The GNSS PRO technique and in-orbit demonstration aboard PAZ

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With contributions by:
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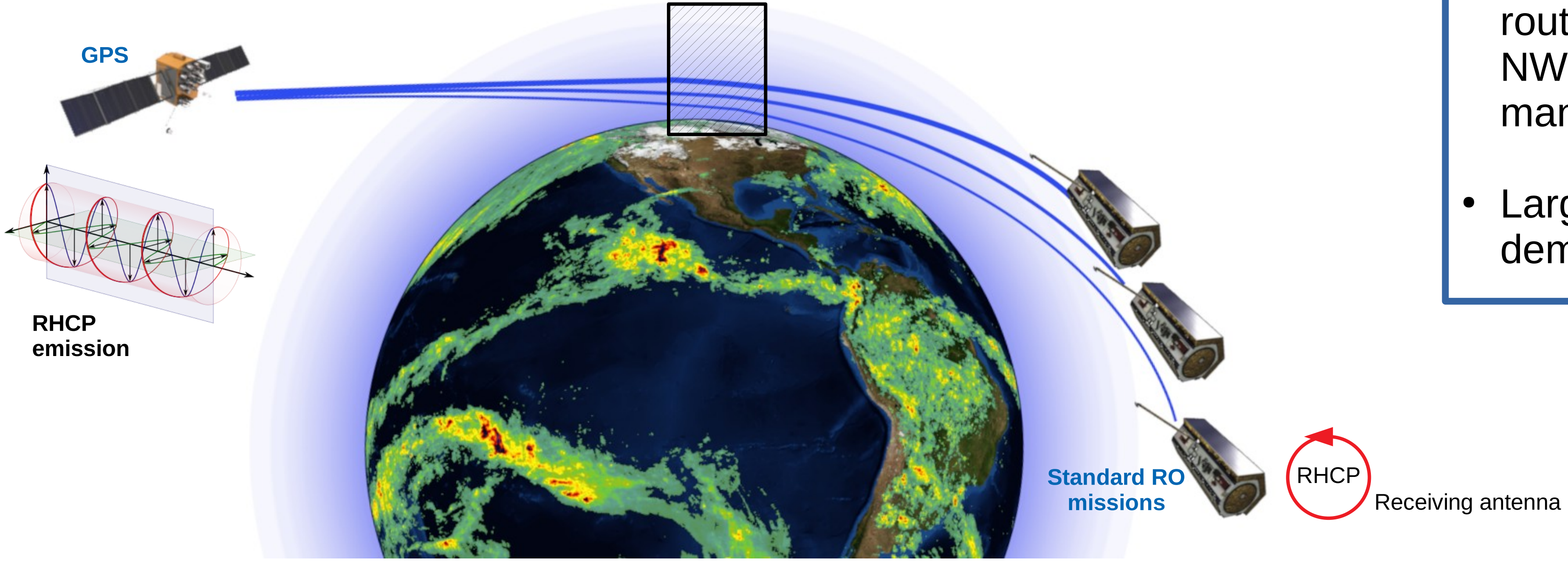
Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea NextGenerationEU

Contents

- The Polarimetric Radio Occultation technique
- In-orbit demonstration aboard PAZ (ROHP-PAZ): status of the mission and data
- Hypothesis and confirmation: sensitivity to heavy rain
- Complementing the hypothesis: sensitivity to frozen particles
- Recent activities:
  - Studies towards the use of GNSS PRO for and in NWP
  - New opportunities with commercial GNSS PRO: clusters of profiles, larger data sets for NWP?

Traditional Radio Occultations (RO)

- GPS emitted electromagnetic waves cross the atmosphere before reaching a Low Earth Orbiter occulting behind the horizon
- **Observables:** Amplitude and phase (ϕ) of the received EM wave → Doppler measurements → bending angle
- The rays bend due to changes in the refractive index of the atmosphere. Such **bending angle** can be derived, and **refractivity vertical profiles** are retrieved → (T, p, q).



Data assimilation of RO

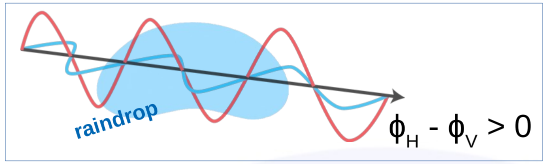
- RO- **Bending angle** profiles routinely assimilated into NWP prediction models for many years now
- Large Impact has been demonstrated

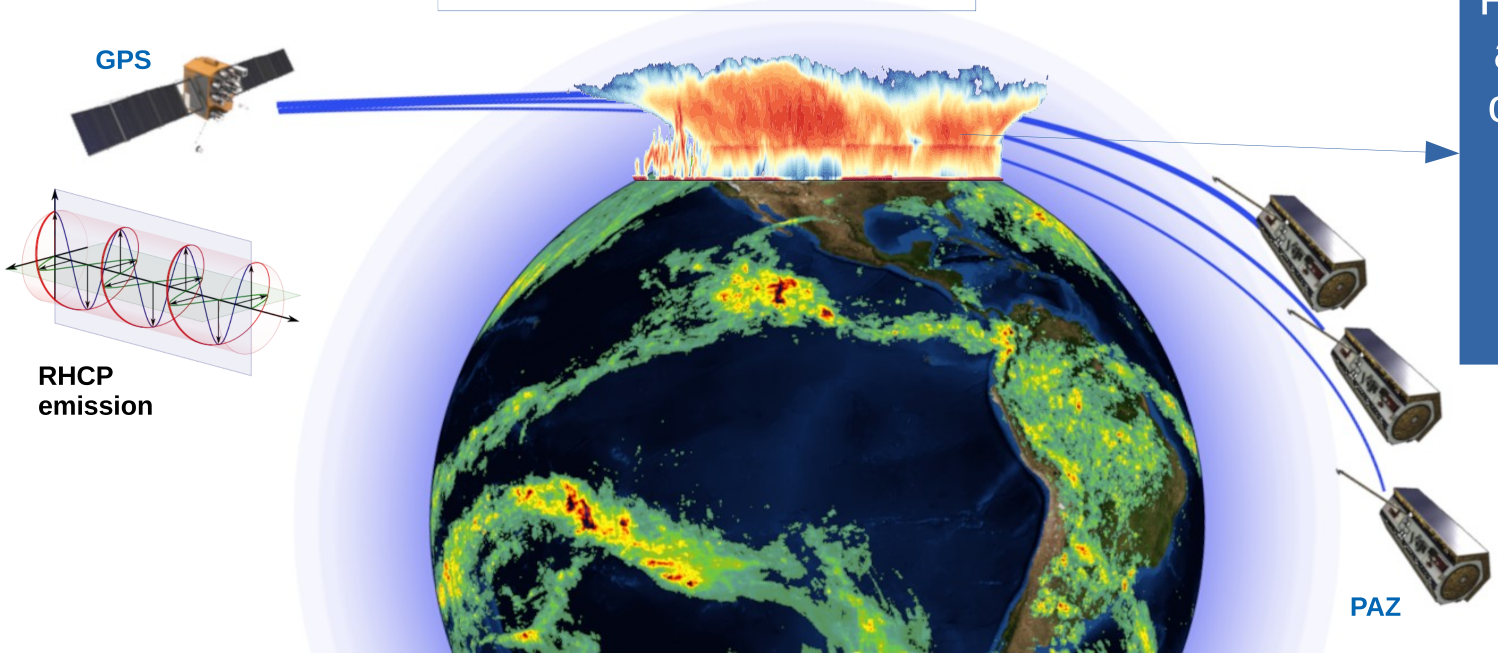
- Globally distributed
- Over all surfaces
- All weather conditions
- High vertical resolution
- Cost-effective

Polarimetric Radio Occultations (PRO)

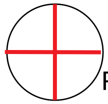
- Concept introduced in 2009
- RO rays are collected using a 2-linearly **polarized** antenna (H,V)

