Jet Propulsion Laboratory
California Institute of Technology

6U Instruments for Weather

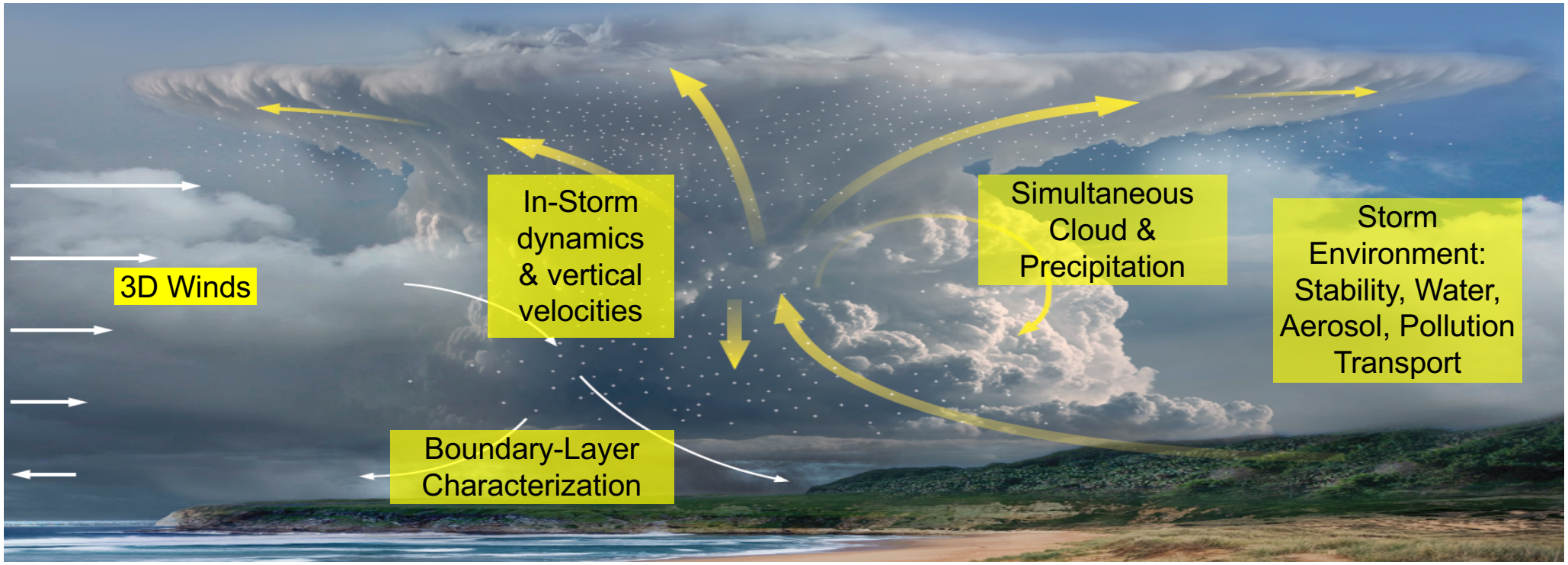
Jason Hyon
Jet Propulsion Laboratory
California Institute of Technology
February 14, 2017

Jet Propulsion Laboratory
California Institute of Technology

Complexity of Understanding Weather Science – Need for multiple measurements

- Constellations or GEO to monitor **storm evolution**
- Higher spatial resolutions to capture **mesoscale structure**
- Capture **microphysical processes** key to precipitation growth
- Advancing technology to characterize the atmospheric **boundary-layer**
- Improved atmospheric profiling to characterize the **storm environment**
- Characterizing storm dynamics and extremes with **Doppler radar**
- **Miniaturization** of sensors for **CubeSats**, constellations and lower costs

>=3 missions in order to provide all measurements



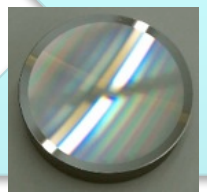
Jet Propulsion Laboratory
California Institute of Technology

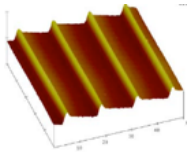
JPL's Miniaturized Weather Instruments

Visible

Miniature Dyson spectrometer

JPL e-beam grating

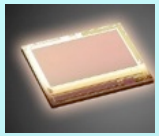




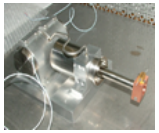
Infrared

JPL IR&D Wide-Field Grating Spectrometer (WFGS)

