# Recent Approach toward More Physically-based Convection Scheme in the JMA Operational Global Model

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## Introduction & Summary

- The Japan Meteorological Agency (JMA) adopts a spectral mass-flux convection scheme based on Arakawa and Schubert (1974) in its operational global model.
- A spectral scheme can represent many types of plumes explicitly, while an effective plume is considered in a bulk parameterization.
- However, many not physically-based processes were included in the past scheme for practical reasons such as avoidance of computational complexities.
- Because of the ad hoc treatments, the overall scheme looked like a "jenga tower", and it made further improvement of the scheme difficult.
- In 2016 and 2017, the scheme was improved. Furthermore, a drastic development of the scheme is under way.
- One of the major objectives in these developments is to maintain and **take advantages of the spectral type convection scheme**, and make the scheme **more physically-based**.
- This presentation shows two topics of how we improved/are currently developing in order to achieve the objective.

(1) The refinement of microphysics in the updrafts was adopted in the recent upgraded scheme with effort to reduce computational cost of the model.
(2) The cloud model based on Chikira and Sugiyama (2010) is currently tested to make the scheme more sensitive to environmental relative humidity (RH) .

## Overview of the convection scheme in JMA

- Spectral mass-flux scheme based on Arakawa and Schubert (1974) and Moorthi and Suarez (1992) considering ice phase and simple microphysics.
  - Cloud top of each plume is set to a model full level (Lord et al. 1982). (Fig.1)
  - Entrainment rate of each plume is inversely determined so that the plume loses buoyancy at the model full level assuming the following normalized mass flux.

$$\eta_i = 1 + \lambda_i (z - z_B) \quad (1)$$

η:normalized mass flux, λ: entrainment rate [1/m], z: height [m], $z_B$: height of cloud base[m], i: an individual plume of an ensemble

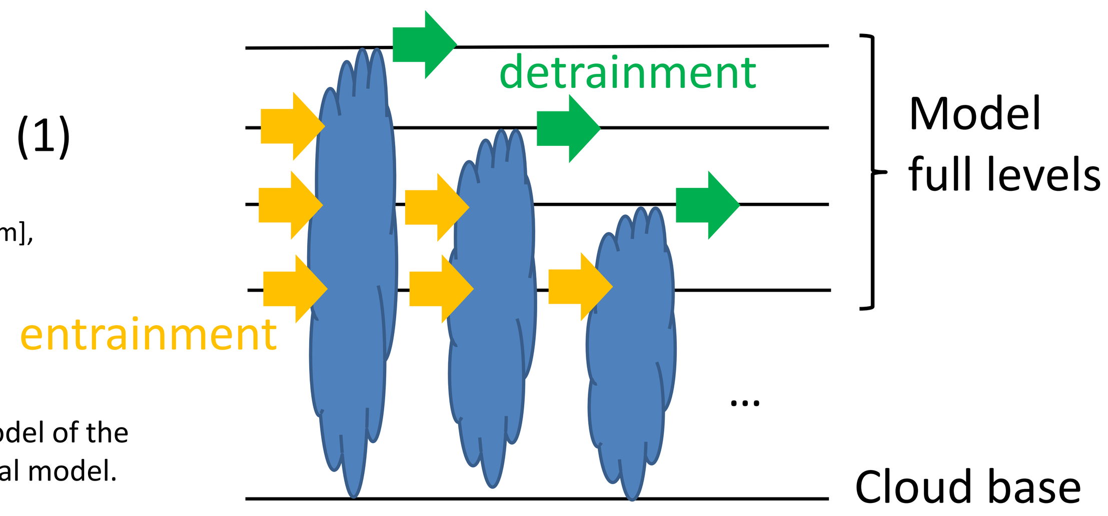



Figure 1. Schematic of the cloud model of the convection scheme in the JMA global model.

- Prognostic closure based on Randall and Pan (1993) and Pan and Randall (1998) with many modifications.
- Triggering mechanism using DCAPE concept (Xie and Zhang 2000).
- More details can be found in JMA (2019).

## Topic 1: Refinement of microphysics

- Before the upgrade of the scheme in 2016, a conversion process from cloud water to precipitation between the cloud base and top in the updraft cloud model was not considered due to its computational cost.
- It requires an iterative calculation to obtain the entrainment rates with the "full level cloud top" framework and consideration of ice-phase.
- The lack of the process led to the excessive ice generation in the updrafts. (Fig. 2a)
- It was also the reason of the top-heavy convective heating profile pointed out by Lin et al. (2012).

