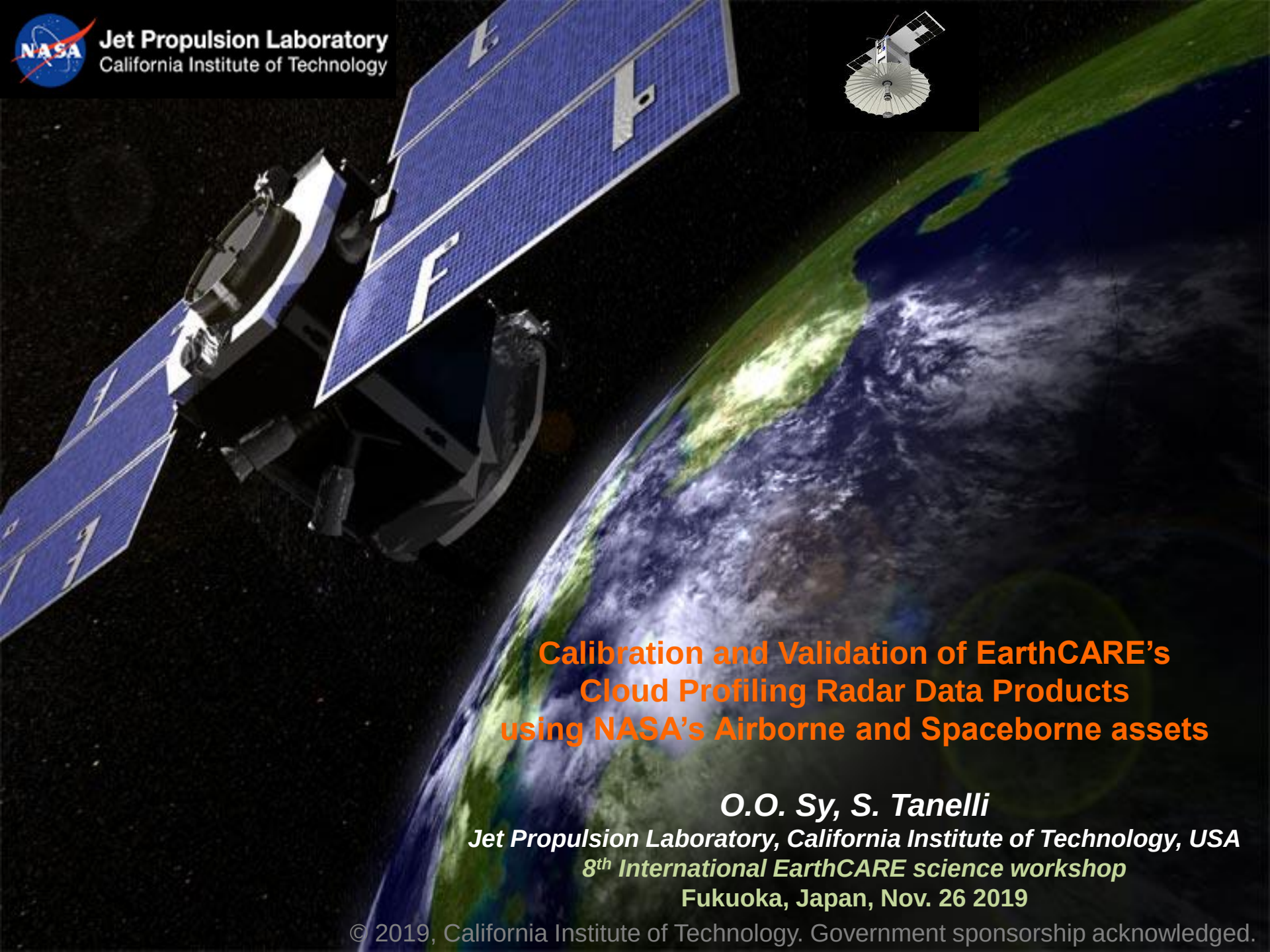
Jet Propulsion Laboratory
California Institute of Technology



Calibration and Validation of EarthCARE's Cloud Profiling Radar Data Products using NASA's Airborne and Spaceborne assets

O.O. Sy, S. Tanelli

Jet Propulsion Laboratory, California Institute of Technology, USA

8th International EarthCARE science workshop

Fukuoka, Japan, Nov. 26 2019

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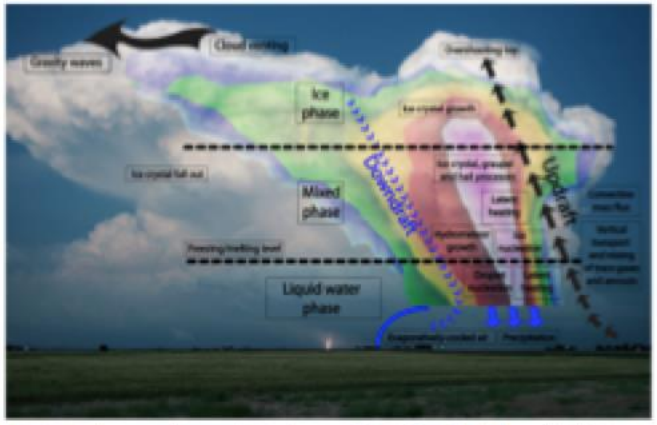
Science Driver on Next-Generation Atmos Radars – Process Study

- ``**Clouds, Convection, and Precipitation** DO, *Candidate Measurement:* **combination of radar frequencies and Doppler [...]**
  the radar can be descoped to a single band, while **retaining Doppler capability**.''
  (NASA Decadal Survey 2017)

- Capture **cloud/precipitation process** via
  - **Multi-frequency** radar data
    to increase measurement dynamic range & study microphysics
    TRMM → GPM
  - Simultaneous **Doppler velocity**
    to associate dynamics to hydrometeors
    CloudSat → EarthCARE
  - Capture **time evolution** processes
    - **GEO** radars (e.g. life cycle of cyclones)
    - **LEO** radar **constellation**



GV activities in synergy with CloudSat, GPM and CCP

NASA airborne campaigns:

(APR-3, airMASTR)

Synergies and opportunities

Part 1

EarthCARE

Part 2

RainCube:

New paradigm

Part 3

Forward modeling

for algorithm development and validation:

High-Resolution Radar based, or Model Based

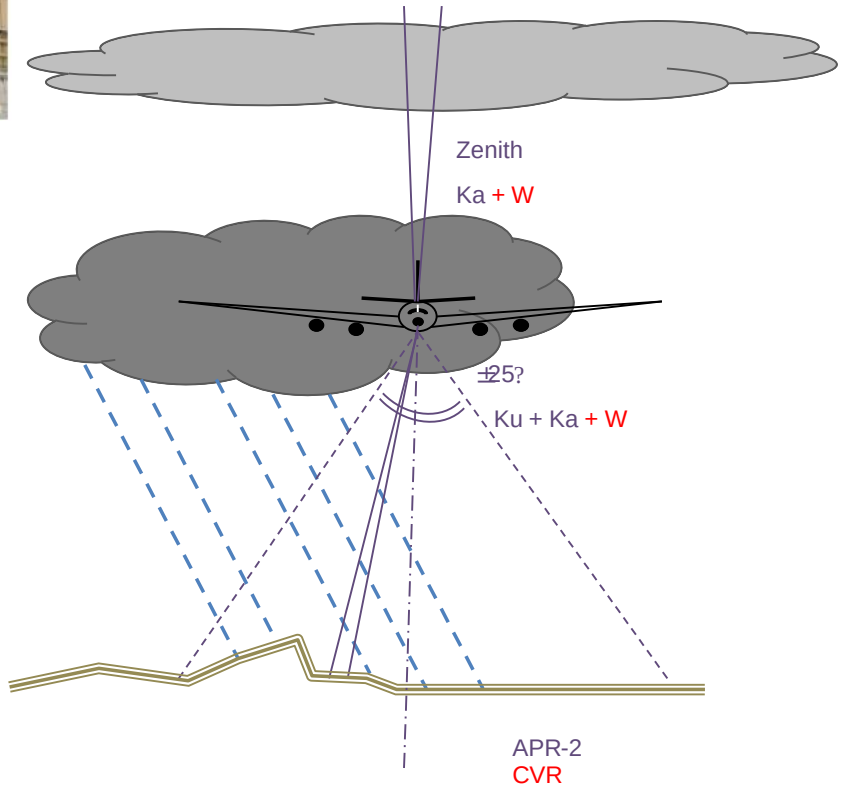
APR-3 (S.L. Durden PI, S. Tanelli PI)

3 bands, collimated through the scanning antenna on nadir port,
Ka and W also radiate at zenith

1st deployment
ACE RADEX/OLYMPEX 2015

support science of GPM, CloudSat, ACE, CCP, RainCube, SWOT.

Parameters	Ku-band	Ka-band	W- band
Frequency(GHz)	13.4	35.6	94
Polarization	HH, HV	HH	HH
Antenna eff. diameter	0.4 m	0.14 m	0.3 m
Antenna gain	34 dBi	34 dBi	50 dBi
Antenna sidelobe	-30 dB	-30 dB	-30 dB
Antenna scan angle	±25˚	±25˚	±25˚
Polarization isolation	-25 dB	-	-
Peak power	200 W	500 W	1400 W
Bandwidth	4 MHz	4 MHz	4 MHz
Pulsewidth	3 - 20 ms	3 - 20 ms	0.25,0.5, 1ms
PRF (pulse rep. freq.)	5 kHz	5 kHz	5 kHz
Vertical resolution	60 m	60 m	50, 80, 150m
Hor.res.(@10 km alt.)	800 m	1000 m	200 m
Ground Swath	10 km	10 km	10 km
Sens.(@10km range)	10 dBZ	-10 dBZ	-35 dBZ
Doppler precision	0.3 m/s	0.3 m/s	0.3 m/s



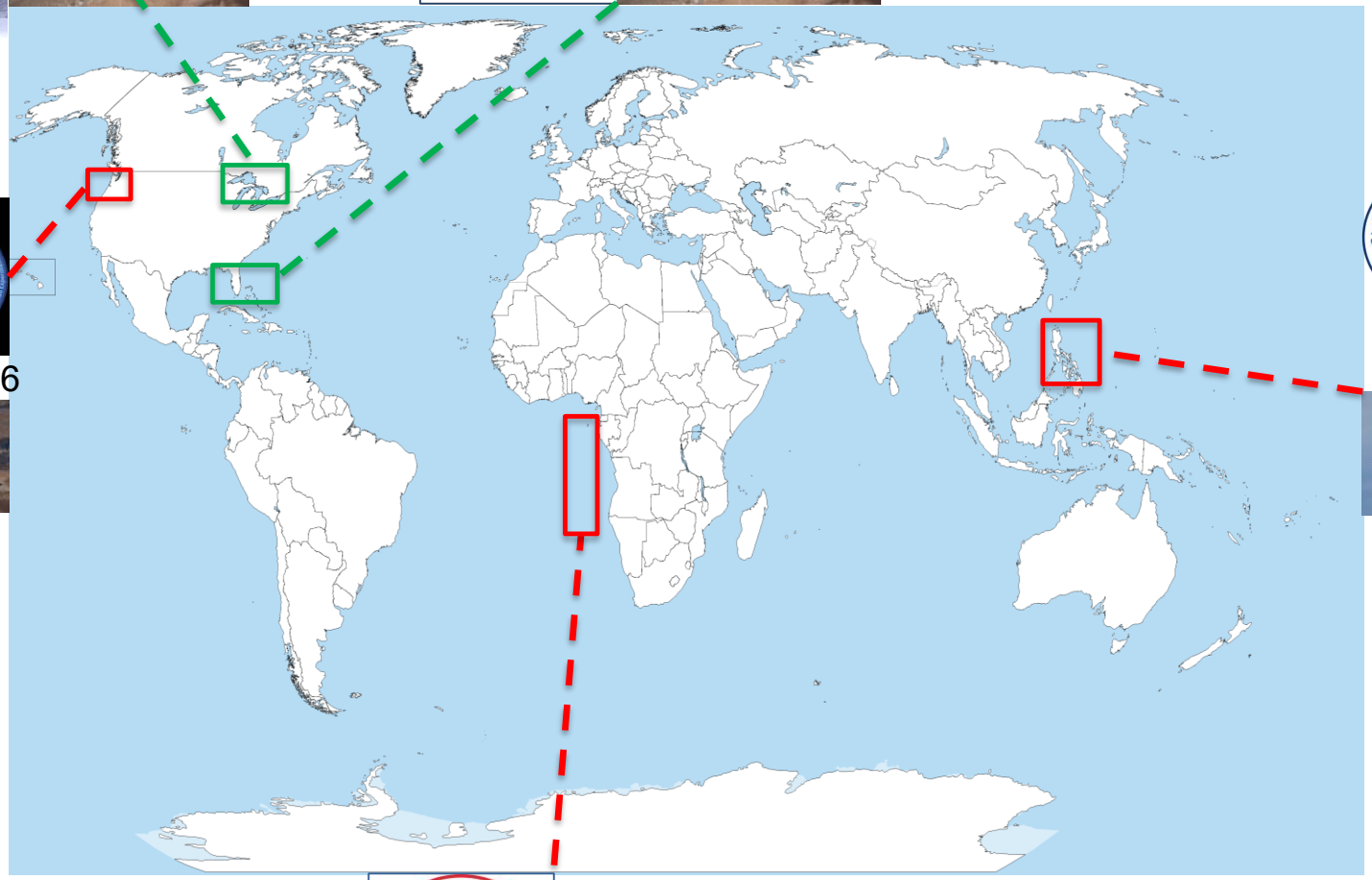
APR deployments since 2012

Jan-Mar 2012

Jun-Jul 2017

APR2 (Ku,Ka)
APR3 (Ku,Ka,W)

