A 170 GHz Airborne Radar for Humidity and Cloud Remote Sensing

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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 a major ingredient of cloud growth and radiative properties.

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 Differential Absorption Radar 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$_{\text{min}}$ at 1 km range | appx. -43 dBZ


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

“Anew generation of room-temperature frequency-multiplied sources with up to 10x 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

- Larger dB/km region averaged in below left
- Spurious artifacts

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

$r = 0.96$
RMSE = 0.8 g/m$^3$
Winter 2019-2020 VIPR Airborne Testing

Beam clearance check

Sierra Nevada

CA coast

VIPR operators

VIPR flights 11/19-1/20
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.
Twin Otter flight path

Acquisition starts with banking over water

Spiral descent over Vandenberg coincident with sonde launch

VAFB

Acquisition ends with landing at SLO airport.

Partial Water Column Measurements in Clear Air
First DAR humidity profiling from airborne platform

VIPR retrievals likely biased high by variation in differential extinction through the cloud.
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?

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