Calibration, Validation, and Science Results from PAZ Polarimetric Radio Occultations

Chi O. Ao[1], Ramon Padullés[1,2], F. Joseph Turk[1], Manuel de la Torre Juárez[1], Kuo-Nung Wang[1], Estel Cardellach[2]

[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

[2] Institut de Ciències de l'Espai, ICE, CSIC, IEEC, Barcelona

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ROHP-PAZ (Radio Occultation Heavy Precipitation with PAZ)

rohp-PAZ

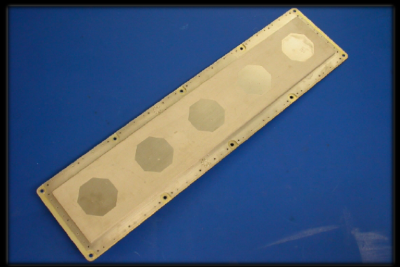
PI: Dr. Estel Cardellach (ICE – IEEC/CSIC, Barcelona)
JPL Participation through the NASA ESUSPI program

- Proof of concept mission on the Spanish PAZ satellite
- Main PAZ payload: X-band SAR
- PAZ launched **Feb 22, 2018** from VAFB
- Sun-synchronous dusk/dawn polar orbit
- **Polarimetric experiment** activated on May 10, 2018

PAZ artistic view

Credit: Hisdesat

PAZ Dual Polarization antenna



Credit: Hisdesat

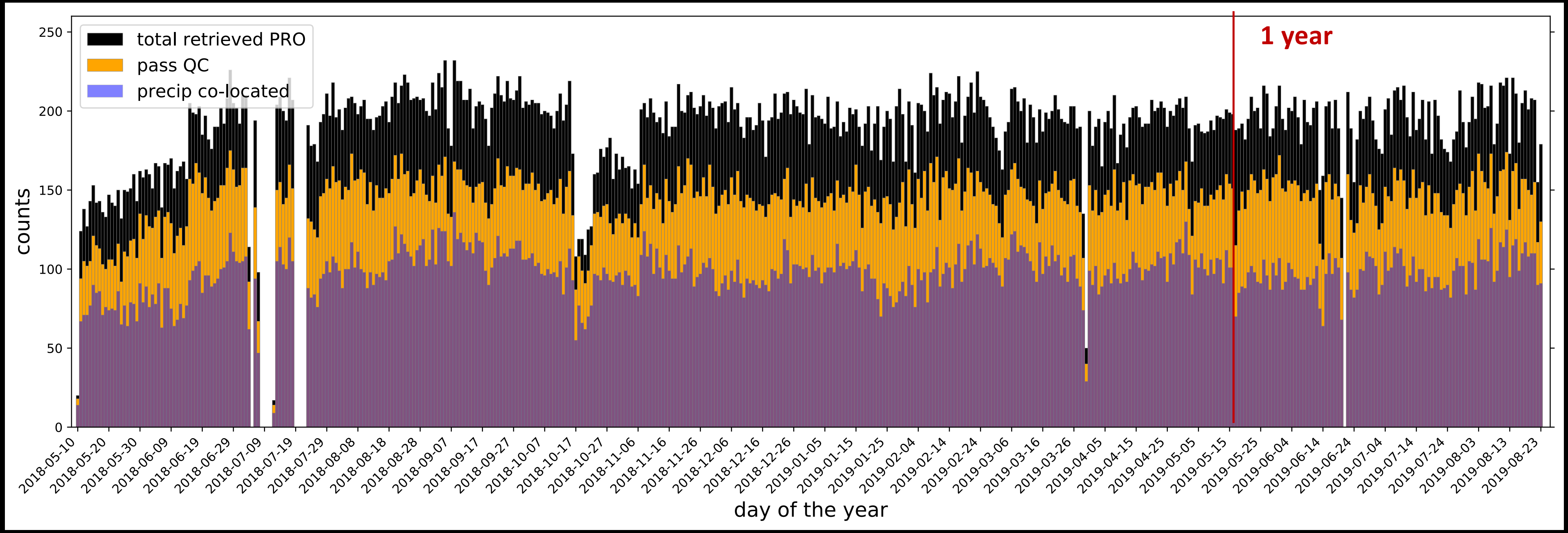
PAZ satellite deployment

Credit: SpaceX

Credit: SpaceX

Status of PAZ processing at JPL

Total number of processed Polarimetric ROs [up to 2019 – 08 – 23]



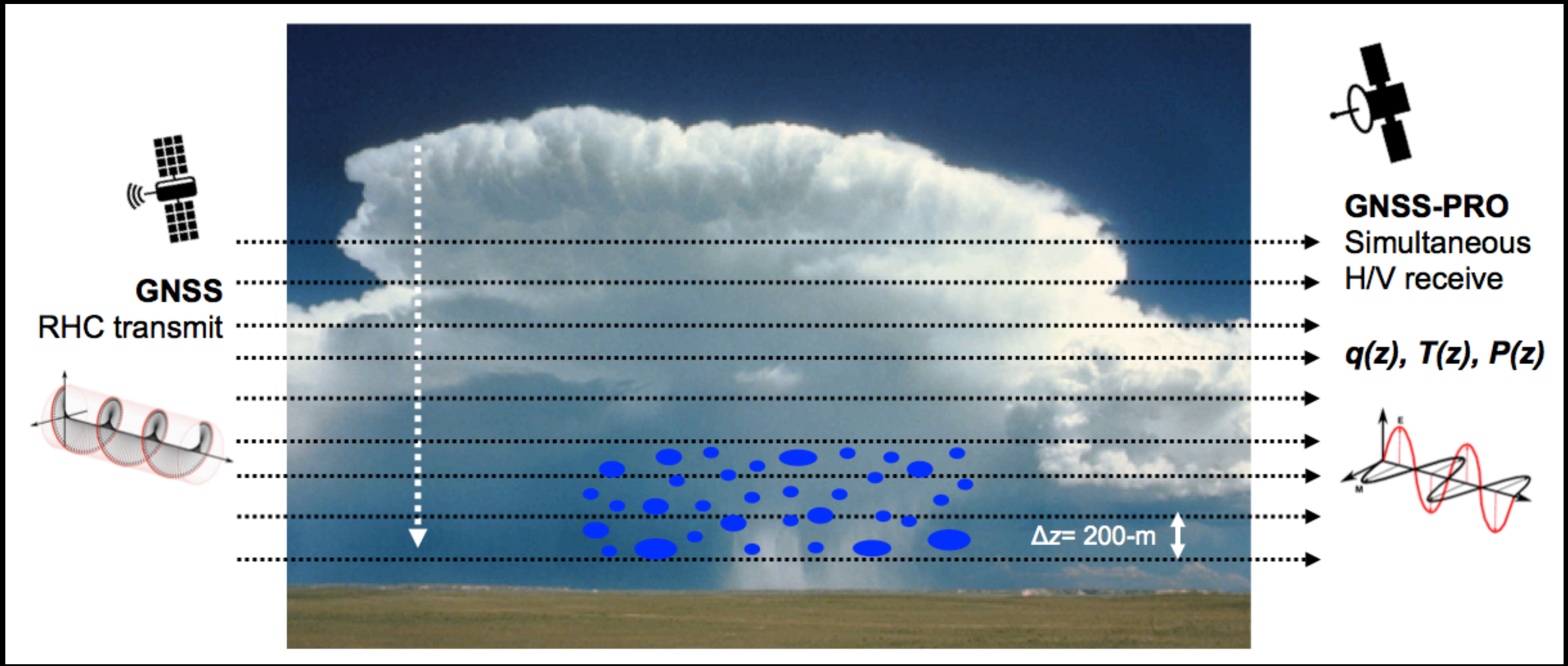
Total number of processed profiles: 87,938
Total gone through QC: 68,557
Precipitation information (surface): 47,228