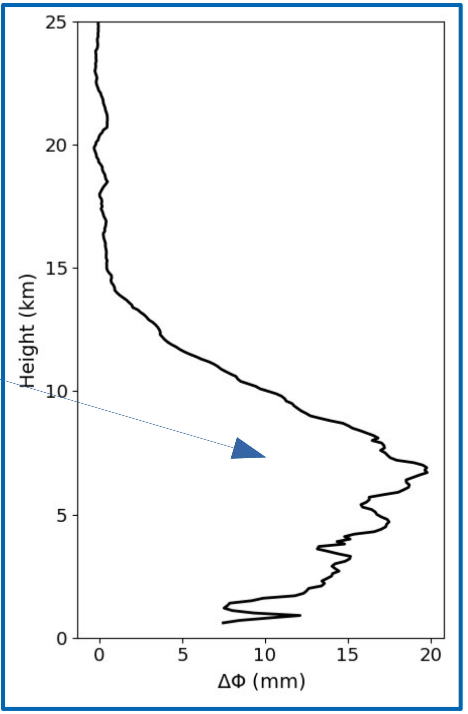
- If these rays happen to cross precipitation, a **positive differential phase** shift $\Delta\Phi=\Phi_H-\Phi_V$ is expected owing to the asymmetric shape of precipitating hydrometeors





Precipitation occurs at the lower layers of the atmosphere, where the RO ray propagates tangentially (local horizontal)





Polarimetric Radio Occultations (PRO)

- This is a **new measurement concept**.
- It combines **radio occultation links** of the GNSS with the **polarimetric properties** of the forward **scattering off big rain droplets** (and other hydrometeors).
- The hypothesis is that this polarimetric information is sensitive to heavy precipitation.
- If successful, it would represent the only sensor that can infer both

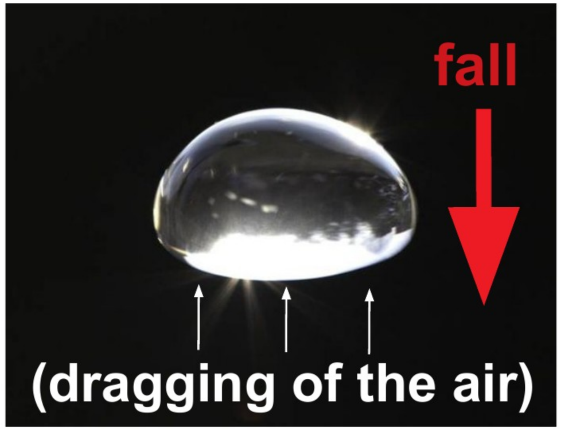
VERTICAL PROFILES OF ATMOSPHERIC THERMODYNAMICS (T, p, q)

+

VERTICAL PROFILES OF HYDROMETEORS

Polarimetric Radio Occultations (PRO)

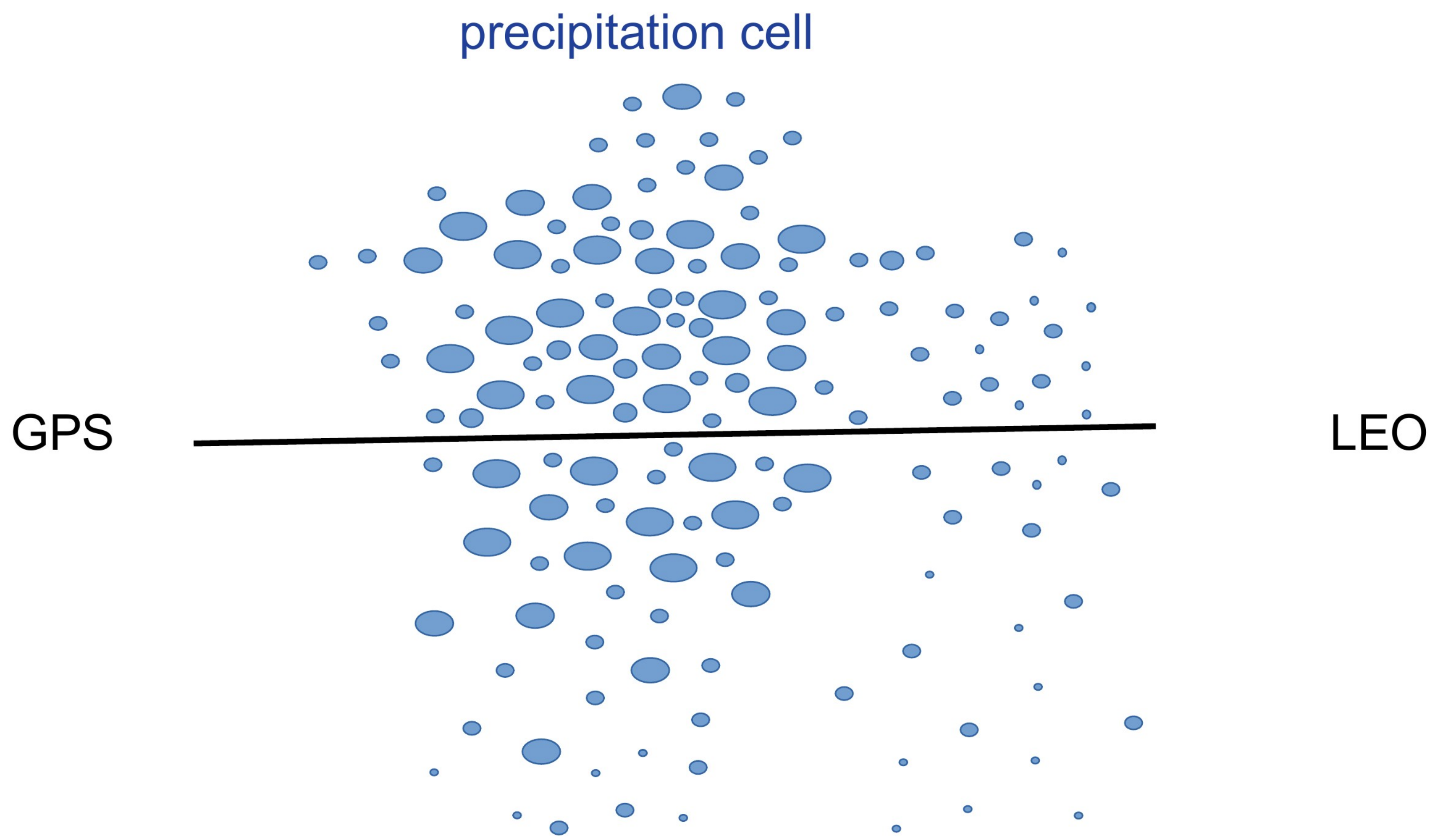
To understand this concept it is important to keep in mind that the big falling rain drops are not spherical, but flattened:



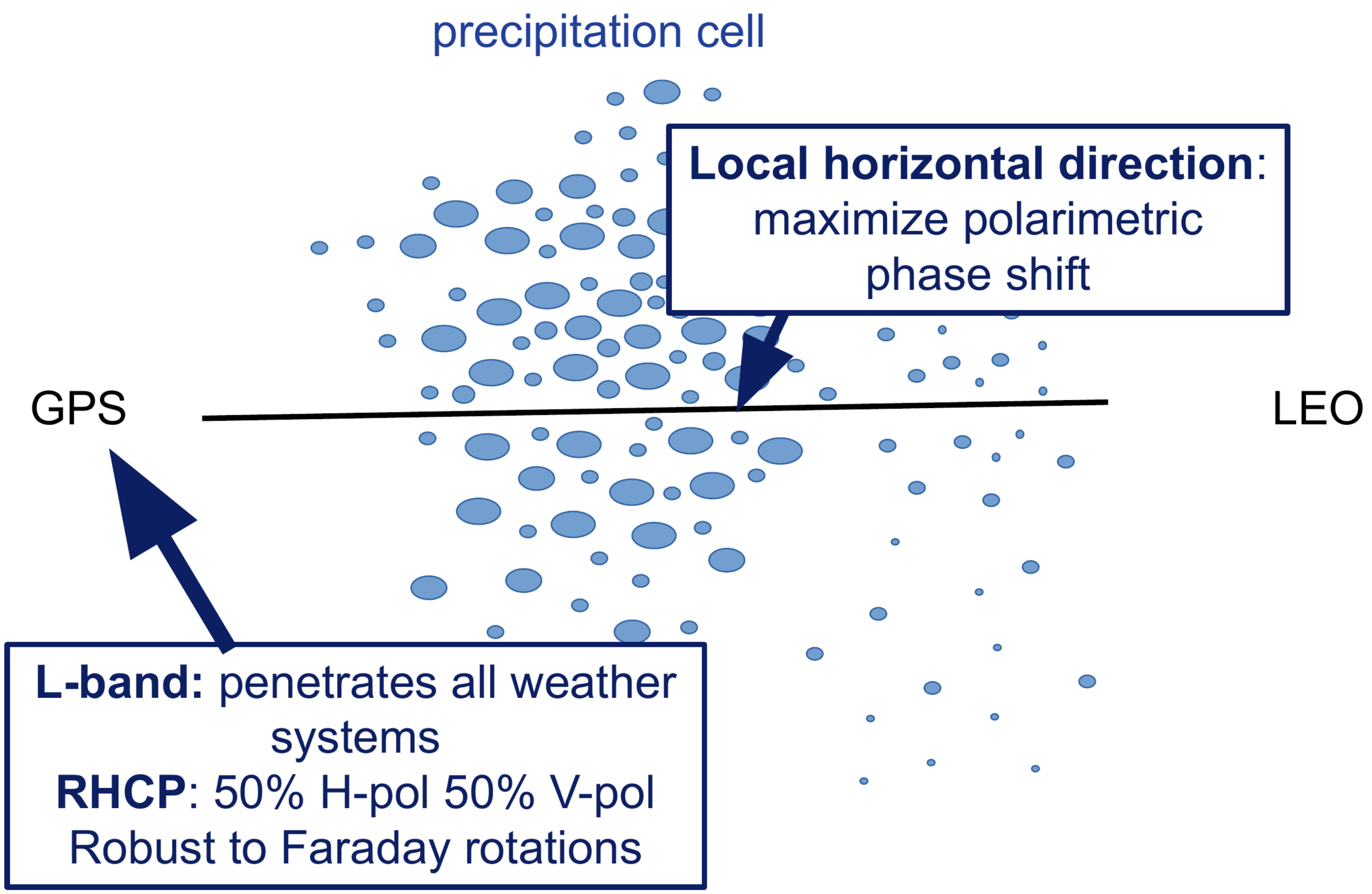
The bigger the drop, the larger the asymmetry effect.

