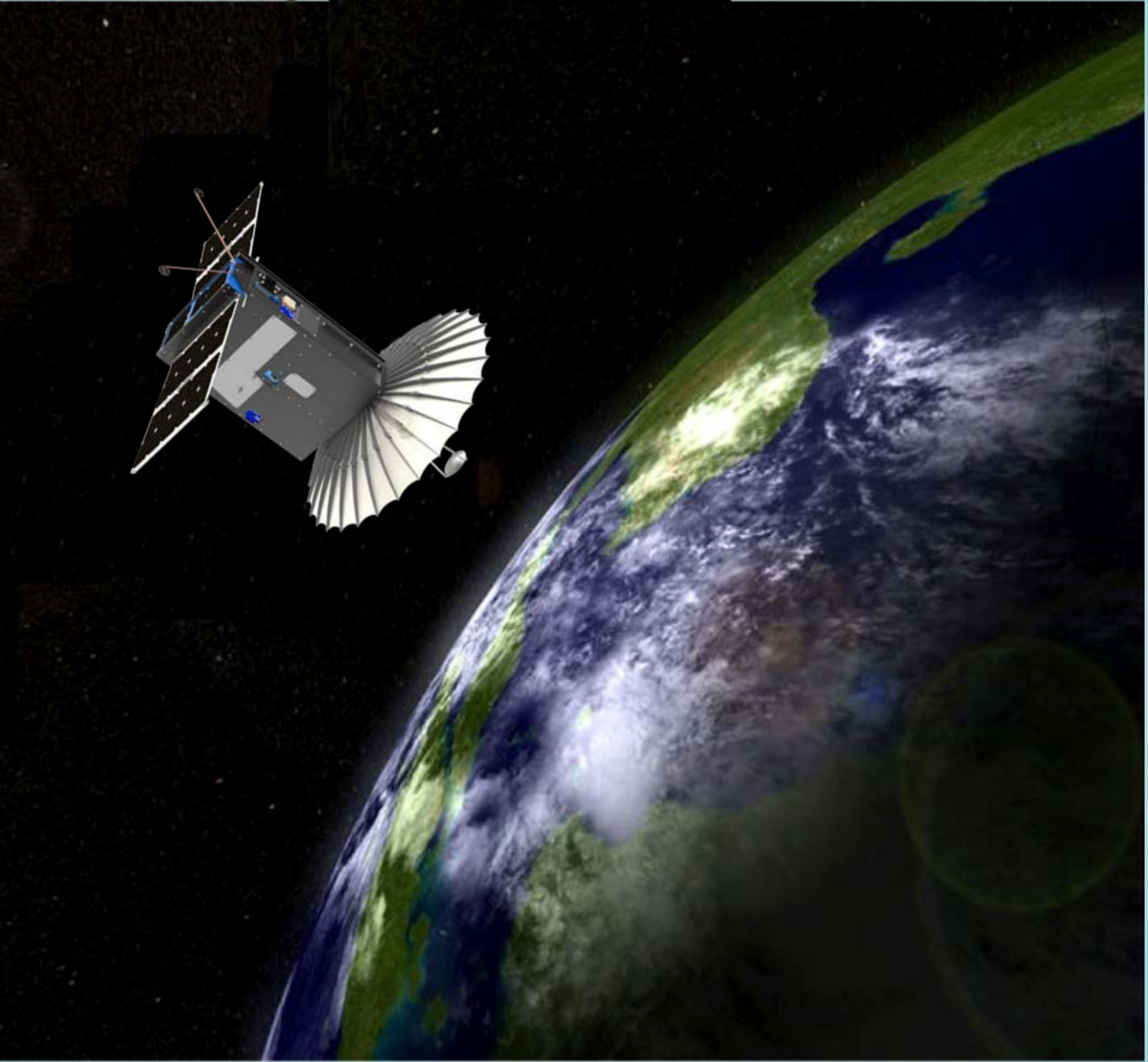


ESTF2020 NASA

RainCube

Summary of Two Years Of Operations In Space

Presenter: Shivani Joshi[1](Mission Operations Manager)

Principal Investigator: Dr Eva Peral[1]

Project Scientist: Dr Simone Tanelli[1]

Project Manager: Dr Shannon Statham[1]

Mission Operations Lead: Chris Shaffer[2]

