Ice cloud modeling for simulating mixed-phase low-clouds

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Abstract

This study improved a single-moment bulk cloud microphysics scheme (SM) to realistically simulate supercooled-liquid water within low-level mixed-phase clouds in polar regions. Low-level clouds in polar regions are known to have unique structure: Cloud ice slowly settles down to cloud bottom while super-cooled liquid water remains near the cloud top. CMIP5 GCMs poorly simulated this cloud structure because of difficulty in simulation using their simple cloud microphysics [e.g., Williams et al., 2013]. As a result, they underestimated low-level cloud fraction over the polar region, and hence, cloud radiative forcing was significantly biased [e.g., Bodas-Salcedo et al., 2012]. The same issue also arises in a global high-resolution GCM NICAM [Kodama et al., 2015; Hashino et al., 2016], which uses single-moment cloud microphysics schemes (SMs) with five categories of hydrometeors [Lin et al., 1983; Tomita, 2008; Roh and Satoh, 2014]. Recently, Seiki and Nakajima [2014] implemented a double-moment bulk cloud microphysics scheme (DM) based on Seifert and Beheng [2006]. Seiki et al. [2015a] achieved more realistic simulation of global cloud distribution using the DM scheme. We found that low-level clouds over the Southern Ocean was also simulated well (See Fig. 1).

We used a single column model to evaluate ice cloud microphysics of the SM [Roh and Satoh, 2014] and DM. The model only includes microphysics and gravitational sedimentation with no external forcing. Initial condition was given by simplifying a vertical column at 60 S in a global simulation [Seiki et al., 2015b] (see Figs. 2a; 2b): a cloud layer exists from 1000 m to 2000m altitude, atmospheric temperature slightly fell below the freezing level in the cloud layer, cloud water linearly decreases from cloud top to cloud bottom with cloud top mixing ratio of $3.5e^{-4}$ kg kg^{-1}. The super-cooled liquid water is maintained unless ice hydrometeors initiate and consume ice supersaturation.

We found that a significant difference in super cooled liquid water between the SM and DM was observed quickly after running the single column model. Thus, the bias in NICAM originated from artificial settings in the SM scheme rather than the boundary layer processes. Budget analysis showed that underestimation of supercooled liquid water originated from strong Bergeron-Findeisen process when using the SM. We newly introduced several thresholds to suppress growth of cloud ice, snow, and graupel.

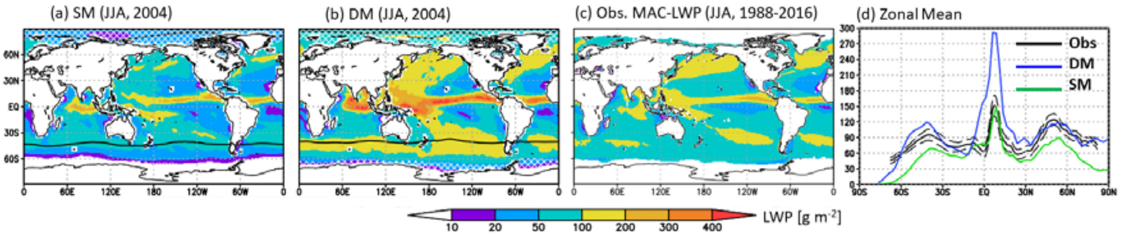

Figure 1. Global distribution of liquid water path [g m^{-2}] on JJA from (a) the SM experiment, (b) DM experiment, and (c) satellite product of MAC-LWP [Elsaesser et al., 2017]. Polar regions covered by sea-ice was shown by white tiles and the freezing level at 850 hPa was shown by black solid lines in (a) and (b).

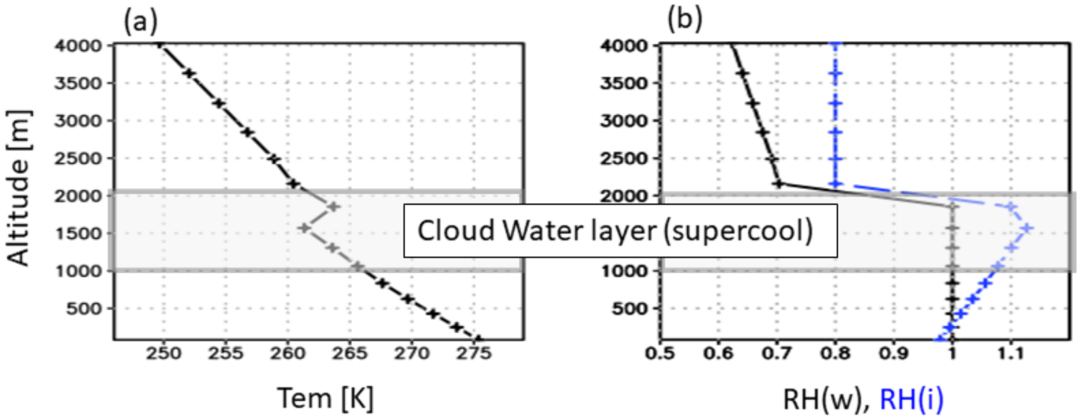

Figure 2. Initial condition of the single column model: (a) the vertical profiles of the atmospheric temperature and (b) relative humidity with respect to liquid cloud (black line) and with respect to ice cloud (blue line).