Heavier rain has more large drops.

Polarimetric Radio Occultations (PRO)

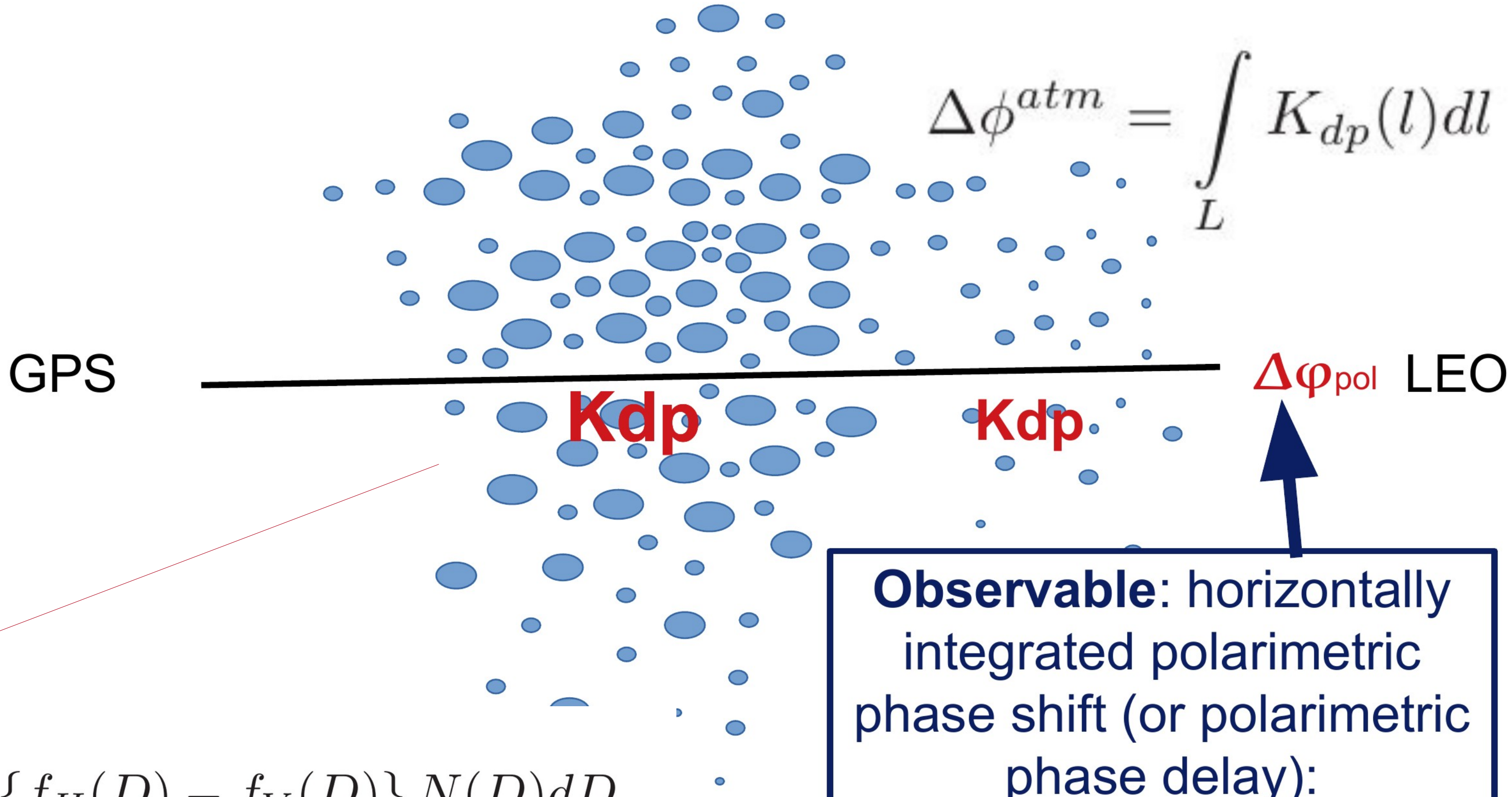


Polarimetric Radio Occultations (PRO)



Polarimetric Radio Occultations (PRO)

precipitation cell



$$\Delta\phi^{atm} = \int_L K_{dp}(l)dl$$

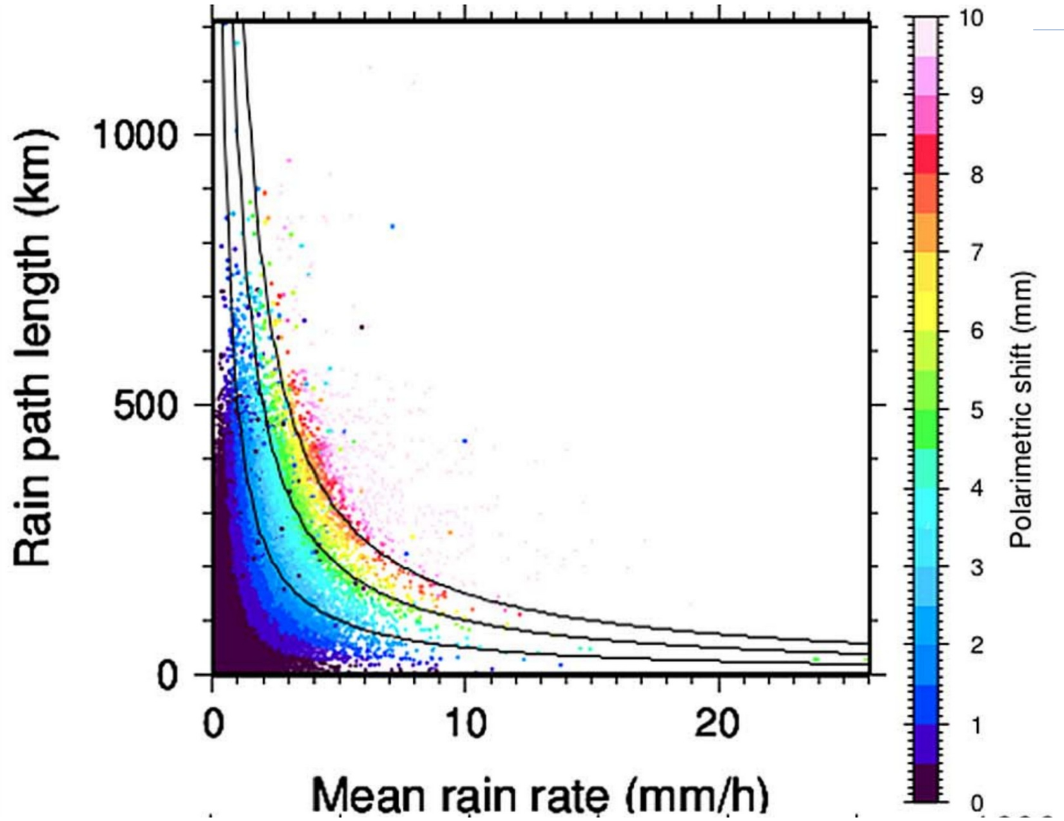
$$K_{dp} = \frac{\lambda^2}{2\pi} \int \Re\{f_H(D) - f_V(D)\} N(D) dD$$

Observable: horizontally integrated polarimetric phase shift (or polarimetric phase delay):

$\Delta\varphi_{pol} = \varphi_H - \varphi_V$

Polarimetric Radio Occultations (PRO)

- Simulations based on realistic rain systems showed that ΔΦ must be tiny!