1. Jet Propulsion Laboratory, California Institute of Technology, CA, USA

2. Tyvak Nano-Satellite Systems Inc., CA, USA

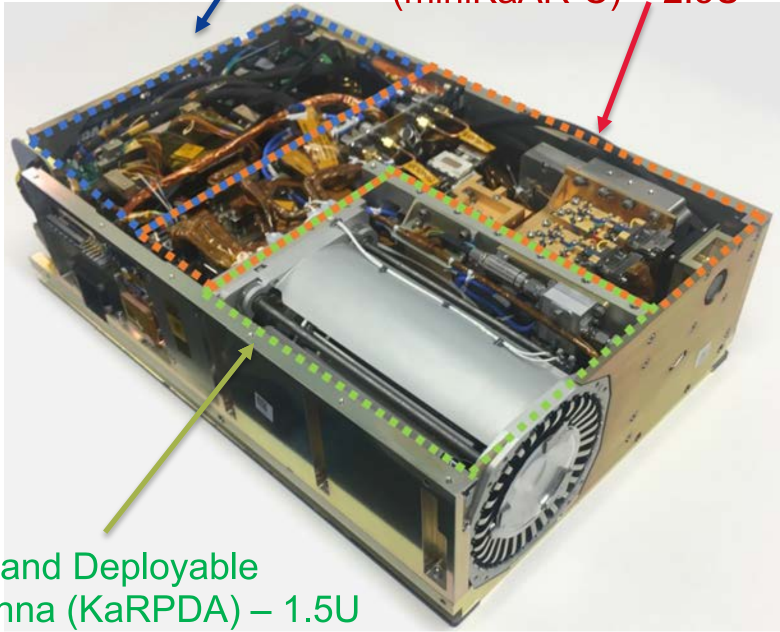
MISSION OVERVIEW

Why is RainCube Special?

MISSION OVERVIEW

Why is RainCube Special?

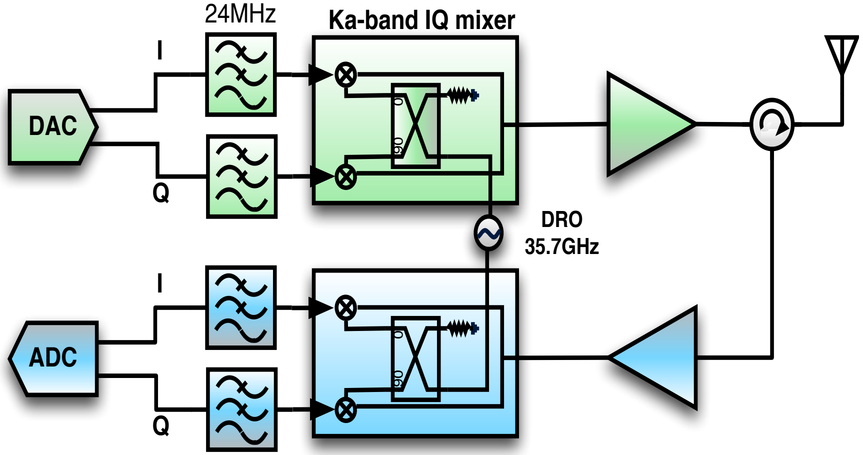
- **First radar and active payload in a CubeSat**
- **Demonstrates Two new technologies in Ka-Band on a 6U CubeSat platform**
  1. **Miniaturized Ka-band Atmospheric Radar for CubeSats (miniKaAR-C)**
     - **Reduces number of components, mass and volume by an order of magnitude compared to traditional atmospheric radars**
     - **Constellation will enable precipitation profiling at smaller time-scales – accurately characterize rapidly evolving weather systems**
  2. **0.5 meter Ka-band Radar Parabolic Deployable Antenna (KaRPDA)**
     - **Stows in 1.5U volume**
     - **First demonstration of in-space deployment**
- **First in-space demonstrated use of pulse compression techniques on a precipitation radar**



