VIPR: Vapor In-Cloud Profiling Radar (IIP-16)

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Scientific Motivation

Problem

- Existing remote sensing platforms have limited ability to retrieve *high-resolution, unbiased* water vapor profiles in the presence of clouds

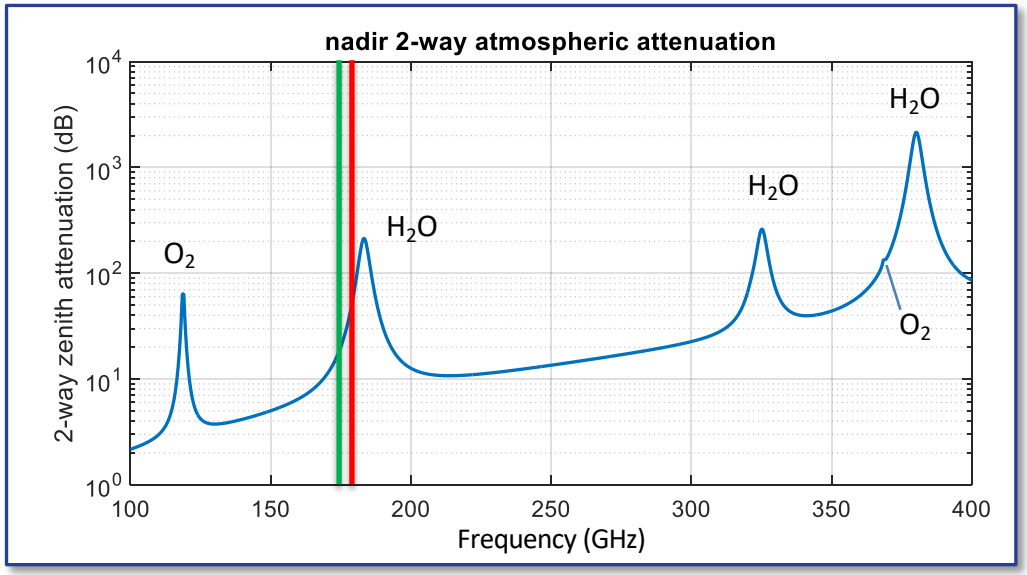
- Problem recognized by NWP community (WMO, 2018):
  "Critical atmospheric variables that are **not adequately measured** by current or planned systems are temperature and **humidity profiles** of adequate vertical resolution **in cloudy areas**."

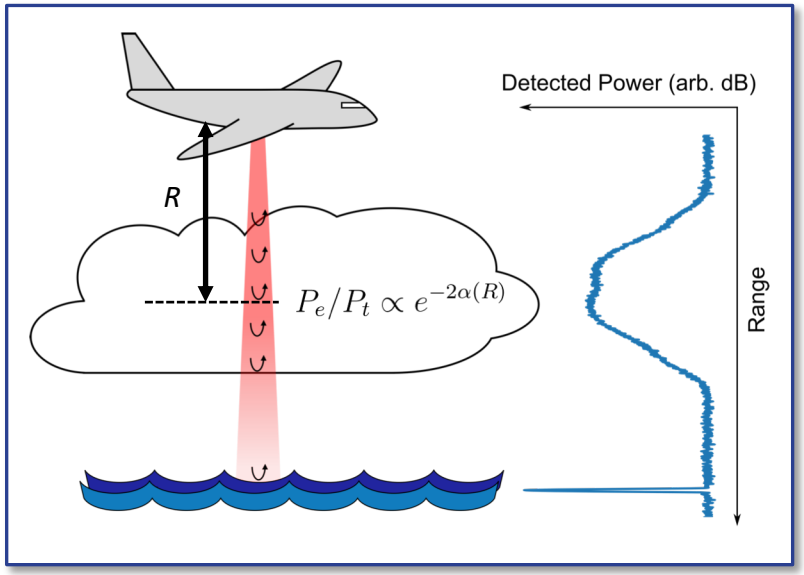
Proposed Solution

- Utilize range-resolved radar signal *and* frequency-dependent attenuation on flank of 183 GHz water vapor absorption line, so-called *differential absorption radar* (DAR)

- Microwave analog of differential absorption lidar(DIAL) –but can measure inside clouds

Measurement basis





- Differential reflectivity between two closely spaced frequencies proportional to absorbing gas density (integrated)

$$\mathrm{dBZ}(r, f_1) - \mathrm{dBZ}(r, f_2) \propto \int_0^r \rho_{\mathrm{gas}}(r')dr'$$

- *Important assumption*: Reflectivity and extinction from hydrometeors independent of frequency
- Frequency dependence from hardware cancels out (common mode)
- Airborne platform ⇒ Surface echoes (total column water)

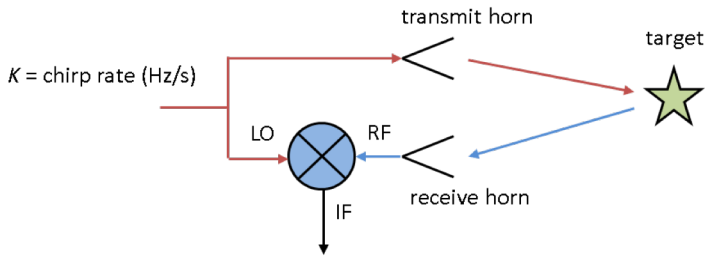
Connection to Decadal Survey

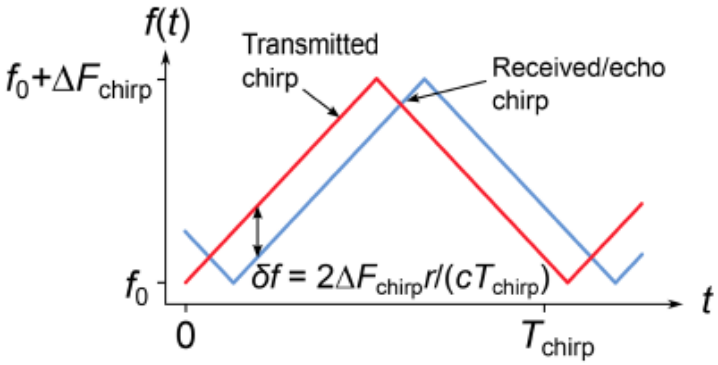
TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Planetary Boundary Layer	**Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights.	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height			X

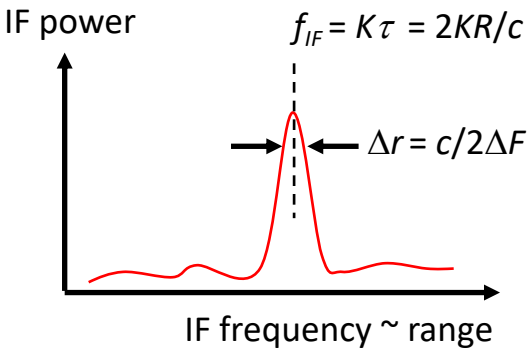
VIPR addresses the measurement needs for the Planetary Boundary Layer (PBL) incubation area by providing high vertical resolution water vapor profiles within PBL clouds and precipitation

