A Comparison of In-cloud and Environmental Properties in Numerical Results between Cloud-resolving and Parameterized Simulations for a Tropical Cyclone Rainband

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1. Introduction

Precipitation in a tropical cyclone appears to be sensitive to the formulation for cumulus parameterization because latent heat release is a key factor for tropical cyclone intensification. Smith (2000) pointed out that the details of tropical cyclone evolution seemed to be sensitive to the treatment of convection in numerical models. We also showed that representation of a prominent rainband in a tropical cyclone was sensitive to the choice of cumulus parameterization (Murata et al. 2003).

Recently, we investigated the vertical profiles of fractional entrainment rate as to cumulus convection (Murata and Ueno 2003). Numerical simulations of a tropical cyclone rainband were conducted using a high-resolution three-dimensional cloud-resolving model (CRM) with the 200-m horizontal resolution. Fractional entrainment rate, derived from the calculation based on the vertical gradient of cloud mass flux, showed larger near cloud base and top. Entrainment rate was smaller in between and was even negative in many cases that suggested laterally detrained air from a cumulus into the environment.

In this study, on the basis of the results of the CRM simulations, vertically variable entrainment rate is applied to the Arakawa-Schubert (AS) cumulus parameterization. We then compare in-cloud and environmental properties in the result of a parameterized simulation for a tropical cyclone rainband to that of a cloud-resolving simulation.

2. Formulation of entrainment rate in the modified scheme

We modify the formulation of entrainment rate in a version of AS scheme operationally used in Japan Meteorological Agency, which has the prognostic equation that predicts the cloud-base mass flux and has a downdraft and a mid-level convection (Kuma et al. 1993). The modified version adopts vertically variable entrainment rate that represents larger values near cloud base and top, instead of vertically constant entrainment rate used in the original version. The rate has negative values, representing lateral detrainment, in a part of the cloud layer. Detrainment at cloud top, same as the original version, is also included.

Firstly, for each cloud spectrum, we prescribe the lateral detrainment layer and set the heights of the base, z_{DB}, and top, z_{DT}, of the layer. Below the base, the vertical profile of entrainment rate, λ, should increase with height, z. For simplicity's sake, we assume an equation of cloud mass flux, M, as follows: $M/M_B=az^2+bz+c$ ($z_B<z<z_{DB}$), where the subscript B denotes cloud base and a, b and c are constants determined from following conditions: $\lambda=\lambda_B$ at $z=z_B$ and $\lambda=0$ at $z=z_{DB}$, where λ_B is entrainment rate at the height of cloud base, z_B. Above the base of the detrainment layer, entrainment rate is assumed as follows: $\lambda=\lambda_D$ ($z_{DB}<z<z_{DT}$), λ_T ($z_{DT}<z<z_T$), where λ_D (<0) denotes the effect of lateral detrainment. The constants, z_{DB}, z_{DT}, λ_B, and λ_D, are determined on the basis of the results of the CRM simulations. The remaining constant, λ_T, is automatically determined so that the following condition is satisfied: cloud top height is located where buoyancy in the cumulus disappears. This is the same condition as that adopted in the original AS scheme.

3. Comparison of properties in convective updrafts between the results of cloud-resolving and parameterized simulations

The Meteorological Research Institute / Numerical Prediction Division nonhydrostatic model (MRI/NPD-NHM; Saito et al., 2001) is used for comparison of the results between cloud-resolving (200-m horizontal grid spacing) and parameterized (20-km horizontal grid spacing) simulations for a rainband in typhoon Saomai (2000). Compared variables in convective updrafts are cloud mass flux, moist static energy and specific humidity.

The vertical profile of cloud mass flux, normalized by the value at cloud base, obtained by the simulation with the modified scheme is more consistent with that of the cloud-resolving simulation, compared to that obtained by the simulation with the original scheme. The mass flux in the cloud-resolving experiment has the maximum at 4.5 km high and increases rapidly from cloud base to 2-km high (Fig.1). The features are consistently reproduced by the modified scheme, although the peak value is slightly larger than that produced by the CRM one and the values above 5.5-km high is overestimated. The mass flux reproduced by the original scheme, on the other hand, increases linearly from cloud base to top, which is completely different from that obtained by the CRM.

