Sensing Heavy Precipitation Using a GNSS Radio Occultation as a 'Radar of Opportunity' aboard the PAZ Satellite: Early Results From Commissioning Phase

Estel Cardellach[1], Ramon Padulles[2], Chi On Ao[2], Fernando Cerezo[5], Jennifer Clapp[4], Garth W. Franklin[2], Douglas Hunt[3], Byron A. Iijima[2], Da Kuang[2], Thomas K. Meehan[2], Santiago Oliveras[1], Antonio Rius[1], William S. Schreiner[3], Sergey Sokolovskiy[3], Sergio Tomas[1], Manuel de la Torre Juarez[2], Joseph Turk[2], Teresa Vanhove[3], Jan Weiss[3], Wei Xia-Serafino[4], Yoke Yoon[3], Zhen Zeng[3]

[1]Institute of Space Sciences (ICE, CSIC, IEEC), Spain, [2]Jet Propulsion Laboratory, California Institute of Technology, U.S.A., [3]University Corporation for Atmospheric Research (UCAR), U.S.A., [4]National Oceanic and Atmospheric Administration (NOAA), U.S.A., [5]Hisdesat, Spain

1- A NEW MEASUREMENT CONCEPT TO ADDRESS OPEN SCIENTIFIC QUESTIONS:

In Spring 2009 the Earth Observation Group at ICE (IEEC-CSIC) conceived a **NEW MEASUREMENT CONCEPT.**

The concept combines **radio occultation links** of the Global Navigation Satellite System (GNSS) with the **polarimetric properties** of the forward **scattering off big rain droplets** (and other hydrometeors): GNSS polarimetric radio occultations (GNSS-PRO).

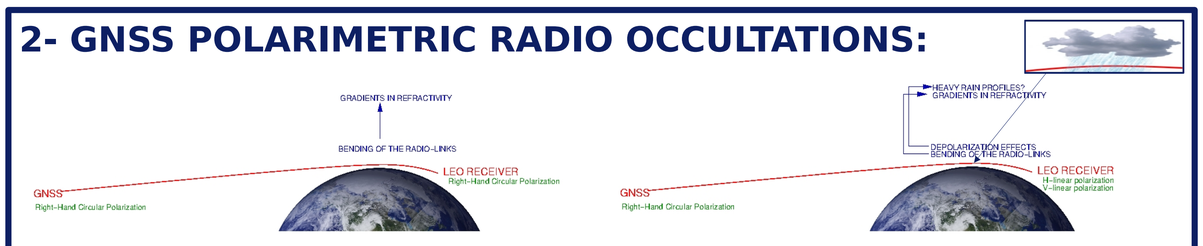
Big rain droplets are associated to **heavy precipitation.**

If successful, GNSS-PRO would represent the **only sensor** that can infer **both VERTICAL PROFILES OF ATMOSPHERIC THERMODYNAMICS + VERTICAL PROFILES OF HEAVY RAIN.**