Near real time standard RO products are processed by UCAR and being distributed via the GTS for NWP data assimilation.

Polarimetric RO (PRO) Concept

GNSS (L-band) propagation through precipitation induces a cross-polarized component, measured as a differential phase delay (1-way analogy to the polarimetric upgrade to the 170+ US NEXRAD radars)

Extend the capabilities of normal RO, with ***simultaneous*** measurements of the profile of water vapor (q), temperature (T) and an *indication* of heavy precipitation (P), along each ray



The polarimetric phase difference (H – V) observable depends on many factors (instrument and ionosphere).

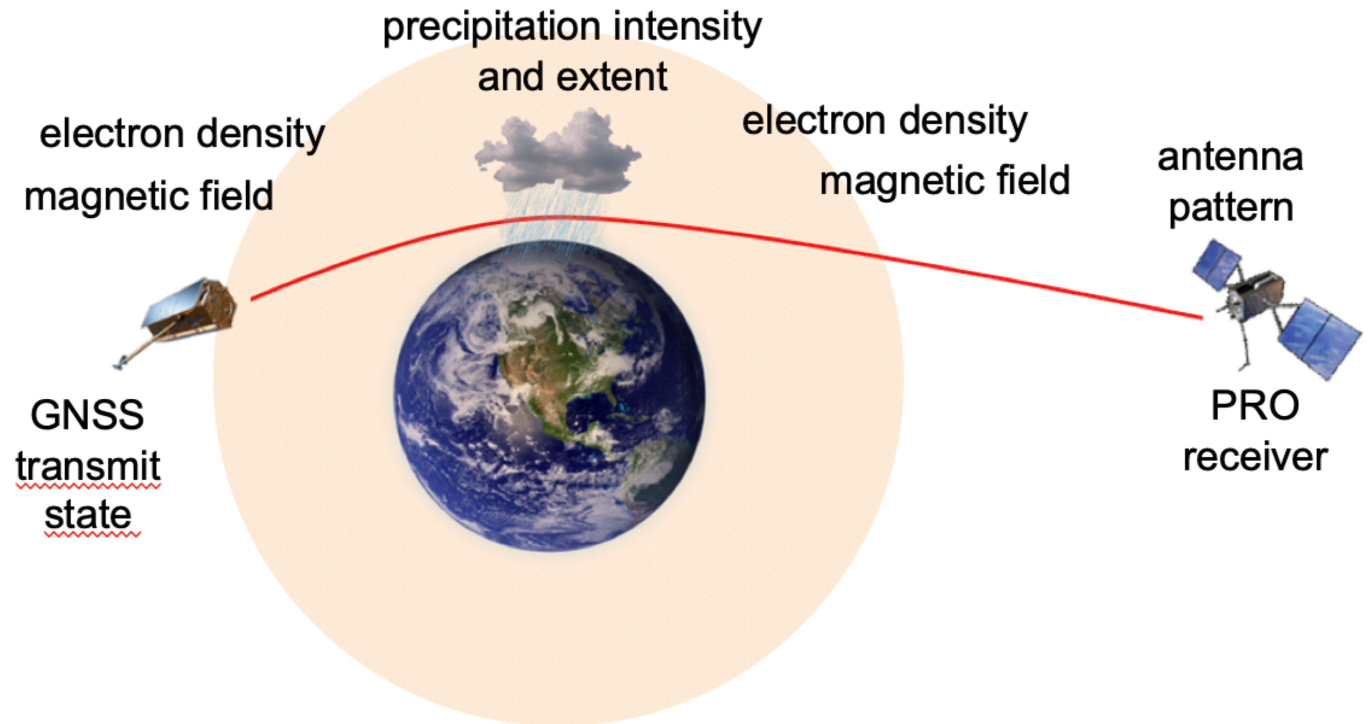
Tomas et al., IEEE TGRS, 2018

Careful calibration is needed to remove non-hydrometeor effects.

