Jet Propulsion Laboratory
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Status of the Vapor In-cloud Profiling Radar (*VIPR*)

A New Method to Remotely Sense Water Vapor Within Clouds

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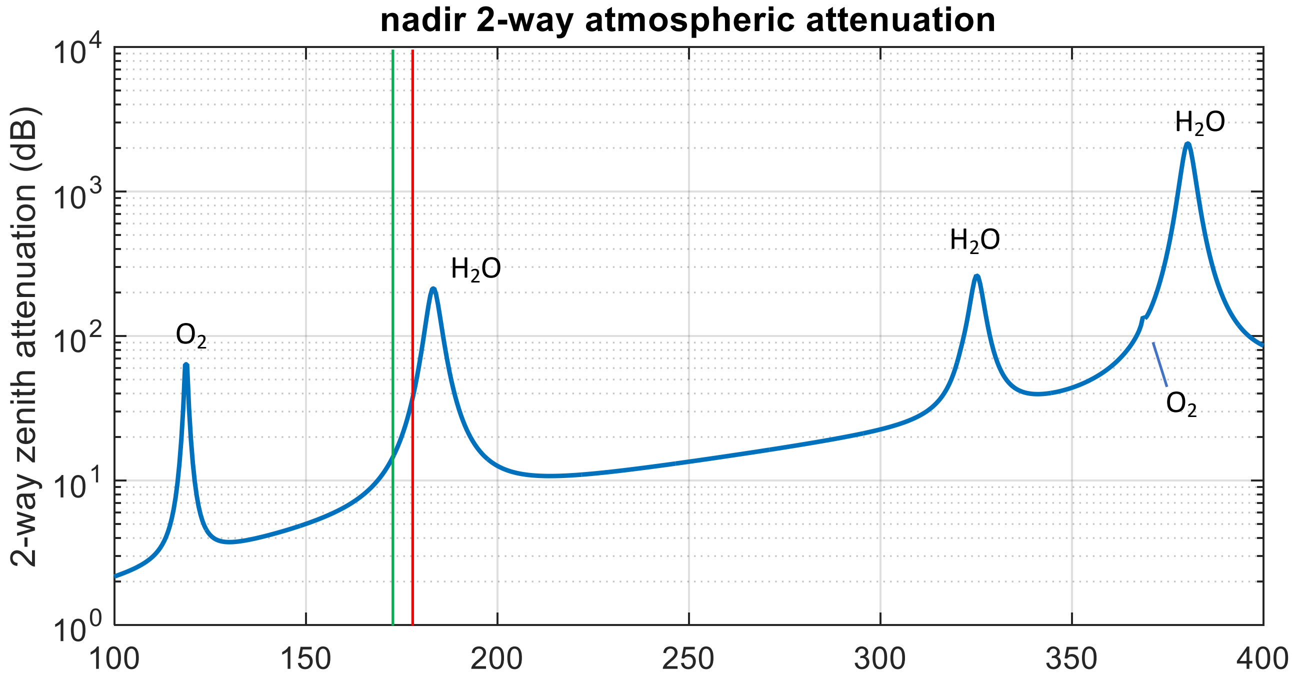
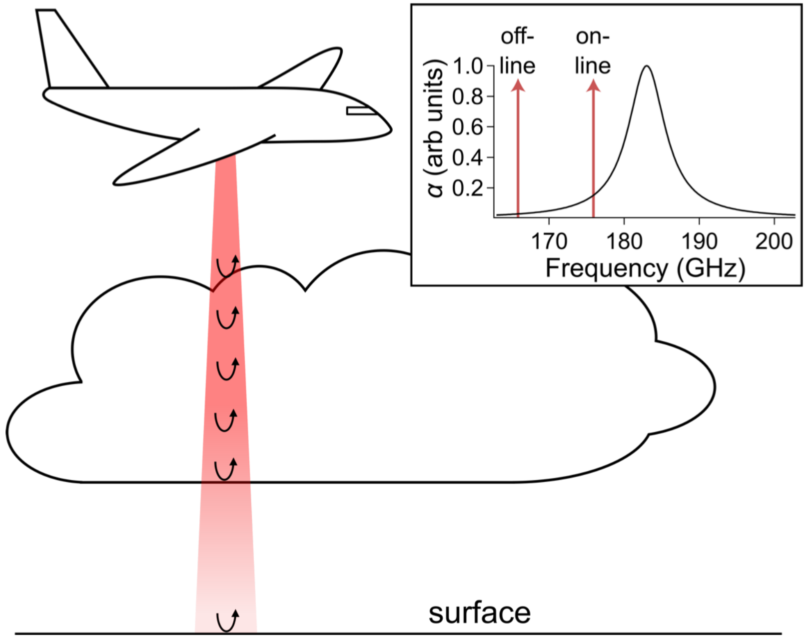
What is it?

- (VIPR) Vapor In-cloud Profiling Radar
- (DAR) Differential Absorption Radar
  - Microwave analogue of DIAL
- A concept to profile water vapor within the cloudy atmosphere.
  - Complements existing water vapor observations
- CWV measurements :
  - High spatial resolution
  - All surface types
  - Most storm conditions

Measurement Principle?





