A new double moment approach for the warm-rain process based on the WSM6 scheme (WDM6)

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1. Introduction

The double-moment approach for the bulk microphysics schemes that allows more flexibility of the size distribution enabling the mean diameter to evolve in contrast to the single-moment approach has become one of the promising methods to improve microphysical processes in the mesoscale modeling area. Cohard and Pinty (2000b) showed the superiority of a double-moment approach in two-dimensional experiments using a non-hydrostatic model even though the strength of these double-moment schemes relies on the accuracy of the representation of several microphysical processes. Such a scheme with prognostic equations of the raindrop number concentration is able to produce large drops in a reasonable concentration, compared with single-moment scheme.

This study attempts to clarify the impact of the double moment approach over the single moment microphysics. To this end, a double moment warm rain microphysics is implemented into a single moment scheme, that is, the Weather Research and Forecasting (WRF)-Single-Moment 6-class (WSM6) Microphysics scheme. All microphysical parameters and ice-phase microphysics are identical for both single and double moment approach, which enables us to clarify the principle impact of double moment to the three-dimensional real time forecasting.

The paper is organized as follows. Section 2 describes the proposed bulk microphysics scheme. Section 3 outlines the numerical experiments conducted in this study, and section 4 presents their results. Concluding remarks appear in the final section.

2. Development of the double-moment warm-rain microphysics scheme

2.1 general remarks

This study is the expanded works of Hong and Lim (2006, hereafter HL2006). In addition to the prediction of hydrometeors mixing ratios, the number concentrations of warm species such as cloud water and rain are also predicted in the current scheme. Thus, it is called as the WRF-Double-Moment 6-class with the prognostic water substance variables of water vapor, cloud, rain, ice, snow, and graupel (WDM6) microphysics scheme.

In the WDM6 scheme, warm-rain processes such as autoconversion and accretion followed the works of Cohard and Pinty (2000, hereafter CP2000), which contains only warm phases such as cloud droplets and raindrops. Other processes except for the autoconversion/accretion processes were basically adopted from the WSM6 scheme. This enables us to understand what makes the fundamental differences between the single-moment and double-moment schemes within the similar approach of microphysical processes.

The evolution of number concentration for each species is given by

$$\frac{\partial N_X}{\partial t} = -\vec{V}\nabla_3 N_X - \frac{N_X}{\rho}\frac{\partial}{\partial z}(\rho V_X) + S_X \qquad (1)$$

where the 1st and 2nd terms in the r.h.s. represent the 3D advection and sedimentation of warm species, respectively. The term S_x represents the source and sink of number concentration of X.

2.2 CCN activation

In this new scheme, one of the distinct features is that the activated CCN number concentration, n, is predicted and formulated by the drop activation process based on the relationship between the number of activated CCN (n_a) and supersaturation S (Twomey 1959; Khairoutdinov and Kogan 2000), which enables one to add a level of complexity to the traditional bulk microphysics schemes by adding the explicit CCN-cloud drop concentration feedback. The number of activated CCN can be expressed as following:

$$n_a = (n + N_C)(S_w / S_{\max})^k . \qquad (2)$$

Here k is the parameter that can be derived from observation. And $S_{\max}$ represents the supersaturation needed to activate the total particle count of $n + N_C$, where n is the total CCN number concentration and N_C is the cloud droplets number concentration.

Flowchart of the microphysics processes for the prediction of the mixing ratios and the number concentrations in the WDM6 scheme are represented in Figure 1.

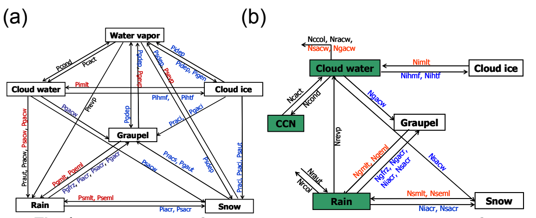

Fig.1. Flowchart of the microphysics processes for the prediction of (a) the mixing ratios and (b) the number

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concentrations in the WDM6 scheme. The terms with red (blue) colors are activated when the temperature is above (below) 0 ℃, whereas the terms with black color are in the entire regime of temperature.

3. Numerical experimental setup and cases

The model used in this study is the WRF version 2.2, which was released in December 2006. 3D real -data simulations were carried out which is for the h eavy rainfall event over the Korean during 24 h, ending at 0000 UTC July 16, 2006.