Thermodynamic properties reproduced by the modified scheme are also more consistent with those in the CRM result. From a comparison of moist static energy (Fig.2), it is found that the rapid decrease in the quantity from cloud base to 3-km high and vertical uniformity between 3- and 6-km high are represented well in the simulation with the modified scheme, although the absolute values are larger than that in the cloud-resolving experiment. Underestimates of specific humidity above 5-km high, shown in the experiment with the original scheme, is slightly improved (Fig.3).

4. Comparison of environmantal properties between the results of cloud-resolving and parameterized simulations

Thermodynamic properties in the environment is more consistent with those produced by the CRM when we use the modified scheme, where the term “environment” refers to grid-scale for the parameterized simulations and refers to an average of 100x100 horizontal grid points, corresponding to the 20-km resolution, for the cloud-resolving simulation.

The vertical profiles of moist static energy and specific humidity in the simulation with the modified scheme approach those of the CRM result, suggesting the reduction of underestimates in the quantities (Fig.4 and 5). In particular, noticeable improvement is evident from middle to upper troposphere than below. The result suggests that cloud mass fluxes at those levels are suppressed owing to lateral detrainment, which reduces the mass fluxes above. The improvement, on the other hand, is insufficient in the lower troposphere, indicating that the cloud mass flux there is still too large. To improve the profile of cloud mass flux, it is necessary to verify arbitrary parameters in the modified scheme.

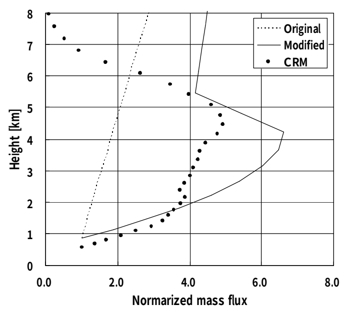

Fig.1 Vertical profiles of normalized cloud mass flux in a convective cloud in a rainband obtained by the parameterized model with the original and modified AS scheme and by the CRM.

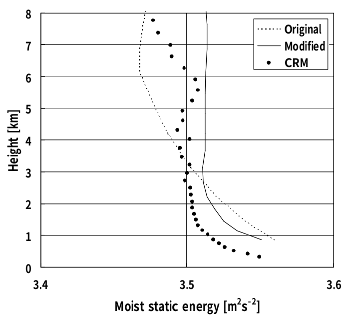

Fig.2 Same as in Fig.1, but moist static energy.

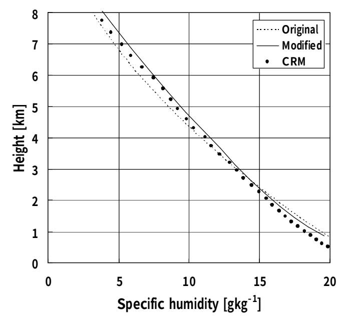

Fig.3 Same as in Fig.1, but specific humidity.

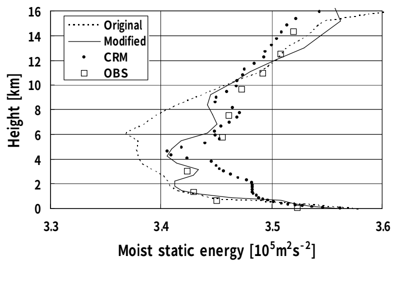

Fig.4 Vertical profiles of environmental moist static energy in a rainband obtained by the parameterized model with the original and modified AS scheme and by CRM. Observational data at the island of South-Daito are also plotted.

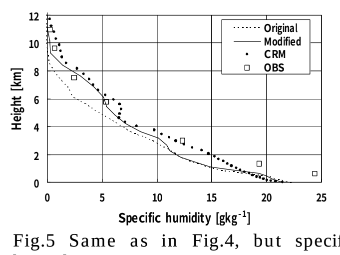

Fig.5 Same as in Fig.4, but specific humidity.

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