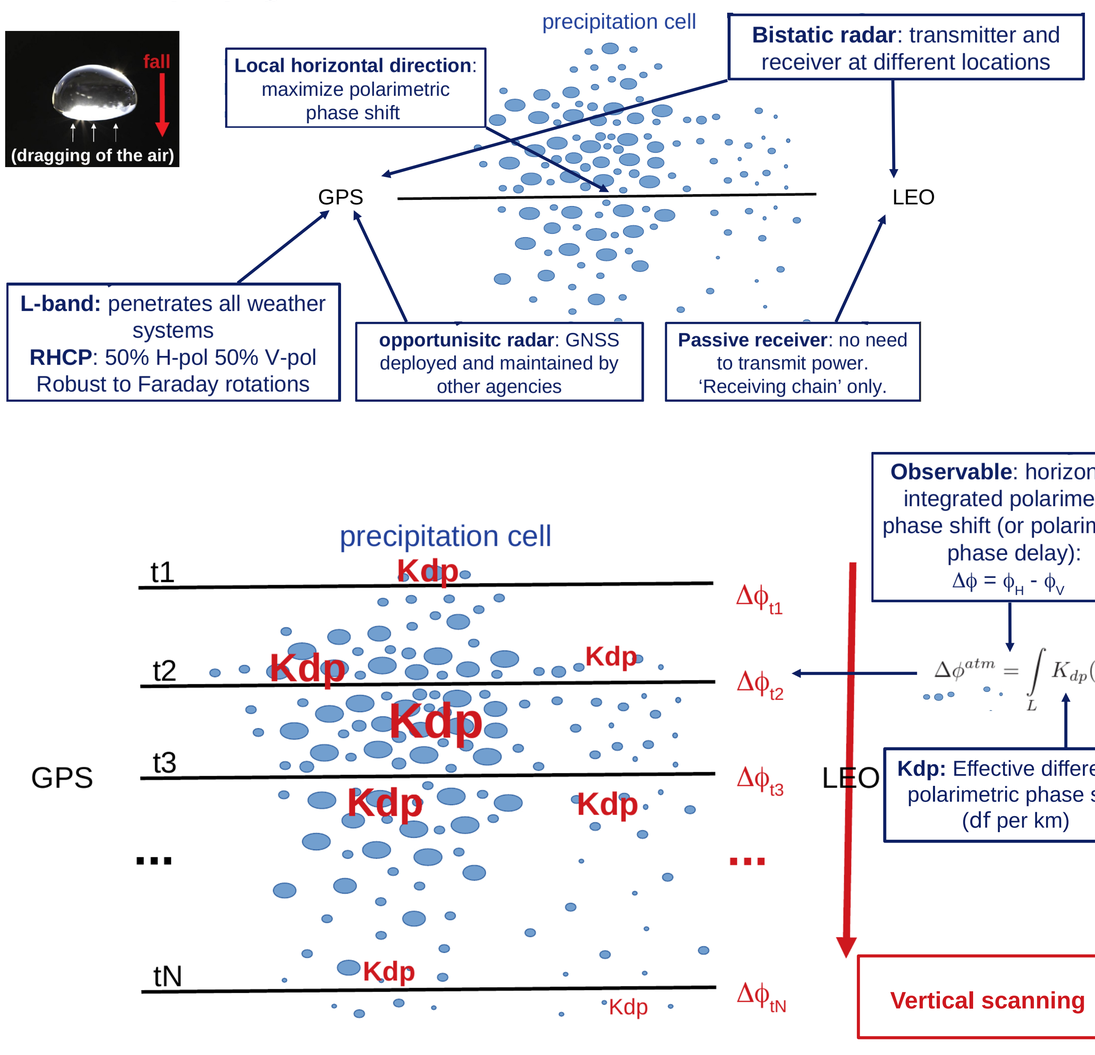
Why are coincident thermodynamic and precipitation vertical profiles required?

- To help understanding the thermodynamic conditions underlying intense precipitation.
- This is relevant because extreme events remain poorly predicted with the current climate and weather model parametrization.
- A better understanding is necessary towards improving climate models and quantifying the impact of climate variability on precipitation.

2- GNSS POLARIMETRIC RADIO OCCULTATIONS:

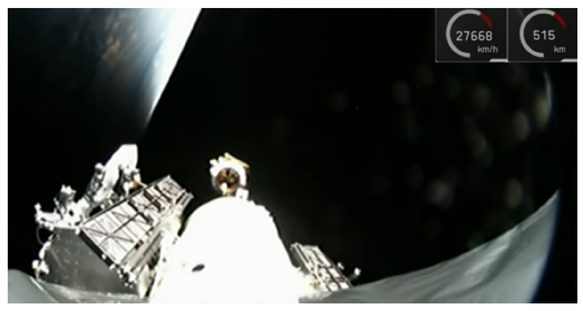


Right: sketch of a 'standard' GNSS RO, where a circularly polarized antenna receives signals in occulting geometry, the receiver measures the additional Doppler effects induced by the vertical gradients in the refractive index of the atmosphere to finally generate vertical profiles of thermodynamic variables (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**.