- Differential reflectivity from cloud/rain/surface is proportional to the gas density

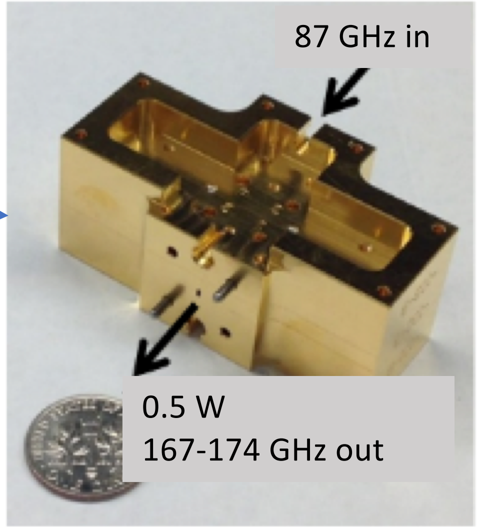
$$\Delta Z \equiv dBZ(\nu_1, r) - dBZ(\nu_2, r) \propto u_{gas} = \int_0^r \rho_{gas} dr$$

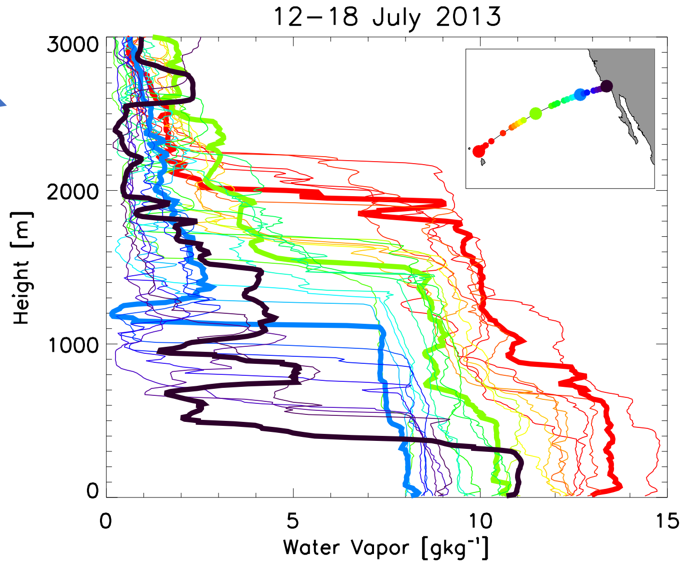
- *Key Assumption*: Unattenuated reflectivity is spectrally invariant

- <u>Radar:</u> provides range resolution / differential technique is self-calibration

VIPR (Vapor In-cloud Profiling Radar)

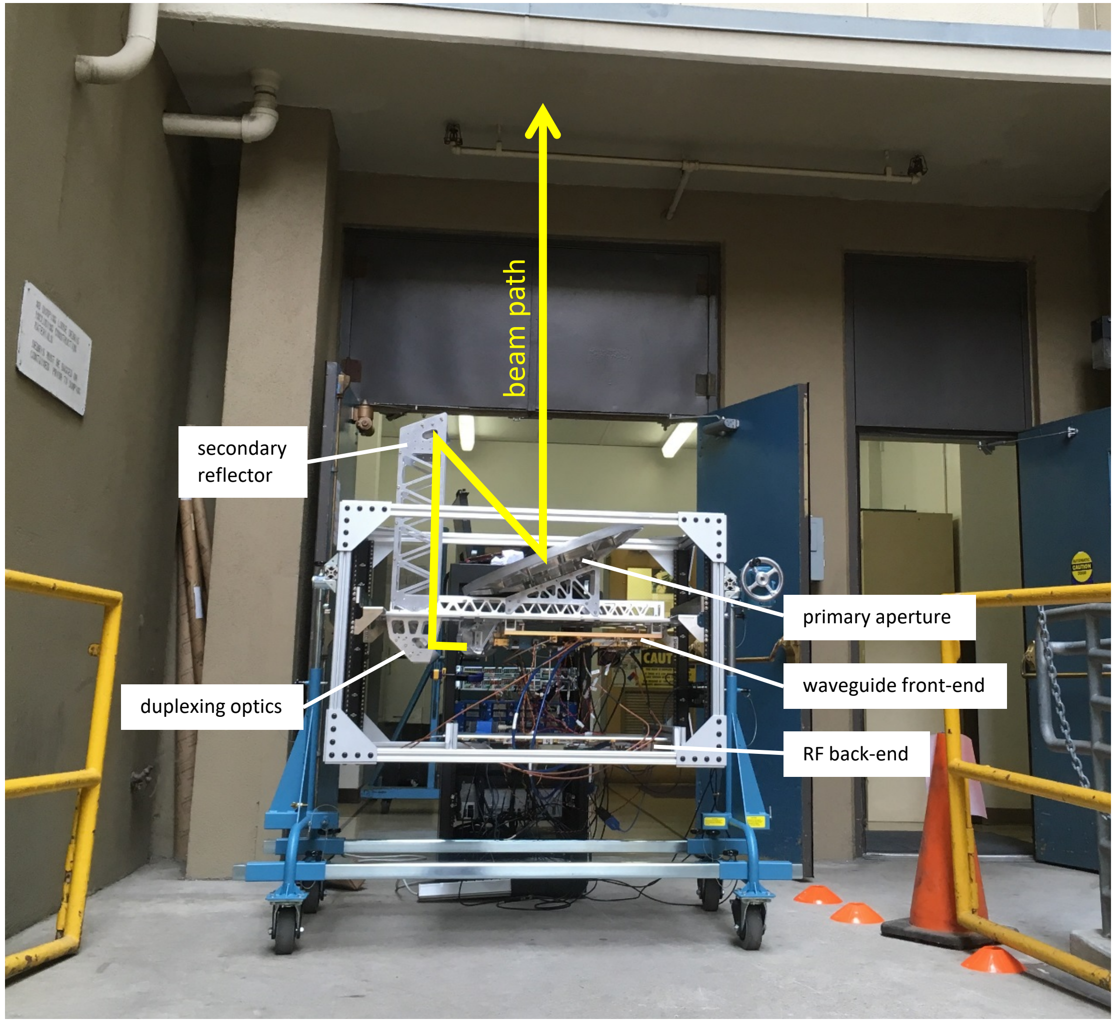
- Currently funded by NASA Instrument Incubator Program
- Entry TRL = 3, Exit TRL = 6 (*2020*)
- 0.5 W Solid-state FMCW DAR
- 60 cm primary antenna
- Tunable Bandwidth [167.1-174.7] GHz
- Uncertainty (20%), Sensitivity (-30 dBZ)
- Target boundary layer clouds and column vapor
- Simultaneous cloud/vapor sounding
- Demonstration flights on Twin Otter in 2019

