Virtual Research Presentation Conference

Technology Development for Orbital Planetary Boundary Layer Humidity Sounding Radar

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Program: Strategic Initiative

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Tutorial Introduction

Abstract

The 2017 Earth Science Decadal Survey identifies water vapor in the Planetary Boundary Layer (PBL) as a Targeted Observable for technology incubation, because of humidity's role in cloud thermodynamics, weather, and climate processes. In the next Decadal Survey's Earth Science mission cycle, there will likely be an opportunity to deploy new sensors for mapping PBL humidity on the global scale.

Therefore, our Strategic R&TD effort involves a system engineering study and parallel technology development effort to conceive of and prepare for a future humidity sounding PBL orbital sensor using the recently demonstrated principle of differential absorption radar.

Our focus is on advancing the maturity of two emerging technologies: microwave photonic (i.e., laser-based) signal sources and solid-state amplifier power-combining, both operating over the difficult-to-access 155-175 GHz frequency band where radar signals are most likely to detect water vapor in the PBL. The photonic sources' low noise can improve the radar's sensitivity to near-surface clouds, while the power-amplifier modules will simplify the complexity of a high-transmit-power orbital 170 GHz radar system.

Additionally, the R&TD effort involves the synergistic development of a 240 GHz Doppler radar test bench to make JPL more competitive for non-NASA funding opportunities.

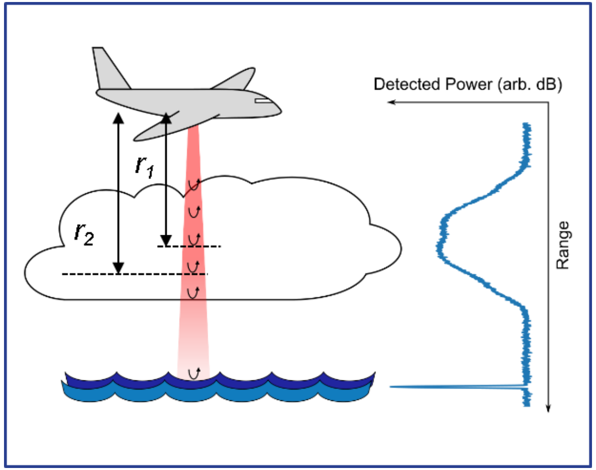
JPL's VIPR radar system, developed under IIP-16, is the foundation of the orbital differential absorption radar concept. It measures humidity profiles inside of clouds, and total water vapor columns, with accuracy better than 1 g/m³.

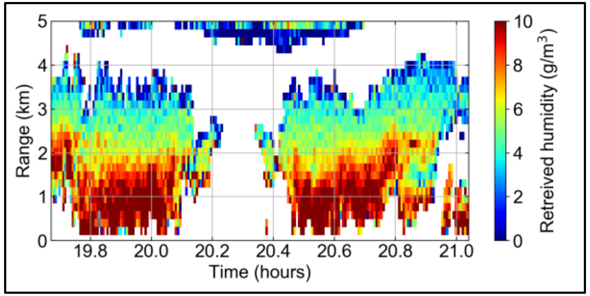
Problem Description

NASA seeks global measurements of PBL humidity in the next Decadal Survey cycle.

The high spatial resolution needed (e.g., 200 m vertical scales) means current approaches to water vapor remote sensing are impossible or impractical. Passive microwave radiometry has too-course resolution and is unreliable over land, while emerging lidar methods are lower-TRL and cannot penetrate clouds. JPL is investigating how a differential absorption radar (DAR) near the 183 GHz water line can be deployed from orbit. In ground and airborne testing of the VIPR instrument (IIP-16 & AITT-19 programs), our team demonstrated the basic measurement principles. Now, we are investigating how to make DAR work to extract water profiles inside clouds from an orbital platforms with hundreds-of-meter vertical resolution and several-km horizontal resolution.

Our work has already led to multiple small technology proposals (ACT-20), and we anticipate proposing to space mission opportunities in the near-term (e.g., InVEST) and longer-term (e.g., Earth Ventures or a directed mission) for technology demonstration and PBL science observations.





