# Development of a Cumulus Parameterization Scheme for the Operational Global Model at JMA

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## 1. Introduction

The Japan Meteorological Agency (JMA) adopted a prognostic Arakawa-Schubert scheme (Arakawa and Schubert 1974; Moorthi and Suarez 1992; Randall and Pan 1993; Pan and Randall 1998) for cumulus parameterization in Global Spectral Model (GSM). JMA revised this scheme in March 2001 to include a reevaporation effect of the convective precipitation (GSM0103) with a view to improving its performance in the medium- to long-range predictions of tropical precipitation and associated circulation. Preliminary forecast experiments indicated that the GSM without the cooling and moistening effects of the reevaporation tended to produce stronger precipitation over the intertropical convergence zone as compared with observation and weaker one in the vicinity of the Philippines. This erroneous precipitation distribution was the main reason for poor medium- to long- range weather prediction of the GSM prior to the implementation of GSM0103. However, GSM0103 had a cold bias and an associated systematic error for geopotential height field in forecast at the lower troposphere over wide areas of the low latitudes especially in the summer hemisphere on early forecast days. The main reason for these errors was the excessive cooling by evaporating convective precipitation.

JMA has developed a new cumulus parameterization scheme which considers the detrainment effect in addition to the entrainment between the cloud top and the cloud base in convective downdraft and abolishes reevaporation of convective precipitation (GSM0305). This paper gives results of forecast/assimilation experiments to evaluate two versions of GSM.

## 2. Experiment setup

The model used in this paper is GSM with triangular truncation at the wave number 213. In the vertical, the model places 40 layers up to 0.4 hPa. For further details of GSM and the data assimilation system, see JMA (2002). The major differences between GSM0103 and GSM0305 are as follows:

(i) The cumulus parameterization scheme is upgraded to consider the detrainment effect in addition to the entrainment between the cloud top and the cloud base in convective downdraft and to abolish the reevaporation of convective precipitation.

(ii) The estimation of the moist static energy at the cloud base is changed from the sum of the average in the planetary boundary layer and the effect of turbulent flow to the maximum value in the planetary boundary layer.

(iii) The convective momentum transport scheme is revised to include the entrainment and detrainment effects between the cloud top and the cloud base.

(iv) Time constants to reduce a cloud work function and to dissipate cumulus kinetic energy are shortened.

(v) The conversion rate from cloud water to precipitation in the large scale precipitation scheme is modified to consider the effect of convective rain.

In GSM0103, detrainment from a convective downdraft is assumed to occur only below the cloud base, whereas entrainment is assumed to occur between the cloud top and the cloud base. The effect of detrainment between the cloud top and the cloud base is considered in GSM0305 to represent convective downdraft which cools and moistens lower troposphere more realistically. At the same time, the reevaporation of convective precipitation is omitted because the evaporation of raindrop falling through humid air should be negligible.

The 3D-Var data assimilation system is also renewed. The raw ATOVS radiance data are directly assimilated in the new system instead of conventional retrieved thickness data (Kazumori et al. 2004). As a result, we can avoid errors due to retrieval and reflect moisture observations as well as temperature observations to the analysis. Regression coefficients and the background error covariance matrix in the 3D-Var assimilation system are also updated (Fujita 2004).

To test the impact of the new scheme, two forecast/assimilation experiments are conducted. One consists of GSM0103 and the old version of 3D-Var assimilation system (hereafter CNTL), while the other comprises GSM0305 and the new 3D-Var assimilation system (hereafter TEST). The periods for the experiments are from 28 June to 8 August 2002 and from 28 November 2001 to 8 January 2002. Nine days forecasts are performed for 31 initials of 12UTC 1-31 July 2002 and 1-31 December 2001 for both CNTL and TEST. The results are compared with each other.