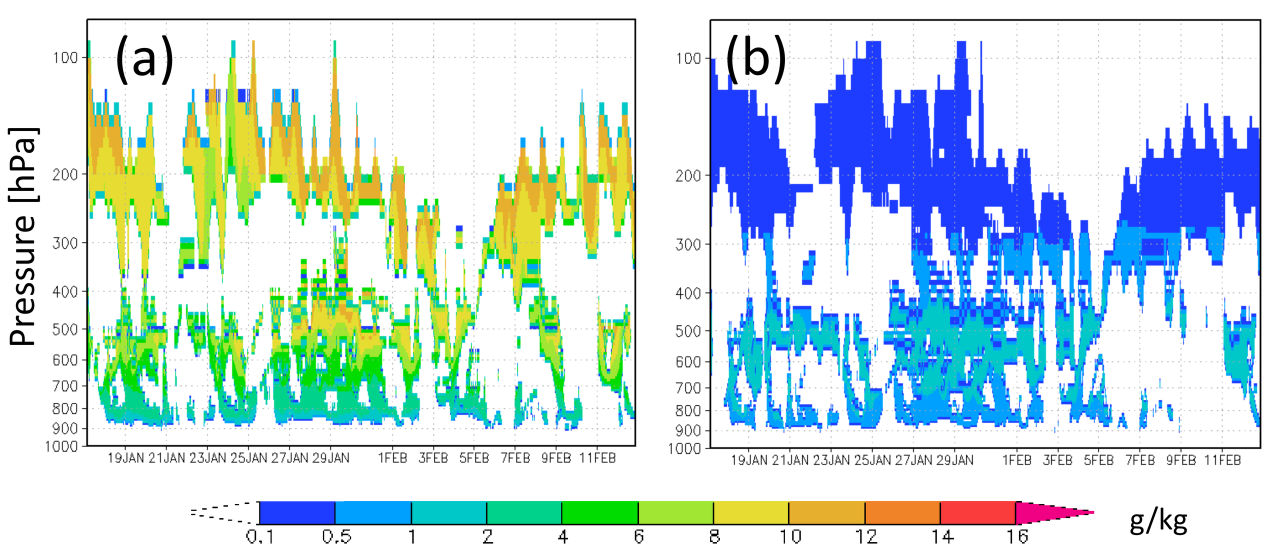



Figure 2. Cloud water content [g/kg] conveyed to the cloud top in each plume of cumulus ensemble (a) without and (b) with the conversion of cloud water to precipitation between the cloud base and top in the updrafts using the SCM of the TWP-ICE case.

- To fix these problems and make the scheme more physically-based, we added an auto-conversion term to the cloud model (Eq. 2). Speedup of the entire model is also conducted to make up the increased computational cost for the iteration. The result is shown in Fig. 2b.

$$\frac{\partial \eta q_t}{\partial z} = \epsilon \bar{q} - \delta q_t \boxed{- \eta c_0 \max(q_c - q_{c0}, 0)} \quad (2)$$

η: normalized mass flux, $q_t$: total water (=$q_c$+$q$) [kg/kg], $q$: specific humidity [kg/kg] $q_c$: cloud water content [kg/kg], ε: entrainment rate [1/m], δ: detrainment rate [1/m] $c_0$: auto-conversion rate, $q_{c0}$: threshold cloud water content of auto-conversion [kg/kg]

- This change also contributed to the improvement of the melting process.
- Before 2016, the melting process was not explicitly calculated. The melting of the excessive ice generated in the updraft could cause computational instability. Its cooling effect was implicitly and artificially distributed through the mid- to lower troposphere.
- A melting process (simple relaxation) is implemented along with the change of the precipitation process in the cloud model.
- With the improvement, the atmosphere around the freezing level is adequately cooled. The convective activity of the new scheme shows clear existence of cumulus congestus above the freezing level (Fig. 3).

