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Revised Response to Comments

RESPONSE TO COMMENTS ON "PARAMETERIZATION OF THE AUTOCONVERSION PROCESS, PART I: ANALYTICAL FORMULATION OF THE KESSLER-TYPE PARAMETERIZATIONS"

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Reply

We welcome and appreciate the comment by Wood and Blossey (2005, hereafter WB) on our paper (Liu and Daum 2004, hereafter LH). In response, we would like to make the following points.

First, as clearly stated in LH, Kessler-type parameterizations take the form of a product of two different functions:

$$P = P_0 H\left(r_d - r_c\right), \tag{1}$$

where P_0 represents the autoconversion rate after the onset of the autoconversion process (autoconversion function hereafter), and the Heaviside step function H represents the threshold behavior such that the autoconversion rate is zero when the driving radius r_d is less than the critical radius r_c. Differences between the various Kessler-type parameterizations arise from how P_0 and r_d are specified. In the Liu-Daum parameterization, both P_0 and r_d are determined by the mean radius of the sixth moment of the cloud droplet size distribution instead of the mean radius of the third or fourth moment of previous parameterizations. It is noteworthy that WB essentially compares the autoconversion rate calculated from a detailed collection model to the autoconversion function P_0, not the Liu-Daum parameterization, which is the product of P_0 and the Heaviside step function introduced to represent the threshold behavior. Furthermore, as demonstrated in WB's Fig. 2b, WB tends to focus more on the threshold behavior. This figure shows the ratio of P_0 to P as a function of the volume-mean radius, and reveals that the real autoconversion rate falls sharply after the driving radius r_d is less than some threshold value between 10 and 15 μm.

Second, there are two different approaches that have been used to mathematically define the autoconversion rate. According to Kessler's original ideas, autoconversion starts once some threshold is crossed, and the autoconversion rate represents the growth rate by the collection process integrated over drops from the critical radius to sizes that are large enough to fall as small raindrops. Existing Kessler-type parameterizations, including the Liu-Daum parameterization derived in LH, basically follow this definition, and assume an abrupt threshold behavior described by the Heaviside step function. The other approach, pioneered by Beheng and his group (e.g., Beheng 1994), is used in WB. The Beheng approach separates self-collection of cloud droplets (collected cloud droplets remain as cloud droplets) from the autoconversion process, and seems reasonable at first glance. However, as correctly pointed out in WB, the result obtained using this approach is highly sensitive to the separation radius r_0. Separation radius is introduced to distinguish cloud droplets from raindrops, but there appears to be no fundamental basis for choosing a value for it, and values from 20 μm (e.g., WB) to 50 μm (e.g., Beheng 1994) to 100 μm (Simpson and Wiggert 11969) have been used. Note that WB appears to confuse the separation radius with the critical radius as defined in Liu et al. (2004) and McGraw and Liu (2004).

Finally, the results presented in WB indeed raise questions as to the representation of the threshold behavior and the effect of truncating the cloud droplet size distribution on the autoconversion rate. It is clear from WB's Fig. 2b that the "all-or-nothing" representation of the threshold behavior by the Heaviside step function used in Kessler-type parameterizations, including the Liu-Daum parameterization, does not accurately describe the threshold behavior; the change of the autoconversion rate near the threshold is smooth, not discontinuous as characterized by the Heaviside step function. Therefore, to further improve the autoconversion parameterization requires going beyond the commonly used Kessler-type parameterizations. Another related issue is the choice between the two different definitions of the autoconversion rate, which should be consistent with the other processes (e.g., accretion) that need to be parameterized in atmospheric models.

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