COMPARATIVE SIMULATION BETWEEN WITH BULK AND WITH BIN TYPE CLOUD MICROPHYSICAL SCHEME ON NON-HYDROSTATIC REGIONAL MODEL

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Takamichi Iguchi*
Center for Climate System Research, the University of Tokyo, Chiba, Japan

Teruyuki Nakajima
Center for Climate System Research, the University of Tokyo, Chiba, Japan

Alexander P. Khain
The Institute of Earth Sciences, the Hebrew University of Jerusalem, Jerusalem, Israel

Toshihiko Takemura
Research Institute for Applied Mechanics, Kyushu University, Fukuoka, Japan

1. INTRODUCTION

There are two methods that are generally used in high-resolutional model to represent cloud microphysics. One is a mode (bulk) method that predicts variables such as cloud mixing ratio and number concentration represented by integrated values of a prescribed size-distribution function. And another is a bin (spectral) method that size-distribution functions of cloud hydrometeors are discrete-approximated by a number of size bins and are predicted by a cloud microphysics scheme. As for an influence of aerosols on clouds, significant factors are changes of cloud droplets number consideration, mean radius, and total volume, which cause a change of the radiation property and residence time of clouds. Thus, a bin method, which is able to estimate those values directly, is more adapted than a bulk method to analyze the aerosol indirect effects.

This study presents the results of nest-grid simulation by a three dimensional non-hydrostatic model with mode-type cloud microphysical scheme and with bin-type cloud microphysical scheme. The comparison between the results can make clear problems and improvements of both two-type cloud schemes.

2. MODEL DESCRIPTION

A numerical model for atmospheric dynamics used in this study is based on a multi-purpose non-hydrostatic atmospheric model developed by the Forecast Research Department of the Meteorological Research Institute and the Numerical Prediction Division of the Japan Meteorological Agency (MRI/NPD-NHM) (e.g., Saito et al., 2001). This dynamical frame adopts a mode-type cloud microphysical scheme (Ikawa and Saito, 1991). Hydrometeors tracers are mixing ratios of 5 forms (cloud water, rain, cloud ice, snow and graupel) categorized in this bulk-type scheme. This scheme treats condensation, evaporation, auto-conversion from cloud water into rain, freezing and melting and so on. Then, we replaced it with a bin-type cloud microphysical scheme based on the Hebrew University Cloud Model (e.g., Khain et al., 2000). Model tracers are size distributions of cloud condensation nuclei (CCN) and hydrometeors categorized into 7 forms (water droplets, ice plate crystals, ice dendrite crystals, ice column crystals, snow flakes, graupels and hails). As cloud microphysical processes this scheme treats nucleation from CCN, condensation growth, evaporation, sublimation, freezing, melting and collision coagulation growth.

3. NUMERICAL EXPERIMENTS

We practice nest-grid simulations with the bulk-type and with the bin-type cloud microphysical scheme and compare between these results. Numerical simulations are carried out in a region around the East China Sea within a radius of 1,400 kilometers whose center is the sea near the Kyushu region (Fig. 1). Calculations are made from 18:00 to 24:00 of April 7th, 2003. Japan Meteorological Agency meso-analysis dataset, with horizontal grid of 10 km, vertical 20 layers, and time step of 6 hours interval, is used for initialization and nesting of dynamical variables, i.e., horizontal velocities, temperature and relative humidity. CCN data needed by the bin-type cloud microphysical scheme for initialization and nesting are prepared from the results of a numerical model, SPRINTARS aerosol transport and radiation model (e.g., Takemura et al., 2001) coupled with CCSR-NIES/AGCM (Numaguti et al., 1995) with a horizontal resolution of T106 and 20 vertical layers. The horizontal grid size of the model is set as 7 km (for 202 grid points) and the atmosphere up to 12 km is divided by 38 vertical layers with intervals increasing with altitude (40 m for the bottom layer to 580 m for the top layer). The basic time step is taken as 20 seconds.

Figure 2 shows the horizontal distribution of precipitation amount simulated with the bulk-type cloud microphysical scheme during 23:00 - 24:00 UTC on 7 April 2003. Figure 3 and Figure 4 show simulated with bin-type cloud microphysical scheme and

Corresponding author address: Takamichi Iguchi, Center for Climate System Research, the University of Tokyo, 5-1-5, Kashiwanoha, Kashiwa-shi, Chiba, 277-8568, Japan; e-mail: iguchi@ccsr.u-tokyo.ac.jp

