New precipitation and cloud ice observations with polarimetric GNSS RO aboard the PAZ satellite

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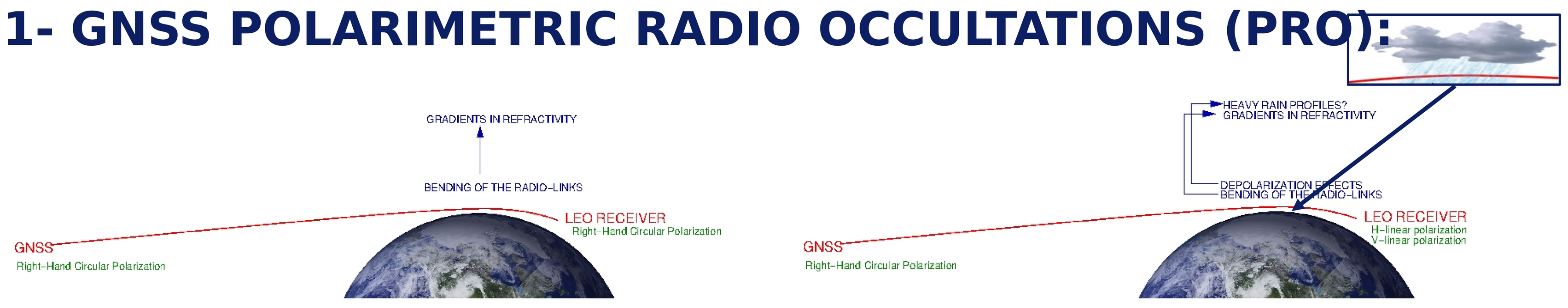
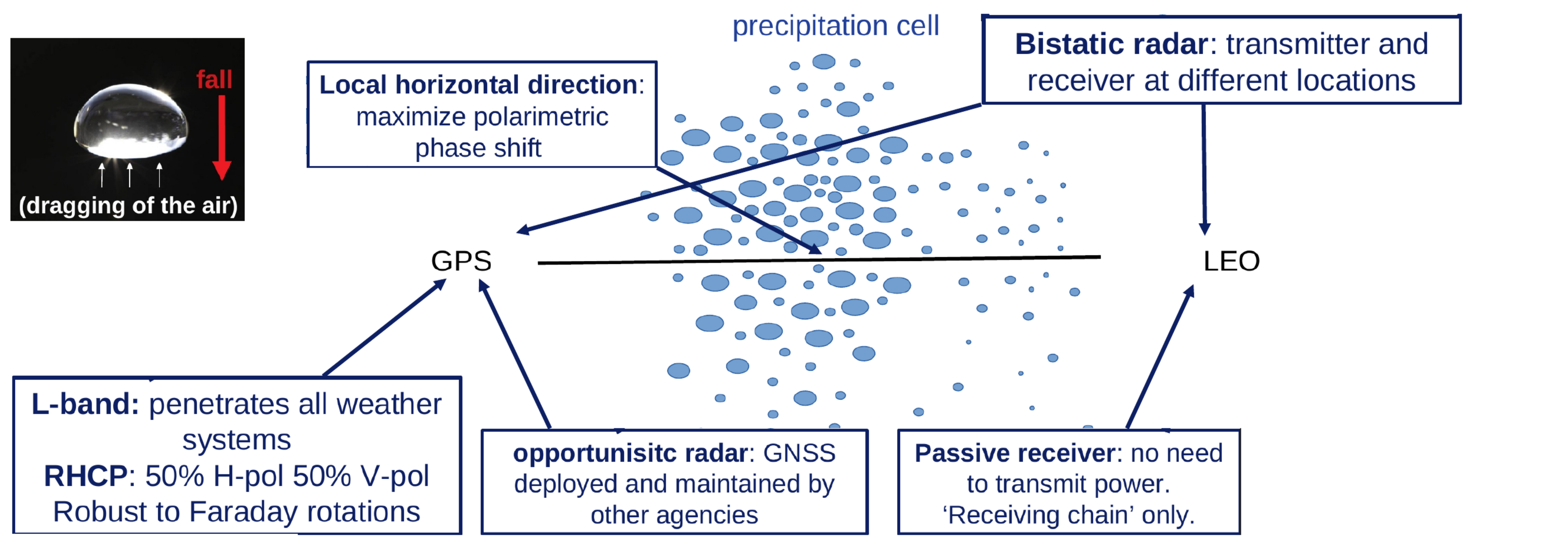
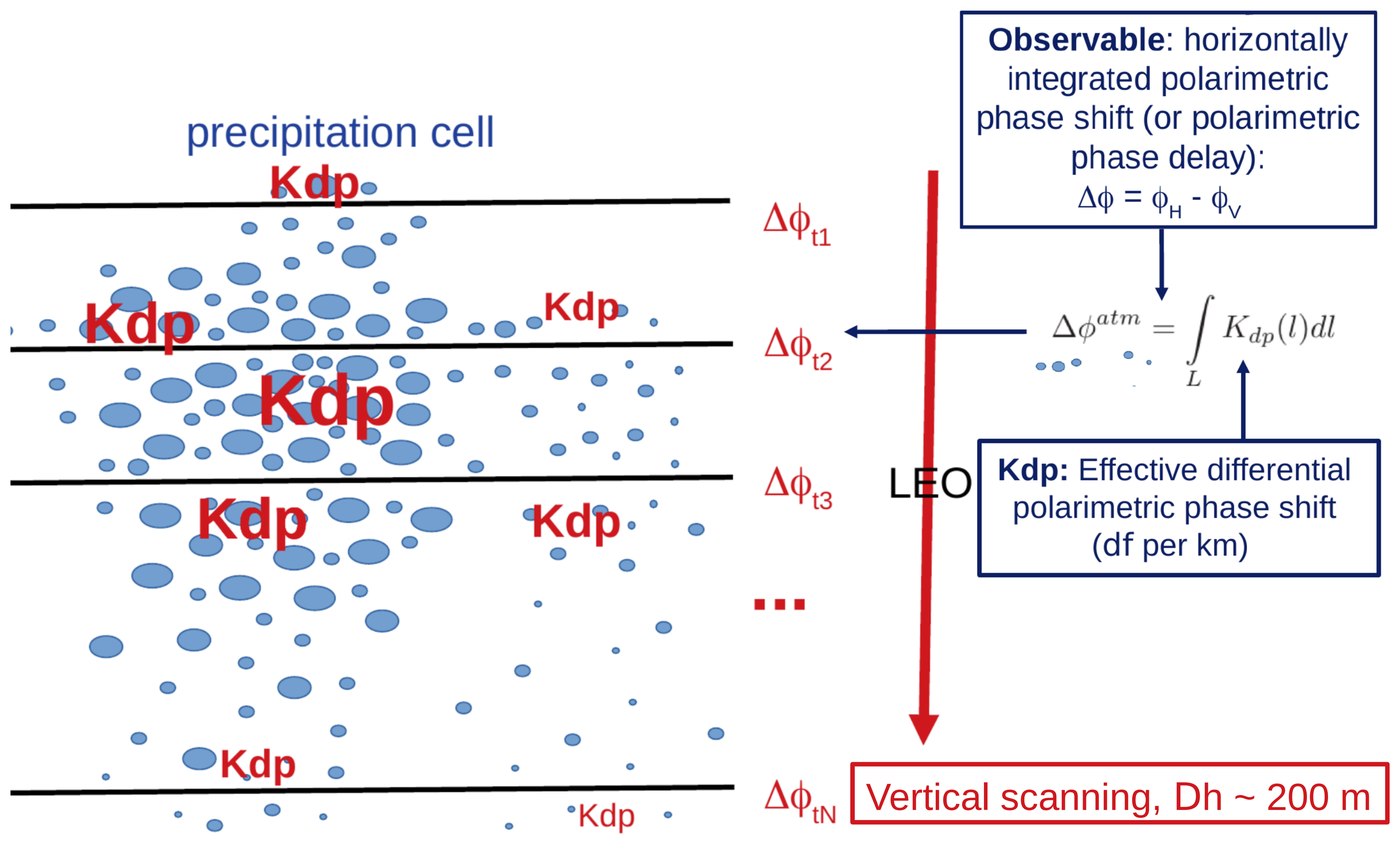
1- GNSS POLARIMETRIC RADIO OCCULTATIONS (PRO):