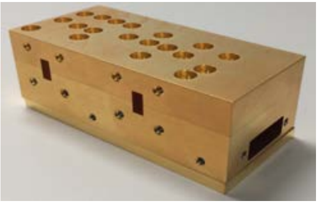
MISSION OVERVIEW

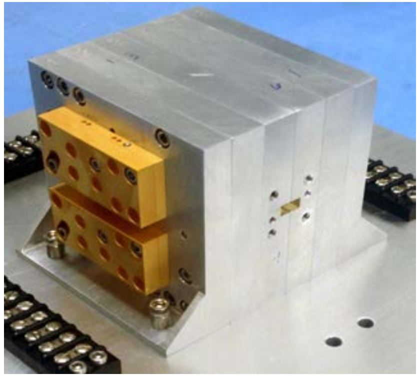
Summary of Development

May – July 2013
Brain-storming to Initial concept



July 2014
Lab Demo with Prototype Hardware



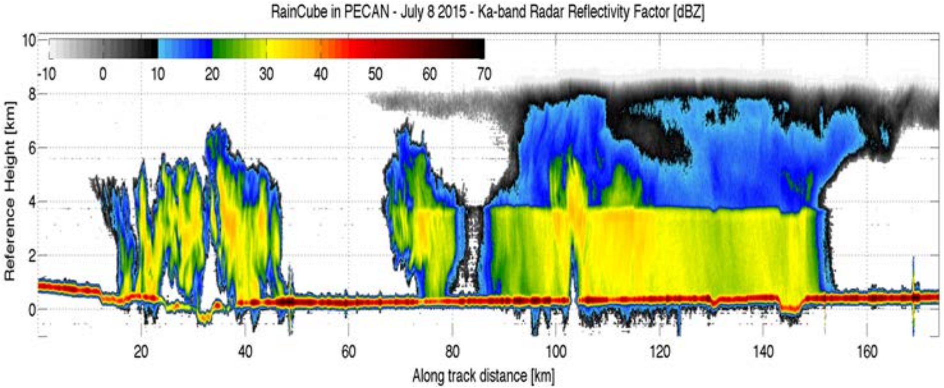


MISSION OVERVIEW

Summary of Development

July 2015 Airborne Demo
(pictured here Doug Price and Simone Tanelli)

November 2015 InVEST Selection



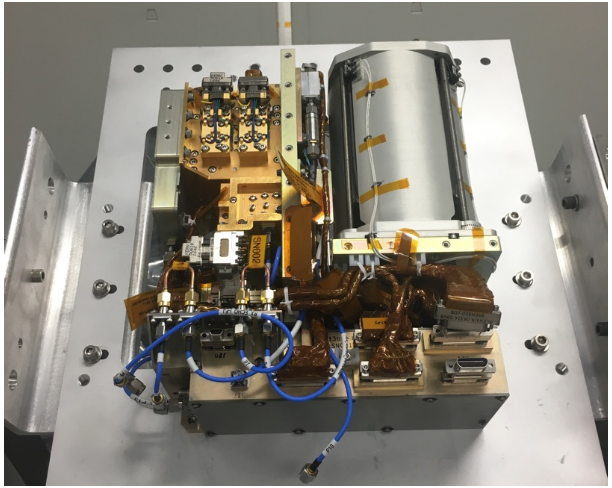
MISSION OVERVIEW

Summary of Development

May 2016
Tyvak Nanosatellite Systems Inc. Selected as SC Bus Vendor

Tyvak
A Terran Orbital Corporation

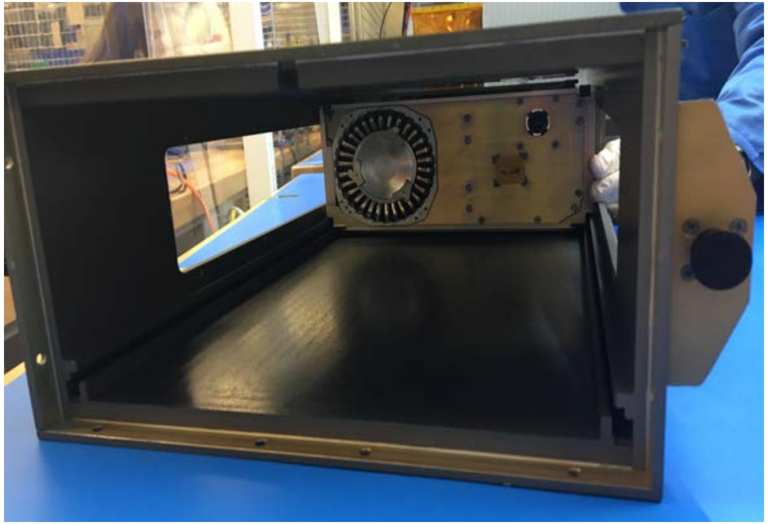
March 2017
Flight Instrument delivered to Tyvak for System I&T



