Testing a Cumulus Parameterization Scheme for the Convective Gray Zone in JMA's Global Model

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1. Introduction

In 2018 the Japan Meteorological Agency (JMA) established a strategic plan toward 2030 that includes development direction to enhance the horizontal resolution of its global model to ≤10 km and develop new physical processes that are more suitable for such a high-resolution model. The horizontal grid spacing of JMA's operational Global Spectral Model (GSM) was upgraded from ~20 km to ~13 km in March 2023 and will reach the convective gray zone in a future upgrade. In this study, a cumulus parameterization scheme for the convective gray zone is developed and tested for the GSM, following Malardel and Bechtold (2019).

2. Model and Parameterization

The forecast model used in this study is the GSM, which is based on a spectral semi-implicit semi-Lagrangian hydrostatic dynamical core and was employed in an operational forecasting system from March 2020 until March 2021 (JMA, 2019; Yonehara et al., 2020). It has a horizontal spectral truncation of TL959 (~20 km) and 100 vertical layers up to 0.01 hPa. The cumulus parameterization scheme implemented in the GSM is a prognostic Arakawa–Schubert scheme (Arakawa and Schubert 1974). This scheme assumes that subgrid-scale convective updrafts and downdrafts are completely compensated by environmental subsidence in each grid column. Although this is a common assumption in conventional cumulus parameterization schemes, its validity becomes questionable with smaller grid boxes when approaching the convective gray zone. Malardel and Bechtold (2019) relaxed this assumption by transferring the subgrid convective mass source to the continuity equation and subsequently reported improved simulation results in the convective gray zone. In this study, we implemented the scheme of Malardel and Bechtold (2019) in the GSM with the addition of the parameter α which represents the ratio of compensating subsidence computed in the cumulus parameterization scheme to the overall compensating subsidence. The continuity equation is written as follows:

$$\frac{\partial \bar{\rho}}{\partial t} = -\boldsymbol{\nabla}_{\mathrm{H}} \cdot (\bar{\rho}\,\bar{\boldsymbol{u}}_{\mathrm{H}}) - \frac{\partial (\bar{\rho}\,\bar{w})}{\partial z} - (1-\alpha)\frac{\partial M_{net}}{\partial z} \quad (1)$$

where ρ is density, u_{H} is horizontal wind, w is vertical velocity, and M_{net} is the net convective mass flux (i.e., the net effect of the updraft M_u and downdraft M_d); overbars denote grid-box means. The balance equation for a conservative variable ϕ is written as follows:

$$\bar{\rho}\frac{\partial \bar{\phi}}{\partial t} = -\bar{\rho}\,\bar{\boldsymbol{u}}_{\mathrm{H}} \cdot \boldsymbol{\nabla}_{\mathrm{H}}\bar{\phi} - \bar{\rho}\,\bar{w}\frac{\partial \bar{\phi}}{\partial z} - \frac{\partial M_u(\phi_u - \bar{\phi})}{\partial z} - \frac{\partial M_d(\phi_d - \bar{\phi})}{\partial z} - (1-\alpha)M_{net}\frac{\partial \bar{\phi}}{\partial z} \quad (2)$$

The first and second terms on the right-hand side of equation (2) are computed in the dynamics,

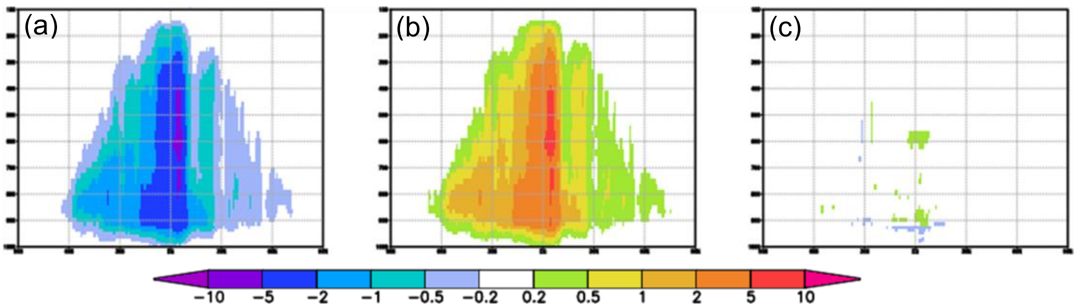

Fig. 1: Zonal mean cross-sections of the difference in temperature tendencies (i.e., TEST minus CNTL; K/day). (a) Convective tendencies. (b) Dynamical tendencies. (c) Sum of (a) and (b).

