Calibration and Validation of EarthCARE's Cloud Profiling Radar Data Products

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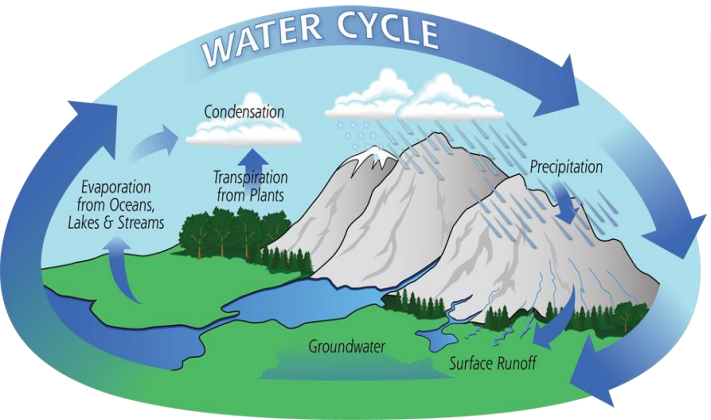
Jet Propulsion Laboratory, California Institute of Technology, USA
ESA-JAXA Pre-Launch EarthCARE Science and Validation Workshop
ESA-ESRIN, Frascati, Rome, Nov 13-17 2023

EarthCARE GV in synergy with NASA/JPL activities

- **EarthCARE: 1st spaceborne** profiling **Doppler** radar to characterize atmospheric dynamics
- **Synergies** with activities at **JPL**
  - **NRC Decadal Survey 2017** recommendation: ***Doppler*** for NASA's future ***spaceborne radar*** to study **clouds, convection, precipitation**



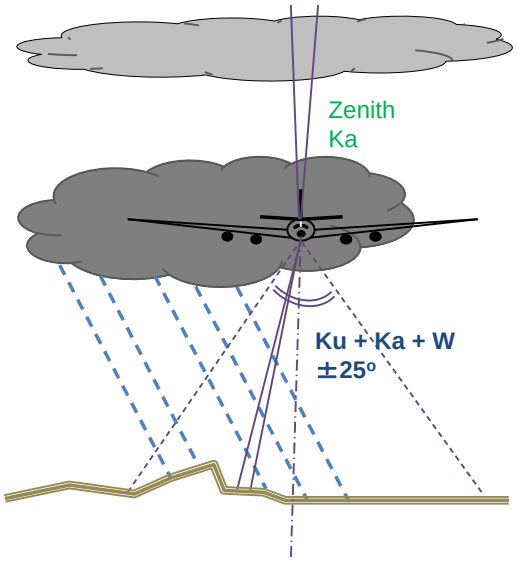
EarthCARE

<u>Airborne/ground-based</u>
(APR-3, CloudCube)

<u>Spaceborne comparisons</u>
(RainCube to INCUS)

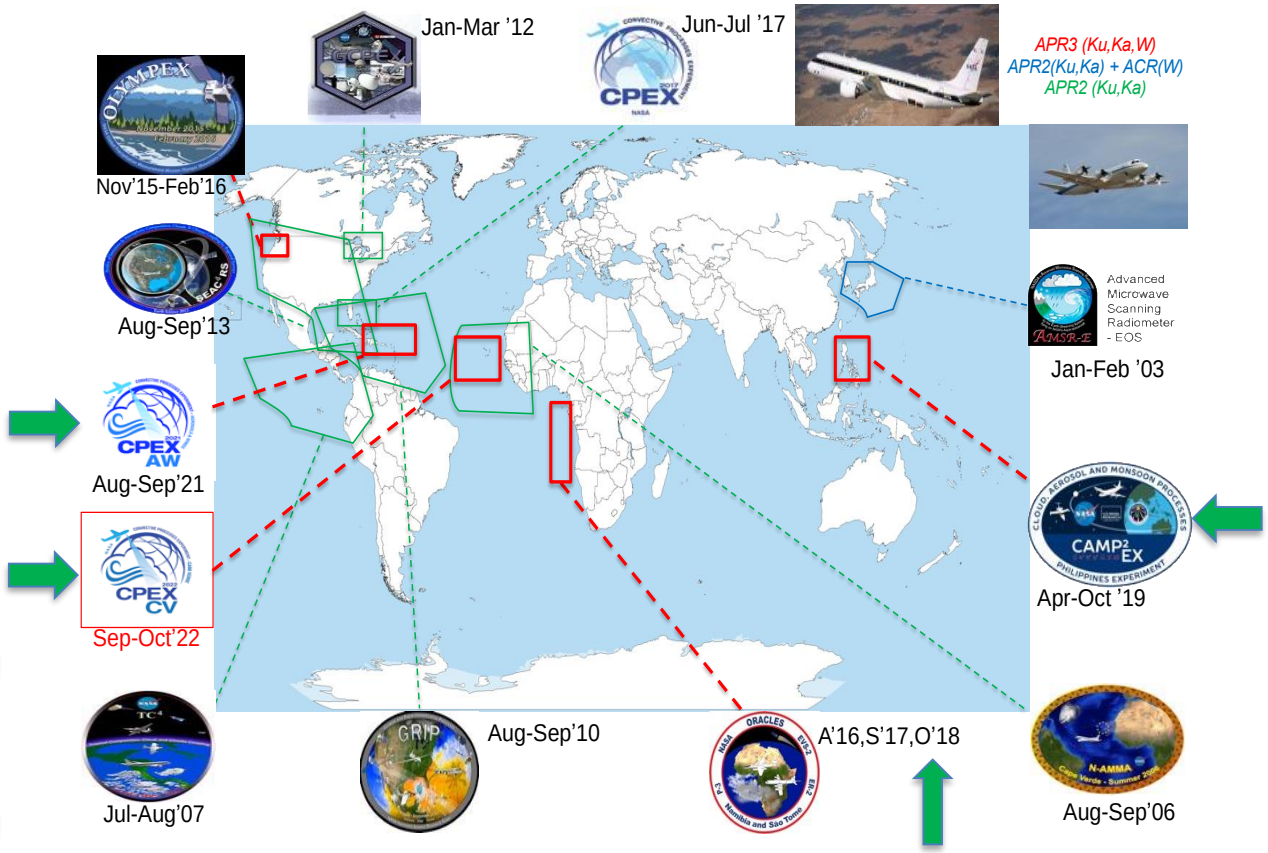
<u>Numerical modeling tools</u>
(OSSE, suborbital-to-orbital, microphysics)

APR-3: Airborne Precipitation & Cloud Radar 3rd gen.



