

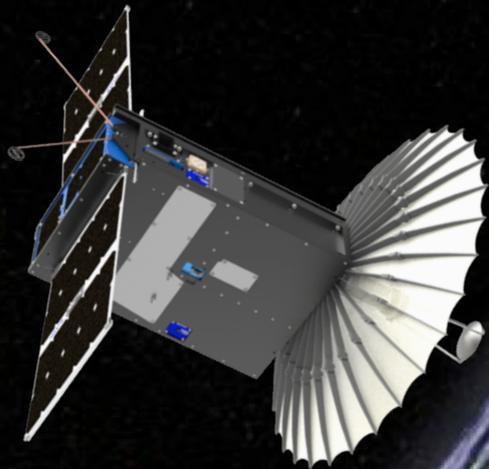


RainCube



**Jet Propulsion Laboratory**  
California Institute of Technology

# RainCube - First Ka-Band Precipitation Radar in CubeSat: From Concept To Mission



**Presenter - Shivani Joshi (Mission Operations  
Manager)**

**Principal Investigator - Eva Peral**

**Project Scientist - Simone Tanelli**

**Project Manager - Shannon Statham**

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

**Mission Operations Lead – Chris Shaffer**

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

CubeSat Developers Workshop – April 2019  
Cal-Poly San Louis Obispo, CA

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# Mission Overview and System Architecture



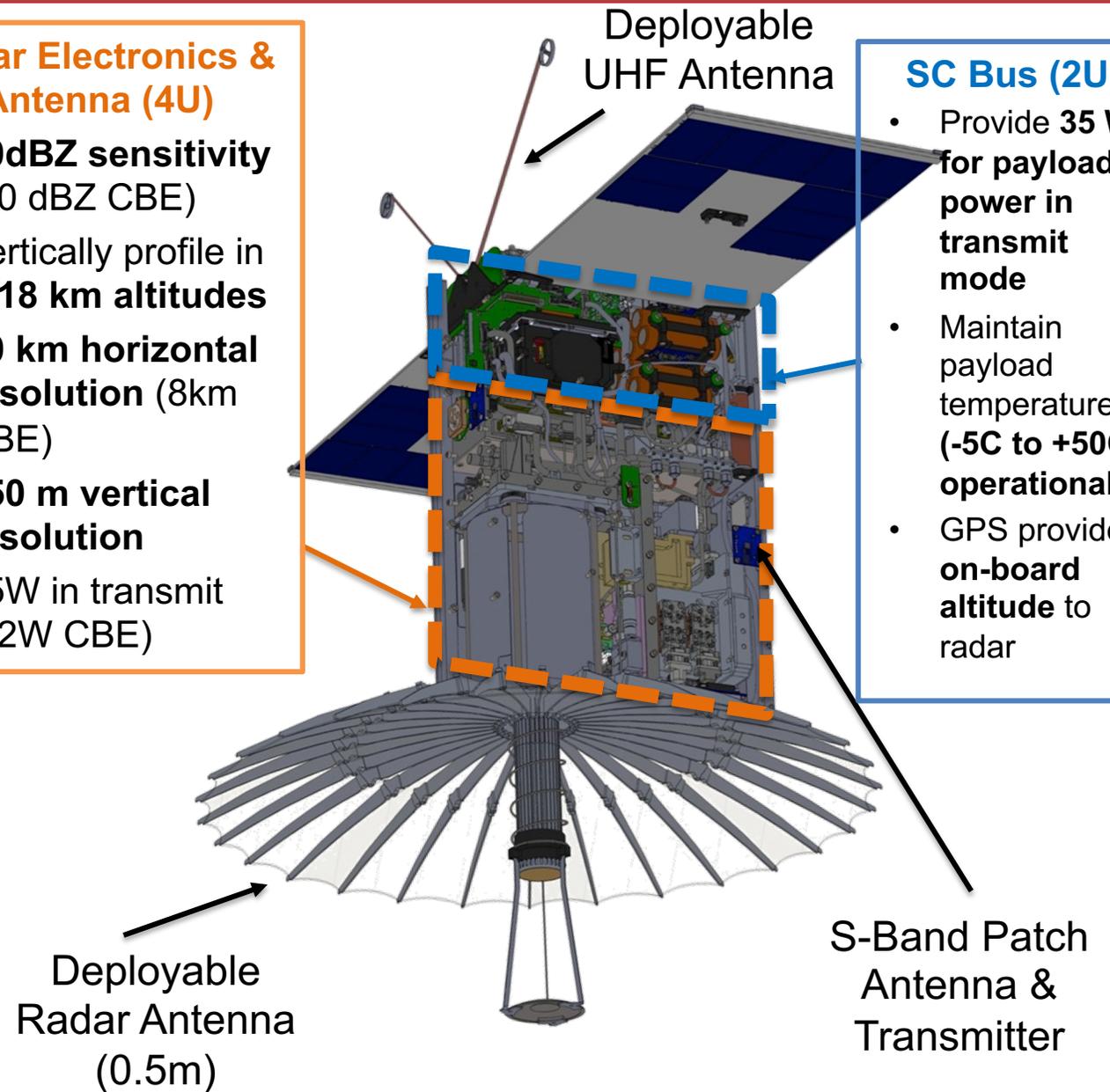
- RainCube (Radar in a CubeSat) is the first active radar instrument in a CubeSat platform to operate in Low Earth Orbit.
- RainCube is funded through the NASA Science Mission Directorate's (SMD) Research Opportunities in Space and Earth Science (ROSES) 2015 In-Space Validation of Earth Science Technologies (InVEST) solicitation with the goal of raising the instrument TRL from entry 4-5 to exit 7.