Measurement Approach

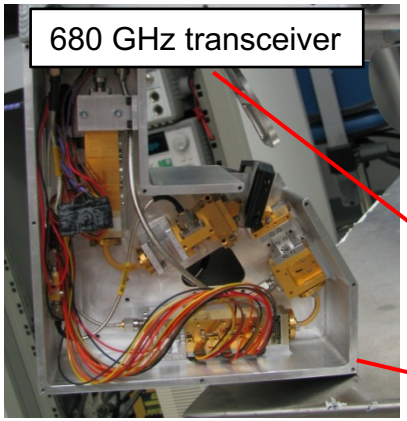
FMCW Radars

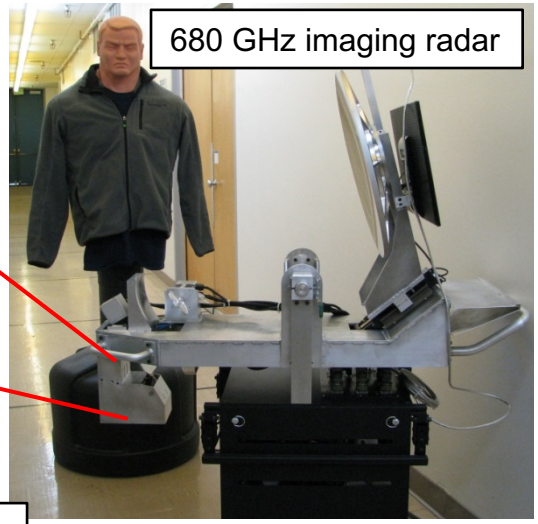


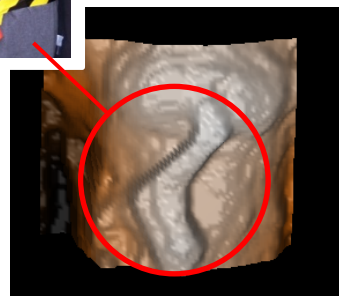


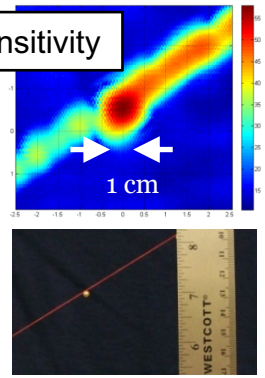


THz radar imaging radar for Standoff Personnel Screening





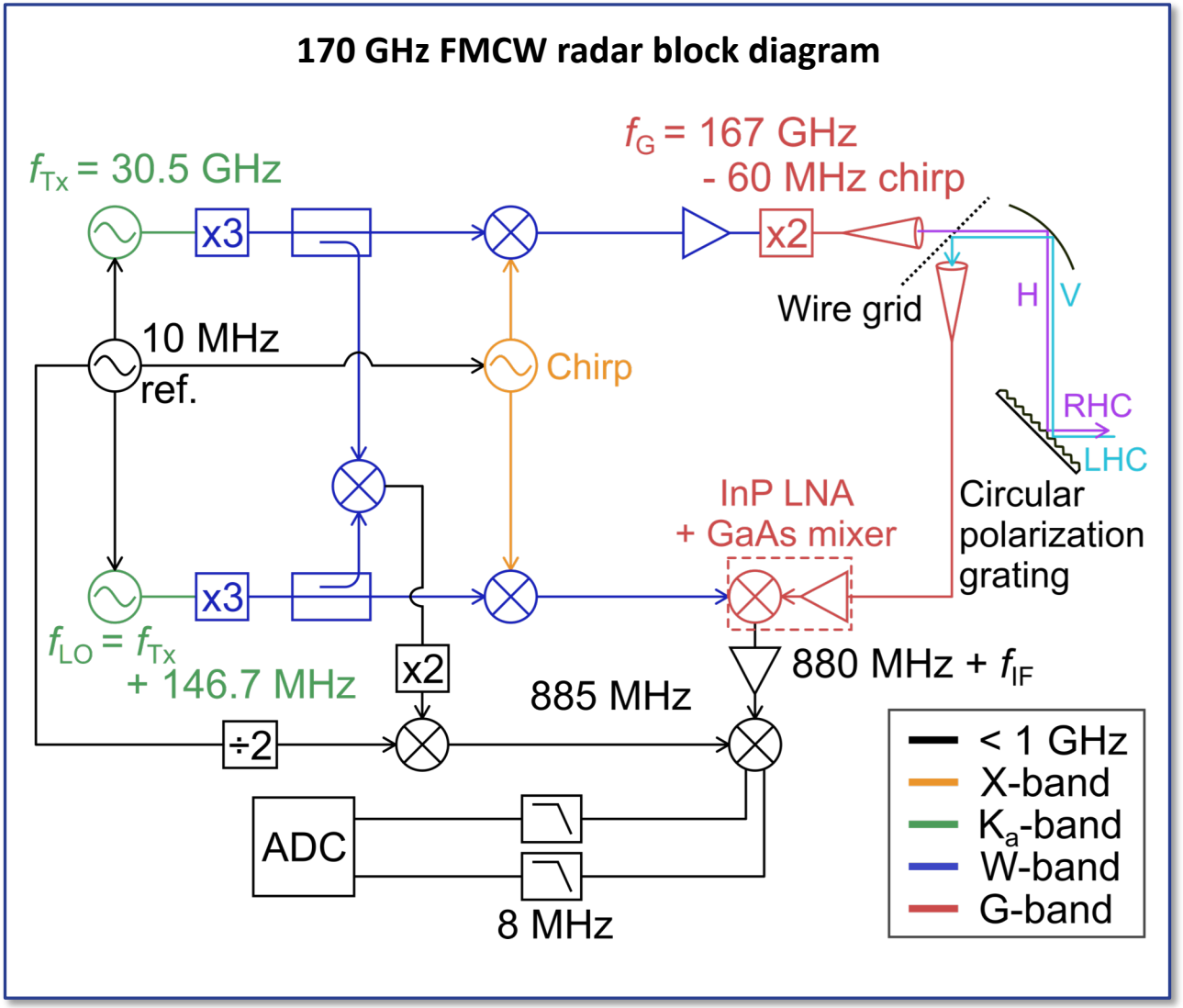




K.B. Cooper R.J. Dengler N. Llombart B. Thomas G. Chattopadhyay P.H. Siegel "THz imaging radar for standoff personnel screening" IEEE Trans. Terahertz Technol. vol. 1 no. 1 pp. 169-182 2011.

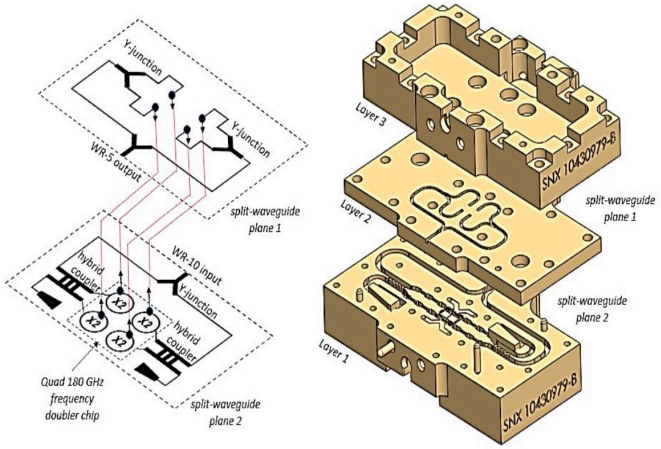
VIPR architecture

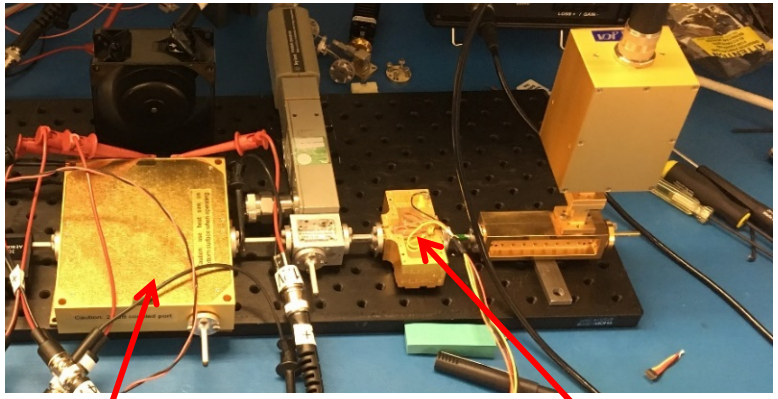
- Transmitter tunable from 167 to 174.8 GHz
- Nominal range resolution 2.5 m (60 MHz chirp bandwidth)
- Very high quasi-optical isolation permits simultaneous operation of Tx/Rx **and** single common aperture
- Oscillator phase-noise cancellation (homodyne) techniques enable thermal-noise-limited detection