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

Campaigns since the last EarthCARE workshop (2018)

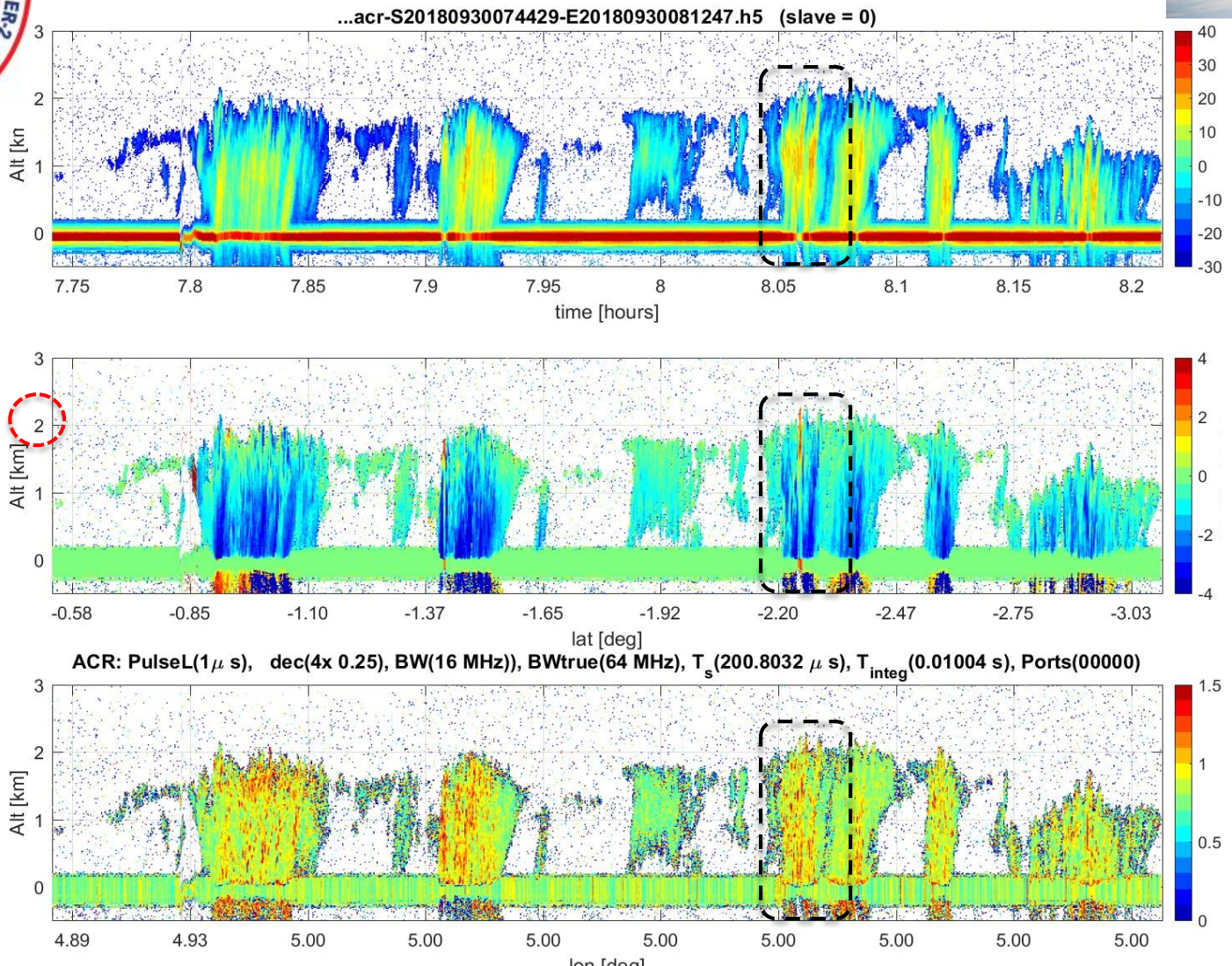


- Developed in 2014, NASA AITT / **Dr. Steve Durden**
- PI: Dr. **Raquel Rodriguez-Monje**
- **(Ku,Ka,W)** collimated on nadir port; **Ka** at **zenith**

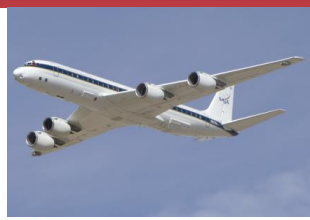
- Observables: **reflectivity**, **mean Doppler, spectral width**, **LDR**

APR-3 measurements: ORACLES 2018

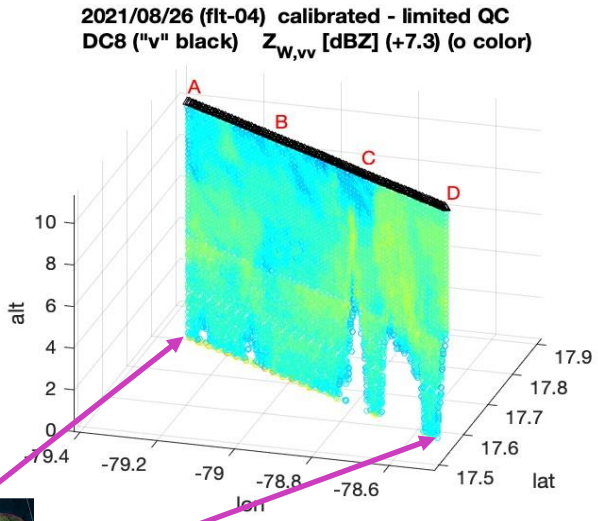
- **Drizzle** in the S.E. Atlantic (30 Sep. 2018)
- **W-band Doppler** moments

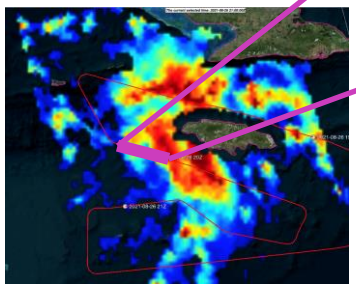


APR-3 measurements: CPEX-AW 2021

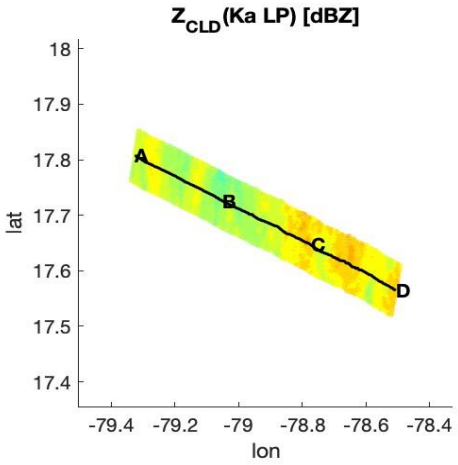


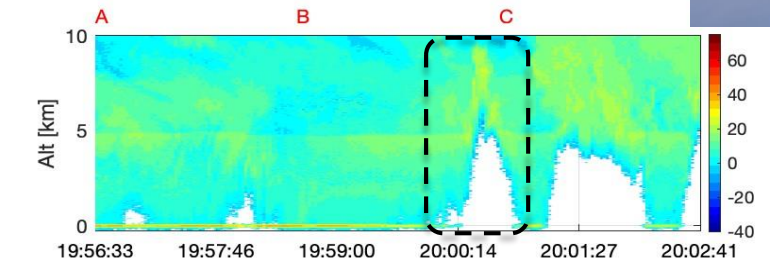
- **Tropical storm Ida**, West coast Jamaica (26/08/2021)
- Multi-frequency Doppler moments



