2.1 - Next-Generation Cloud Radars: How Do We Obtain Rapid Three-Dimensional Observations of Clouds?

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Abstract

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. Over the last 20 years, 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 (i.e., high-temporal resolution, continuously sampled in space). 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 and convective structures. Such studies are critical to improving scientific understanding and NWP representation of convective initiation. 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. Finally, rapid-scan radar observations would provide synergistic observations with (1) aircraft data by providing continuously updating 3D measurements along flight paths and (2) satellite measurements by enabling a near-simultaneous volumetric view for intercomparisons with GPM and future satellite missions.

To investigate candidate radar technologies to address this need, a study of different rapid-scan cloud radars has been undertaken. One result of this effort is a concept called the Ka-band Rapid-scanning Volume Imaging Radar (KaRVIR). KaRVIR builds upon the emerging use of digital beamforming with weather radars, such as the Atmospheric Imaging Radar (AIR) and C-band Polarimetric Atmospheric Imaging Radar (PAIR), to obtain vertically continuous, rapid-scan radar observations of clouds. Another option is a Ka-band active electronically scanned array (AESA) architecture, which would permit an electronically steered beam with improved sensitivity and lower sidelobes compared to an imaging radar architecture. However, the cost of Ka-band AESAs is considerably more expensive than the imaging radar architecture. Alternative designs could include millimeter-wavelength radars using frequency hopping to increase the number of independent samples and to increase radar rotation rates. However, such designs would still require numerous elevation angles to be scanned to completely observe cloud vertical structure without gaps.

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