JPL BIRD MWIR Detectors



JPL Qualified Thales Cooler

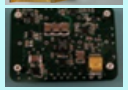


Microwave

Dual-Frequency Feedhorn

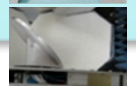
MMIC Receiver including Detector

Radiometer Backend and Power Conditioning



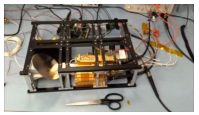
Motor and Drive Electronics

Reflector



Command and Data Handling: Onboard FPGA

MASC

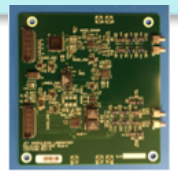


Radar

SSPA & Power Combiner

Up/Down Converter

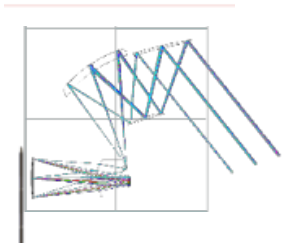
Processing (Pulse Compression and Modulation)



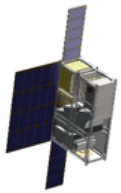
Gravity/formation Flying

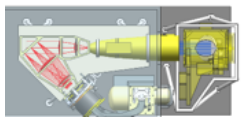
MicroGRACE Gravity Measurement
Spatial: submm accuracy
SWAP: 6U, 20 kg, 30 W, <1 Mbps

Snow and Water Imaging Spectrometer
Spatial: ±5°, 0.28 km
Spectral: 228 Bands, 350 nm – 1.65 µm
SWAP: 6U, 9 kg, 15W, 5 Mbps

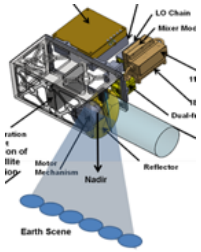


CubeSat Infrared Atmospheric Sounder (CIRAS)
Spatial: ±48.3°, 13.5 km
Spectral: 1000 Channels, 4.1-5.4 µm
SWAP: 6U, 20 kg, 30 W, 1 Mbps

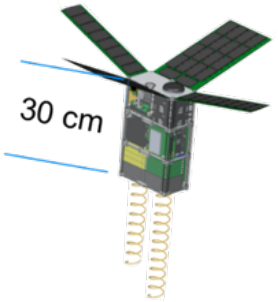




Microwave Atmospheric Sounder on CubeSat (MASC)
Spatial: ±45°, 15 km (183) – 20 km (118)
Spectral: 8 Channels: 118-183 GHz
SWAP: <0.01 m^3, 3 kg, 7 W, 10 kbps



RainCube: Precipitation Profiler
Spatial: 5 km (Horiz) x 250m (Vert)
Spectral: 35.6 GHz
SWAP: 6U, 20 kg, 30 W, <1 Mbps



Total Identified Here: 72kg, 112W, 8 Mbps

RainCube & MASC First Airborne Observations of Clouds and Precipitation during the PECAN Experiment (June-July 2015)

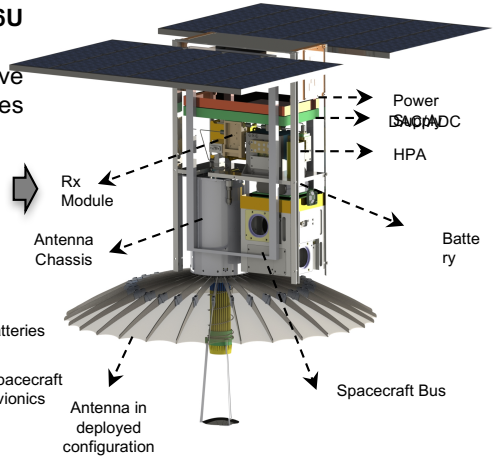
RainCube & MASC are instruments developed at JPL for deployment in **6U CubeSats**.

They will enable **affordable LEO constellations** to observe **cloud and precipitation processes** as they evolve at the timescales needed to validate and improve weather and climate models.

RainCube

PI: Eva Peral

- nadir-pointing Ka-band precipitation radar (35.7 GHz)
- novel architecture to achieve the required sensitivity with low-power radar electronics that fit in 2U
- High-performance pulse compression to reduce surface clutter contamination and achieve sensitivity and range resolution.
- Lightweight Deployable antenna stowes in 1.5 U (no… replaced by a horn-lens antenna).

