

Potential Future NASA Satellite Data and Applications for Tropical Cyclones

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With contributions from many others

Earth Science Missions and Instruments

- Formulation
- Implementation
- Primary Ops
- Extended Ops

Altimetry-FO (Formulation in FY16; Sentinel-6/Jason-CS)

Earth Science Instruments on ISS:
 RapidScat, CATS,
 LIS, SAGE III (on ISS), TSIS-1, OCO-3,
 ECOSTRESS, GEDI,
 CLARREO-PF

CYGNSS
 ~2016-18

The Future

GRACE-FO (2)

ICESat-2

CYGNSS

SORCE,
 TCTE (NOAA)

NISTAR, EPIC
 (NOAA's DSCOVR)

Landsat 7
 (USGS)

Aqua

CloudSat

CALIPSO

Aura

GRACE (2)

OSTM/Jason 2
 (NOAA)

PACE

Landsat 9,
 TIR-FF

NI-SAR

SWOT

TEMPO

JPSS-2 (NOAA)
 RBI, OMPS-Limb

New-ish Satellites

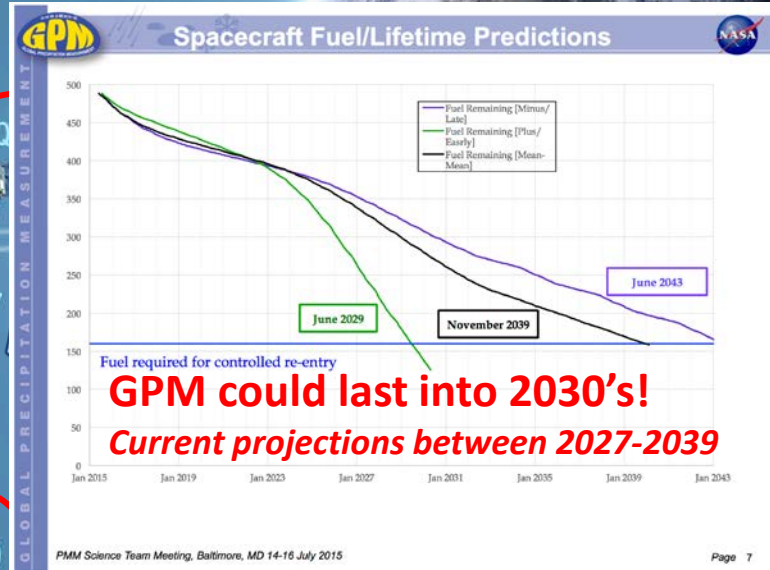
SMAP

Suomi NPP
 (NOAA)

Landsat 8
 (USGS)

GPM

OCO-2



NASA's Role is Technology Development and Research

Earth Venture Mission (full satellite missions) competed every 4 years

- **CYGNSS selected in EVM-1**, launch NET Oct 2016
 - Small sat constellation to measure ocean surface wind speed in hurricanes

