Challenges in constraining cloud and precipitation susceptibilities to aerosols: Satellite observations and global climate models

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Aerosol-cloud interactions (ACI) remain elusive and are one of the most uncertain processes in climate modeling due to their nonlinear complexity. There is still a large gap in the magnitude of ACI between model estimates and satellite retrievals. A key complexity arises from the hypothesized response of clouds to perturbed aerosols through two competing pathways, i.e. the traditional “cloud lifetime” effect and more recent “buffered system” effect. A systematic difference is found in the response of liquid water path (LWP) to aerosol perturbations between MIROC GCM simulations and A-Train satellite observations. The model results indicate a near-global uniform increase of LWP with increasing aerosol loading, while the sign of the response of the LWP from the A-Train varies from region to region. The satellite-observed response of the LWP is closely related to meteorological and/or macrophysical factors (e.g., cloud type), in addition to the microphysics. The model does not reproduce this variability of cloud susceptibility to aerosols because the parameterization of the autoconversion process assumes only suppression of rain formation in response to increased cloud droplet number, and does not consider macrophysical aspects explicitly that serve as a mechanism for the negative LWP responses. The autoconversion process can also be a source of uncertainty in warm rain initiation, which is generally “too light and too frequent” in GCMs. The satellite-based constraints on the warm rain process is found to cause unrealistic negative effective radiative forcing due to ACI (ERFaci), implying that compensating errors exist between the precipitation process and other key processes in the model, likely due to the lack of the buffered system. In order to improve the above issues, we introduced a comprehensive two-moment microphysics scheme into the global aerosol-climate model, MIROC6-SPRINTARS, which includes prognostic precipitation for both rain and snow and considers their radiative effects. We found that the prognostic precipitation significantly mitigates the LWP susceptibility to aerosols through collection processes among precipitating hydrometeors and cloud droplets. The precipitation-driven buffering effects would explain the model-observation discrepancy in ERFaci. The warm rain formation process is slowed down, which is in good agreement with satellite observations, implying that the new scheme reconciles the error compensation between precipitation process and required energy budget. These results strongly support the necessity of prognostic precipitation framework in GCMs for more reliable climate simulation with intrinsic buffered systems.

Keywords: aerosol-cloud interactions, climate, radiative forcing