MISSION OVERVIEW

Summary of Development

Feb 2018
Delivery to NanoRacks for Launch

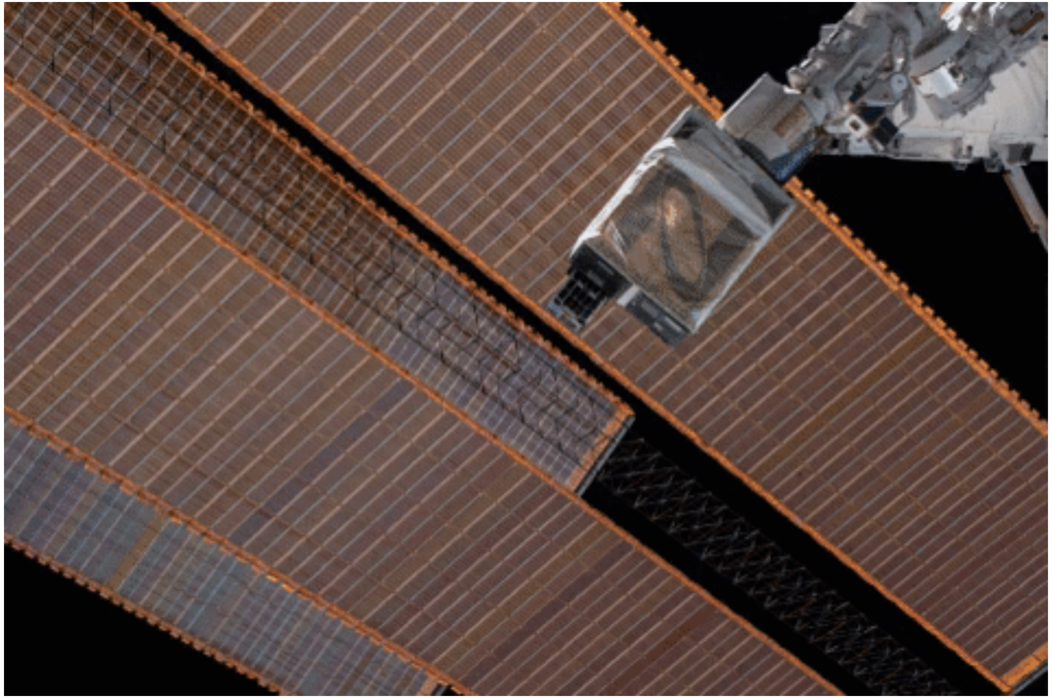


May 21, 2018
Launch aboard Cygnus mission
From Wallops Island, VA

MISSION OVERVIEW