Nov'15-Feb'16



Apr-Oct 2019

A2016,S'17,O'18

1. OLYMPEX: Olympic Mountains Experiment (Pacific NW) Nov 2015 – Jan 2016

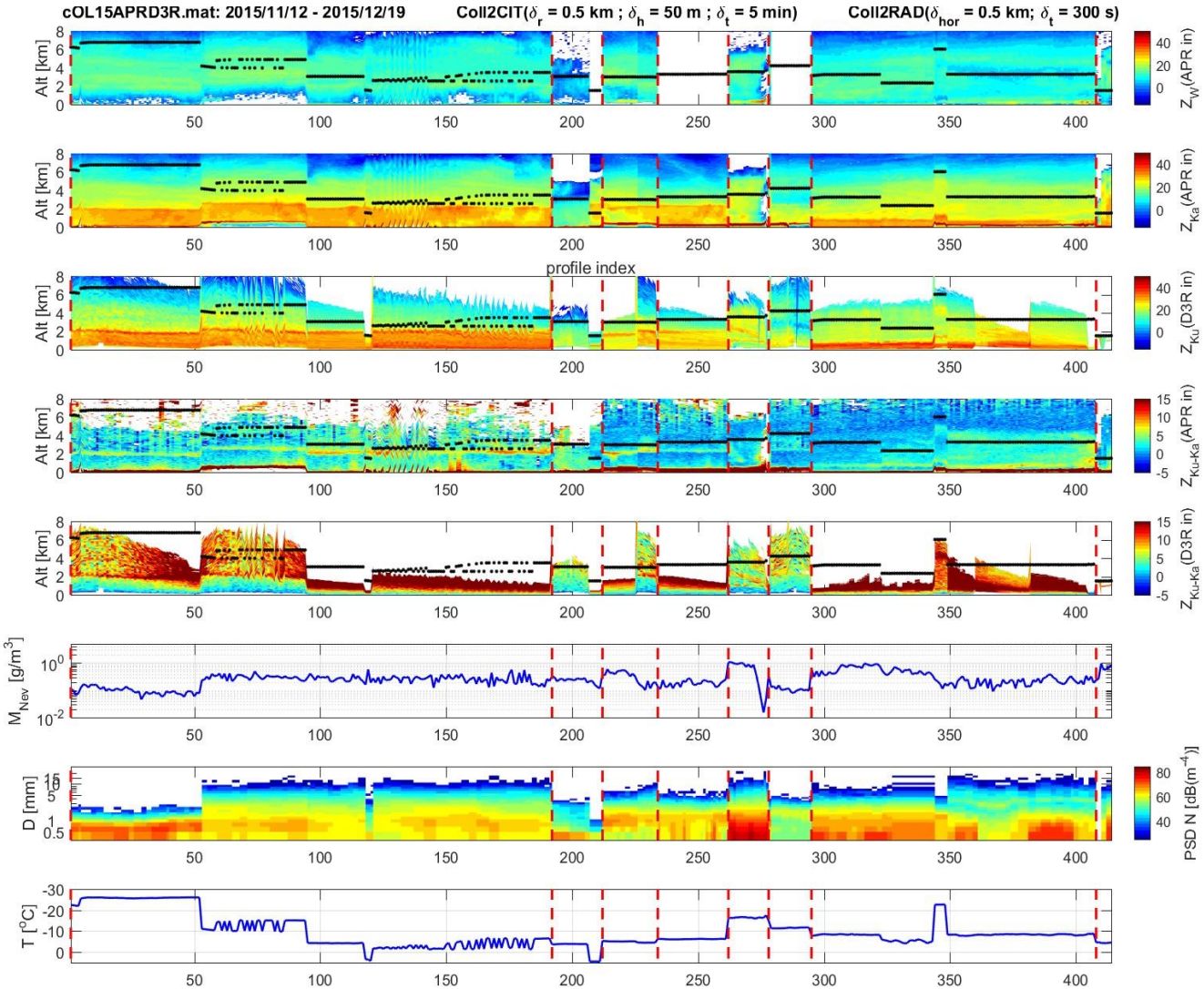
PI: Prof. R. Houze, U.W.

Science Goals:

- Physical Validation of **GPM Precip Algos**
- Midlatitude **frontal systems** and modification by complex **terrain**
- Test **hydrological applications**

Instrumentation:

- **Surface**: Rain gauge, Disdrometers, Pluvios
- **Radars**: WSR-88D, NPOL, **D3R**, MMR, X and W-band from Canada,
- Aircraft: DC-8 **(APR-3)**, UND Citation, ER-2



- Heymsfield, A., et al., 2017: Toward Improving Ice Water Content and Snow Rate Retrievals from Radars Part II: Results From Three Wavelength Radar /Collocated In Situ Measurements and CloudSat/GPM/TRMM Radar Data, *J.App.Met.Clim.*
- Chase, R. J., et al., 2018: Evaluation of Triple-Frequency Radar Retrieval of Snowfall Properties using Coincident Airborne In-Situ Observations during OLYMPEX, *Geophys. Res. Lett*
- Durden, S.L., et al., 2019: Comparison of GPM DPR and Airborne Radar Observations in OLYMPEX. *GRSL.*

2. ORACLES: ObseRvations of Aerosols above CLouds and their intEractionS

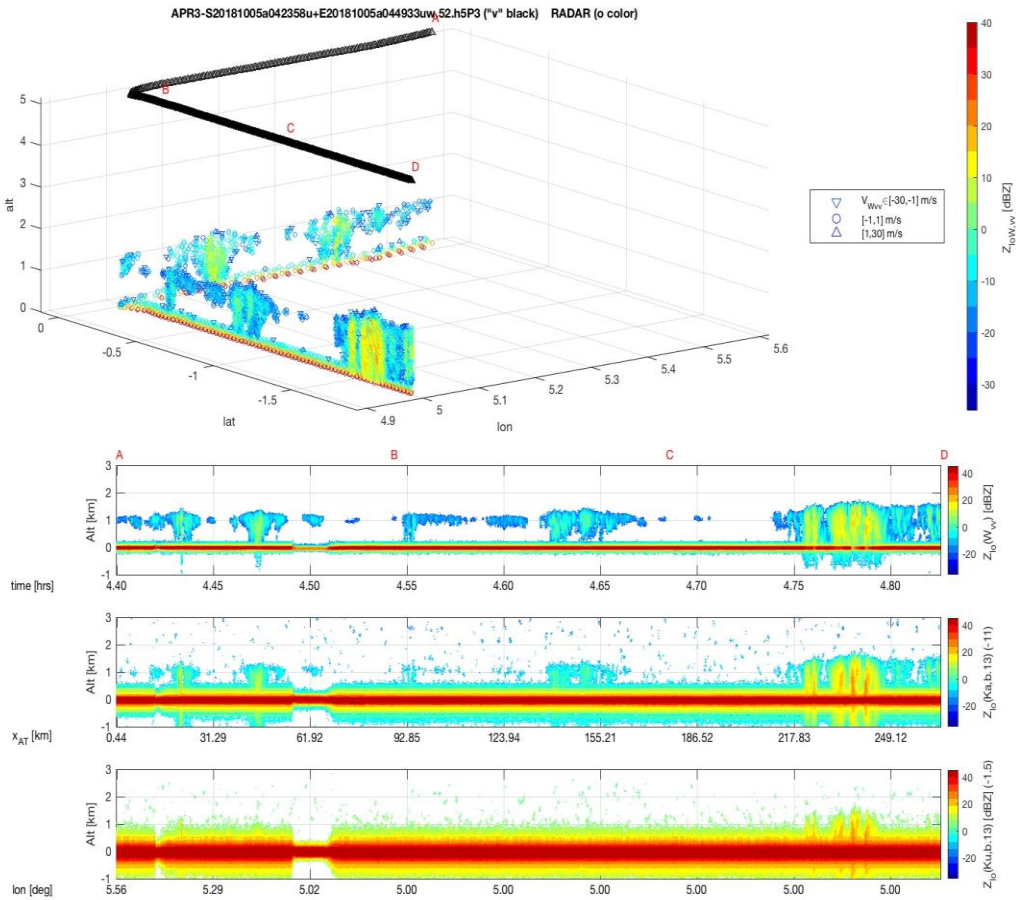
PI: J. Redemann, NASA/ARC

- **climate impacts** of **African Biomass Burning aerosols**.
- **aerosol-cloud interactions in the SE Atlantic**,
- multi-year airborne observations 2016-2018

Instruments on P-3	
Spectrometer for Sky-Scanning, Sun- Tracking Atmospheric Research (4STAR)	Russell (NASA ARC)
Cloud in situ	McFarquhar/Poellot (UI/UND)
Solar Spectral Flux Radiometer (SSFR)	Schmidt/Pilewskie (CU)
CO Measurement Activity (COMA)	Podolske (NASA ARC)
Aerosol & cloud in situ - Hawaii Group for Environmental Aerosol Research (HiGEAR)	Howell/Clarke/Small (UH)
Airborne Cloud/Precipitation Radar (ACR/APR-2)	Tanelli (JPL)
High Spectral Resolution Lidar (HSRL-2)	Hostetler/Ferrare (NASA LaRC)
Research Scanning Polarimeter (RSP)	Cairns (NASA GISS)

Instruments on ER-2	
Enhanced MODIS Airborne Simulator (eMAS)	Platnick/Myers (NASA GSFC/ARC
Solar Spectral Flux Radiometer (SSFR)	Schmidt/Pilewskie/Gore (CU/ ARC
High Spectral Resolution Lidar (HSRL-2)	Hostetler/Ferrare (NASA LaRC)
Research Scanning Polarimeter (RSP)	Cairns (NASA GISS)
Airborne Multiangle SpectroPolarimetric Imager (AirMSPI)	Diner (JPL)

In JAXA EarthCARE GV Science Team



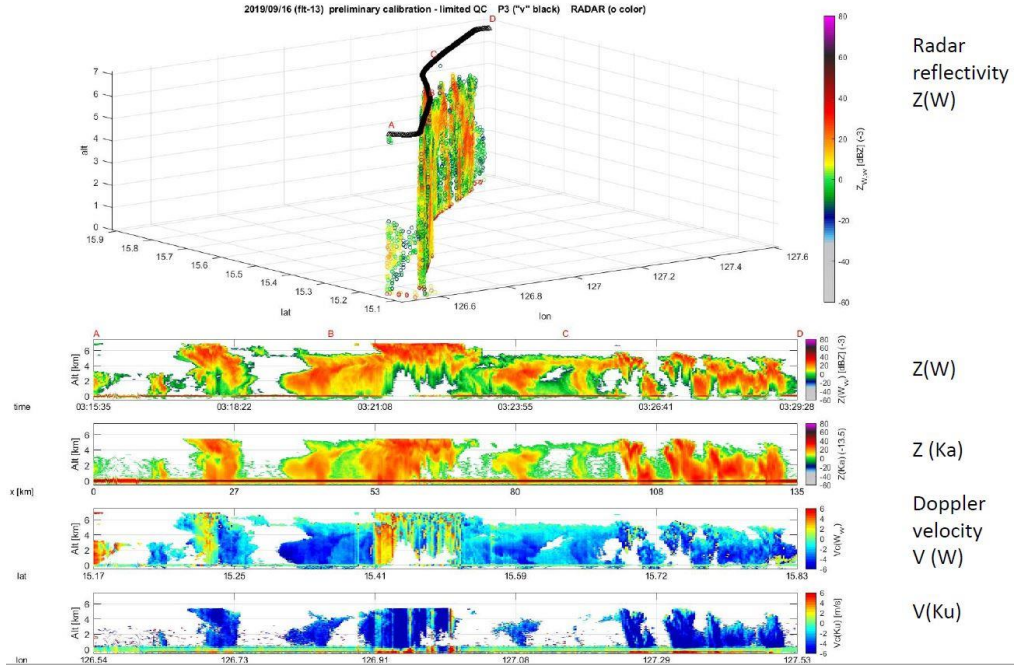
- Dzambo, A.M., et al, 2019: The Observed Structure and Precipitation Characteristics of Southeast Atlantic Stratocumulus from Airborne Radar during ORACLES 2016–17. *J. Appl. Meteor. Climatol.*, **58**, 2197–2215

