ESTF 2023

CloudCube

A Multi-frequency Solid-State Radar for Affordable Cloud and Precipitation Observations from Space

NASA ESTO IIP-19

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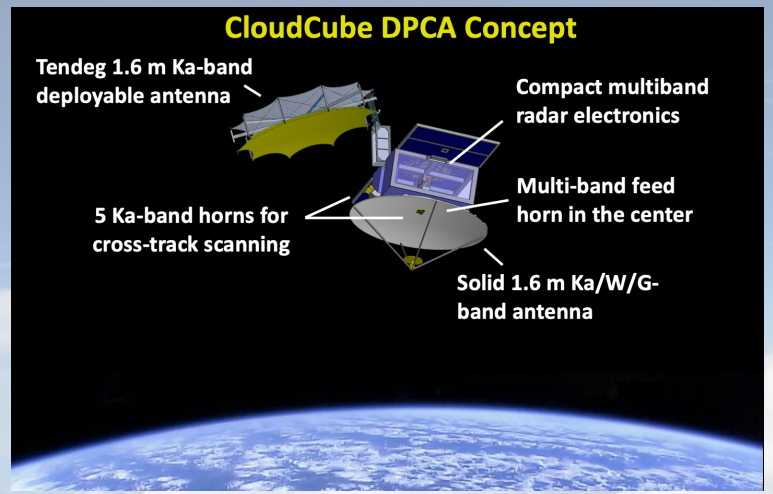
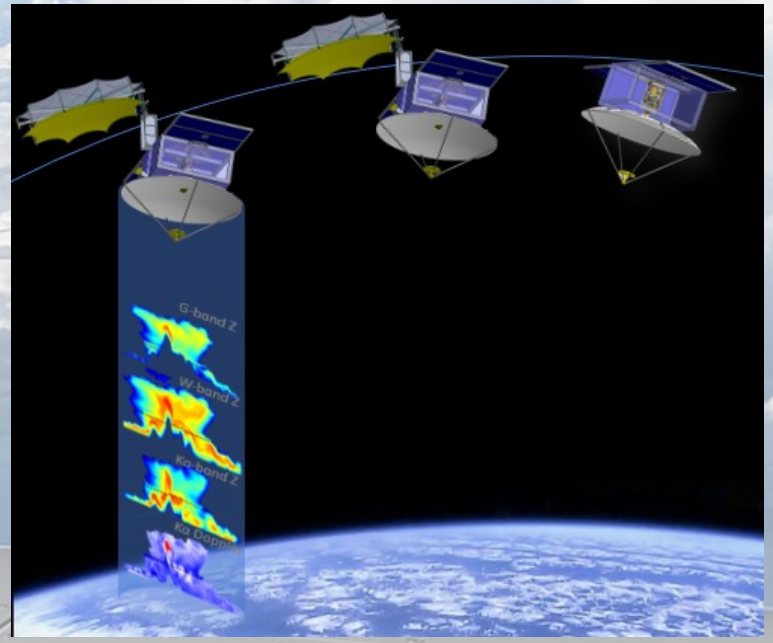
CloudCube: Introduction





- CloudCube is been developed under the NASA ESTO Instrument Incubator Program (IIP) 2019.
- For the first time, CloudCube combines Ka-, W- and G-band (35/94/239 GHz, respectively) radar backscatter with Doppler velocity measurement capability. Combines the 3-band radar electronics, using a minimalistic architecture that vastly reduces mass, power and size, development time and recurring cost.
- The electronics design of CloudCube is optimized for small size and low power consumption. It utilizes mature solid-state components integrated in a compact architecture that is compatible with SmallSat accommodations. To achieve these design goals, a combination of direct up/down conversion radar architecture and pulse compression techniques are employed.

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Applicability and Benefits to Earth Science Measurements

Applicability

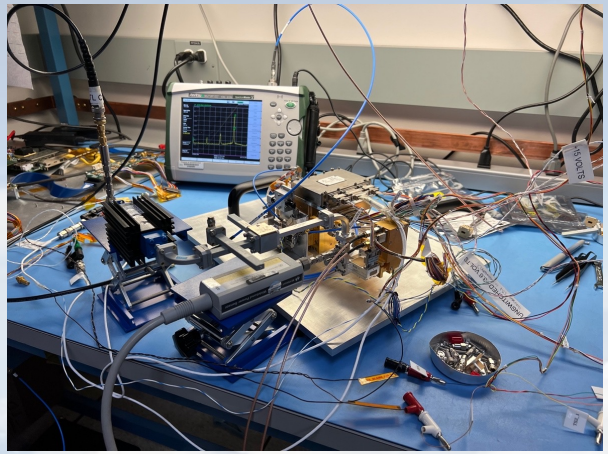
- CloudCube is a low-cost radar for small spacecraft, observing cloud, convection, and precipitation, monitoring atmospheric winds, and measuring planetary boundary layer elements in Earth science.
- Modular instrument architecture: Flexibility for addressing specific science needs, targeting snowfall processes in polar regions or convective processes in tropics and mid-latitudes.
- Single radar or constellation: Improve temporal resolution and global spatiotemporal sampling of diurnal cycle, enhancing study of cloud and storm processes on a global scale.

Benefits:

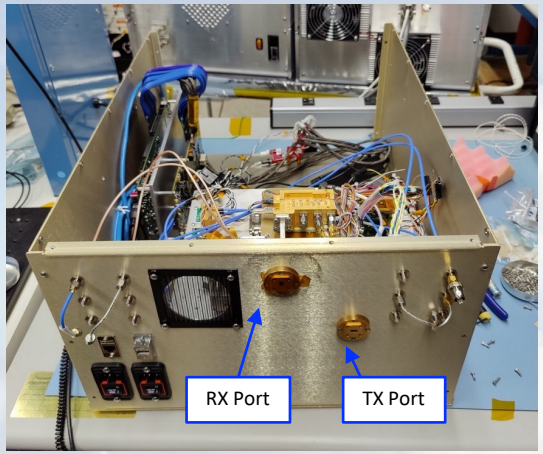
- Cost-effectiveness: Accessible for missions with limited budgets, small size and simplicity contribute to cost savings in implementation.
- Versatility and flexibility: Easy adaptation to specific science needs, different frequency configurations without modifications.
- Enhanced observational capabilities: Fills gaps in cloud and precipitation observations, affordable constellations for process-oriented investigations on a global scale.

