New parameterizations of ice-phase processes in 3-ice bulk microphysical model

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1. Introduction

Ice-phase processes in the 3-ice bulk microphysical model (Ikawa and Saito 1991; Murakami 1990) integrated in the non-hydrostatic model of the Japan Meteorological Agency (hereafter JMA-NHM: e.g., Saito et al. 2006) have been used for a long time without substantial updates. Recent developments in bulk microphysical models (e.g., Ferrier 1994; Harrington et al. 1995; Morrison and Grabowski 2008), however, urge to improve the bulk models for better representation of clouds and precipitation. High performance bulk microphysical models are still indispensable because bulk models are widely used in numerical studies. This report describes some improvements in ice-phase processes in the 3-ice bulk microphysical model of JMA-NHM and preliminary results.

2. Outline of the new parameterizations of ice-processes

Improvements were mainly involved in cloud ice, snow, and graupel formation processes. These will be separately described below.

a. Cloud ice process

The size distribution of cloud ice is assumed to be an inverse-exponential type as for the snow and graupel. This assumption differs greatly from the mono-disperse assumption in the current model. The aggregation among cloud ice is computed by the strict solution (e.g., Verlinde et al. 1990) using temperature-dependent collection efficiency. The depositional growth of clod ice and the conversion from cloud ice to snow are modeled following the work of Harrington et al. (1995). Cloud ice whose diameter exceeding a prescribed value (set equal to 120μm in this study) is converted snow category. An excellence of this conversion lies in that only the portion of cloud ice of large size is transfered to snow unlike the current autoconversion which does not take into account the size of cloud ice particles. In this conversion calculation, an accurate and fast code for the calculation of incomplete Gamma function is employed.

b. Aggregation of snow

The current model of snow aggregation parameterization by Passarelli (1978) is substituted for the strict solution as for cloud ice. The temperature-dependent collection efficiency is also employed. A lower bound of the slope of the snow size distribution is imposed in order to implicitly include the disruption of snow as in Ferrier (1994).

c. Graupel formation

Graupel particles form by the interaction between supercooled drops and ice particles, its formation processes is, however, not sufficiently clarified yet. Graupel is formed when cloud ice and snow interact with supercooled droplets and supercooled rain drops collide with ice particles (cloud ice and snow). In the present study, the parameterization of graupel formation is based on the bin-like approach in the interaction of supercooled water with cloud ice and snow. In addition, an idea of "partial conversion" in each bin is introduced.

(1) Interaction between supercooled cloud droplets and cloud ice

The grauple formation by the interaction between supercooled cloud droplets and cloud ice is based on the change in bulk density and the rimed mass of supercooled water in a unit time, or riming ratio. The change in the bulk density comes from the adherence of droplets on the surface of spherical cloud ice and rimed cloud ice. In the riming process, the size distribution are divided into several bins, the riming ratio in each bin is then computed using a representative size of cloud ice in each bin. When dividing the size distribution into bins, the lower and upper bounds of the size of cloud ice are specified. The riming calculations are not made for the cloud ice whose size does not fall into between these two bounds. Very small cloud ice may not easily be transfered into graupels because of small collection efficiencies, while very large solid particles may require large amount of riming for the graupel formation.

(2) Interaction between supercooled cloud droplets and snow

The formation of graupel by the interaction between supercooled cloud droplets and snow is modeled in a similar manner as in the collision between the supercooled cloud droplets and cloud ice. For the riming process of snow, another type of riming model is taken into account in addition to the model considered for cloud ice. Since snow has lacuna, supercooled water droplets collected in such airspace are assumed to incite the change in bulk density of snow. For this type of riming, the size of snow is unchanged during riming.

(3) Interaction of supercooled rain with cloud ice

When graupel particles form excessively from the collision between supercooled rain with cloud ice, this process is re-computed in a similar manner as the riming process of cloud ice. The size distribution of rain is sub-divided into several bins, and the collision between rain and cloud ice is considered using a representative size of cloud ice. The criteria of excessive formation of graupel is tentatively the same as in Ferrier (1994).

3. Preliminary results of the new model and summary

Preliminary experiments were made using JMA-NHM for a snowfall event during a cold outbreak over the Sea of Japan in order to check the performance of the new 3-ice bulk microphysical model relative to the current one. Two-moment models were employed for the solid particles of cloud ice, snow, and graupel. The model domain centered at (37.426°N, 138.887°E) was 300 km × 300 km wide in the horizontal with the grid size spacing of 1 km, and the 50 layers were considered in the vertical. The initial condition was from the meso analysis of the Japan Meteorological Agency at 12 UTC on January 16, 2011, and the lateral boundary condition was supplied from the meso analysis at three-hour intervals.

Figures 1 and 2 show surface precipitation from the new and current models, respectively. Main differences are summarized in the following two points. First, the new model ameliorates “unnatural” concentration of snowfall on the upwind slope (e.g., compare snowfall in ovals in pink in these figures). Second, the new model produced more snowfall over the Sea of Japan in wider area. It was also found that more graupels were formed in the new model (not shown).

Preliminary tests have shown that the impact of the new model is not small, and that the new model appears to have higher performance with respect to the current one.

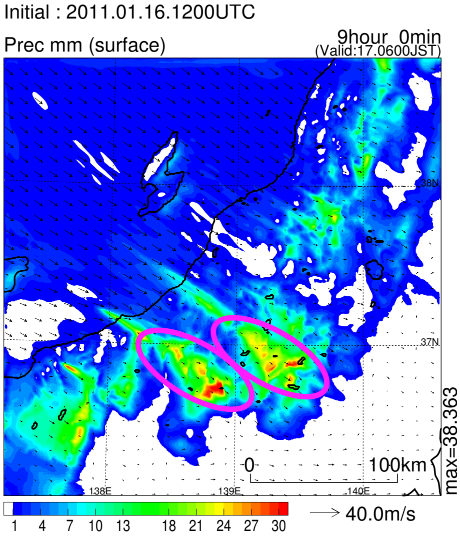

Figure 1: Hourly surface precipitation (in mm in water equivalence) between 8 and 9 forecast hours from the new model.

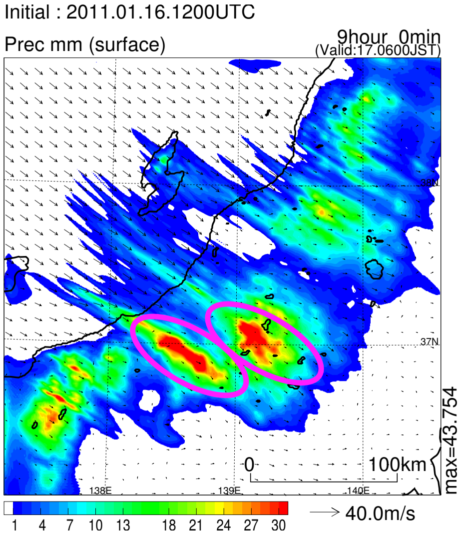

Figure 2: As in Fig. 1, except for the current model.

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