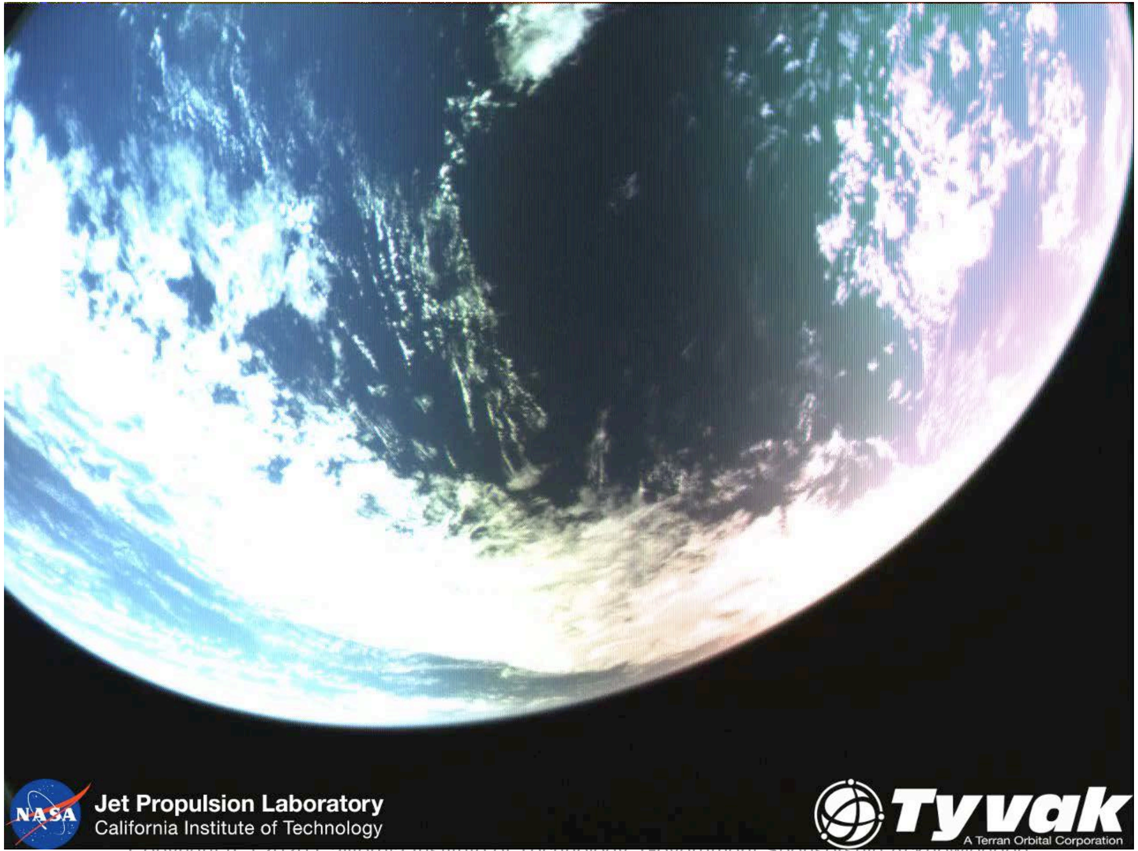
Summary of Development

July 13, 2018
Deployment in in orbit from ISS



HIGHLIGHTS FROM YEAR 1 IN ORBIT

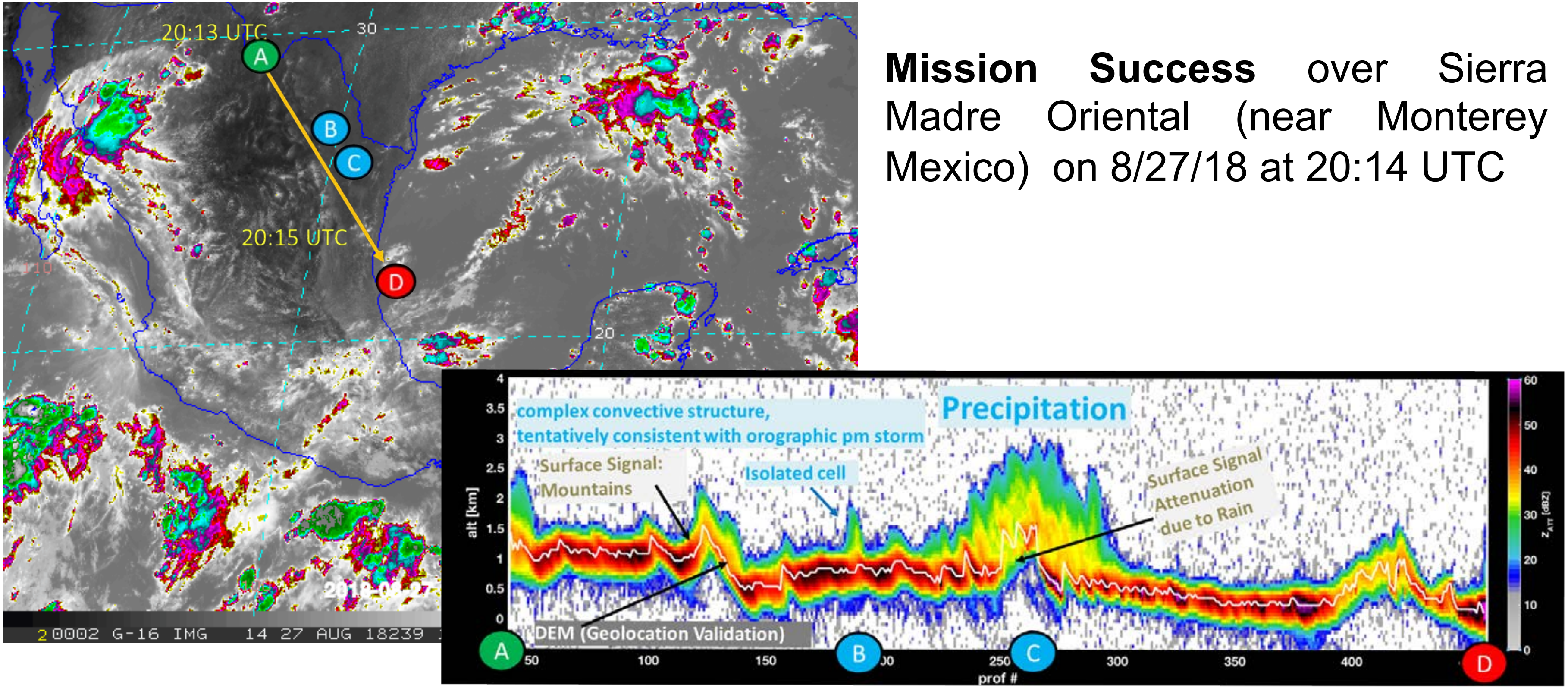
Primary Mission – Antenna Deployment in Space