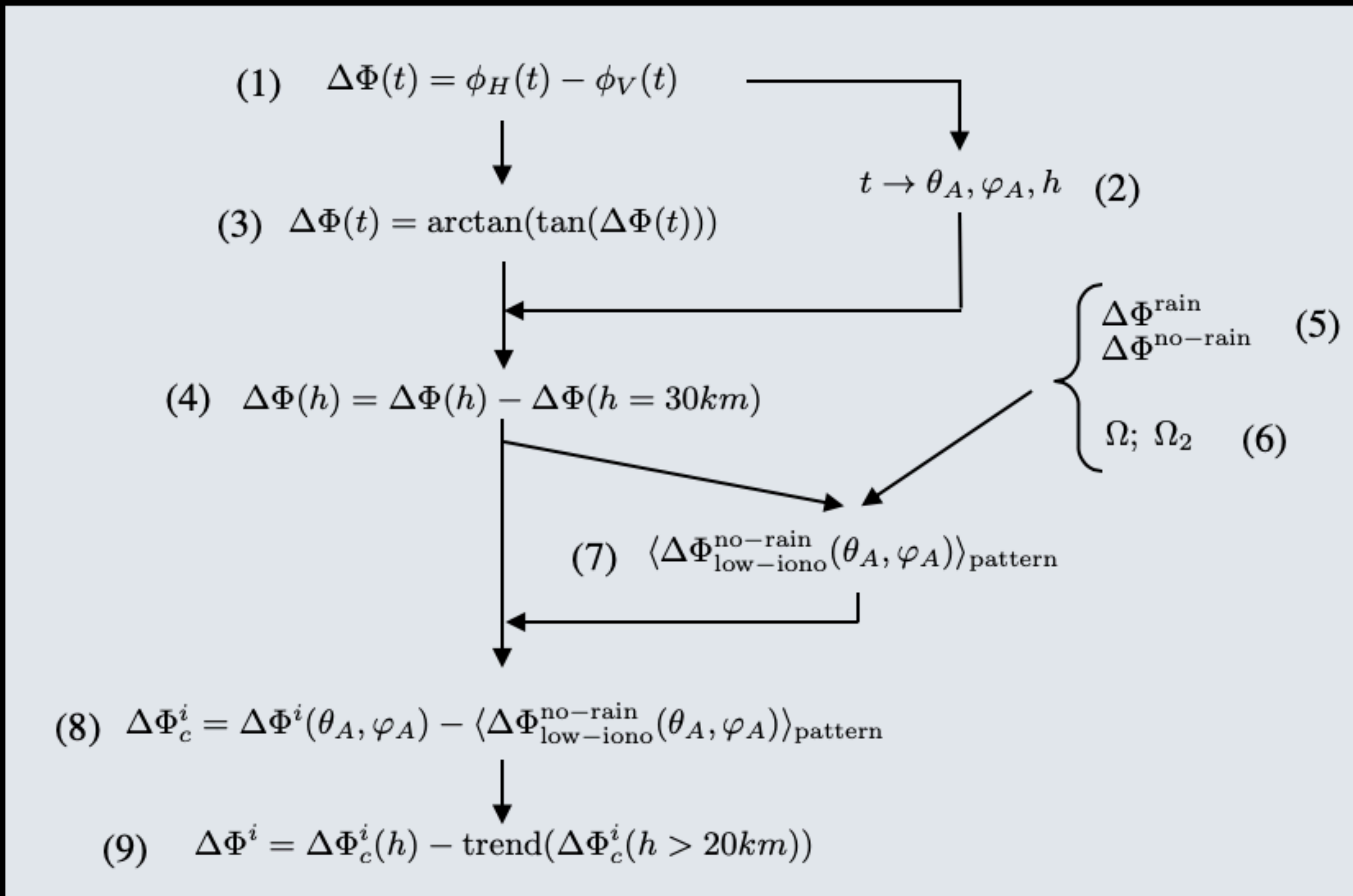
emission state
precipitation intensity
precipitation extension
electron density
magnetic field
antenna pattern
receiver

$$\Delta\Phi = \Delta\Phi\left(E, K_{dp}, L, n_e, \vec{B}, A, R\right)$$

$$\mathbf{E} = e^{-i\Phi}\,\frac{e^{-ikr}}{r}\begin{bmatrix}1 & 0\\ 0 & e^{i\phi_{arc}}\end{bmatrix}\begin{bmatrix}a_{\mathrm{hh}} & 0\\ 0 & a_{\mathrm{vv}}e^{i\phi_{\mathrm{ant}}}\end{bmatrix}\mathbf{R}(\Omega_2)\begin{bmatrix}e^{-ik_h} & 0\\ 0 & e^{-ik_v}\end{bmatrix}\mathbf{R}(\Omega_1)\;\mathbf{E}^{\mathrm{i}}{}_{\{\hat{e}_h,\hat{e}_v\}}$$



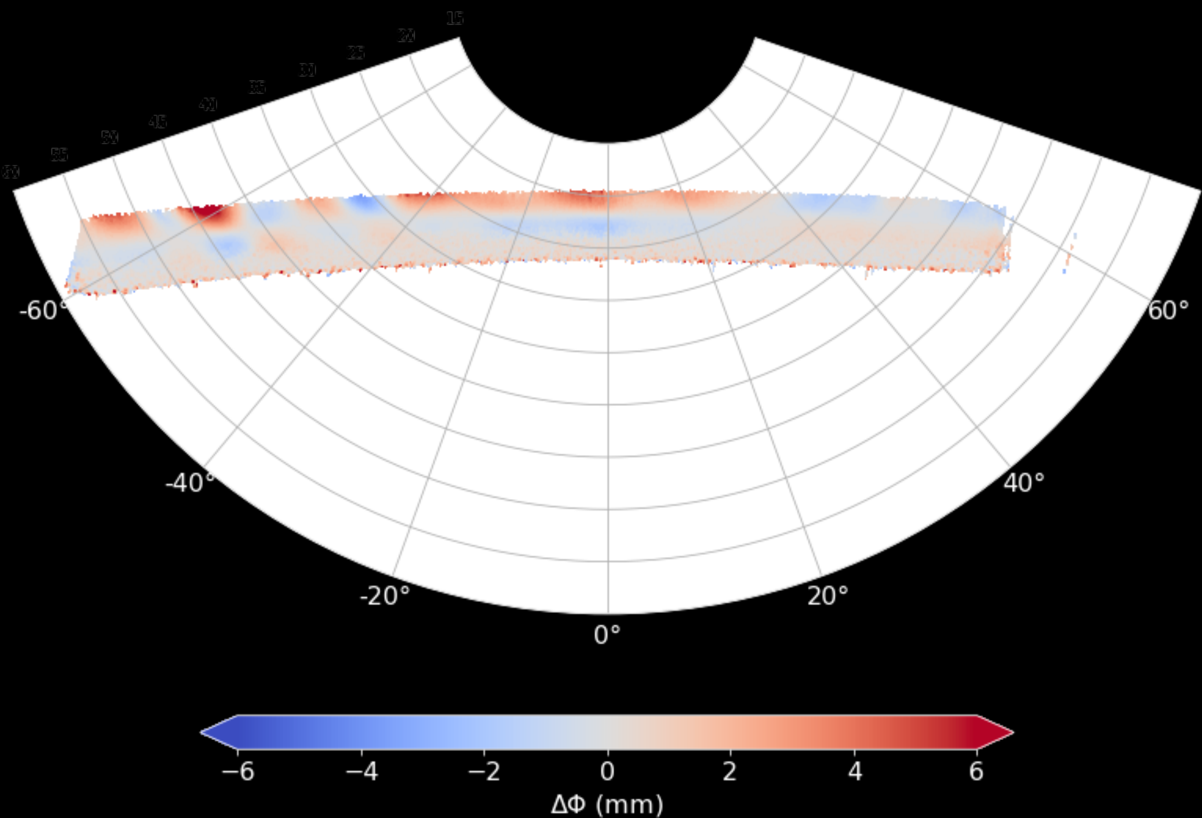
Calibration of polarimetric phase difference