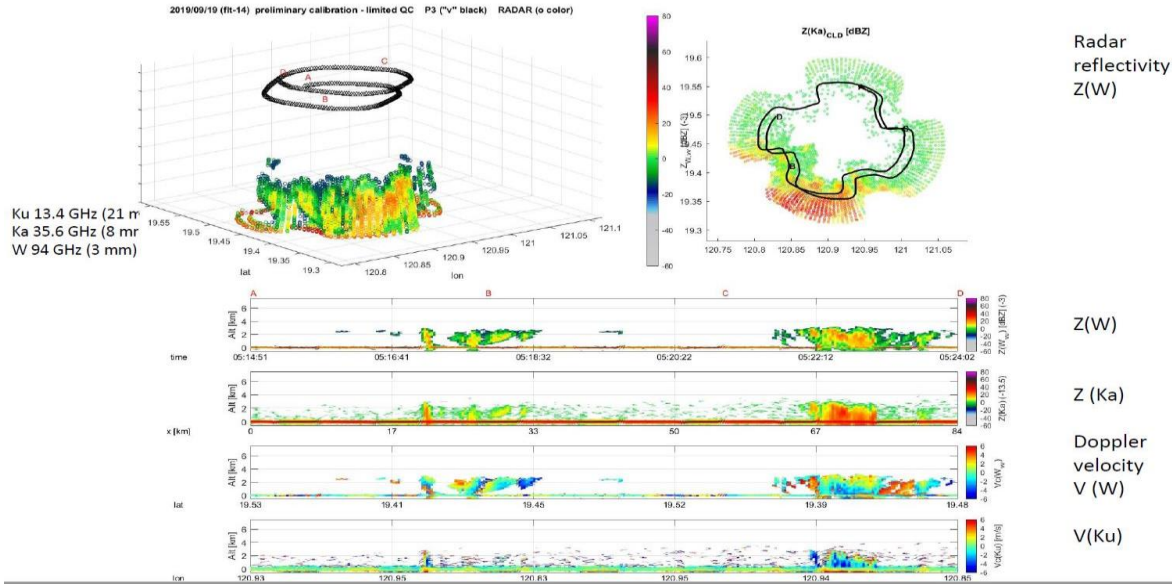
3. CAMP^{2}Ex: Cloud & Aerosol Monsoonal Processes: Philippines Experiment (ASO 2019)

Principal Investigator: J. Reid, NRL

Science Questions:

- Interaction **aerosol** & **precipitation in tropical environments**?
- Interaction **aerosol clouds & feedback**
- Effect of **land use on cloud and precipitation**?



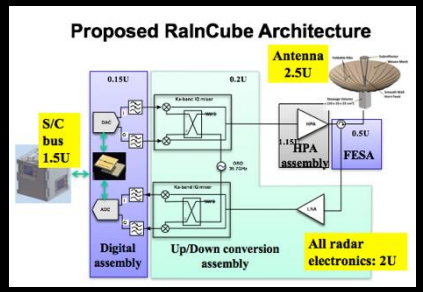


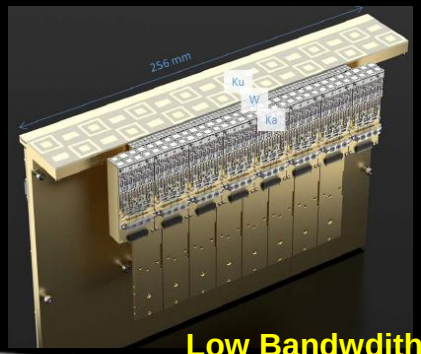
C. Multi-Application SmallSat Tri-band Radar (MASTR)

miniKaAR
back end
reduce # of parts
Simple

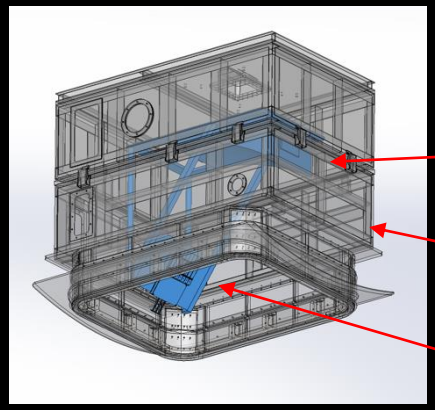
+

3CPR
antenna scheme
scanning
Agile





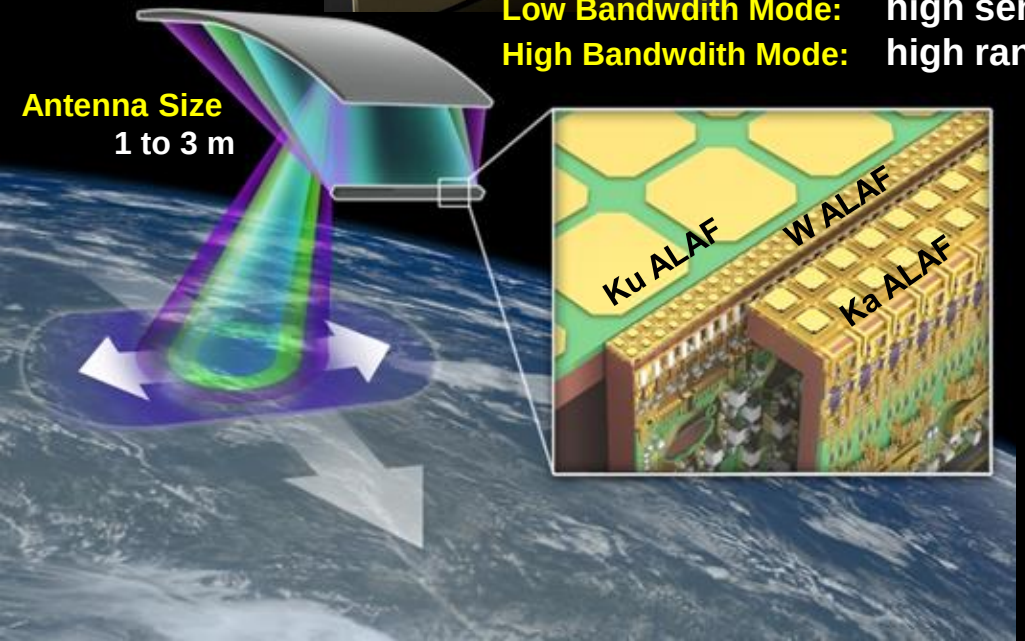
Airborne Prototype
airMASTR
ESTO IIP – 2017/19 – PI: M. Sanchez-Barbetty

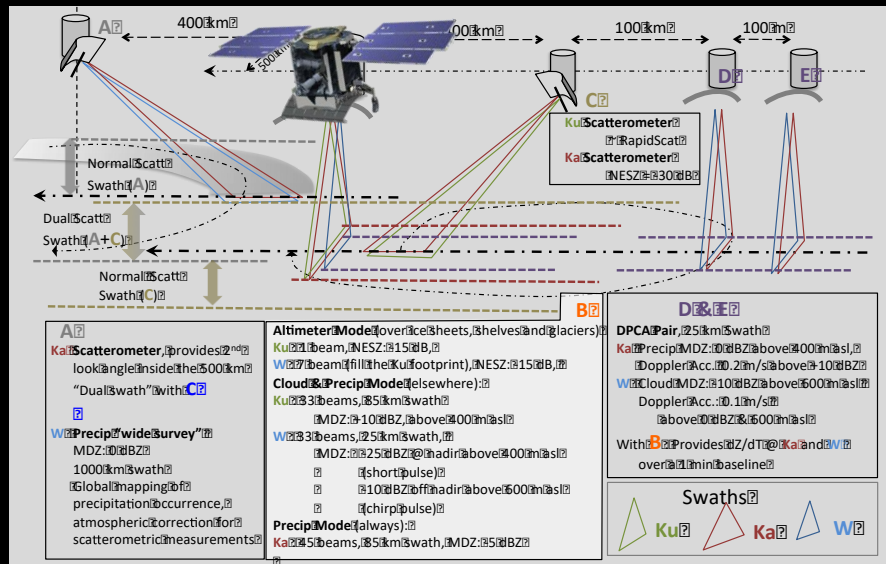


Planned first flight :
Nov 2019

Low Bandwdith Mode: **high sensitivity *(Clouds and Precipitation, Scatterometry)***
High Bandwdith Mode: **high range res *(Altimetry, Snow Depth, Sea Ice freeboard)***

Antenna Size
1 to 3 m





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NASA airborne campaigns:

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Synergies and opportunities

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EarthCARE

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RainCube:

New paradigm

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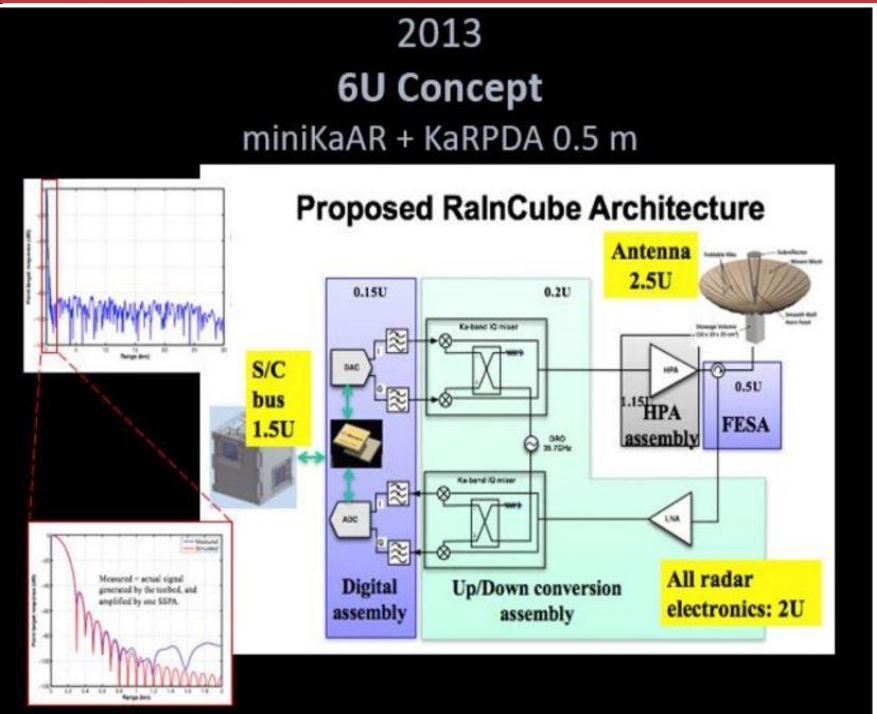
for algorithm development and validation:

High-Resolution Radar based, or Model Based

RainCube: 1st Radar in a CubeSat: Dr. Eva Peral (PI, JPL)

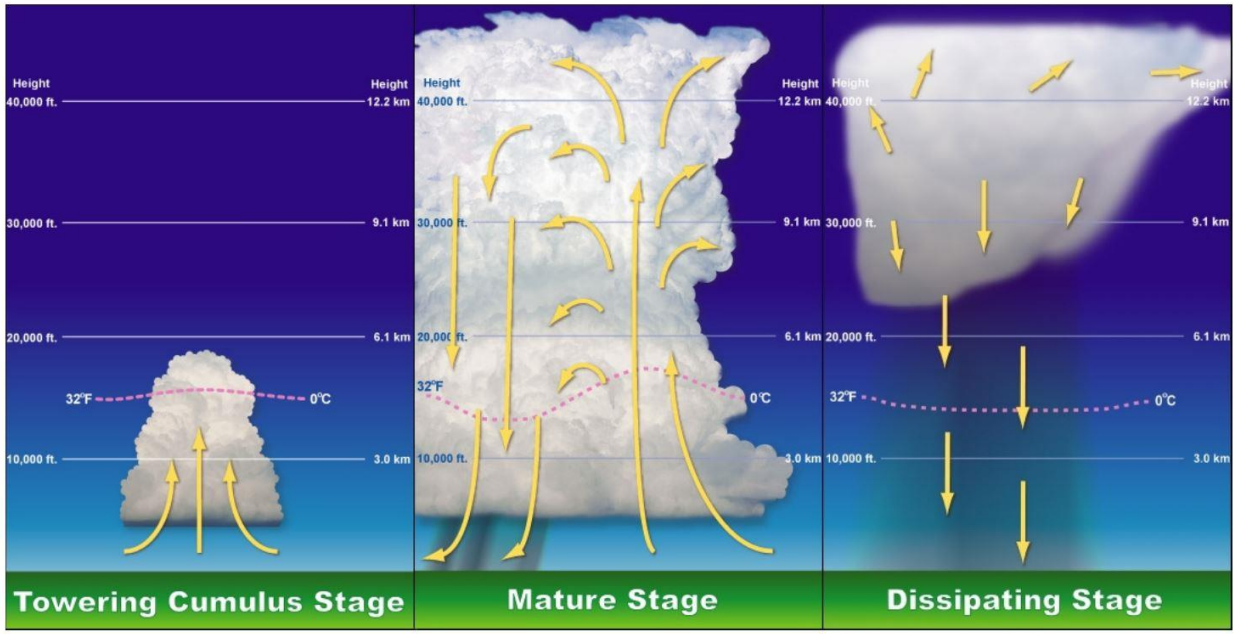


- NASA ESTO InVEST program
- NASA Earth Science Division's Flight and R&A Programs

Frequency	35.75 GHz
Antenna size	0.5 m
Volume	6U ($10 \times 20 \times 30$ cm^3)
Mass	5.5 kg
RF Power	10 W
Processing	PC & Offset (I,Q) modul.
Beams	1 (nadir)
Hor. Resolution	8 km
Range Res	250 m

E. Peral et al., "Radar Technologies for Earth Remote Sensing From CubeSat Platforms," in *Proceedings of the IEEE*, vol. 106, no. 3, pp. 404-418, March 2018

Why a radar in a CubeSat?



