A 170 GHz Airborne Radar for Humidity and Cloud Remote Sensing

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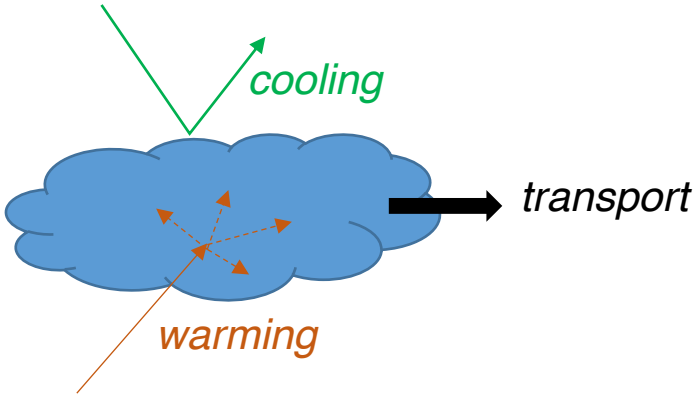
Humidity Profiling: a Gap in Atmospheric Observations

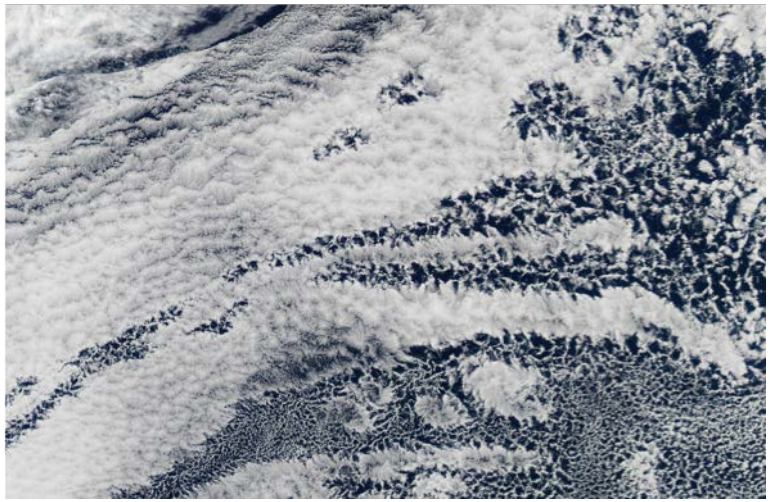
Scientific Motivation

Clouds and precipitation are the *largest source of uncertainty* in weather and climate simulations

- Clouds reflect sunlight into space (cooling) but also trap infrared from surface (warming)
- These effects can partially offset, or amplify, CO2-induced warming
- Clouds also transport and release latent heat
- Humidity is major ingredient of cloud growth and radiative properties



