

# Dual-Doppler 3D Mobile Ka-band Rapid-Scanning Volume Imaging Radar for Earth System Science (KaRVIR)

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## I. Introduction.

Utilizing digital beamforming phased array radar (PAR) technology, the proposed Ka-band Rapid-scan Volumetric Imaging Radars (KaRVIR) will enable transformative scientific studies by completing volumetric scans every 20 s and will possess the highest spatial resolution and radar sensitivity of any existing phased array radar (PAR) for atmospheric research. KaRVIR will provide ground-breaking mmWave capability for polarimetric radar observations in time and 3D space and unprecedented 4D information about cloud and environmental processes. While PARs have provided invaluable observations of severe thunderstorms, KaRVIR offers the shorter wavelength necessary to make radar measurements of both small cloud droplets and ice as well as larger precipitation particles in the Mie scattering regime, creating the capacity to conduct studies not currently possible with existing PAR technology at centimeter wavelengths.

## II. Enable Research with KaRVIR PAR's

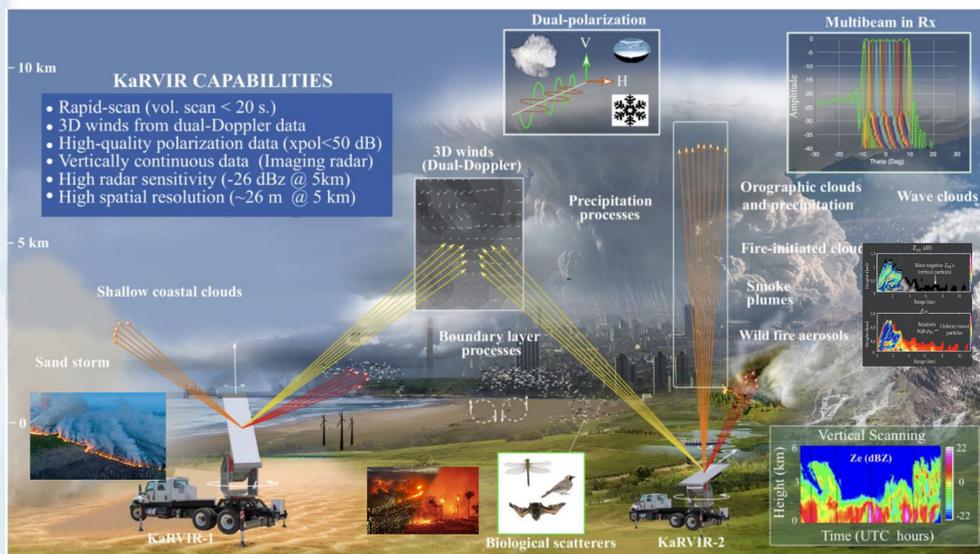


Figure 1: KaRVIR capabilities and enabled research in atmospheric science.

## III. KaRVIR Architecture

KaRVIR will be composed of two polarimetric mobile ground-based Ka-band rapid-scan volumetric imaging radar systems that will enable unprecedented science research capabilities. The combination of unique radar architecture, using mature Ka-band phased array antenna technology with digital beamforming on reception, makes the proposed radar systems feasible and cost-effective. The proposed system allows multiple simultaneous beams in elevation with mechanical scanning in azimuth that will provide excellent temporal resolution (<20 s), spatial resolution (24 m at 5 km), and radar sensitivity (-26 dBz at 5 km) due to the continuous-wave (CW) transmitter design. High-quality polarimetric radar products can be ensured since electronic scanning is not required. Leveraging the expertise of the team in the design and calibration of high isolation array antennas, unprecedented cross-polarization isolation (better than -50 dB) can be obtained using slotted waveguide antenna arrays and high isolation (better than -90 dB) between transmit and receive subsystems. Different phase centers of the separated arrays on transmit, receive, and for the Horizontal (H) and Vertical (V) polarizations will be corrected appropriately during the radar calibration process. KaRVIR's system concept, beam patterns, and use of imaging are illustrated in Fig. 2 (a-b).