(Lifecycle of a thunder storm). Credit: NOAA

	Cloudsat (2006)	GPM (2014)
Max size/ weight	5.1 m/995 kg	13 m/3850 kg
Swath [km]	nadir	125–250
I_{orbit} [°]	98	65
Altitude [km]	705	407
Revisit time	$\sim$ 16 days	$\sim$ 3 hours

Lifetime

Single cell 30 mins

Multi-cell: few hours

Possible options

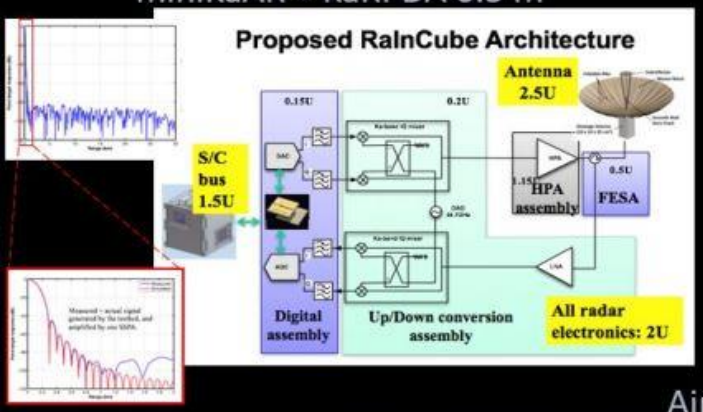
- GEO
- Doppler in space
- Constellation of radars