## Radar Electronics & Antenna (4U)

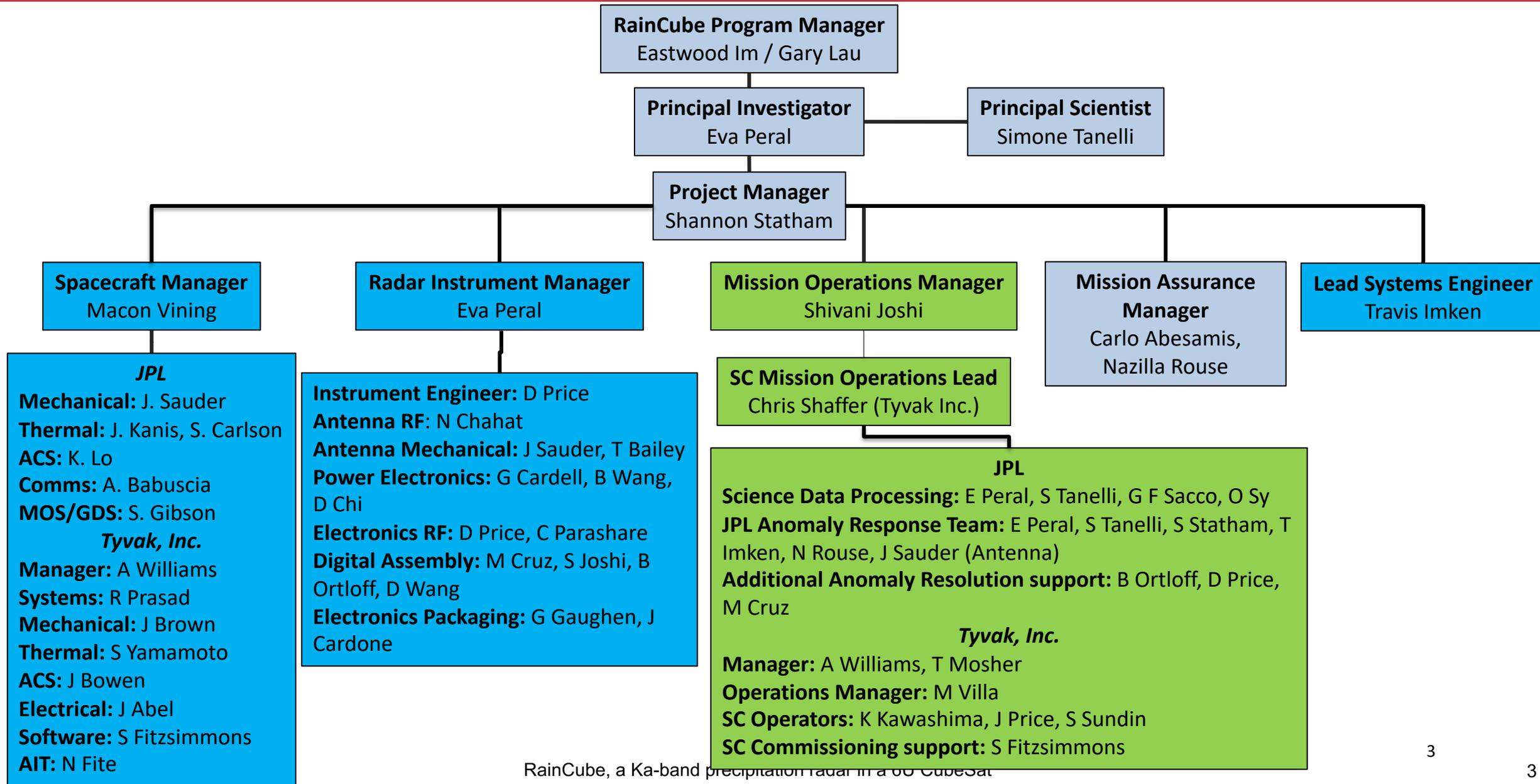
- **20dBZ sensitivity** (10 dBZ CBE)
- Vertically profile in **0-18 km altitudes**
- **10 km horizontal resolution** (8km CBE)
- **250 m vertical resolution**
- 35W in transmit (22W CBE)

## SC Bus (2U)

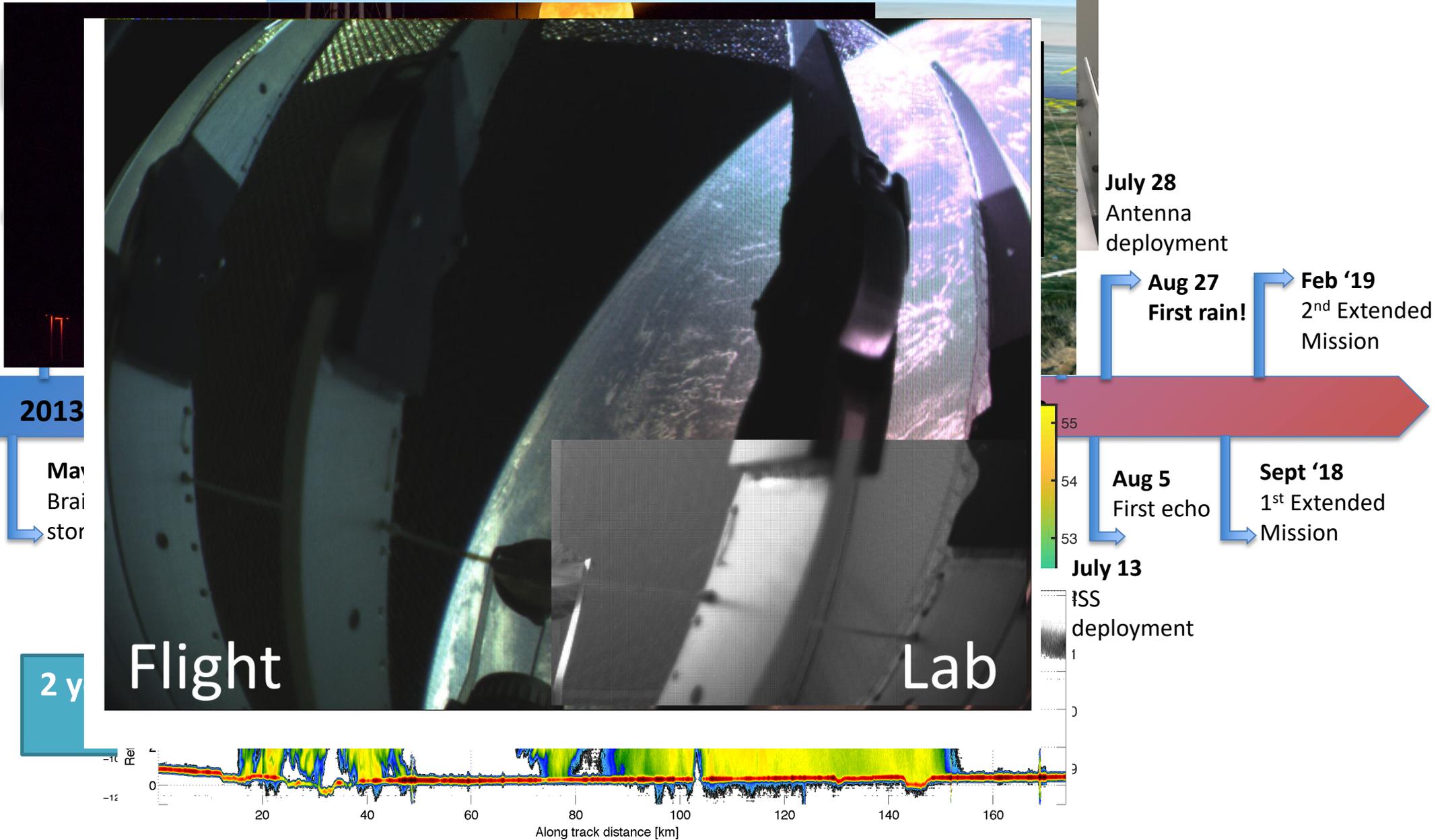
- Provide **35 W for payload power in transmit mode**
- Maintain payload temperatures (**-5C to +50C operational**)
- GPS provides **on-board altitude** to radar