Three experiments were carried out for the heavy rainfall case. To examine the generality and applicability of the WDM6 scheme and compare the characteristics of a double-moment scheme with a single-moment scheme, the WSM and WDM experiments, applied the WSM6 and WDM6 microphysics schemes respectively, are conducted. The experiment WARM is conducted to examine the effect of warm rain physics implemented in the WDM6 scheme and investigate the fundamental differences between the single-moment and double-moment schemes. In the WARM experiment, autoconversion and accretion processes in the WDM6 are replaced to the ones in the WSM6 with constant cloud droplets number concentration.

4. Results

4.1 Comparison between the WSM and WDM

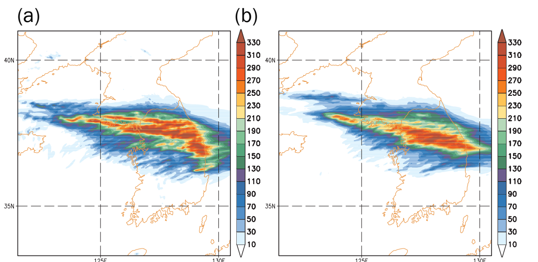

Fig.2. 24-h accumulated rainfall (mm) ending at 0000 UTC 16 July 2006, obtained from the (a) WSM and (b) WDM experiments.

It is seen that both experiments capture the observed heavy rainfall across the central eastern part of the Korean peninsula. The WSM experiment shows intense and localized precipitation characteristics and the WDM experiment relatively weakened ones. An intense precipitation core with the WSM experiment results in the increase of the domain-total precipitation.

Figure 3 shows the simulated radar reflectivity from the two experiments for each heavy precipitation core event. Generally speaking, the WRF model reproduced the distribution of precipitation despite using different microphysical schemes at 0600 UTC 15 July. That is, in both runs the main precipitation event organizes into a convective line near the Kang-Won province as observed. However, the WSM experiment fails to capture the intense precipitation core over the northeastern part of Seoul at 2100 UTC 15 July, whereas the WDM experiment shows better distribution of precipitation intensity . It is also seen that the WDM experiment develops the mature stage of the precipitation event later, as compared to the WSM experiment, especially for the second mature stage (not shown). These characteristics in the WDM agree well with observed features.

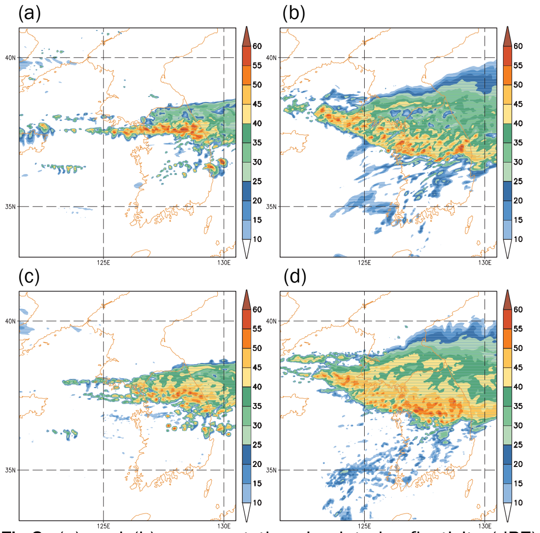

Fig.3. (a) and (b) represent the simulated reflectivity (dBZ) derived from the WSM experiment at (a) 0600 UTC 15 July and (b) 2100 UTC 15 July 2006, respectively. And (c) and (d) are from the WDM experiment at (c) 0600 UTC 15 July and (d) 2100 UTC 15 July 2006, respectively.

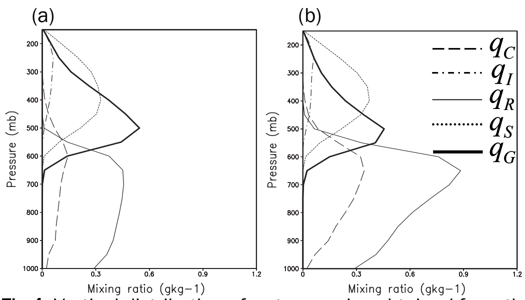

Fig.4. Vertical distribution of water species obtained from the (a) WSM and (b) WDM experiments, averaged over the heavy rainfall region (36.9-38.2 N, 125.9-129.1 E) during the 24-h forecast period. Units are gkg^{-1} for rain, snow, and graupel, and $10gkg^{-1}$ for cloud ice and cloud water.