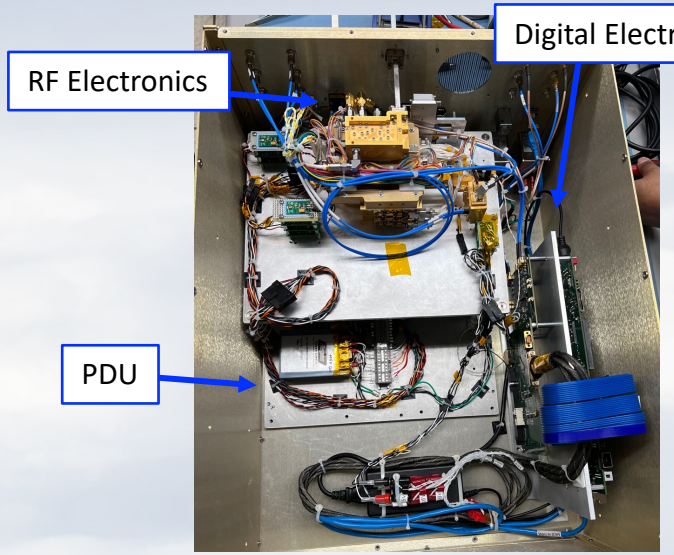
CloudCube Instrument Development

Ka-band RF Electronics



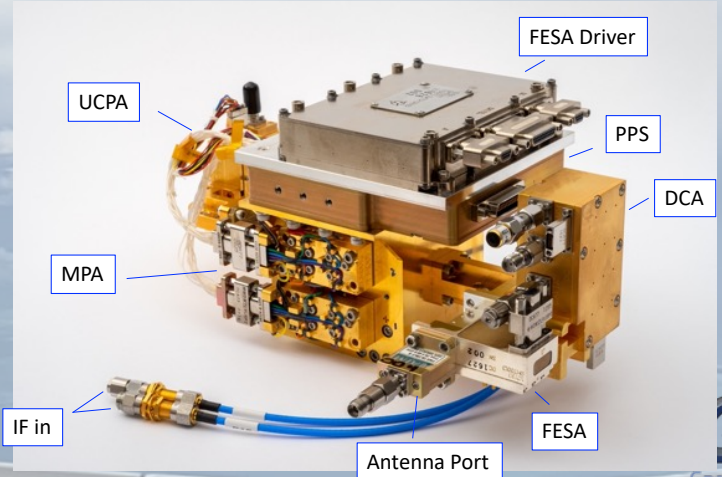
lab test setup





Chassis containing RF, digital and power subsystem for easy installation and operation in field deployments

- Ka-band electronics build to print or spare units from RainCube Mission.
- Packed the Ka-band channel in a rack-mounted chassis that include all the power supplies (6 Acopians, 9 regulators boards), RF and digital electronics (Kintex board, ADC/DAC board and interface board).
- Easy to install and operate. Controlled with a PC, using the firmware and GUI designed for the W-band.



Ka-band Compact Prototype

MPA: Medium Power Amplifier
DCA: Down-Converter Assembly
FESA: Front-End Switch Assembly
PPS: Pulsed-Power Supply
UCPA: Up-Converter Pre-amplifier Assembly

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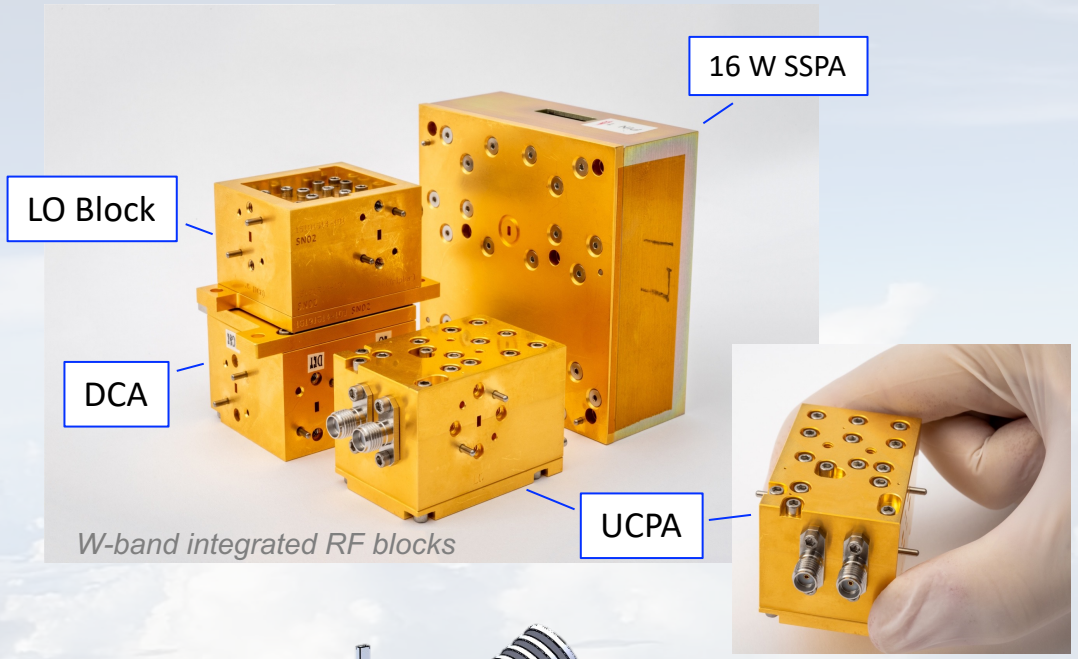
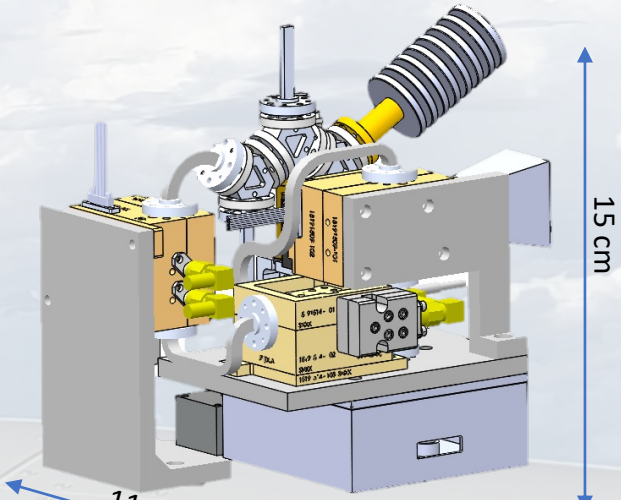
CloudCube Instrument Development