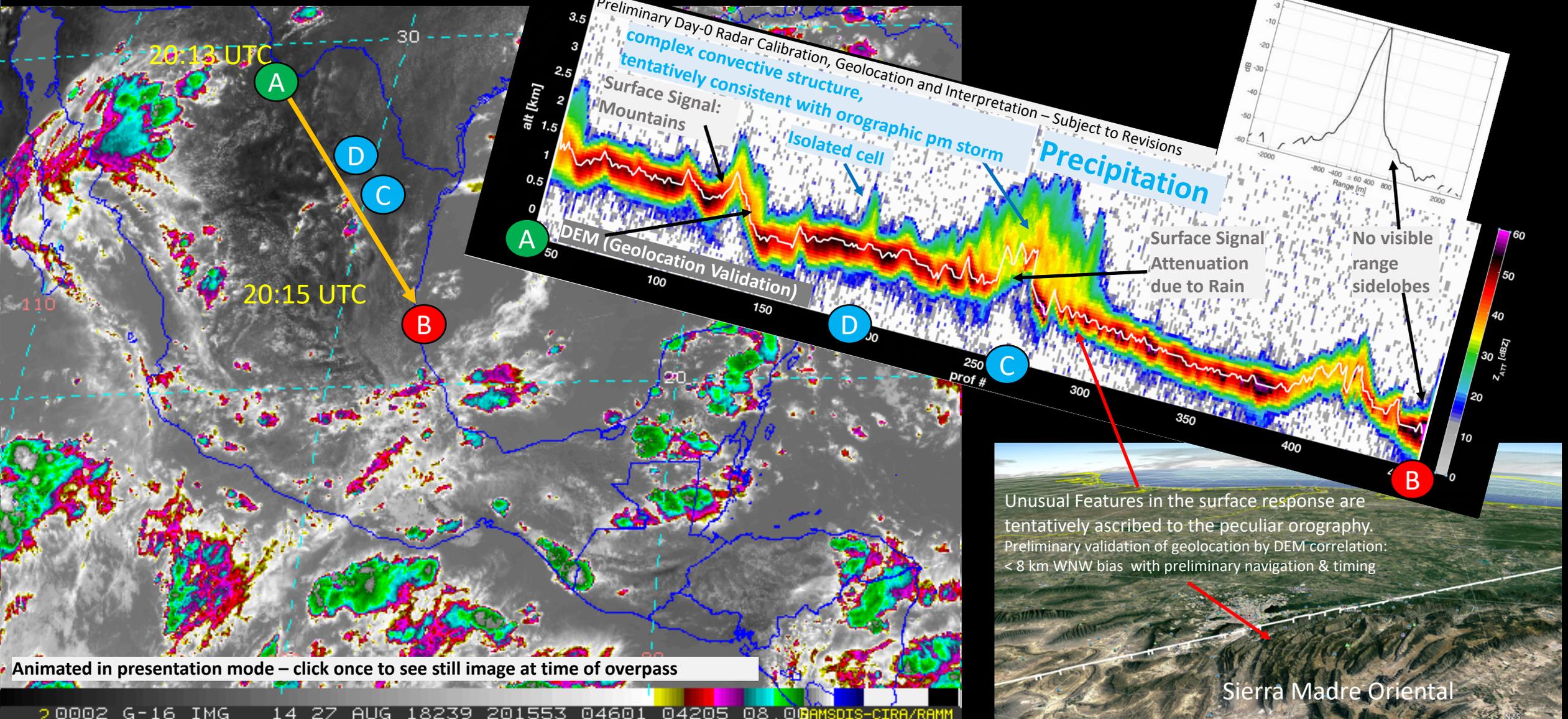
# Organization Chart



# Timeline from TRL0 to TRL 7

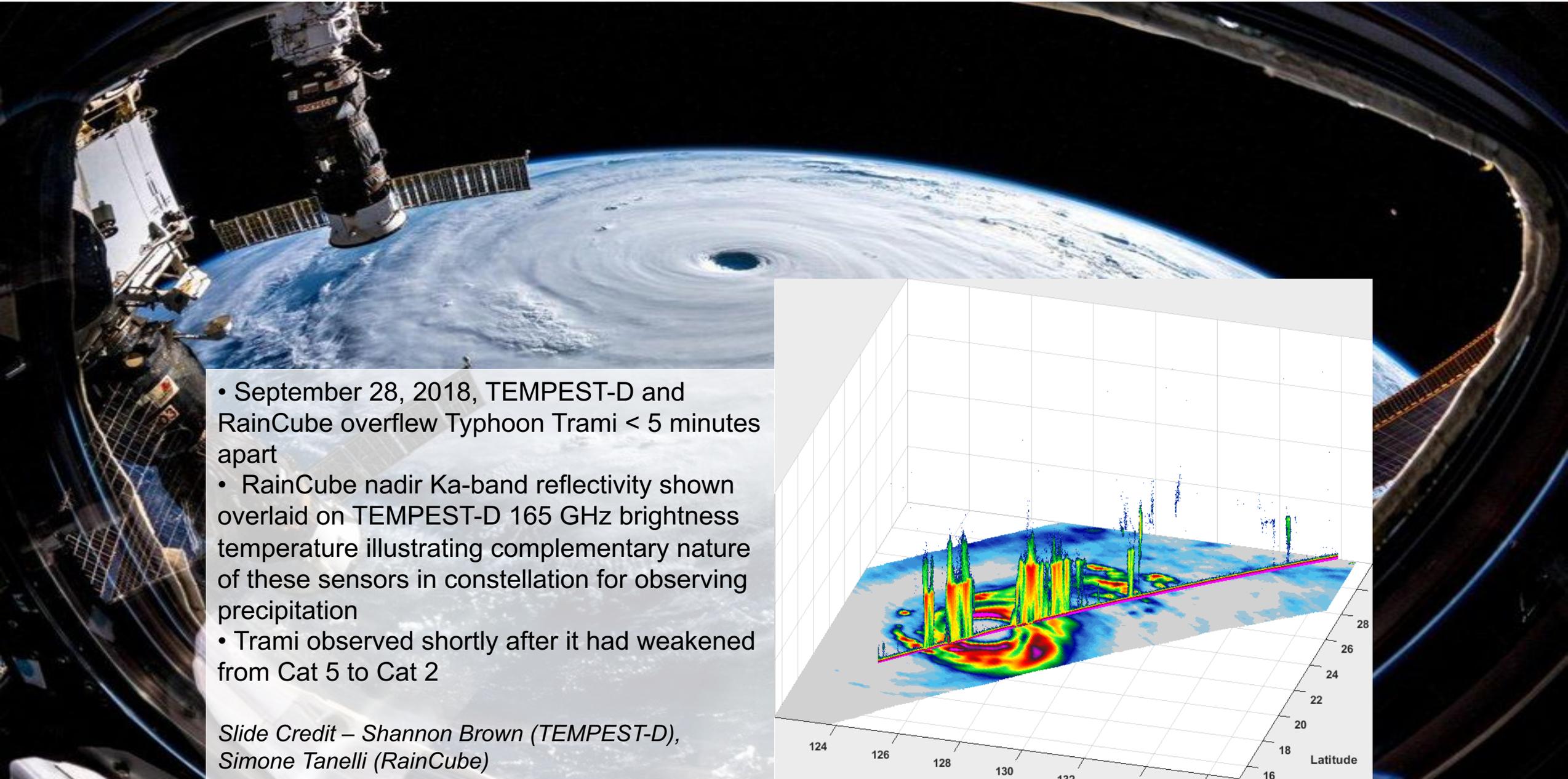


First successful operation in Nadir Pointing & first detection of rain over the Sierra Madre Oriental, near