10 mm *2π rad /190 mm = 0.33 rad = 0.05 cycle
or
30 picoseconds (3E-11 s)

	COSMIC (mm)	COSMIC-3dB (mm)	H (km)
1-port σ_ϕ	0.1	0.15	≥ 10
	0.3	0.35	5-10
	0.6	0.8	2-5
	0.7	1	<2
Polarimetric $\sigma_{\Delta\phi}$	0.1	0.2	≥ 10
	0.4	0.5	5-10
	0.9	1.1	2-5
	1	1.4	<2

DOI: 10.1109/TGRS.2014.2320309

Questions

- Is it technologically possible to measure the polarimetric RO?
- Are the GNSS PRO signatures sufficiently large to be measured?
- Do they relate to [heavy] precipitation?
- Can the ‘traditional’ (thermodynamics) profiles be recovered from GNSS PRO data?
- How can these measurements be used in meteorology and climate studies?

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GNSS PRO aboard PAZ

- A **proof-of-concept experiment** aboard the Spanish **PAZ satellite: Radio Occultation and Heavy Precipitation with PAZ (ROHP-PAZ)**
- Modified IGOR receiver
- Agreements with **NOAA** and **UCAR** for dissemination in **NRT of ‘traditional’ RO** profiles
- Close collaboration with **NASA/JPL** for **scientific investigations**

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- PAZ launched in 02/2018
- ROHP-PAZ activated in 05/2018
- Continuous data acquisitions since then...

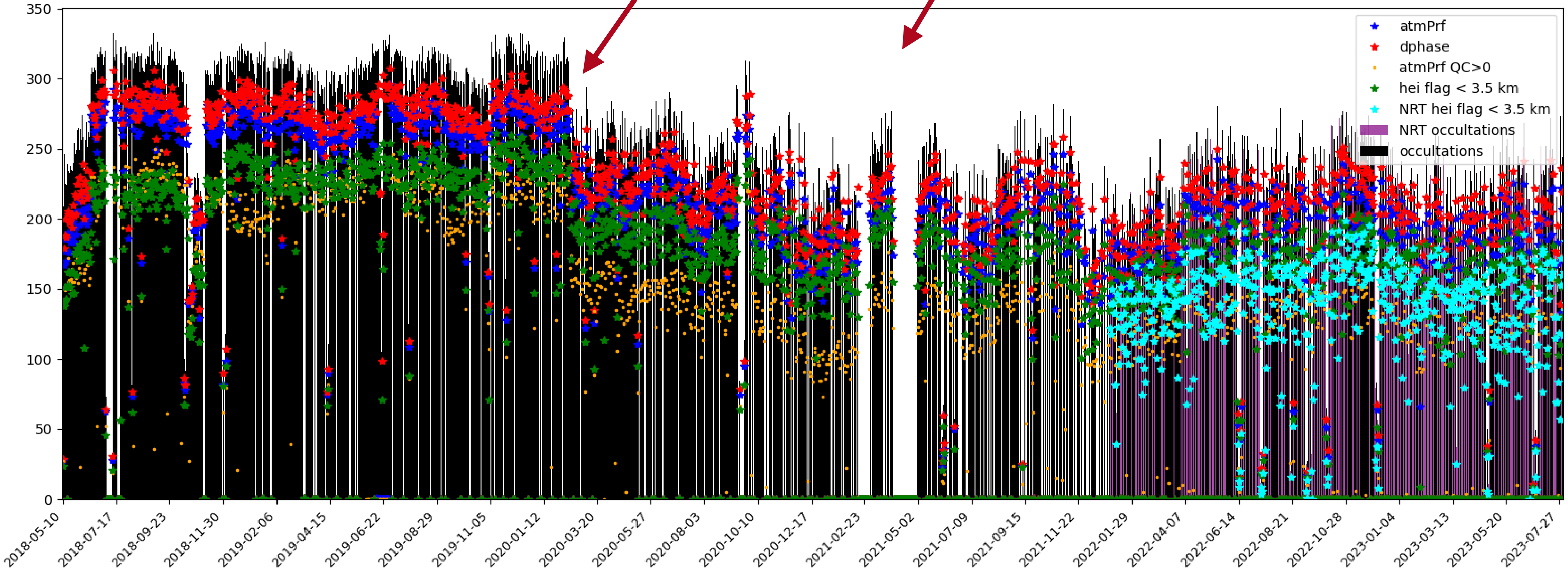
Visit **https://paz.ice.csic.es**

Status of the data

Acquisitions since May’18...

GPS power flex

Changes in processing chain



Status of the data

- Where to download data...

	ICE-CSIC, IEEC: https://paz.ice.csic.es/	UCAR, CDAAC https://data.cosmic.ucar.edu/gnss-ro/paz/postProc/	JPL https://genesis.jpl.nasa.gov/data/ftp/
'Traditional' RO	(from UCAR processing)	**L1a**, **L1b** and **L2** (bending/impact, T,p,q) for RHCP-equivalent signals	**L2** (N, T, p, q) from H-pol signals
PRO profiles	Calibrated **polarimetric phase shift** as function of **tangent point height** Co-locations with: • GPM radiometers and radars • IMERG surface rain rate • Brightness temperature • Tropical Cyclones		Calibrated **polarimetric phase shift** as function **tangent point height** SNR_h, SNR_v

Status of the data

NRT GTS

NOAA NESDIS

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Status of the data

- A SESSION LATER TODAY!

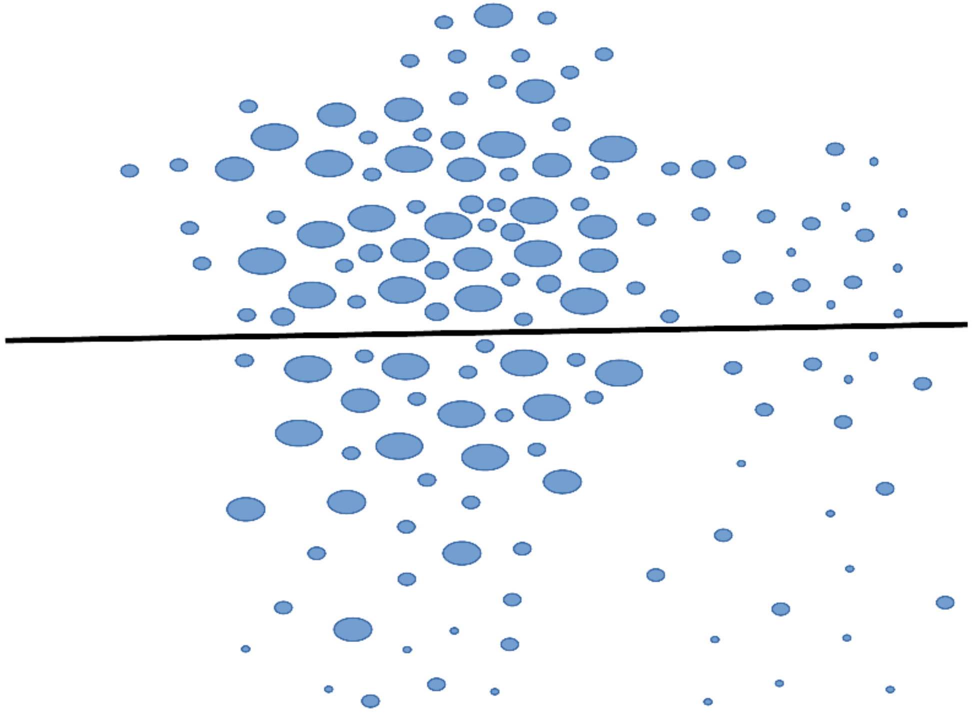
Data processing status [chair: John Braun and Jan-Peter Weiss]				
9:00-9:20	18:00-18:20	01:00^{+1}-01:20^{+1}	R. Padullés (ICE-CSIC, IEEC)	ICE-CSIC/IEEC GNSS PRO processing and new data set
9:20-9:40	18:20-18:40	01:20^{+1}-01:40^{+1}	K.-N. Wang (JPL)	JPL data processing status
9:40-10:00	18:40-19:00	01:40^{+1}-02:00^{+1}	Doug Hunt(UCAR)	Recovery of thermodynamic RO products from PRO data

Contents

Hypothesis

Hypothesis: the H-polarized component of the GNSS signals suffers a larger delay than the V-polarized one, due to the presence of non-spherical, flattened big rain droplets associated to intense precipitation along the ray-path.