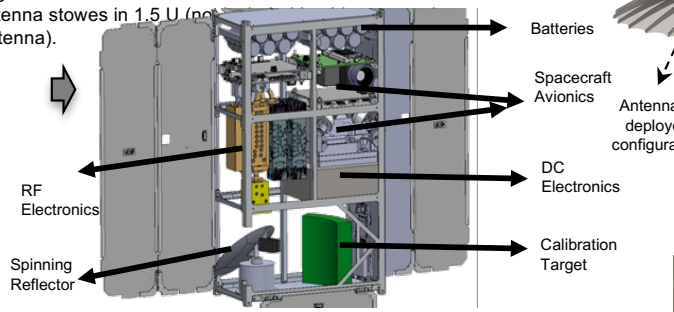


MASC

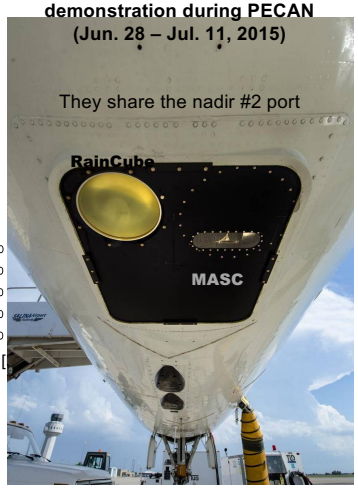
(Microwave Atmospheric Sounder on CubeSat)

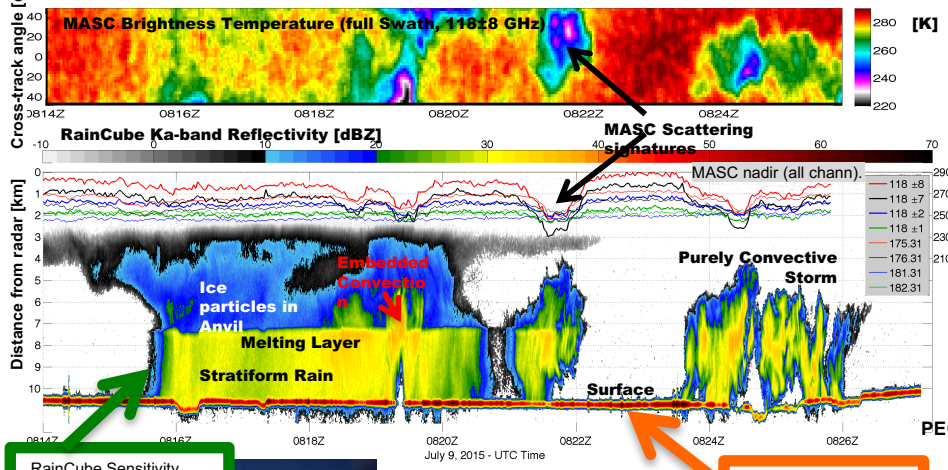
PI: Sharmila Padmanabhan

- 8 channel mm-wave radiometer (4 channels near 118GHz, 4 channels near 183 GHz)
- Cross-track scanning (±50˚)



Both operated successfully on the NASA DC-8 for their **first airborne test and demonstration during PECAN (Jun. 28 – Jul. 11, 2015)**





RainCube Sensitivity and Resolution : confirmed

RainCube Pulse Compression performance: confirmed

- No faults or glitches from first flight to last flight.
- Fine calibration and science analysis: in progress.
- Coordinated operations with ground based weather radars

PECAN = Plains Elevated Convection At Night

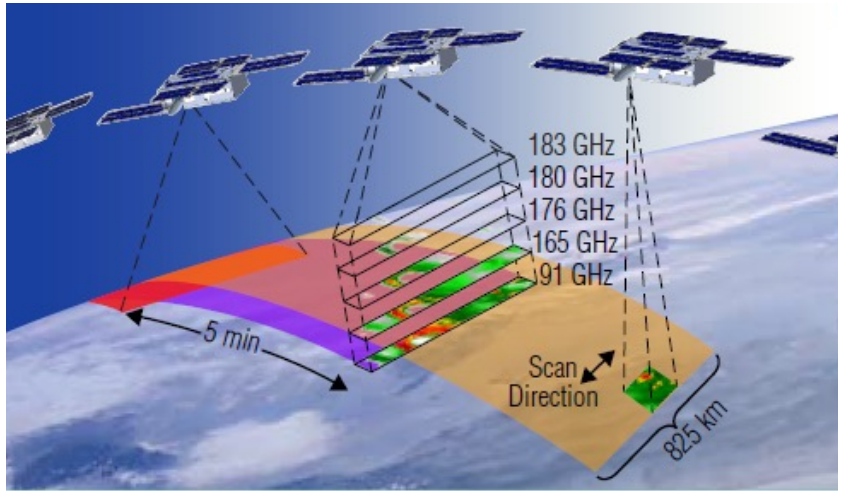
https://www.eol.ucar.edu/content/pecan-iss
http://asr.science.energy.gov/meetings/stm/2013/presentations/PECAN-update.pdf
http://www.nssl.noaa.gov/projects/pecan