Monterrey, Mexico. Fast growing orographic precipitation developed shortly before RainCube's pass which overflowed its north-eastern edge



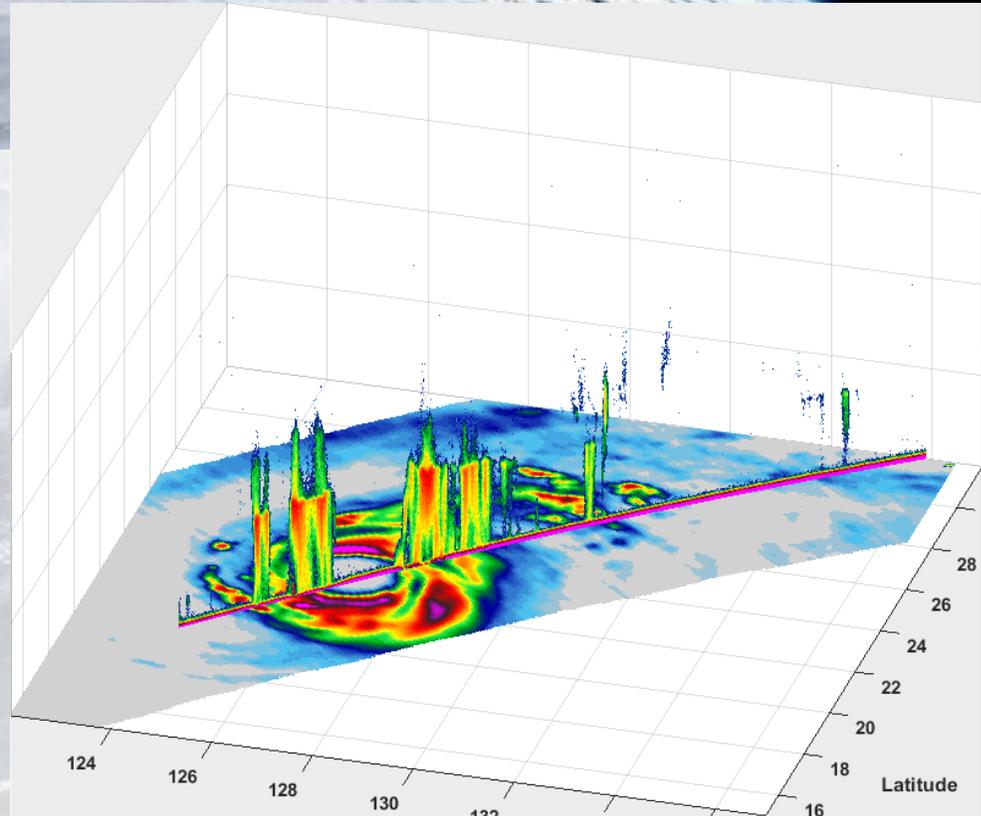
Animated in presentation mode – click once to see still image at time of overpass