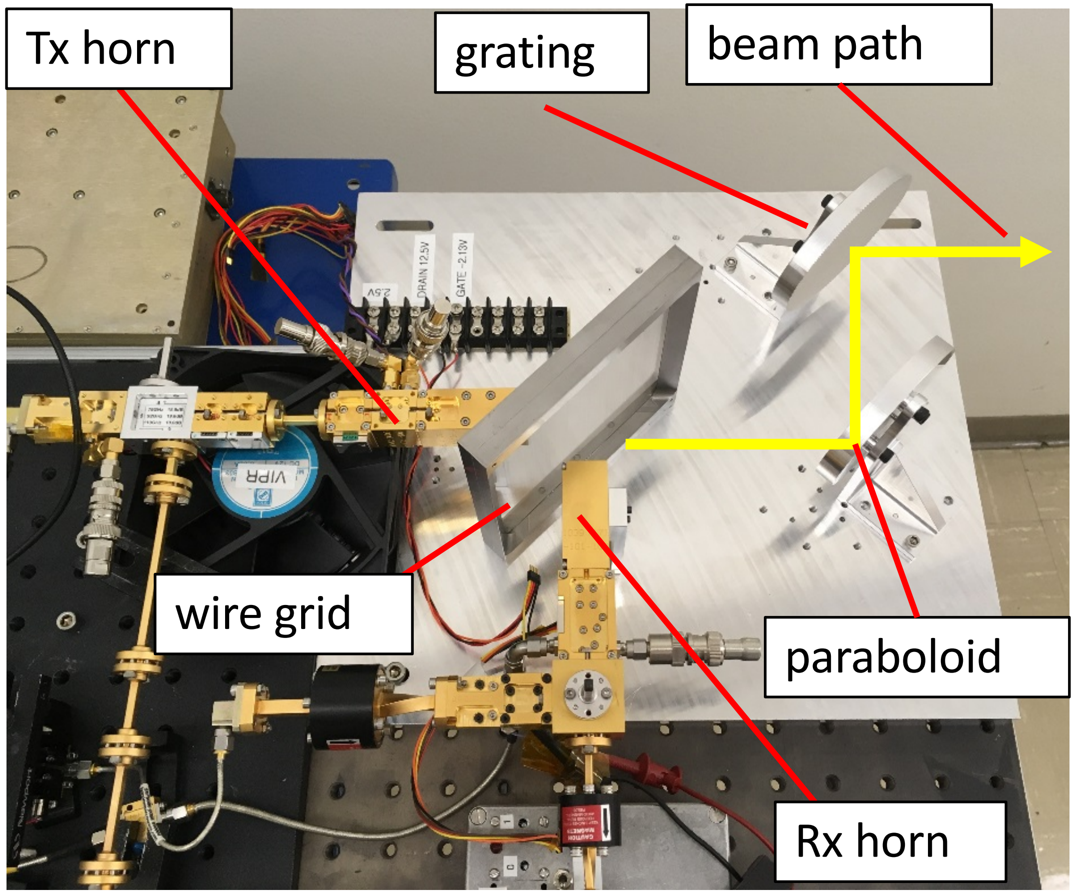




Airborne VIPR Development

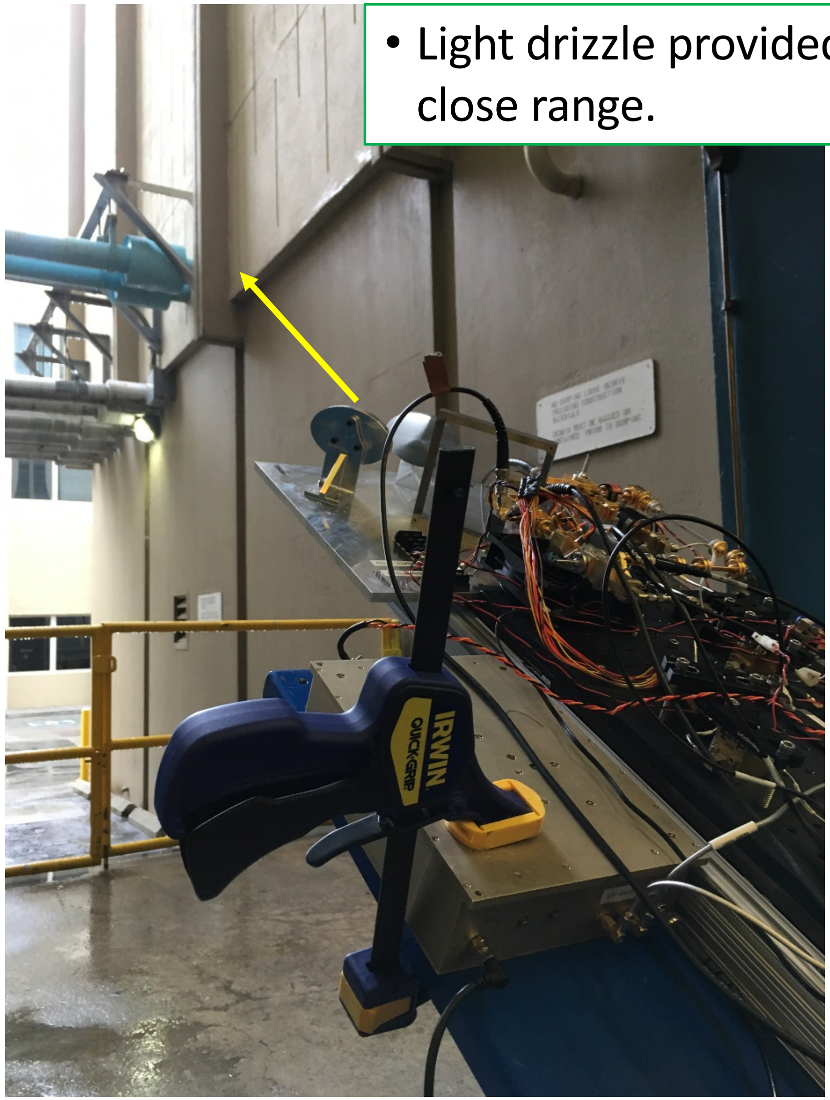
The VIPR system is mounted on Flotron rotation stage with the beam pointing upward. It uses a 60 cm diameter (58 dB gain) aperture.