Key Technologies

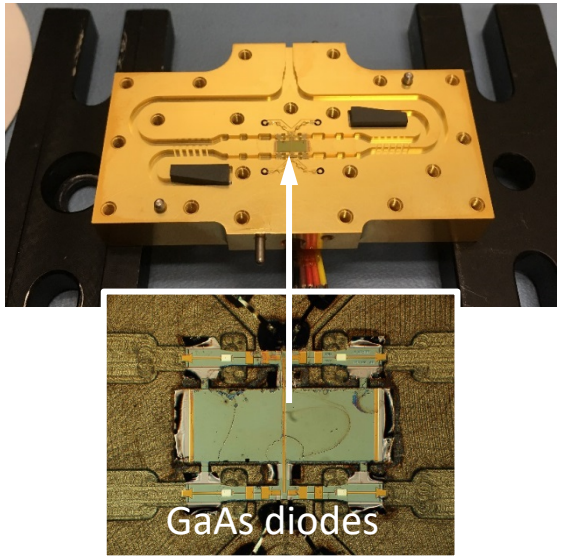
Power-combined (4x) frequency multiplier (2x) technology at JPL

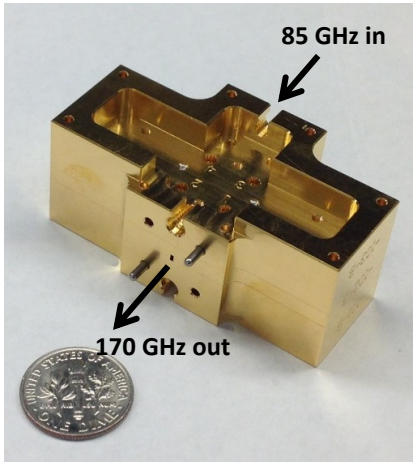


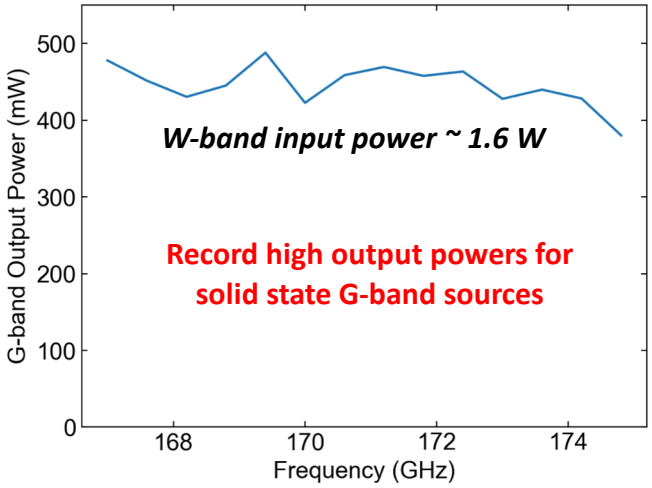


Millitech power-combined W-band PA module with 85 GHz Raytheon GaN MMICs

G-band quad doubler



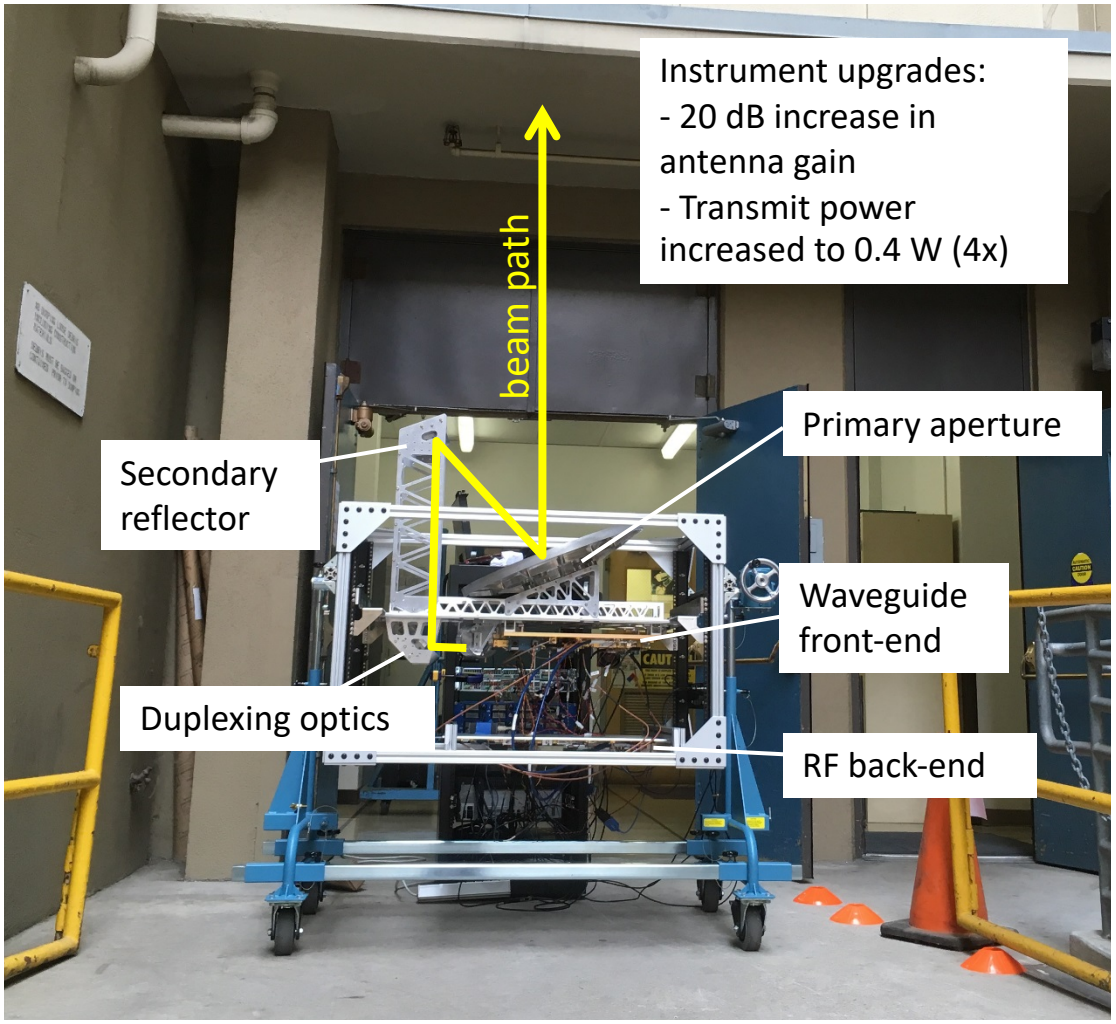


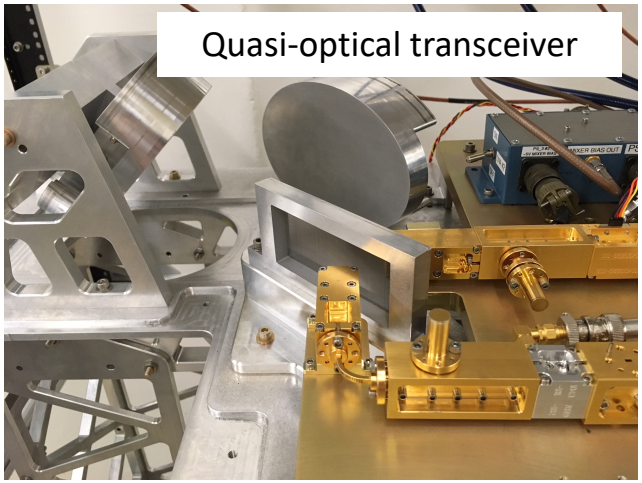


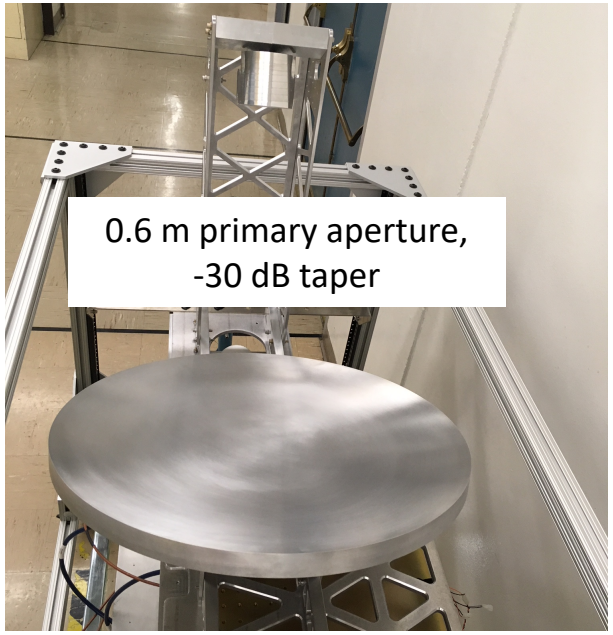
Jose Siles *et al., IEEE Transactions on Terahertz Science and Technology*, vol. 8, no. 6, pp. 596-604, Nov. 2018.