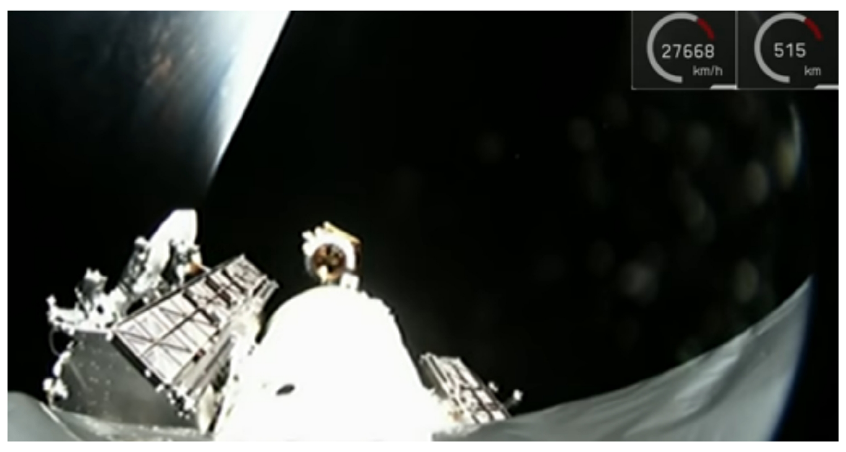
Right: sketch of a 'standard' GNSS Radio Occultation (RO), where a circularly polarized antenna receives signals in occulting geometry, the receiver measures the additional Doppler effects induced by the vertical gradients in the refractive index of the atmosphere to finally generate vertical profiles of thermodynamic variables (T, p, q). **Left:** The only modification in the GNSS PRO is the replacement of the circular antenna by a dual-polarized one: horizontally + vertically polarized. **The hypothesis of the experiment is that hydrometeors, especially big rain droplets associated to heavy rain, will increase the phase delay of the horizontal propagation w.r.t. the vertical one**.





2- THE ROHP-PAZ EXPERIMENT:

This new measurement concept is being proved aboard the satellite PAZ Low Earth Orbiter: the **Radio Occultation and Heavy Precipitation experiment aboard PAZ** (ROHP-PAZ) **https://paz.ice.csic.es**



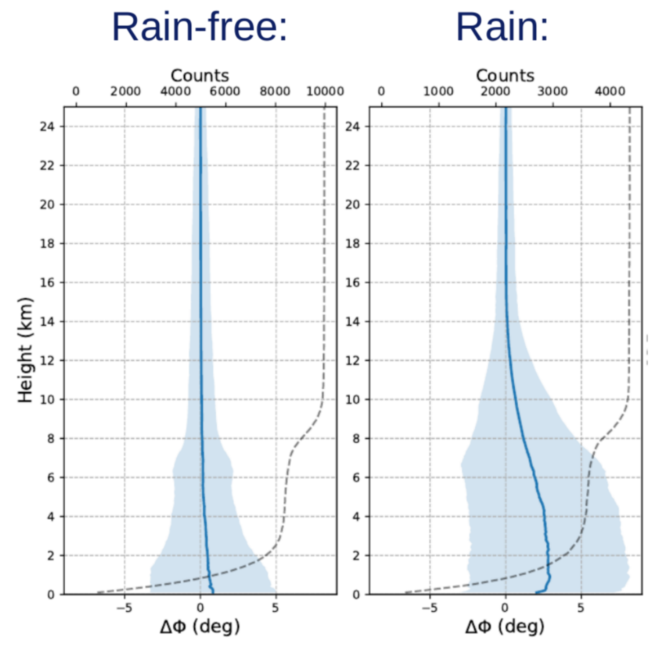
Sucessful **launch on February 22, 2018**, by SpaceX (Falcon9) into a polar orbit (97.4º) at ~514 km altitude, sun-synchronous dusk/dawn. **GNSS RO experiment activated on May 10, 2018**.

3- FIRST POLARIMETRIC RESULTS (I): Strategy

- Published in GRL Jan'19 [https://doi.org/10.1029/2018GL080412].
- Co-located with IMERG 2D rain products + successful QC: 14,297 with 4,338 rainy cases.
- IMERG provides 2D rain rate combined from different sources, in 30 minute interval, but ~14% detection failures.
- Co-location by averaging wide areas of IMERG rain around the GNSS-PRO central point.