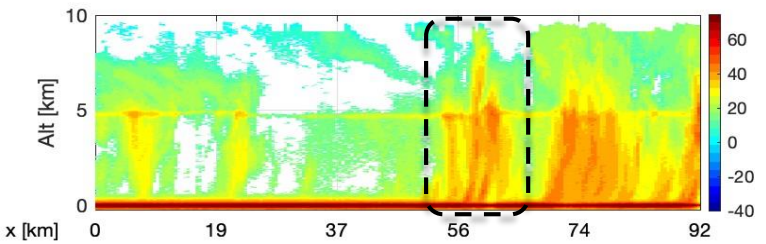


Rain Index
GCOM-W1 (AMSR-2)
Dr. S. Hristova-Veleva

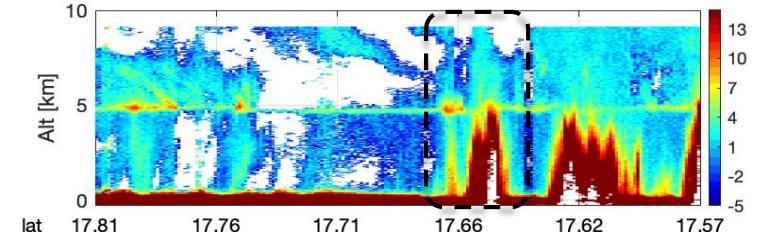




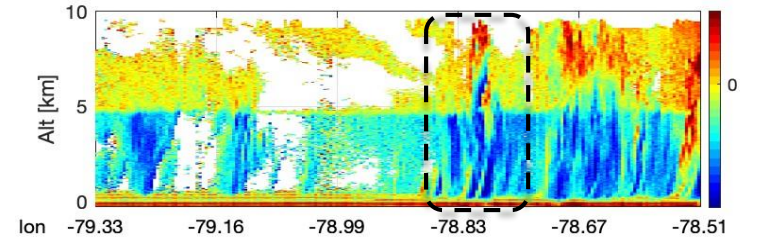
Reflectivity
Z(W)
[dBZ]



Z(Ku)
[dBZ]



DWR
Z(Ku - Ka)
[dB]

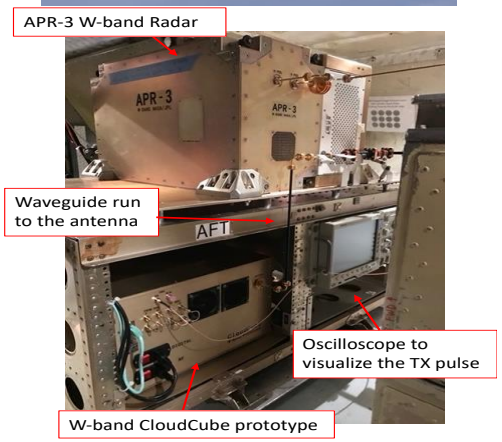


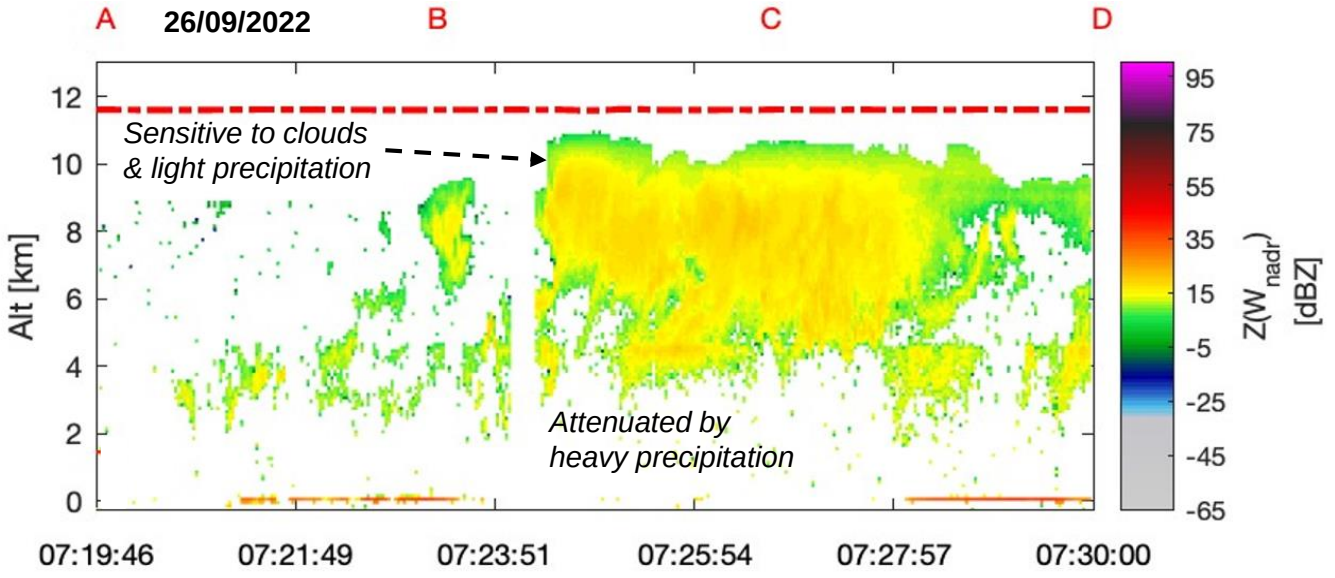
Mean
Doppler
V(Ku)
[m/s]

CloudCube Instrument (airborne)

- NASA-JPL ESTO IIP-19
- *1st ultra-compact pulsed-compression radar that combines **(Ka/W/G)-band***
- PI: **Dr. Raquel Rodriguez Monje**
- Field-campaign participations
  - **CPEX: AW2021 & CV2022**
    - **airborne**: NASA DC-8
    - $Z_{CLOUDCUBE}$(W), with APR-3

Parameters	Ka-band	W-band	G-band
Frequency (GHz)	35.7	94.9	238.5
Antenna eff. Diameter	0.30 m	0.30 m	0.2 m
Antenna gain	40 dBi	47 dBi	51 dBi
Peak Power	10 W	10 W	0.4 W
Bandwidth	2 MHz	2 MHz	2 MHz
Pulsewidth	10-20 us	10-20 us	10-20 us
PRF	0.5 kHz	0.5 kHz	0.5 kHz
Vertical resolution	75 m	75 m	75 m
X-track Hor. Res. (@10 Km alt.)	346 m	127 m	100 m
Sens. (@10km range)	**-7.2 dBZ**	**-14.6 dBZ**	**-15.5 dBZ**

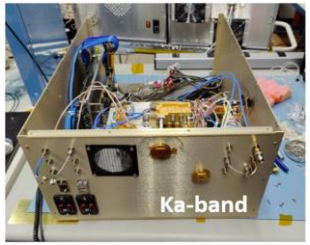


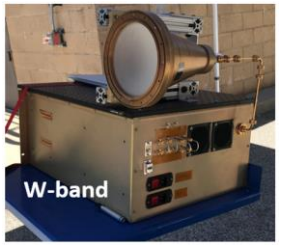


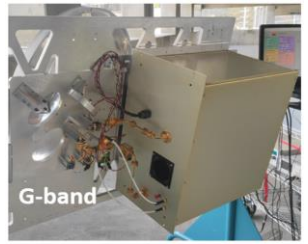
https://esto.nasa.gov/forums/estf2021/Presentations/June3/Monje_ESTF2021_June3.pdf

CloudCube Instrument (ground-based, spaceborne)

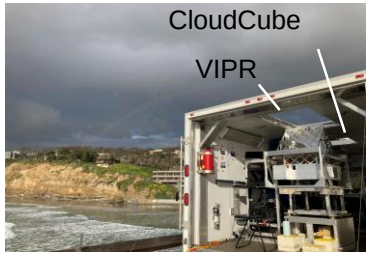
- Field-campaign participations
  - **EPCAPE (DoE) 2023-2024**:
    - **Ground-based (trailer)**
    - **Ka/W/G-band**
    - **Full Doppler**

