Local ensemble transform Kalman filtering with an AGCM at a T159/L48 resolution

Takemasa Miyoshi*† and Shozo Yamane**
*Numerical Prediction Division, Japan Meteorological Agency
**Chiba Institute of Science

In August 2005, we began to develop the local ensemble transform Kalman filter (LETKF, Hunt 2005) with AFES (AGCM for the Earth Simulator, Ohfuchi et al. 2004) at a T159 horizontal and 48-level vertical resolution in collaboration among the Numerical Prediction Division, Japan Meteorological Agency (NPD/JMA), the Chiba Institute of Science, and the Earth Simulator Center (ESC). We developed the LETKF system based on the system constructed by Miyoshi (2005) at the University of Maryland where originally LETKF has been invented.

A main limitation of ensemble Kalman filter (EnKF) experiments published thus far is the lower resolutions than the currently operational data assimilation or ensemble prediction systems (EPS). The experimental resolutions are at most as large as T62, whereas operational EPS have at least as large as a T106 resolution. A higher resolution model uses more precise physical processes and resolves smaller scale phenomena, possibly introducing larger substantial degrees of freedom of the dynamical error structures. This causes the increase of required ensemble size for stable EnKF, an important disadvantage. This research tackles the limitation by applying LETKF to the T159 AFES model, corresponding grid size of 480x240x48, a similar resolution to operational systems.

Generally EnKF has two parameters: the covariance inflation parameter and covariance localization scale parameter. The former parameter is objectively estimated as in Miyoshi (2005) following a suggestion by Kalnay (pers. comm.). LETKF requires two types of localization parameters: the local patch size and observational localization scale. In LETKF, it is better that we choose local patch size sufficiently larger than the observational localization scale, although larger local patch size requires more computations. We assume horizontal isotropy, but vertically we define different localization parameters. We choose 11x11x5 local patch and 2.0-grid horizontal and 1.0-grid vertical observational localizations in the following experiments.

We follow observing systems simulation experiment (OSSE) methodology in a perfect model scenario, where we generate the true nature run by a long-term integration of the same T159/L48 AFES model and sample observations from it. We take observations every 6 hours in the time domain and in the spatial domain regularly one at every 5x5x4 grid points, just 1% of the entire grid points. The observed variables are the zonal and meridional wind components, temperature, specific humidity, and surface pressure with error standard deviations of 1.0 m/s, 1.0 K, 0.1 g/kg, and 1.0 hPa, respectively. The initial ensemble members to initiate the data assimilation cycle are randomly chosen from a nature run in a similar season, the initial ensemble mean is an analogue of the climatological mean.

Fig. 1 shows time series of the analysis root mean square errors (RMSE) of the surface pressure for 30 days. It is noted that even with 10 members, LETKF seems stable, at least it is not diverging. Increasing ensemble size, we see LETKF be more stable with lower error levels, about half as large as the observational error level. Fig. 2 shows the sensitivity to the ensemble size. At the first assimilation step, we see linear decrease of the analysis errors up to about 80 members. Increasing the ensemble size beyond 320 does not show significant change of the analysis error levels, which is consistent with the fact that the substantial degrees of freedom in the local patch are around 400. After 10-day data assimilation cycles, the error decreasing trend is slower than linear, the difference between 40 and 80 members becomes smaller.

Table 1 shows timing results of one-step LETKF computations without forecast computations. If we use as many computational nodes as the ensemble size and they are less than 80, it takes just less than 4 minutes on the Earth Simulator, peak performance of 64 GFlops per node. The parallel efficiency increases with ensemble size, about 99.99% parallelization ratio with more than 80 members.

---

† Corresponding author address: Numerical Prediction Division, Japan Meteorological Agency, 1-3-4 Ote-machi, Chiyoda-ku, Tokyo 100-8122, Japan. E-mail: miyoshi@naps.kishou.go.jp

In summary, we developed and tested LETKF with the T159/L48 AFES model and found that even with the resolution as high as operational EPS, ensemble size of the order of less than 100 shows quite stable and good filter performance. The computational time is also applicable for operations, we are now at a stage of developing realistic observational operators and assimilating real observations.

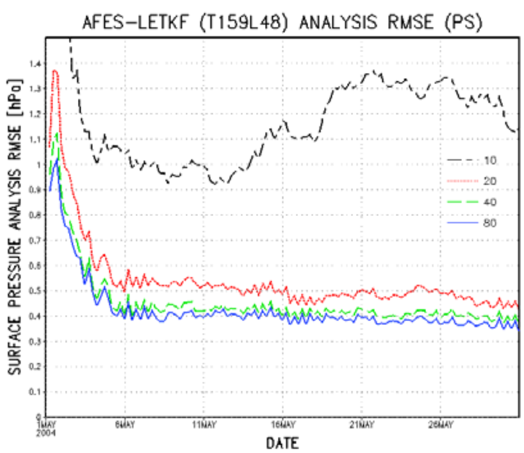

Figure 1. Time series of the analysis errors of LETKF for 30 days with 10 (black long-short-dashed line), 20 (red broken line), 40 (green dashed line), and 80 (blue solid line) ensemble members. The errors are measured by the RMSE of the surface pressure.

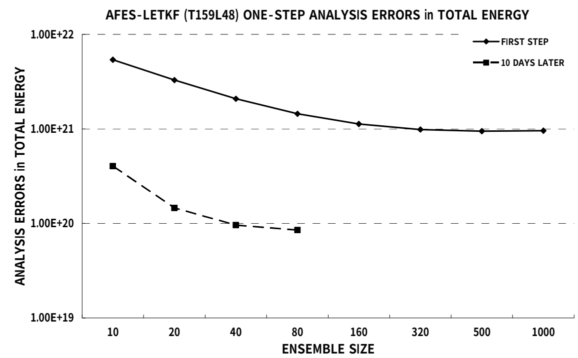

Figure 2. Analysis errors in the total energy norm at one-step analyses of LETKF with changing the ensemble size. Solid and dashed lines show the analyses at the first-step and 10 days later from the first-step, respectively.

Table 1 Timing (sec.) of LETKF on the Earth Simulator

Ensemble size	5 nodes	10 nodes	20 nodes	40 nodes	80 nodes	160 nodes	200 nodes	240 nodes
10	382	195	115	67	47			
20	714	360	197	107	66			
40	1389	708	360	189	112			
80		1583	824	413	220			
160				1205	626	336		
320						1139		
500							2270	1924
1000							10595	

Acknowledgements

We thank members of the chaos/weather group of the University of Maryland, especially Prof. Eugenia Kalnay for fruitful discussions. We also thank Drs. Wataru Ohfuchi and Takeshi Enomoto of ESC, and Yoshiaki Takeuchi and Ko Koizumi of NPD/JMA for kind understanding and support for this project. Most computations of this research have been performed on the Earth Simulator.

References

Hunt, B. R., 2005: Efficient Data Assimilation for Spatiotemporal Chaos: a Local Ensemble Transform Kalman Filter. arXiv:physics/0511236v1, 25pp.

Miyoshi, T., 2005: Ensemble Kalman filter experiments with a primitive-equation global model. Ph.D. dissertation, University of Maryland, 197pp.

Ohfuchi, W., H. Nakamura, M. K. Yoshioka, T. Enomoto, K. Takaya, X. Peng, S. Yamane, T. Nishimura, Y. Kurihara, and K. Ninomiya, 2004: 10-km mesh meso-scale resolving simulations of the global atmosphere on the Earth Simulator: Preliminary outcomes of AFES (AGCM for the Earth Simulator). *J. Earth Simulator*, **1**, 8–34.