

## Evaluation of rain microphysics of a two-moment bulk scheme using radar simulator and numerical models

\*久芳 奈遠美<sup>1</sup>、清木 達也<sup>2</sup>、鈴木 健太郎<sup>1</sup>、Woosub Roh<sup>1</sup>、佐藤 正樹<sup>1</sup>

\*Naomi Kuba<sup>1</sup>, Tatsuya Seiki<sup>2</sup>, Kentaroh Suzuki<sup>1</sup>, Woosub Roh<sup>1</sup>, Masaki Satoh<sup>1</sup>

1. 東京大学 大気海洋研究所、2. 海洋研究開発機構

1. Atmosphere and Ocean Research Institute, The University of Tokyo, 2. Japan Agency for Marine-Earth Science and Technology

This study proposed a method to evaluate rain microphysics using space-borne radar observational data with a forward simulator of satellite measurements, by comparing a two-moment bulk and a two-moment bin scheme. Using the relationships between horizontally averaged radar reflectivity  $Z_m$  and optical depth from the cloud top  $\tau_d$  ( $Z_m$ - $\tau_d$  relationship), an improvement of the bulk scheme was proposed based on the numerical results for a shallow warm cloud using a two-dimensional kinematic driver model.

The two-moment bulk scheme, which was constructed by *Seiki and Nakajima* [2014] based on *Seifert and Beheng* [2006] with slight modifications, was compared with the two-moment bin scheme developed by *Kuba and Fujiyoshi* [2006] and modified by *Kuba and Murakami* [2010]. We focused on the conversion processes from cloud droplets to raindrops in shallow cumulus clouds, using a two-dimensional kinematic driver model. In particular, we compared radar reflectivity profiles near the cloud tops calculated from two schemes using a forward simulator of satellite measurements. This method can be used to evaluate the parameters in two-moment bulk cloud microphysics schemes near the cloud top using observational data from satellite remote sensing.

Our results showed that the two-moment bulk scheme was almost comparable to the two-moment bin scheme, but with the following differences:

(1) The final rainfall amount was slightly smaller in the bulk scheme than in the bin scheme. The difference was caused by the overestimation of the falling velocity of raindrops in the bulk scheme rather than differences in the accretion process.

(2) The slope value ( $d \ln Z_m / d \tau_d$ ) of the relationships between  $Z_m$  and  $\tau_d$  ( $Z_m$ - $\tau_d$  relationships) near the cloud top in the later stage of the cloud lifetime was smaller in the bulk scheme than in the bin scheme. Although previous studies related the slope value to bulk collection efficiency, the bulk collection efficiency assumed in the present bulk scheme was almost the same as that estimated in the bin scheme near the cloud top. The slope value also depended on the increasing rate of rainwater mass for  $\tau_d$ , which can depend on the falling velocity of raindrops. The overestimation of the falling velocity of raindrops led to the smaller slope value in the bulk scheme.

(3) Observational satellite data and the rainfall amount could be used to constrain the shape parameter  $\nu_r$  of the gamma distribution assumed as the raindrop size distribution in the bulk scheme

(4) Even a fixed value of  $\nu_r$  could reproduce surface rainfall similar to the observational data, if the value was derived from the observational  $Z_m$ - $\tau_d$  relationship near the cloud top in case of shallow clouds as studied in this paper.

This study confirmed that the shape parameter of the gamma distribution assumed as the raindrop size distribution in the two-moment bulk scheme affected rainwater generation. The new finding of our study was that an appropriate value of the shape parameter near the cloud top could be derived from observational satellite data. The diagnostic function of the shape parameter or the three-moment bulk scheme is ideal. However, a fixed value of the shape parameter derived from the observational  $Z_m - \tau_d$  relationship near the cloud top is useful in case of shallow clouds as shown in this study. The results may depend on cloud type, and the method therefore needs to be used for observational data classified by a condition of atmosphere (CCN number density, updraft velocity in a cloud, liquid water content, etc.). It should also be noted that other factors in bulk schemes (turbulence and feedback from cloud microphysical processes to dynamics, etc.), not investigated in the present study, may affect the  $Z_m - \tau_d$  relationship. The investigations including these effects are the future works using cloud resolving model (not kinematic driver model). This study is detailed in *Kuba et al.* (2018).

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