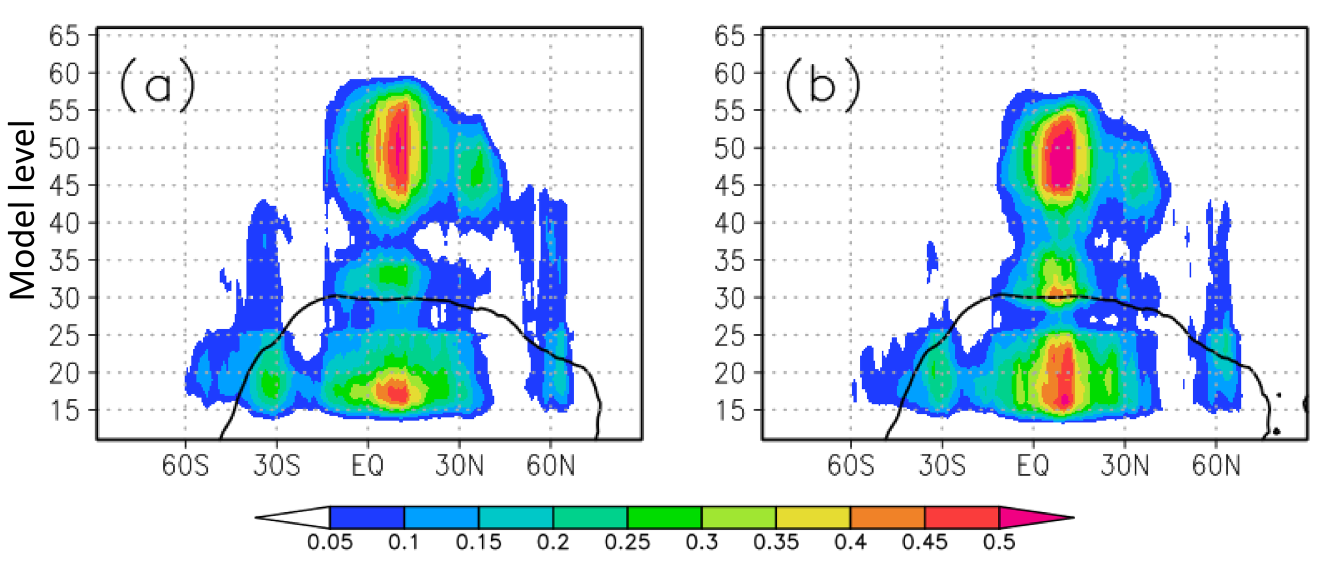



Figure 3. The zonal mean of fraction of convective cloud top detected at each level (shade) from T+18h to T+24h (a) before the upgrade in 2016, and (b) after 2017. The solid black line indicates the level of 0 °C. The initial time is August 1, 2015.

## Topic 2: Sensitivity to environmental RH

- One of the key issues in the current development of the convection scheme is its sensitivity to the environmental relative humidity (RH).
- The convection scheme in the JMA global model is tested using the SCM setting described in Derbyshire et al. (2004). It exhibits some sensitivity to the RH, but not enough compared to de Rooy et al. (2013). (Fig. 4).

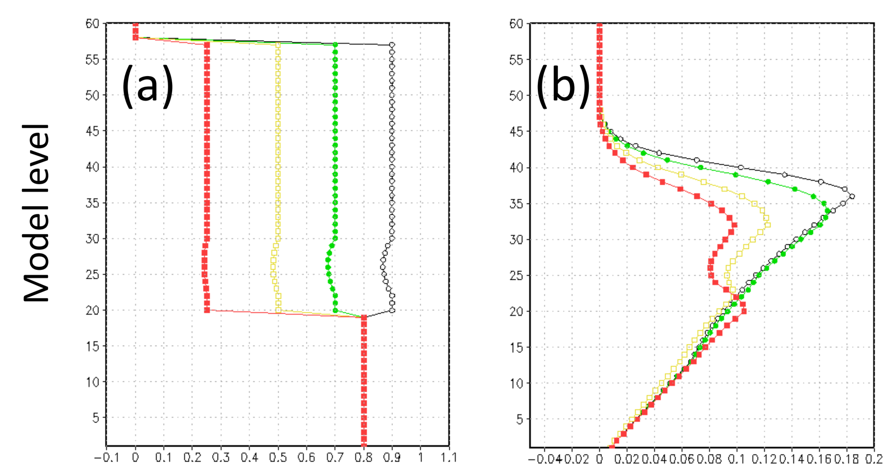



Figure 4. Results of SCM experiment of the Derbyshire et al. (2004) setting using the GSM physics schemes. (a) Four different target RH settings and (b) upward mass flux [kg/(m²s)] in the four settings.

- In the current scheme, both the cloud model and the closure explain its sensitivity to RH. However, the closure includes several ad hoc tunings (Eq. 3), and RH effect is very complex (terms with red circles are sensitive to RH).

$$\frac{dM_B^u}{dt} = \max\left(\frac{A - fA_0}{2\alpha}, 0.0\right) \min\left(\frac{\lambda}{\lambda_{\min}}, 1\right) \max(\lambda_{\max}, 0) \frac{\Delta p}{\Delta p_{\mathrm{eff}}} - \frac{M_B^u}{2\tau_D} \quad (3)$$

$M_B$: mass flux at the cloud base [kg/(m²s)], $A$: cloud work function [J/kg], $A_0$: Observed cloud work function in the tropics [J/kg] (Lord and Arakawa 1980), λ: entrainment rate [1/m], $\tau_d$: time of cumulus kinetic energy decay [s]. More details can be found in JMA (2019).