Marine stratocumulus

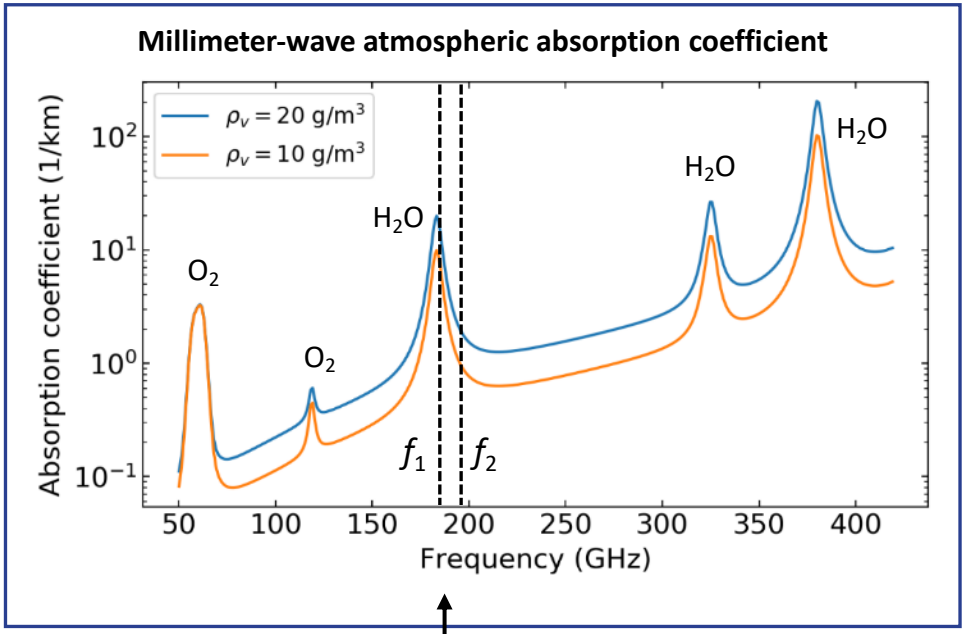


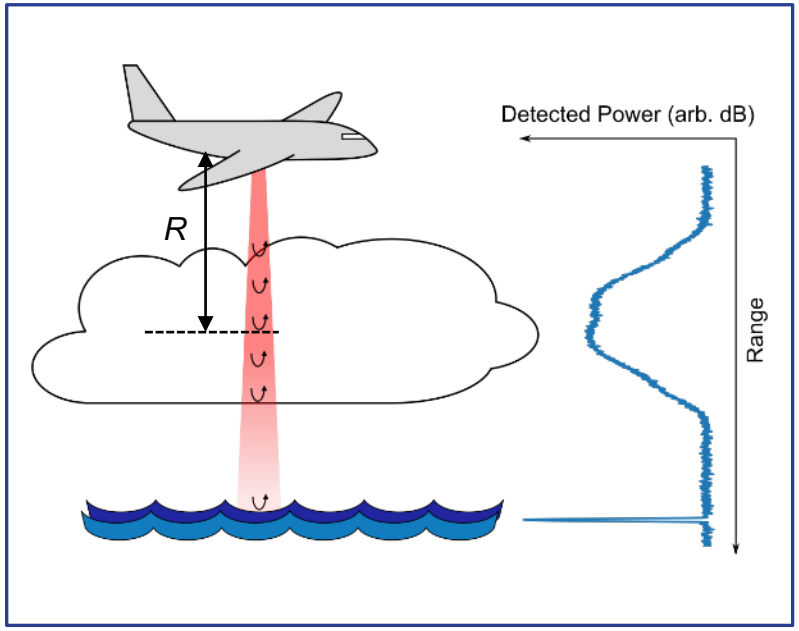
earthobservatory.nasa.gov

Problem recognized by 2017 NASA Decadal Survey and the 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**."

High Frequency Differential Absorption Radar (DAR)

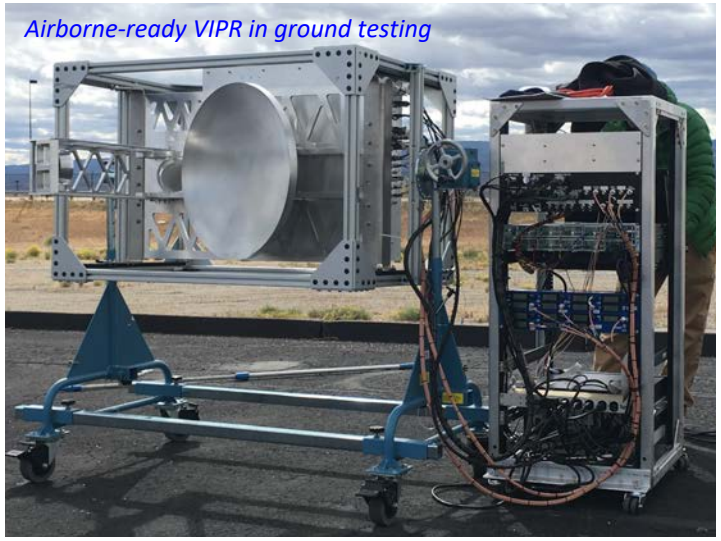




- The (old) concept of <u>Differential Absorption Radar</u> can measure water vapor *inside clouds*!
- 183 GHz band: prominent water line, relatively accessible frequency, and sensitive to cloud particle scattering
- This will improve understanding of cloud thermodynamics, water cycle, weather forecasting, climate models, & cloud microphysics.

Can we use submm-wave radar techniques to build a 183 GHz DAR?