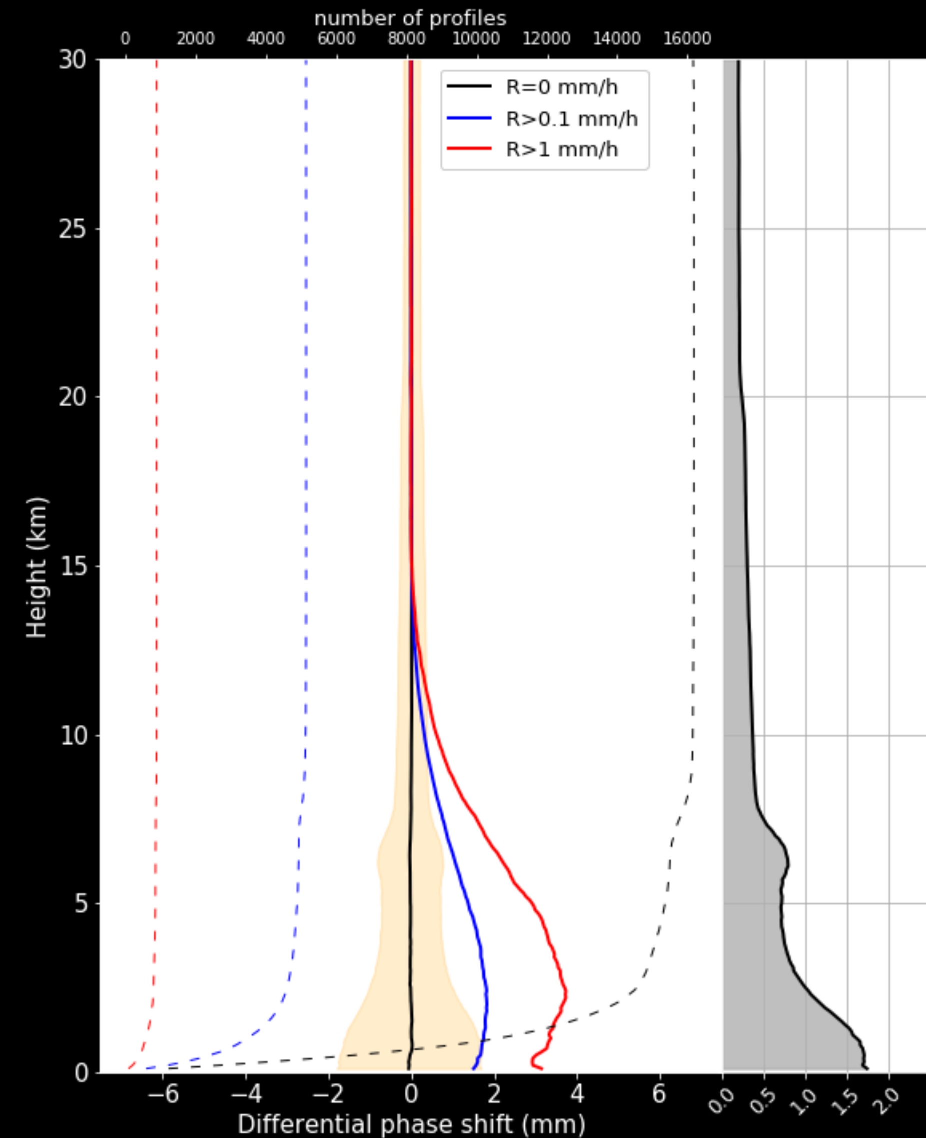


1) “Raw” observable
2) Mapping time -> height, elevation, azimuth, etc…
3) Correction of remaining cycle slips
4) Set a zero-reference at the top of the observation (well above clouds)
5) **Colocations with Precipitation**
6) **Colocations with n_e & B**
7) **Antenna pattern (free of rain data and low ionospheric activity)**
8) **Correction of antenna pattern**
9) **Remove remaining trends**

Padulles et al. *Atmos. Meas. Tech. Discuss.*, https://doi.org/10.5194/amt-2019-237.