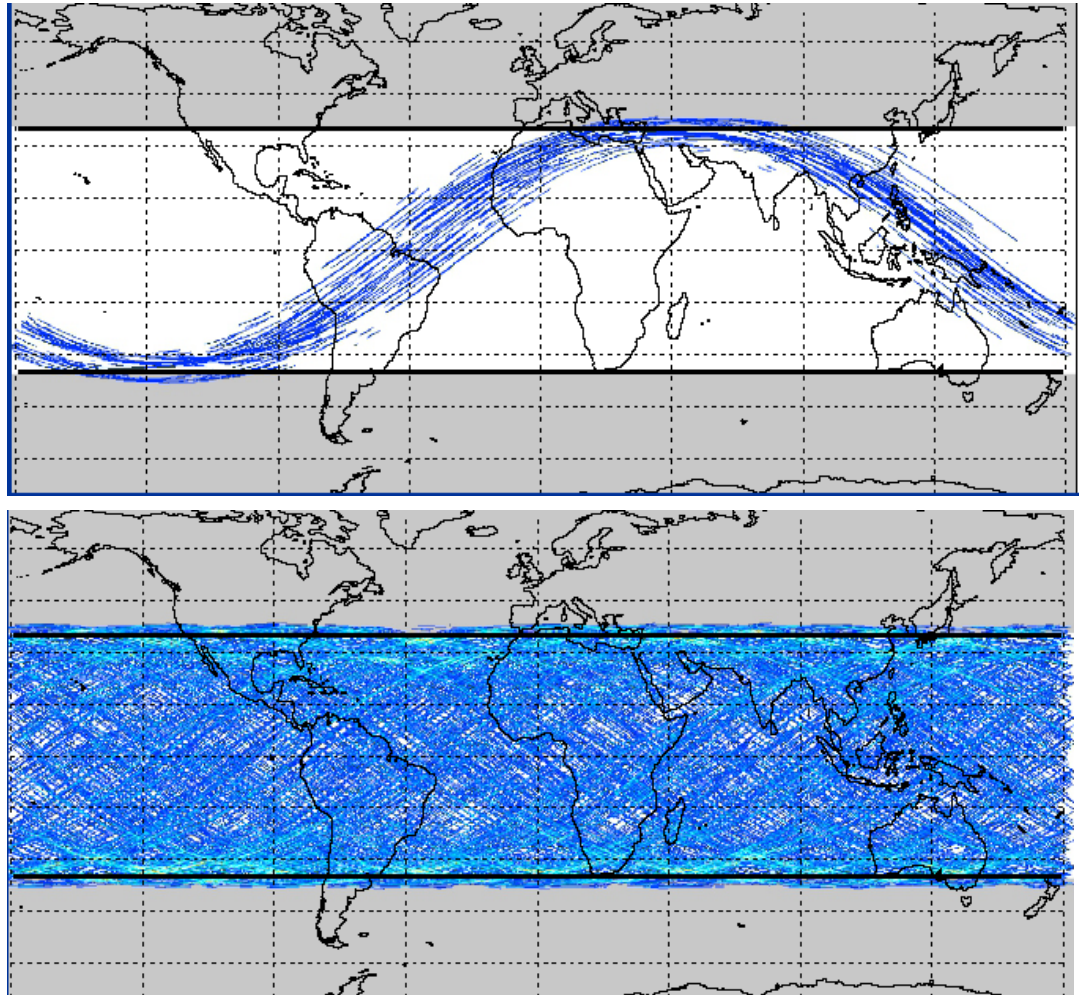
Earth Venture Instrument (satellite instruments and cubesat missions) competed every 18 months

- **TROPICS selected in EVI-3**, launch ~2019-ish
 - Cubesat constellation with sounding radiometers to measure thermodynamic and precip structure with frequent (~hourly?) re-visits

Other programs support initial instrument development, testing

CYGNSS Earth Coverage

- 90 min (one orbit) coverage showing all specular reflection contacts by each of 8 s/c
- 24 hr coverage provides nearly gap free spatial sampling within ± 35 deg orbit inclination



Courtesy Chris Ruf, University of Michigan, cruf@umich.edu



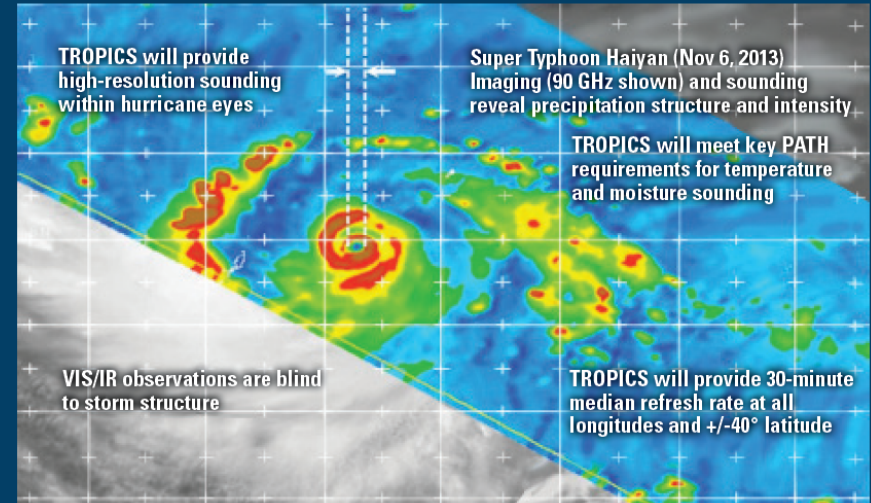
Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