W-band RF Electronics



W-band integrated RF blocks



Complete W-band Compact Radar (not included the digital and PDU)

- Demonstrate a direct up/down conversion and pulse compression on a W-band prototype that it was successfully integrated into NASA's DC-8 and participate on its second field campaign CPEX-CV/AW.
- We the design, fabrication, assembly and test of the integrated blocks that constitute the W-band compact radar. The blocks included low-DC power consumption commercially available MMICs for the IQ mixer and the Ka and W-band preamps and JPL designed NGC fabricated W-band LNA.
- The compact radar prototype is complete and all the subsystem have been tested in the lab, including a very compact 16 Watt SSPA from Raytheon.

<u>W-band compact radar prototype:</u>

Total DC power (CBE):: **24 W** (including digital subsystem at a 10% duty cycle)
Total Mass (CBE):: **2 kg**

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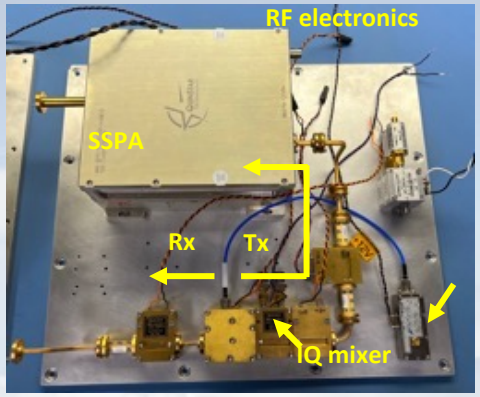
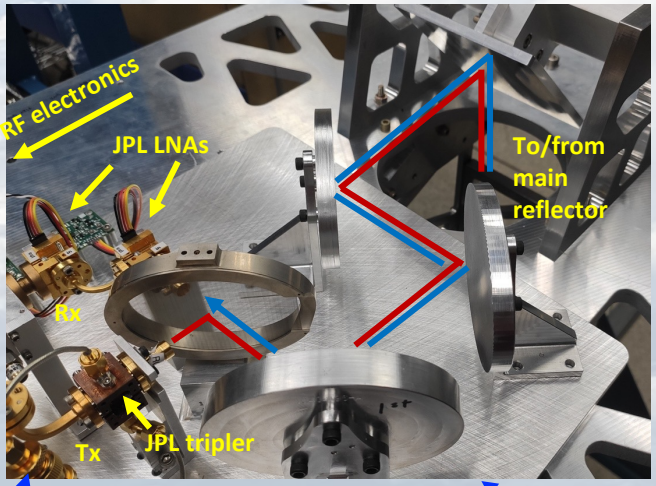
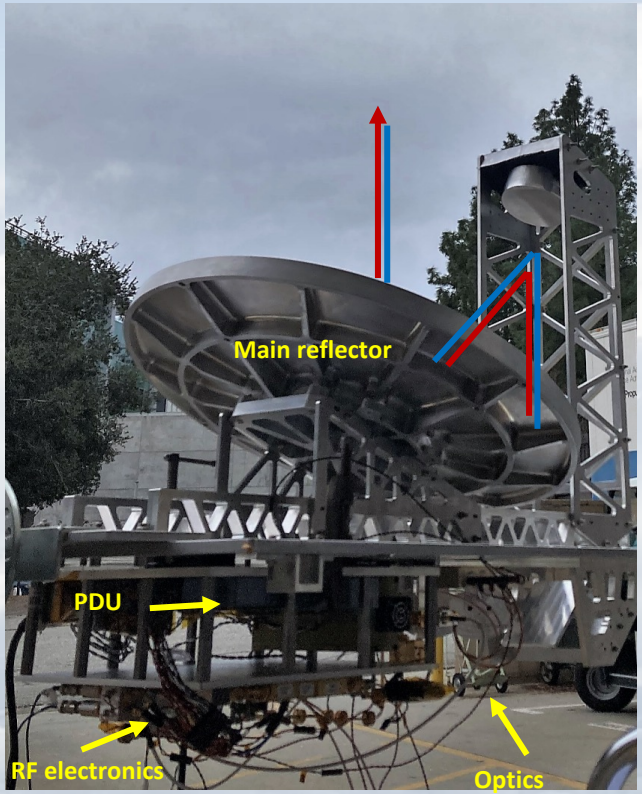
CloudCube Instrument Development