On-orbit calibration of antenna pattern



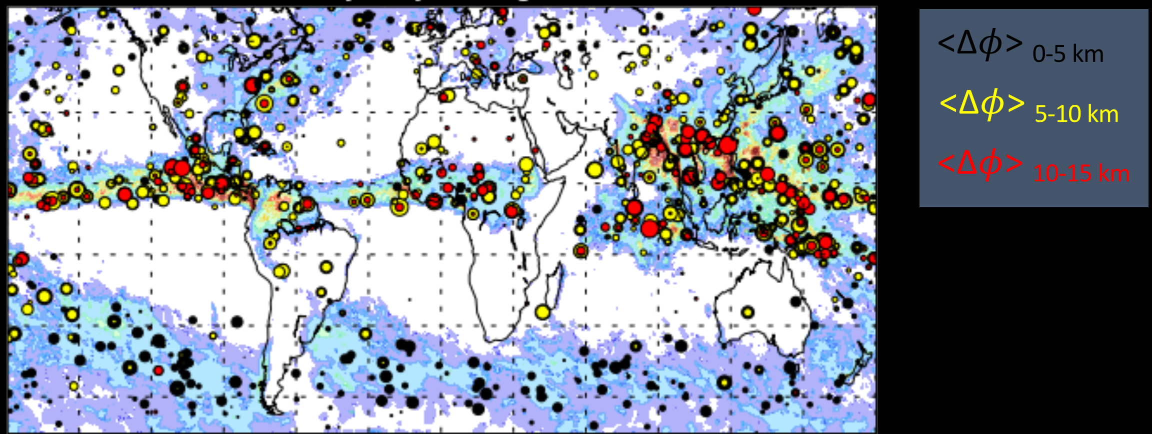


Validation with Precipitation Products

Vertical structure of $\Delta\phi$: geographical distribution

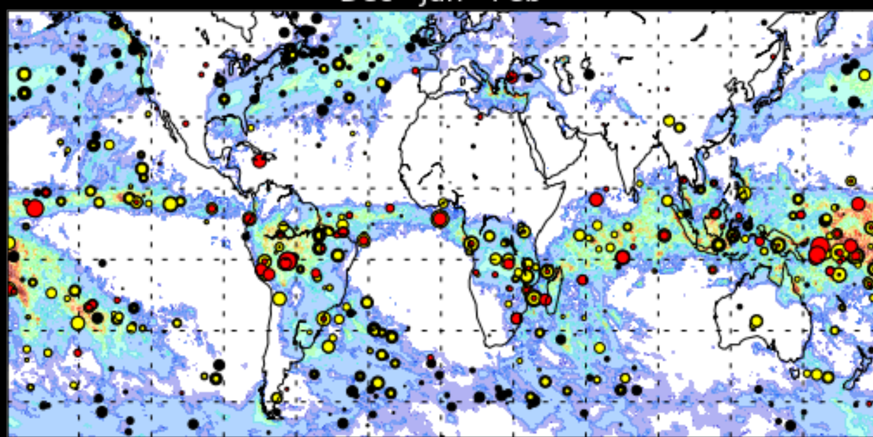
Jun - Jul - Aug

JJA



Dec - Jan - Feb

DJF

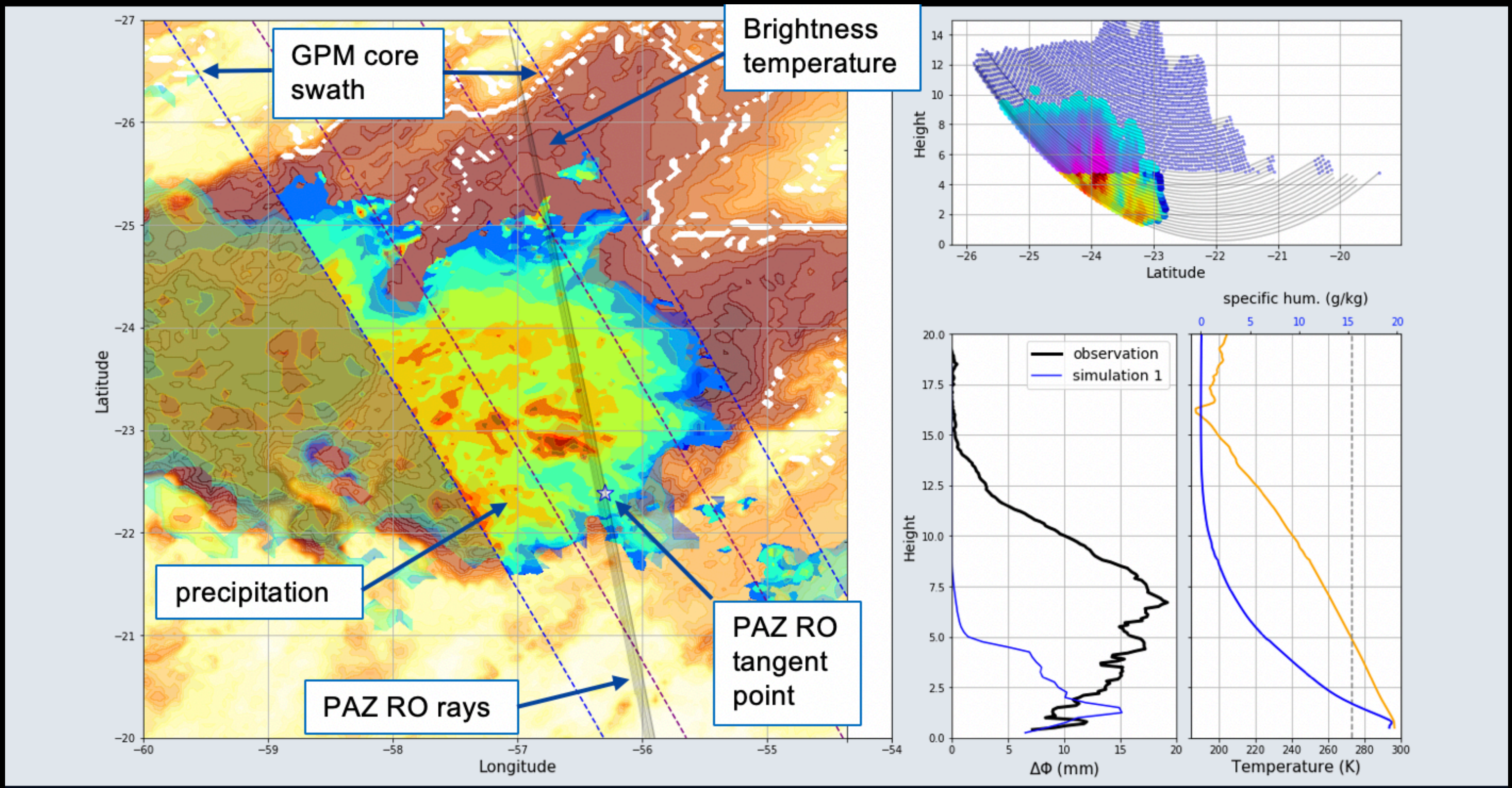


Background: accumulated precipitation from GPM

- Agreement of $<\Delta\phi>$ with precipitation climatologies
- Agreement with vertical structures:
  - Sensitivity above 10 km only in deep convective regions
- Strong precipitation in the lower layers not restricted to tropics