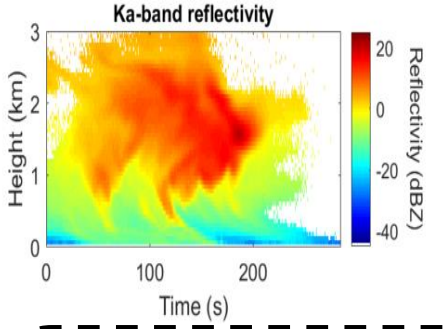


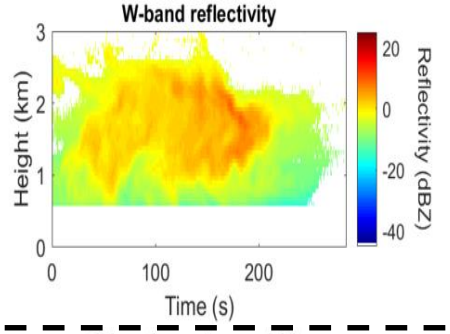


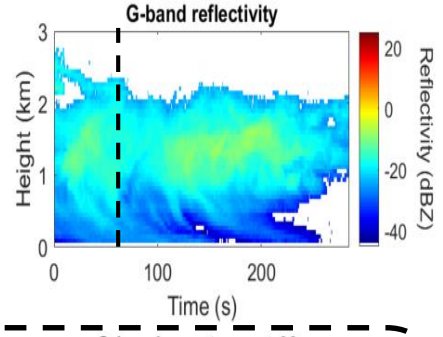


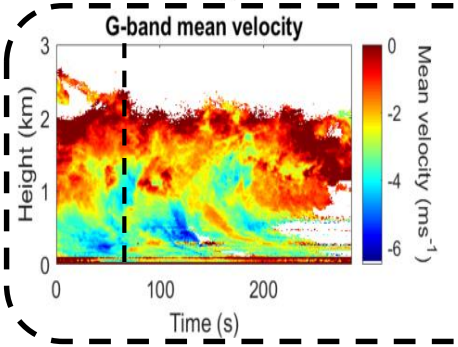
03/30/2023 **La Jolla, CA**

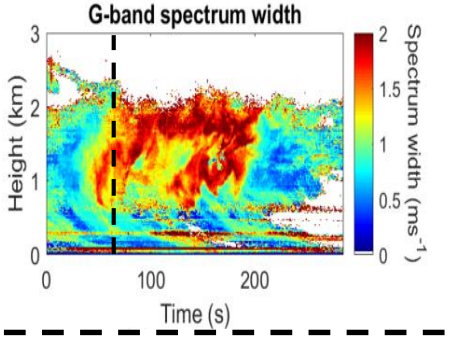


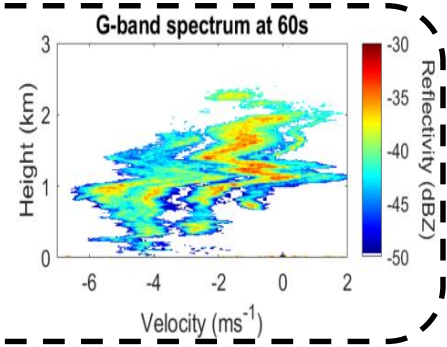








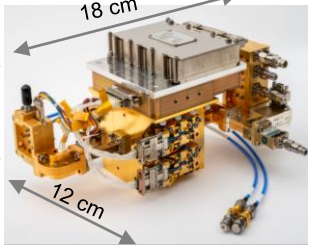




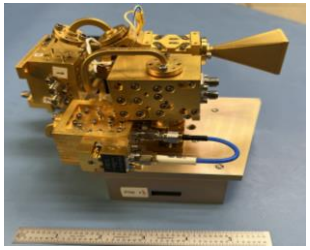
Spaceborne CloudCube Radar Electronics **compatible** with **SmallSats**

- ✓ **Compact**: **<3U volume** per frequency channel
- ✓ **Low power RF**: **20-30 W** DC power per frequency channel