# RainCube and TEMPEST-D coincidental measurement of Typhoon TRAMI



- September 28, 2018, TEMPEST-D and RainCube overflew Typhoon Trami < 5 minutes apart
- RainCube nadir Ka-band reflectivity shown overlaid on TEMPEST-D 165 GHz brightness temperature illustrating complementary nature of these sensors in constellation for observing precipitation
- Trami observed shortly after it had weakened from Cat 5 to Cat 2

*Slide Credit – Shannon Brown (TEMPEST-D), Simone Tanelli (RainCube)*



# Science Operations Planning



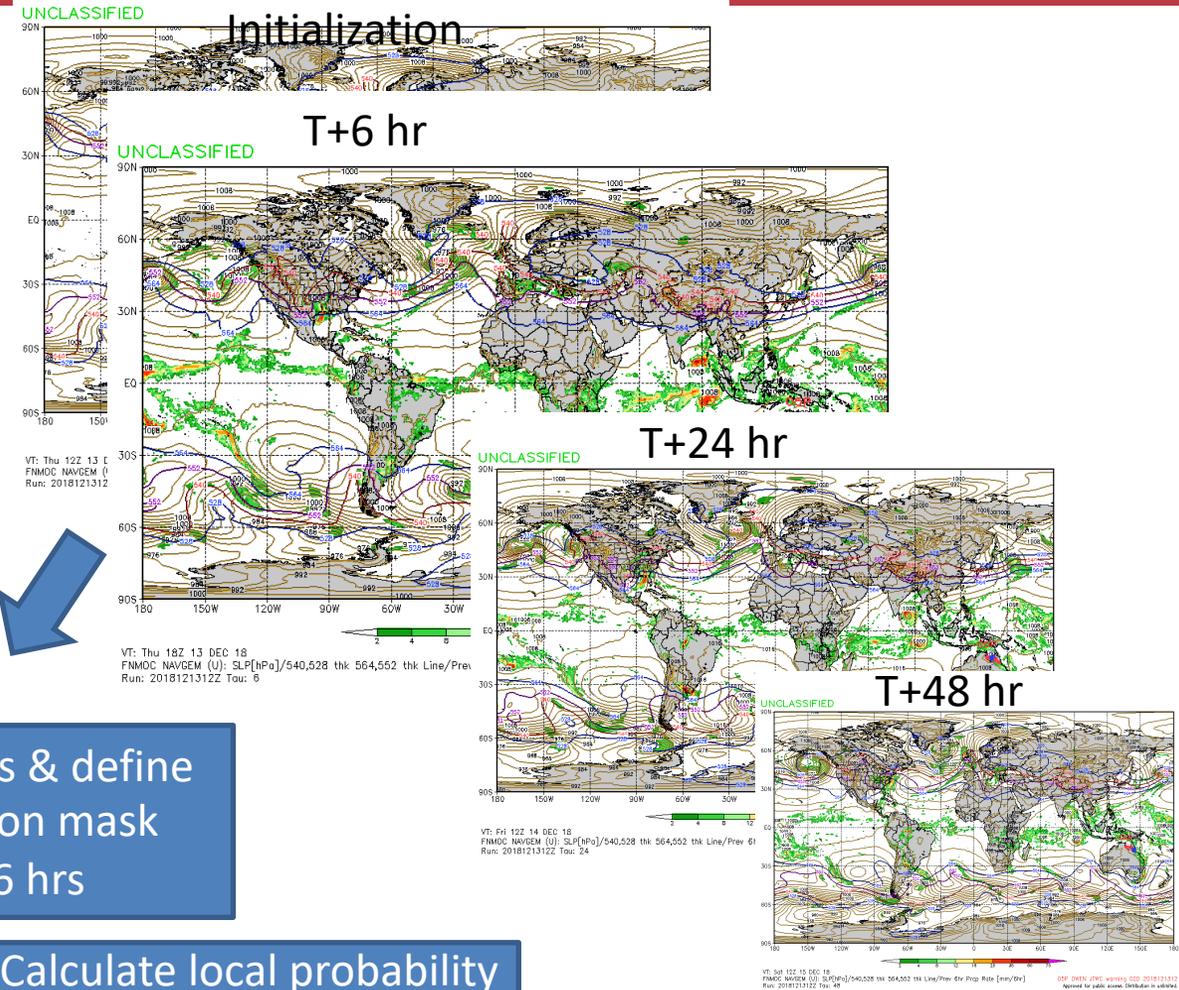
In order to improve efficiency of mission operations, we increased automation starting with automating the planning of events in a prioritized way

## • Constraints

- Maximum of 6 20 minute Radar Acquisitions per day
  - Imposed by spacecraft power system
- No operations on consecutive orbits
  - Imposed by spacecraft power system
- No operations in umbra
  - Preferred because of higher occurrence of reboots in umbra

## • Target Priorities

- Forecasted presence of precipitation
- CONUS – for NEXRAD
- GPM – for DPR
- Storms of interest



Parse images & define precipitation mask every 6 hrs

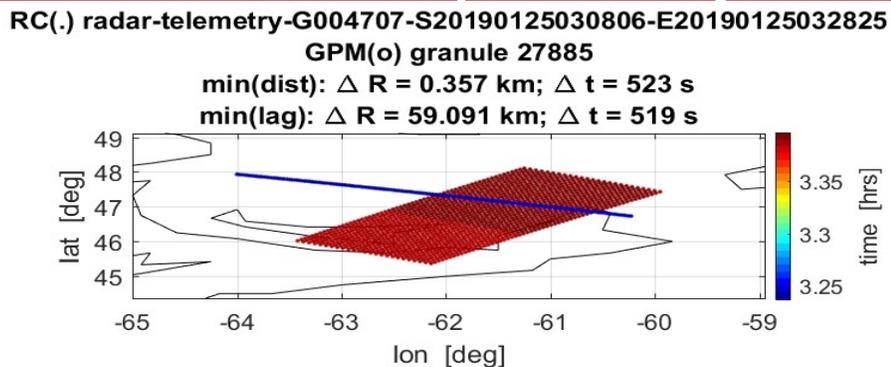
Calculate local probability of precipitation along the predicted orbit of RainCube

