FY23 Strategic Initiatives Research and Technology Development (SRTD)

Technology Development and Design for an Orbital Differential Absorption Radar on a Future PBL Mission

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Strategic Focus Area: Next Earth Science Decadal Survey: Technology & Architecture for Planetary Boundary Layer (PBL)/ Surface Topography & Vegetation **| Strategic Initiative Leader:** Rashmi Shah

Objectives:

1) Study the feasibility of a multi-beam 170 GHz (G-band) spaceborne Differential Absorption Radar (DAR) for the purpose of reducing the along-track averaging distance necessary to obtain accurate estimates of inside-cloud water vapor.

2) Prove how a multi-element coherent array of 170 GHz RF sources could be used to generate a coherent, power-combined radar beam that is steerable by simultaneously deflecting low-mass subreflectors of each antenna array element.

Background:

Earth's Planetary Boundary Layer (PBL) is at the heart of fundamental science challenges, such as: reducing uncertainty in cloud-climate feedback, understanding the sensitivity of extreme weather to a warming world, quantifying the exchanges of energy, water and carbon between the free-atmosphere and the ocean/land surface, and improving forecasts of near surface air quality that significantly affect human health. A compelling remote sensing technique that has emerged in the last decade is Differential Absorption Radar for mapping vertical distributions of water vapor inside of clouds. JPL pioneered this method, which relies on advance millimeter-wave radar technology. However, to be competitive for consideration in a space mission in the future, the added capabilities of far higher transmit power, better along-track spatial resolution, and agile beam steering are critical for the application of DAR on a global basis.

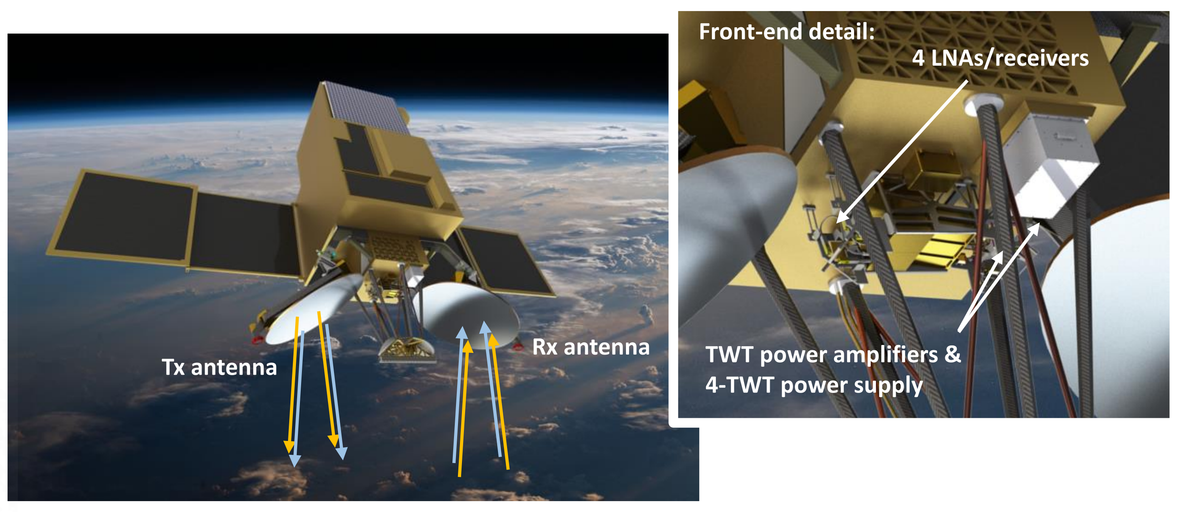
Approach and Results:

Our proposed DAR architecture improves along-track resolution by using four 100-W travelling wave tube transmitters pulsing in sequence for an effective 100% duty cycle of pulses-in-the-air. We developed a detailed optics model using a 2-m diameter primary antenna, showing that 10-cm displaced symmetric feeds result in a directivity penalty of only 0.5 dB. The four receive ports use a second identical antenna, with the two-antenna structure folding, clamshell-like, to fit in a SpaceX Falcon-9 Fairing. The mass/power estimate is 80 kg /1300 W (at 100% orbital duty cycle), putting the DAR instrument in a class similar to SWOT. We also analyzed retrieval accuracy for shorter along-track averaging distances, quantifying using a Large Eddy Simulation (LES) model how well DAR can work with 10-km along-track averaging (resolution).