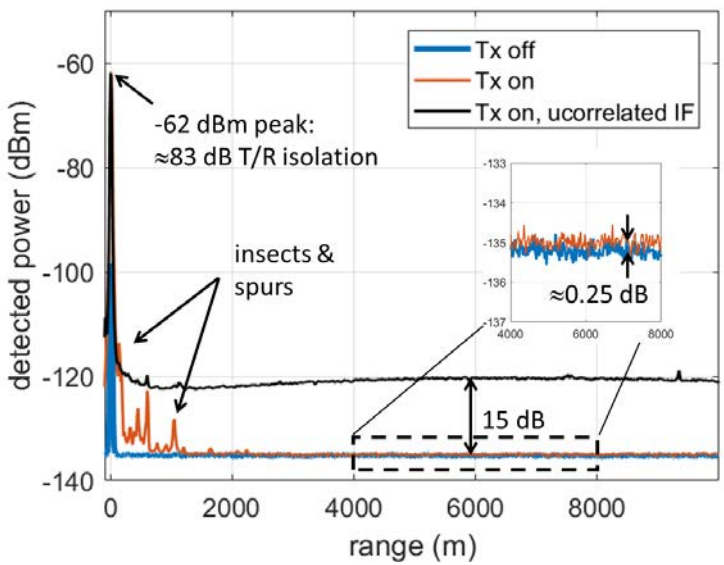
VIPR Instrumentation

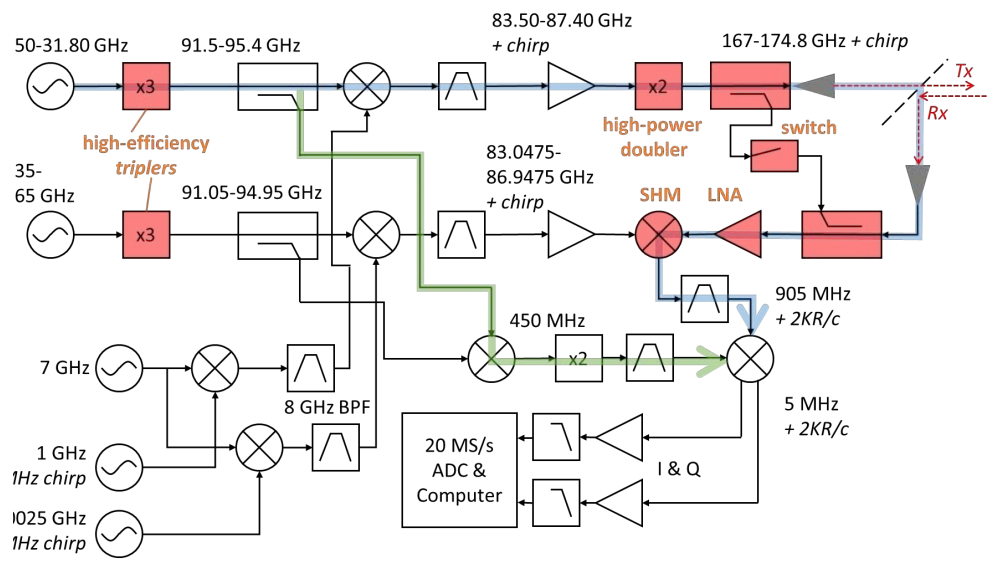


VIPR Radar Parameter	Value
Radar frequency	167-174.8 GHz
Transmit power	~300 mW
Antenna gain	58 dB
Noise figure	~8 dB
Range resolution	15 m
Detection noise bandwidth	1 kHz
Single-chirp dBZ_{min} at 1 km range	appx. -43 dBZ

"A G-band Radar for Humidity and Cloud Remote Sensing", Cooper et al., *IEEE Transactions on Geoscience and Remote Sensing*, 2020

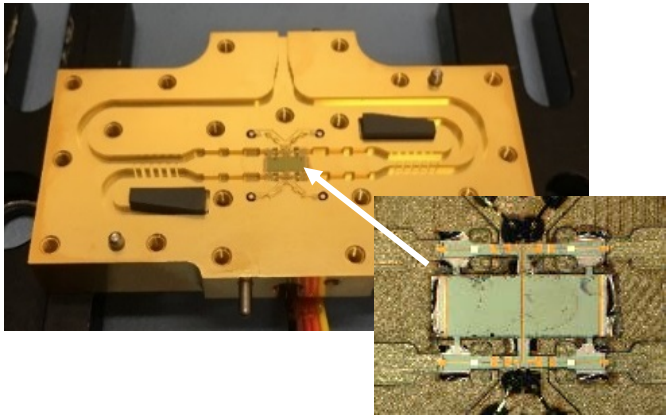
thermal noise limited sensitivity even with single antenna!



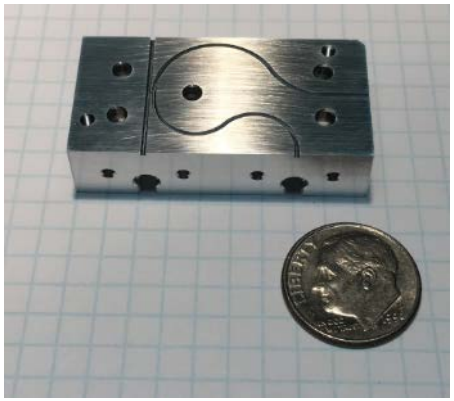


Enabling G-Band Technology Innovations

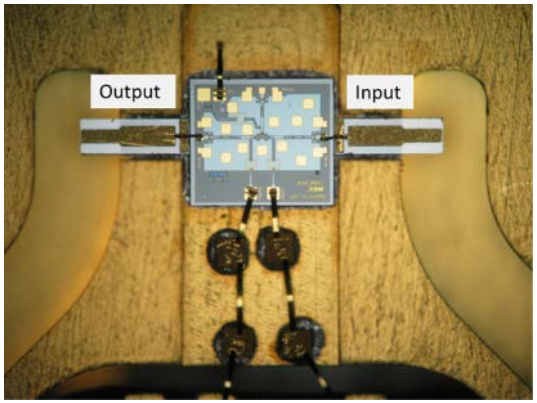
High-power Schottky diode frequency-doubler:



Low-loss 170 GHz coupler

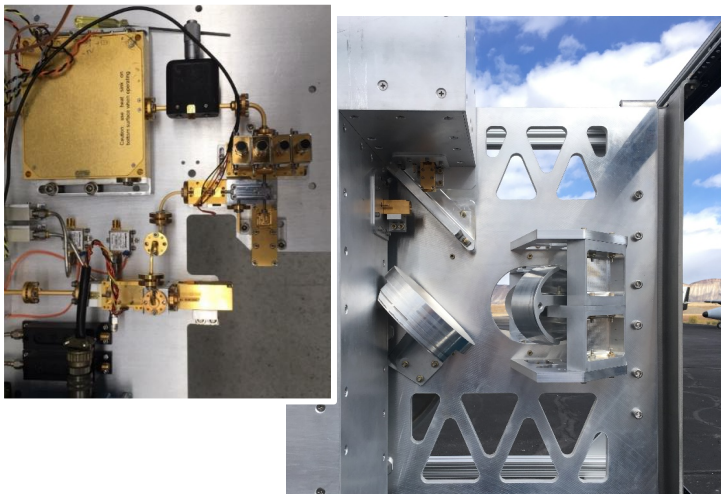


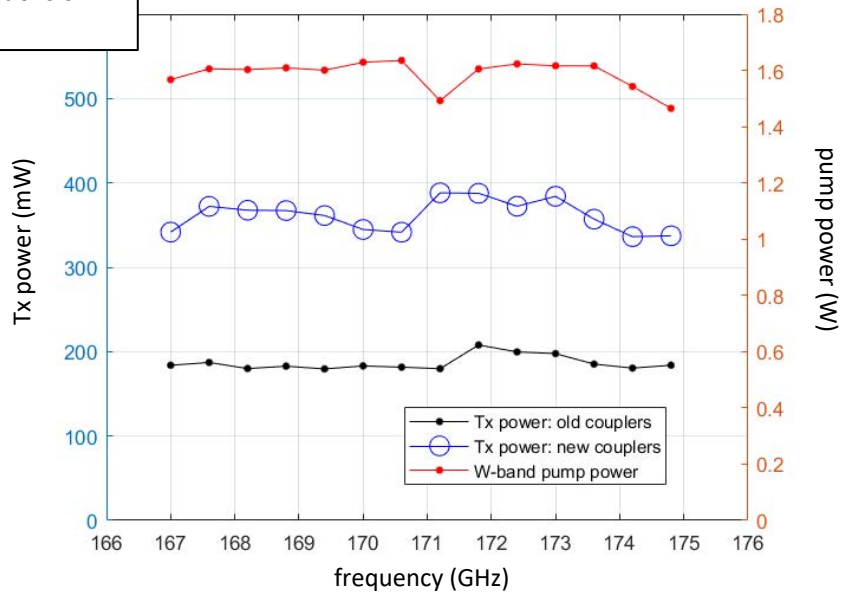
170 GHz RF switch



"A new generation of room-temperature frequency-multiplied sources with up to 10× higher output power in the 160-GHz–1.6-THz range," Siles et al., *IEEE Transactions on Terahertz Science and Technology*, 2018

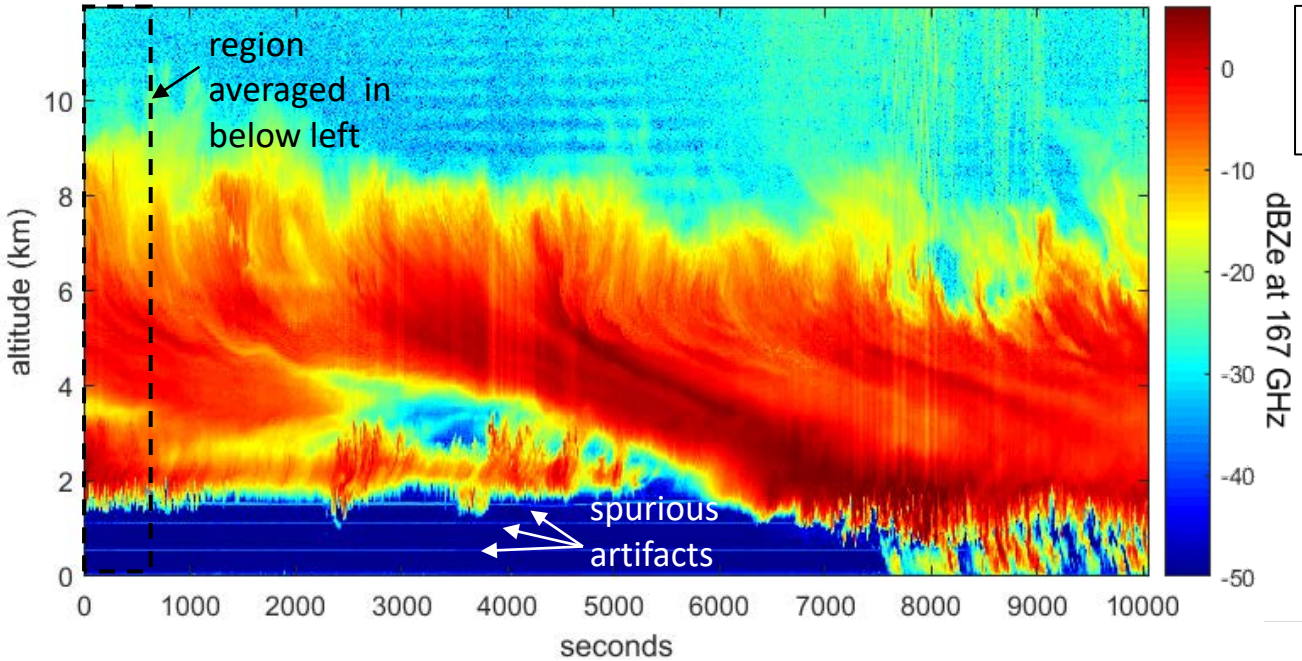
Transmit/receive quasi-optical duplexing:



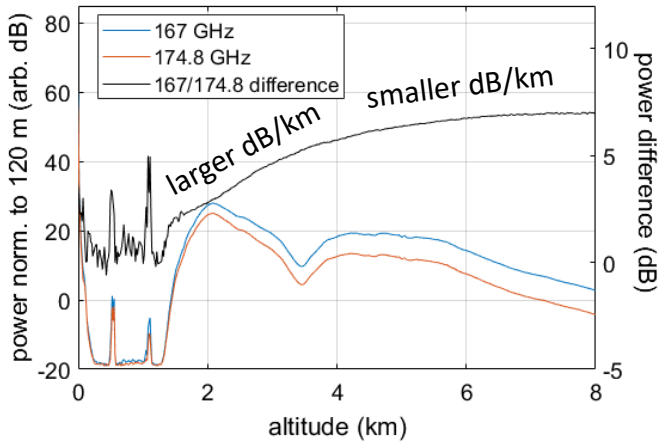


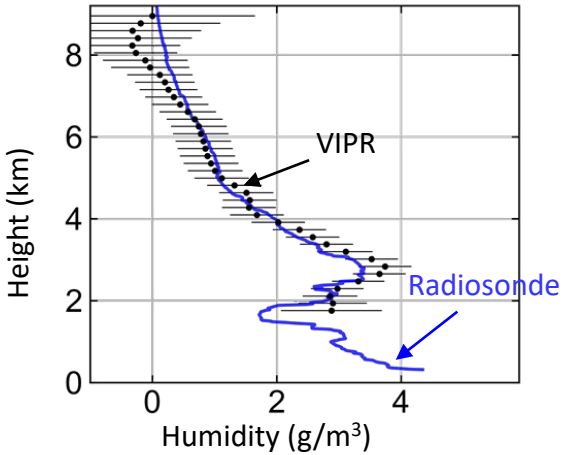
Ground Deployment at DOE ARM Site in Oklahoma

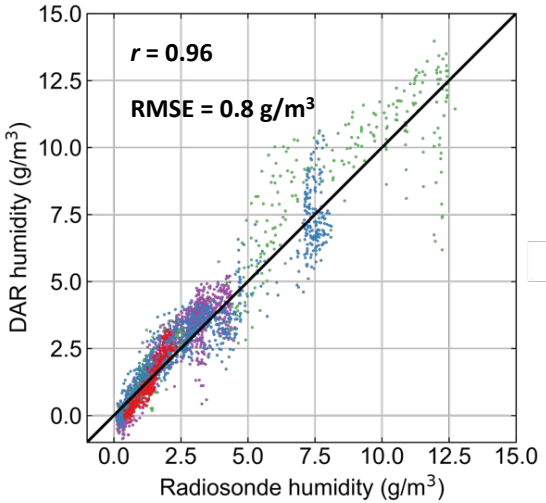
April 13, 2019



"Validation of a G-band differential absorption cloud radar for humidity remote sensing", Roy et al., *Journal of Atmospheric and Oceanic Technology*, 2020