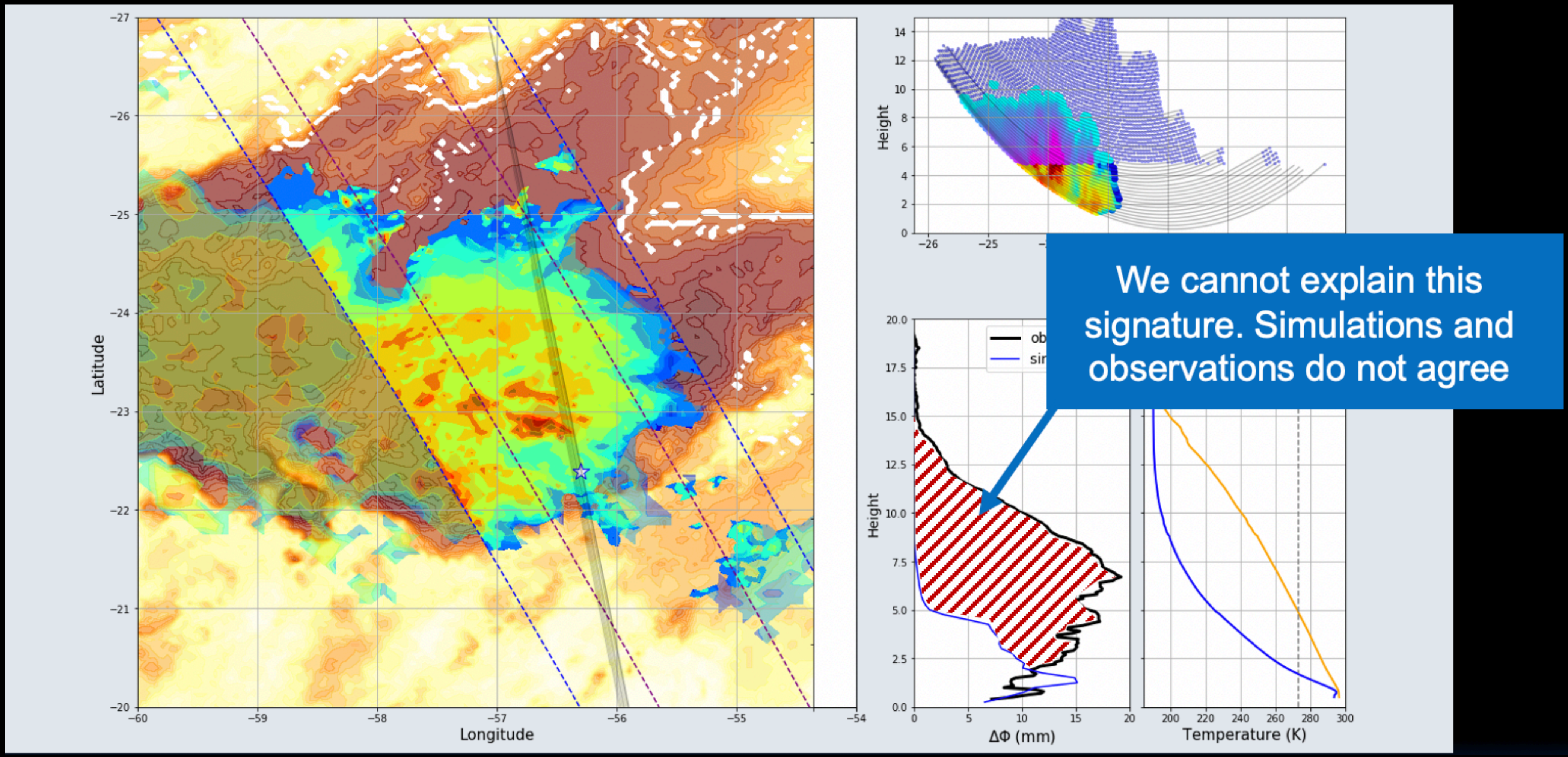
Validation with Precipitation Products

Colocations with GPM core radar

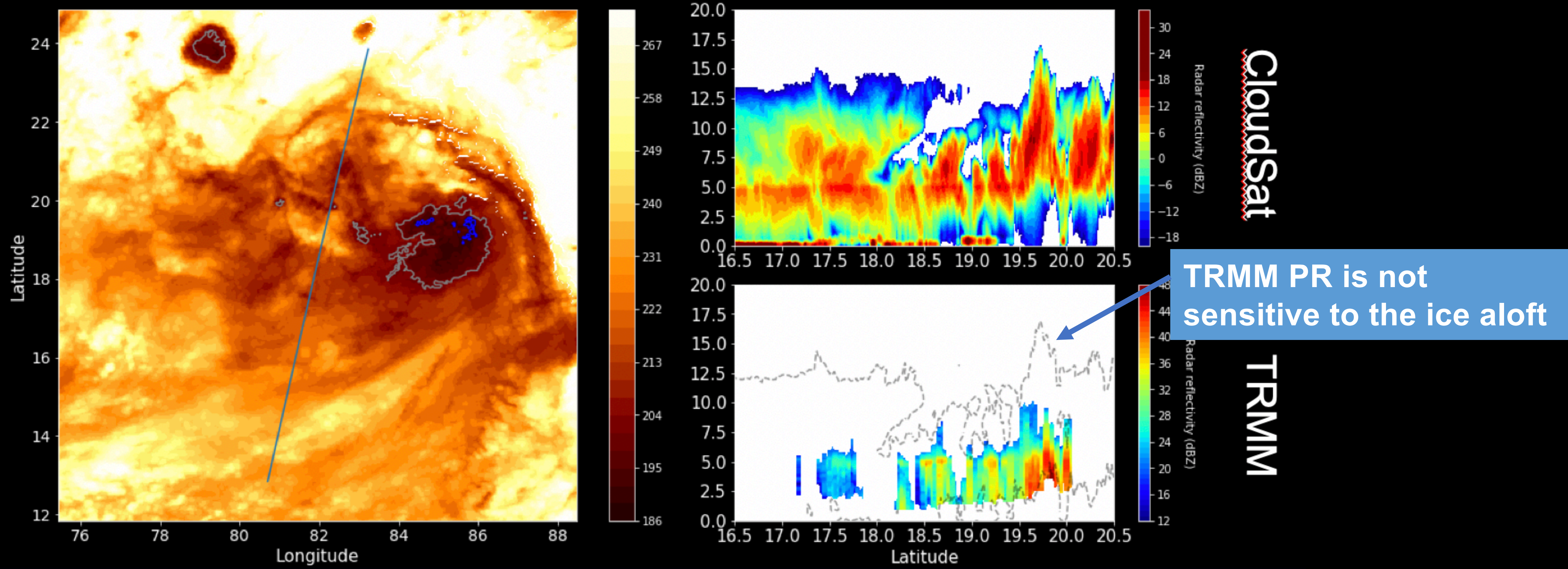


Validation with Precipitation Products