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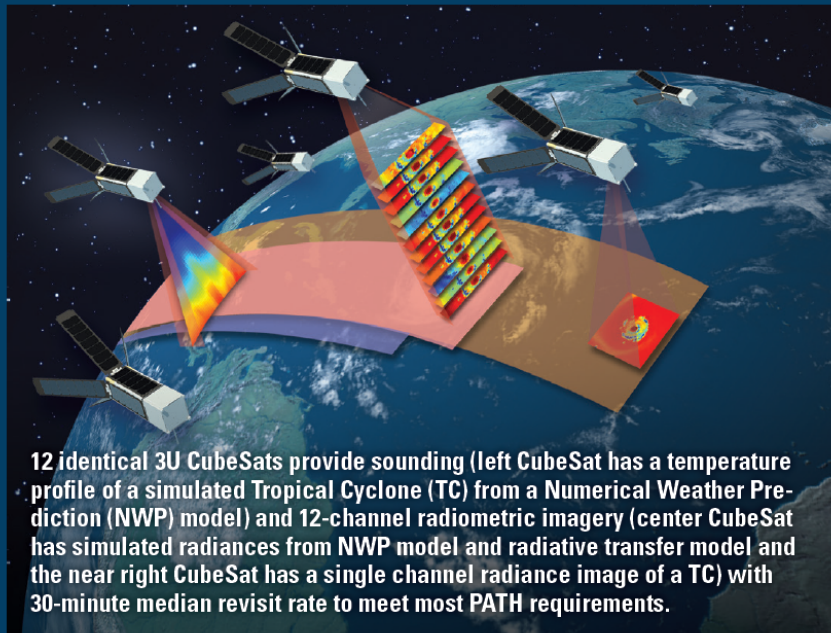
Science Objectives

- Relate precipitation structure evolution, including diurnal cycle, to the evolution of the upper-level warm core and associated intensity changes
- Relate the occurrence of intense precipitation cores (convective bursts) to storm intensity evolution
- Relate retrieved environmental moisture measurements to coincident measures of storm structure (including size) and intensity
- Assimilate microwave radiances and/or retrievals in mesoscale and global numerical weather prediction models to assess impacts on storm track and intensity



Significance to NASA

- First high-revisit microwave nearly global observations of precipitation, temperature, and humidity
- Fulfills most of PATH Decadal Survey mission objectives using a low-cost, easy-to-launch CubeSat constellation
- Complements GPM, CYGNSS, and GOES-R missions with high refresh, near-all-weather measurements of precipitation and thermodynamic structure
- Increases understanding of critical processes driving significant and rapid changes in storm structure/intensity



12 identical 3U CubeSats provide sounding (left CubeSat has a temperature profile of a simulated Tropical Cyclone (TC) from a Numerical Weather Prediction (NWP) model) and 12-channel radiometric imagery (center CubeSat has simulated radiances from NWP model and radiative transfer model and the near right CubeSat has a single channel radiance image of a TC) with 30-minute median revisit rate to meet most PATH requirements.

In-Space Validation of Earth Science Technologies (InVEST)

Not necessarily a complete list:

- The Microwave Radiometer Technology Acceleration (MiRaTA) CubeSat (Jan 2017, JPSS-1)
- Precipitation Profiling Radar in a CubeSat (RainCube – launch NET Aug 2017)
- Compact Infrared Radiometer in Space (CIRiS)
- CubeSat Infrared Atmospheric Sounder (CIRAS)

Concepts in Various Stages of Development

- Next slides cover some concepts I'm aware of that are relevant... *not all-inclusive*
- *This does not imply any official endorsement*

Temporal Experiment for Storms and Tropical Systems (TEMPEST)

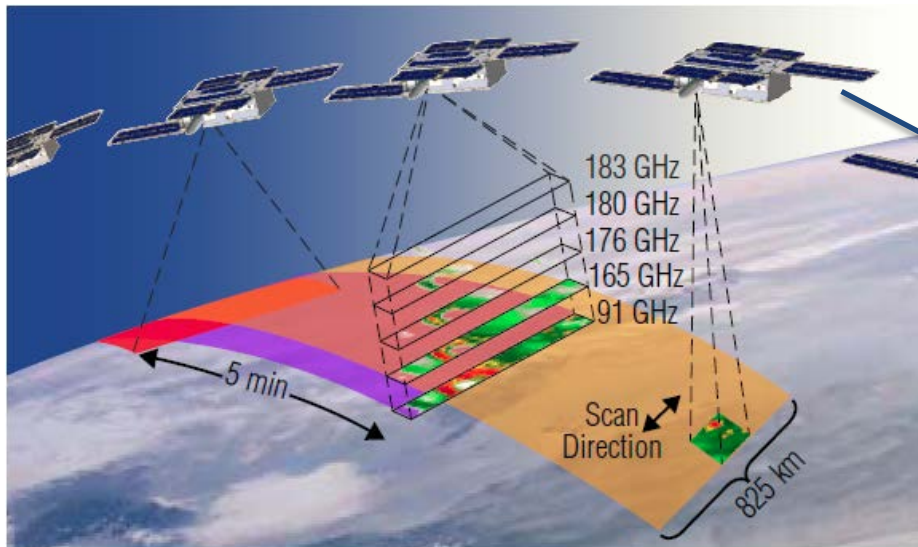
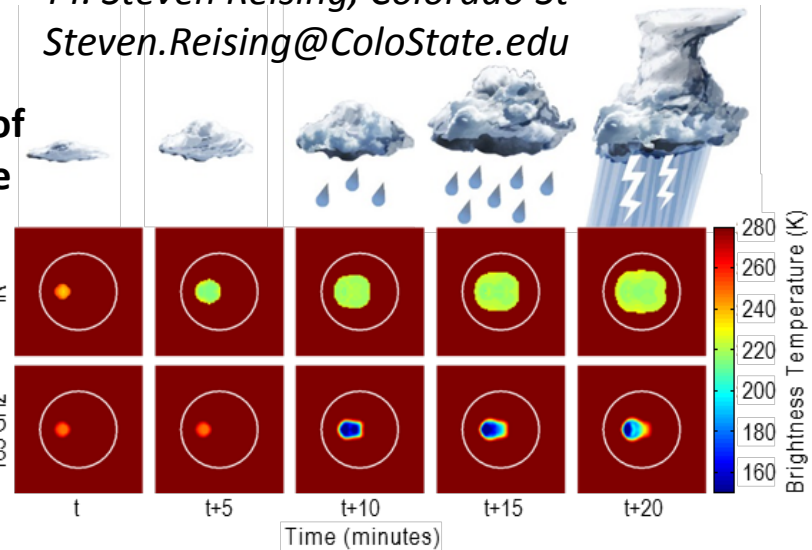
BENEFITS AND STRENGTHS