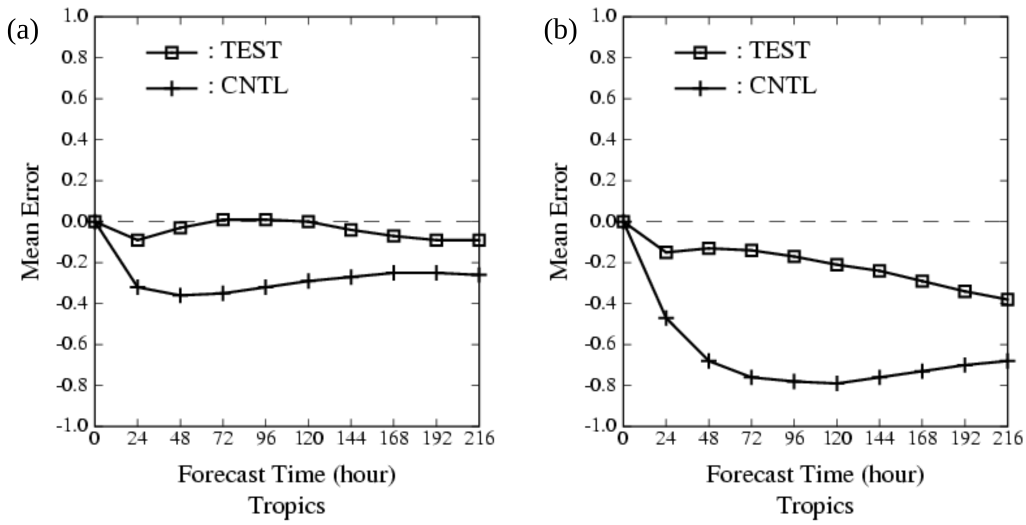


Fig. 1. Time series of the mean forecast error of 850 hPa temperature (K) over the tropical zone (20S - 20N) averaged over the 31 forecasts. (a): July 2002, (b): December 2001, +: CNTL, □: TEST.

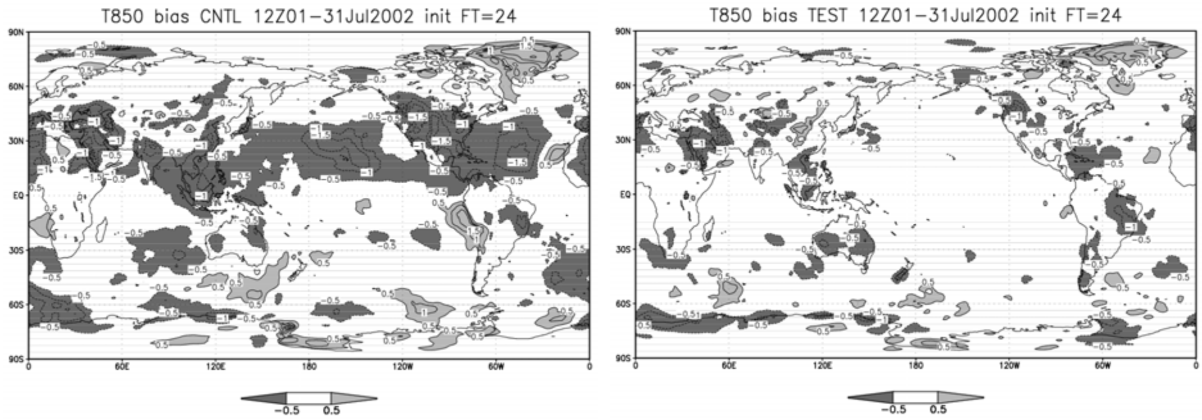


Fig. 2. Mean error of 24-hour forecast for 850 hPa temperature (K) averaged over the 31 forecasts in July 2002 by CNTL (left) and TEST (right). Areas with mean forecast errors larger than 0.5 K are lightly shaded and those less than –0.5 K are darkly shaded.

**3. Results**

Figure 1 shows the time series of the mean forecast error of 850 hPa temperature over the tropical zone (20S-20N) averaged over the 31 forecasts. It is seen that CNTL shows a systematic cold bias throughout the forecast periods both in July 2002 and December 2001 experiments. The bias is much smaller in TEST than in CNTL. This difference can be attributed to the change in the cumulus parameterization scheme. It is found that the heating rate by cumulus convection in the tropical zone at the lower troposphere of TEST forecast is larger than that of CNTL forecast, which can cause the reduction of bias. The tendency to predict the 500 hPa geopotential height field lower than the analysis field in CNTL is also reduced in TEST (not shown), which can be explained by the reduced cold temperature bias in the lower troposphere.