G-band RF Electronics





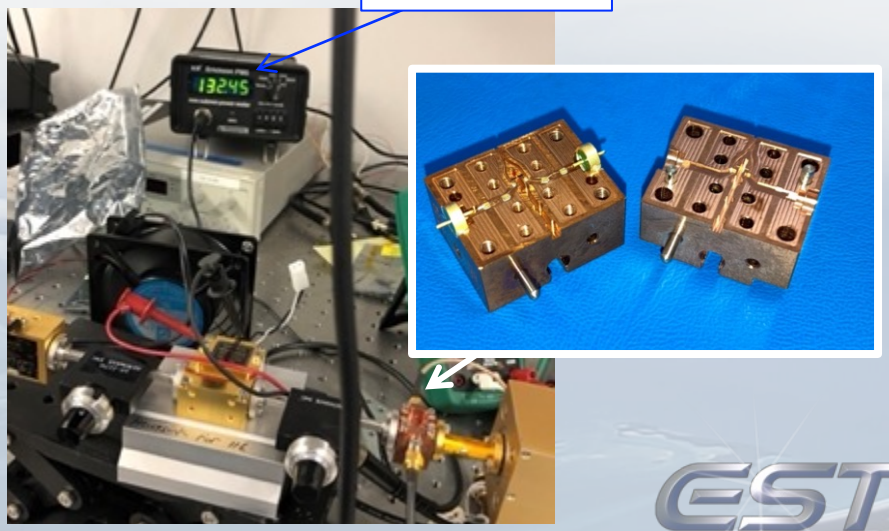


G-band components are kept close to the optics to reduce losses.

quasi-optical subsystem

- The G-band prototype has been completed and successfully tested in outdoor measurements.
- The radar was installed on VIPR optics with 60 cm aperture with expected >60 dB antenna gain and currently uses a quasi-optical duplexer to provide high T/R isolation
- The radar uses a high-efficiency tripler as a transmiter that provides >100 mW transmitted power and 240 GHz.

record power



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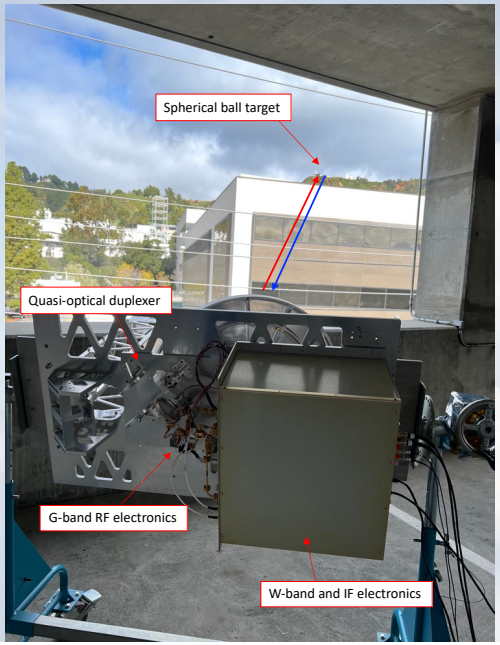
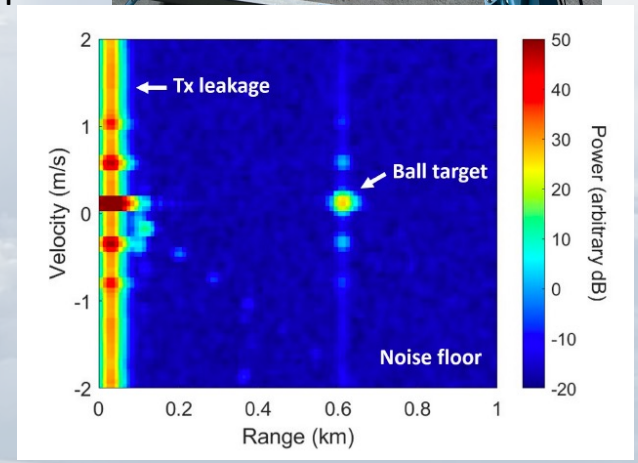
CloudCube Instrument Development

G-band RF Electronics

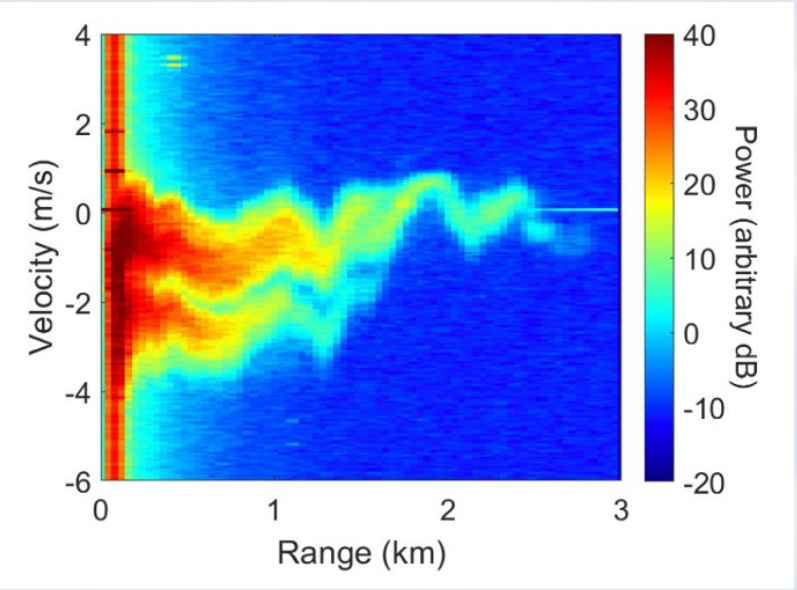
Calibration

- The G-band radar was calibrated using a ~100mW transmitted power source.
- A 4-inch metal sphere was hung at the Mesa facility, at approximately 600 m from the parking structure.
- The sphere return was successfully detected in the G-band Doppler spectrum
- After integrating the echo signal over the Doppler spectral width, the calibration factor can be obtained to convert amplitude to reflectivity from different targets.