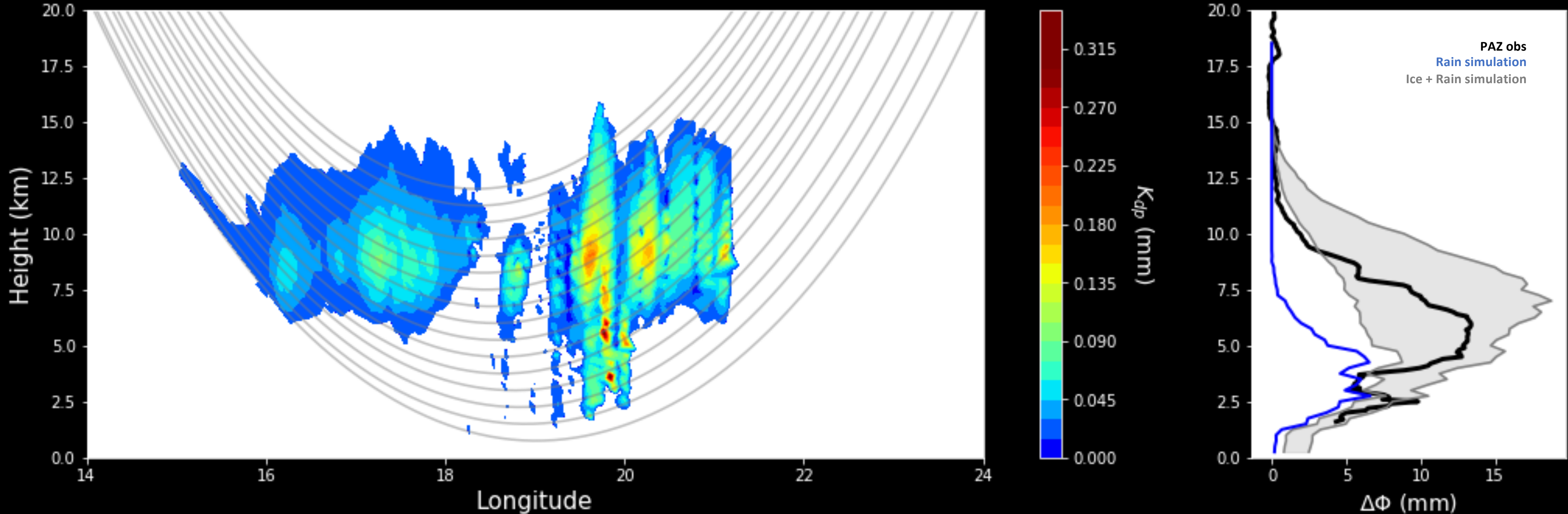
Colocations with GPM core radar



TRMM PR and CloudSat Collocations



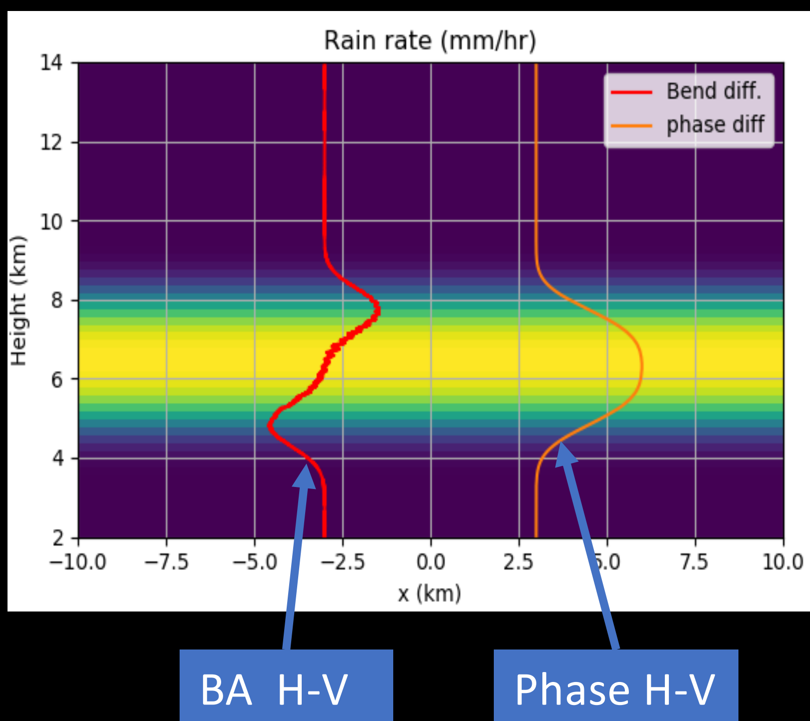
Simulations of PAZ observable with TRMM/CloudSat Collocations