Prioritize close approaches with GPM and passes over GPM GV sites (CONUS, Japan, Australia)

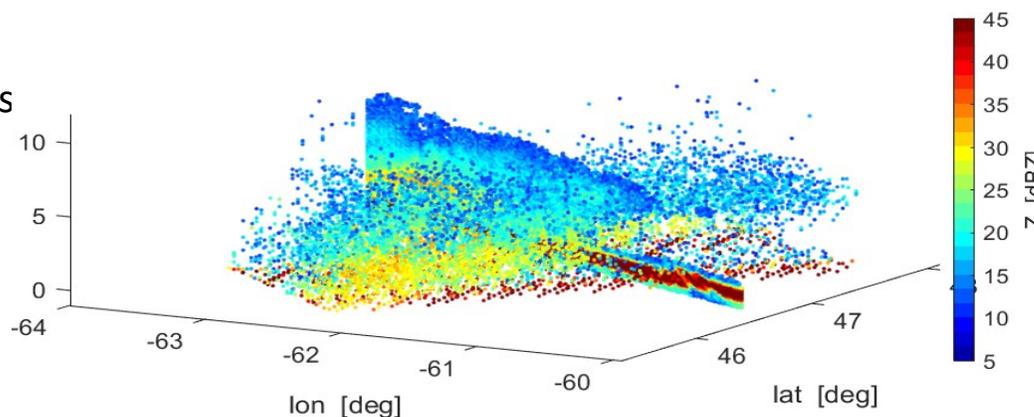
# RainCube Collocated Observations with GPM (Post Optimisation)



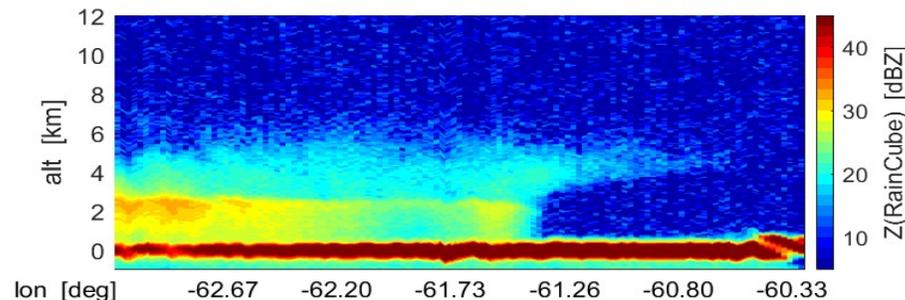
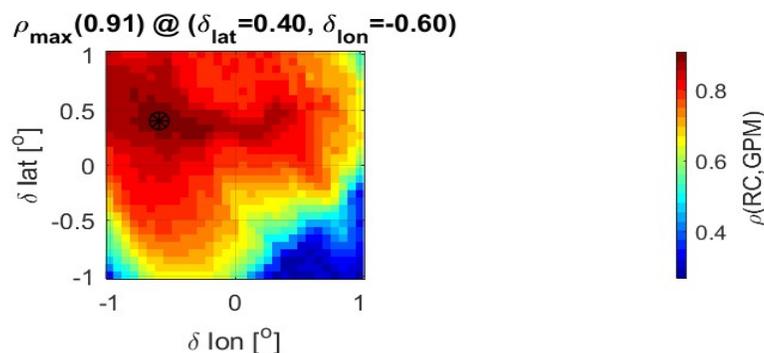
RainCube  
GPM  
tracks vs time



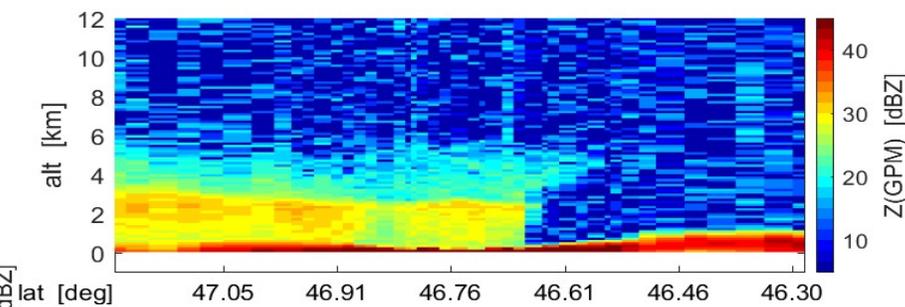
3D view of  
Observations  
close to  
intersection



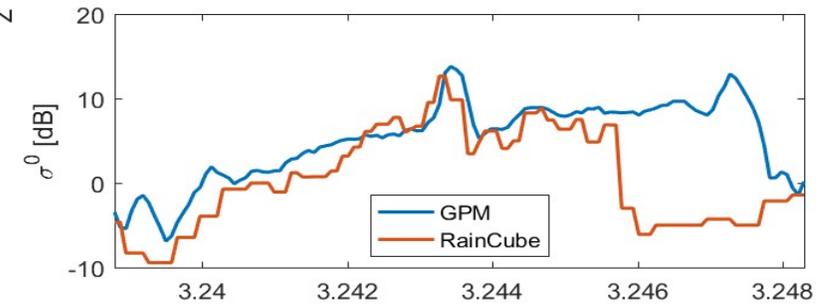
Pointing  
assessment



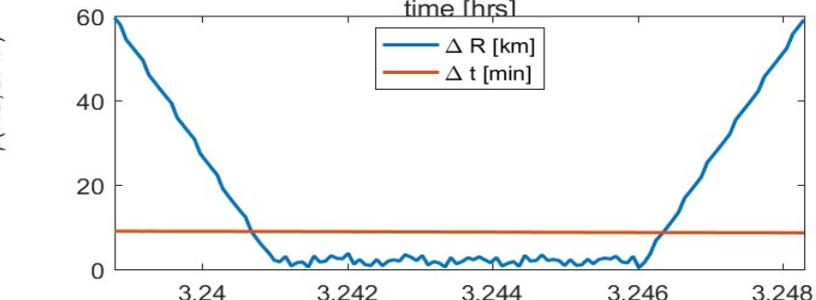
Z(RainCube)