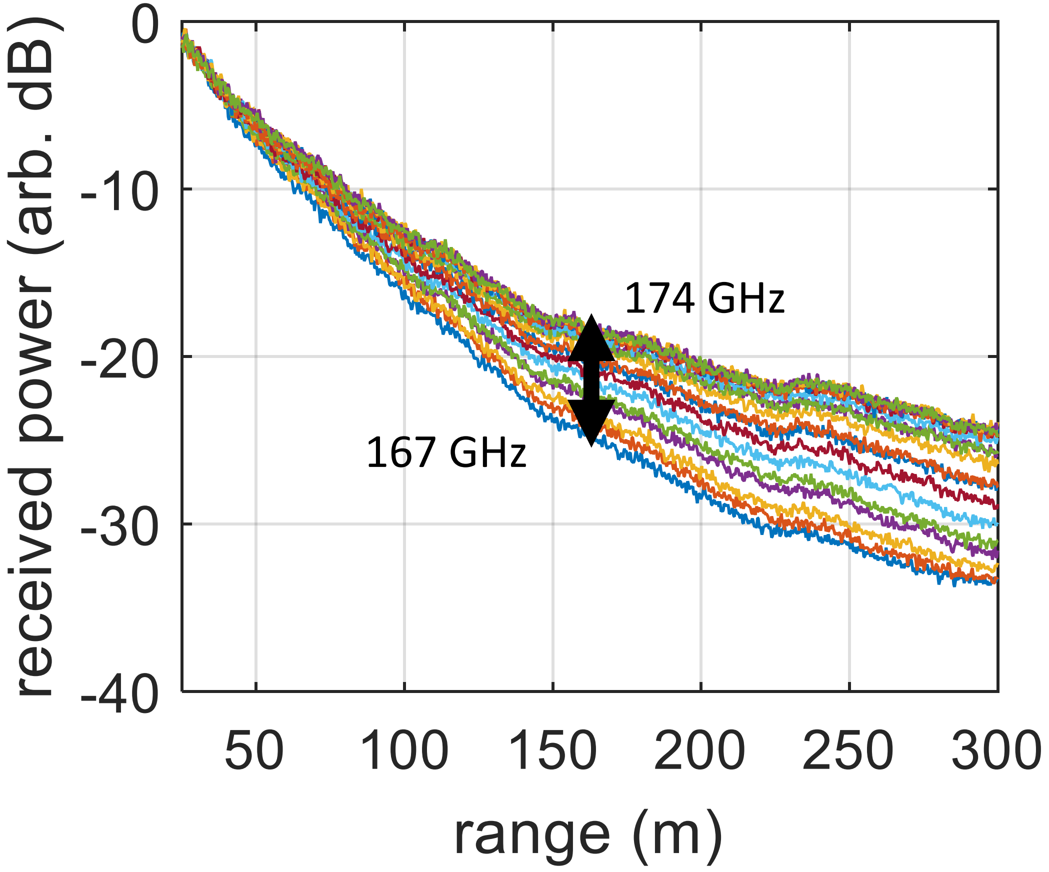




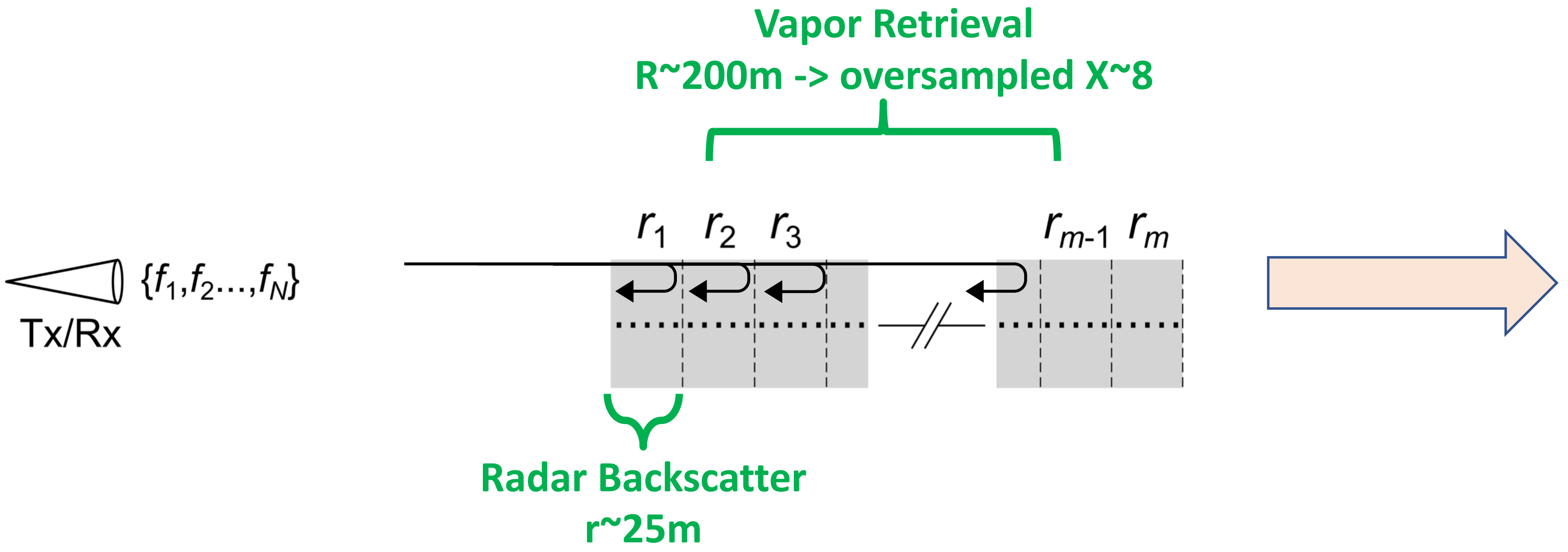
VIPR Preliminary Observations

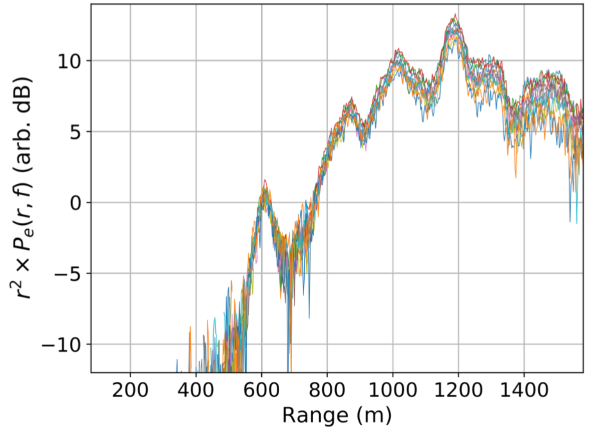
- Light drizzle provided bright target at close range.



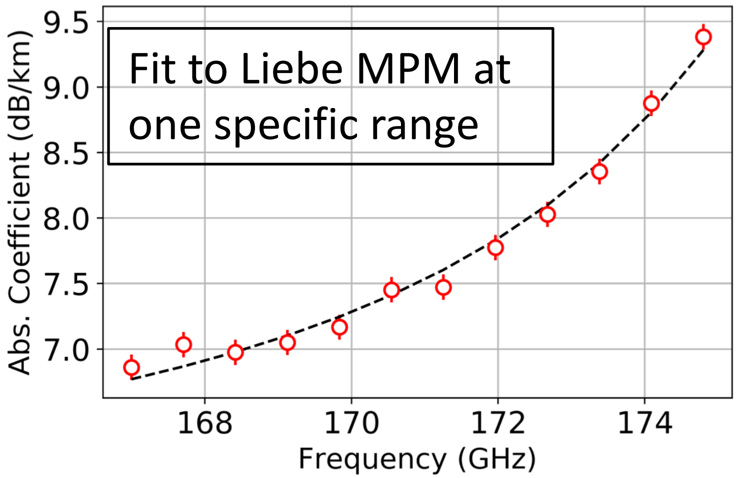


Range-resolved water vapor profile retrieval