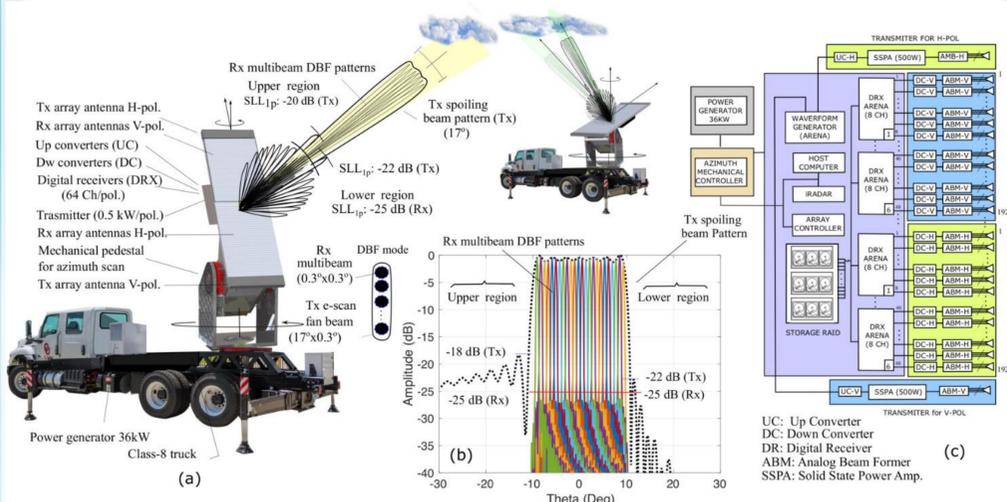


Figure 2: (a) Renderings of two mobile KaRVIR radars, (b) simulated two-way antenna patterns, and (c) high-level system block diagram of proposed KaRVIR radars.

## IV. KaRVIR Predicted Performance

The DoE Atmospheric Radiation Measurement (ARM) program operates the primary ground-based network of mm-wavelength radars, including Ka- and W-band mechanically scanning and zenith-pointing systems. The ARM Ka-band Scanning Radar (Ka-SACR), widely used for cloud studies and considered the benchmark system, is shown in Figure 4 with a simulated comparison. The Ka-SACR offers excellent sensitivity (-21 dBz at 5 km) and dual-polarization capability. Its fine angular resolution ( $0.33^\circ \times 0.33^\circ$  beamwidth) surpasses that of cm-wavelength radars (e.g.,  $1^\circ$  Doppler on Wheels) and airborne cloud radars ( $0.5^\circ - 0.7^\circ$  Wyoming Cloud Radar).