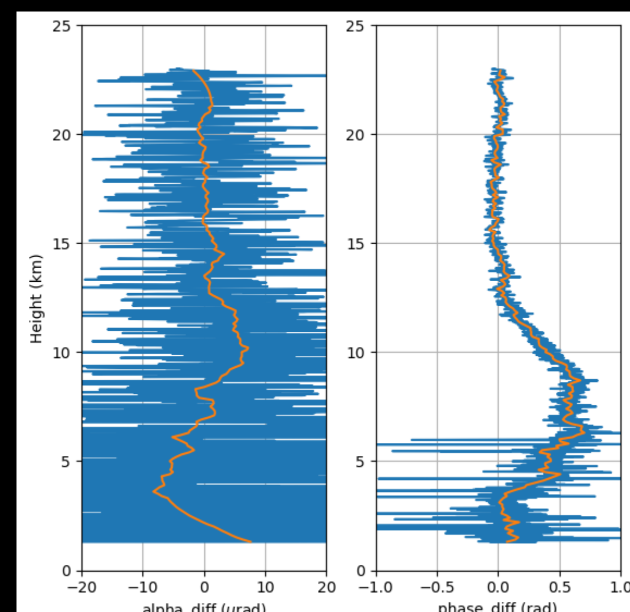
Polarimetric bending angle

- The use of bending angles (BA) has some advantage over phase, especially in the presence of atmospheric multipath.
- BA are also commonly used in NWP data assimilation.
- Our analysis demonstrates that H-V BA shows similar sensitivity to precipitation as H-V phase.

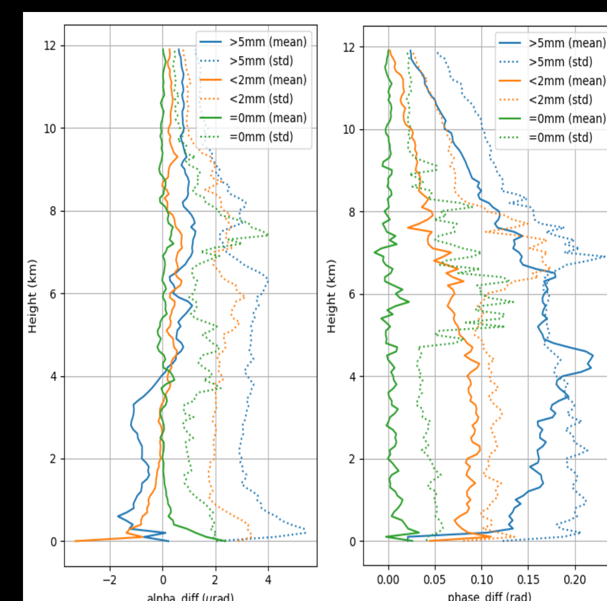
Simulation



PAZ (example)



PAZ (statistics)



Summary

- PAZ has been in orbit for almost 2 years. It has provided more than 80,000 polarimetric RO.
- On-orbit calibration has been proven useful to remove non-hydrometeor effects.
- $\Delta\phi$ shows sensitivity to precipitation intensity and agrees well with precipitation climatology.
- The vertical structure of Δφ correlates with deep convective events, showing the ability to sense whole vertical precipitating structures.
- Realistic simulations of ice particles strongly suggest that $\Delta\phi$ is sensitive to ice associated with tropical convection.

PAZ polarimetric products will be available from ICE-CSIC/IEEC (https://paz.ice-csic.es) and JPL (https://genesis.jpl.nasa.gov) in about mid-February

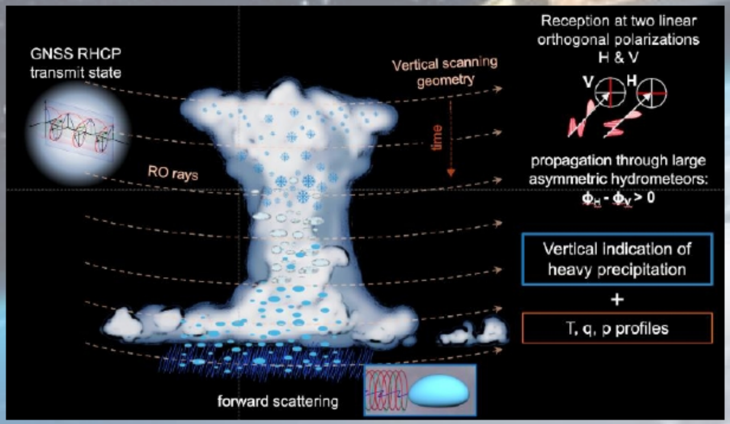
1st PAZ Polarimetric Radio Occultations User Workshop
ICE-CSIC/IEEC, Barcelona, April 23, 2020

Institute of Space Sciences (ICE-CSIC) and Institute for Space Studies of Catalonia (IEEC)

Polarimetric Radio Occultation is a new atmospheric sounding technique that has been validated with data from the Radio Occultations Through Heavy Precipitation (ROHP) instrument aboard the PAZ low Earth orbiting satellite.

In addition to the 'standard' GNSS radio occultation (RO) products (vertical profiles of T, p, q), this experiment exploits the polarimetric phase shift, $\Delta\phi$, between the horizontal and vertical polarization for detecting and quantifying hydrometeors (heavy precipitation events, convective rain, frozen particles and mixed phase).

The vertical structure of the hydrometeors, at a few hundreds of meter vertical resolution, emerges as the near-horizontal integral of the specific phase shift along the radio occultation link:



Status of the mission:

- Satellite launched Feb'2018.
- The **R**adio **O**ccultation and **H**eavy **P**recipitaton experiment (ROHP-PAZ https://paz.ice.csic.es), was activated in May'2018.
- Data continuously acquired since then.
- Sensitivity of $\Delta\phi$ to hydrometeors.

Objectives of the workshop:

- Provide potential users with an understanding of the data, their geophysical content, possibilities and limitations.
- Enable data providers better understanding on the needs of scientific users, and link the two communities to develop new products and applications.

Target audience:

Scientists working on observational or modelling aspects of

- precipitation,
- convection,
- extreme events,
- microphysics schemes,
- model evaluation (climate, NWP),
- RO data assimilation

that might benefit from this expanded RO capability.

Interested? POC: Estel Cardellach
paz@ice.csic.es