GNSS



PAZ

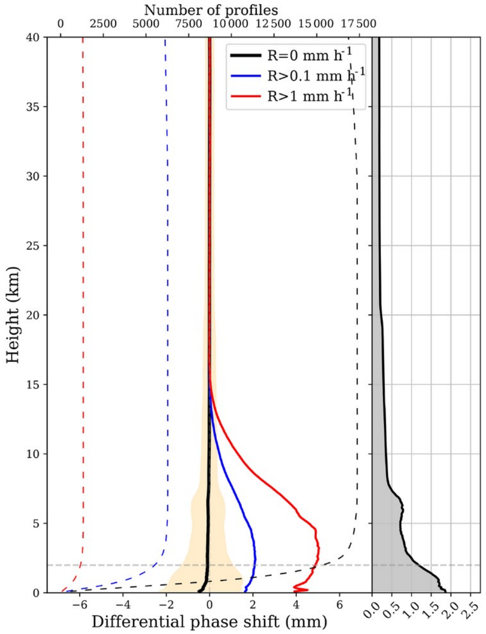
$$\Delta\phi = \phi_H - \phi_V$$

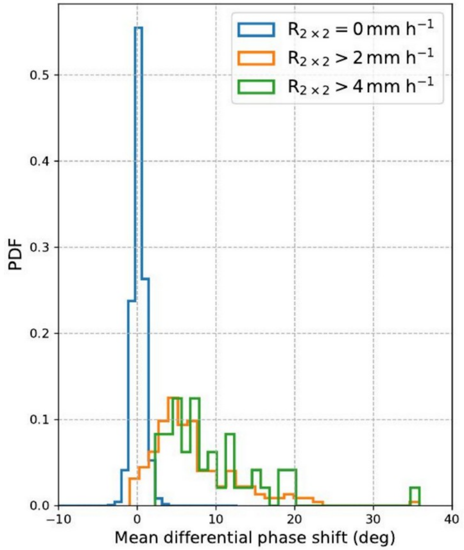
DOI: 10.1109/TGRS.2014.2320309

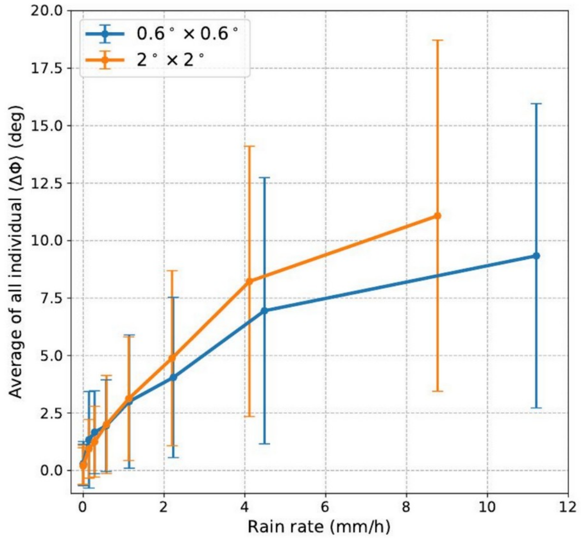
Confirmation of the hypothesis

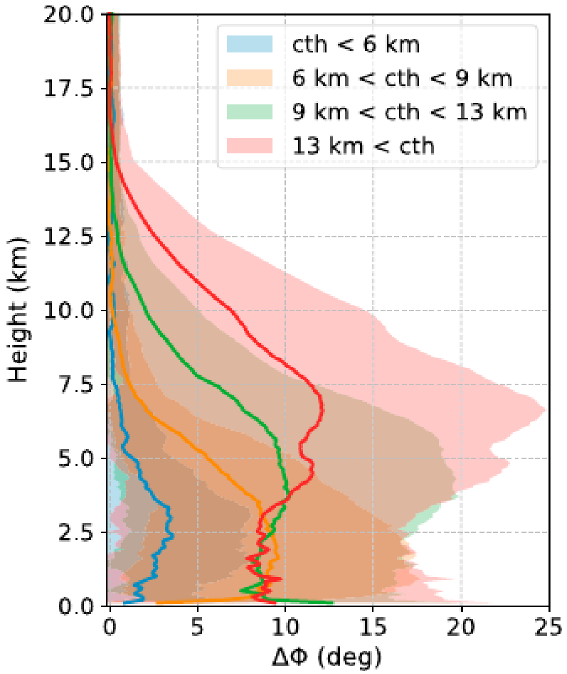
Hypothesis: the H-polarized component of the GNSS signals suffers a larger delay than the V-polarized one, due to the presence of non-spherical, flattened big rain droplets associated to intense precipitation along the ray-path.

Few months after activating the experiment, the hypothesis was confirmed
DOI: 10.1029/2018GL080412, **DOI:** 10.5194/amt-13-1299-2020









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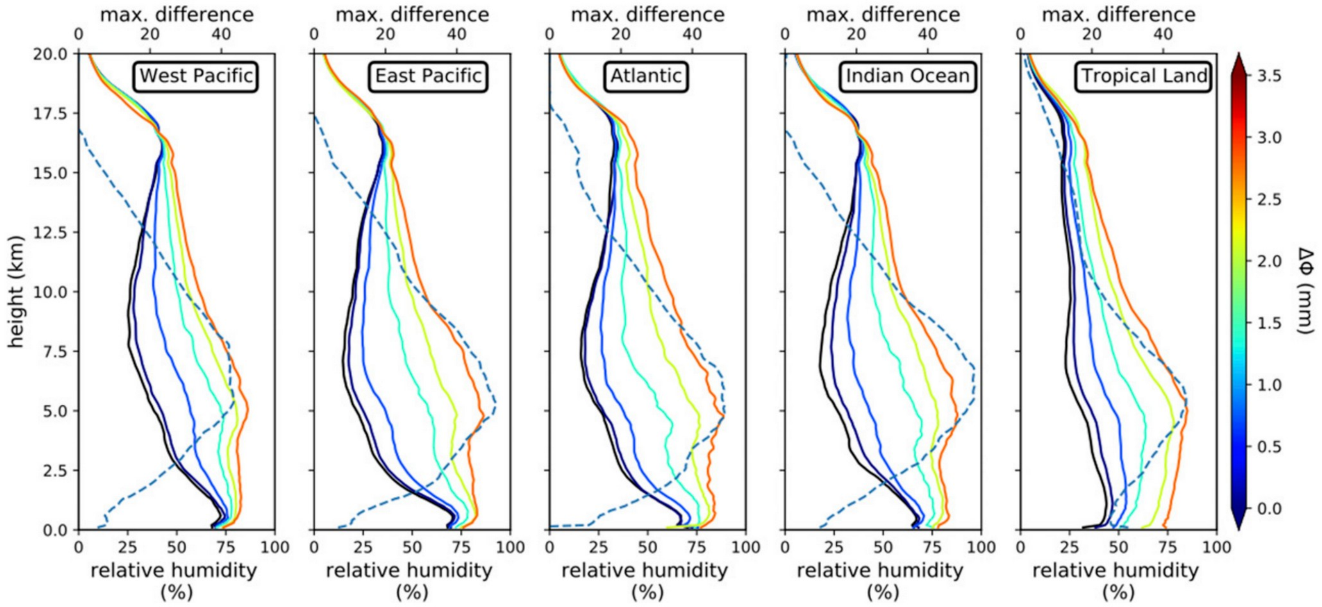
Relationship between relative humidity and the strength of the polarimetric shift at different altitudes
DOI: 10.1175/JTECH-D-21-0044.1