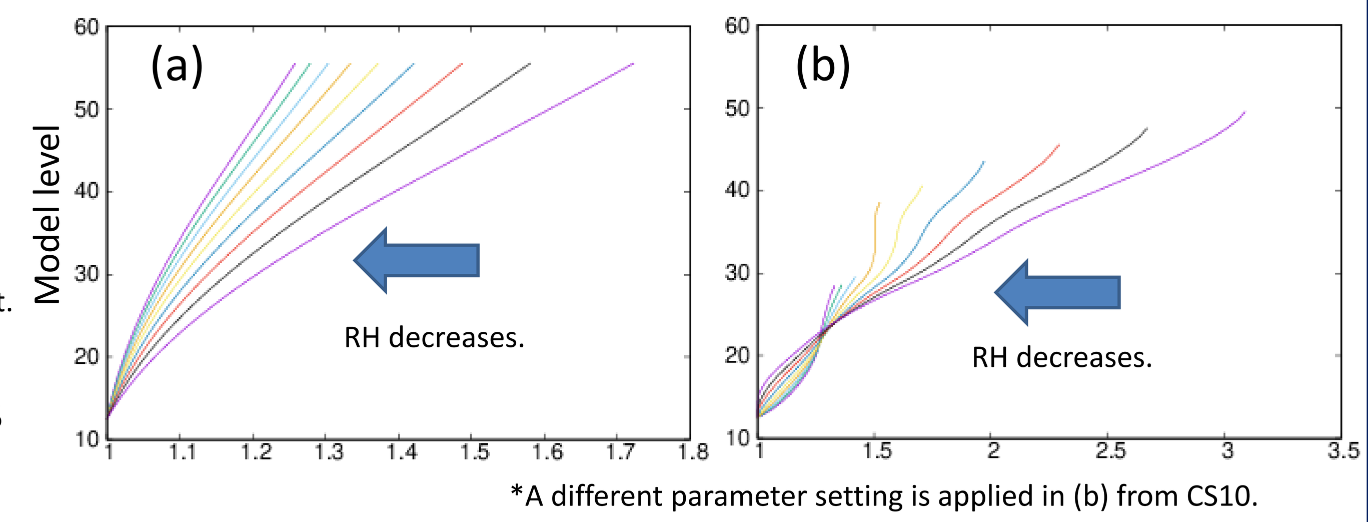
- In order to build more physically-based scheme using the spectral mass-flux scheme, a cloud model proposed by Gregory (2001) is tested based on Chikira and Sugiyama (2010, hereafter CS10), which inherits the spirit of the Arakawa-Schubert scheme.
- Spectral plume based on several vertical velocities at the cloud base is adopted instead of the "full level cloud top" framework.

$$\frac{\partial \hat{w}^2}{\partial z} = a(1 - C_\epsilon)B - \frac{1}{z_0}\frac{\hat{w}^2}{2} \quad (4) \qquad \epsilon = C_\epsilon \frac{aB}{\hat{w}^2} \quad (5)$$

w: vertical velocity [m/s], z: height [m], B: buoyancy [m/s²], a,$C_\epsilon$: constant parameter, $z_0$: constant parameter [m], ε: entrainment rate [1/m]

- Following CS10, the SCM experiment using the version 2.1 of the Intensive Flux Array averaged fields of the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) (Ciesielski et al. 2003) with several environmental RH settings is conducted.
- Fig. 5 indicates that the test cloud model exhibits more sensitivity to RH than the current one. The test result is consistent with CS10.

Figure 5. Normalized mass flux of a plume that reaches the highest top among the spectral in the SCM experiment using the forcing data made from the version 2.1 of the Intensive Flux Array averaged fields of the TOGA-COARE (Ciesielski et al. 2003) with different RH environment. (a) The current cloud model, and (b) test. The color indicates different environmental RH settings from 10% to 90% with 10% increment.




*A different parameter setting is applied in (b) from CS10.

- Sensitivity to RH can be expressed with the more-physically based cloud model, so the ad hoc tunings in the closure should be removed.
- Next target is to make the closure simpler.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