Recent Improvements to the JMA Global NWP Model

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1. Introduction

The JMA global NWP suite consists of a four-dimensional variational data assimilation system, a deterministic prediction system and two ensemble prediction systems. One of the two ensemble prediction systems is for one-week prediction, and the other is for predicting possible typhoon tracks over a short time span, where typhoons are defined as severe tropical cyclones in the western North Pacific. All these systems are based on a global spectral atmospheric model referred to as JMA-GSM, which has been in operation since 1 March, 1988. The T959 linear Gaussian grid model is currently used in the deterministic prediction system, and also serves as the outer model in the data assimilation system. As the inner model, the T159 quadratic Gaussian grid model is employed, while the ensemble prediction systems use the T319 linear Gaussian grid model. The number of vertical layers in all systems in the global NWP suite is 60. JMA-GSM is also used in the JMA seasonal prediction suite, and is further adopted for research on climate change.

The model has been improved many times over the last 20 years (e.g., Iwamura and Kitagawa, 2008). However, the basic structure of its source program remained old-fashioned in many ways. Additionally, repeated efforts to improve the model's accuracy and efficiency had left the source program disorganized. Accordingly, we decided to renovate the implementation of the model, thus making it faster and more accurate without changing its fundamental principles.

The renovated model is currently employed in the deterministic prediction system and the one-week ensemble prediction system. It is also used as the outer model in the data assimilation system. The inner model is scheduled for renovation in the near future (Kadowaki, 2009), and preparations are also under way to replace the typhoon ensemble prediction system.

2. Changes from the previous model

Major changes to JMA-GSM under the renovation are as follows: the reduced spectral transformation (Juang, 2004; Miyamoto, 2006) was introduced; a two-dimensional decomposition method was employed to decompose the calculation domain of the model for MPI parallelization; the procedures of inter-node communication were refined; and OpenMP directives were adopted for shared memory parallelization. Additionally, a number of deficiencies were corrected, and the source program was reorganized.

The introduction of the reduced spectral transformation lowered the model's number of grid points and the number of wave number components. Accordingly, it now has a kind of reduced Gaussian grid system. The number of grid points is 28.8% (22.9%) smaller than that of the conventional model in the case of the T959 (T319) linear Gaussian grid. As a result, the model's execution time has been shortened.

The employment of a two-dimensional decomposition method, the refinement of inter-node communications and the adoption of OpenMP directives improved computational efficiency, especially on scalar-type computer systems with a large number of computational nodes. The strategy for decomposing the calculation domain of the model and the procedures of inter-node communications were designed to minimize the occurrence of such communications. Load balancing among computational nodes and minimization of the amount of data communicated among such nodes were also considered. OpenMP directives allow us to parallelize outer loops in the manner expected, regardless of the kind of compiler used.

The renovation corrected the following deficiencies: the highest degree of integrands in spherical harmonic transformation exceeded the limit of Gauss-Legendre quadrature; the tables of Gaussian latitude, Gaussian weight and associated Legendre functions were evaluated in double precision arithmetic in the same way as the other variables; negative hydrometeor values were occasionally caused by unnatural local minima occurring in the semi-Lagrangian advection process; the coefficient

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of horizontal diffusion for divergence was double that for vorticity as a relic of the implicit advection scheme previously employed. In the renovated model, the tables of Gaussian latitude, Gaussian weight and associated Legendre functions are evaluated in quadruple precision arithmetic. Additionally, a monotonic semi-Lagrangian advection scheme is employed.

The source program was also reorganized. A spectral model includes grid space and wave number space; the primary focus was changed to the grid space from the wave number space. This makes the source program clearer and allows numerical modelers to design physical parameterizations more flexibly. The reorganization reduced the minimum memory space needed to operate the model. The renovated version can be run on 12 nodes of HITACHI SR11000K1 at JMA, whereas the older model needed at least 30 nodes to implement.

3. Improved execution time

The renovation shortened the execution time for an 84-hour deterministic prediction by an average of 8 minutes and 19 seconds. The previous model took 38 minutes and 47 seconds to perform 84-hour deterministic prediction based on the average of the 36 days before the day of the replacement. The renovated model took 30 minutes and 28 seconds based on the average of the 36 days after it. At the time of the replacement, every deterministic prediction produced a special dataset for a scientific project. Accordingly, the extra time taken was included in the execution time. After the project, the renovated model took 28 minutes and 43 seconds based on the 36-day average.

4. Improved accuracy

The renovation improved RMSE in almost all the variables we investigated by an average of a few percentage points in the resolutions of both the T959 and T319 linear Gaussian grids. Tables 1 and 2 show the values of the improvement rate achieved by the renovation. The improvement rate shows the extent to which modification of the model diminishes the RMSE of each variable on average over a 216-hour prediction. The values were evaluated though two one-month assimilation / prediction experiments. One of the two experiments used the original model, and the other used the modified version. In the experiment, the four-dimensional variational data assimilation system was used with the model to produce assimilated fields at intervals of six hours (00, 06, 12, 18 UTC) over a one-month period. A 216-hour prediction was then started from each of the assimilated fields at 12 UTC with the same model.

Table 1: Improvement rate [%] resulting from the renovation on T959

	Psea	T850	Z500	Wspd850	Wspd250
Aug. 2006	1.49	1.46	1.57	1.06	0.95
Jan. 2007	1.95	1.78	2.1	1.39	0.92

Table 2: Improvement rate [%] resulting from the renovation on T319

	Psea	T850	Z500	Wspd850	Wspd250
Aug. 2004	1.26	1.27	1.39	0.78	0.69
Jan. 2006	0.62	0.63	0.52	0.52	0.39

References

Iwamura, K. and H. Kitagawa, 2008: An upgrade of the JMA Operational Global NWP Model. *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling*, **38**, 06-03 – 06-04.

Juang, H.-M.H., 2004: A Reduced Spectral Transform for the NCEP Seasonal Forecast Global Spectral Atmospheric Model. *Mon. Wea. Rev.*, **132**, 1019-1035.

Kadowaki, T., 2009: Development of a Semi-Lagrangian Inner Model for Improving the Inner Resolution of the JMA Global Analysis System. *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling*, **39**, in printing.

Miyamoto, K., 2006: Introduction of the Reduced Gaussian Grid into the Operational Global NWP Model at JMA. *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling*, **36**, 06-09 - 06-10.