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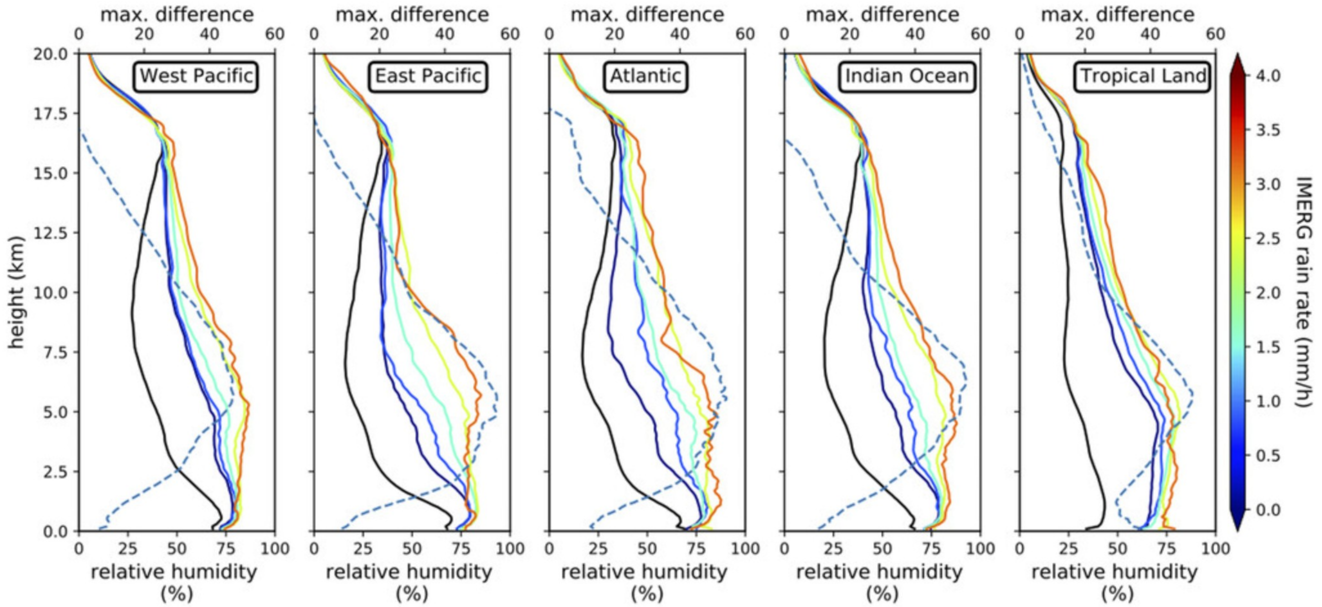

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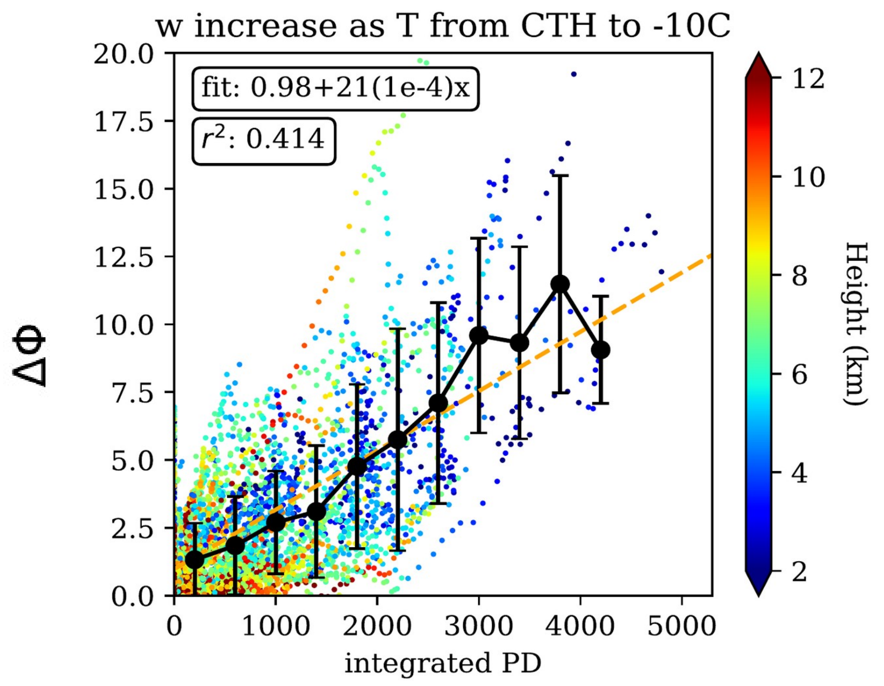
Sensitivity to oriented frozen hydrometeors

Co-locations between PAZ and GPM radar+radiometers (**DOI**: 10.1109/TGRS.2021.3065119)

PAZ



GPM GMI @ 166 GHz **PD** = $Tb_V - Tb_H$
(non-spherical oriented frozen particles)