RainCube development

2013

6U Concept

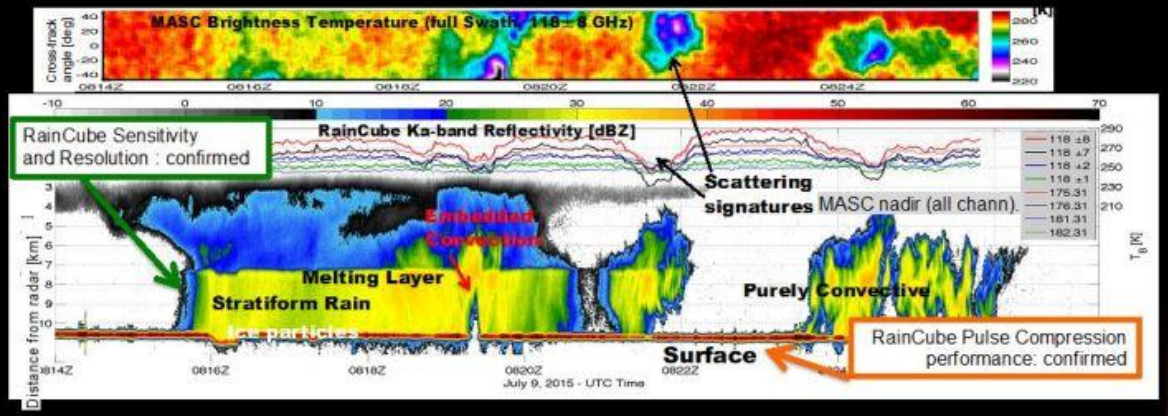
miniKaAR + KaRPDA 0.5 m



2015

PECAN

Airborne Demo of miniKaAR

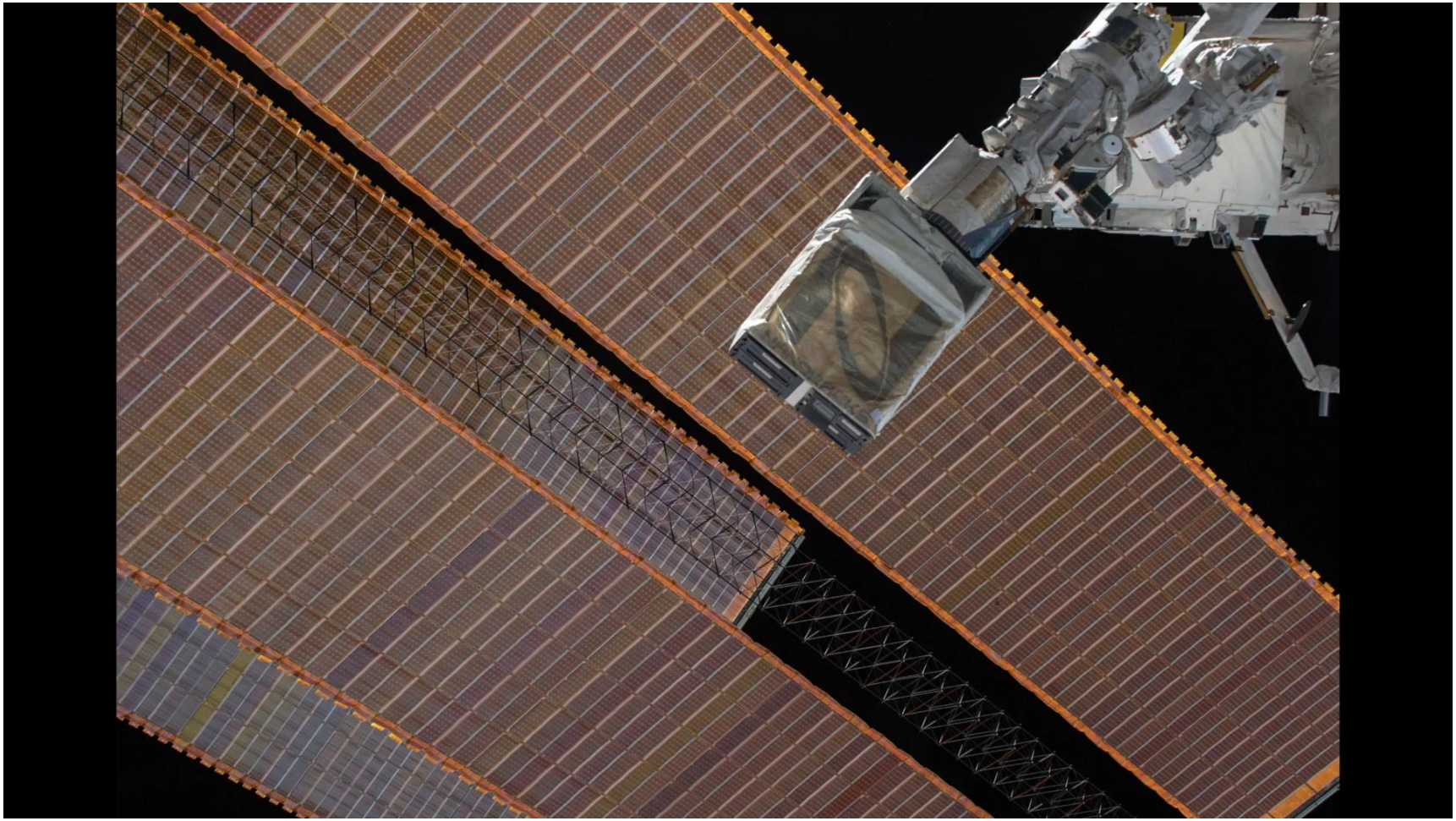


May 2018

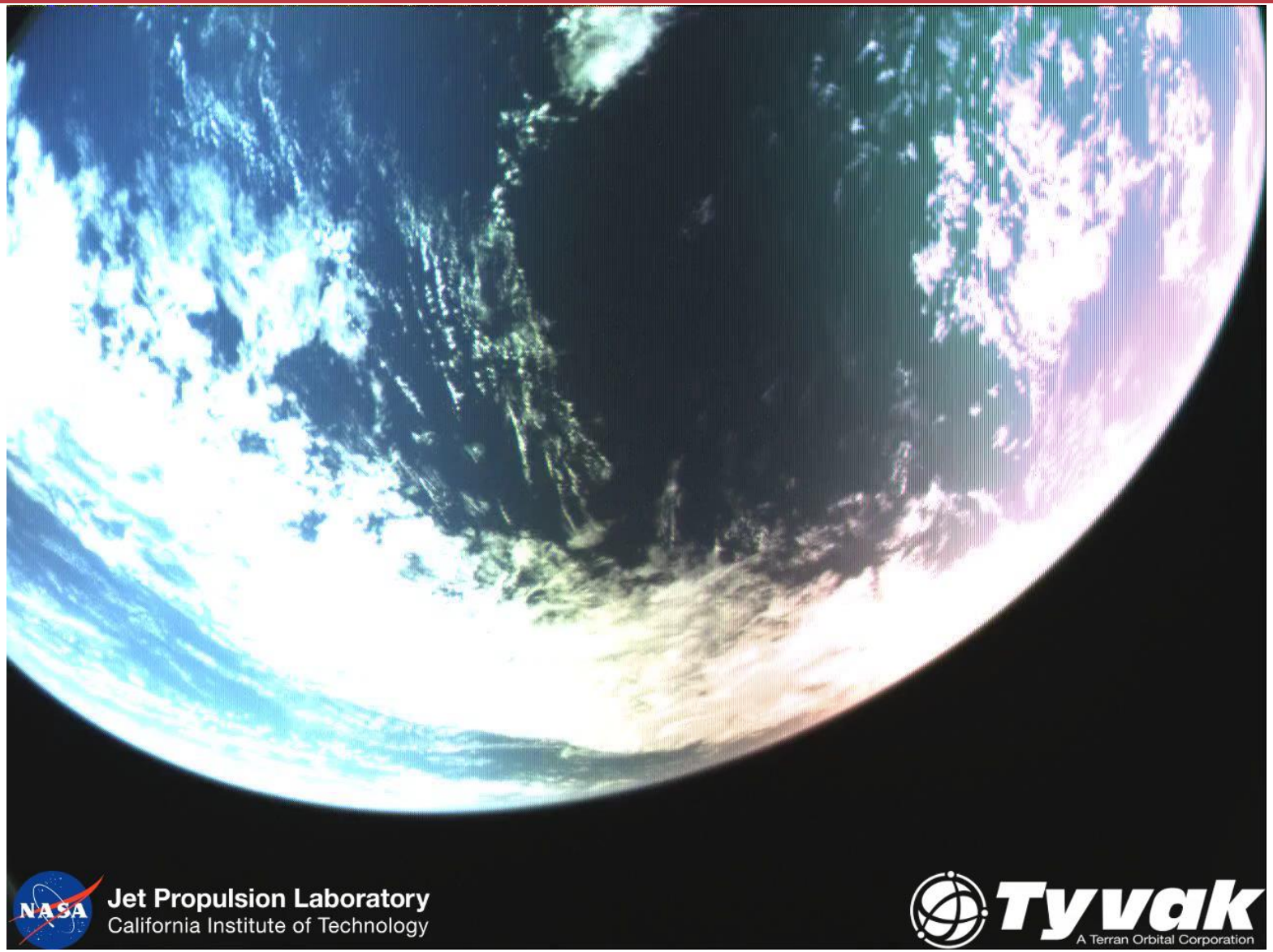
RainCube 6U

Launched to ISS

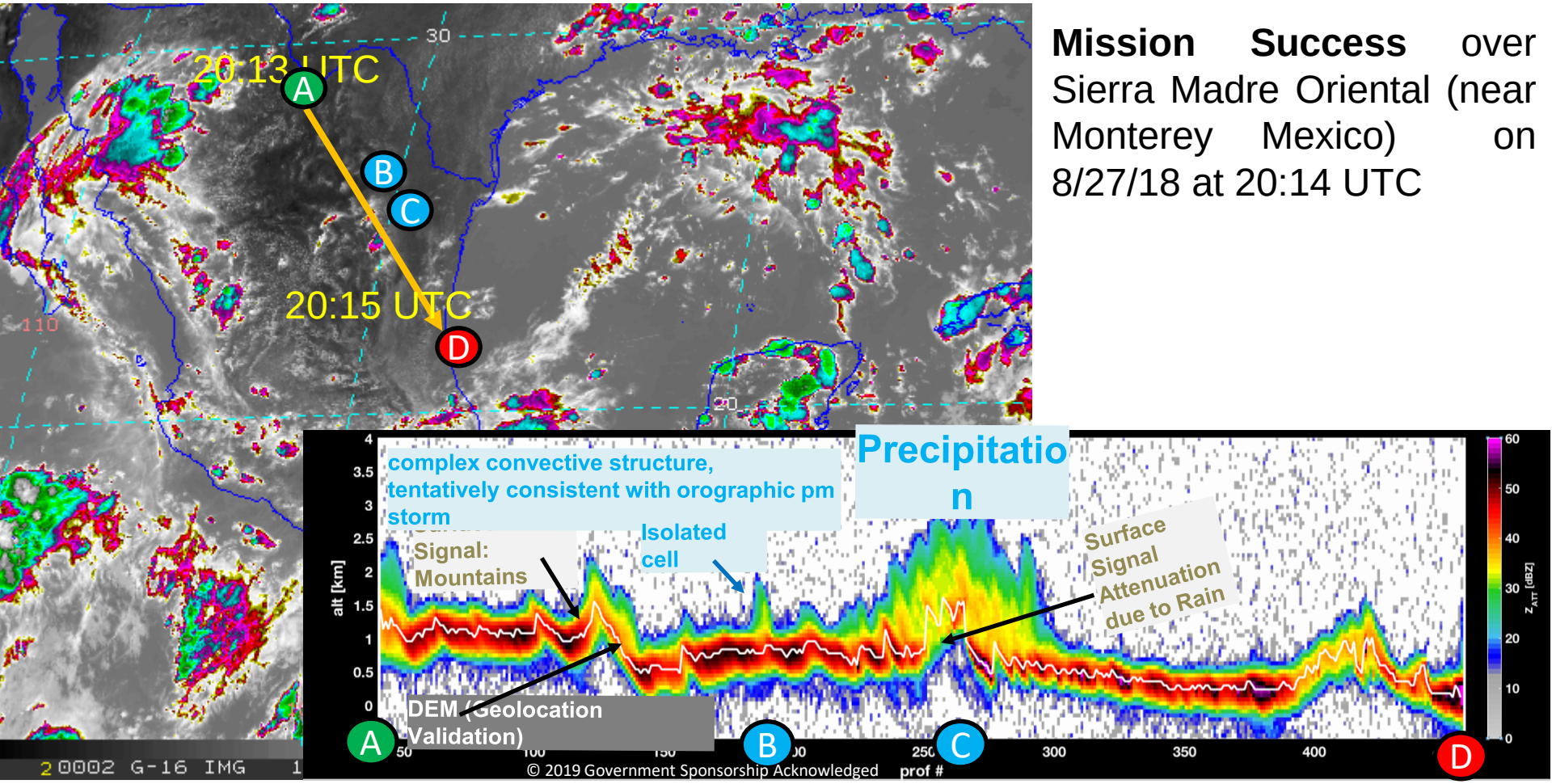
ISS Deployment: July 13th, 2018



Antenna Deployment: July 28th, 2018

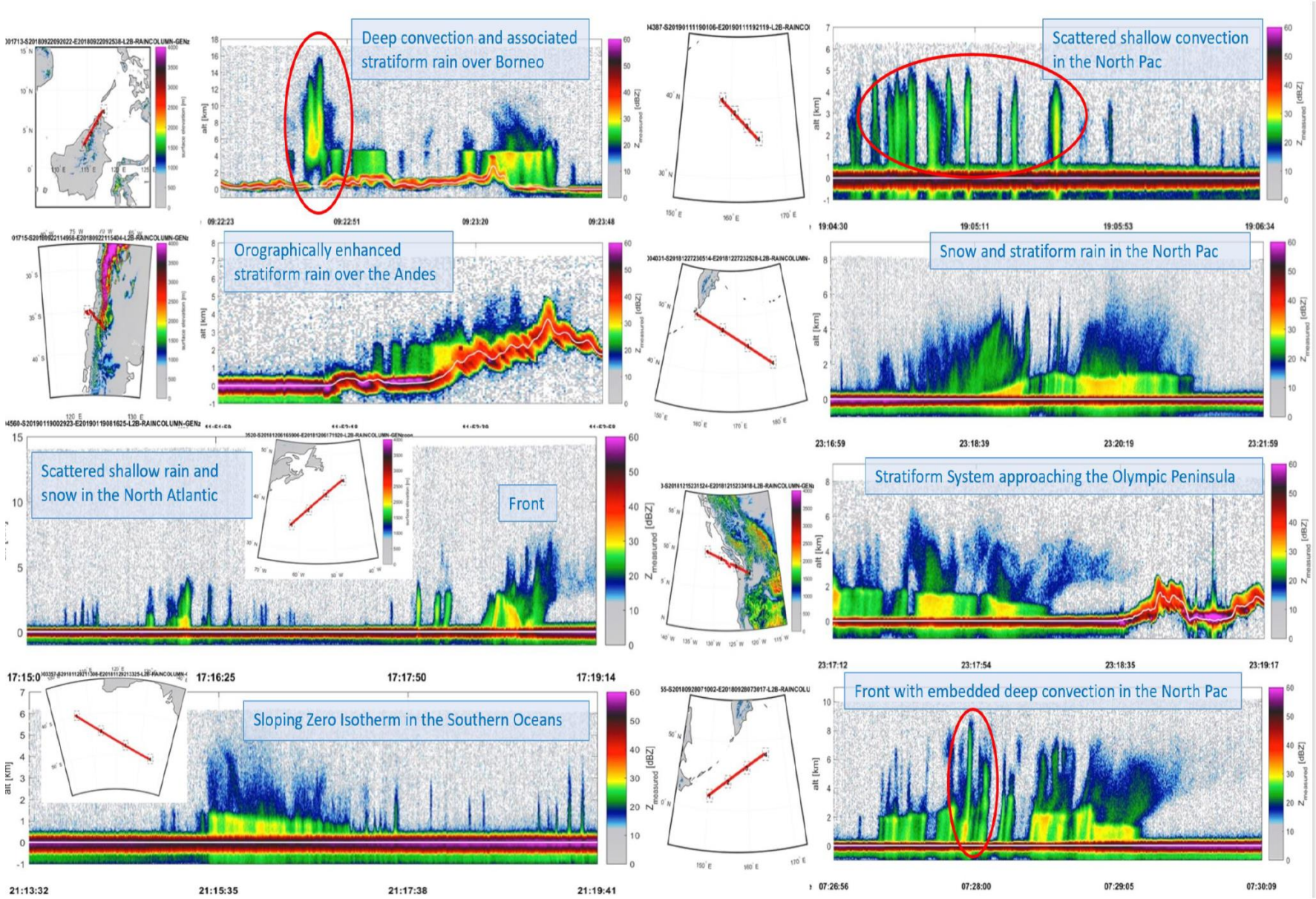


First Rain for RainCube: August 27th, 2018



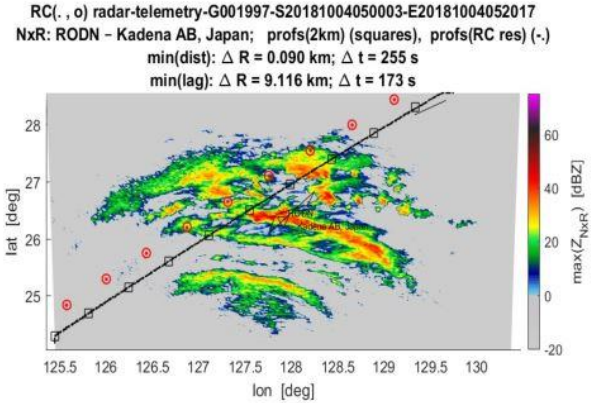
Mission Success over Sierra Madre Oriental (near Monterey Mexico) on 8/27/18 at 20:14 UTC

