Development of a Semi-Lagrangian Inner Model for Improving the Inner Resolution of the JMA Global Analysis System

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In JMA, a four-dimensional variational data assimilation (4D-Var) system for the Global Spectrum Model (GSM) was introduced in February 2005 (Kadowaki, 2005; JMA, 2007). The resolution of the analysis increment was originally T63L40, and was upgraded to T106L60 in March 2006 (Narui, 2006) and to T159L60 in November 2007. T159L60 resolution is insufficient against the Tl959L60 resolution of the current forecast model. Since the resolution of the inner model is constrained by the available computational resources, it is necessary to speed up 4D-Var in order to implement higher resolution for the analysis increment. As the inner model in operational 4D-Var uses the Eulerian advection scheme, one way to accelerate calculation is to introduce a semi-Lagrangian advection scheme to the 4D-Var inner model, which is the aim of our work here.

The new inner model is based on the current JMA forecast model, which uses a two-time-level semi-Lagrangian advection scheme and a reduced Gaussian grid (Miyamoto, 2009). In the linearization of the model to make tangent-linear and adjoint models, many simplifications are performed. For instance, schemes to improve the conservative properties of mass and water vapor are ignored. The linearized fixed-point iteration involved in the semi-Lagrangian advection scheme is based on TLM2 (Polavarapu and Tanguay, 1998). Although Gauthier et al. (2007) noted that additional horizontal diffusion in the wind field was needed to avoid unstable behavior resulting from violation of the Lipschitz condition, particularly near the polar regions, no special care is taken in regard to this kind of problem, except that according to Buizza (1998), horizontal diffusion in tangent-linear and adjoint models are set to be stronger than those of the original forecast model. To examine stability near the polar regions, singular vectors were calculated using the new inner model for 40 cases in August – September 2007 with a resolution of Tl159L60, an integration time step of 1,800 seconds and an optimization time of 6 hours. The two target areas of 30°S – 90°S and 30°N – 90°N were examined. Figure 1 shows the maximum-value positions of the initial total energy of the five leading singular vectors for all cases. A few singular vectors were calculated in the vicinity of the poles, but they had neither noisy structure nor an excessive growth rate (not shown). Accordingly, the new inner model can be considered practically stable, at least for a resolution of Tl159L60 and a time step of 1,800 seconds. One reason for this stability may be the fact that our inner model uses a reduced Gaussian grid, so the increased horizontal resolution resulting from the convergence of the meridians is more moderate than that of the standard grid model. We ported most of the physical processes from the operational inner model to the new inner model and developed a new analysis system using the new version.

Forecast-analysis cycle experiments were performed for a one-month period (January 2008) using a low-resolution setting with Tl159L60 (T106L60) resolution for the analysis increment in the new (operational) analysis system and Tl319L60 resolution for forecasting. As a result, differences of analysis from both systems were found, probably resulting from the difference in gravity wave control.

Accordingly, we plan to continue the development of gravity wave control in the new system.

The new analysis system with Tl319L60 resolution and a 900 s integration time step for the inner model uses about twice as much computational time as the operational analysis system with T159L60 resolution for the inner model (the integration time step varies according to the flow) when 60 nodes of SR11000K1 are used for both systems. The computational time of the new analysis system is barely within the operational resources available at JMA; we will continue to develop the new inner model and introduce it as the next operational global analysis system as soon as it achieves comparable or better performance than the current system. The communication costs of the forecast model would present a serious problem in the future. About 35% of the computational time for the new analysis system is devoted to inter-node communications, and the ratio is almost the same for the forecast model with Tl959L60 resolution. It will be necessary to reduce inter-node communications in the forecast model itself to make the new analysis system faster.

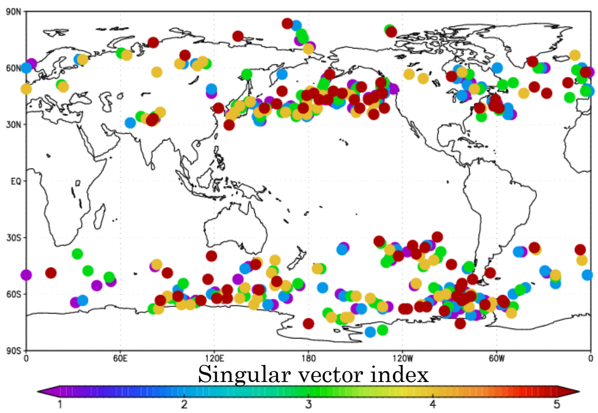

Fig 1. Maximum-value positions for the initial total energy of the five leading singular vectors (see text)

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