Next-generation cloud radars: Applications of rapid-scan cloud radars for three-dimensional mapping of clouds

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Mapping the three-dimensional (3D) structure of clouds is critical for advancing our process-level understanding and accurate model representation of the radiative, convective, and microphysical processes acting at the cloud-scale, especially in shallow cumuli clouds. Millimeter wavelength radars have provided unique insights of such processes in 1-D (profiling). However, when performing volume scans with mechanically scanning cloud radars, 15 minutes or more are required to obtain 3D observations of the cloudy atmosphere. Such revisiting times, make it impossible to capture the 3D cloud evolution and sample the lifecycles of populations of clouds without violating stationarity assumptions. For example, precipitation can develop within a cumulus cloud in 30 minutes, with considerable changes in cloud microphysics and dynamics occurring that cannot be resolved by conventional radar scans. Moreover, numerical simulations of cumulus clouds show considerable 3D structural evolution every 1 to 2 min in updraft intensity, width, and turbulence, lateral and cloud-top entrainment, and microphysical composition. On sub-cloud scales, vertical motion and turbulence measurements in shallow and deep clouds require temporal sampling less than 10 s.

This study focuses on examining new weather and climate research that would enabled by rapid-scan cloud radars, which would provide near four-dimensional (4D) views of cloud processes. Such 4D data would permit fundamental studies of cumulus clouds and convection needed to evaluate conceptual models and parameterizations of convection and entrainment (e.g., plumes, thermals). Within fields of cumuli, detailed time-histories of microphysical and dynamic characteristics would be enabled to identify factors that contribute to different modes of updraft evolution and their coupling to boundary layer processes. Rapid-scan cloud radars would also provide unique insight into spatial variations in turbulence and microphysics over complex terrain, in mammatus clouds, winter storms, land-falling tropical cyclones, deep convective systems, and other gaps in model representation. After discussing enabled science research, the study concludes with a discussion of radar technologies that could address these needs and their benefits and limitations.

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