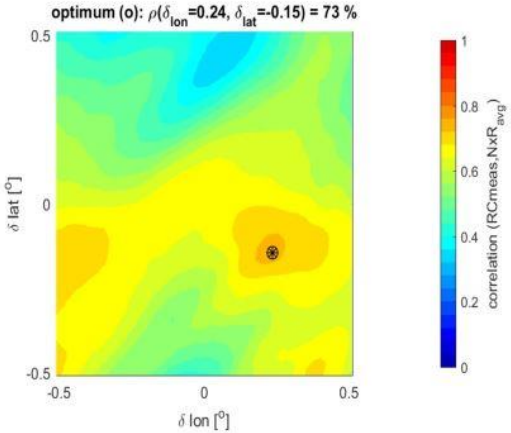
A Collection of RainCube Storms

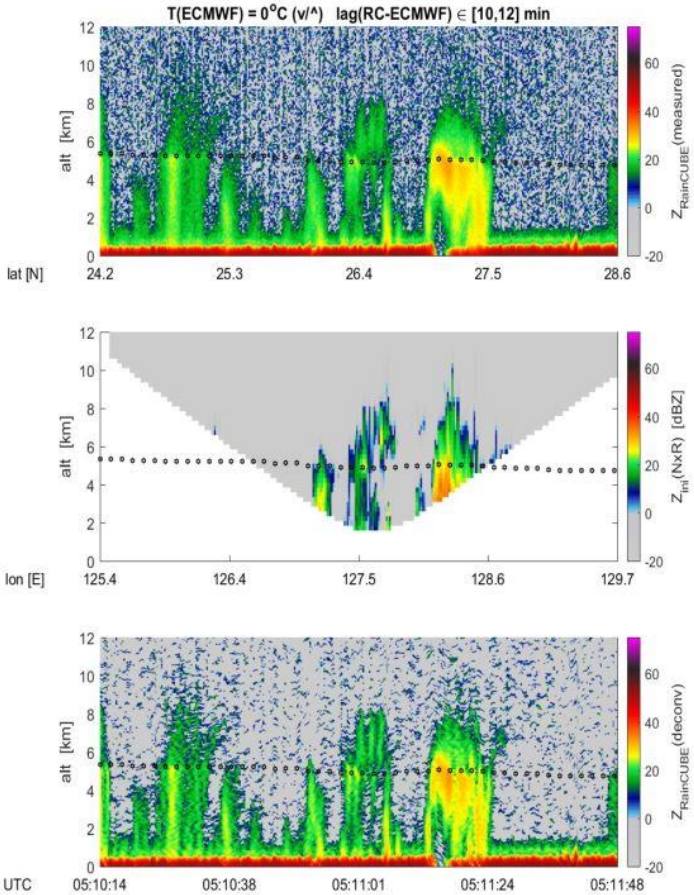


Co-location to NexRAD

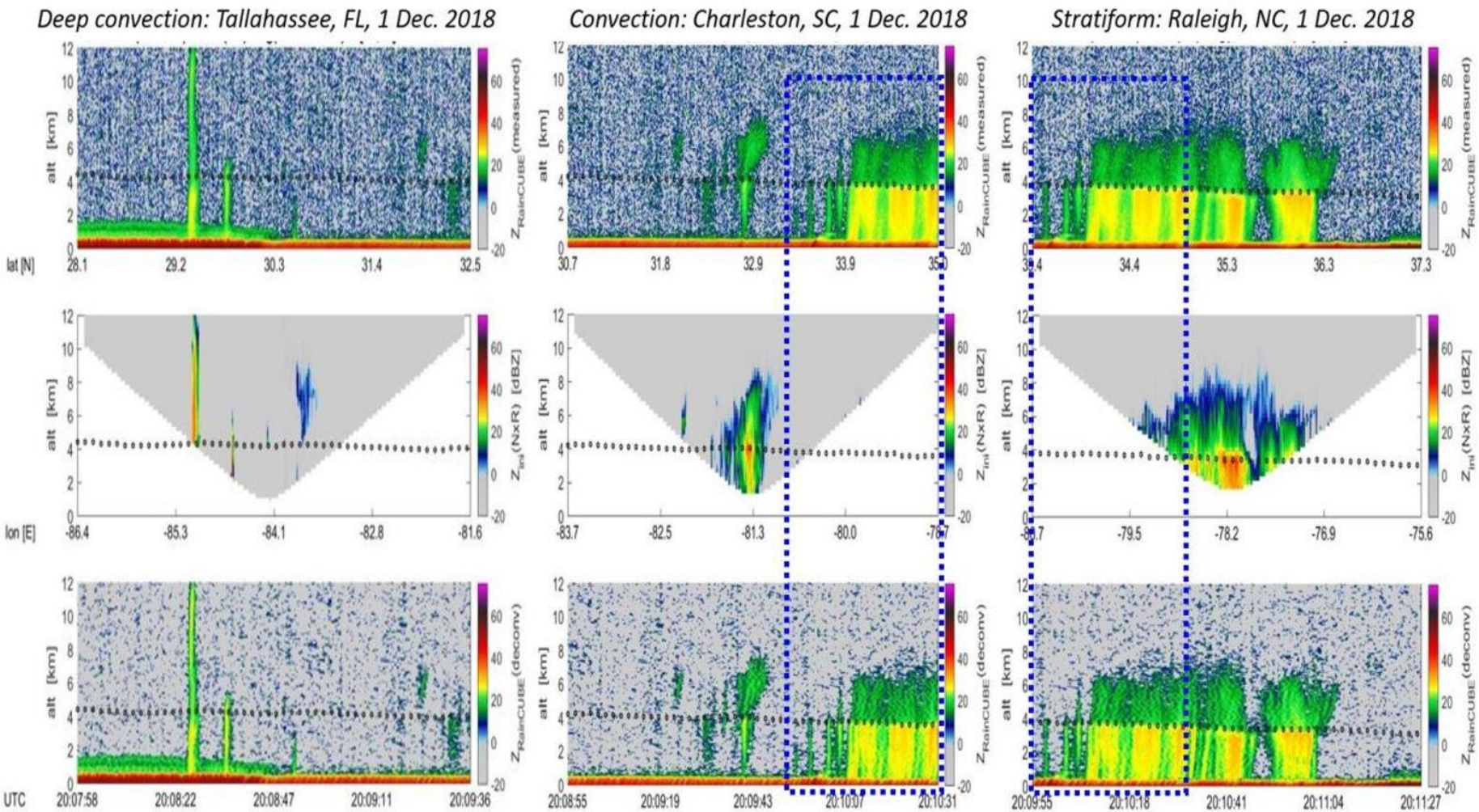
- National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA)
  https://www.roc.noaa.gov/WSR88D
- S-band (2.8 GHz) data every 5-10 mins
- resampled to a $2 \times 2 \times 0.25\ \mathrm{km}^3$ resolution





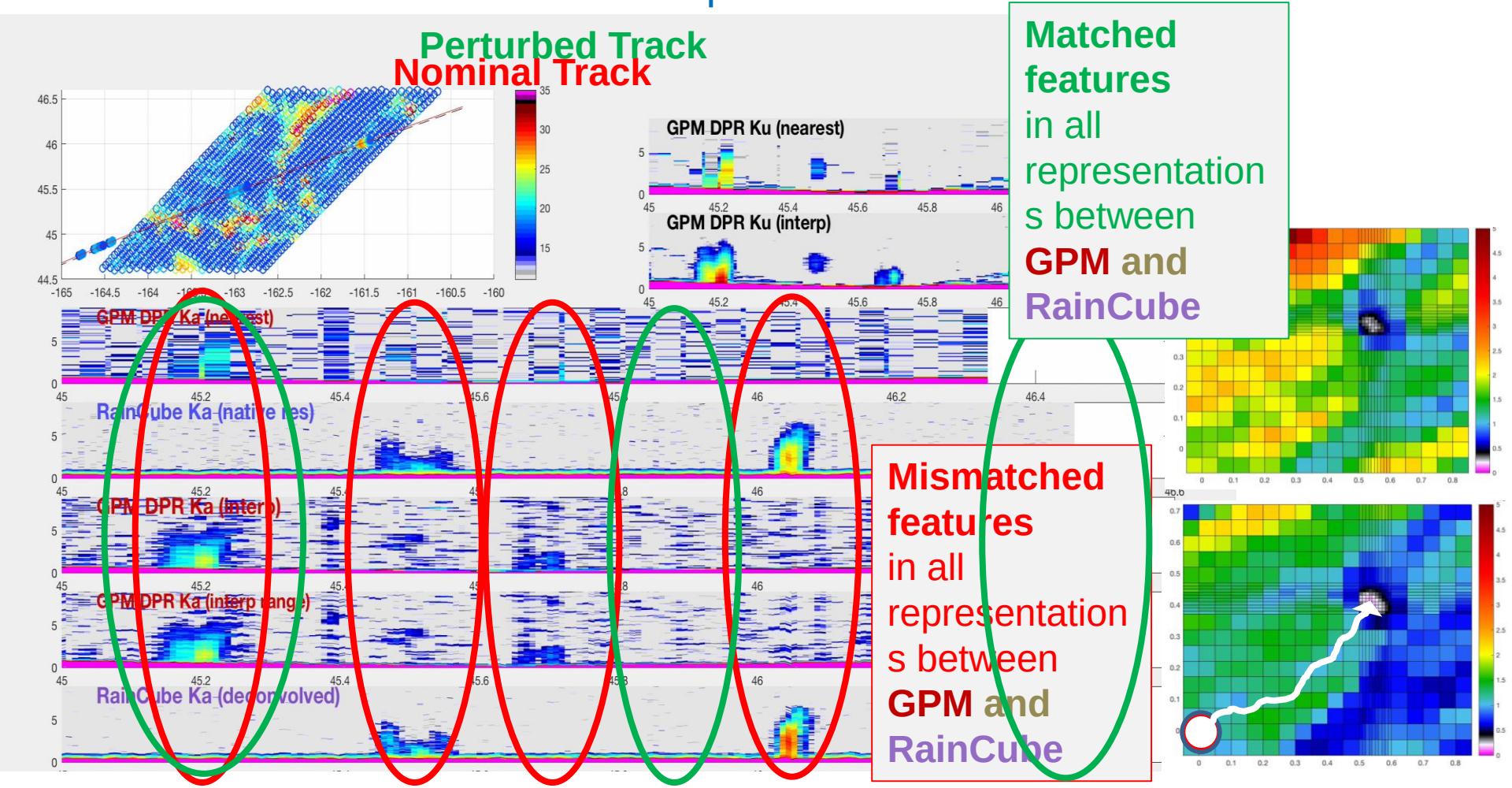


Co-location to NexRAD

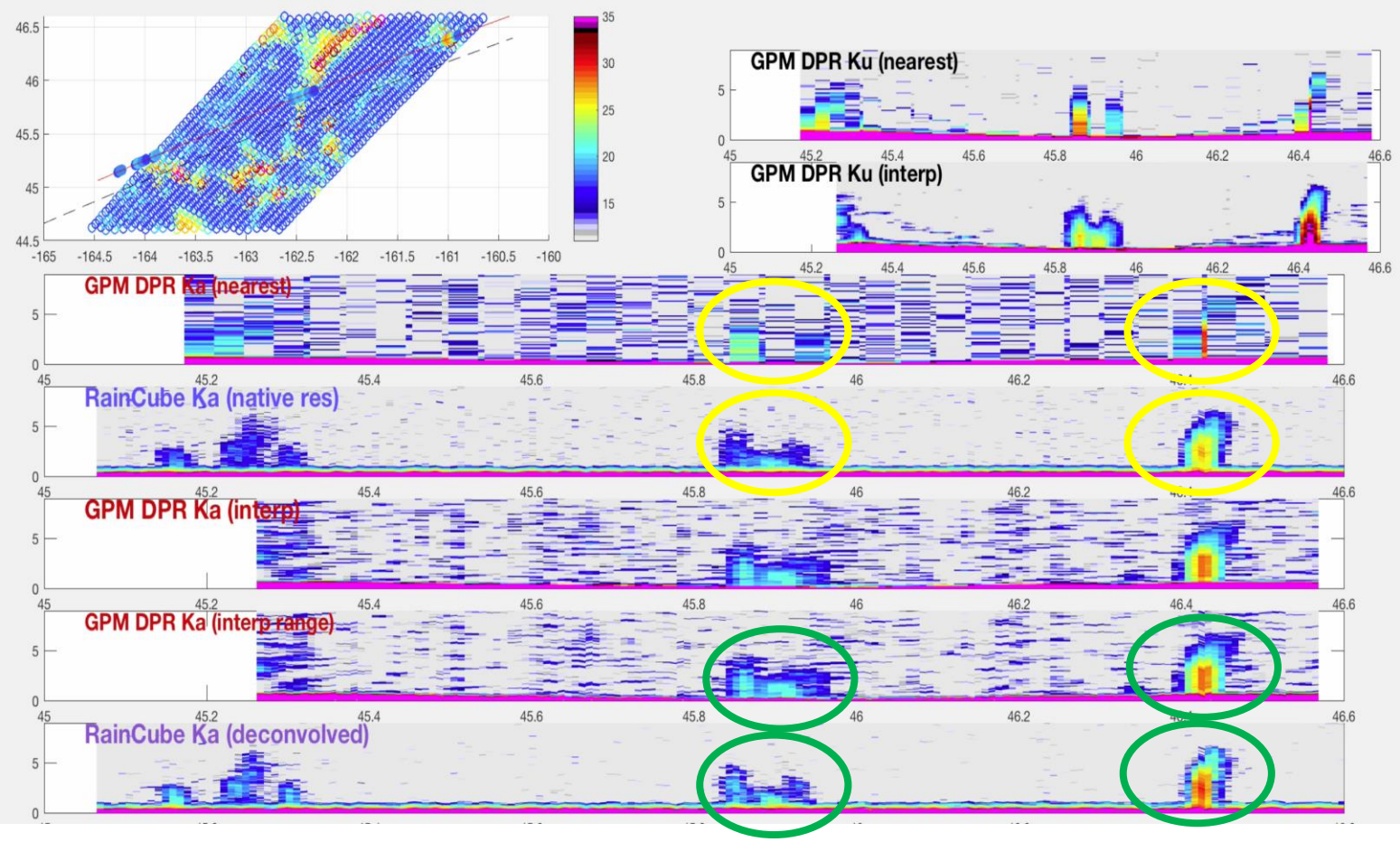


Complementarity $\neq$ viewing geometries, $\neq$ frequencies

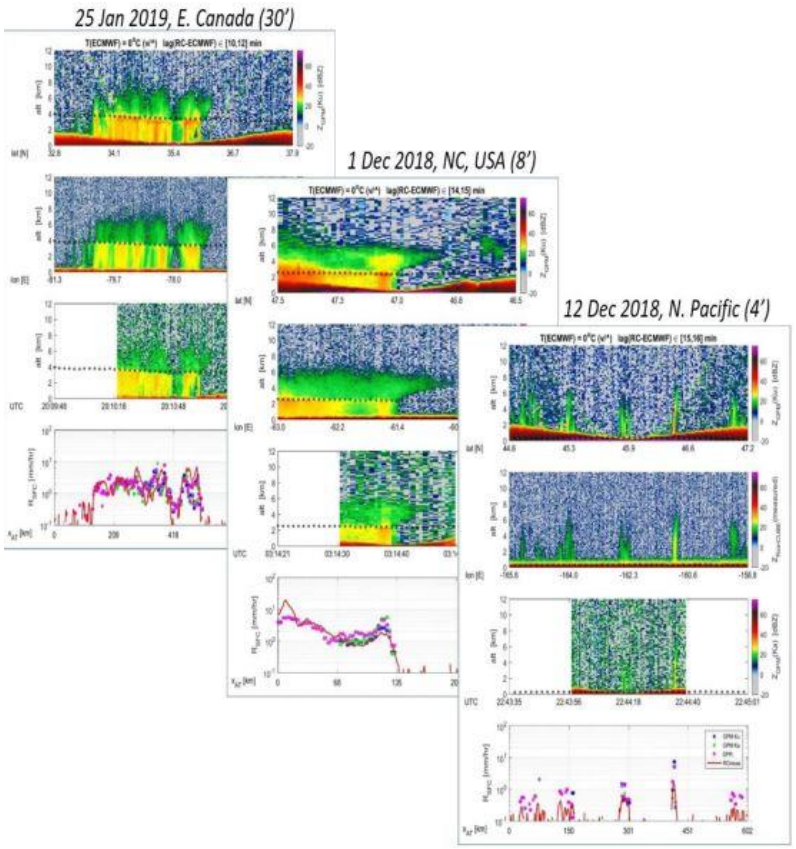
DPR's Swath and Resolution enable validatation of RainCube products

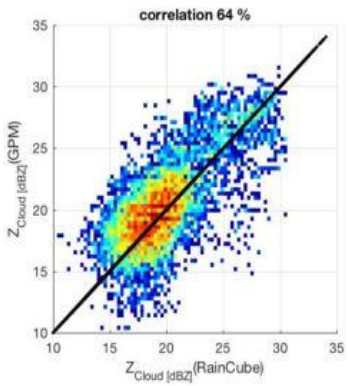


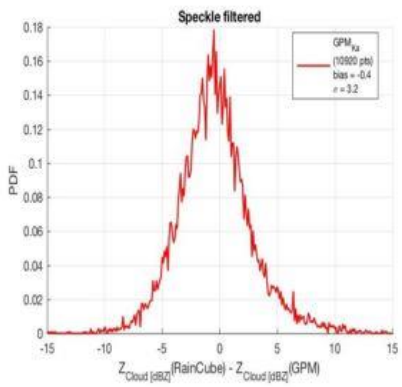
DPR's Swath and Resolution enable validatation of RainCube products