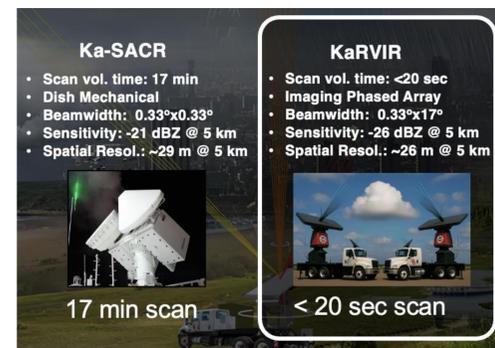


Figure 3: Ka-SACR vs. KaRVIR

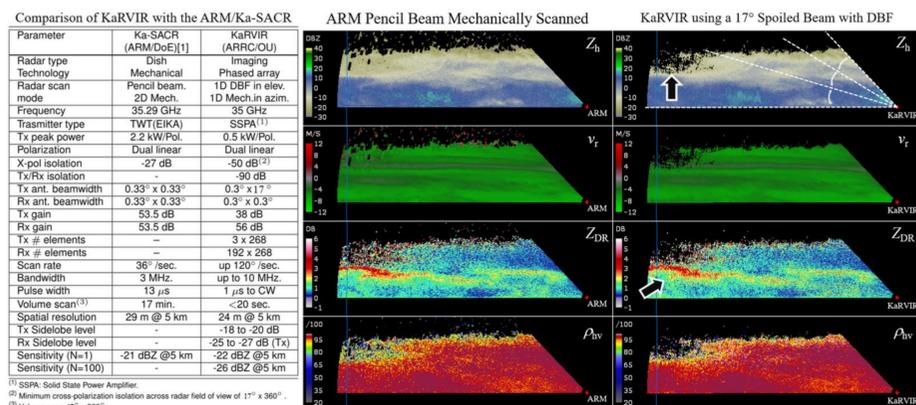


Figure 4: Specification comparison between the proposed KaRVIR and ARM/DOE Ka-SACR radars (left). Polarimetric products from the ARM/Ka-SACR radar (middle). Simulated polarimetric products with a 17 elevation beam spoil, using ARM/Ka-SACR data (right). Results show that a 17 spoiled transmit beam can reduce scan time by a factor of 30, bringing volume scans to 20 s.

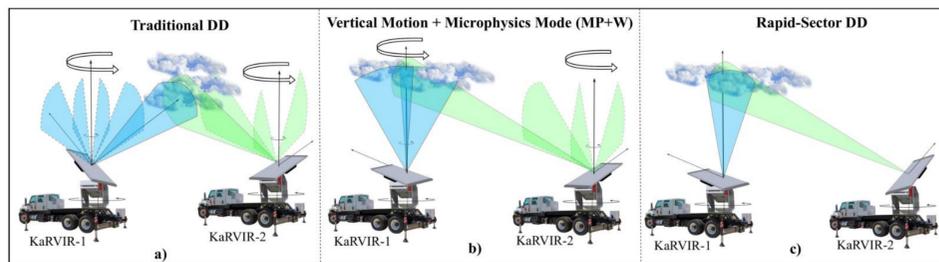


Figure 5: Example KaRVIR dual-Doppler configurations. a) Two KaRVIRs acquire U, V, W and dual-pol data in 3D space every 20 s or deeper volumes in 60 - 100 s. b) Vertical velocities and dual-pol spectra are collected with KaRVIR-1, 3D volumes of near-horizontal dual-pol and wind data are collected with KaRVIR-2. c) In-plane winds from near-instantaneous RHIs are observed at 0.1-s temporal resolution to capture along-plane and vertical velocity variances and covariance

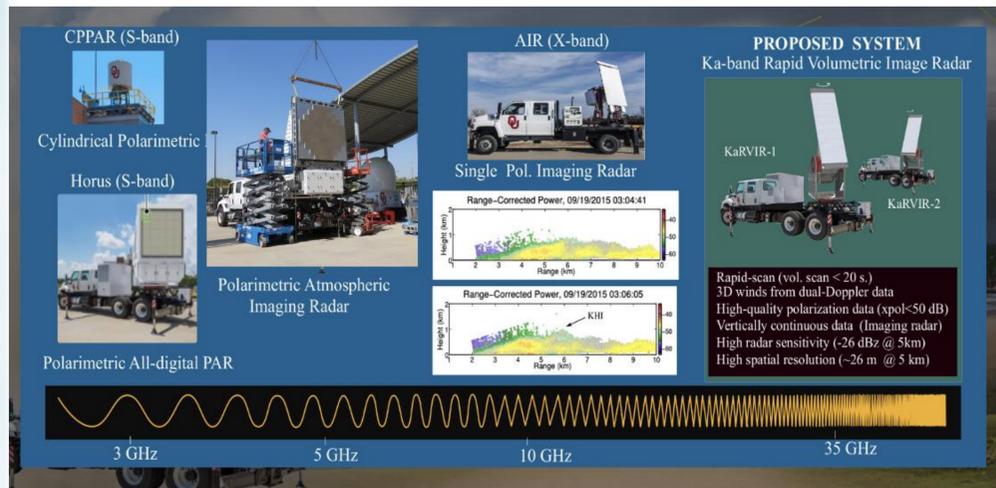


Figure 6: OU phased array radars. On the left, two S-band phased array radars. The Cylindrical Polarimetric PAR (CPPAR), and the dual-polarized all digital phased array radar demonstrator (Horus). In the middle, the C-band PAIR, and the X-band AIR (retired 2019). In the right, the two proposed Ka-band Rapid-Scanning Volume Imaging Radars (KaRVIR).