Toward airborne deployment

Airborne compatible VIPR system on Flotron rotation stage

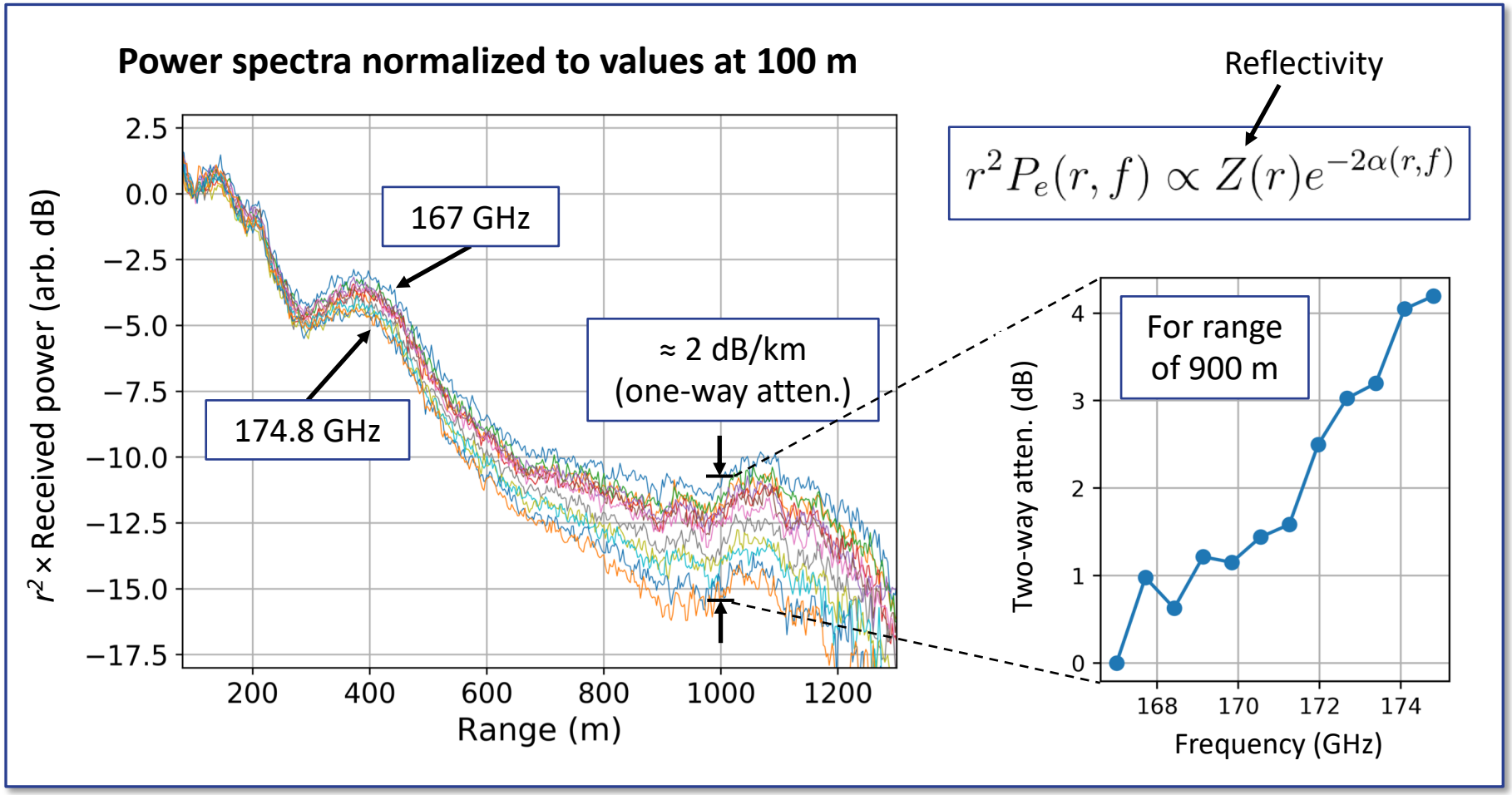






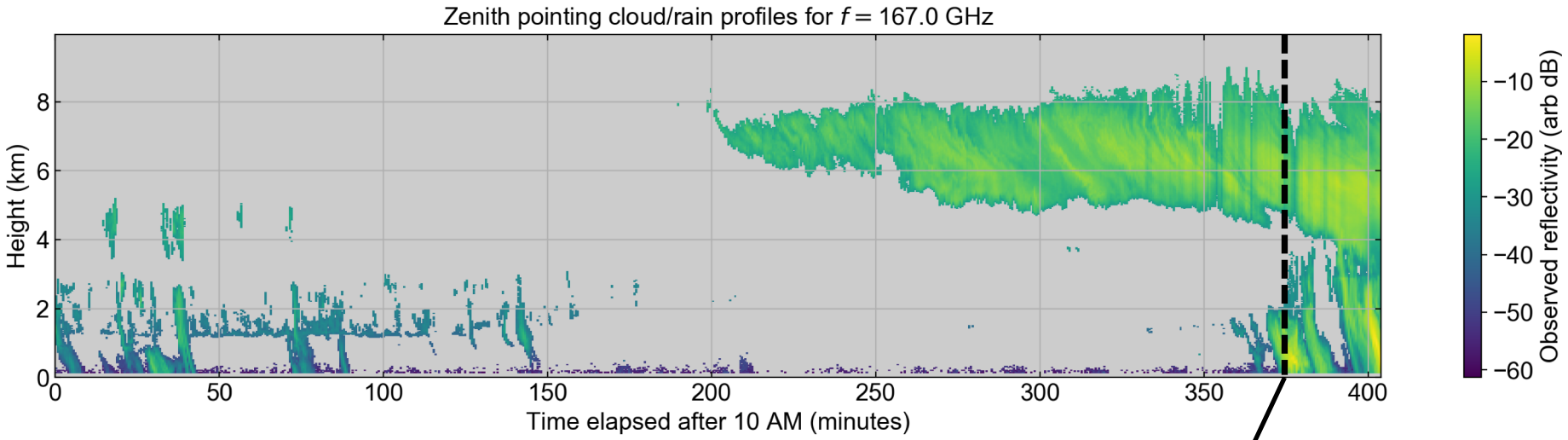
Rain/cloud field tests @ JPL

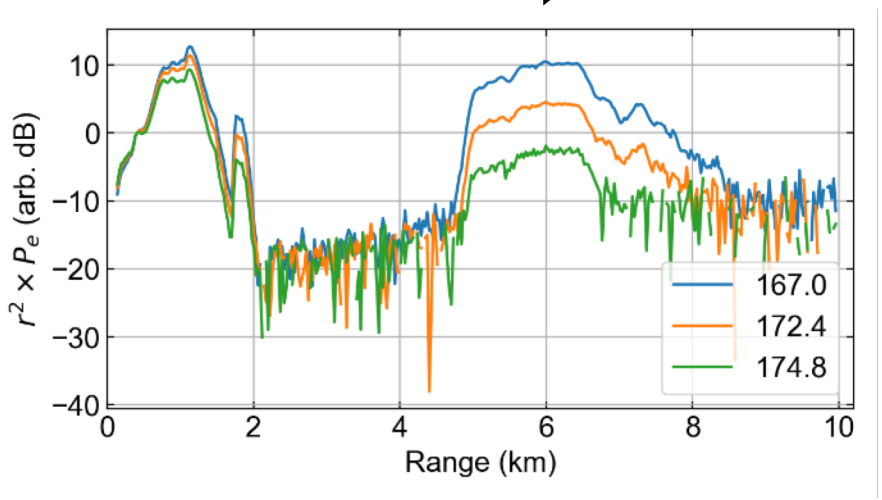
Precipitating clouds



First Full-VIPR Detections of Clouds and Humidity

October 3, 2018 @ JPL – Clouds detected beyond 8 km in height

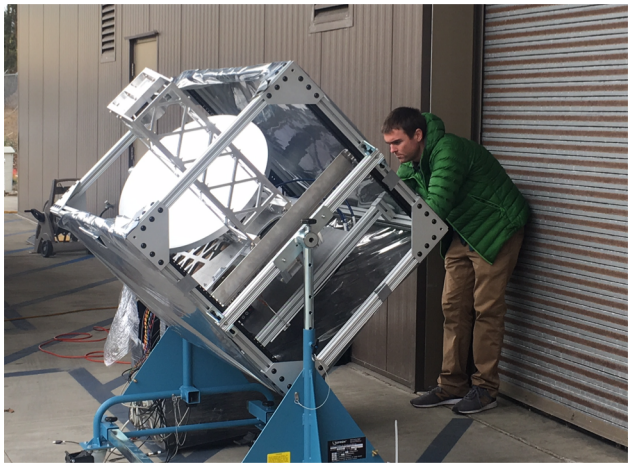