Co-location to GPM DPR







Bias RainCube vs DPR Ka

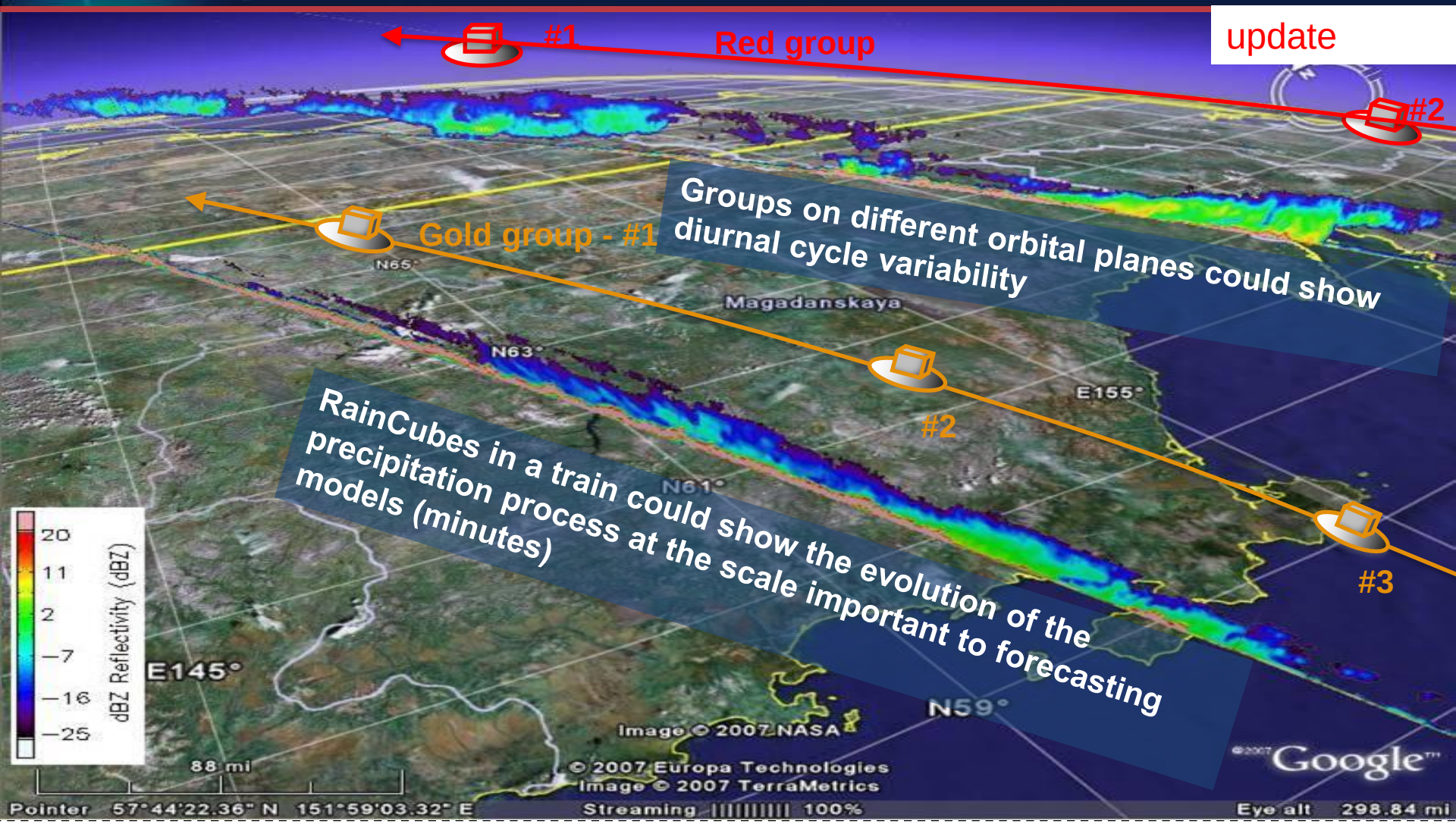
- $|Bias| < 1.5$ dB
- $|Bias| \ll \sigma$

<u>Outcomes</u>:

→ no calibration correction planned for next public release of science data

→ inclusion of this assessment in the product document for user awareness

RainCube: Science motivation



Z.S. Haddad, O.O. Sy, S. Hristova-Veleva, G.L. Stephens, "Derived Observations From Frequently Sampled Microwave Measurements of Precipitation- Part I: Relations to Atmospheric Thermodynamics", *IEEE TGRS*, vol. 55 (6), 2017

Sy, O.O., Z.S. Haddad, G.L. Stephens, S. Hristova-Veleva, "Derived Observations From Frequently Sampled Microwave Measurements of Precipitation. Part II: Sensitivity to Atmospheric Variables and Instrument Parameters", *IEEE TGRS*, vol. 55 (5), 2017

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RainCube:

New paradigm

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Forward modeling

for algorithm development and validation:

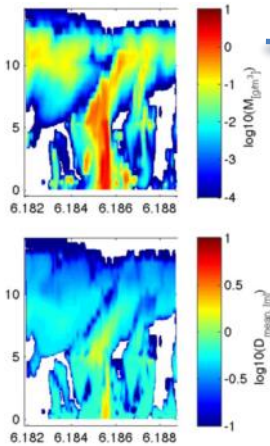
High-Resolution Radar based, or Model Based

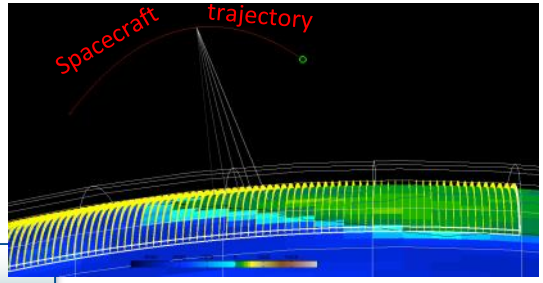
A. NEOS^3: NASA Earth Observing Systems Simulator Suite

Now available online to US investigators: https://neos3.jpl.nasa.gov

Account requests: simone.tanelli@jpl.nasa.gov

Beta testing phase





IRM Geophysics

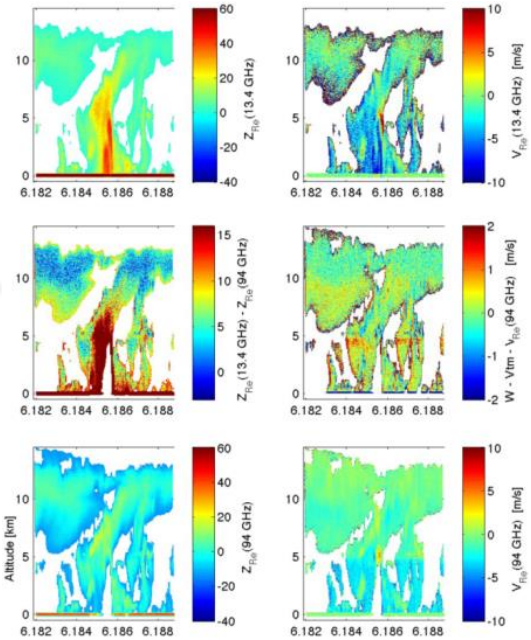
SEAM Electromagnetic signatures

ISM Propagation & Instrument/platform specs

Mass Size Shape
Orientation
Composition
Temperature
Pressure
Wind speed
Surface roughness
Sand fraction
Grain size Density
Soil moisture
Salinity SWE WRF
LIS DHARMA SAM

Refractive index
Extinction
Absorption
Polarization
Scattering Phase function Albedo
DDSCAT Rayleigh
SNOWFAKE T-Matrix
Geometric Optics
HITRAN FASTEM
Emissivity NRCS

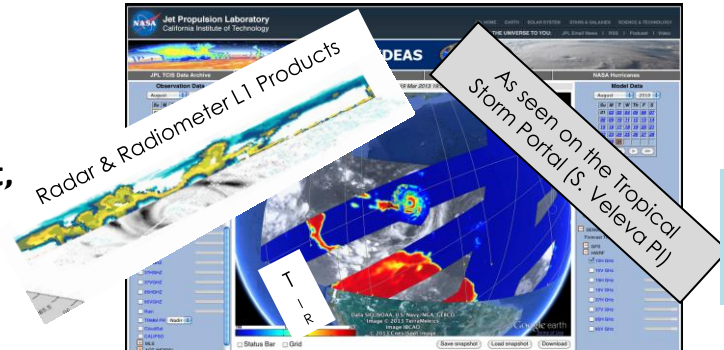
Instrument type
Antenna pattern
Scanning Orbit
Pulse integration
Conical Cross-track
Inclination Angle
Elevation angle
Filters DOMUS
SHDOM Radiative Transfer Model
Monte-Carlo RTM
SOI



a service-based tool suite providing simulated measurements for a wide range of instruments aimed at remote sensing of the atmosphere, on missions such as EarthCARE, ACE, GPM, A-Train, Nexrad in Space, and others, based on input from atmospheric models.

Allows user to

- **select simulated storm,**
- **specify instrument(s) and orbit,**
- **specify calculation modules and produces expected measurements**



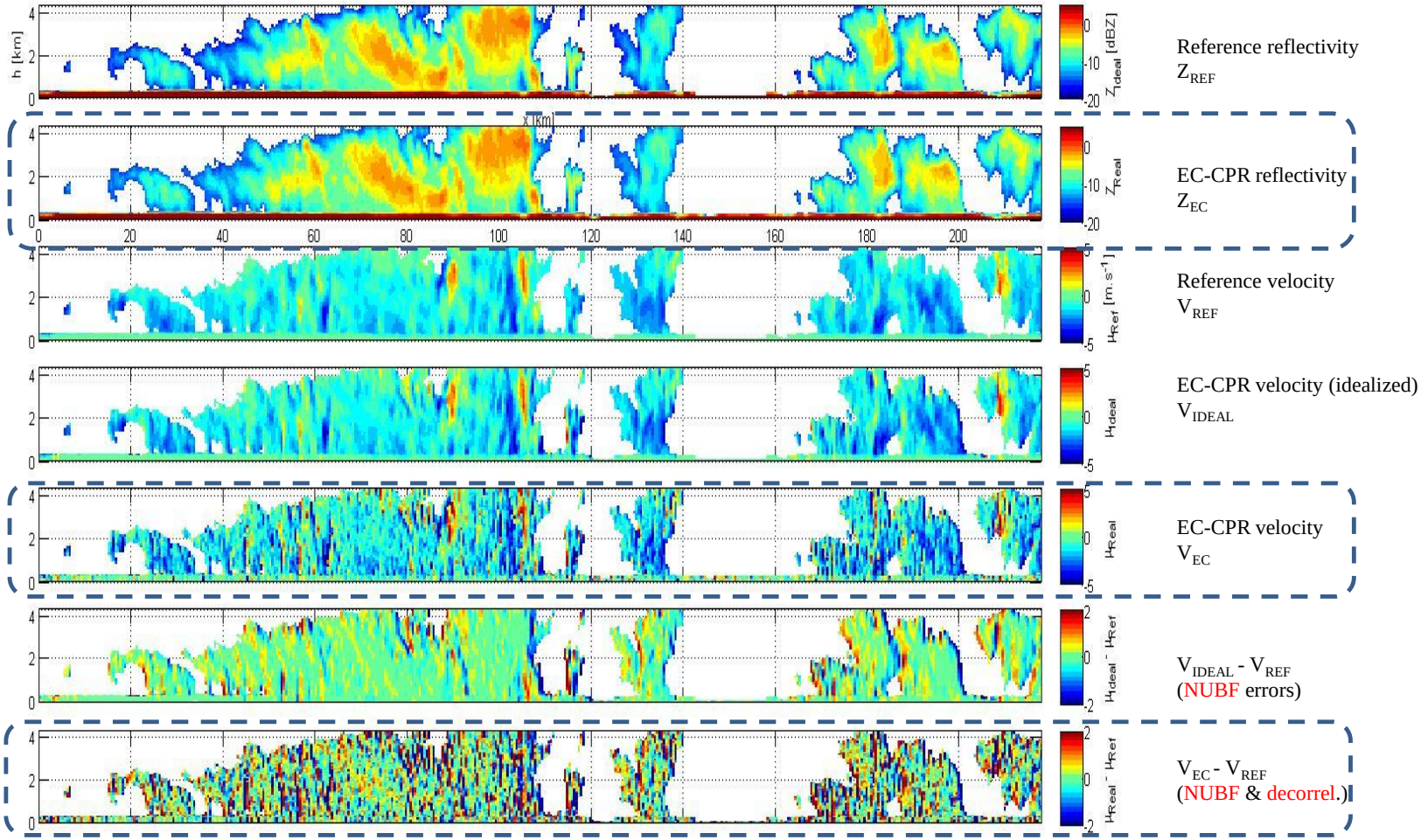
This tool is developed and available. It needs a user base for beta testing, customization, and improvements.

