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An investigation of the connections between convection, clouds and climate sensitivity in a Global Climate Model

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This study explores connections between process-level modeling of convection and GCM (global climate model) simulated clouds and cloud feedback to global warming through a set of perturbed-physics and perturbed-sea-surface-temperature experiments. A bulk diagnostic approach is constructed and a set of variables is derived and demonstrated to be useful in understanding the simulated relationship. In particular, a novel bulk quantity, the convective precipitation efficiency or equivalently the convective detrainment efficiency, is proposed as a simple measure of the aggregated properties of parameterized convection important to our GCM simulated clouds. As the convective precipitation efficiency increases in the perturbed-physics experiments, both liquid and ice water path decrease, with low and middle cloud fractions diminishing at a faster rate than high cloud fractions. This asymmetry results in a large sensitivity of top-of-atmosphere net cloud radiative forcing to changes in convective precipitation efficiency in this limited set of models.

For global warming experiments, intermodel variations in the response of cloud condensate, low cloud fraction, and total cloud radiative forcing are well explained by model variations in response of total precipitation (or detrainment) efficiency. Despite significant variability, all the perturbed-physics models produce a sizable increase in precipitation efficiency to warming. A substantial fraction of the increase is due to its convective component which depends on the parameterization of cumulus mixing and convective microphysics processes. The increase in convective precipitation efficiency and associated change in convective cloud height distribution to warming explains the increased cloud feedback and climate sensitivity in recently developed Geophysical Fluid Dynamics Laboratory GCMs. The results imply that a cumulus scheme using fractional removal of condensate for precipitation and inverse calculation of entrainment rate tends to produce a lower climate sensitivity than a scheme using threshold removal for precipitation and entrainment rate formulated inversely dependent on convective depth.