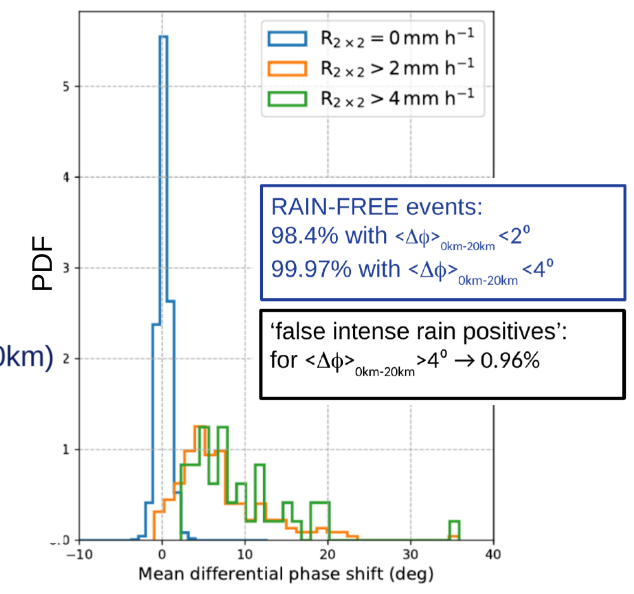
IMERG co-location not perfect, invalid set of data for one-to-one validation, but valid approach to **statistically check the response of GNSS-PRO to hydrometeors**

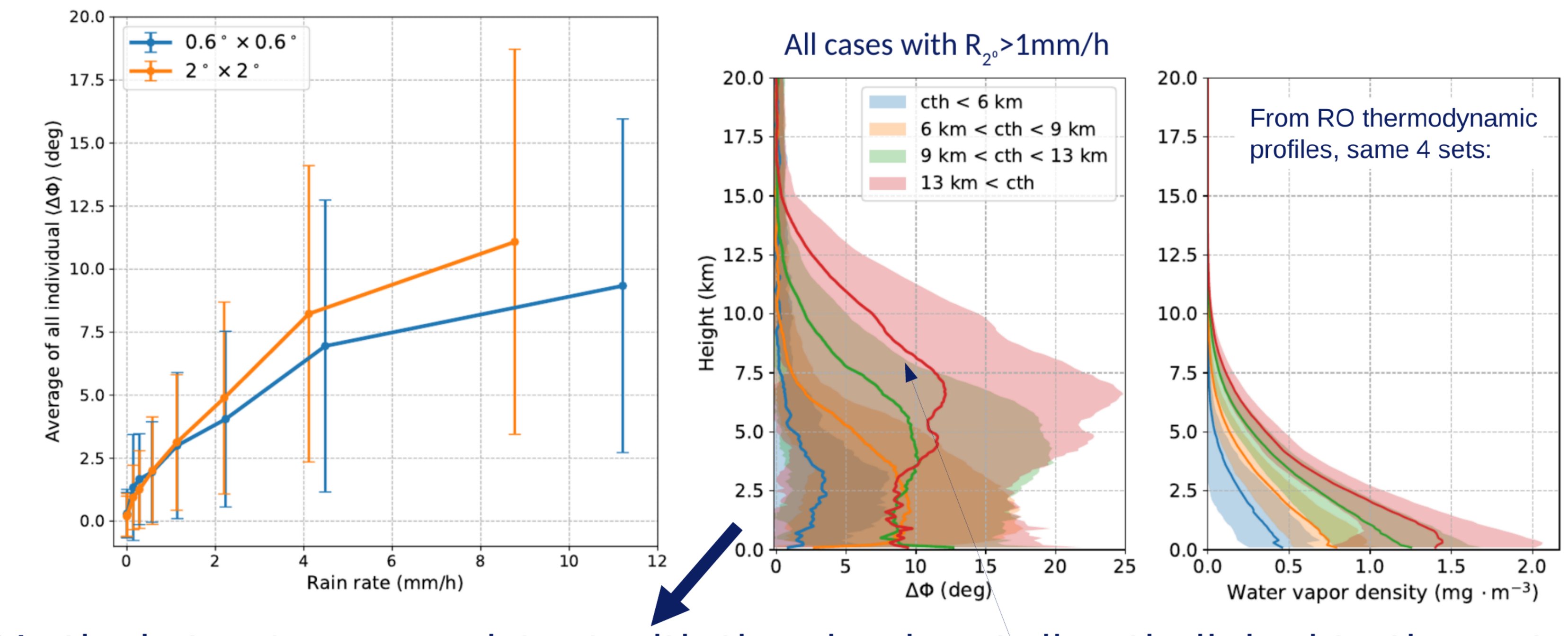
4- FIRST POLARIMETRIC RESULTS (II): Sensing rain