Sensitivity to oriented frozen hydrometeors

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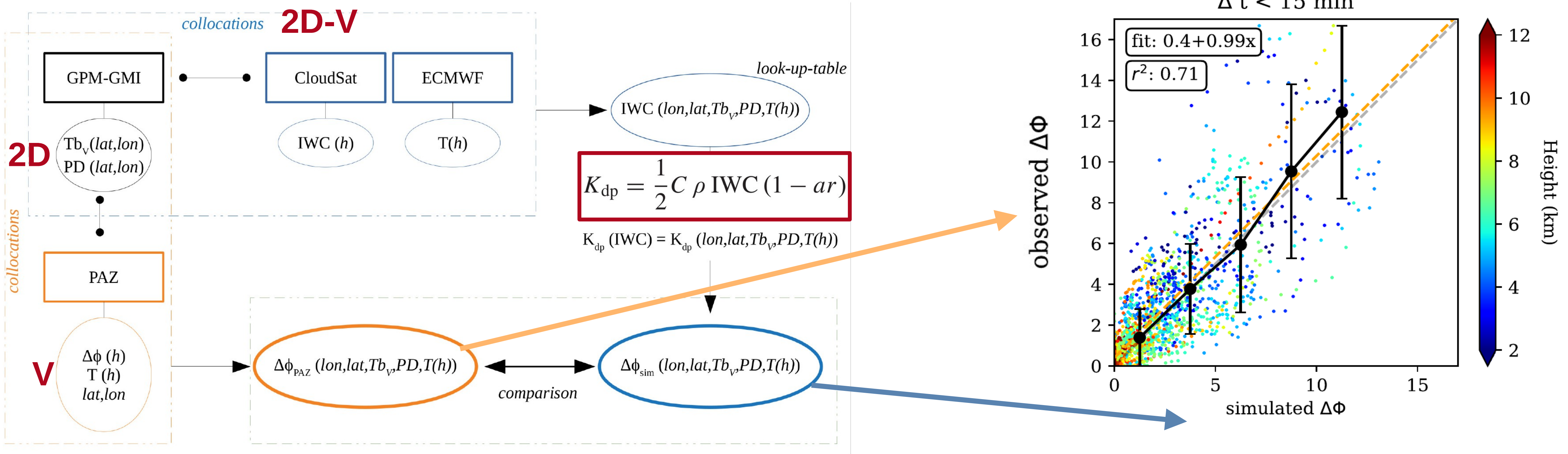
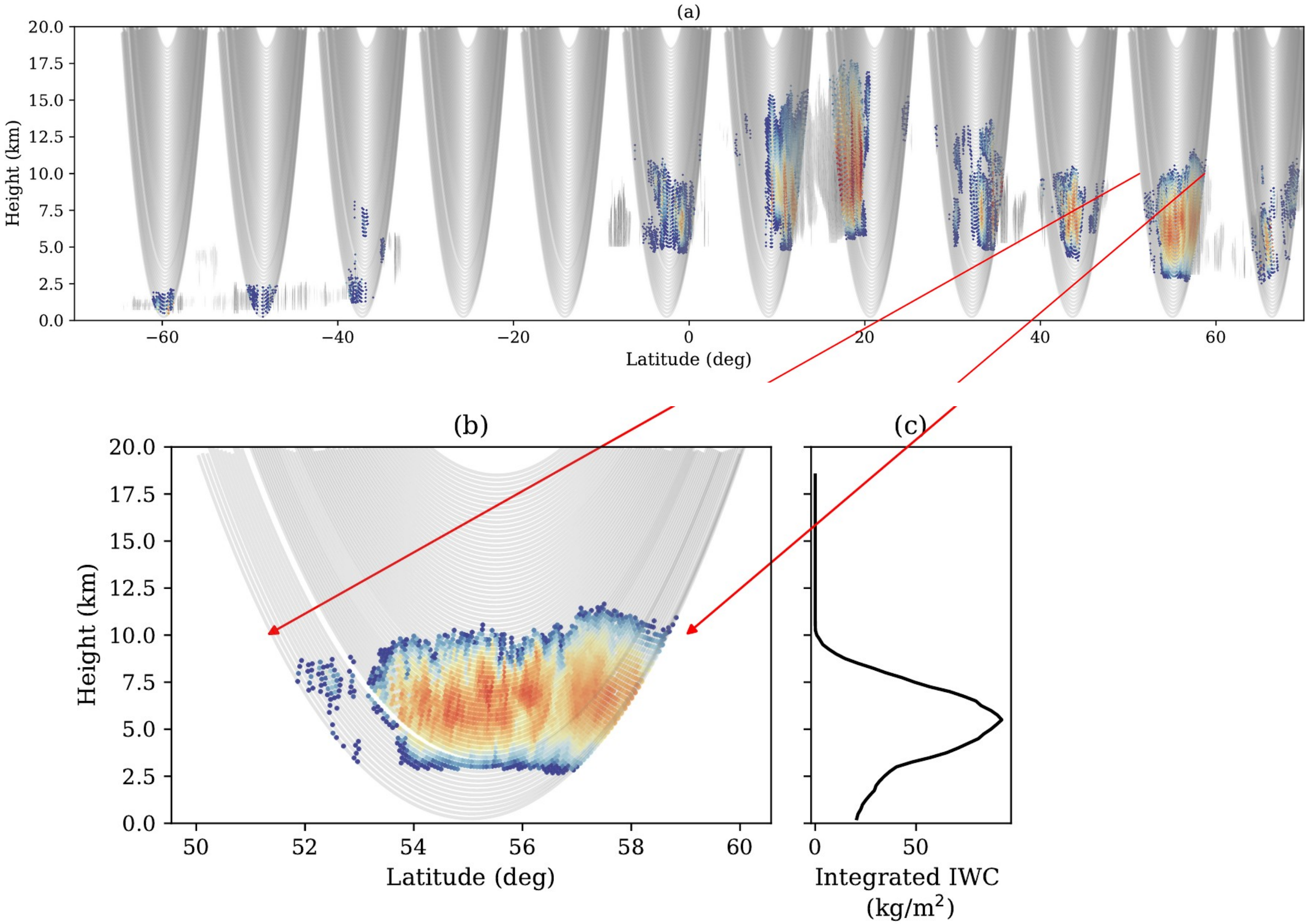
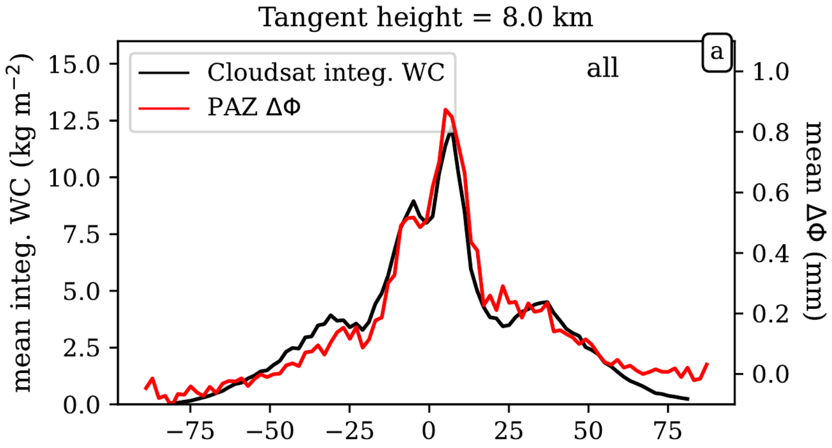
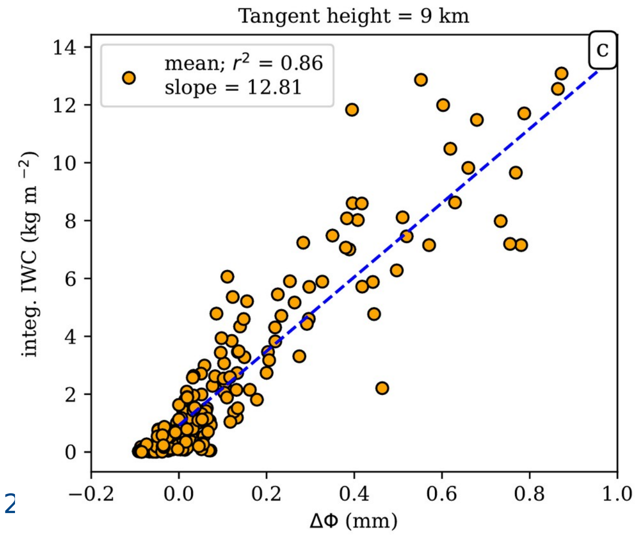


Sensitivity to frozen hydrometeors

Comparison between CloudSat IWC and PAZ Δφ climatologies (**DOI**: 10.5194/acp-2022-300)