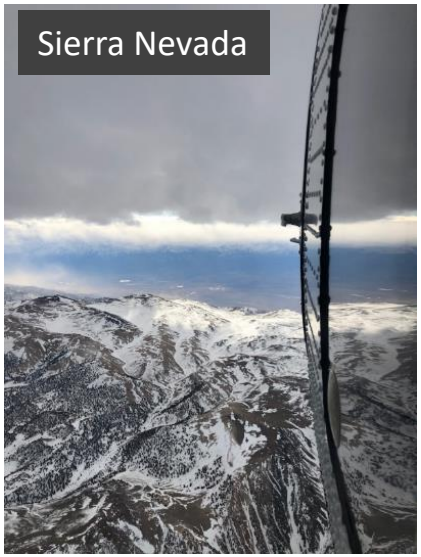


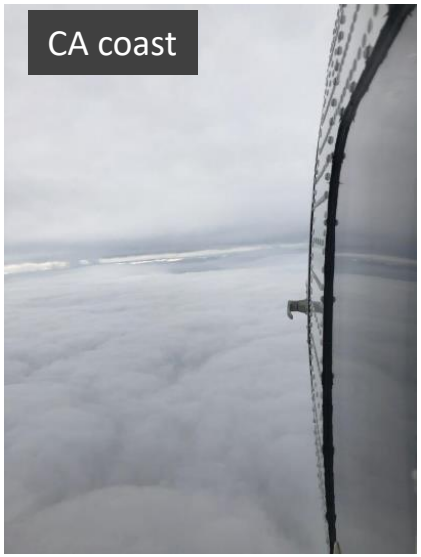




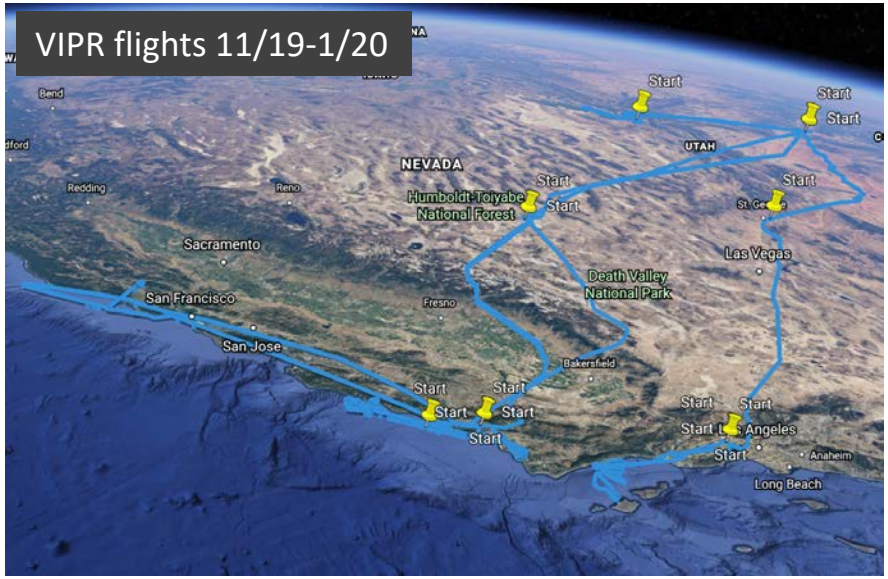
Winter 2019-2020 VIPR Airborne Testing


Beam clearance check


Sierra Nevada

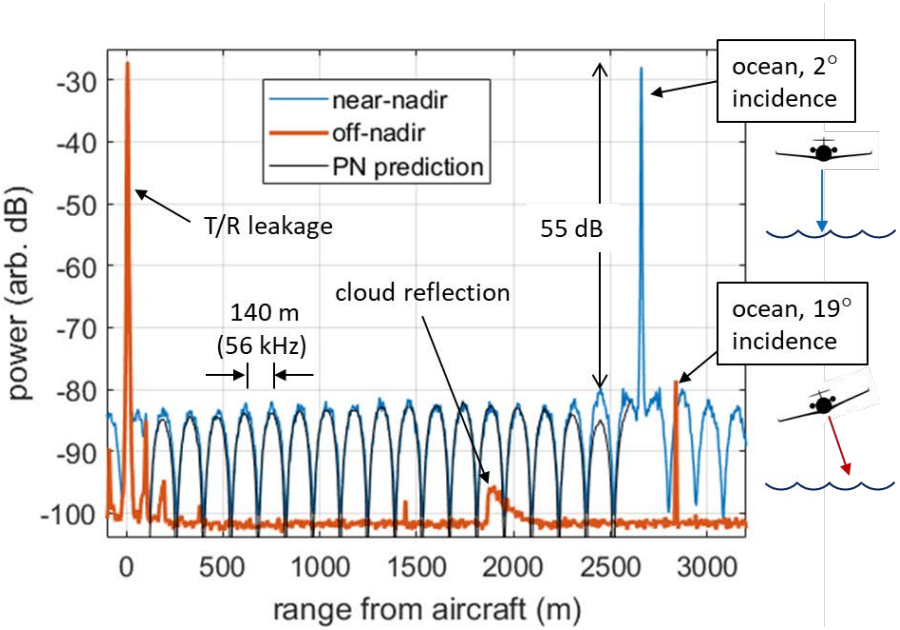

CA coast


VIPR operators

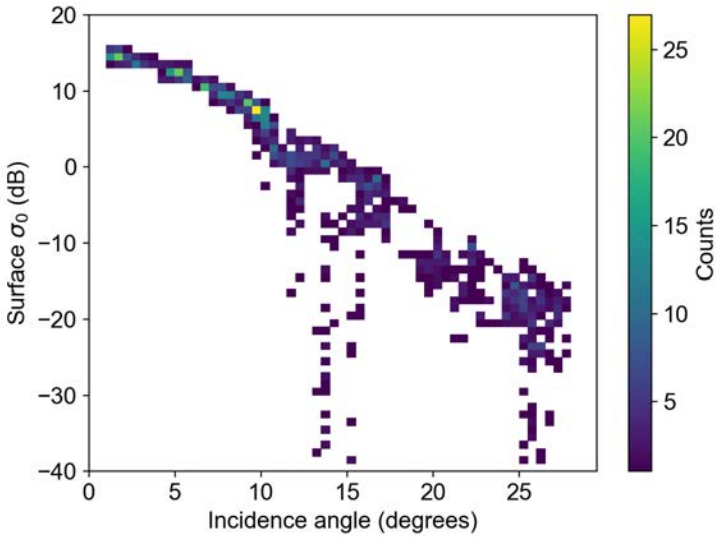


Phase Noise Range Side-lobes over Water in Clear Air

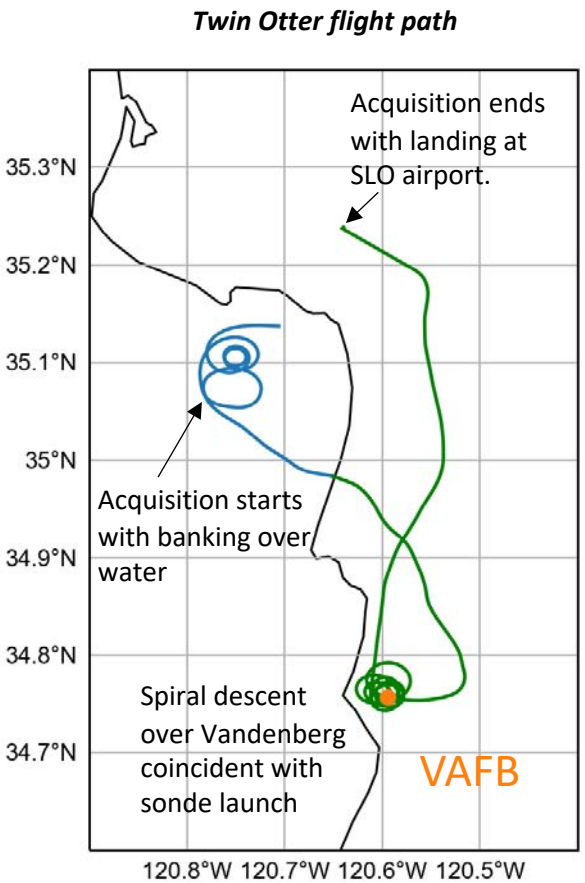
- We have a quantitative understanding of the origin of strong range side-lobes that originate from synthesizer phase noise.
- Effect is mitigated by off-normal incidence, as well as cloud/rain attenuation.