Methodology

The research task comprised four parallel efforts:

1. System engineering study to define requirements for space-borne DAR

   One highlighted result: a DAR with 100 W transmit power and 2 m antenna as a CloudSat-class mission can achieve 200 m vertical scale humidity profiles for 100 km horizontal averaging, and total or surface-to-cloud water vapor column with 10 km horizontal averaging. Such an instrument will require accommodations of ~260 W and ~60 kg.

2. Power amplifier packaging for improved DAR transmit power and/or reduced complexity

   An eight-way waveguide/cavity power combiner using new MMICs now available from Teledyne Corp. has been designed, and test blocks/chips are now in hand to make groundwork measurements. Target module will output >1 W of continuous wave power over 155-175 GHz.

3. Microwave photonic source development for compact and ultra low noise G-band sources, to improve radar dynamic range for cloud detection amid bright surface clutter

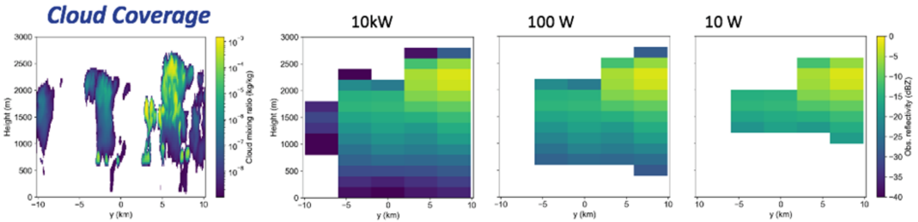
   A new JPL-developed Brillouin laser is being developed, with lasing first demonstrated in Summer 2020. Tests on a similar commercial laser product (OEwave Corp.) using a fast photomixer demonstrated record phase noise at W-band (95 GHz).

4. Building a synergistic 240 GHz radar test bench for future reimbursable proposal opportunities

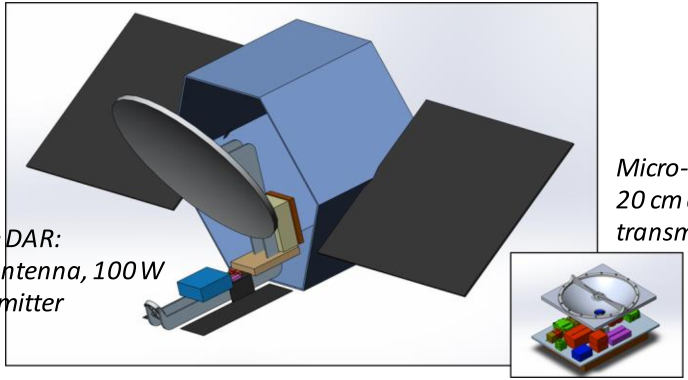
   Components and architecture are shared with projects VIPR (IIP-16), CloudCube (IIP-19), and GAISR (MatISSE-14).

Results – Trade Studies

100-W source, 2-m antenna is acceptable threshold for orbital cloud detection



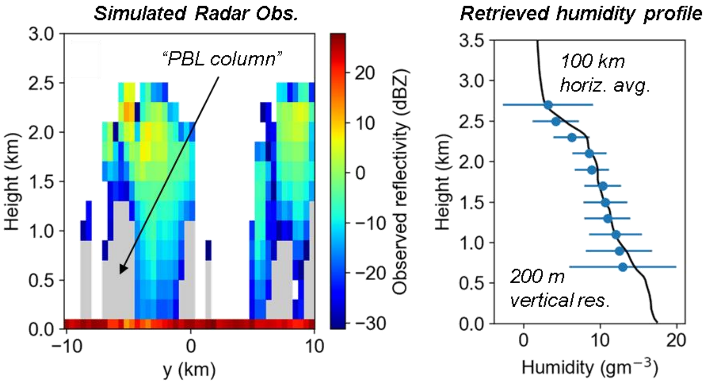
Large, orbital DAR (humidity profiling, 260W/60kg) and micro-DAR (water column only, 90W/20kg) concept models.