- First global observations of time evolution of precipitation
- Low-cost approach using 6U-Class satellites
- Unique data sets to enable improved weather and climate prediction models
- Significant impacts on agricultural forecasting, forest management and disaster preparedness
- Experienced collaborative team: Colorado State University (CSU), Caltech JPL and BCT

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Temporal
evolution of
convective
system

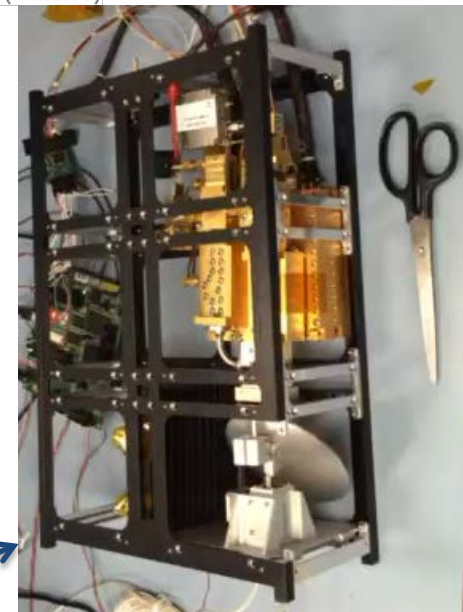
IR
Brightness
Temperature
mm Brightness
Temperature



5 identical 6U CubeSats, each with an identical
5-channel radiometer, flying 5 minutes apart



MASC prototype
(S. Padmanabhan)



RainCube and MASC

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

- 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 stows in 1.5 U (not included in airborne version, replaced by a horn-lens antenna).

MASC (Microwave Atmospheric Sounder on CubeSat)

- 8 channel mm-wave radiometer (4 channels near 118GHz, 4 channels near 183 GHz)
- Cross-track scanning ($\pm 50^\circ$)

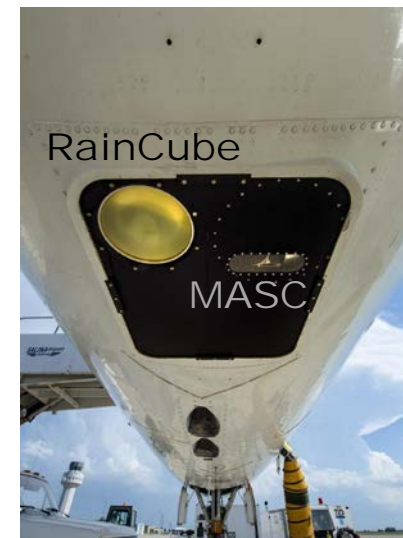
MASC POC: *Sharmila Padmanabhan, JPL*
Sharmila.Padmanabhan@jpl.nasa.gov

Ongoing Developments for next decade:

Scanning Doppler radars in low earth orbit, to provide a swath of precipitation and vertical motion with acceptable (a few km) horizontal resolution

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

Courtesy Simone Tanelli, JPL
simone.tanelli@jpl.nasa.gov



Hurricane Imaging Radiometer (HIRAD)

Dual-polarization version of HIRAD to measure wind speed and direction from Low Earth Orbit

Want to develop airborne version of this capability first, then LEO

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