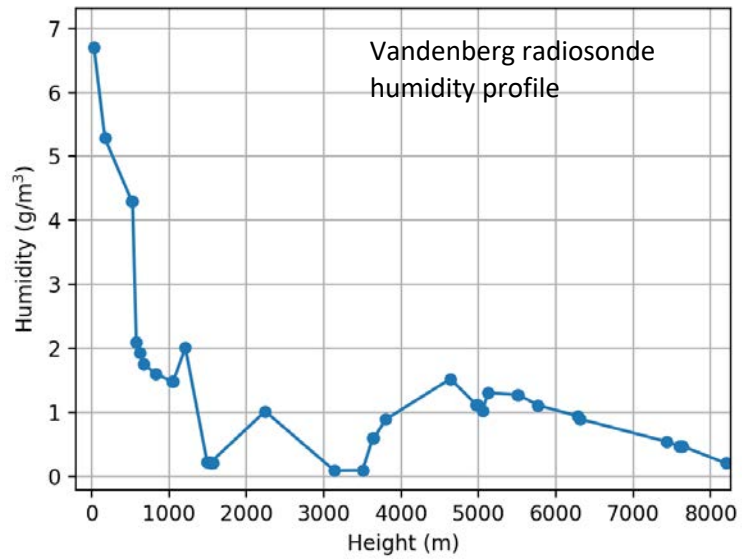


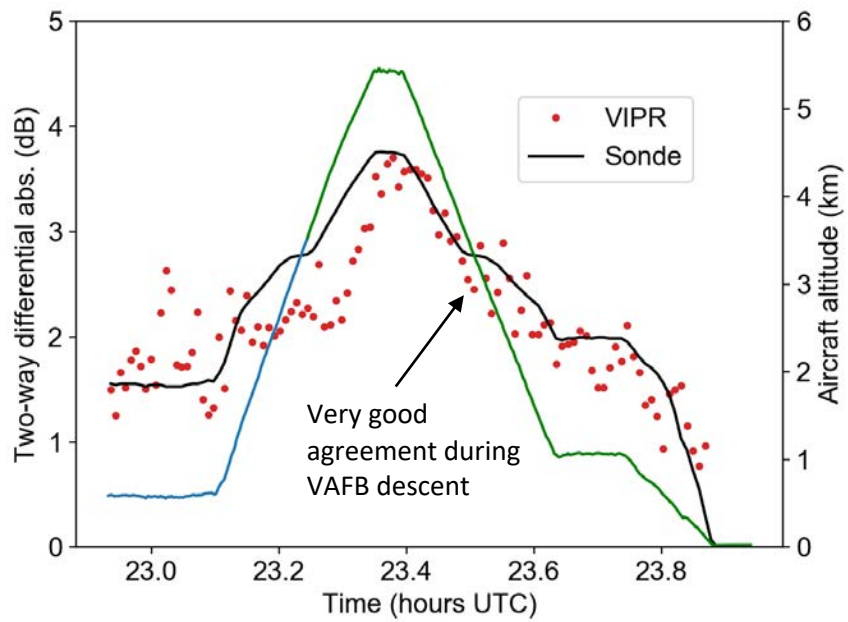
167 GHz over-ocean measurements:



Partial Water Column Measurements in Clear Air

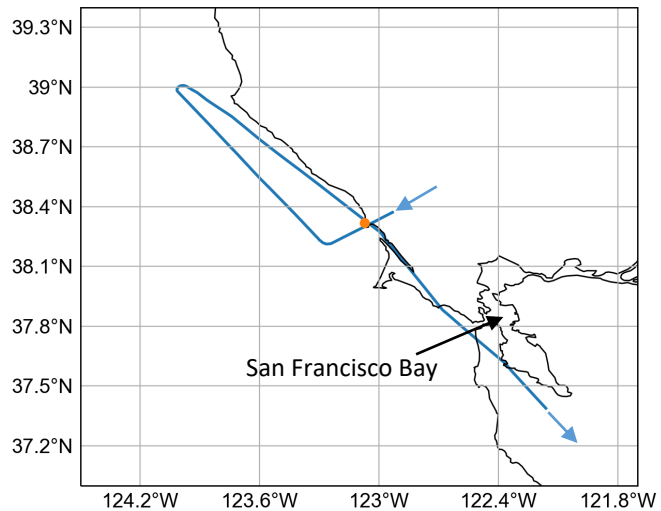


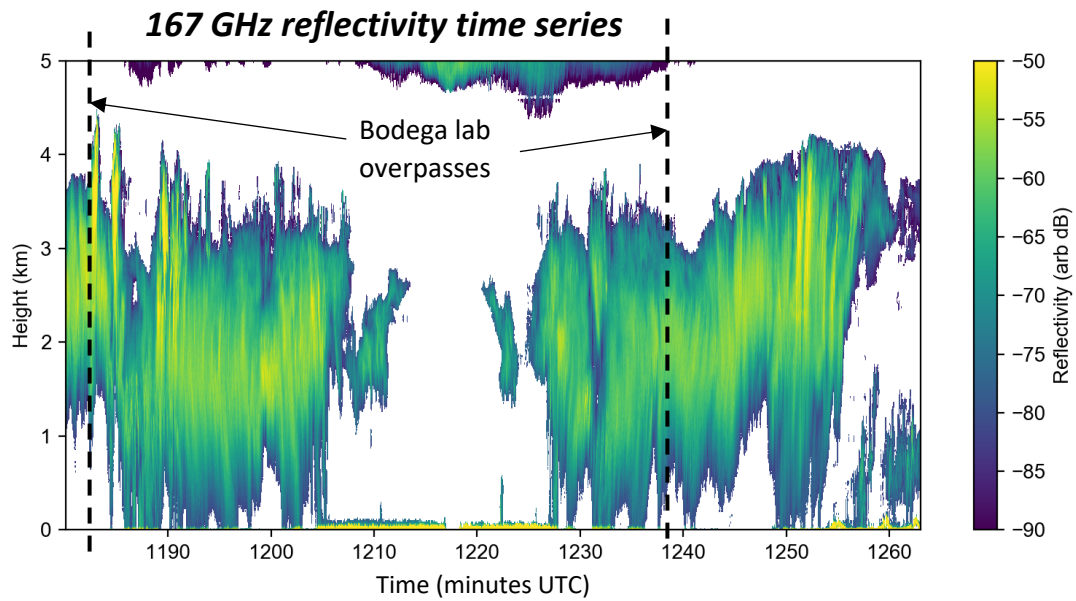


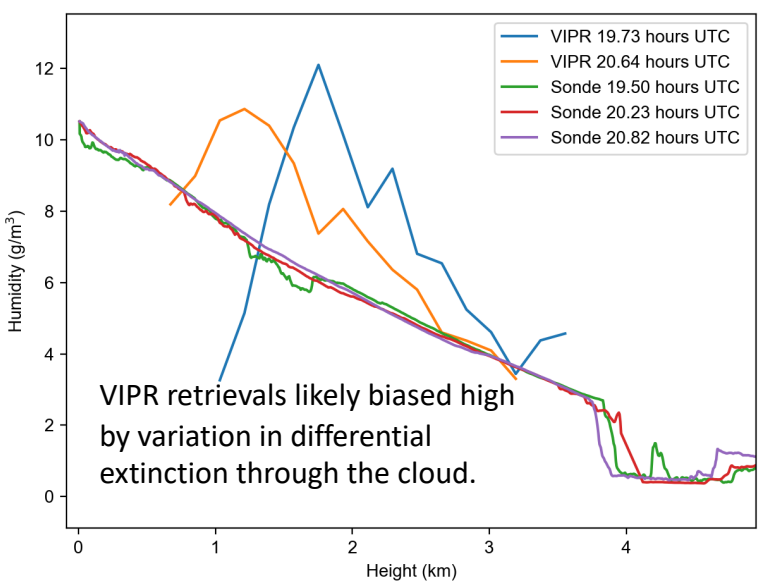


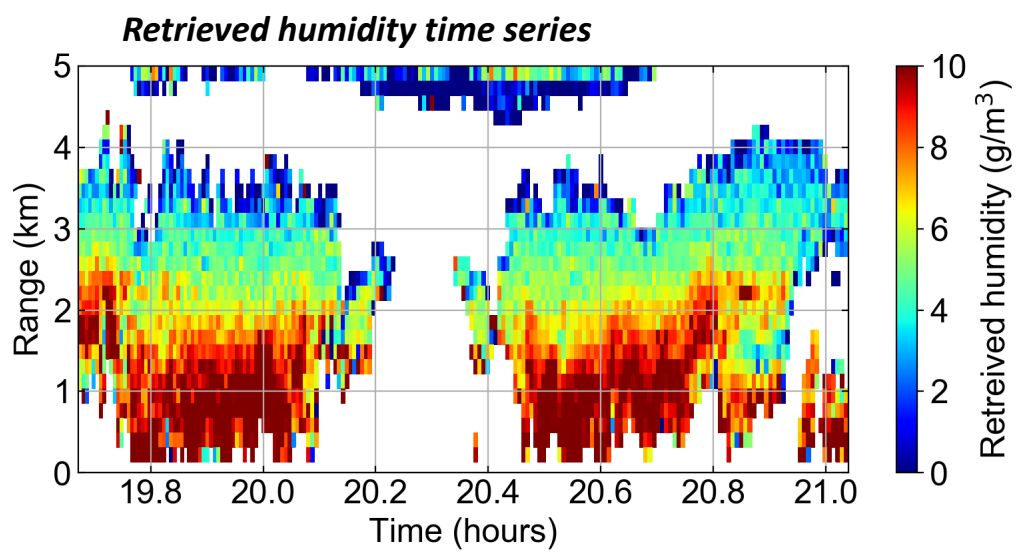
First DAR humidity profiling from airborne platform

Jan. 21, 2020









VIPR's Future and Path to Space

- VIPR has been selected under the AITT program to be integrated onto a more capable aircraft (pressurized, higher-flying, longer-duration) for joint observations with other synergistic instruments (e.g., lidar, dropsondes).

- Inside-cloud humidity profiling from space requires ~100 W transmit power and >1 m aperture. This would be a large, CloudSat-scale instrument.
  - 100 W at 170 GHz is difficult. What makes more sense: a single vacuum electronic (tube) amplifier, or power-combining of hundreds of solid-state sources?
  - Will emerging InP MMIC amplifiers at G-band be an enabling technology?

- Total-column spaceborne humidity measurements are far easier than cloud measurements because only surface scattering needs to be detected.
  - Small satellite missions are conceivable with only ~1 W transmit power and <0.5 m apertures.

Questions?

Thanks to NASA ESTO for funding the project.