JMA/Radar-AMeDAS analysis precipitation amount the same per hour. A row of thick convective clouds developed from the center of Japan Sea to Naha region and Taiwan by the cold front. There is a row of precipitation associated with the clouds from Radar-AMeDAS analysis (Fig. 4). Both simulations (Fig. 2 and Fig. 3) well reproduce the profile of precipitation. The precipitation amount simulated with the mode-type scheme is less than that with the bin-type scheme. The total precipitation amount on the area simulated with the bin scheme is one and a half times as much as that with the mode scheme (Table 1). In particular, there is a clear difference of the precipitation amount on the sea to the north of the Chugoku region. In Fig.3 areas on which the precipitation amount is larger than 5 mm/h are distributed on the sea, whereas in Fig. 2 such areas are too small. Similar distribution of the strong precipitation is in Fig. 4 so that the simulation with the bin scheme can reproduce better on this area.

Figure 5 and 6 show the horizontal distributions of liquid water path (LWP) (g/m^2) and ice water path (IWP) (g/m^2) of clouds simulated with the mode-type and the bin-type cloud microphysical scheme at 24:00 UTC on 7 April 2003. The horizontal distributions of LWP are quite similar. The total of LWP on the domain simulated with the bin scheme is nearly one and a half times as much as that with the mode scheme (Table 1). This ratio is quite similar to that of the precipitation amount. In Fig. 5(b) a row of ice clouds extending east and west on the center of the domain is simulated, whereas there are no such ice cloud in Fig. 6(b). This row of ice clouds is probably corresponds to cirrus related to a homogeneous ice nucleation. However, the cirrus is due to a poor simulation with the mode-type scheme because there is no cloud corresponding to such cirrus in the infrared satellite image of GMS5 (Fig. 7).

Figure 8 shows horizontal distributions of the component ratios of liquid hydrometeors (cloud water and rain) categorized in the mode-type cloud microphysical scheme for LWP at 24:00 UTC on 7 April 2003. Figure 9 is similar panels in the bin-type cloud microphysical scheme. The component of liquid hydrometeor in the bin-type scheme is only water droplet so that for comparison with e.g. Fig. 8 the liquid hydrometeor is divided in two categories, a group of small droplets whose radii are less than 30 μm and a group of large droplets over 30 μm.

In the simulation with the mode-type scheme the distributions of cloud water and rain are divided clearly (Fig. 8). An area where rain is dominant is in agreement with the precipitation area (Fig. 2) because processes for cloud water do not include a gravitational falling so that cloud water cannot settle on ground as precipitation. On the other hand, liquid hydrometeors of the two categories in the bin-type scheme are mixed than in the simulation with the mode-type scheme (Fig. 9). Table 2 shows the total component ratios on the area for LWP of hydrometeors categorized in the two-type cloud microphysical schemes. The component ratio of cloud water categorized in the mode-type scheme is larger than that of droplets less than 30 μm in the bin-type scheme so that a radius dividing between cloud water and rain in the mode-type scheme corresponds to larger than 30 μm.

Figure 10 shows horizontal distributions of the component ratios of ice hydrometeors (cloud ice, snow and graupel) categorized in the mode-type cloud microphysical scheme for IWP at 24:00 UTC on 7 April 2003. Figure 11 shows similar panels in the bin-type cloud microphysical scheme. The ice hydrometeors (ice plate crystals, ice dendrite crystals, ice column crystals, snow flakes, graupels and hails) are re-categorized into three groups (ice crystals, snow flakes and graupels + hails) in Fig. 11 for comparison.

Each ice hydrometeor simulated with mode-type scheme is distributed separately (Fig. 10) similarly in the case of LWP (Fig. 8). Areas where cloud ice or graupel are dominant are almost limited within areas where IWP is less than 1 g/m^2. Snow categorized in the mode-type scheme accounts for the most part of IWP. In the simulation with bin-type scheme the distribution of each ice hydrometer is seamless. A group of ice crystals are dominant on borders of ice clouds where IWP is small, whereas a group of snow flakes is dominant on centers of ice clouds. Table 3 shows the total component ratios on the area for IWP of hydrometeors categorized in the two-type cloud microphysical schemes. Snow in the mode-type scheme and snow flakes in the bin-type scheme account for more than 90 % of each IWP. The component ratios of ice hydrometeors are quite similar.

4. DISCUSSION

There have been large differences of precipitation amount and LWP between the results of simulations with the mode-type cloud microphysical scheme and the bin-type cloud microphysical scheme. The precipitation amount and LWP simulated with bin-type scheme are much larger than those with mode-type scheme. The distribution of precipitation amount simulated with the bin-type scheme is in more agreement with that by Radar-AMeDAS analysis. A radius dividing between cloud water and rain categorized in the mode-type scheme is over 30 μm from the comparison to the result with bin-type scheme. Capture by large droplets is easy to occurred for droplets whose sizes are more than about 20 μm so that collision coagulation growth is dominant between droplets over 30 μm. Thus, the present radius dividing between cloud water and rain is too large and the auto-conversion rate from cloud water to rain has to be improved. The auto-conversion rate has relation to the precipitation amount.