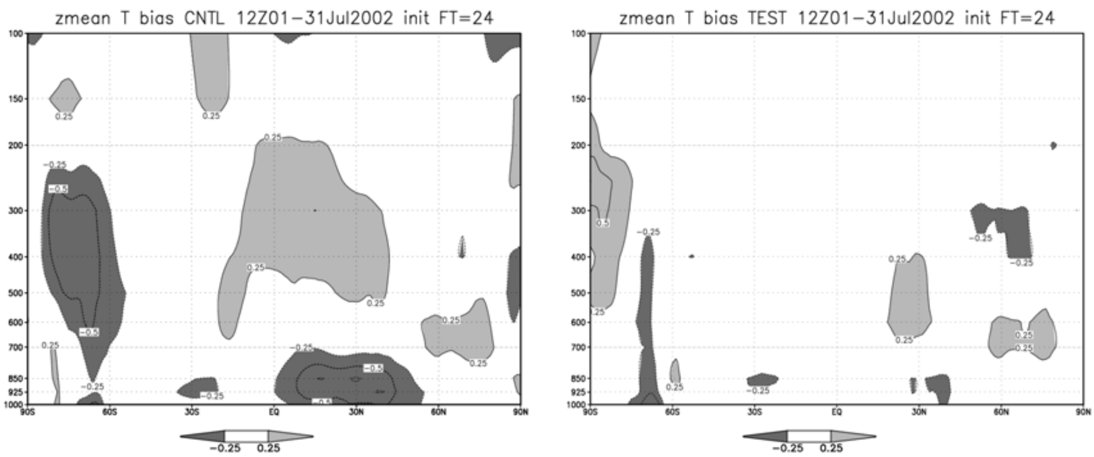


Fig. 3. Vertical cross sections of mean error in 24-hour forecast for the zonal mean temperature (K) averaged over the 31 forecasts in July 2002 by CNTL (left) and TEST (right). Areas with mean forecast errors larger than 0.25 K are lightly shaded and those less than –0.25 K are darkly shaded.

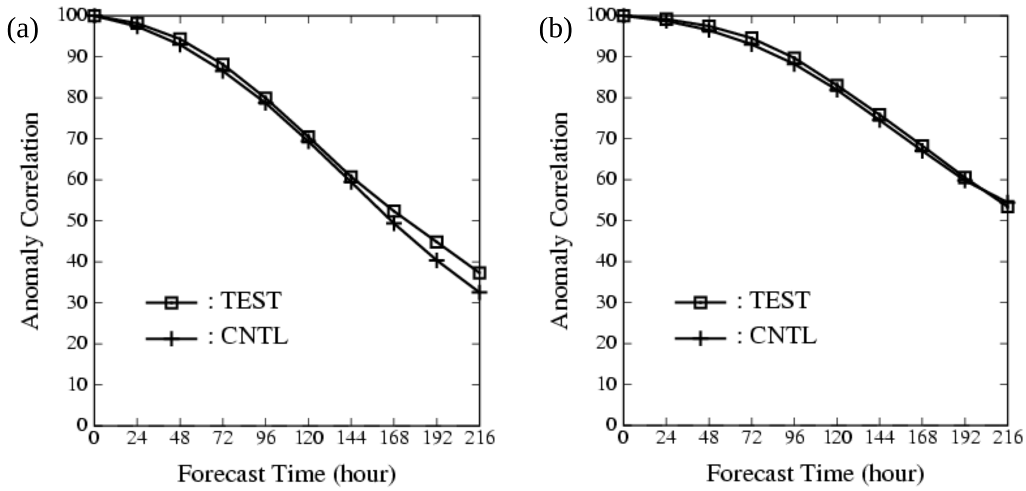


Fig. 4. Time series of the global anomaly correlation of 500 hPa geopotential height averaged over the 31 forecasts. (a): July 2002, (b): December 2001, +: CNTL, □: TEST.

The mean error of 24-hour forecast of 850 hPa temperature for July 2002 experiment is shown in Fig. 2. The area with cold bias lower than –0.5 K is shaded thick. The forecast field by CNTL is systematically lower than the analysis field on wide areas in the Northern (summer) Hemisphere. TEST produces much better forecasts than CNTL, which is consistent with the smaller temperature bias at lower troposphere as shown in Fig. 1.