In parallel, we have developed a novel and disruptive method of power-combining G-band signals generated by solid-state components in free space with a coherent array of medium-gain reflectors. Electro-mechanical beam steering with this architecture is achieved with a larger angle and greater agility than a heritage single-dish antenna of the same total size. Coherent phasing of the array-elements is achieved by adjusting the bias-voltages of the JPL-built W-band and G-band frequency multipliers of the individual transmitters. Far-field measurements at JPL's mesa antenna range demonstrated that the three separate beams could be combined with a perfectly predictable beam-pattern. Electro-mechanical beam steering was also demonstrated with only 0.2 dB scan losses at a fixed angle of 1° using tilted sub-reflectors 3D-printed at JPL's Additive Manufacturing Center. Methods for one-dimensional mechanical and phase alignment of the array elements have been developed and implemented successfully.

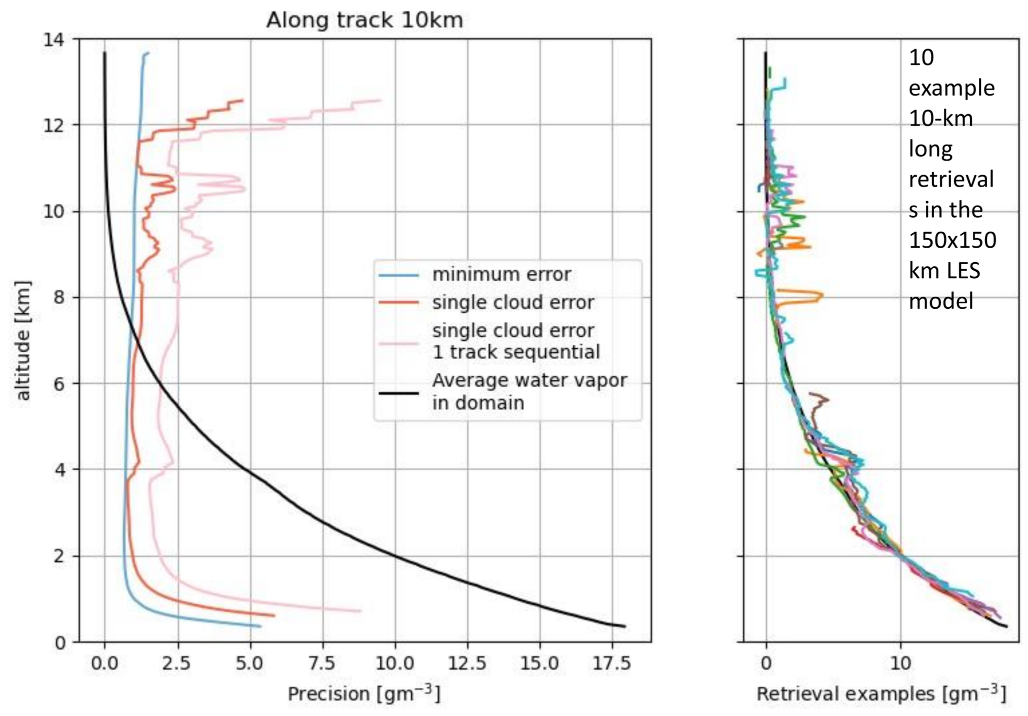
Significance/Benefits to JPL and NASA:

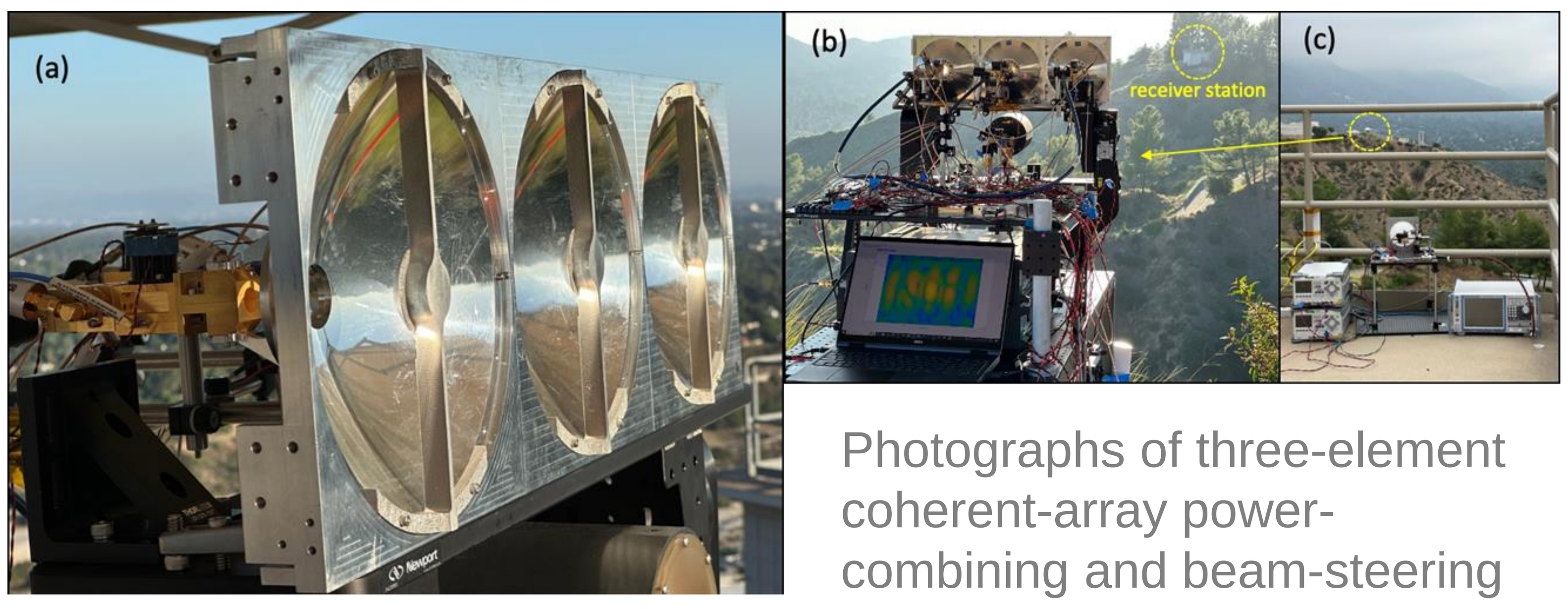
The excellent results of our coherent-array experiments make a compelling case for this radical approach to building high-gain, high-power, beam-steerable radars at G-band. When completed as planned in Year 2 (FY24) of this SRTD task, our concept study for a high-resolution spaceborne version of DAR will feed into our team's roadmap for infusion of a DAR instrument into a large PBL mission likely to be given high priority in the next decadal survey.



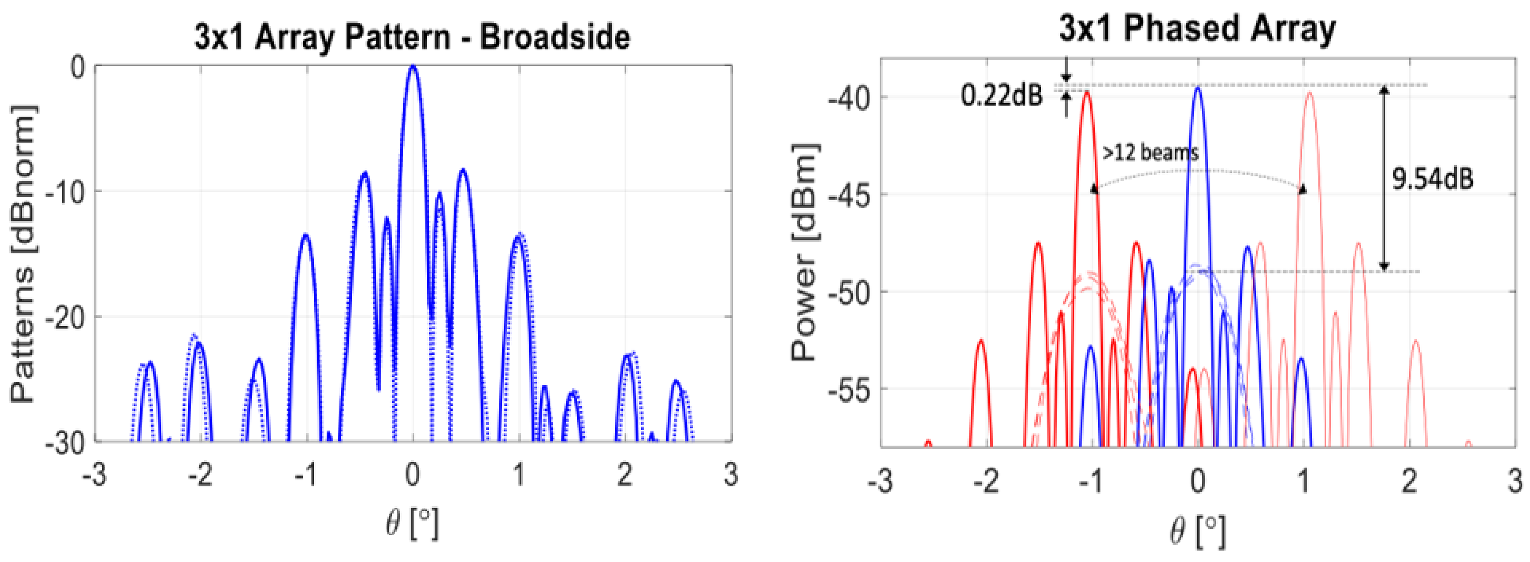
One design concept for a spaceborne DAR uses four TWT amplifiers, each 100 W peak power, to illuminate two parallel tracks with four beams (two frequencies per track).