A row of cirrus is simulated with only mode-type scheme. However, there is no ice cloud corresponding to that in a satellite image. The amounts and component ratios of ice hydrometeors of IWP are similar between in the simulations with both schemes. This is possibly because in the bin-type scheme nucleation of droplets is through consumption of CCN directly, whereas nucleation of ice crystals is occurred without consumption of ice nuclei (IN) explicitly. The mode-type scheme do not include both effects of CCN and IN explicitly so that the profile of the ice clouds in both simulations can become more similar than that of water clouds.

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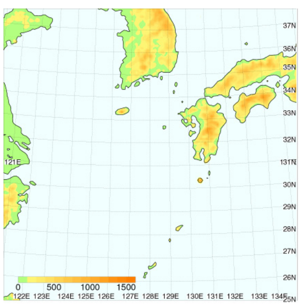

Figure 1. The calculation area of this simulation

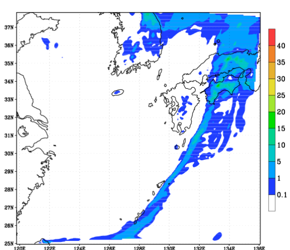

Figure 2. Horizontal distribution of precipitation amount (mm/h) simulated with the mode-type cloud microphysical scheme during 23:00-24:00 UTC on 7 April 2003.

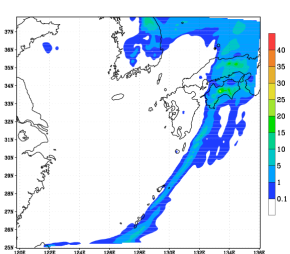

Figure 3. Horizontal distribution of precipitation amount (mm/h) simulated with the bin-type cloud microphysical scheme at the same term as Figure 2.

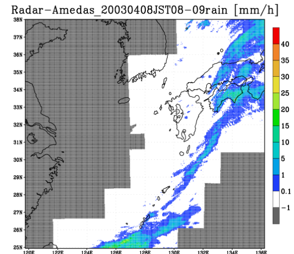

Figure 4. Horizontal distribution of precipitation amount (mm/h) by JMA/Radar-AMeDAS analysis at the same term as Figure 2.

a **b**

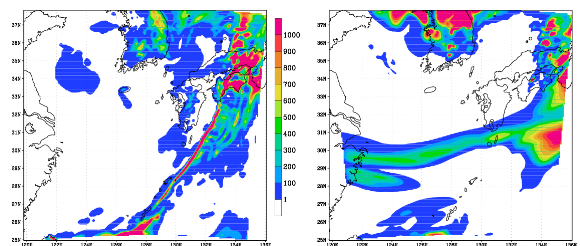

Figure 5. Horizontal distribution of (a) liquid water path (g/m^2) and (b) ice water path (g/m^2) simulated with the mode-type cloud microphysical scheme at 24:00 UTC on 7 April 2003.

a **b**

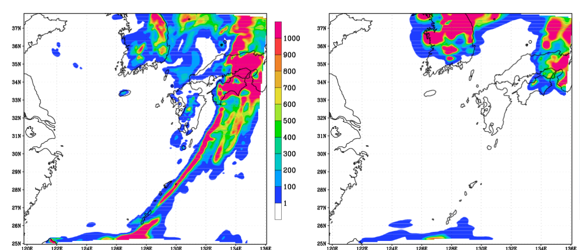

Figure 6. As in Figure5 but simulated with the bin-type cloud microphysical scheme.

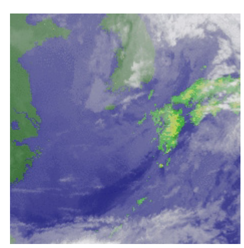

Figure 7. Infrared satellite image of GMS5 at 24:00 UTC on 7 April 2003.

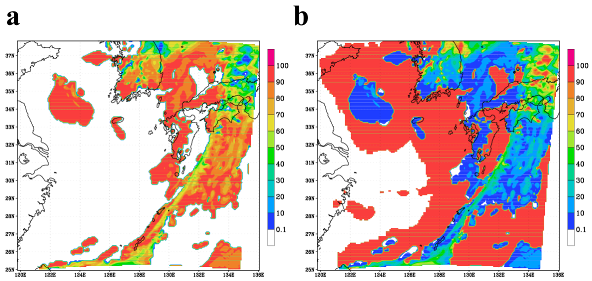

Figure 8. Horizontal distributions of component ratios (%) for LWP of (a) cloud water and (b) rain categorized in the mode-type scheme at 24:00 UTC on 7 April 2003.