Z(GPM)  
collocated



NRCS  $\sigma^0$



Separation  
between  
RainCube and  
closest GPM  
profile

# RainCube Data is Available on TCIS Portal

Jet Propulsion Laboratory  
California Institute of Technology

## TROPICAL CYCLONE INFORMATION SYSTEM

Welcome to Cyclone Info

The JPL Tropical Cyclone Information System (TCIS) was developed for tropical cyclone research. It has two main components: a multi-sensor archive of multi-sensor data and what was supported the 2002 Intensification Process Campaign. Together, they provide the near-real time data used to study hurricanes, improve models, algorithms and data products. Below you will find information you can view different

Supertyphoon Pongsona struck the U.S. Island of Guam on Sunday, December 8, 2002. The composite image (left) of the supertyphoon was made by overlaying data from the infrared, microwave, and visible/near-infrared sensors that make up the AIRS sounding system. This storm can also be seen with the standard AIRS Vis/NIR (right).

Site Manager: Svetla M Hristova-Veleva

PRIVACY

JPL HOME | EARTH | SOLAR SYSTEM | STARS & GALAXIES | SCIENCE & TECHNOLOGY

Browser address bar: <https://tcis.jpl.nasa.gov/data/>

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California Institute of Technology

## TROPICAL CYCLONE INFORMATION SYSTEM

### TCIS Data Repository

Here you will find data files from the JPL Tropical Cyclone Information System campaign portals. For additional information, please visit <https://tcis.jpl.nasa.gov/>

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Name	Last modified	Size
<a href="#">Parent Directory</a>		
<a href="#">camp2ex/</a>	2018-06-01 07:10	
<a href="#">cpex/</a>	2018-06-12 20:42	
<a href="#">epoch/</a>	2017-09-11 12:37	
<a href="#">hs3/</a>	2018-06-27 20:04	
<a href="#">raincube/</a>	2018-12-19 11:10	
<a href="#">shout/</a>	2017-10-18 09:51	
<a href="#">TC Data Archive/</a>	2018-06-29 10:02	

Site Manager: Svetla M Hristova-Veleva

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Browser address bar: <https://tcis.jpl.nasa.gov/data/>

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## TROPICAL CYCLONE INFORMATION SYSTEM

### Data from the RainCube Mission

For additional information, please visit <https://www.jpl.nasa.gov/cubesat/missions/raincube.php>.

Name	Last modified	Size	Description
<a href="#">Parent Directory</a>		-	
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<a href="#">L1A/</a>	2018-12-19 10:47	-	
<a href="#">L2A-GEOPROF/</a>	2018-12-19 11:01	-	
<a href="#">L2B-RAINCOLUMN/</a>	2018-12-19 11:10	-	

Site Manager: Svetla M Hristova-Veleva

PRIVACY

Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)

The Tropical Cyclone Information System will host RainCube data.  
Huge thank you to PI : Svetla Hristova-Veleva, Site Administrator Quoc Vu, and Data Manager Brian Knosp)

Tested posting data and accessing through url.  
L2 Data will be made public when QC is satisfactory.  
No plan to open L0 and L1 data to the public.

# Lessons Learned

## 1. Extended Formulation Phase

- Resulted in simplification of the architecture and **early execution of de-scopes** which focused the team on the core challenges needed for a successful technology demonstration.
- The many table top reviews with internal team of subsystem experts ensured that project and radar-system requirements captured mission's goals **without placing implementation burden on TBD bus vendor.**

## 2. Tailored versions of NASA and Institutional Flight Practices

- RainCube's project philosophy was to meet with all of the groups that are normally involved in flight projects and work with them to determine what benefits could be provided within the cost and schedule limits.
- For these items in which RainCube could not directly comply, the DTAB worked with the team to identify alternatives or mitigations. **The DTAB experts also provided guidance on the development of risk likelihoods, consequences, and mitigations that were specific to the mission.**

## 3. Pros and Cons of 6U form factor 4. Revise mass growth contingency

### Pros

- easy access to space through a standardized dispenser
- Most CubeSat bus vendors support this form factor
- More support and lessons learned available in CubeSat community

### Cons

- Routing of cables can be challenging
- Thermal control can be challenging
- Limits size of deployable antenna for radar applications

- The project was too conservative on mass through formulation and implementation due to the application of traditional 'large spacecraft' contingencies for mass growth.
- This overestimation is problematic on CubeSats since delivering significantly under mass could impact Earth orbit lifetime or require ballast to be installed into the spacecraft.
- The traditional 5-30% contingency applied to mass growth on large spacecraft should be reduced in CubeSat implementations, since the volume limits inhibit mass growth.

# Lessons Learned

## 5. Value of pre-Operations ORT

- RainCube's pre-operations readiness reviews with operations team at Tyvak gave the team chance to rehearse operations procedures for nominal and off-nominal situations.

## 6. Value of Anomaly Response Team

- Members of RainCube's ART provided valuable 24x7 anomaly response support to the operations team. They were instrumental in ensuring successful commissioning phase and prime mission success.

## 7. Prioritized mission objectives

- RainCube's PI and project scientist had clear objectives for operations team that went well beyond primary mission objectives.

# What's Next?

- Constellation of RainCube's "as is"

- Analyze the current dataset to demonstrate science questions.

- Constellation with a larger/scanning antenna

- To address a larger set of science questions
- Development of **technologies** and of **mission concepts** is ongoing

- Constellation with other Radars and Radiometers:

- A study team in the Earth Science Decadal Survey 2017 will consider RainCube-like constellations for measurements of convection and precipitation
- Higher frequency versions of RainCube for cloud and water vapor observations

- Planetary applications

- An evolution of this instrument could support altimetry and cloud and precipitation on planetary targets

**D-TRAIN The Dynamical Train Investigation**

D-Train will observe the rapid evolution of radar reflectivity profiles in storms, relate time-differenced reflectivity profiles to vertical transport of water in convection, and develop statistically robust relationships between convective mass flux, storm properties, and the environments in which storms form.

