the upgrades is provided in a separate paper, which is now in preparation. Here, results are briefly presented.

The typhoon Rananim case indicated excellent ensemble forecasts by the LETKF (Fig. 5). The control forecast by 4D-Var analysis failed to predict the westward movement of the typhoon, resulted in a false alert to Japan. Only a few members capture the westward movement. Alternatively, LETKF captures the westward movement almost perfectly. In addition, ensemble spread is much smaller than the operational singular-vector (SV) or bred-vector (BV) EPS, indicating higher confidence of the forecast. Not only for this case but also on average, the typhoon track forecast errors are reduced by the LETKF analysis.

The forecast anomaly correlation scores indicate much improvement by applying the adaptive bias correction for satellite radiances (Fig. 6). The bias coefficients for most satellite sensor channels did not change significantly. As shown in Fig. 7, only the satellite channels sensitive to surface emissivity such as AMSU-A ch. 4 showed significant drift from the initial values estimated by the variational bias correction of the operational 4D-Var. After investigation, it was found that the drift was related to the different version of the radiative transfer model (RTM). Operational systems, 4D-Var and quality control, uses RTTOV-7, whereas RTTOV-8 has been applied to LETKF. A known bug exists in the surface emissivity model FASTEM-2 in RTTOV-7, causing spurious positive bias in the computed surface emissivity; the bug has been fixed in RTTOV-8. Therefore, the different bias in the RTM was the reason for the drift. There seems to be some more bugs in the treatment of satellite radiances, which need to be identified and fixed to obtain right results.

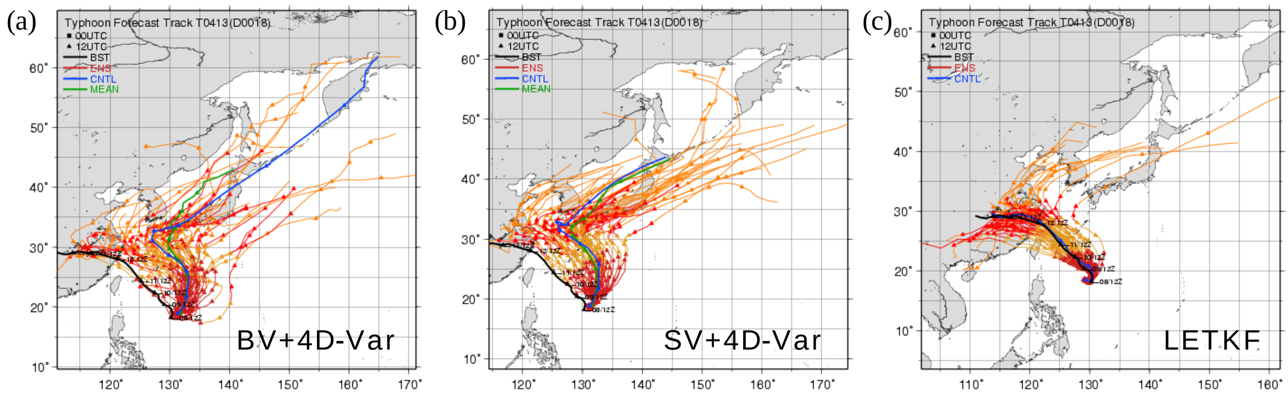

Figure 5 51-member ensemble prediction of the 13th typhoon Rananim in 2004 initialized on 12 UTC August 8. Thick black lines indicate the best track. The previous operational bred-vector EPS (a) and LETKF (c) use the same TL159/L40 GSM. The current operational singular-vector EPS (b) uses a higher resolution TL319/L60 GSM.

