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Spectral cumulus parameterization employing in-cloud parameterization based on cloud-resolving model simulation

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Improvements of cumulus parameterization have been reported in preceding studies even recently, however, there still remains uncertainties. The uncertainties in the cumulus parameterization are related to the expression for unresolved cloud properties, thus some recent cumulus parameterizations attempted to introduce detailed parameterization for the unresolved cloud properties, i.e. in-cloud parameterization (e.g., entrainment), based on the findings from analysis on convective cloud structure. However, only few in-cloud parameterizations that actually can be used in cumulus parameterization have been proposed, since still little is known for the in-cloud structure. In order to parameterize the structure, long-range cloud-resolving model (CRM) simulation was performed, and conditionally averaged in-cloud quantities were analyzed to lead the in-cloud parameterization. The results showed that entrainment is partly proportional to in-cloud buoyancy as preceding studies indicates, but the relationship no longer holds for higher altitudes. Detrainment becomes dominant and acts to reduce in-cloud buoyancy at the region. Based on these findings, an in-cloud parameterization which describes the relationship between buoyancy, entrainment and detrainment has been proposed, and the in-cloud parameterization was applied to a spectral cumulus parameterization. The spectral cumulus parameterization with the developed in-cloud parameterization (new scheme) was validated using Atmospheric Model Intercomparison Project (AMIP) type experiments. To clarify the improvement compared to existing parametrizations, one recent existing formulation similar to the present in-cloud parameterization was employed and the results were compared. The mean state of atmospheric circulation simulated by new scheme was found to be better than that simulated by existing scheme. Analyzing convective cloud structure, the improvements were found to be derived from the difference in entrainment profile of convective clouds. The difference also had significant influences on the behavior of variability in the atmospheric circulation. The analysis on the intraseasonal variability revealed that the new scheme could simulate realistic eastward propagating speed and moderate intensity of Madden-Julian Oscillation (MJO) than the existing scheme.