3- THE ROHP-PAZ EXPERIMENT:

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



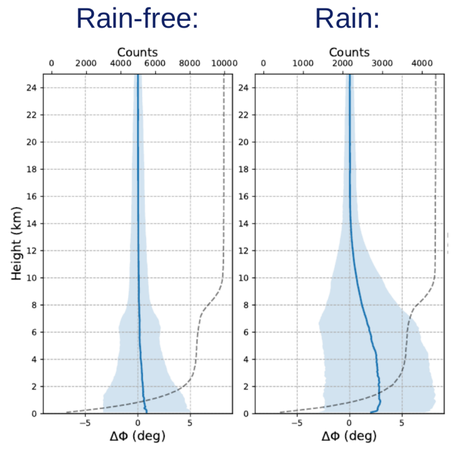
Sucessful **launch on February 22, 2018**, by SpaceX (Falcon9) into a polar orbit (97.4º) at ~514 km altitude, sun-synchronous dusk/dawn. **GNSS RO experiment activated on May 10, 2018**.

4- FIRST POLARIMETRIC RESULTS:

- 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.

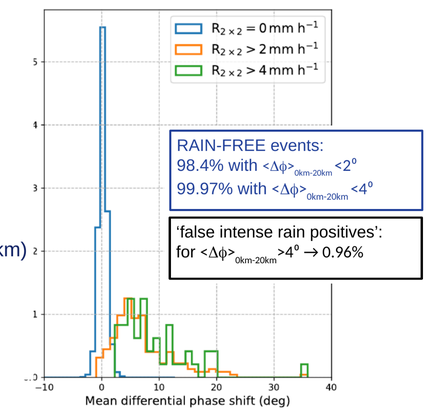
IMERG co-location not perfect, invalid set of data for one-to-one validation, but valid approach to **statistically check the response of GNSS-PRO to hydrometeors**

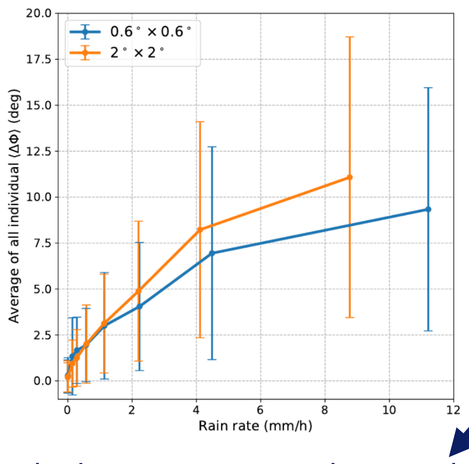
Rain-free: Rain:



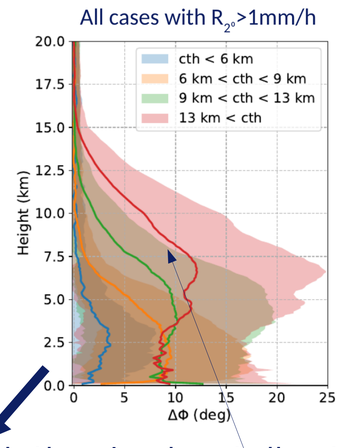
RAIN FREE:
- average → 0
- bias ~ 1º (bottom)
- dispersion:
  <2º @ h>4.5km
  <4º @ surface

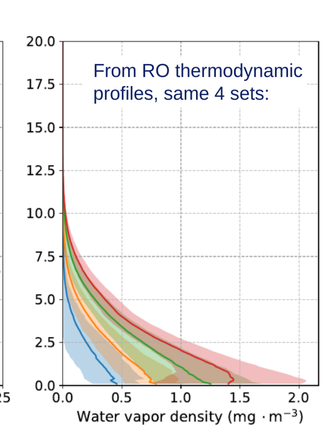
RAIN EVENTS:
- clear positive mean (<~10km)
- mean > rain-free dispersion (except bottom)
- dispersion larger:
  diversity of rain rate
  inaccuracy co-location





All cases with $R_{2º}$>1mm/h





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- CONCLUSIONS:

- 5 months analysis, co-location with IMERG 2D rain rates.
- **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**, unrelated to moisture structures (but hydrometeors).

Polarimetric ROs sense hydrometeors!

Hypothesis of the experiment!

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