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Getting the liquid to ice proportion in mixed-phase clouds right and why it matters in a warmer climate

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Uncertainties associated with cloud feedbacks are the largest among those contributing to equilibrium climate sensitivity (ECS) estimates by global climate models (GCMs). Here, we show that thermodynamic phase partitioning in mixed-phase clouds plays a fundamentally important role in cloud feedbacks in a doubled CO_2 climate, and hence ECS estimates, despite often being overlooked as an important aspect of cloud modelling. Liquid droplets and ice crystals not only influence the Earth's radiative budget via their contrasting optical properties, but also through the effects of their lifetimes in the atmosphere. Cloud thermodynamic phase hence plays a critical role in impacting climate sensitivity. Using CESM1.0.5 as the GCM of choice, the following six pairs of simulations (the one listed with present-day and doubled CO_2 concentrations) were conducted: a control, one with an excessively high concentration of ice nuclei present in the atmosphere ("HighIN"), one with virtually no ice nuclei present in the atmosphere ("LowIN"), and three more with six different cloud microphysical tuning parameters in CAM5.1 adjusted in each simulation so as to most accurately reproduce observations of cloud thermodynamic phase obtained by NASA's CALIOP over a 79-month-long period (November 2007 to June 2014) in 20° latitudinal bands at the $-10°$C, $-20°$C and $-30°$C isotherms ("CALIOP-1", "CALIOP-2", "CALIOP-3"). The current study is a follow-up to a previous study in which the authors have obtained the most accurate match to CALIOP observations via Quasi-Monte Carlo sampling of a six-dimensional parameter space of cloud microphysical parameters in CAM5.1. ECS values were calculated for these six pairs of simulations and various climate feedback parameters, including cloud feedback parameters, at the global and regional scales were quantified to elucidate the mechanisms responsible for the ECS values. The calculations reveal that the control simulation has the lowest ECS among all the simulations, while the ECS of LowIN is on the other extreme, nearly doubling that of the control simulation.