RainCube

Summary of Two Years Of Operations In Space

Presenter: Shivani Joshi (Mission Operations Manager)
Principal Investigator: Dr Eva Peral
Project Scientist: Dr Simone Tanelli
Project Manager: Dr Shannon Statham
Mission Operations Lead: Chris Shaffer

1. Jet Propulsion Laboratory, California Institute of Technology, CA, USA
2. Tyvak Nano-Satellite Systems Inc., CA, USA

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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
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Summary of Development

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

November 2015
InVEST Selection
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Summary of Development

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

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

Feb 2018
Delivery to NanoRacks for Launch

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

July 13, 2018

Deployment 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)

RainCube + Tempest-D
Radar-Radiometer observation of the asymmetric structure of Typhoon Trami as its intensity changed rapidly

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 \((Z, \sigma^0)\) to Ka-band observations from GPM

• “best comparisons” with persistent stratiform scenes

• Implemented an optimization approach that correlates RainCube’s \((Z, \sigma^0)\) 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 boresight –
  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
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 Precipitation) 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.

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

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

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California Institute of Technology

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