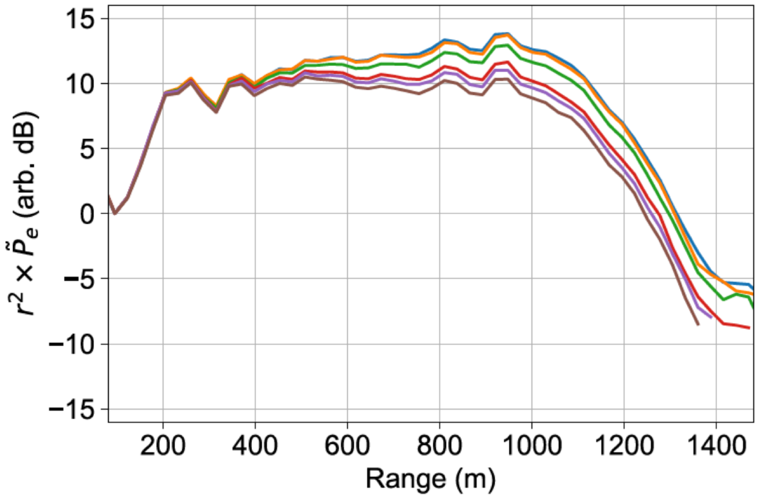


- Measurement quantity is differential attenuation per unit distance (a double difference)
  - Difference in range
  - Difference in frequency
- All instrument and range dependent terms cancel! *Self calibrating technique*