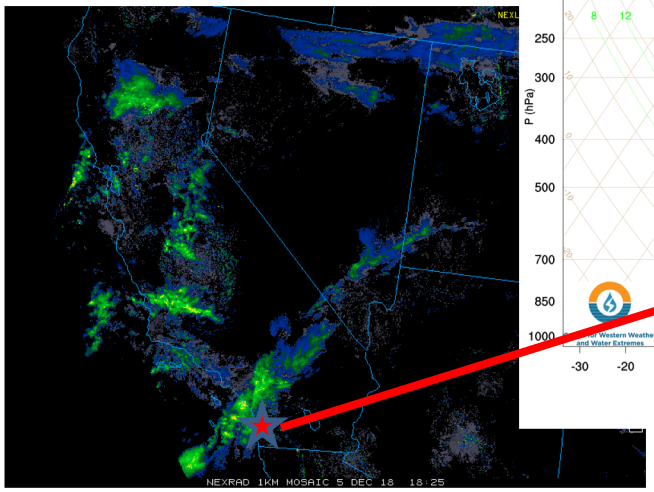


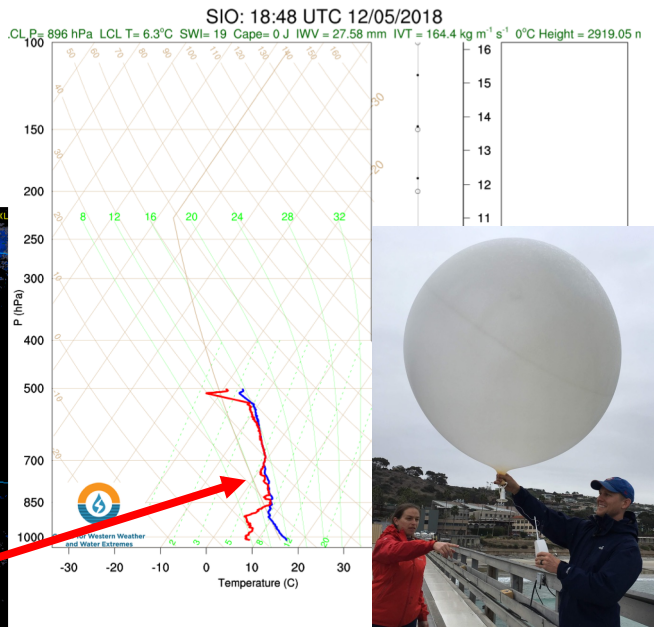
Jet Propulsion Laboratory
California Institute of Technology

Scripps Field Testing and Radiosonde Validation

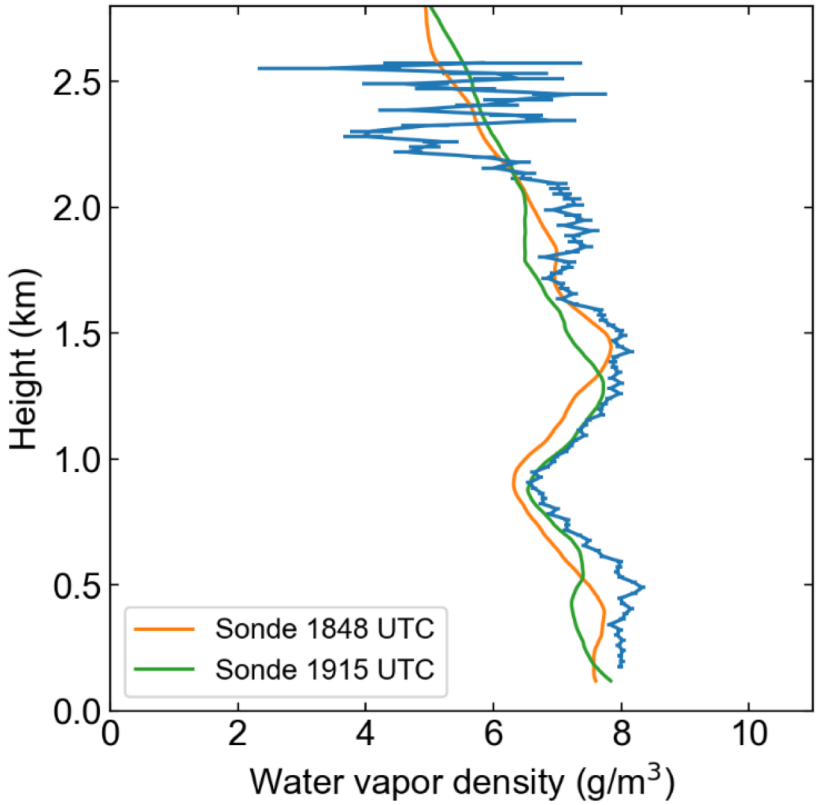
- Scripps validation deployment (12/5/2018) in collaboration with the Center for Western Weather and Water Extremes
- VIPR Observed 6 hours of a cold-frontal passage
- Scripps CW3E Launched 8 radiosondes