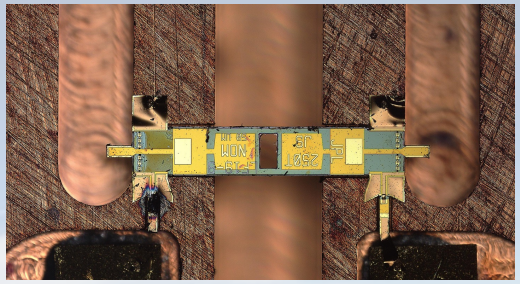
Doppler Velocity Measurements



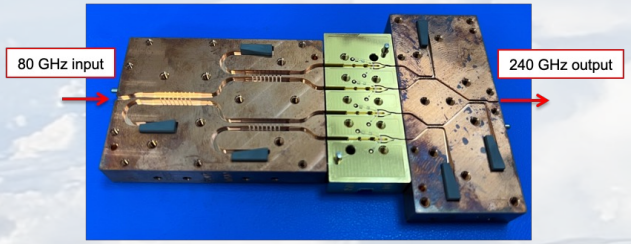
In December we measured very light rain with the Doppler radar processing software, which revealed a clean Mie resonance indicating how different diameter droplets fall at different velocities.

CloudCube Instrument Development

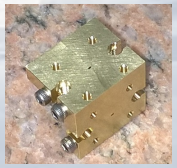
G-band RF Electronics



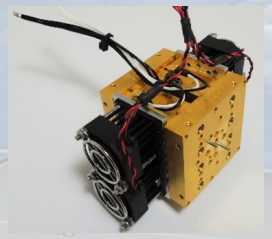
240 GHz Dual-chop mounted on a single split waveguide block



4-way power combiner 240 GHz Multiplier



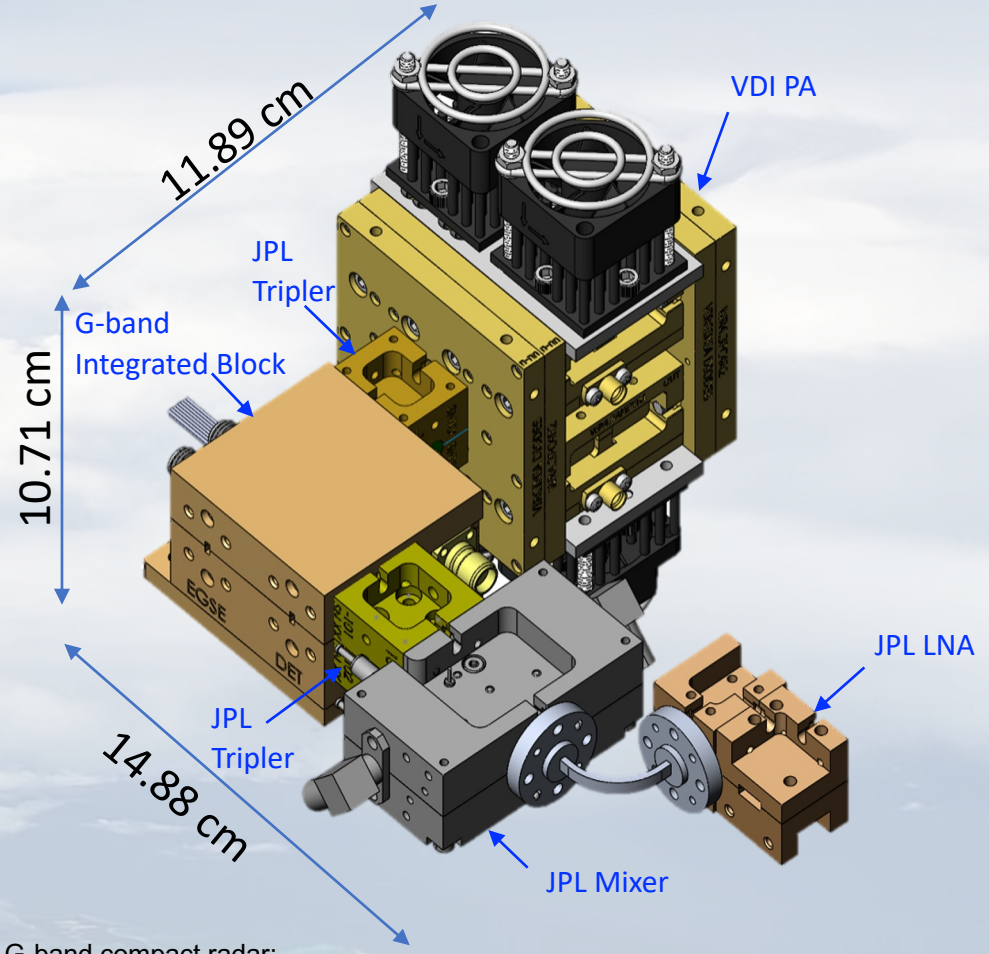
240GHz LNA block



VDI 240 GHz PA

G-band key technology:

- Multipliers: JPL designed and fabricated GaAs Schottky diode multiplier. 240 GHz tripler design combines two diode circuits on a single chip for efficient and well balanced combining. Measures over 100mW of 240 GHz Power.
- Fundamental IQ mixer using discrete Schottky diodes mixers (25 dB image rejection).
- For-way power combiner of diode multipliers. Anticipated output power 400 mW. We have currently measured 240mW (lower efficiently than expected). We believe that mismatches in the tripler chips' output phases and amplitudes are most likely responsible for the lower efficiency.
- InP LNA designed by JPL and fabricated at NGC with NF of 4.5 dB system noise figure.
- As an alternative to the multiplier and as part of SBIR (contract # 80NSSC80C0147) phase II, Virginia Diodes packaged new state-of-the-art III-V (InP) semiconductor power amplifiers from Teledyne Corp. that generate 220 mW of output power



