How does the treatment of rain in GCMs improve aerosol-cloud-precipitation interactions?

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General circulation models (GCMs) still have a large uncertainty in their process representation of aerosol-cloud-precipitation interactions. The biases focusing here are, responses in cloud water mass to aerosols, onset of precipitation, and their effects on the radiative forcing. One of the major sources of these biases is the diagnostic treatment of rain (DIAG) in the model. Here we investigate the effects of precipitation modeling in GCMs on the regime dependence of the aerosol-cloud interaction for warm clouds, by comparing prognostic (PROG) and DIAG rain schemes. The newly introduced PROG scheme well represents shallow drizzle over coastal stratocumulus deck, but has been difficult to simulate with climate models based on the traditional DIAG scheme. Given that the PROG preserves a “memory” of rainwater during the course of the model simulation, the drizzle and raindrop thus kept in the atmosphere operate to enhance contributions of the accretion process over those of the autoconversion process. Since only the latter process is a pathway through which the aerosols influence the rain formation, enhanced contributions of accretion lead to reduced magnitudes of the aerosol-cloud interaction. This modulation of the rain formation process is also shown to help mitigate the overestimates of the cloud water susceptibility to aerosol perturbations in traditional climate models. Particularly notable is that both increasing and decreasing responses of liquid water path (LWP) to increased aerosols are reproduced with the PROG in better agreement with A-Train satellite observations and large-eddy simulations in literature. This is in stark contrast to what is obtained from the traditional DIAG scheme that reproduced the positive LWP response alone as the so-called cloud lifetime effect. Furthermore, the PROG improves the onset of precipitation that is reasonable to A-Train retrievals, whereas the DIAG shows too rapid rain generation as reported by the other GCMs as well. These improvements propose that the PROG scheme is promising for better process representations of aerosol-cloud-precipitation interactions.

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