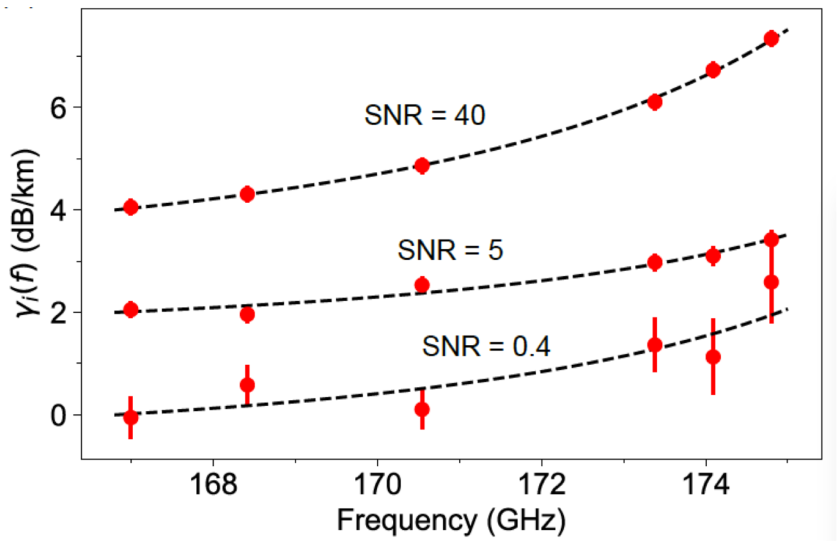


Observations and Retrievals

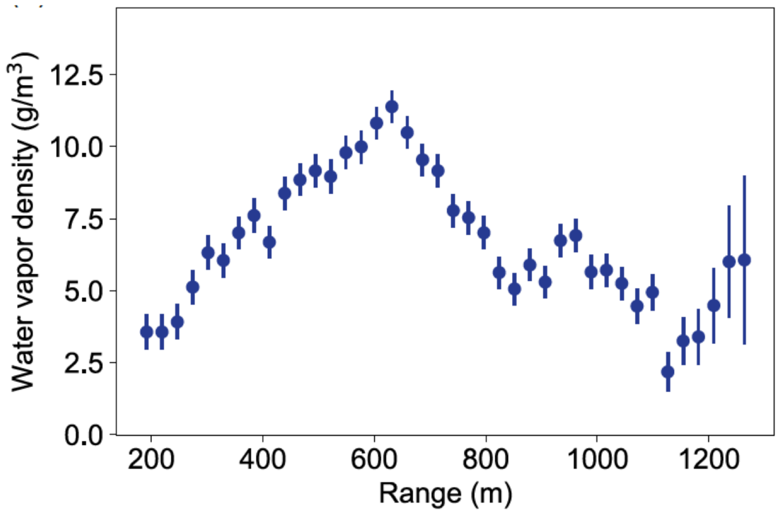
Observations



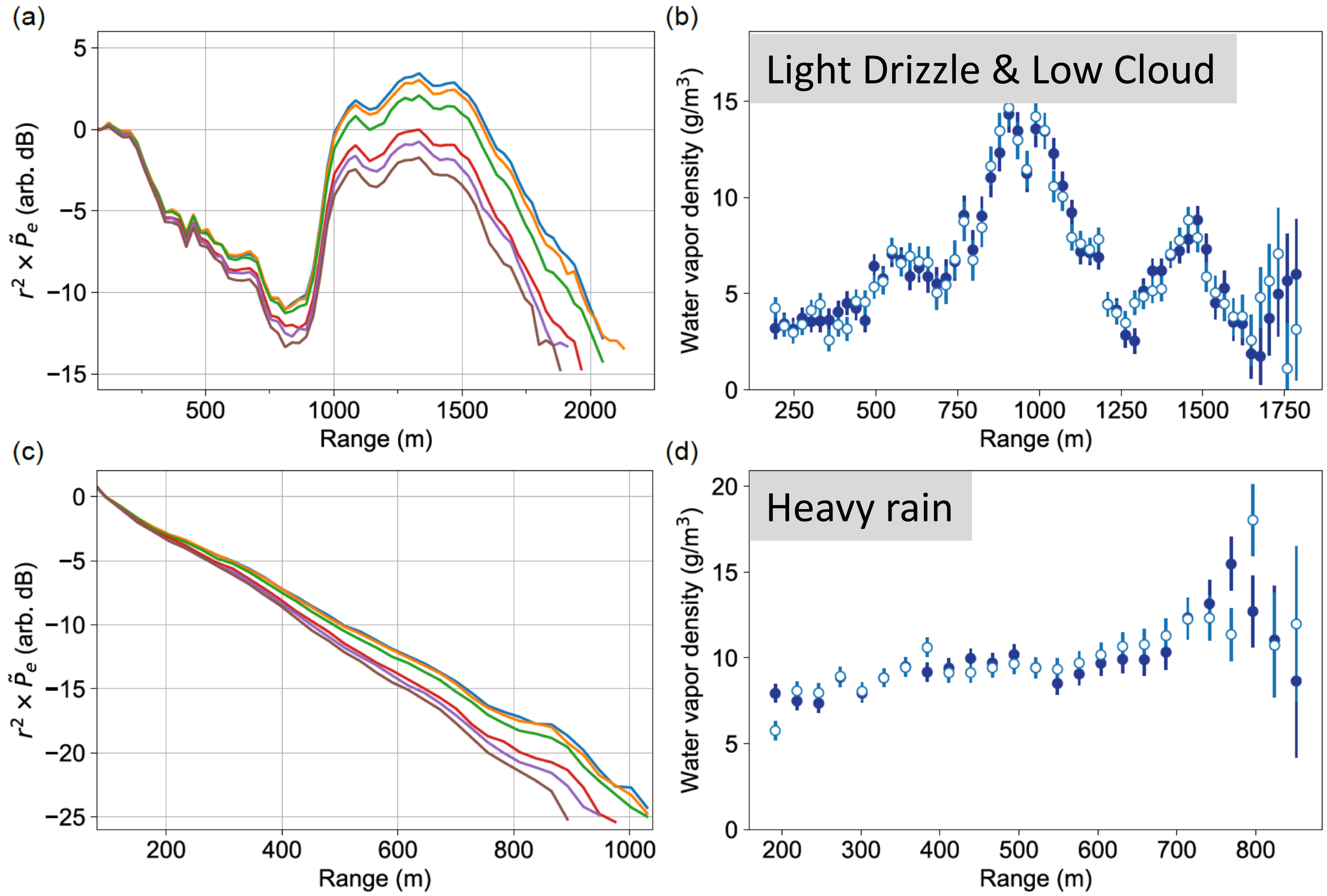
Fits at three different ranges



Derived Profile



More Humidity Retrievals



Upcoming VIPR Activities

- Dec, 2018
  - Validation: Ground-based deployment to SCRIPPS
- Mar, 2019
  - Validation: Ground-based deployment to the ARM-SGP site
- Summer-fall 2019
  - Airborne demonstration, location TBD

Space….

- Airborne VIPR will exceed error and resolution requirements set forth in the decadal survey -> from an airplane. ✈️ 📡
  - Near term need to demonstrate VIPR on a common platform with other thermodynamic sounders (DIAL, passive IR/microwave) and dropsondes.

- Is there a path to space? 🚀 🛰️
  1. Plausible but immature profiling concept.
  2. Within-reach: high-resolution column integral concept

How does DAR complement other satellite techniques?

Sounding	Potential Techniques	DAR Enables	DAR instrument characteristics
	IR Sounding	• In cloud sounding • High vertical resolution	Large transmit power (>100 W) • Large vacuum electronics solution requires technology development • Potentially large/heavy/expensive
	Microwave Sounding		
	Radio Occultation		
	Limb Sounding		
	Differential Absorption Lidar		

