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How robust are models of precipitation response to aerosols?

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Models of cloud-aerosol interaction and effects on precipitation are complex and therefore slow to run, so our understanding mostly relies on case studies and a very limited exploration of model uncertainties. Here we address the concept of cloud model robustness. A robust model is one that is reliable under different conditions in spite of uncertainties in the underlying processes. To assess model robustness, we quantify how the accumulated precipitation from a mixed-phase convective cloud responds to changes in aerosol accounting for the combined uncertainties in ten microphysical processes. Sampling across the full uncertainty space is achieved using statistical emulators, which essentially enable tens of thousands of cloud-resolving model simulations to be performed. Overall, precipitation increases with aerosol when aerosol concentrations are low and decreases when aerosol concentrations are high. However, when we account for uncertainties across the ten-dimensional parameter space of microphysical processes, the direction of response can no longer be defined with confidence except under some rather narrow aerosol conditions. To assess robustness of the modelled precipitation response to aerosols, we select a set of model "variants" that display a particular response in one aerosol environment and use this subset of models to predict precipitation response in other aerosol environments. Despite essentially tight model tuning, the model has very little reliability in predicting precipitation responses in different aerosol environments. Based on these results, we argue that the neglect of model uncertainty and a narrow case-study approach using highly complex cloud models may lead to false confidence in our understanding of aerosol-cloud-precipitation interactions.