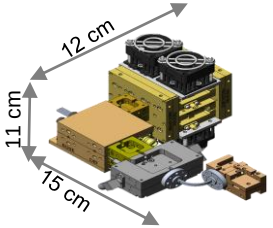
Ka band



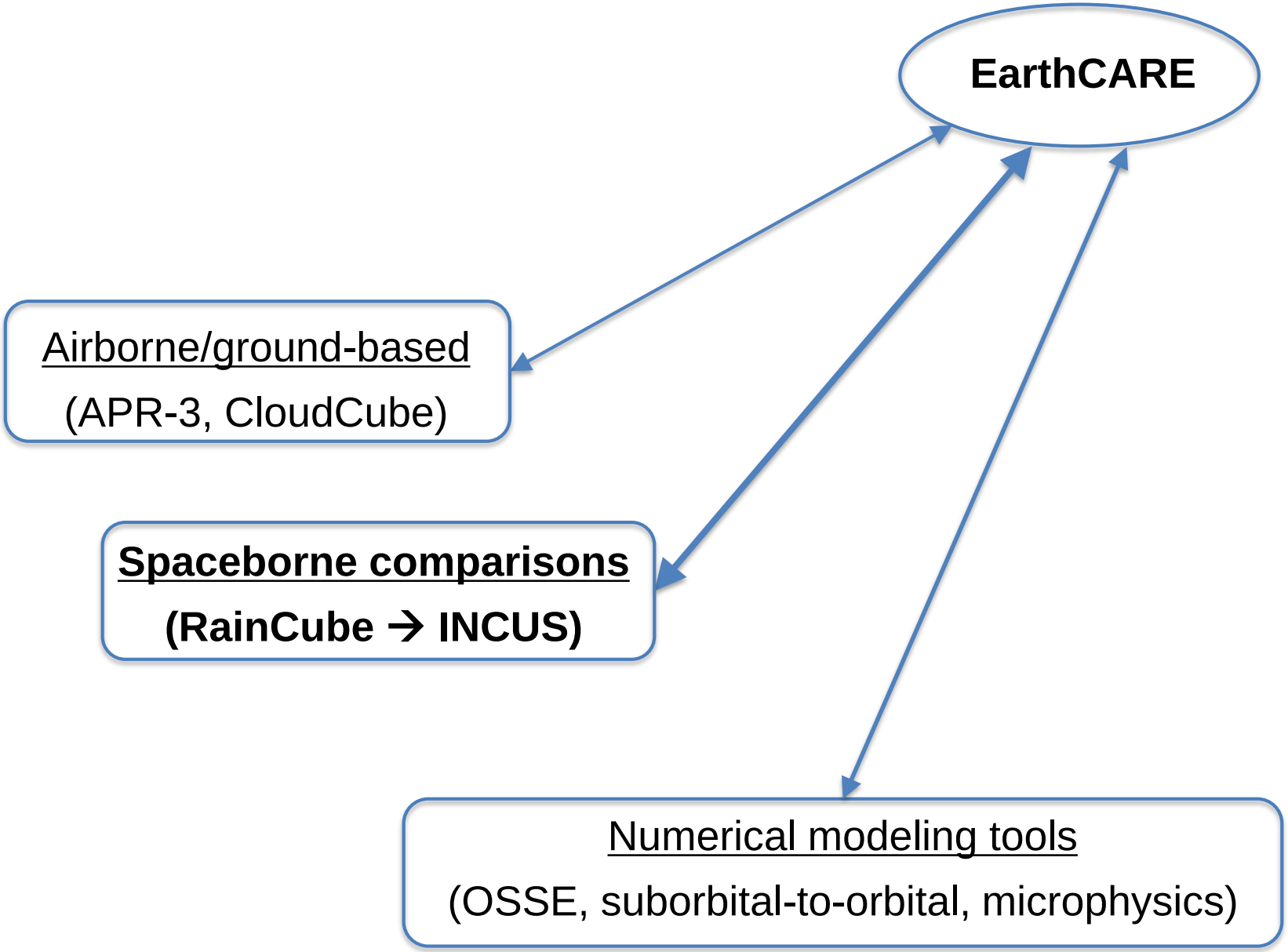
W band



G band



EarthCARE GV in synergy with NASA/JPL activities

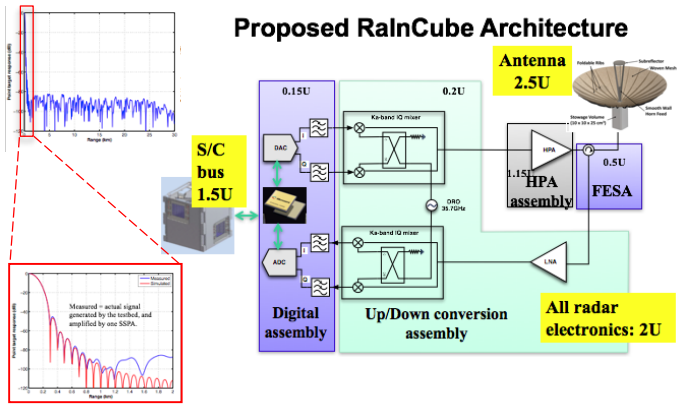


RainCube (PI Dr. Eva Peral, NASA ESTO Tech. demo)

2013

6U Concept

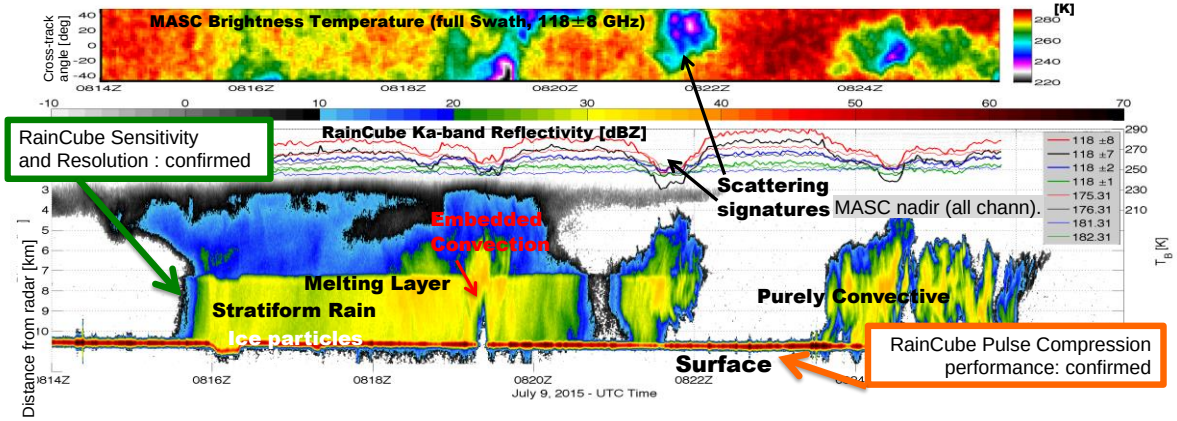
miniKaAR (**35.75 GHz**) + KaRPDA **0.5 m**



2015

PECAN

Airborne Demo of miniKaAR



EarthCARE Cal/Val
Workshop **June 2018**

RainCube 6U

Antenna deployment: **Jul. 2018**

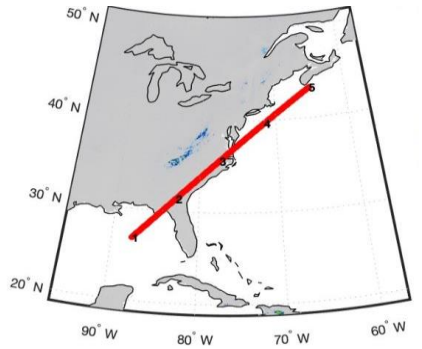
RainCube 6U

Deployed from ISS **July 2018**

RainCube 6U

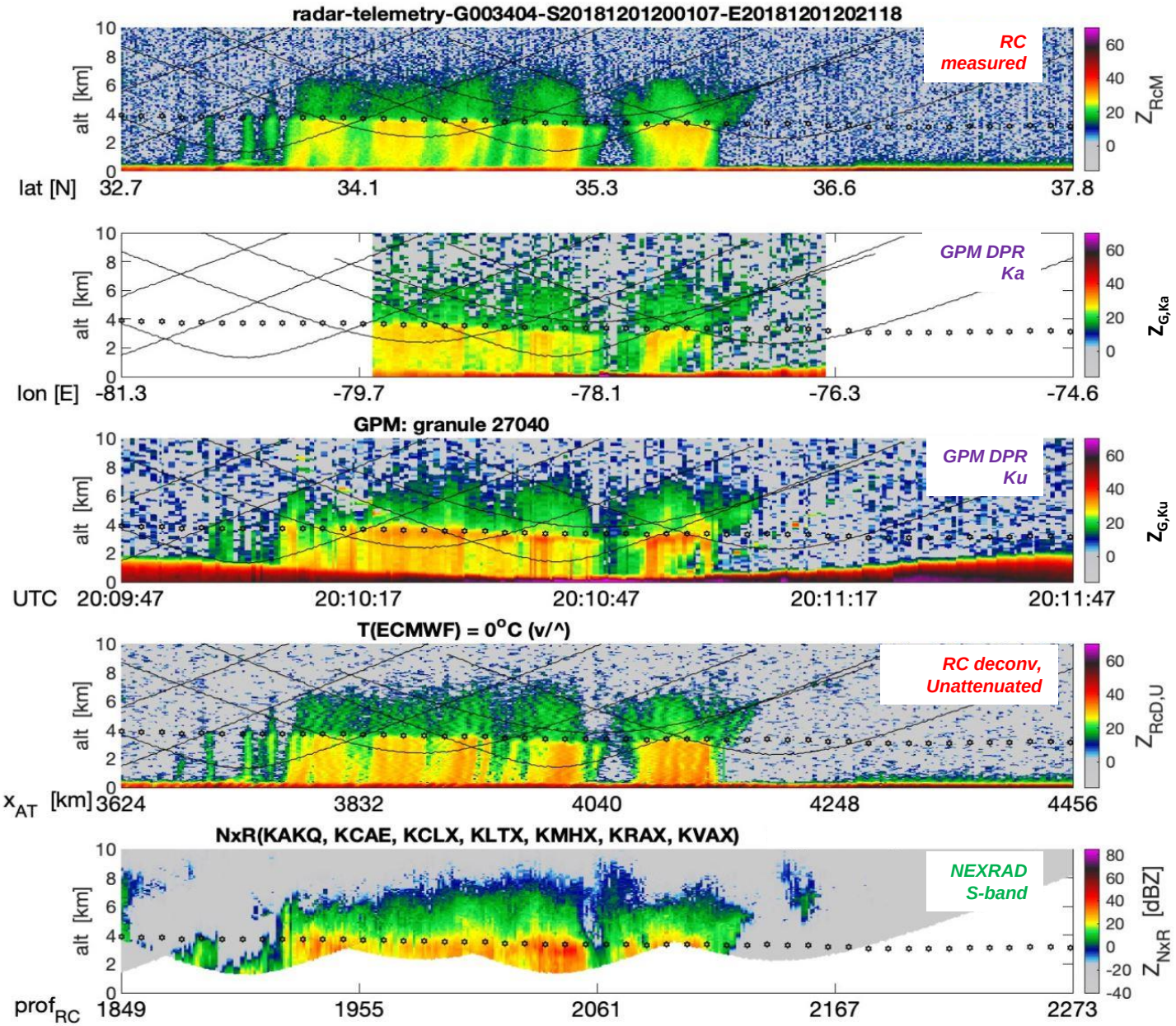
5.5 kg, 10x20x30 cm³
RF Power: 10 W
Launched to ISS **May 2018**

