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Aerosols, Clouds, and Precipitation as Scale Interactions in the Climate System and Controls on Climate Change

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Clouds are major regulators of atmospheric energy flows. Their character depends on atmospheric composition, dynamics, and thermodynamic state. Clouds can assume organized structures whose scales are planetary, while processes important for determining basic properties occur on the scale of microns. The range of processes, scales, and interactions among them has precluded the development of concise theories for the role of clouds in climate, and limitations in modeling clouds in complex climate models remain among the key uncertainties in understanding and projecting climate change. The distribution function of vertical velocities (updraft speeds) in clouds is an important control on climate forcing by clouds and possibly a strong correlate with climate sensitivity. (Climate forcing refers to the change in Earth's energy balance as atmospheric composition changes, in particular, due to human activity. Climate sensitivity is defined here as the equilibrium change in globally averaged annual surface temperature as a result of doubled carbon dioxide.) Vertical velocities are central because they determine the thermodynamic environment governing phase changes of water, with both equilibrium and non-equilibrium phenomena important. The spatial and temporal spectra of relevant vertical velocities includes scales both numerically resolved by climate models and below their resolution limit. The latter implies a requirement to parameterize these smaller scale motions in models. The scale dependence of vertical velocities and emerging observational constraints on their distribution provide new opportunities for representing aerosols, clouds, and precipitation in climate models. Success in doing so could provide important breakthroughs in understanding both climate forcing and sensitivity.