Figure 3 shows the vertical cross sections of mean error in 24-hour forecast for the zonal mean temperature averaged over 31 forecasts in July 2002. In the low latitudes, CNTL shows cold bias at the lower troposphere and warm bias at the middle troposphere, whereas the bias of TEST is smaller.

Anomaly correlation of 500 hPa geopotential height forecast is shown in Fig. 4. It is seen that the impact of the new convection scheme and data assimilation system is positive in both July 2002 and December 2001 experiments. To separate the impact of the new convection scheme from that of the new data assimilation system, a preliminary experiment using the new convection scheme and the old data assimilation system is conducted with the exception that the ATOVS channels sensitive to the moisture is directly assimilated. Heating rate by the cumulus convection in the tropical zone at the lower troposphere of GSM0305 forecast is larger than that of GSM0103 forecast, which results in the reduction of the forecast bias at the lower troposphere. In contrast, the anomaly correlation shows almost no improvement. These results suggest that the improvement seen in Fig. 2 is due to the new convection scheme and that seen in Fig. 4 may be attributed to the direct assimilation of the ATOVS channels sensitive to the temperature field.

It is expected that the improvement in forecast for the tropics leads the better performance in the typhoon track prediction. Figure 5 shows the forecast tracks of typhoon Halong (0207) by CNTL and TEST along with the best track analyzed by the RSMC Tokyo – Typhoon Center. It is seen that CNTL track shows northeastward error. This error may be caused by the tendency to predict the subtropical anticyclone weaker, which is related to the

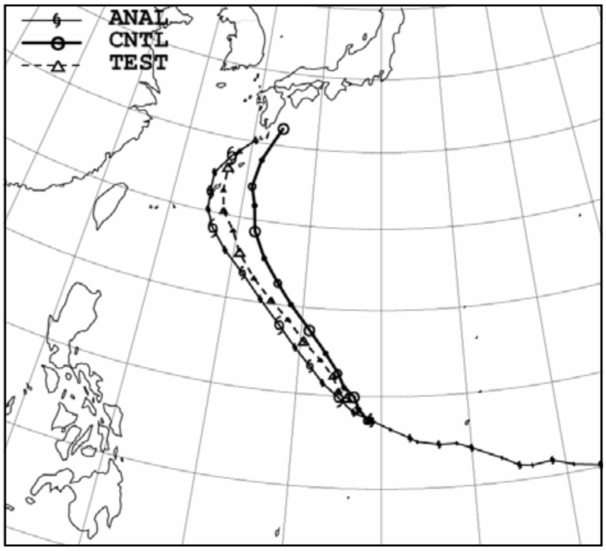


Fig. 5. Tracks of Typhoon Halong (0207) predicted by CNTL (thick line with circle) and TEST (broken line with triangle) at 12 UTC 11 July 2002. Analyzed best track (ANAL) is plotted by a thin line with section marks.

systematic negative error in forecast of the geopotential height field at the lower troposphere. TEST makes a much better forecast than CNTL, which is consistent with the smaller bias of the geopotential height field.

## 4. Summary

JMA has developed a new cumulus parameterization scheme in order to reduce the cold bias and associated negative bias for the geopotential height field in forecast at the lower troposphere. The data assimilation system is also renewed.

Forecast/assimilation experiments are conducted to test the impact of the new convection scheme and data assimilation system. The bias apparent in forecast of CNTL is substantially reduced in TEST. This improvement can be attributed to the change of the cumulus parameterization scheme. The anomaly correlation of the TEST forecast for the 500 hPa geopotential height field is higher than the CNTL forecast.

Typhoon track prediction is improved significantly by TEST in several cases as compared with CNTL. This improvement in TEST is explained by the reduction of the systematic negative error apparent in the CNTL forecast for the geopotential height field at the lower troposphere.

It is clear that the new cumulus parameterization scheme suppresses the systematic error of GSM0103 in temperature and geopotential height fields at lower troposphere. JMA implemented in May 2003 the new convection scheme and the 3D-Var data assimilation system with the direct assimilation of ATOVS radiance data in the operational GSM.

## References

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