Acknowledging:

- **AFRC**: excellent coordination and rapid implementation
- **PECAN** Science Leadership: outstanding flexible and creative collaboration
- **OU ARRC**: coordinated deployment of X-band ground based weather radars
- **Weather Focus Area** Leads: additional flight hours to PECAN for RainCube and MASC
- **Kansas City Star** picture gallery: http://www.kansascity.com/news/local/article27710704.html

Jet Propulsion Laboratory
California Institute of Technology

Constellation of CubeSats: Calibration



Instrument performance flow-down from science requirements.

Characteristic	Instrument Capability	From Science Requirement
Half-Power Beamwidth (HPBW)	2.9° (118 GHz) 1.8° (183 GHz)	<4° (118 GHz) <3° (183 GHz)
Intersatellite Precision	0.6 K	1.2 K
Absolute Tb Accuracy	3 K	4 K

Instrument Thermal Stability Requirements

Component	Operating Temp	Thermal Stability
Calibration target	20°C–40°C	±3.0°C/orbit
Receiver electronics	0°C–40°C	±1.5°C/orbit
Back-end electronics	20°C–40°C	±5.0°C/orbit

The science requirements are

- **a precision among all CubeSats of 2 K and**
- **an absolute accuracy of 4 K**

The 2 K precision requirement has two major components:

(1) instrument noise, including calibration uncertainty and antenna pattern knowledge, and

(2) observation noise due to sampling and Earth incidence angle (EIA) errors. We allocate 1.2 K to instrument noise and 1.6 K to observation noise (for an RSS of 2 K).

Instrument error allocation for intersatellite precision requirement.

Error Allocation	118 GHz	183 GHz
Measurement noise (NEΔT, 1/f, 2 Instruments)	0.48 K	0.61 K
Residual antenna temperature error	0.1 K	0.1 K
Residual brightness temperature calibration	0.15 K	0.15 K
RSS total error allocation	0.51 K	0.64 K
Flowed down from Science Requirement	1.2 K	1.2 K

Jet Propulsion Laboratory
California Institute of Technology

Mission Trade

	Ocean focus – Cubesat	Ocean focus	Coasts focus - Cubesat	Coasts focus	Land focus	Landsat-like
Spatial Res	1 km	1 km	200 m	200 m	60 m	30 m
Global Revisit	1 day	1 day	9:30 AM + 3:30 PM Daily	9:30 AM + 3:30 PM Daily	10 day	16 day
Global Coverage each revisit	100%	100%	8%	40%	100%	100%
# of Satellites	30	4	18	4	4	12
FOV [deg]	40	40 x2	12 (36 FOR)	30	9	1.5
# of Launches	3	1	2	1	1	3
Altitude [km]	561	561	561	561	626	619
Instrument dimensions	0.01x0.02x 0.01 m	(0.01x0.02x 0.01 m) x2	0.01x0.02x 0.01 m	0.3x0.2x 0.2 m	0.6x0.45x 0.45 m	0.3x0.2x 0.2 m
# of x-track detector elements	400	600 x2	600	1600	1600	600
F stop	F 1.8	F 1.8	F 1.8	f 1.8	f 1.8	f 3
Spacecraft class	Cubesat	SSTL 150 class	Cubesat	SSTL 150 class	SSTL 300 class	SSTL 300 class

Jet Propulsion Laboratory
California Institute of Technology

Recommendation

- Define science missions only CubeSat can solve with the lower cost
  - Temporal sampling and heterogeneous instruments
- Miniaturized science instruments that are fully self calibrated
- Establishment of a reliable ground network
- Class C spacecraft
- Industry driven – propulsion, communication, avionics, power