Development of a two-moment three-ice bulk microphysical model for ice

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1. Introduction

A two-moment three-ice bulk microphysical model for ice is developed, as one of the options of the Japan Meteorological Agency non-hydrostatic model (hereafter, JMA-NHM: e.g. Saito et al. 2006), in order to improve the representation of snow clouds and the associated snowfalls. It was found that the current bulk microphysical model did not sometimes represent heavy snow fall events in the Ishikari Plane in Hokkaido very well. This deficiency implies the necessity of the improvement in the bulk microphysical model. Indeed, the current ice-phase processes in the three-ice bulk microphysical model (Ikawa and Saito 1991; Murakami 1990) integrated in the JMA-NHM have been used for a long time without substantial updates. This paper briefly describes the outline of the new bulk microphysical model and results of the preliminary test.

2. Outline of the new microphysical model

The newly developed bulk microphysical model predicts both the mixing ratios and the number concentrations of cloud ice, snow, and graupel. The model incorporates a bin-like approach in the graupel formation. Significant features of the new model are as follows: (a) Size distributions are represented by Gamma function as $n(D) = n_0\, D^{\nu} \exp(-\lambda D)$, where D is the size of particles; (b) Mass-size relations are expressed by power laws as $m = \alpha_m\, D^{\beta_m}$; (c) Cloud ice whose size is larger than a prescribed value is converted into snow as in Harrington et al (1995). For this conversion calculation, a fast and accurate program for calculating the incomplete Gamma function is implemented; (d) Formation of graupel by riming of cloud ice and snow is modeled by introducing a bin-like idea, in which the graupel formation is determined by the riming rates of cloud ice and snow. Their size distributions are divided into certain number of bins first, then riming rates of particles (cloud ice or snow) in each bin are computed based on the continuous growth model. The resultant riming rate of a single particle is used to determine the occurrence of graupel. Two different thresholds for the riming rate are prescribed for each of cloud ice and snow. When a calculated riming rate exceeds the upper threshold, all particles in the bin considered are converted to graupel. For the riming rate lying between the two thresholds, a portion of the particles in the bin is transferred to graupel. The riming rate falling below the lower threshold leads to the riming of cloud ice and snow without graupel formation; (e) The aggregation of cloud ice and snow is modeled by a strict solution expressed by Gamma and Gauss hypergeometric functions, in which temperature-dependent collection efficiencies are employed; (f) When the collision between cloud ice and rain produces too much graupel, the bin-like approach as the above-mentioned graupel formation is applied to the interaction between these two species.

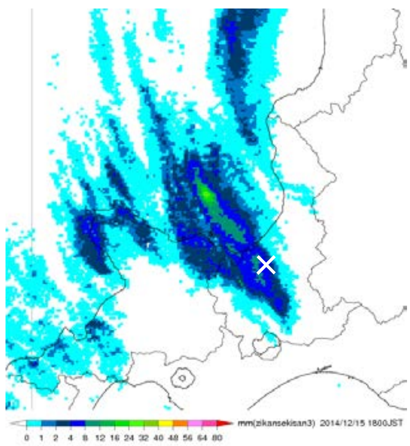

Figure 1. Accumulated precipitation for three hours (shaded area) between 16 and 18 JST from JMA radars. The position of Sapporo is marked by a cross mark. Light blue color indicates precipitation less than 1 mm in water equivalent.

3. Results of a preliminary test

The new bulk microphysical model described in section 2 was tested for a heavy snowfall event at and around Sapporo in Hokkaido, Japan, occurred on December 15, 2014. This snowfall was brought about a band-like snow clouds (Fig. 1). Daily precipitation and the daily accumulated snow fall amount at Sapporo Observatory were 25 mm in water equivalence and 39 cm, respectively. Maximum accumulated precipitation for three hours was 10 mm in water equivalent from 16 to 19 JST at this observatory.

Experiments were carried out by employing

JMA-NHM at a 1-km horizontal resolution for a domain size of 1000 km x 1000 km centered at the location of Sapporo city in order to investigate a performance of the new model relative to the current one. Number of vertical layers was 60, and the top of the model domain was set to 21.8 km. The model run started at the initial time of 00 UTC on Dec. 15 up to 9 forecast hour. The initial and boundary conditions were supplied from the meso analysis of JMA. Except for the bulk microphysical models, other model setting was common to all experiments. No convective parameterization was used, and the turbulent model was Mellor-Yamada-Nakanishi-Niio level 3. For the new microphysical model, the following parameters were tentatively used; the parameters of ν in the size distributions were set equal to 0.5, 2, and 3 for cloud ice, snow, and graupel, respectively; mass-power-laws for broad branches and snowflakes were adopted for cloud ice and snow, respectively; velocity-power law for dendrites was employed for both cloud ice and snow. The mass-size and velocity-size relations for graupel were the same as in Saito et al (2006).

Figure 2 shows simulated precipitation fields from the new and current models. An area of large amount of precipitation exhibits an elongated band pattern in the north-northwest and south-southeast direction for the both models. In particular, the precipitation area associated with the new model is much wider, like that of the radar-derived one shown in Fig. 1 although there is a slight difference in time between the model and the observation. Indeed, a heavy snowfall at Sapporo as well as less intense precipitation in its surrounding area are reproduced very well. The preliminary tests suggest that the new model may have better performance for the snowfall forecast than the current one, and that the snowfall forecast may be sensitive to the microphysical model.

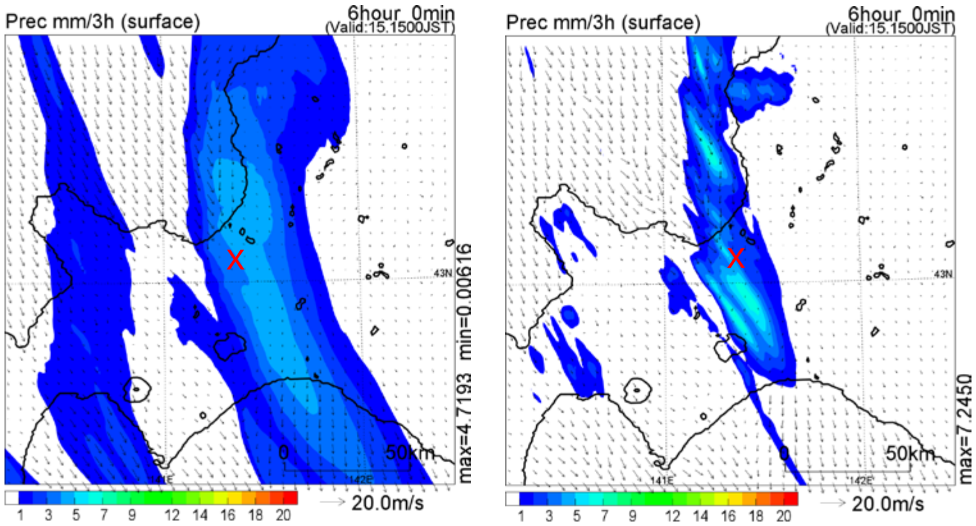

Figure 2. Accumulated precipitation in water equivalence for three hours between 3 and 6 forecast hour is indicated by shading. The left and right panels correspond to the new and current bulk microphysical models, respectively. The position of Sapporo city is shown by a cross mark. The arrows show surface wind.

Acknowledgements

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