HIGHLIGHTS FROM YEAR 1 IN ORBIT

Primary Mission – First Observation of Rain

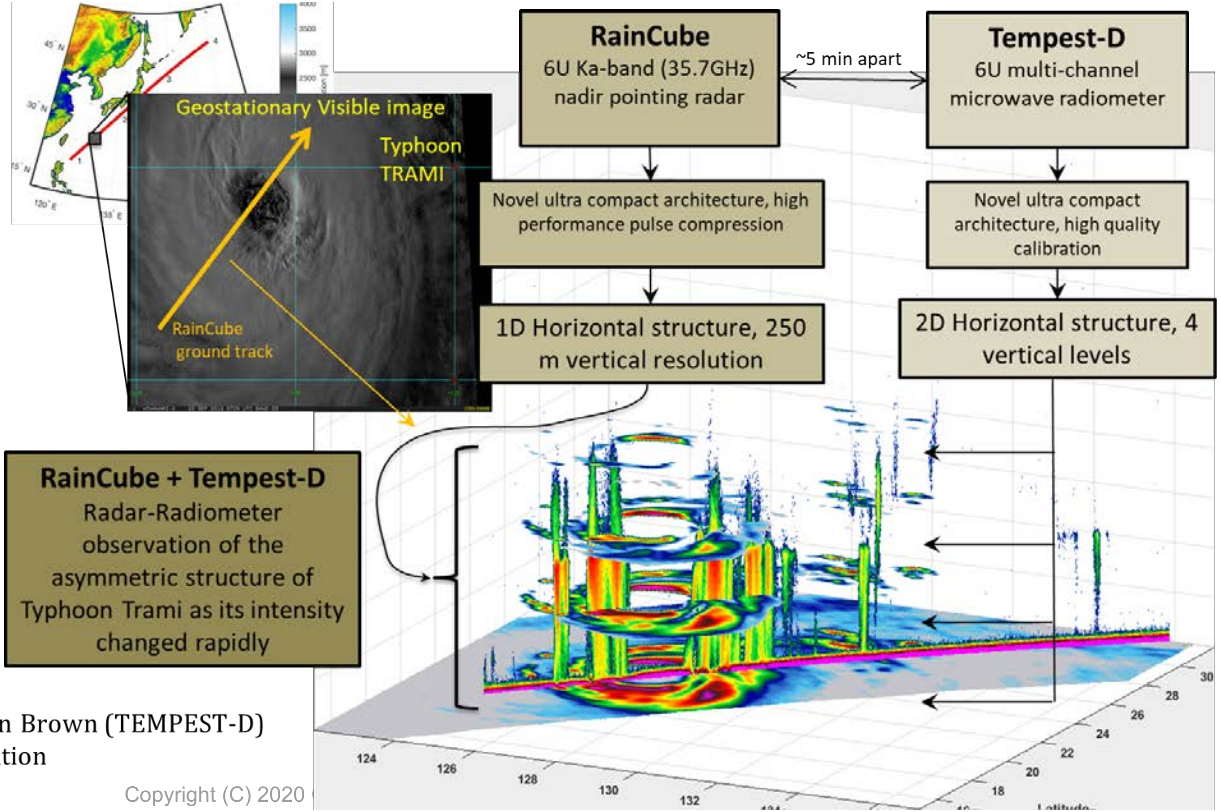
Mission Success over Sierra Madre Oriental (near Monterey Mexico) on 8/27/18 at 20:14 UTC



HIGHLIGHTS FROM YEAR 1 IN ORBIT

Primary Mission – Radar + Radiometer Mini Constellation

Slide Credit – Shannon Brown (JPL - TEMPEST-D) and Simone Tanelli (JPL - RainCube)



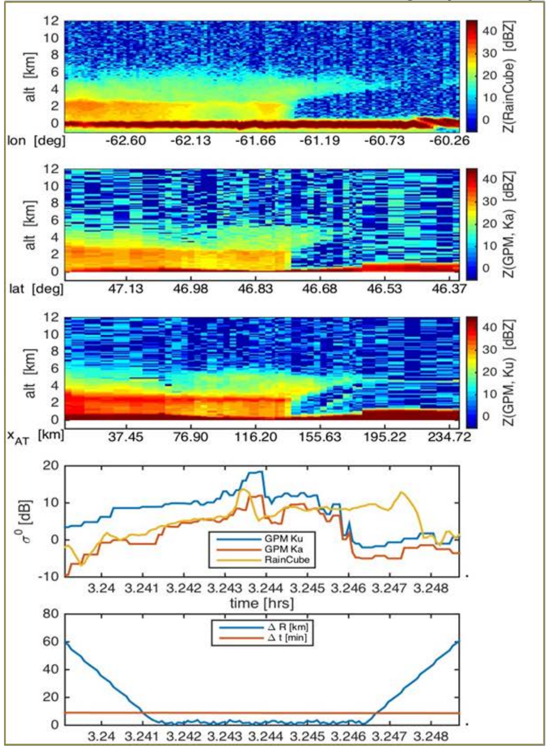
Credit to Shannon Brown (TEMPEST-D) for the 3D-animation

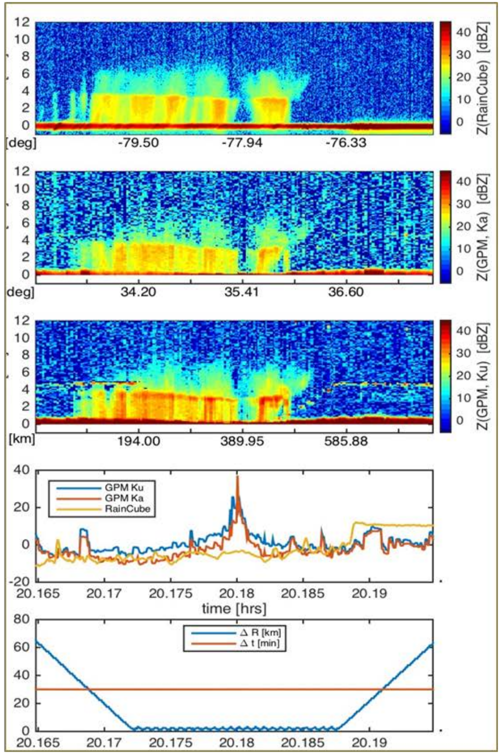
HIGHLIGHTS FROM YEAR 1 IN ORBIT

RainCube Calibration – GPM/DPR Relative Calibration Validation

Slide Credit – Ousmane Sy (JPL)

- Colocations within margins (50 km horizontally, 30 mins)
- Comparing Raincube observations (Z, σ^0) to Ka-band observations from GPM
- “best comparisons” with persistent stratiform scenes
- Implemented an optimization approach that correlates RainCube’s (Z, σ^0) to GPM’s





HIGHLIGHTS FROM YEAR 1 IN ORBIT

Challenges

- Bad radar pulse shape -

  resolved – Thanks to RainCube firmware lead Brad Ortloff (JPL).