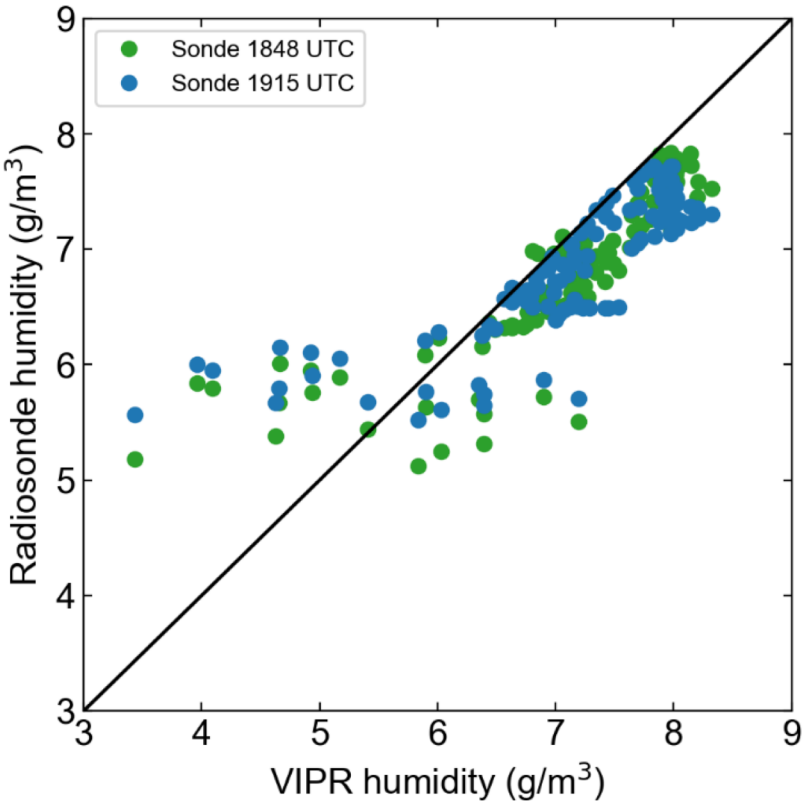






DAR/radiosonde comparisons





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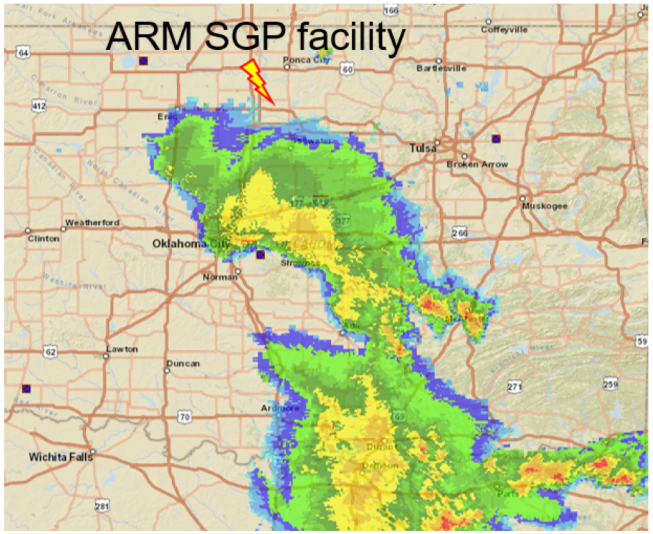
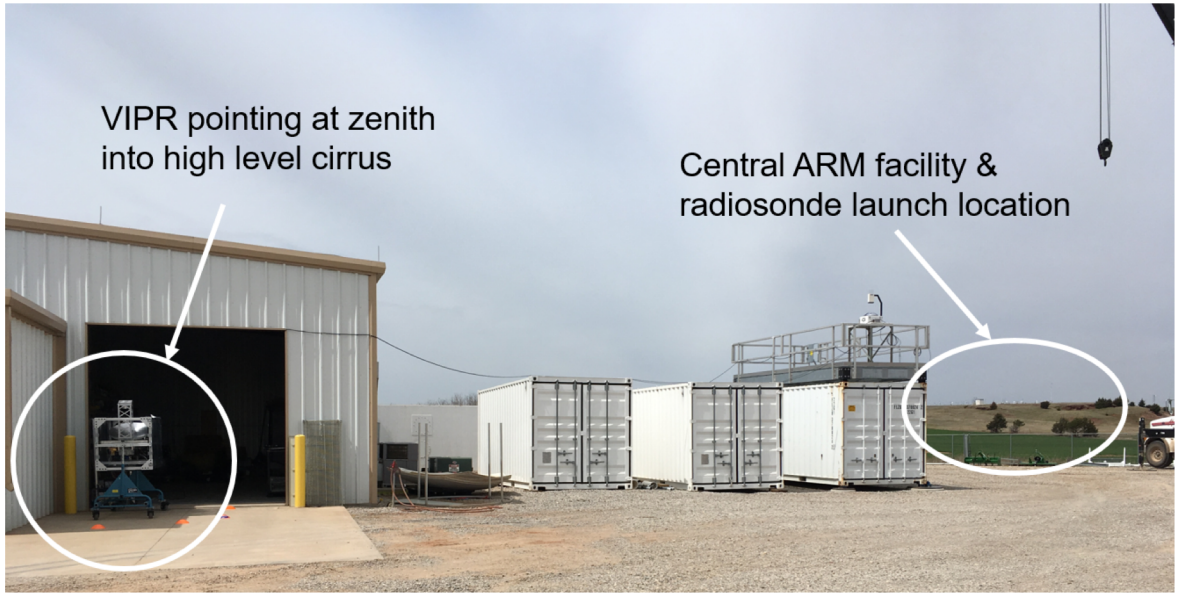
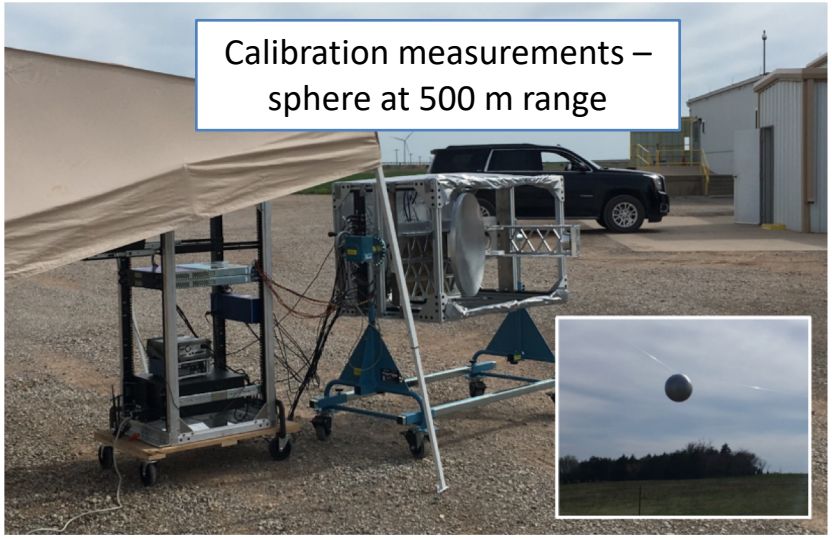
Deployment at ARM SGP site

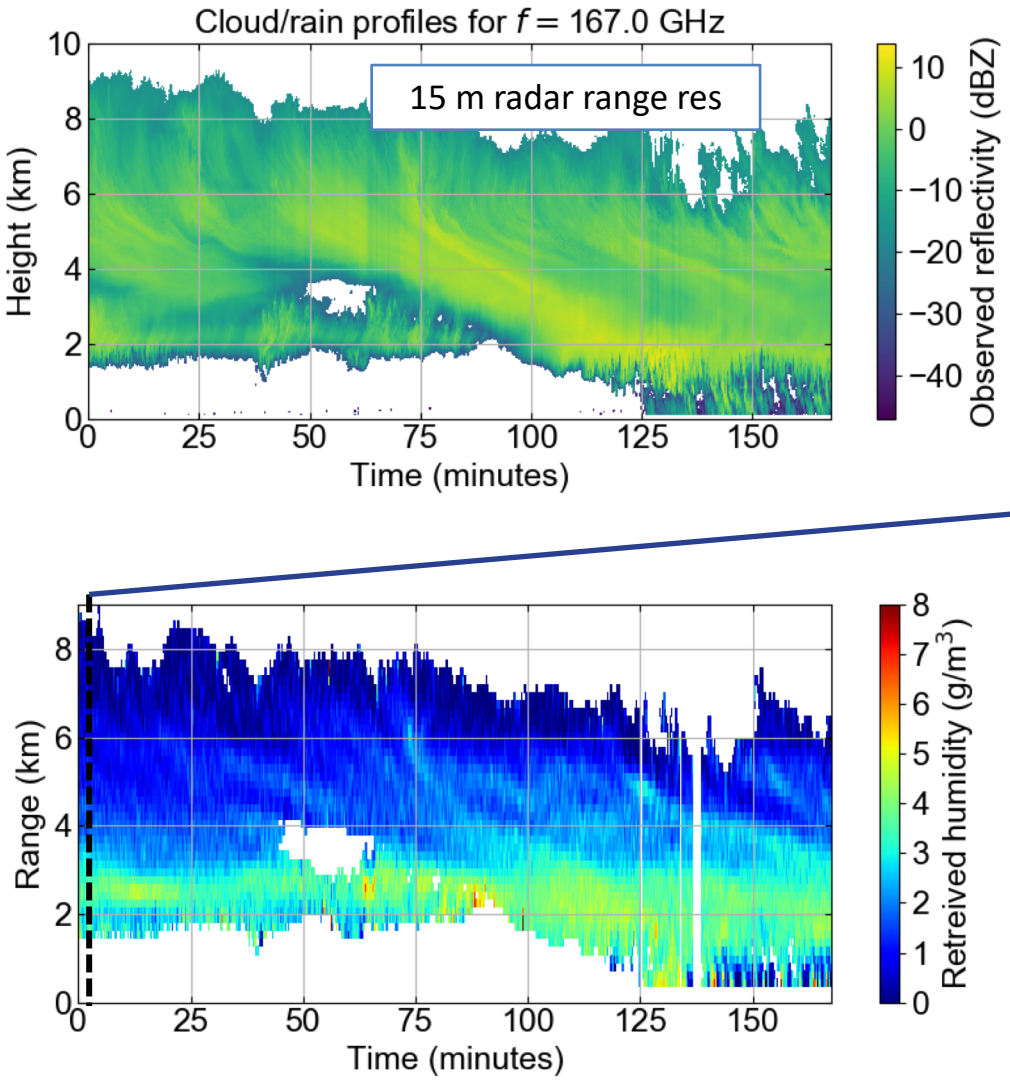




- VIPR deployed from April 2-14, 2019
- Multiple convective systems passed through during the intensive observation period
- 4x daily radiosonde launches at ARM – supplemented with JPL supplied sondes (launched at will)
- Additional ARM humidity measurements include Raman lidar, passive microwave and infrared
- Performed radar calibration with high-sphericity calibration targets