RainCube measurements: Aug. 2018 - Dec. 2020



Calibration vs DPR
Z (RC) - Z (Ka) ~ 1.4 dB

Scientific Products From the First Radar in a CubeSat (RainCube): Deconvolution, Cross-Validation, and Retrievals",
O.O. Sy et al.,
IEEE TGRS, vol. 60, **2022**

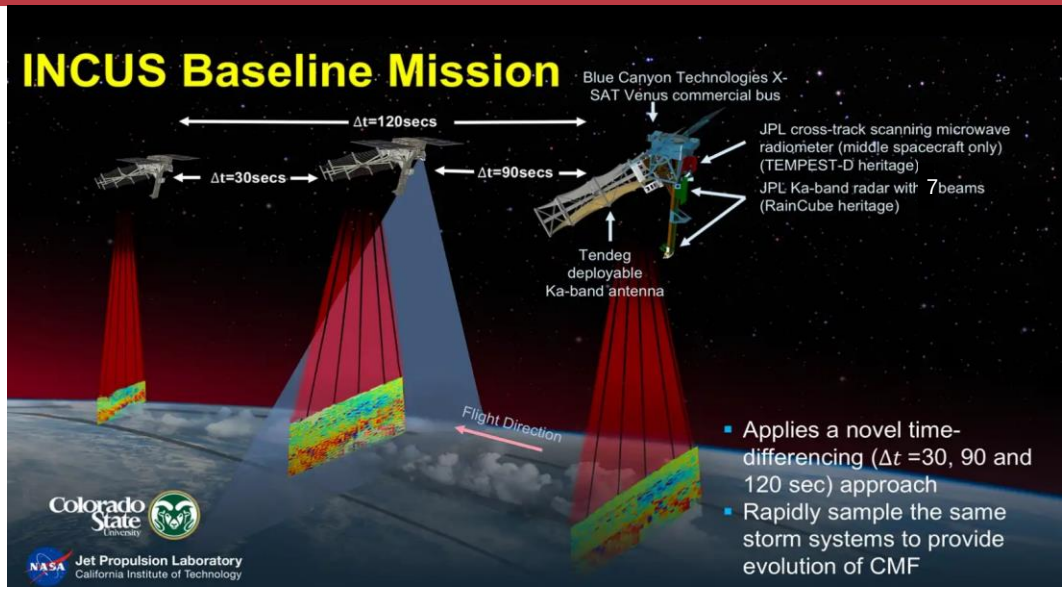


Investigation of Convective Updrafts

- NASA Earth Ventures Mission
  (Nov. **2021**, in **Phase B** as of 13 Nov. 2023)
- Launch: NET **2026**

- PI: **Prof. Susan van den Heever** (CSU)

- Payload:
  - **3 DAR**: radars (*RainCube-like*)
    - **Ka-band;**
    - **1.6 m antenna**
    - **7 beams**
    - **Mass: 7 kg**
    - resolution: 3 km (H), 240 m (V)
    - swath: 9 km
  - **1 DMR**: radiometer (*Tempest-D-like*)
    - **87, 165, 174, 178, 181±0.5 GHz**
    - **Mass: 3.8 kg**
    - resolution: 16 km
    - swath: 1000 km

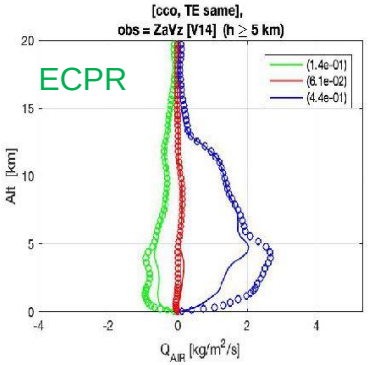


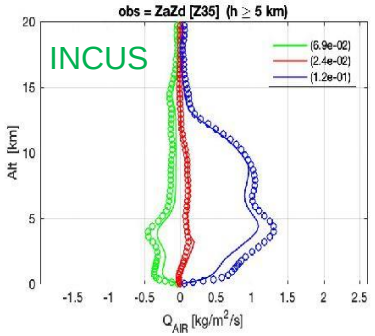
Target: vertical transport of air & water by convective storms

Observables:

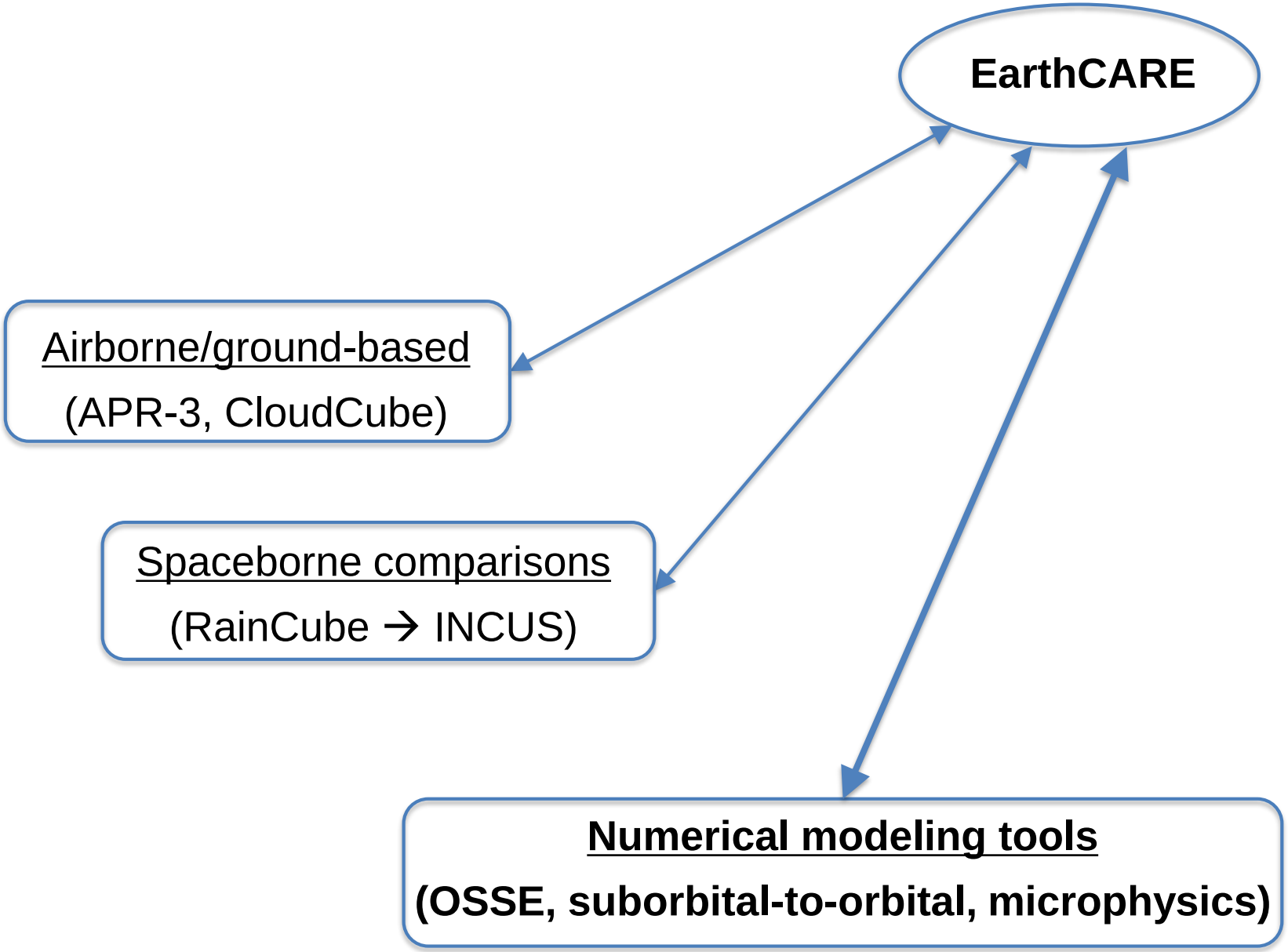
- **Z(h,t), Z(h,t+30), Z(h,t+120)**
  - *derivatives* $\frac{\Delta Z}{\Delta t}$ *(not Doppler)*