(a)

	PseaSurf	T850	Z500	Wspd850	Wspd250
Global	−9.00	−10.45	−10.64	2.38	0.13
N. Hem.	−4.47	−2.95	−1.72	3.74	0.66
Tropics	0.48	−11.66	−17.60	11.69	9.88
S. Hem.	−10.90	−14.51	−13.00	−1.52	−3.81

(b)

	PseaSurf	T850	Z500	Wspd850	Wspd250
Global	−5.21	−2.33	−4.21	3.94	1.73
N. Hem.	−3.89	2.06	1.32	4.30	1.30
Tropics	7.05	6.49	7.44	13.58	9.57
S. Hem.	−6.35	−6.47	−6.20	0.39	−1.14

Figure 6 Improvements (%) of forecast anomaly correlation scores of LETKF relative to 4D-Var, (a) before and (b) after applying the adaptive bias correction, for sea-level pressure (PseaSurf), 850 hPa temperature (T850), 500 hPa geopotential height (Z500), 850 hPa wind speed (Wspd850), and 250 hPa wind speed (Wspd250). LETKF is better when positive.

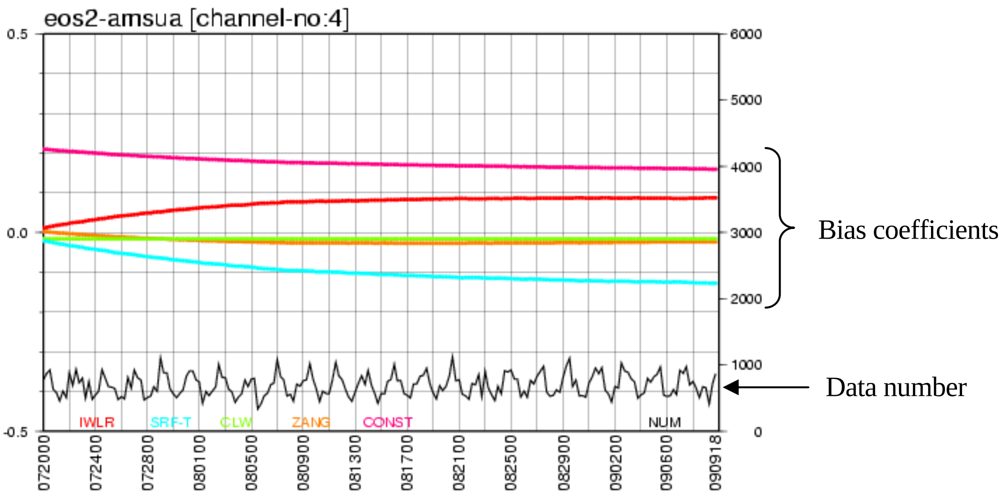

Figure 7 Time series of bias coefficients estimated by the adaptive bias correction within LETKF, shown by colored lines with the scale on the left axis. The black line indicates data number with the scale on the right axis.

SUMMARY

The local ensemble transform Kalman filter has been applied to three models: AFES, NHM, and GSM. With the AFES-LETKF system, an experimental reanalysis ALERA has been performed; the products are available freely for research purposes online at http://www3.es.jamstec.go.jp/. It has been found that the analysis ensemble spread corresponded well with the analysis errors and that the spread indicated some dynamical meanings. We anticipate that a long-term ensemble reanalysis would enable to analyze such dynamical aspects of the analysis errors in various time scales up to decades.

Thus, the advantages of EnKF in reanalysis are two folds. One is on the automatic adjustment of background error statistics without tuning. The other is on the new products of the analysis uncertainty. Before applying EnKF to the operational reanalysis, it is important to use the method in the operational NWP. This leads to the study with the GSM-LETKF system.

The GSM-LETKF system has been embedded into the operational experimental system. In this way, all observation inputs and their quality control are exactly the same as the operational 4D-Var system. The typhoon Rananim case indicated excellent forecasts by LETKF. After applying the adaptive bias correction, LETKF outperforms 4D-Var in the Tropics and generally in the NH. LETKF is disadvantageous in the SH and extratropical surface pressure forecasts. Still some problems seem to exist in the satellite radiance assimilation because the version of the RTM used in LETKF (RTTOV-8) is different from that of 4D-Var and quality control (RTTOV-7). We will continue the development to further improve the LETKF performance towards a possible future operational choice.

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