RAIN FREE:
- average → 0
- bias ~ 1º (bottom)
- dispersion:
  - <2º @ h>4.5km
  - <4º @ surface

RAIN EVENTS:
- clear positive mean (<~10km)
- mean > rain-free dispersion (except bottom)
- dispersion larger:
  - diversity of rain rate
  - inaccuracy co-location

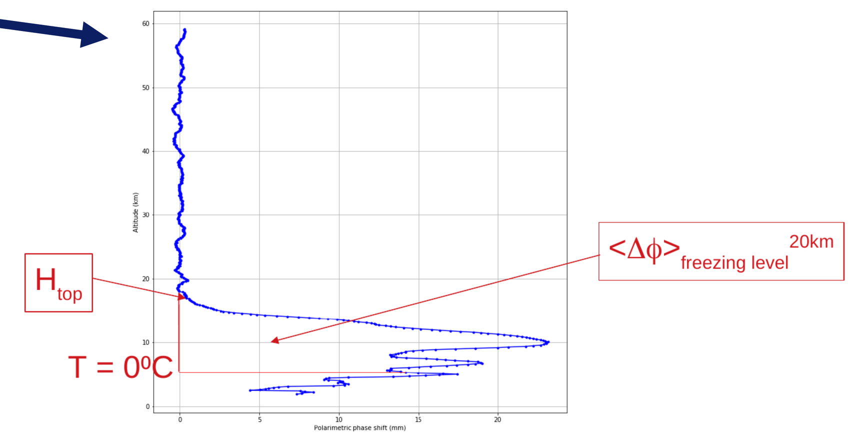




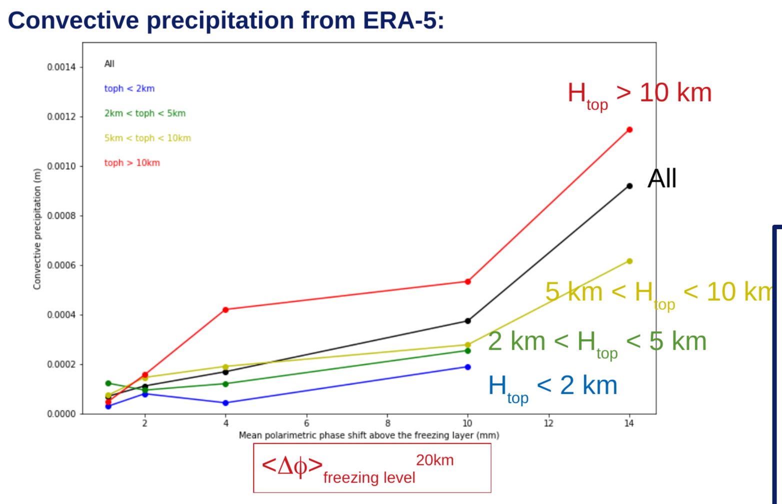
Vertical structures consistent with the cloud, not directly linked to the water vapor, and with high sensitivity to frozen particles (cloud ice, mixed phase)