- ***"Derived Observations From Frequently Sampled Microwave Measurements of Precipitation- Part I: Relations to Atmospheric Thermodynamics"***,
  Z.S. Haddad, O.O. Sy, S. Hristova-Veleva, G.L. Stephens, *IEEE TGRS*, vol. 55 (6), **2017**
- ***"Derived Observations From Frequently Sampled Microwave Measurements of Precipitation. Part II: Sensitivity to Atmospheric Variables and Instrument Parameters"***,
  O.O. Sy, Z.S. Haddad, G.L. Stephens, S. Hristova-Veleva, *IEEE TGRS*, vol. 55 (5), **2017**
- ***"A Distributed Small Satellite Approach for Measuring Convective Transports in the Earth's Atmosphere"***, G. L. Stephens et al., *IEEE TGRS*, vol. 58(1), **2020**

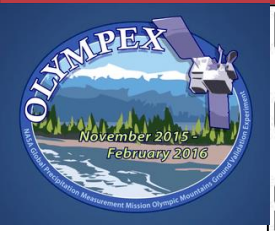




EarthCARE GV in synergy with NASA/JPL activities



APR3 - Satellite under-flight: NUBF-Reflectivity



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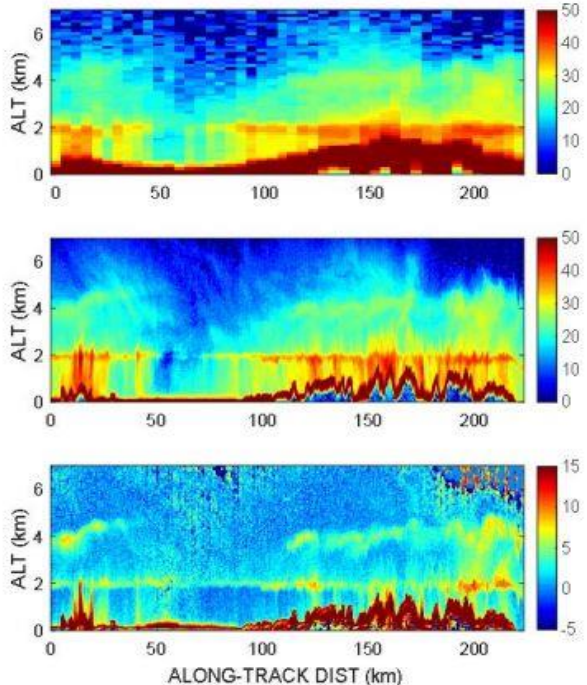
A PUBLICATION OF THE IEEE GEOSCIENCE AND REMOTE SENSING SOCIETY
GRSS
OCTOBER 2020 VOLUME 17 NUMBER 10 IGRSBY (ISSN 1545-598X)

"Comparison of GPM DPR and Airborne Radar Observations in OLYMPEX"

S.L. Durden, S. Tanelli, and O.O. Sy,
IEEE GRSL, vol. 17(10)
2020

Stratiform rain
Olympic mountains, Washington state

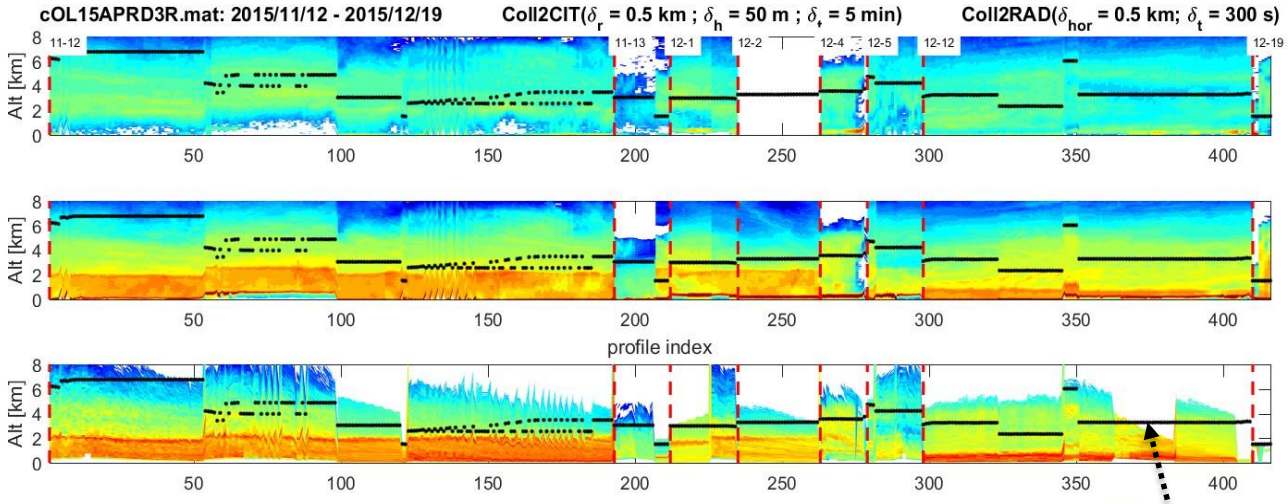
3 Dec 2015



- GPM DPR reflectivity Ku-band
- APR3 reflectivity Ku-band
- APR3 dual-freq. ratio Ku - Ka

APR3 - in situ collocations: microphysical retrievals

- Collocations: **APR3** - **in situ** microphysics - **ground-radar D3R**
- Ancillary datasets: **drop/radiosondes** - **reanalysis** (ECMWF ERA5, MERRA)
- Statistical microphysical analyses (forward/inverse)