**Instrument System, Algorithms and Approach**

- D-Train uses 3 identical miniaturized downward-looking 5-beam Ka-band cross-track scanning radars, in a low-Earth-orbit.
- Each radar provides the 3-D field of equivalent radar reflectivity within the swath.

**Per Instrument Characteristics**

Parameters	Current Best Estimate
Mass	14.4 kg
Electronics Dimensions	20 cm x 20 cm x 10 cm
Antenna Diameter	1.6 m
Frequency	35.75 GHz
Peak Transmit Power	13 W
Data Demand	146 kbps
Power Demand	29 W
Peak Standby	3 W
Horizontal Resolution (nadir beam, 500 km altitude)	3.1 km
Vertical Resolution	240 m
Swath (5 beams across track)	15.7 km
Sensitivity	8 dBZ
Precision/Accuracy	0.4 dBZ / 1.5 dBZ

**NASA's Storm Chaser**

Tropical convective storms transport water and air from near the Earth's surface to the upper troposphere. They produce heavy rainfall and lightning from high clouds that affect Earth's radiation balance, and drive the large-scale atmospheric circulation. Convective vertical transport of water and air plays a critical role in Earth's weather and climate system, yet representing this transport is a major source of error in weather forecasting and climate models. Prediction of current weather and future climates is limited because there are no global observations of convective vertical mass flux.

D-Train will provide the first global measurements of tropical convective mass flux.

**Storm Lifecycle**

Towering Cumulus Stage | Mature Stage | Dissipating Stage

**D-Train Science Goals**

1. Advance our understanding of the relationships between environmental factors, storm properties, and convective mass flux
2. Evaluate the representation of convective mass flux in weather and climate models

**D-Train Key Science Questions**

1. How does the tropical convective mass flux depend on storm properties and environmental factors?
2. How does the convective mass flux impact anvil cloud properties and the severe weather (heavy rainfall, lightning) produced by tropical convection?
3. What are the relative contributions of the different types of tropical convective storms to the convective mass flux within the tropical atmosphere?

**Science Team**

Principal Investigator: Susan van den Heever, CSU  
 Deputy PI: Graeme Stephens, JPL  
 Project Scientist: Simone Tambelli, JPL  
 Project Manager: Raish Basilio, JPL

**Science Team**

M. Anderson, NOAA  
 B. Kahn, JPL  
 Z. Hudson, JPL  
 G. Huffman, GSFC  
 J. Liu, COMC  
 D. Powell, JPL  
 C. Schumacher, TX A&M

**Principal Investigator:** Dr. Susan van den Heever, Colorado State University

**Authorized Organizational Representative:** Dr. Alan S. Rutledge, Vice President for Research, Colorado State University

October 10, 2016  
 Submitted in response to INE17224000-5265

**SPECIAL ISSUE**

**Small Satellites**

Point of View: How Is the Networked Society Impacting Us?  
 Scanning Our Past: Who Invented the Earliest Capacitor Bank ("Battery" of Leyden Jars)? It's Complicated

**IEEE**

## Ka-band ESTO InVEST and ACT programs

	6U	12 U	50 kg
Antenna size [m]	0.5	1.0	2.0
Sensitivity [dBZ]	15	5-10	0-5
Hor Resolution [km]	8	4	2
Range Res [m]	250		
Beams	1	1-3	1-5
RF Power [W]	10	10-20	10-40

# Concluding remarks



- RainCube is **the first CubeSats to fly an active sensing radar payload**, and the mission's success could pave the way for future constellations or convoy of many precipitation profiling radars.
- Since deployment in July 2018 with an originally planned three month demonstration mission, **RainCube has been extended twice and has operated for nine months, three times its original mission length**
- Different methods of operating the instrument and the spacecraft have been demonstrated based on lessons learned on-orbit
- **JPL/Tyvak partnership and agility** has enabled RainCube to exceed original mission expectations
- **The project's lessons learned will be valuable** as JPL and other institutions propose and develop enabling science and technology demonstrations on the small satellite platform.

You can now follow RainCube on NASA's Eyes

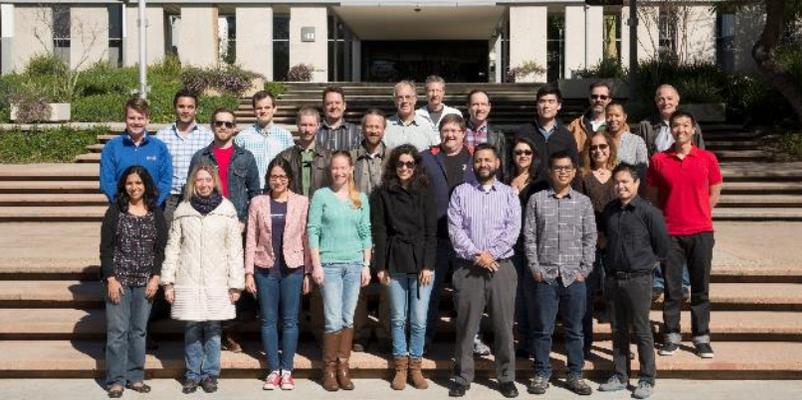
<https://go.nasa.gov/2PGdBus>

QuikSCAT

RainCube

SMAP

<p>DESTINATION</p> <p>CURRENT TARGET: RAINCUBE</p> <p> </p>	<p>DATE + TIME</p> <p>SEP 18, 2018 10:05:37.5 AM</p> <p>NOW</p> <p></p>	<p>YOUR SPEED + RATE</p> <p>54,255 MI/HR 1.00 SEC(S)/SEC</p> <p>REAL RATE</p> <p> </p>	<p>VISUAL CONTROLS</p> <p> </p> <p>FREE FLY - 60.0° </p>
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 RainCube Project Team  
February, 2017