- Loss of one of two MPPTs (Peak Power Tracker) –

  was a known possibility before launch – we chose to accept the risk rather than delay delivery to NanoRacks for launch. Resulted in RainCube system operating at 50% less power capacity.

- Aperiodic system level reboots –

  combined with reduced power capacity, prevents us from operating radar continuously as planned – the longest full power (transmit) radar operation can be 40 mins long. Requires careful planning of radar operations and science data collections

- Reaction Wheel Failure on Z-axis about KaRPDA boaresight –

  Semi-Accurate pointing of the payload boresight is still possible because only XY wheels are needed to point the payload boresight.

  Due to lack of control, the vehicle rotates about the Z axis making it challenging to get consistent star tracker measurements and maintain good attitude knowledge and control

HIGHLIGHTS FROM YEAR 2 IN ORBIT

Efforts to Improve Attitude Determination and Control (ADCS)

Slide Credit – Kyle Clarke (Tyvak)

Objectives

- Increase number of occurrences where current operational requirements are satisfied
- Increase quality of payload data through better pointing accuracy

Updated ADCS code was uploaded to the vehicle containing additional filter features

Based on spacecraft telemetry, a number of areas of improvement were identified through configuration updates that are currently active on orbit.

- Removing nominal restrictions on the filter ingesting star tracker measurements
- Tuning filter such that it is more "confident" with more measurements, and less "confident" with less measurements
- Activate star tracker editing to remove poor measurements when the filter is "confident."

Current Operational Status:

Some operational changes have been implemented to achieve better pointing to enable payload operations. Currently, the payload science collections are activated when the following conditions are satisfied:

- The Attitude Filter is in its Fine Converged state (i.e. expect good attitude knowledge)
- Body Rates are sufficiently low
- Control Error about the X/Y axis is low
- Spacecraft is Nadir pointed

HIGHLIGHTS FROM YEAR 2 IN ORBIT

RainCube as In-Orbit testbed for Advanced Pulse Compression Solutions for ACCP

Slide Credit – Simone Tanelli

- Designed before the 2017 decadal survey's ACCP (Aerosol and Cloud, Convection and Precipitaion) DO (Designated Observable) was outlined
- Concurrent to pre-formulation ACCP study
- RainCube provides data to validate advanced modeling of Pulse Compression Performance
- We enable current ACCP study to consider this new class of compact radars as viable and mature

Goal during Extended Mission: to test specific improvements to pulse compression waveform design to address ACCP projected needs.

ACCP Objective	RainCube's Pulse Compression as-is (preliminary subjective assessment)	Necessary Performance Improvement
Low Clouds	Probably insufficient for many low cloud scenarios	Significant reduction of range sidelobes
High Clouds	Sufficient	n/a
Convective Storms	Sufficient	n/a
Cold Cloud and Precipitation Processes	Sufficient for Minimum Objectives, Insufficient for Enhanced Objectives	Moderate reduction of range sidelobes

First paper based on RainCube's results soon to be published –

Beauchamp, R. M., Tanelli, S., & Sy, O. O. (In Review). Observations and Design Considerations for Spaceborne Pulse Compression Weather Radar. *IEEE Transactions on Geoscience and Remote Sensing*.

PLAN AHEAD

ADCS, Pulse Compression, AWS Demo and Decommissioning

- We will apply a flight software patch in coming weeks that is a possible 2 RW and 3TR solution to achieve stable NADIR pointing of RainCube antenna boresight in the absence of Z-RW.

  Improving Vehicle Controllability

  - A new control law was developed to magnetically regain control over the Z axis using magnetic torque rods
    - Desaturates remaining X/Y reaction wheels without creating parasitic torques about Z
    - Expect <10 degree pointing error about the Z axis
    - Expect Controlled rates to < 0.01 deg/s to enable stable pointing in X/Y
  - Additional guidance updates are also developed to accommodate the new control law for slew planning
- We are in our second pulse compression campaign – we are trying variations in RCRF and pulse widths of radar’s transmit pulse, to better inform ACCP study teams.
- We are working with Amazon Web Services (AWS) teams to use Amazon’s ground stations (both domestic and international) for downlink of science data collections over S-band radio.
- RainCube is projected to stay in orbit until March 2021.