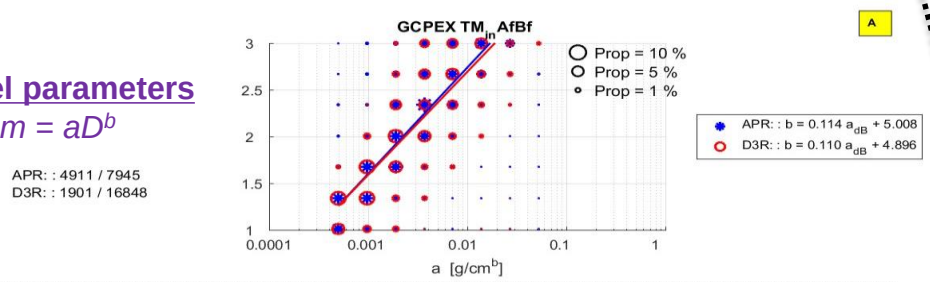
APR3 *Z (W)*

APR3 *Z (Ka)*

D3R *Z (Ka)*

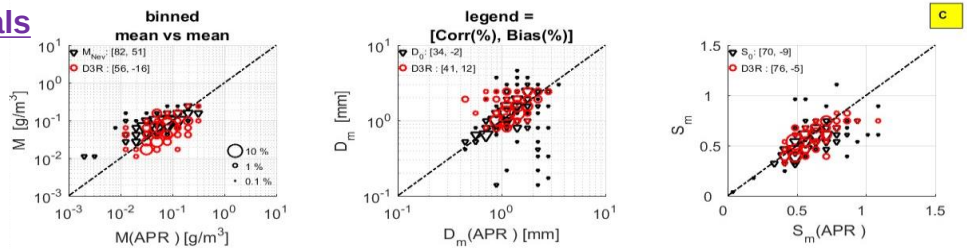
Model parameters

$m = aD^b$



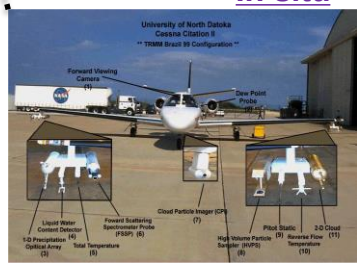
APR: : 4911 / 7945
D3R: : 1901 / 16848

retrievals



IWC **Diameter** **Spread**

In situ



(Image Source: UND Aerospace)

"Impact of Mass–Size Parameterizations of Frozen Hydrometeors on Microphysical Retrievals: Evaluation by Matching Radar to In Situ Observations from GCPEx and OLYMPEx"

O.O. Sy, et al.
J. Atmos. Oceanic Technol.
vol 37, **2020**

HiDReSS: sub-orbital to orbital Doppler resampler

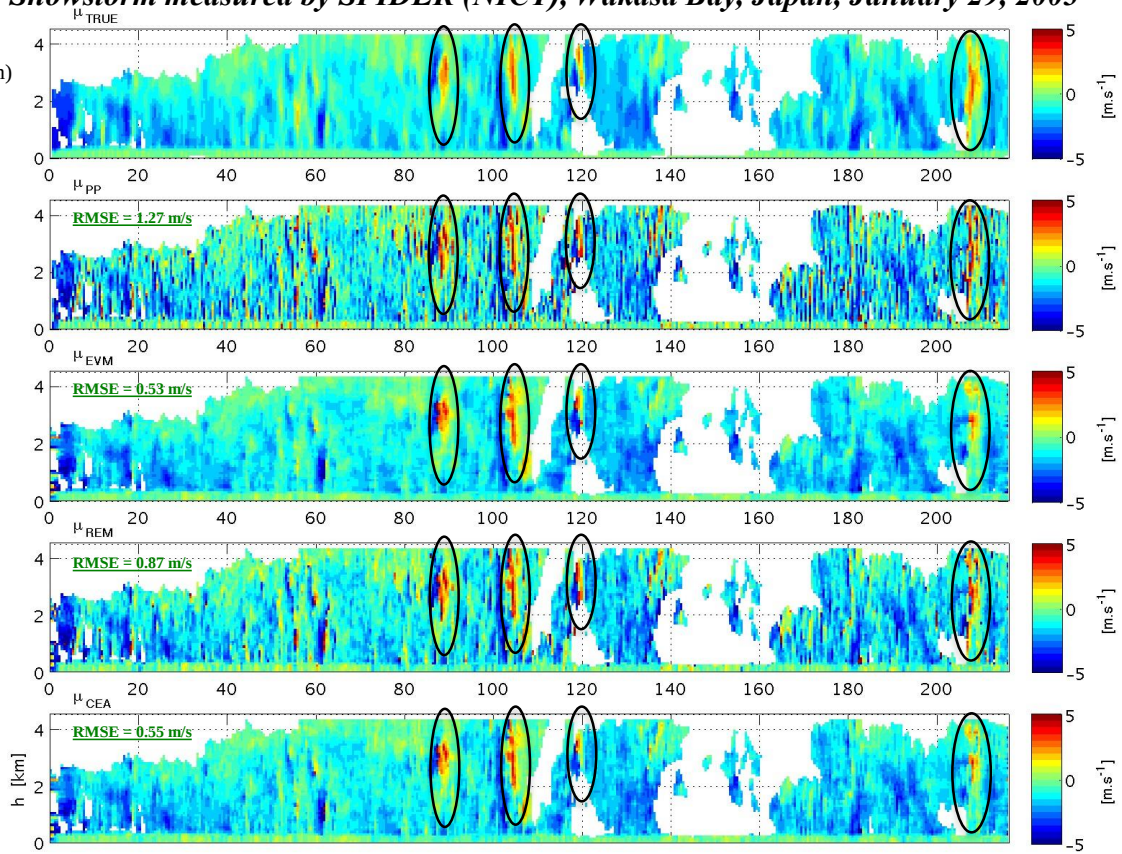
- Acknowledgement: **NASA Earth Science US Participating Investigator** (ES-USPI) grants

- Input: high-resolution suborbital Doppler measurements
  *air (**SPIDER@NICT**, **APR3**), ground (**WACR@ARM**)*
- Output: *Simulated spaceborne Doppler products (Spectrum, PP, Z,V,S)*

Used to develop corrections for

- **Aliasing**
  SPIDER (NICT), WACR (ARM)
  (Sy et al. 2014a)
- **NUBF ⇔ gradient-Z**
  SPIDER (NICT), WACR (ARM)
  (Sy et al. 2014a)
- **NUBF ⇔ deconvolution**
  APR-3
  (Sy & Tanelli 2022)
- **Broadening ⇔ deconvolution**
  APR-3
  (Sy & Tanelli 2022)
- **Broadening ⇔ hierarchical**
  APR-3
  (Sy & Tanelli 2023)
- **Noisiness ⇔ adaptive filters**
  SPIDER (NICT), WACR (ARM)
  (Sy et al. 2014b)

Snowstorm measured by SPIDER (NICT), Wakasa Bay, Japan, January 29, 2003



"Application of Matched Statistical Filters for EarthCARE Cloud Doppler Products"
O.O. Sy, S. Tanelli, **P. Kollias** and **Y. Ohno**, in *IEEE TGRS*, vol.52(11), **2014b**

Thank you!

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RAINCUBE data sets

- **RainCube data**: https://tcis.jpl.nasa.gov/data/raincube/

APR3 data sets

- GCPEX, OLYMPEX: https://ghrc.nsstc.nasa.gov/home/field-campaigns/
- ORACLES 2016-18: https://espo.nasa.gov/oracles/archive/browse/oracles/
- CAMP^{2}EX 2019: https://www-air.larc.nasa.gov/index.html
- CPEX-AW21/CV22: https://ghrc.nsstc.nasa.gov/uso/ds_details/collections/
  https://www-air.larc.nasa.gov/index.html