G-band compact radar:
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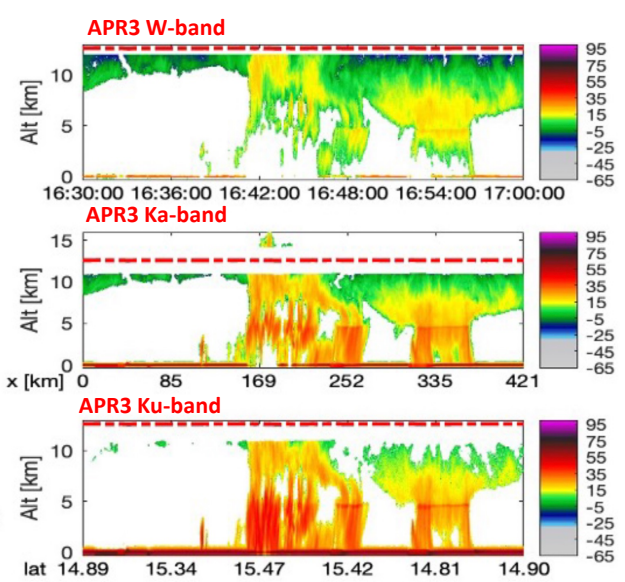
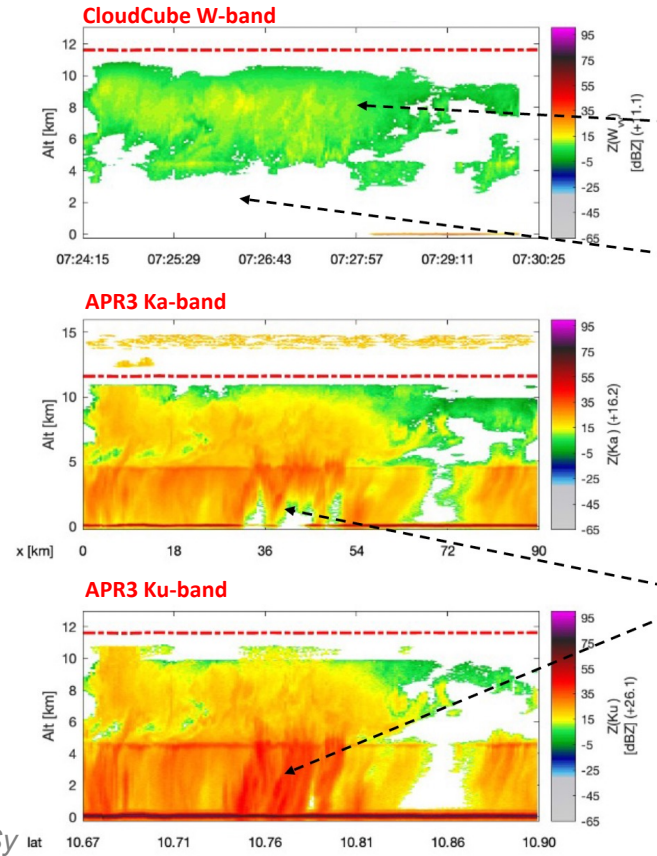
CloudCube Field Experiments

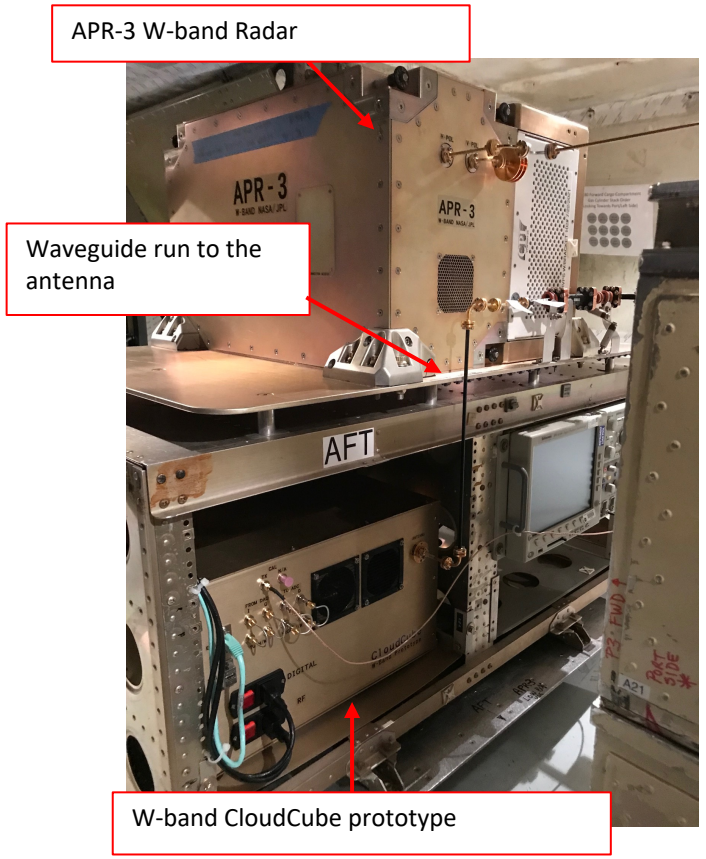
W-band Airborne Demonstration

- The W-band breadboard radar was successfully integrated into NASA's DC-8 Airborne together with the APR-3 (Airborne Third Generation Precipitation Radar), as a technology demonstration instrument, in the Convective Processes Experiment- Aerosol & Winds (CPEX-AW) field campaign in St. Croix, US Virgin Islands in September 2021 and CPEX-CV (Cape Verde) in September 2022.
- CloudCube thus demonstrates for the first time, the direct up/down-conversion radar architecture with pulse compression at W-band from an airborne platform, with the successful detection of ocean surface echo and clouds.