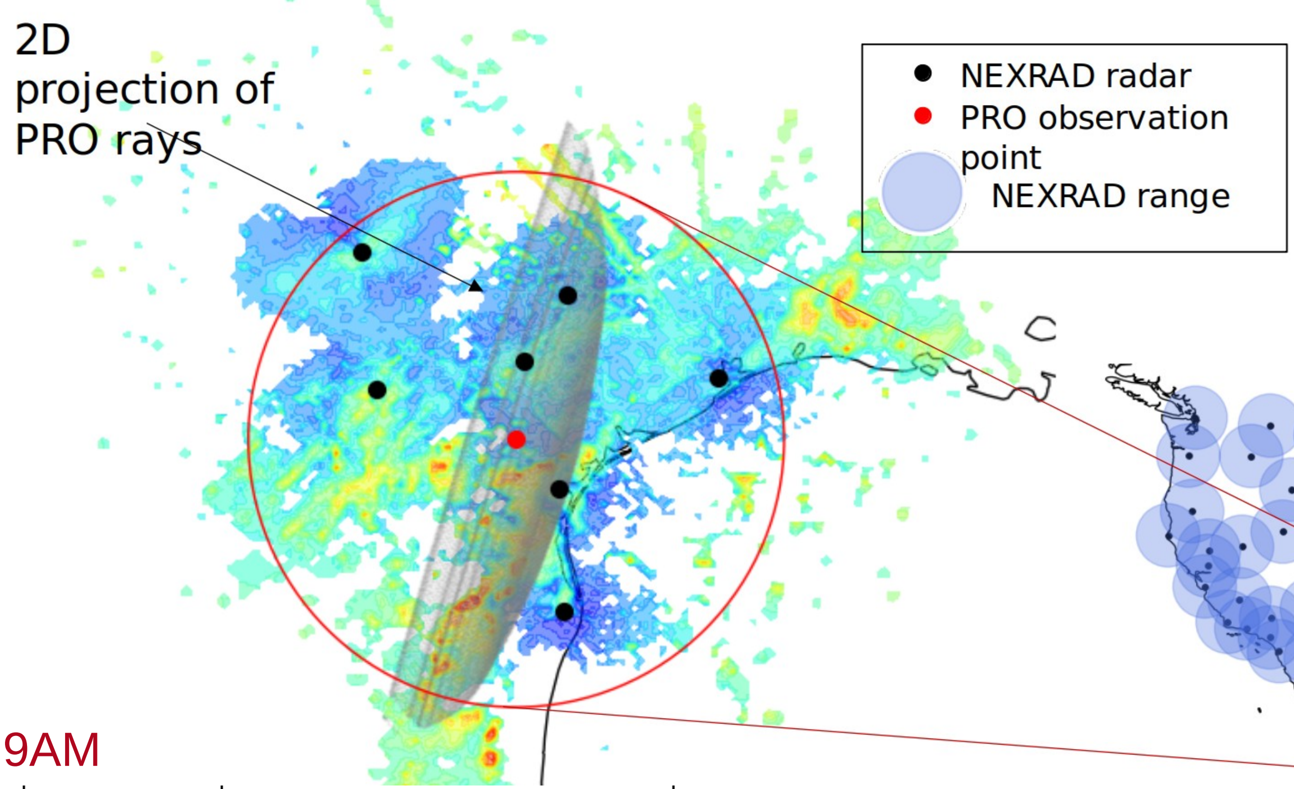




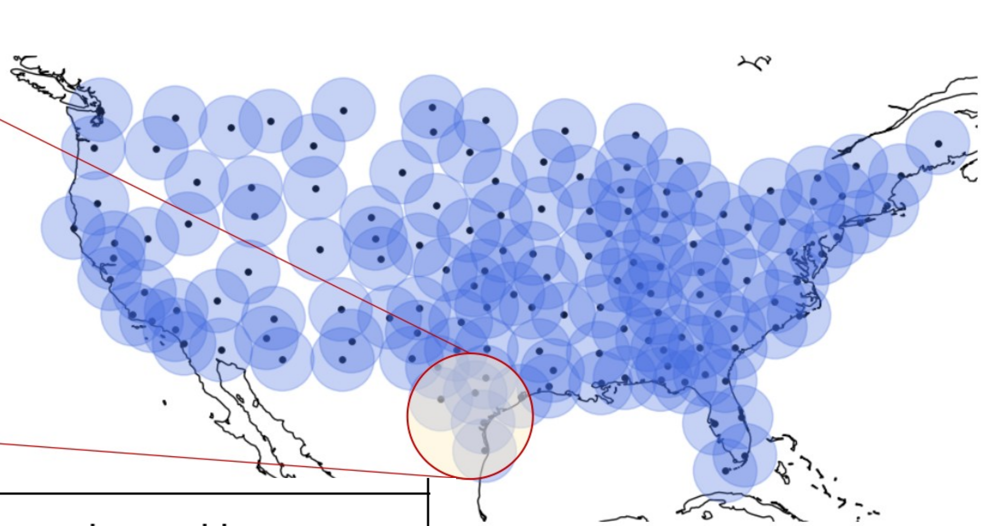


Sensitivity to frozen hydrometeors

Co-locations between PAZ PRO profiles and NEXRAD dual-pol weather radars:



- NEXRAD Level II data.
- Selection of radars inside a circle of **400 km** from RO observation point.



Tomorrow at 9AM

9:00-9:20	18:00-18:20	01:00^{+1}-01:20^{+1}	A.Paz (ICE-CSIC, IEEC)	Co-location of PAZ observations with polarimetric weather radar

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Use for/in NWP

FOR NWP:

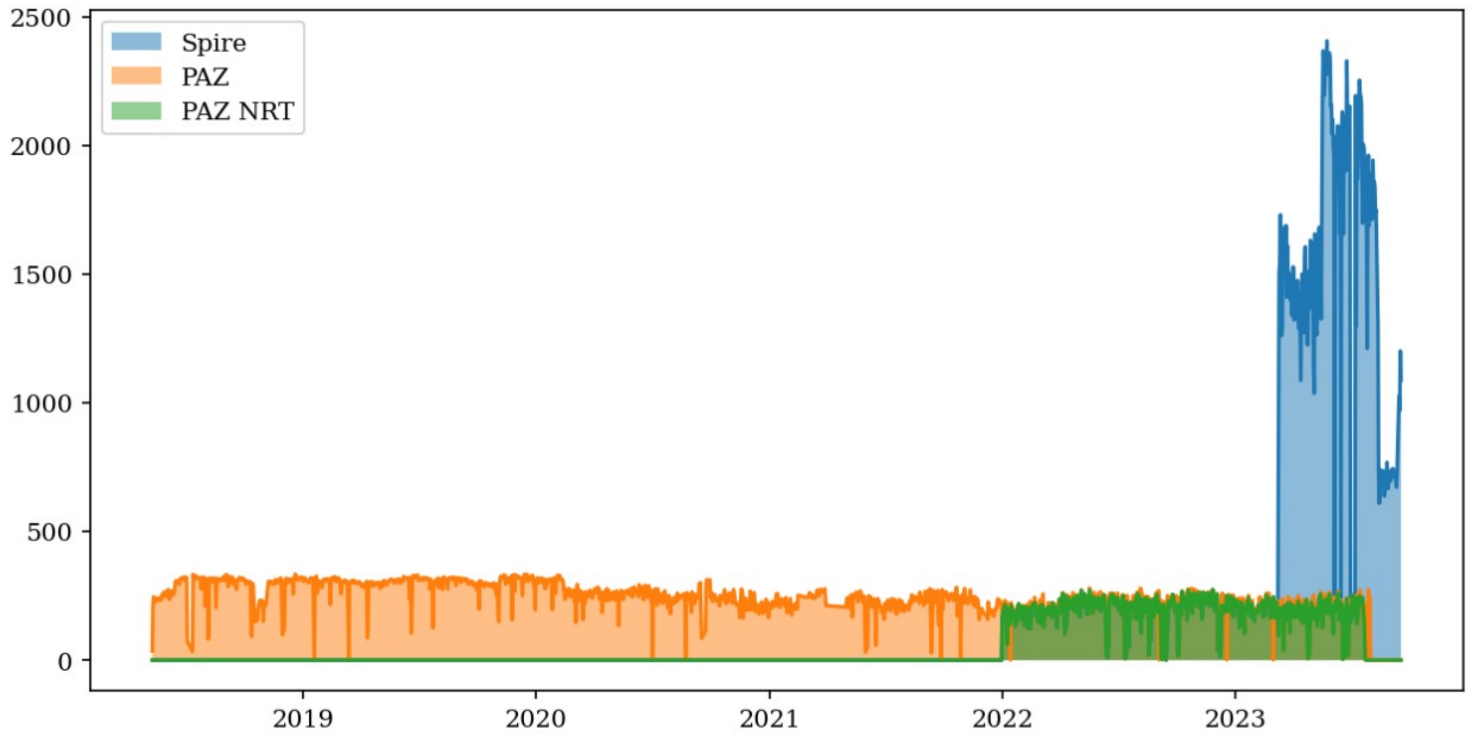
As a **diagnosis** tool, to help identifying and refining **model parametrizations**

IN NWP:

Data Assimilation

Efforts in GNSS PRO for NWP [chair: Lidia Cucurull]				
10:00-10:10	19:00-19:10	02:00+1-02:10+1	E. Cardellach / R.Padullés (ICE-CSIC, IEEC)	Introduction to the Multi-center exercise for PAZ NWP simulations and comparisons
10:10-10:30	19:10-19:30	02:10+1-02:30	BREAK	
10:30-10:50	19:30-19:50	02:30+1-02:50+1	M. Murphy (GMAO, NASA)	WRF Simulations of Atmospheric Rivers
10:50-11:00	19:50-20:00	02:50+1-03:00+1	S.-Y. Chen (NCU)/B.Kuo (UCAR)	WRF Simulations of Tropical Cyclones
11:00-11:20	20:00-20:20	03:00+1-03:20+1	R. Padullés (ICE-CSIC, IEEC)	Results of the multi-center exercise
11:20-11:40	20:20-20:40	03:20+1-03:40+1	D. Hotta (JMA)/K. Lonitz (ECMWF)	GNSS PRO Forward Operator
11:40-12:00	20:40-21:00	03:40+1-04:00+1	B. Johnson (UCAR/JCSDA)	Recent Advances in the CRTM and hydrometeor modeling of relevance to PRO

Commercial GNSS PRO



New opportunities with commercial GNSS PRO:

- clusters of profiles
- larger data sets for NWP

Novelties with respect to PAZ: multiple GNSS constellations, CubeSats, no need of antenna calibration

Commercial GNSS PRO

8:10-8:30	17:10-17:30	24:10-24:30	T. Burger (ESA)	ESA activities in support of GNSS PRO

DAY 2: Nov 29, 2023				
Time LA	Time EU	Time Beijing	Presenter:	Topic/Title:
Commercial GNSS PRO [chair: Ramon Padullés]				
7:00-7:20	16:00-16:20	23:00-23:20	V. Nguyen (Spire Global)	Initial polarimetric RO results from Spire's nanosatellite constellation
7:20-7:40	16:20-16:40	23:20-23:40	R. Kursinski (PlanetIQ)	Dual linear polarization GNSS RO measurements at PlanetiQ in 2024
7:40-8:00	16:40-17:00	23:40-24:00	D. Masters (Muon Space)	Muon Space satellites and payloads

Conclusions

- **Polarimetric RO** experiment aboard PAZ
- **GNSS PRO Hypothesis**: flattened droplets delay the H-component of the circularly polarized GNSS signals with respect to the V-component, delay that can be measured at different altitudes (but really tiny, ~hundredth to tenth of cycle)
- **Hypothesis confirmed**: sensitivity to non-spherical hydrometeors at different altitudes
- Large sensitivity to **frozen particles** proven by comparing with **GPM GMI** radiometers, **CloudSat** climatologies and **NEXRAD** dual-polarization measurements

- Recent work for NWP and related to commercial GNSS PRO → see dedicated sessions!

Thanks!

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