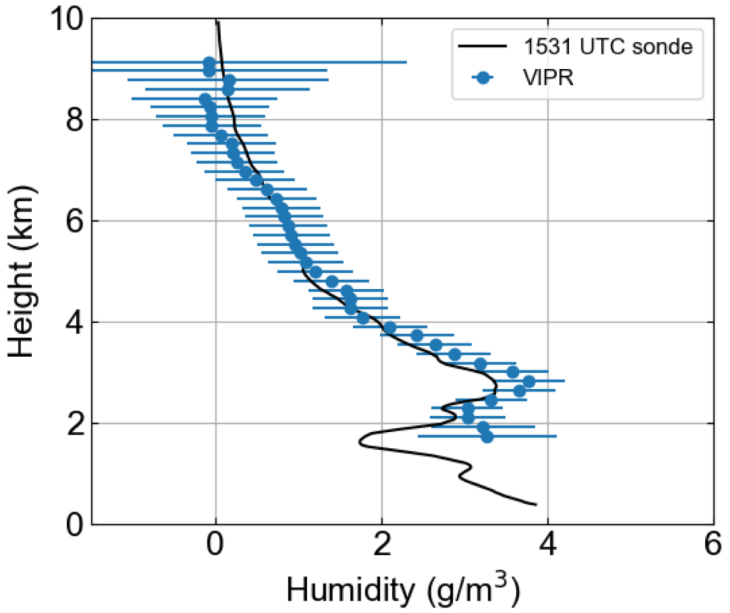


In-cloud Profile Validation



April 13, 2019

Excellent VIPR validation with radiosonde balloons!



Concept for VIPR Twin Otter Deployment

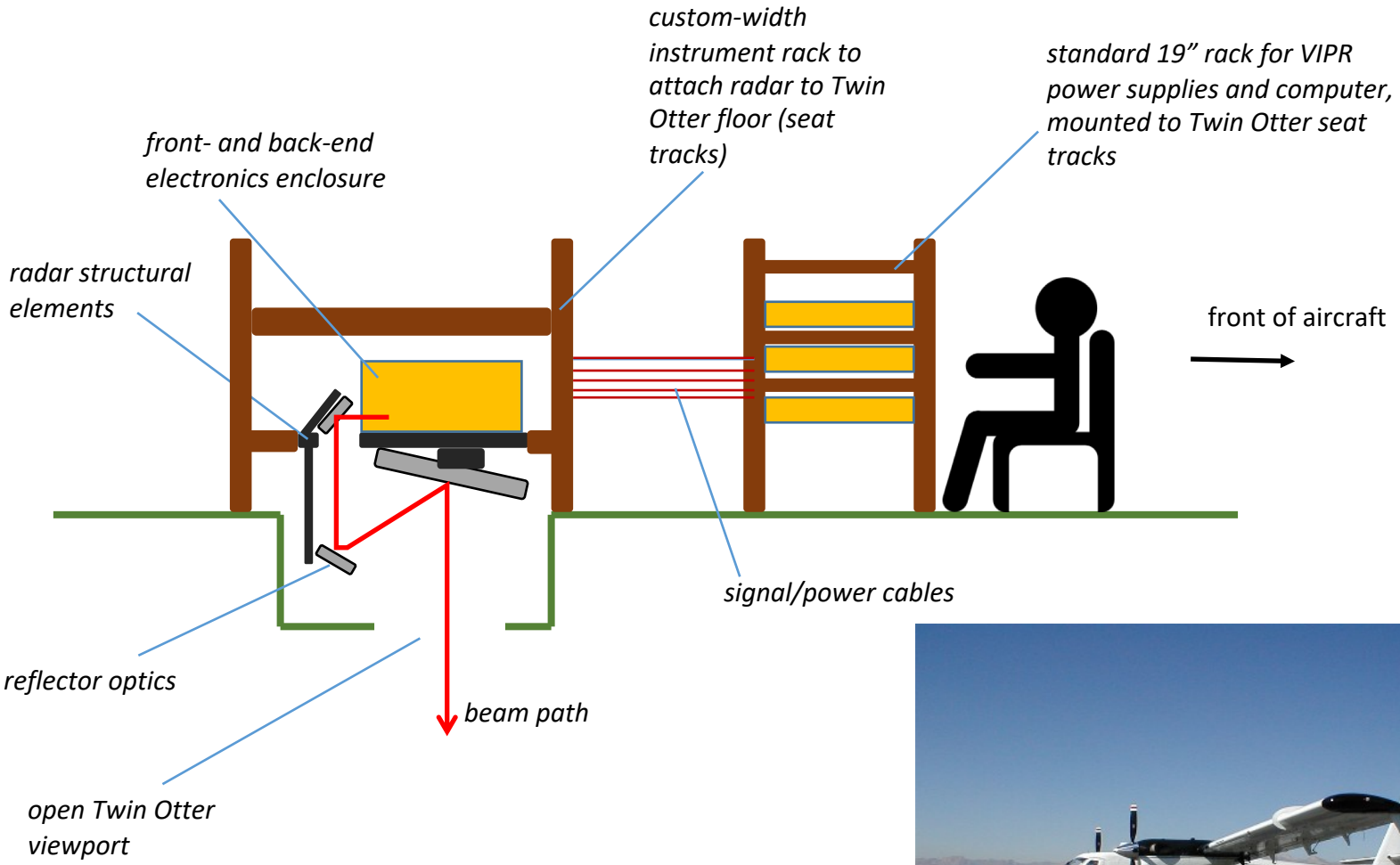
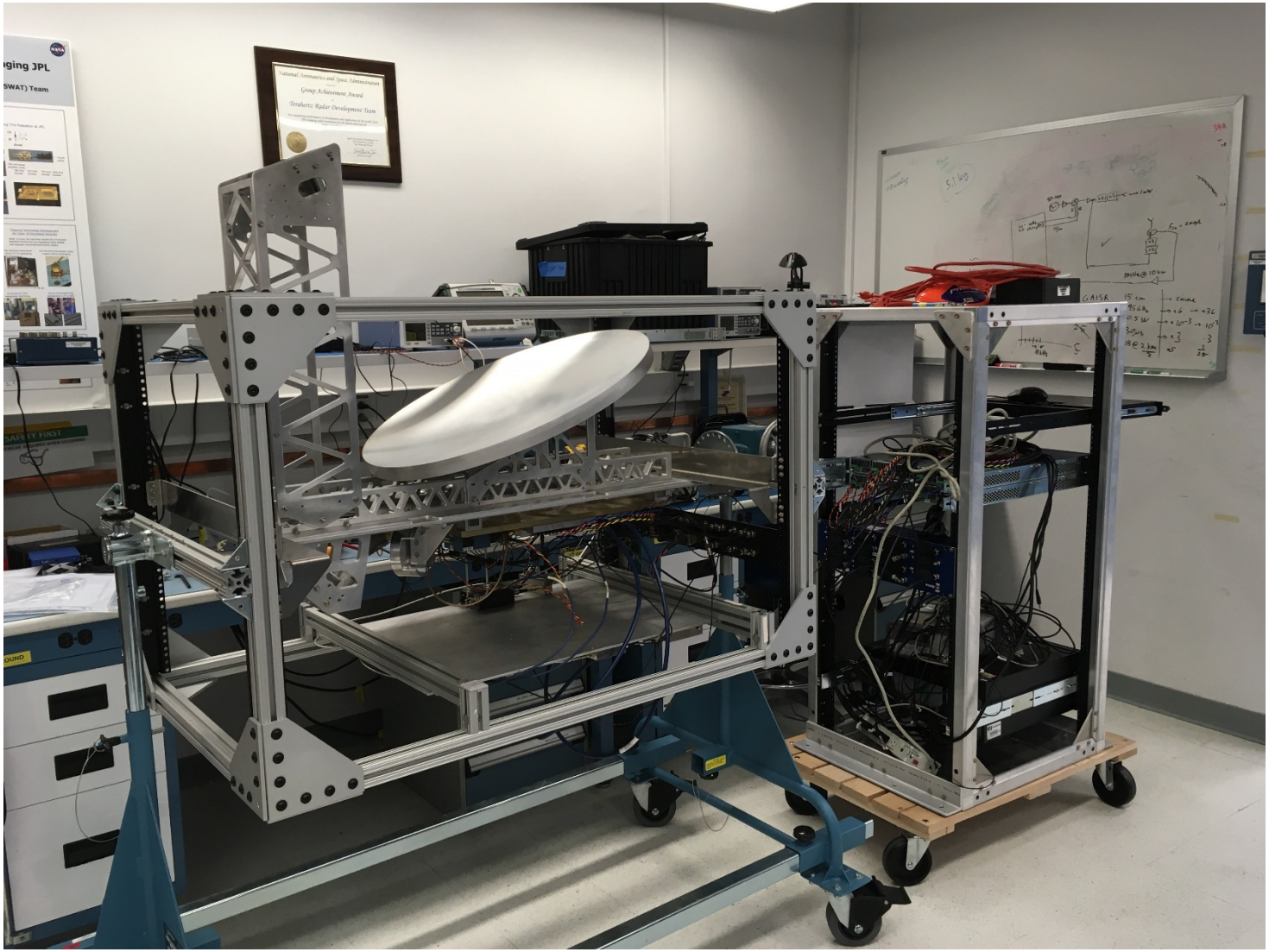
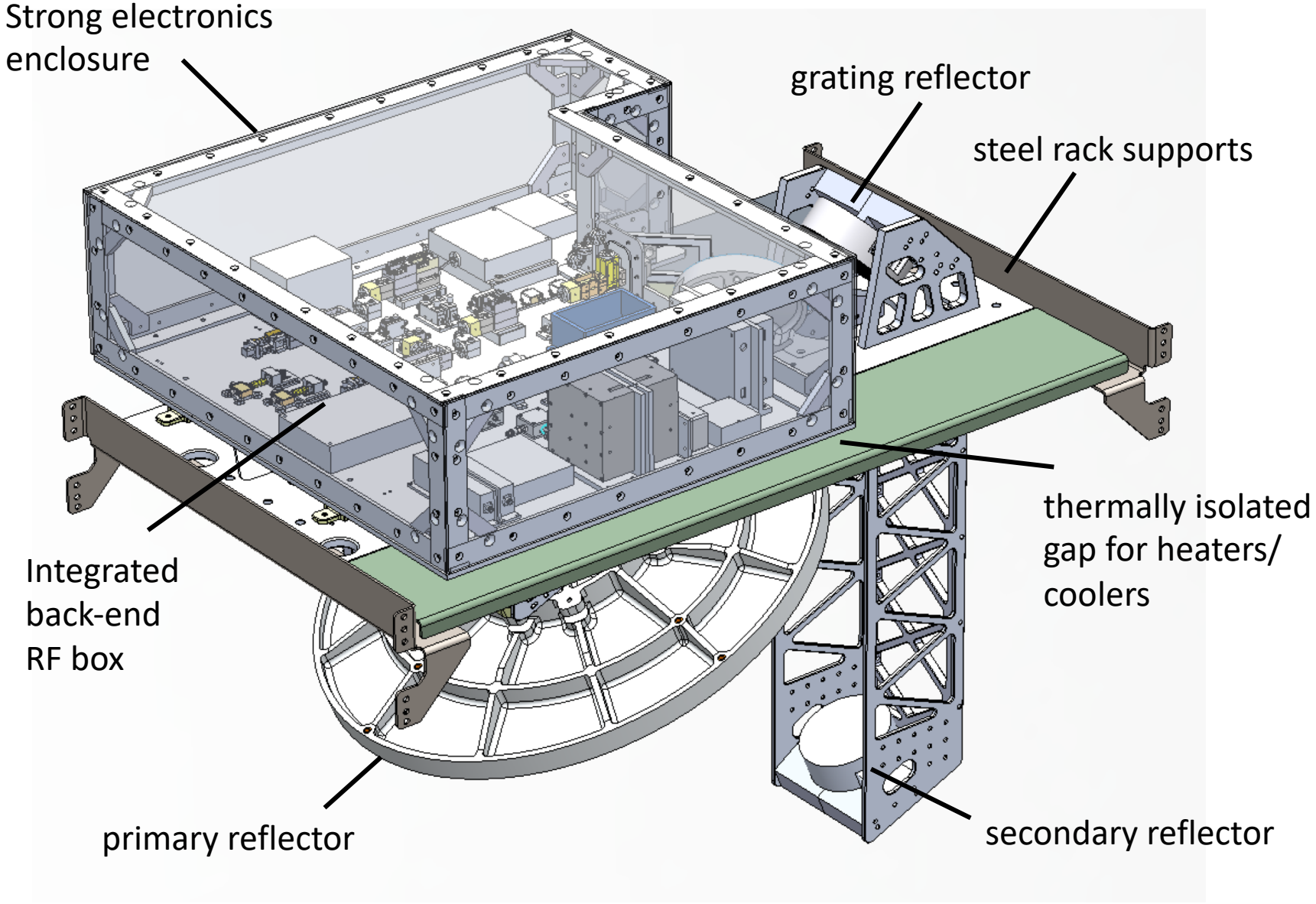