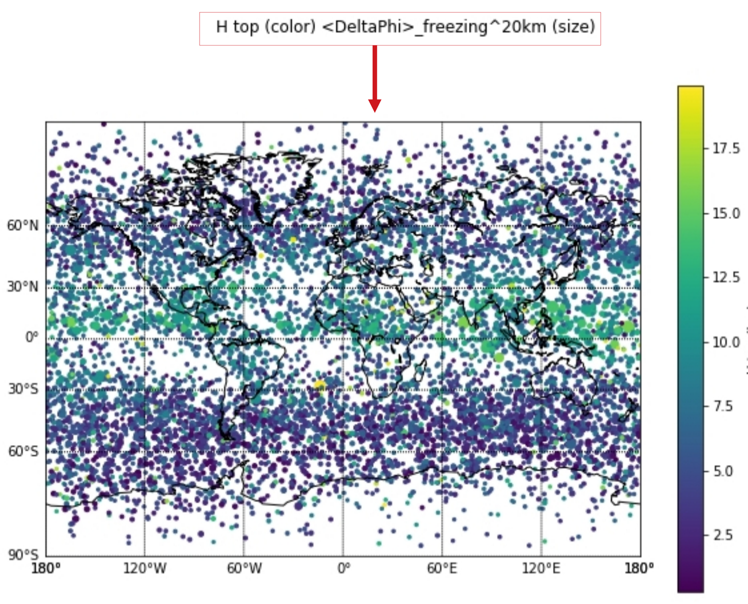
5- FROZEN PARTICLES?

- No cirrus cloud ice detected (layer too thin?).
- $\Delta\phi_{pol}$ signals above the freezing layer are analyzed in terms of its average signal, $<\Delta\phi_{pol}>_{\text{freezing level}}^{20km}$, and the maximum altitude at which $\Delta\phi_{pol}$ is found (H_{top}).
- Strong $\Delta\phi_{pol}$ signals above the freezing layer found in convective systems:



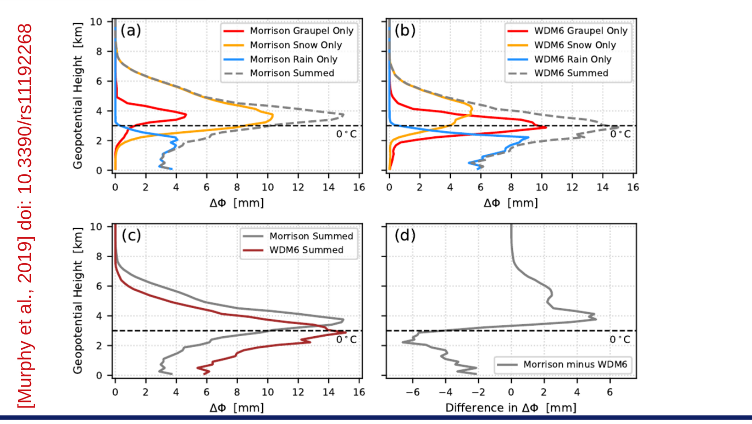
Convective precipitation from ERA-5:





Potential use of PAZ data for validation of microphysic schemes?

- [Murphy et al., 2019]: Simulations of GNSS polarimetric RO aboard an aircraft, during an Atmospheric River event captured during the CalWater 2015 field campaign.
- Two numerical experiments were run using a mesoscale model (WRF) configured with two different microphysical parameterizations:
  - WRF Double Moment 6-class (WDM6), and
  - Morrison double moment.
- The numerical experiments were used to simulate profiles of airborne polarimetric differential phase delay observations, $\Delta\phi_{pol}$.
- The due to hydrometeors, $\Delta\phi_{pol}$ differed significantly in the two experiments, as well as the height of the maximum $\Delta\phi_{pol}$.
- These results suggest that PRO observations have the potential to contribute to validating and improving the representation of microphysical processes in numerical weather forecasts.



6- CONCLUSIONS:

- PAZ carries a polarimetric RO payload, to prove the **GNSS-PRO** concept.
- New measurement concept: **thermodynamics + heavy rain**.
- Launched: **Feb 22, 2018**. RO activated on **May 10, 2018**.
- **Polarimetric phase shift linked to precipitation**, larger signals for more intense rain.
- **Vertical features** in polarimetric phase shift **consistent with storms at reaching different altitudes**.
- Strong signals induced by **frozen particles above the freezing layer**.
- Use of other derived-observables (top height, signal above freezing level, ...) → potential for **convection products?**
- Use of PAZ $\Delta\phi_{pol}$ and PAZ RO moisture profiles → Direct use of PAZ data for better **understanding of deep convection systems?**
- Use of PAZ $\Delta\phi_{pol}$ to **validate or improve micro-physics schemes in NWP?**

DATA PUBLICLY AVAILABLE

Institute of Space Sciences CSIC IEEC Jet Propulsion Laboratory California Institute of Technology UCAR UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH hisdeSAT