B. Airborne/Ground Doppler Radar data as source generate EC-CPR

Algorithm:

- In: *W-Band measurement from **NICT SPIDER** (air), or DOE WACR (ground)*
- *Output: Simulated EarthCARE Doppler products (Z,V)*
- *Correction for NUBF, aliasing, and matched filters vs noise*

Wakasa Bay,
Japan,
29 Jan 2003

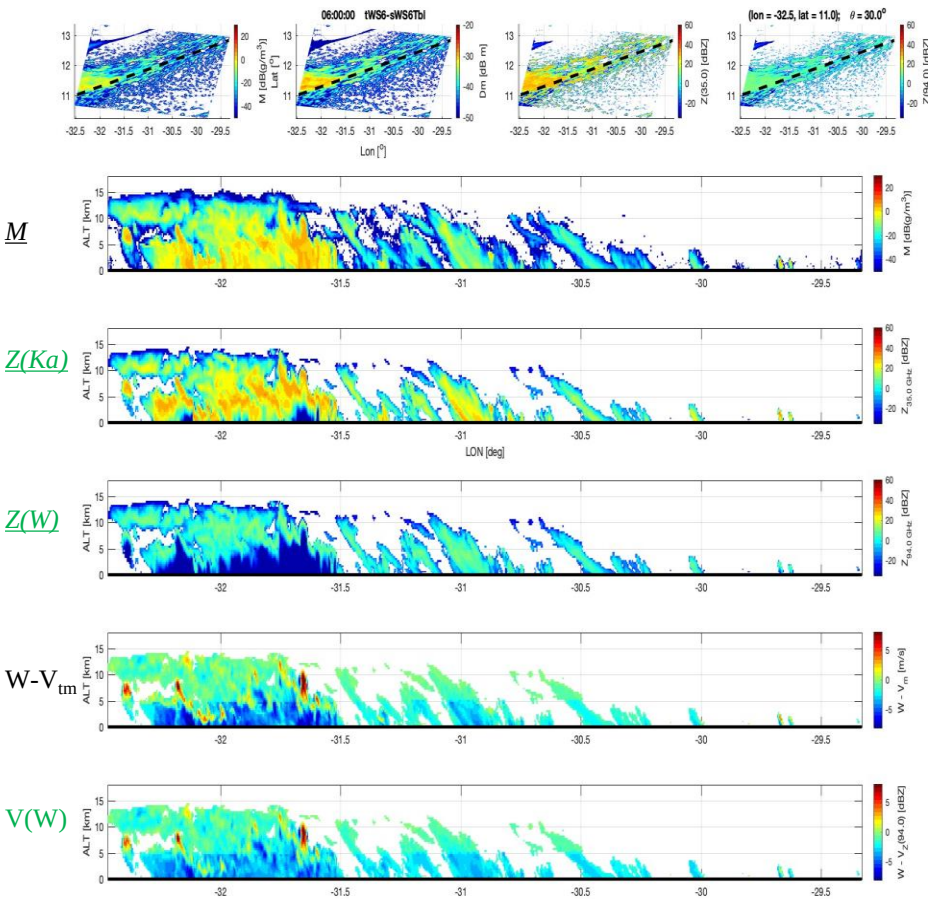


Sy, O.O.; Tanelli, S.; Takahashi, N.; Ohno, Y.; Horie, H.; Kollias, "Simulation of EarthCARE Spaceborne Doppler Radar Products using Ground-Based and Airborne Data: Effects of Aliasing and Non-uniform Beam-Filling", IEEE TGRS, vol.52, no.2, 2014

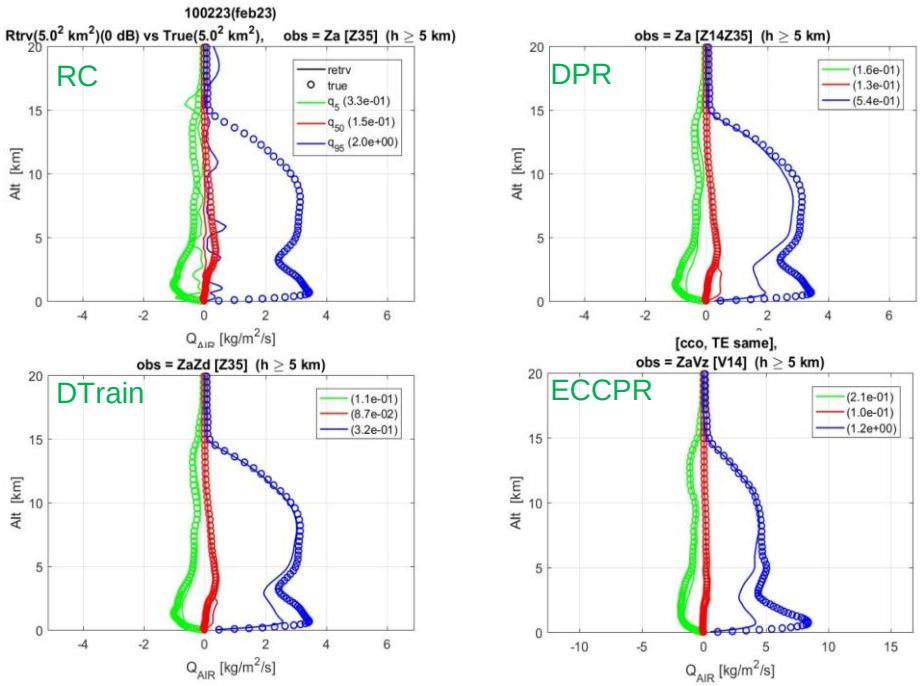
QuickS3: statistical retrieval simulator

- *In: cloud-resolution model simulations at high-temporal resolution (10s, 30s)*
- *Simplified radiative transfer (attenuation, Doppler)*
- *Retrieval operator based on Bayesian-interpolation [4]*
- *Allows to quantify skill of instruments (radar (multi-freq, Doppler), radiometer)*

Example: Tropical Storm Isabel Cabo Verde, (6th Sept 2003),



Assessing ability of various instruments to retrieve vertical air mass fluxes



Poster: ***Observation of Atmospheric Dynamics from Spaceborne radars: Added value of Doppler capability and sequence of "Z-only" observations***

Thank you!

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NEOS^3: noppasin.niamsuwan@jpl.nasa.gov

APR3 data sets

- GCPEX: https://ghrc.nsstc.nasa.gov/home/field-campaigns/gcpex
- OLYMPEX: https://ghrc.nsstc.nasa.gov/home/field-campaigns/olympex
- ORACLES: https://espoarchive.nasa.gov/archive/browse/oracles
- CAMP^{2}EX: https://espoarchive.nasa.gov/archive/browse/camp2ex

GV activities in synergy with CloudSat, GPM and CCP

update

NASA airborne campaigns:

(APR-3, airMASTR)

Synergies and opportunities

Part 1

EarthCARE

Part 2

RainCube:

New paradigm

Part 3

Comparisons vs CloudSat:

Direct comparisons,

Possible applications

Part 4

Forward modeling

for algorithm development and validation:

High-Resolution Radar based, or Model Based

Q4: What direct comparisons are possible?

- **Clear air surface return**: data calibration, gas attenuation correction

- **Marine SCu and shallow cloud detection**: EC is expected to improve wrt CS, widespread regions of frequent occurrence lay along the 12-13S latitude.

- **Deep convection**, **impact of Multiple-Scattering and depth of valid Doppler measurements**: the best area is in the warm pool just north of Darwin

- **Cirrus detection and profiling**: almost ubiquitous.

- Almost **everything else** (small isolated convection) should probably not be targeted for direct comparisons due to **low probability** of **co-location (time & space**)

- **Brightness Temperature product**: CloudSat's Tb derived from *noise floor*, calibration vs AMSR-E (accuracy ~2 K, precision ~ 0.5 to 8 K depending on scene). collocated Tb reduces ambiguities of radar-only retrievals.
  - Similar product expected for EC CPR with calibration on CloudSat or GCOM-W

OLYMPEX: Olympic Mountains Experiment (Pacific NW) Nov 2015 – Jan 2016

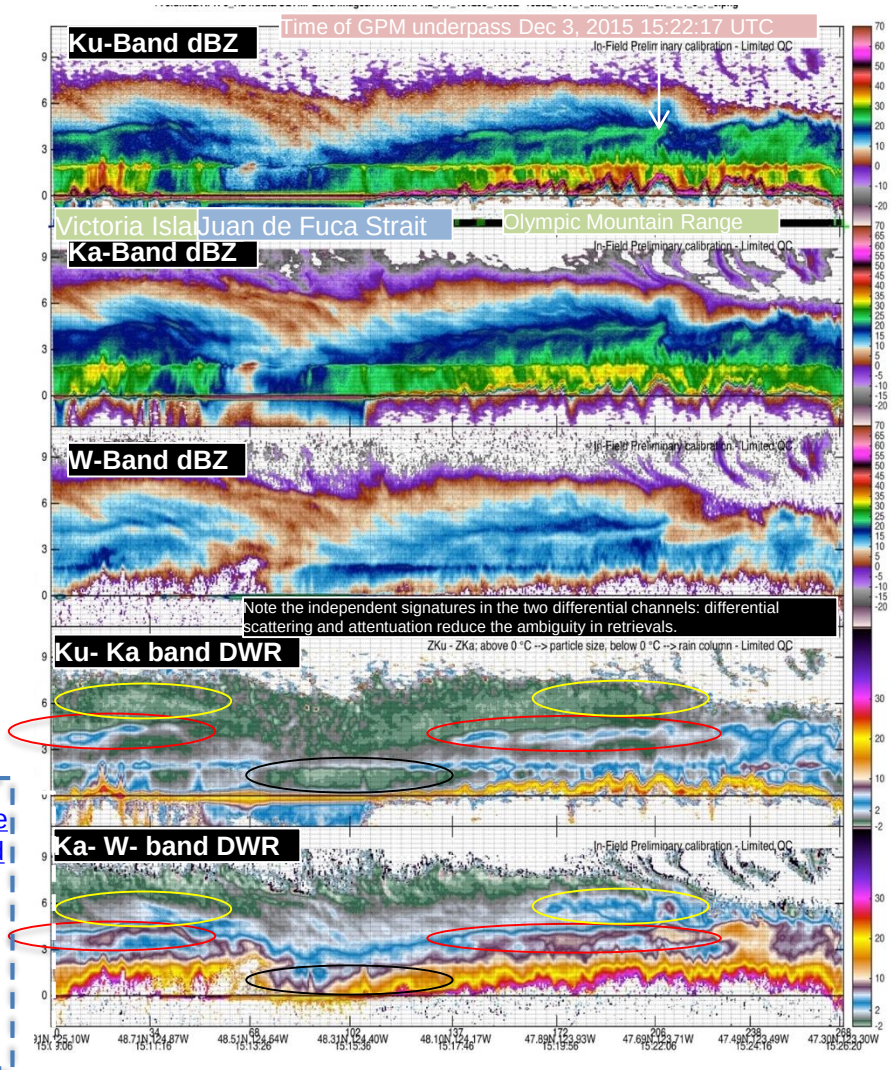
Science Goals:

- Physical Validation of **GPM Precip Algos** (GMI and DPR)
- Midlatitude **frontal systems** and modification by complex **terrain**
- Test **hydrological applications**

Instrumentation:

- **Surface**: Rain gauge networks, SNOTEL, Disdrometers (Parsivel, 2DVD), Pluvios
- **Radars**: WSR-88D, NPOL, D3R, MMR, X and W-band from Canada,
- Aircraft: DC-8 **(APR-3)**, UND Citation, ER-2 (ACE/RADEX).

APR-3 on DC-8 (ESTO/AITT Program) is the first 3-frequency (Ku, Ka, W), scanning, Doppler, airborne radar.



- Heymsfield, A., et al., 2017: Toward Improving Ice Water Content and Snow Rate Retrievals from Radars Part II: Results From Three Wavelength Radar /Collocated In Situ Measurements and CloudSat/GPM/TRMM Radar Data, *J.App.Met.Clim.*
- Chase, R. J., et al., 2018: Evaluation of Triple-Frequency Radar Retrieval of Snowfall Properties using Coincident Airborne In-Situ Observations during OLYMPEX, *Geophys. Res. Lett*
- Durden, S.L., et al., 2019: Comparison of GPM DPR and Airborne Radar Observations in OLYMPEX. *GRSL.*