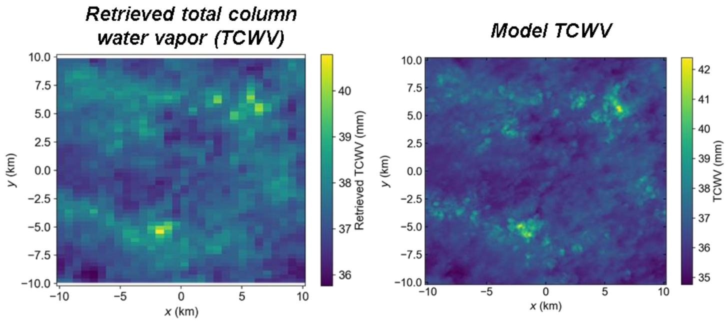


Large DAR:
2 m antenna, 100 W transmitter

Micro-DAR:
20 cm antenna, 1 W transmitter

Example DAR measurement scene: Shallow precipitating cumulus (RICO)

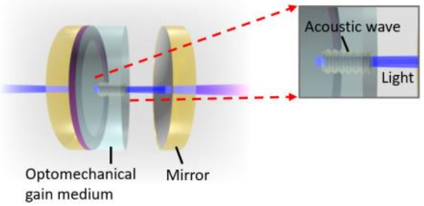




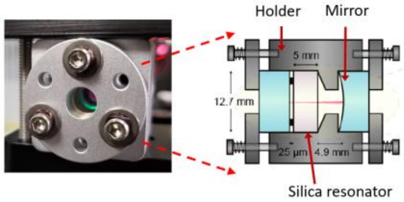
Results – Power Amplifiers & Microwave Photonics

Brillouin lasers use photon-phonon interactions to sharpen laser purity; photomixers convert two tunable lasers to microwave signals.

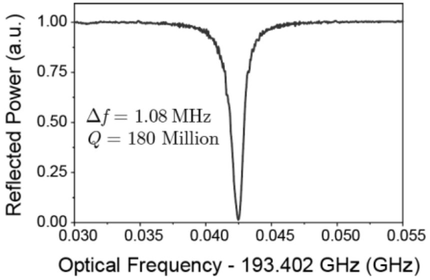
Operation Scheme

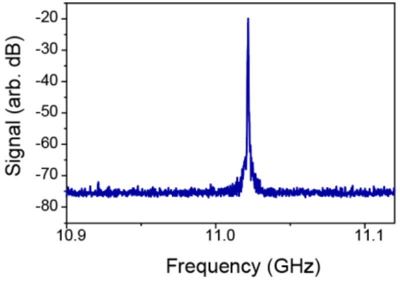


Prototype Device

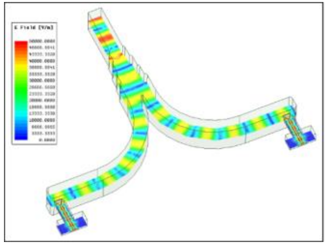


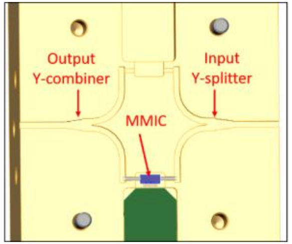
JPL's first Brillouin laser results show excellent Q-factor of the laser line, and a microwave signal at 11 GHz from a photomixer output.



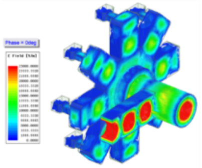


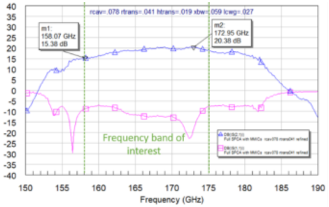
2-way Y-junction power combining test structure: ready for assembly/test

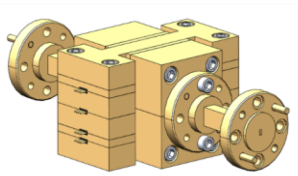




8-way cavity power combiner: ready for fabrication







Next Steps

- System engineering study: complete a comprehensive system report to prepare for future flight proposals, and to define best direction of technology development.
- Microwave photonics: develop a G-band photomixer, and then evaluate a Brillouin laser based 155-175 GHz source's phase noise in comparison to conventional microwave sources.
- Power amplifier packaging: assembly, fabricate, and test 2- and 8-way power combining using designs developed in FY20.
- 240 GHz Doppler radar test bench: assemble front-end waveguide hardware (back-end and optics are done already), and make first outdoor measurements.

Acknowledgements

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