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In search of the best match: probing a multi-dimensional cloud microphysical parameter space to better understand what controls cloud thermodynamic phase

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Substantial improvements have been made to the cloud microphysical schemes used in the latest generation of global climate models (GCMs), however, an outstanding weakness of these schemes lies in the arbitrariness of their tuning parameters, which are also notoriously fraught with uncertainties. Despite the growing effort in improving the cloud microphysical schemes in GCMs, most of this effort has neglected to focus on improving the ability of GCMs to accurately simulate the present-day global distribution of thermodynamic phase partitioning in mixed-phase clouds. Liquid droplets and ice crystals not only influence the Earth's radiative budget and hence climate sensitivity via their contrasting optical properties, but also through the effects of their lifetimes in the atmosphere. The current study employs NCAR's CAM5.1, and uses observations of cloud phase obtained by NASA's CALIOP lidar over a 79-month period (November 2007 to June 2014) guide the accurate simulation of the global distribution of mixed-phase clouds in 20° latitudinal bands at the $-10°$ C, -20°C and $-30°$C isotherms, by adjusting six relevant cloud microphysical tuning parameters in the CAM5.1 via Quasi-Monte Carlo sampling. Among the parameters include those that control the Wegener-Bergeron-Findeisen (WBF) timescale for the conversion of supercooled liquid droplets to ice and snow in mixed-phase clouds, the fraction of ice nuclei that nucleate ice in the atmosphere, ice crystal sedimentation speed, and wet scavenging in stratiform and convective clouds. Using a Generalized Linear Model as a variance-based sensitivity analysis, the relative contributions of each of the six parameters are quantified to gain a better understanding of the importance of their individual and two-way interaction effects on the liquid to ice proportion in mixed-phase clouds. Thus, the methodology implemented in the current study aims to search for the combination of cloud microphysical parameters in a GCM that produce the most accurate reproduction of observations of cloud thermodynamic phase, while simultaneously assessing the weaknesses of the parameterizations in the model. We find that the simulated proportion of liquid to ice in mixed-phase clouds is dominated by the fraction of active ice nuclei in the atmosphere and the WBF timescale. In a follow-up to this study, we apply these results to a fully-coupled GCM, CESM, and find that cloud thermodynamic phase has profound ramifications for the uncertainty associated with climate sensitivity estimates.