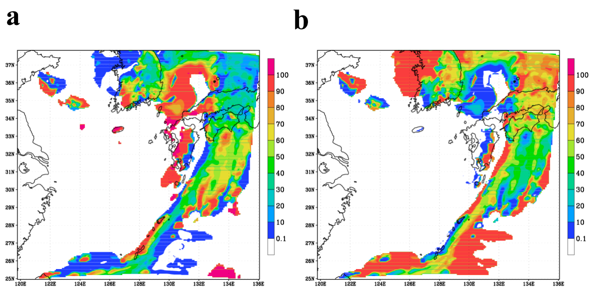

Figure 9. As in Figure 8 but component ratios for LWP of (a) droplets < 30 μm and (b) droplets > 30 μm simulated with the bin-type scheme.

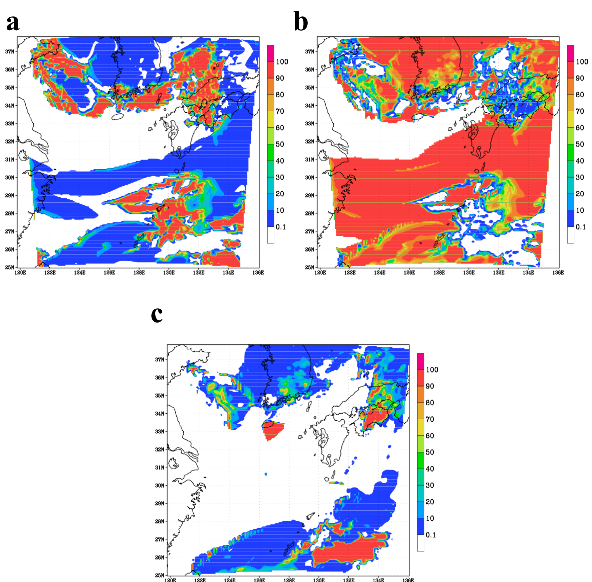

Figure 10. Horizontal distributions of component ratios (%) for IWP of (a) cloud ice, (b) snow and (c) graupel categorized in the mode-type scheme at 24:00 UTC on 7 April 2003.

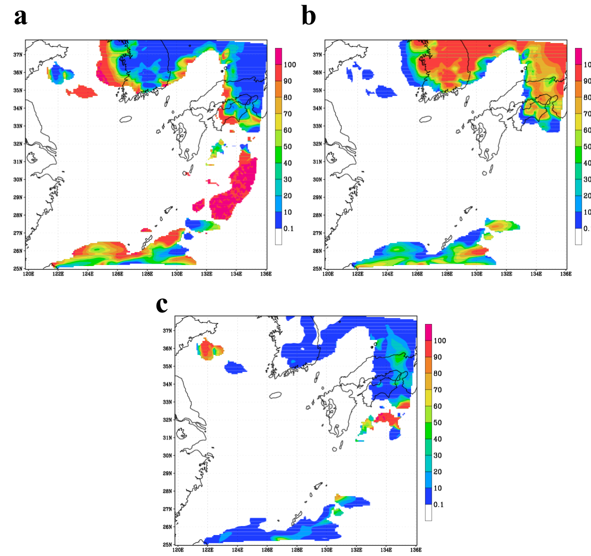

Figure 11. As in Figure 10 but component ratios for IWP of (a) ice crystals (column, plate and dendrite), (b) snow flake and (c) graupel + hail simulated with the bin-type scheme.

Type of scheme	Precipitation [kg/hour]	LWP [kg]	IWP [kg]
Mode	$5.95*10^8$	$1.86*10^7$	$2.48*10^7$
Bin	$9.15*10^8$	$2.97*10^7$	$2.18*10^7$

Table 1. Total Precipitation during 23:00 – 24:00 and total LWP and IWP at 24:00 on 7 April 2003 on the area of the experiments with the two-type cloud scheme

Mode	Cloud water 62.7%	Rain 37.3%
Bin	Droplets < 30μm 42.7%	Droplets > 30μm 57.3%

Table 2. Total component ratios on the area for LWP of hydrometeors categorized in the two-type cloud scheme

Mode	Cloud ice 2.0%	Snow 92.3%	Graupel 5.6%
Bin	Ice crystals 3.8%	Snow flake 92.4%	Graupel + Hail 3.8%

Table 3. Total component ratios on the area for IWP of hydrometeors categorized in the two-type cloud scheme