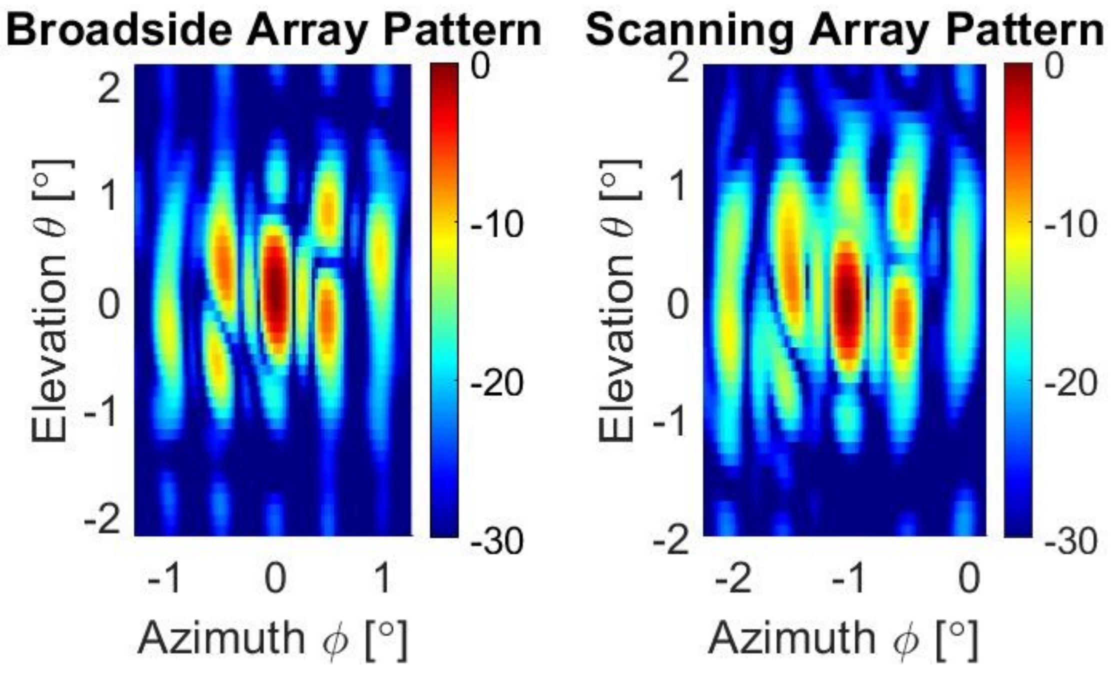
Simulated precision and accuracy for the four-transmitter DAR concept, two frequencies (167 & 175 GHz). This is for the LES model known as "GATE".





Photographs of three-element coherent-array power-combining and beam-steering tests at the JPL mesa.





Measurements show excellent agreement with simulation, resulting in 9.5 dB higher power density and the potential for more than 12 beam widths of electro-mechanical steering capability.

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