Courtesy of Ousmane Sy

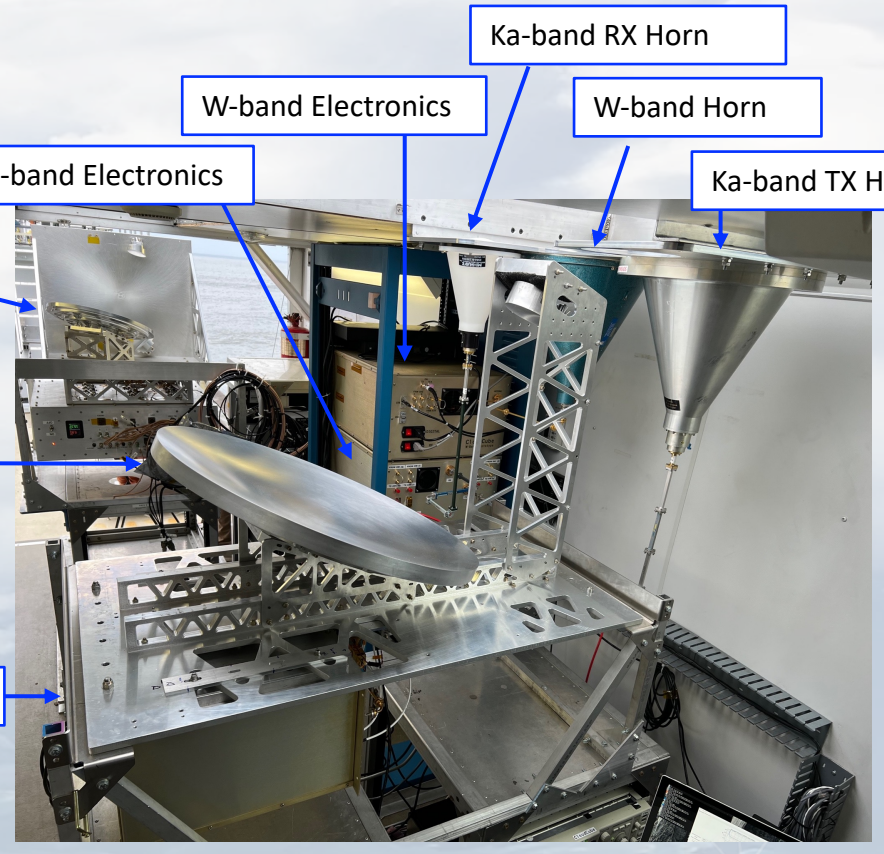


CloudCube Field Experiments

Ka-, W- and G- band Ground Demonstration Demonstration

- CloudCube and VIPR, were deployed for 6 weeks, to the Scripps Pier in La Jolla, CA to support Department of Energy's Eastern Pacific Cloud Aerosol Precipitation Experiment (**EPCAPE**).
- The deployment enable to demonstrate for the first-time synergies between multiple high-frequency radars to derive cloud liquid mass, drop size and water vapor using Ka, W, and G-band radar.