Figure 4 compares the vertical profiles of averaged condensates over the heavy rainfall region centered in Korea. Both experiments named as the WSM and WDM produce similar profiles of ice-phases such as ice, and graupel, even though less amount of the snow phase is revealed in the WDM experiment because of the reduced accretion process of cloud water by snow (Psacw). This is because the WDM6 scheme follows the cold-rain process of the WSM6 scheme and revised processes in the WDM6 scheme do not affect the ice-phases properties directly. However, vertical distributions of cloud species such as rain and cloud water are sensitive to the method of treating warm-rain microphysical process. The increase (decrease) of rain (cloud water) in the middle troposphere is pronounced when the WDM6 scheme is used.

4.2. Effect of warm-rain microphysical physics

Figure 5 shows the simulated properties of surface rain and differences in the vertical distribution of hydrometeors, obtained from the WARM experiment. The distribution of simulated precipitation in the WARM experiment is similar to that from the WDM experiment. However, the maximum intensity of precipitation is enhanced and this results in the deterioration of the bias score of precipitation.

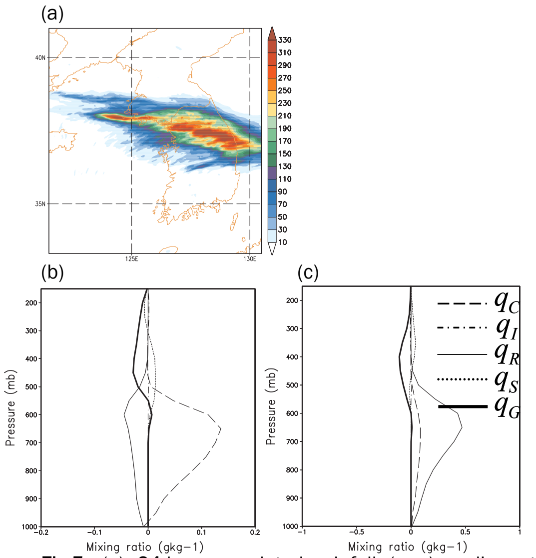

Fig.5. (a) 24-h accumulated rainfall (mm) ending at 0000 UTC 16 July 2006 from the WARM experiment and (b) vertical distribution of the differences in the time-domain-averaged water species (WDM minus WARM) and (c) (WARM minus WSM). Averaged domain is same as Fig. 9 and units are gkg^{-1} for all.

The effect of changed warm rain processes can be evaluated by comparing the WARM with the WDM experiment. Vertical profiles of hydrometeors show that the amount of cloud water is reduced and ice-phases and surface rain are increased, compared with the WDM experiment (Fig. 5b). More intense precipitation in the WARM experiment is induced by more effective autoconversion process of the WSM6 scheme. It is also analyzed that the effect of accretion process to the conversion rate from cloud water to rain is relatively small. Therefore a major reason for the increased maximum intensity in the WARM is for the different autoconversion process.

Fundamental differences between the single-moment and double-moment schemes, which are caused by using more flexible particle size distribution in the double-moment scheme, can be evaluated with same microphysical processes in the WARM and WSM experiments. Thus the reason for the much more rain drops over the entire troposphere in the WARM experiment, compared with the WSM experiment can be deduced from the more flexible size distribution of raindrops (cf. Fig. 5c). A close inspection reveals that the large number of small rain drops can be more easily generated in the double moment approach in which the autoconversion process is the main source of the predicted rain number concentration. Also WARM experiment develops the surface precipitation late (not shown), which is the one of the main characteristics of the double moment approach revealed in the selected case simulation.

5. Concluding remarks

A comparison between the single-moment and double-moment scheme was made within the two different microphysics schemes in previous study (e.g., Ferrier et al. 1995), thus it was hard to verify what causes fundamental differences between the single-moment and double-moment approach. The WDM6 scheme based on the WSM6 scheme makes this possible with the similar approach of microphysical processes of the single-moment scheme. The strength of the WDM6 scheme is its ability to simulate warm-rain microphysical processes with prediction of number concentration of warm-species at a modest cost (the WDM6 code has 45% extra computing burden than the WSM6 code) in a non-hydrostatic mesoscale model. Part of the success of this double-moment scheme relies on its capacity to cope with explicit representation of the CCN number concentration.

Acknowledgements

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