Upgrade of parameterization schemes in JMA's operational global NWP model

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1. Introduction

In March 2016, the Japan Meteorological Agency (JMA) began operation of an upgraded Global Spectral Model (GSM: JMA 2013) in which various parameterization processes (such as deep convection, cloud, radiation, land model and sea surface) were substantially revised to improve the representation of atmospheric characteristics. In this development, careful research was conducted over several interrelated physics schemes to disentangle compensating errors. As a result, several undesirable forecast characteristics that could not be eliminated via single-process refinements were excluded. This report briefly outlines the parameterization upgrades and related aims.

2. Parameterization improvement

(a) Deep convection

In the convection scheme, the artificial energy correction method used to compensate for the lack of melting process was eliminated. As this approach was artificial and ad hoc, heat and humidity tendencies were estimated unphysically and with low accuracy. It was replaced with a melting process for convective rainfall. As this change resulted in excessive heat from melting and unrealistic convective rain distribution, the sub-cloud model of the convective scheme was improved with the introduction of Kessler-type auto-conversion to reduce upward transportation of water content. Below the cloud base, a new entraining plume model based on Jakob and Siebesma (2003) was also adopted, and artificial adjustment of detrained cloud ice was stopped.

(b) Cloud

Clouds are prognostically determined in a fashion similar to that proposed by Smith (1990) with a top-hat-shaped probability distribution function whose width depends on deep convection scheme mass flux. This mass-flux dependency was eliminated to reduce grid point storms occurring as a result of the convection sub-cloud model revision. The prediction equation for cloud icefalling, which included artificial unphysical terms (Kawai 2005), was also revised. Additionally, the time discretization method was improved to reduce dependence on the time integration interval. As these changes resulted in slower cloud ice descent, the amount of high cloud increased in the mid-to-high latitudes and elsewhere. Due to easing of high cloud amount deficiency, downward long-wave radiation error near the surface was reduced.

(c) Sea surface

Surface exchange coefficients based on the Monin-Obukhov similarity theory (Beljaars and Holtslag 1991) were introduced for bulk exchange formulation of sea surface fluxes, and an improved sea ice model with more layers was adopted. Tiling between open water and sea ice was also introduced, with the approach suggested by Best et al. (2004) followed as a coupling strategy. As a result of these improvements, winter boundary layer cold biases at high latitudes were reduced via improvement of low-temperature bias in sea ice areas.

(d) Land model

In the land model, overall specifications were comprehensively updated and refined schemes were introduced. Specifically, the force-restore method for soil temperature prediction was replaced with a multilayer soil heat and water flux model and separate layers for snow. A new snow model with up to four layers was also introduced, with consideration for thermal diffusion, increased density from snow compaction and reduction of albedo due to snow aging. The distribution of vegetation types was further updated based on GLC2000. The new model provides higher levels of detail and precision, but atmospheric issues cause deterioration of boundary layer cold biases at high latitudes in winter with this improvement alone. There were a shortage of downward longwave radiation and low-temperature bias from the sea ice model in such areas. The new land model was suitable for implementation only after the improvement of other parameterization schemes.

(e) Radiation

A practical independent column approximation method for shortwave radiation cloud overlap in the cloudy area of the column was also adopted to replace random overlap (Nagasawa 2012). For a mixed state between spread anvil and narrow tower cloud (i.e., deep convection), cloud optical thickness was overestimated in shortwave radiation calculation with the previous random overlap approach. Parameterization methods for the liquid water cloud optical properties in shortwave and longwave radiation were also improved (Dobbie et al. 1999; Lindner and Li 2000).

3. Verification results

An experiment was conducted to evaluate the upgraded GSM's performance. Figure 1 shows that tropical cyclone track forecast errors for the northwestern Pacific region were reduced, and further verification indicated improvement in the new model's performance for cyclone identification. Figure 2 shows profiles of root mean square errors (RMSE) against analysis for 11-day forecasting of temperature vertical profiles. The verification region was the Northern Hemisphere (20 – 90°N), and the trial period was one month. The GSM upgrade reduced RMSE values for most pressure levels and all forecast times. Overall improvement was also seen in forecasts of other elements such as geopotential height and wind.

4. Summary

In previous GSM development, the omission of consideration for a number of major processes resulted in dramatic accuracy improvements from the enhancement of single processes. Such cases are now rare, and improvement of individual processes often exposes previously hidden issues. Accordingly, there is a need to identify the causes of issues arising and correct other processes at the same time. In the development reported here, several interrelated physics processes were intensively examined toward comprehensive improvement of GSM prediction. This strategy led to overall improvement in forecasts of geopotential height, temperature, humidity, rain, tropical cyclone track forecast error and other elements.

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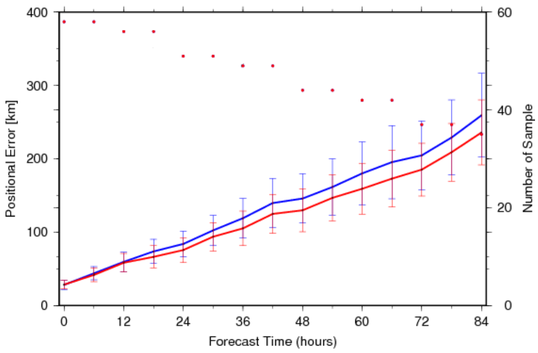

Fig. 1: Tropical cyclone track forecast errors for the northwestern Pacific region with reference to JMA best-track data. The red and blue lines show track errors for the new and old models, respectively (left axis), and each point shows the number of samples (right axis). Error bars indicate the two-sided 95% confidence interval.

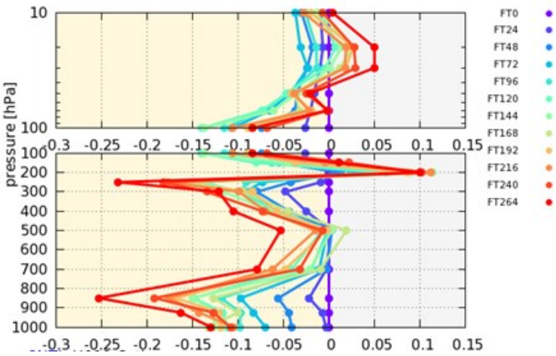

Fig. 2: Profiles of RMSE differences (new – old) for temperature [K]. The reference values are respective analysis results, and the verification region is the Northern Hemisphere (20 – 90°N). The trial period was Aug. 2015. The lines show results for a forecast time from FT = 0 h to FT = 264 h at 24-hour intervals.