INTRODUCTION TO CLOUDCUBE

IIP-2019 Awardee Enabled By Success Of RainCube

- The success of RainCube is generating much interest among the weather radar science and engineering community.

- The miniaturized radar architecture of RainCube is the backbone of recent selection to ESTO's IIP (Instrument Incubation Program) called CloudCube

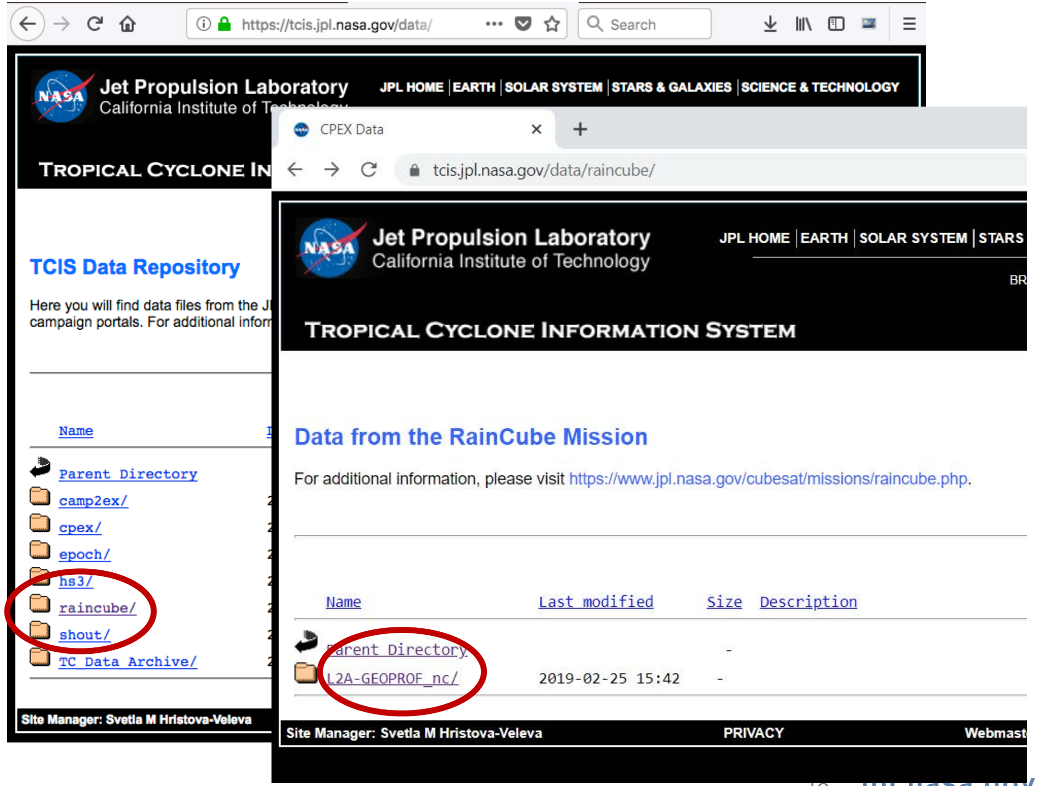
- CloudCube is a multi frequency millimeter-wave radar system that will consist of an ultra-compact 35/94/238 GHz multi-frequency radar with Doppler capabilities at the lower frequency band.

- The instrument will enable unprecedented mission concepts that would fill existing gaps in the observation of a variety of cloud and precipitation processes directly addressing the ACCP DO.

SCIENCE DATA ACCESS

RainCube L2 Data is hosted by TCIS portal

- Go to https://tcis.jpl.nasa.gov/data/
- Select raincube/
- Select L2A-GEOPROF_nc/



Huge thank you to

PI : Svetla Hristova-Veleva,

Site Administrator Quoc Vu, and

Data Manager Brian Knosp)

NASA/JPL-Caltech Team members

Douglas Price, Jonathan Sauder, Travis Imken, Nacer Chahat, Brad Ortloff, Marvin Cruz, Chaitali Parashare, Alessandra Babuscia, Elvis Merida, Carlo Abesamis, Macon Vining, Joseph Zitkus, Richard Rebele, Mary Soria, Arlene Baiza, Stuart Gibson, Greg Cardell, Brandon Wang, Taryn Bailey, Dominic Chi, Brian Custodero, John Kanis, Kevin Lo, Mike Tran, Nazilla Rouse, Miguel Ramsey, Robert Beauchamp, Ousmane Sy and Gian Sacco Franco.

Jet Propulsion Laboratory
California Institute of Technology

jpl.nasa.gov

Tyvak Team Members

Austin Williams, Ricky Prasad, Ehson Mosleh, Jeff Mullen, Jeff Weaver, Sean Fitzsimmons, Nathan Fite, John Brown, John Abel, Craig Francis, Kari Kawashima, Lauren Fitzgibbon, Steven Sundin and Marco Villa.

Tyvak
A Terran Orbital Corporation