Column Integral	Potential Techniques	DAR Provides	DAR instrument characteristics
	Microwave imagery	• All surface types • All weather conditions • High resolution -> small scale variability • Improved precision	Low transmit power (~1 W) • Low mass/volume solid-state power source • compatible with small-sat
	Near-IR imagery		

2017 Decadal Survey

TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		X	X
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
Surface Topography & Vegetation	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar, or lidar**			X

** Could potentially be addressed by a multi-function lidar designed to address two or more of the Targeted Observables

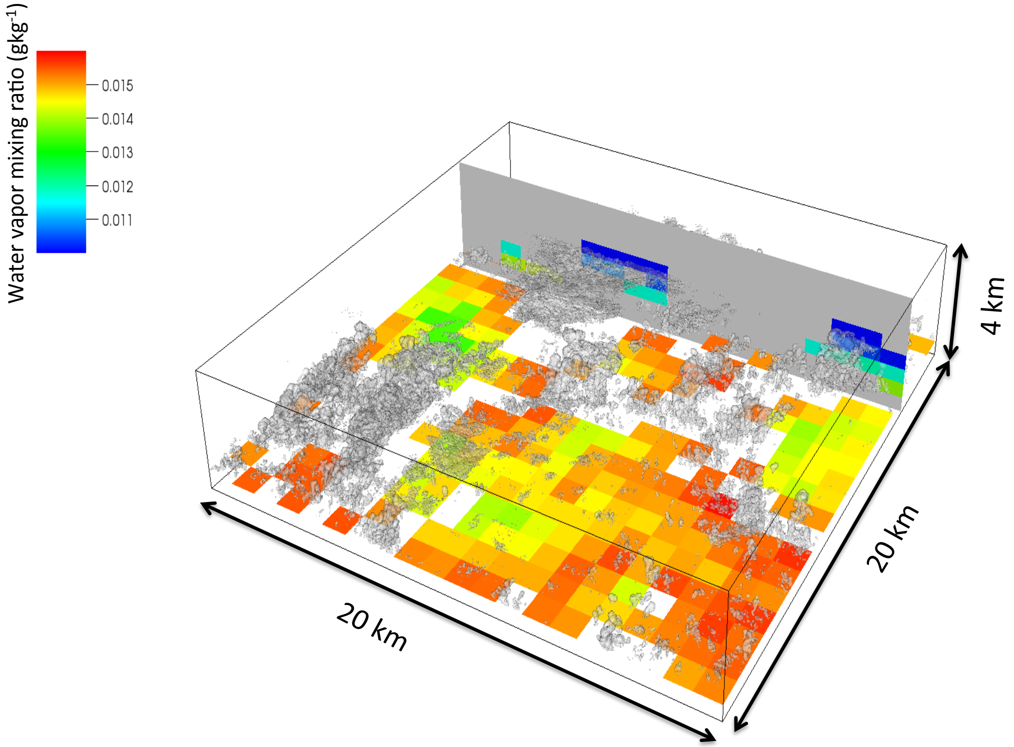
Other ESAS 2017 Targeted Observables, not Allocated to a Flight Program Element	
Aquatic Biogeochemistry	**Radiance Intercalibration**
Magnetic Field Changes	**Sea Surface Salinity**
Ocean Ecosystem Structure	**Soil Moisture**

1. 3D PBL structure requires technology investment. However relevant technical approaches do exist to generate sufficient power and bandwidth at G-Band.

2. What does 2D PBL structure mean? This is unclear in the decadal survey. My answer: small scale horizontal variability in T/q integrated quantities. DAR is well positioned to provide this.