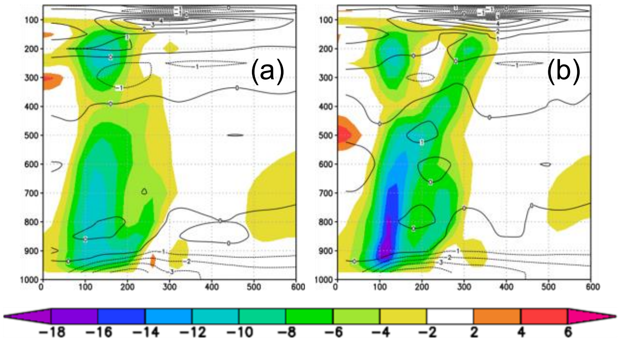

Fig. 2: Radius vs height cross-sections of the azimuthal mean vertical wind (shading) and radial wind (contours) of Typhoon Yagi (T1814) from 36-h simulations using (a) CNTL and (b) TEST.

while the third to fifth terms are computed in the parameterization of convection. Equations (1) and (2) are equivalent to the corresponding equations in Malardel and Bechtold (2019) when $\alpha = 0$ (hereafter TEST), while they are equivalent to the corresponding equations in the conventional scheme when $\alpha = 1$ (hereafter CNTL).

3. Results

Figure 1 shows zonal mean cross-sections of the difference in temperature tendencies (TEST minus CNTL; K/day) from (a) convection and (b) dynamics by 24-h forecasts from TEST and CNTL. The warming effect of the compensating subsidence is transferred from the parameterization of convection to the dynamics, and the change in the sum of these tendencies (Figure 1(c)) is small. However, mass fluxes of cumulus in TEST with a cloud top higher (lower) than ~8 km tend to be smaller (larger) than that in CNTL, which result in smaller (larger) coverage of high- (middle- and low-) level cloud and ~0.15 K lower temperature at ~10 km height in the tropics after 11 days of integration in TEST.

Figure 2 shows vertical cross-sections of the azimuthal mean vertical wind and radial wind of Typhoon Yagi (T1814) from 36-h simulations initialized at 1200 UTC 8 August 2018 using (a) CNTL and (b) TEST. The stronger secondary circulation in the TEST forecast results from divergence (convergence) of the horizontal wind at the top (bottom) of the cumulus, as generated by the vertical derivative term of mass flux in the continuity equation. The precipitation of the TEST forecast is more intense on the southwestern side of Yagi compared to that of the CNTL forecast (Fig. 3). The improvement in typhoon track forecast (Fig. 4) relates to the change in typhoon structure and distribution of diabatic heating.

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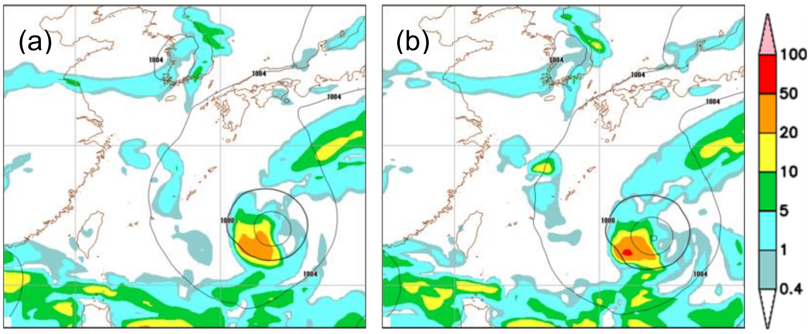

Fig. 3: The 36-h forecasts of 6-h accumulated precipitation (shading) and sea level pressure (contours) with (a) CNTL and (b) TEST initialized at 1200 UTC 8 Aug. 2018.

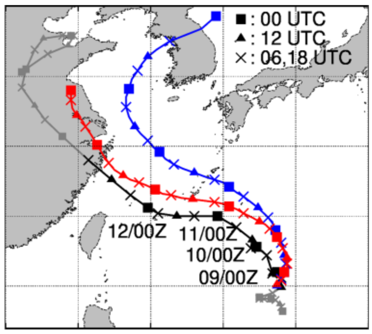

Fig. 4: Best track (black line) and CNTL (blue line) and TEST (red line) track forecasts initialized at 1200 UTC 8 Aug. 2018 for T1814.