Photo of Current VIPR Hardware



Airborne VIPR Mechanical Design



VIPR Next Steps

- Airborne demonstration flights planned for October 2019 in the Pacific Northwest -> TRL-6.

- Moving forward there will be a real need to fly VIPR with a suite of other PBL sounders (e.g. DIAL) and dropsondes to characterize the relative strengths and weaknesses of each measurement approach.

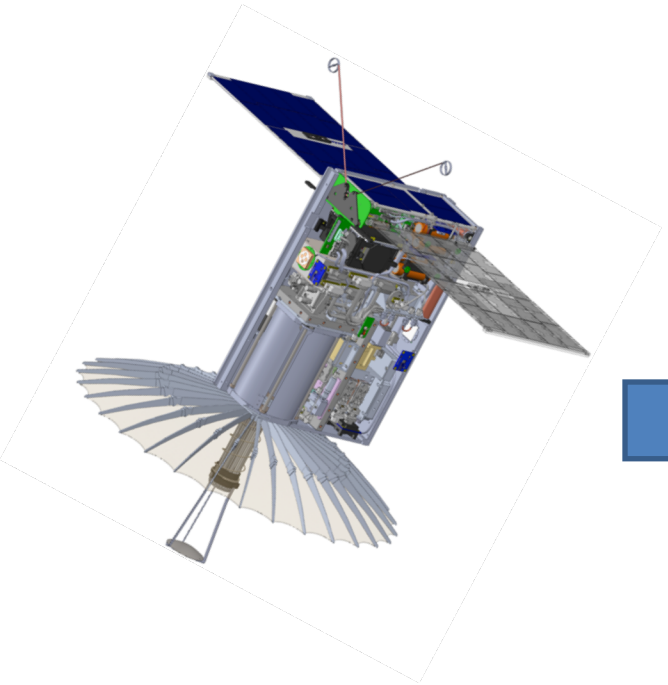
Publications:

Roy, R. J., Lebsock, M., Millán, L., Dengler, R., Rodriguez Monje, R., Siles, J. V., and Cooper, K. B.: Boundary-layer water vapor profiling using differential absorption radar, Atmos. Meas. Tech., 11, 6511-6523.

Roy, R. et al. Validation of a G-band differential absorption cloud radar for humidity remote sensing, *in preparation.*

Other Projects

RainCube



CloudCube

- Low-cost compact multi-frequency radar
- Precipitation and cloud profiling
- Ka- , W- and G- band radar channels.
- Compatible with SmallSat platform