2017 Decadal Survey: PBL White Paper

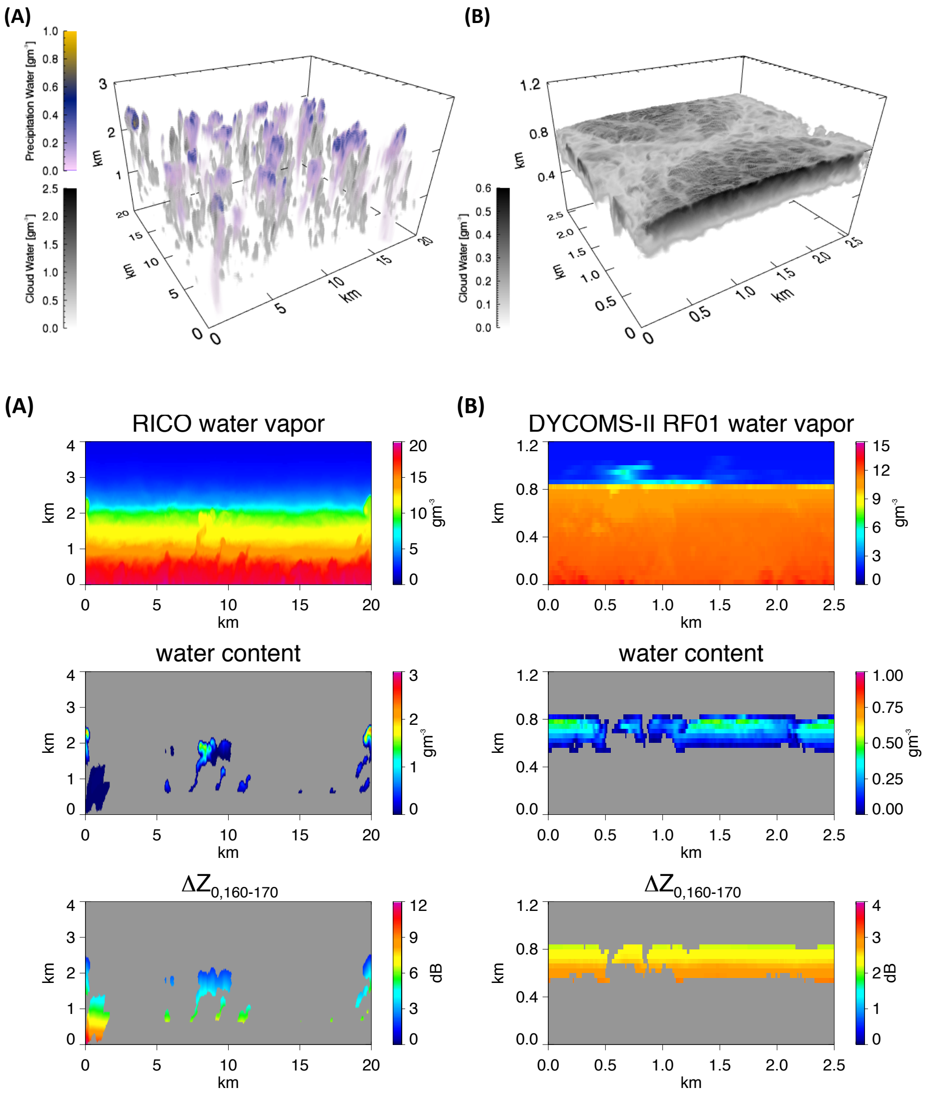
Atmospheric Boundary Layer Thermodynamic Structure: Blending Infrared and Radar Observations



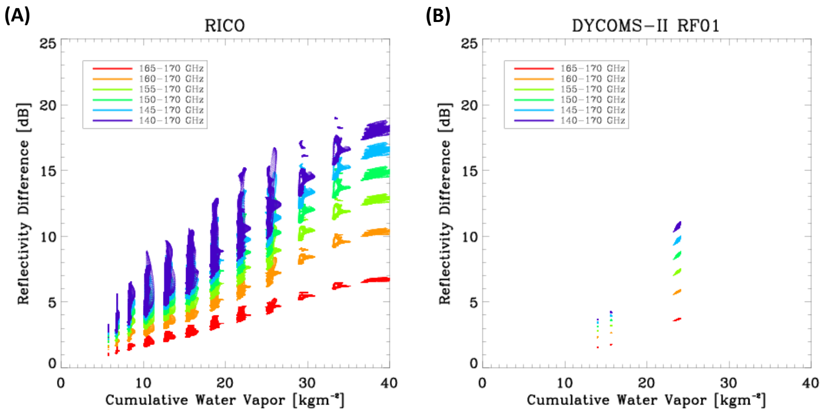
Results from an LES simulation of cumulus show the key characteristics:

- Differential absorption radar on LEO provides water vapor profiles within cloudy areas along a ‘curtain’ (grey in figure) with resolution on the order 2.0x2.0x0.5 km^3.
- IR sounder provides the 3D context of temperature and water vapor structure by sampling the adjacent clear sky regions with resolution of order 1x1 km^2.

Spaceborne Path 1: Profiling



- High-fidelity numerical cloud models allow explorations of:
  - Non uniform beam filling
  - Natural variation in water drop size distributions



- Assume -30 dBZ sensitivity / 1 km footprint
  - Precision better than 4 gm^{-3} @ 500 m resolution (**25%**).
  - Optimal channels: **165/175 GHz**.
  - Sample **40-50%** of cloudy range bins.

Spaceborne Path 2: Column Water Vapor

Measurement Objective:
- High resolution horizontal variability in CWV
- Most CWV variability relates to PBL variability

Spaceborne DAR would enable:
- All surfaces and cloud conditions at high resolution
- Compatible with a cubesat platform -> low mass/power/volume
- Relevant to PBL mission area in combination with passive sounders or lidar system

Simulation: Instrument High-level Parameters
- Antenna diameter 1m
- Horizontal resolution 500m
- Satellite altitude 405km
- Transmit Power 1W