Scripps Pier

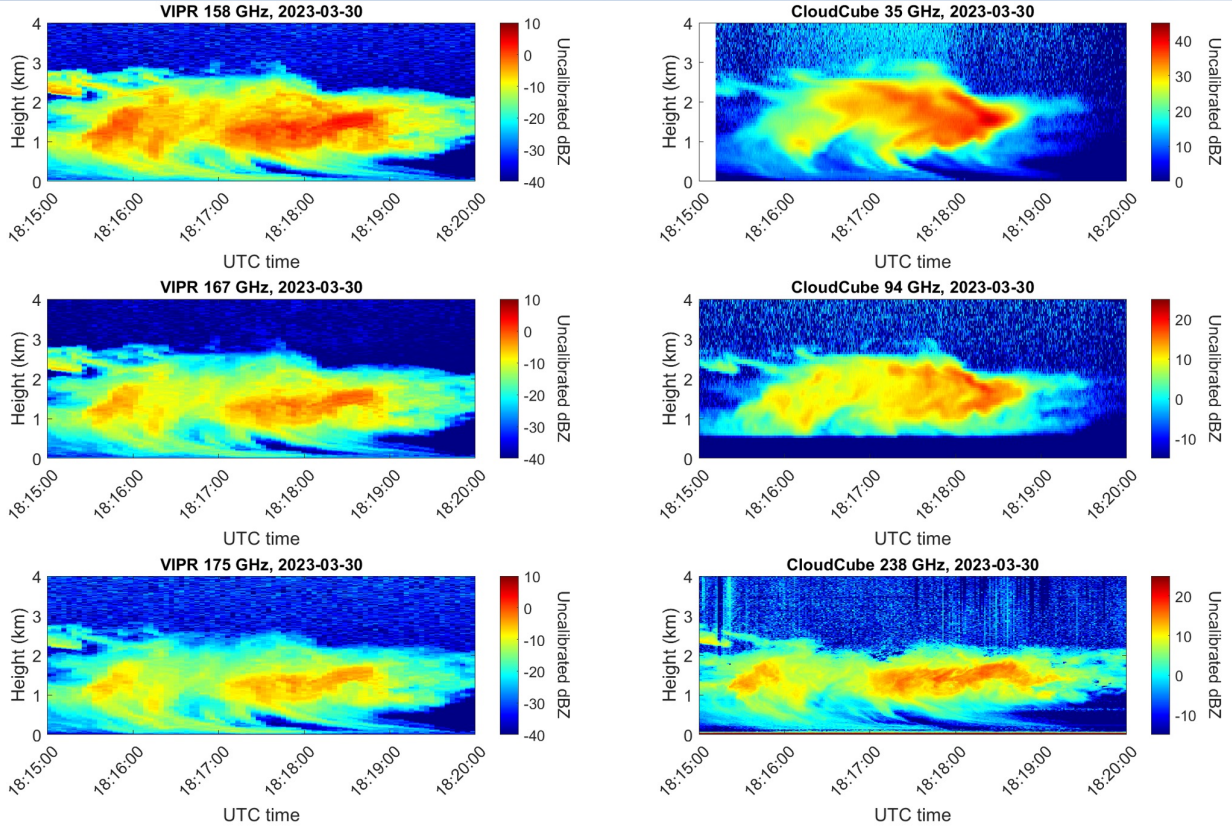


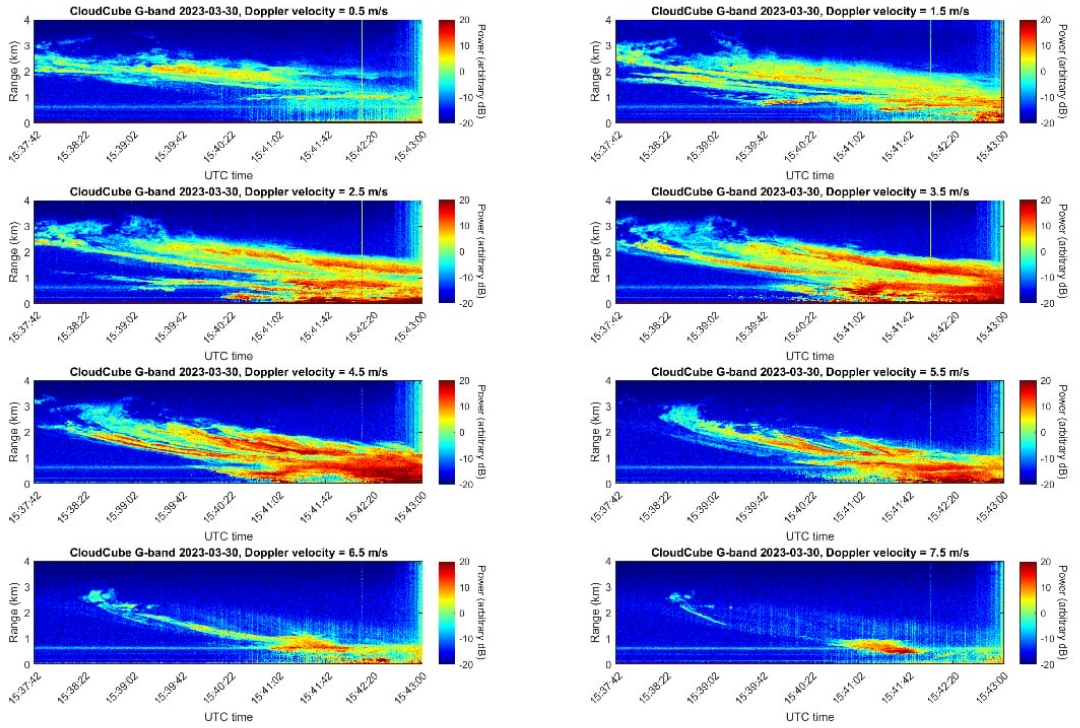
Background information on EPCAPE, a DOE effort led by Lynn Russell of the Scripps Institute of Oceanography to study marine clouds can be found at https://scripps.ucsd.edu/news/scripps-pier-uc-san-diego-mount-soledad-facility-host-coastal-marine-cloud-study

CloudCube Field Experiments

Ka-, W- and G- band Ground Demonstration Demonstration

A collaboration between JPL and the Brookhaven National Laboratory, we deployed the three frequency channels of CloudCube (35/94.05/238.8 GHz), VIPR (158.6/167.12/174.74 GHz) and a W-band radar from BNL near the Ka-band ARM Zenith-pointing radar (KAZR).





The deployment of CloudCube and VIPR provide, for the first time, simultaneous measurements at six different frequencies.

Example of preliminary CloudCube G-band (240 GHz) showing a cloud curtain obtained in different Doppler slices from 0.5 m/s (upper left) to 7.5 m/s (bottom right). One can see at what altitude and time the fastest falling precipitation occurs.

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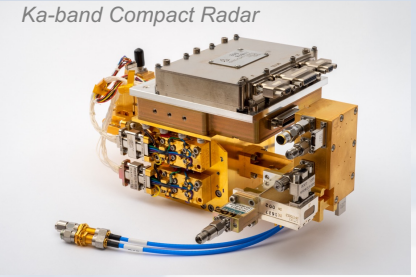
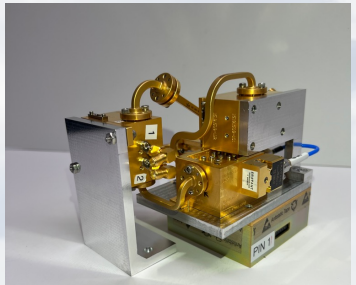
CloudCube Readiness for Earth Science

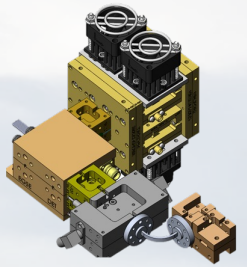
- Ka-band RF electronics is built to print from RainCube's so it is currently at TRL-7. Same RF electronics or equivalent for some parts that are obsolete are being used in INCUS (EVM-3).
- The construction of the W-band compact prototype radar is now complete. The upcoming phase focuses on performing ambient temperature and TVAC tests on the radar subsystems with the goal of reaching TRL 6 by early 2024 (InVEST-23, EVM-4, EVI-6).
- The G-band breadboard design has been successfully finalized, assembled, and tested. Additionally, the design for the flight-like radar is now complete (InVEST-23, EVM-4, EVI-6).
- We have now available a versatile 3-frequency radar instrument for airborne and ground deployment. CloudCube instrument can complement and enhance the science return from near future field deployments or new field deployment concepts (EV-S).



Ka-band Compact Radar



W-band Compact Radar



G-band Compact Radar

Ka, W, G-band Radar on the JPL Trailer for ground measurements

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Thank you!
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