Polarimetric GNSS RO aboard the PAZ satellite: status of the ROHP-PAZ experiment

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rohp-PAZ

https://paz.ice.csic.es

Contents:

SCIENTIFIC INTEREST

THE POLARIMETRIC GNSS RO

THE ROHP-PAZ EXPERIMENT

POLARIMETRIC DATA PROCESSING

OVERVIEW OF STUDIES

DATA STATUS

CONCLUSIONS

Contents:

- Polarimetric RO (PRO) 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): GNSS polarimetric radio occultations (GNSS-PRO)

- HYPOTHESIS: polarimetric information sensitive 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

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Why are coincident thermodynamic and precipitation vertical profiles required?

- They might 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

Why are coincident thermodynamic and precipitation vertical profiles required?

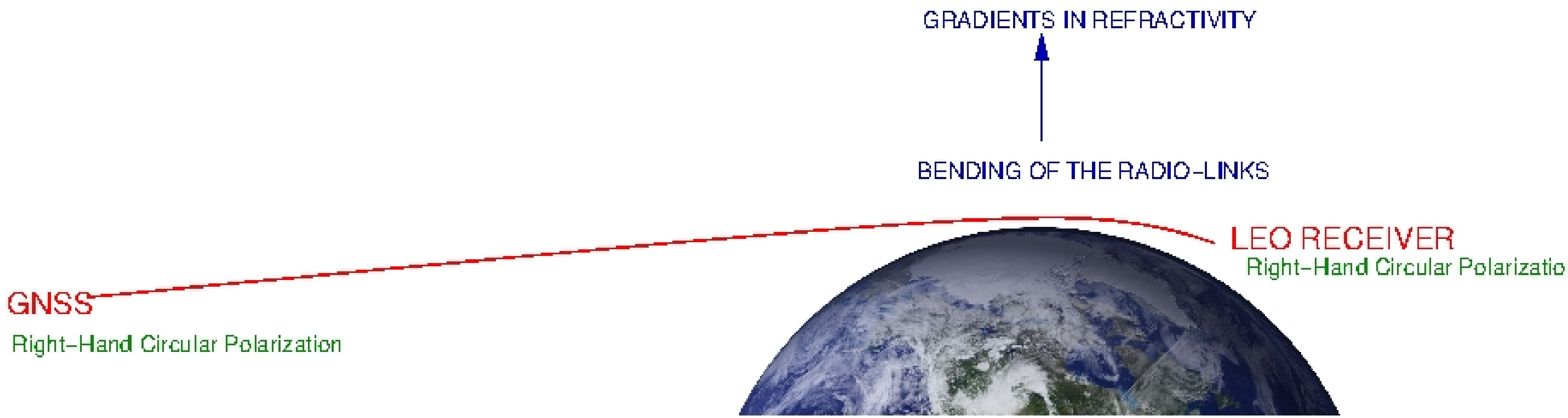
- They might help understanding the thermodynamic conditions underlying in

- This is rele rly w del parame izat

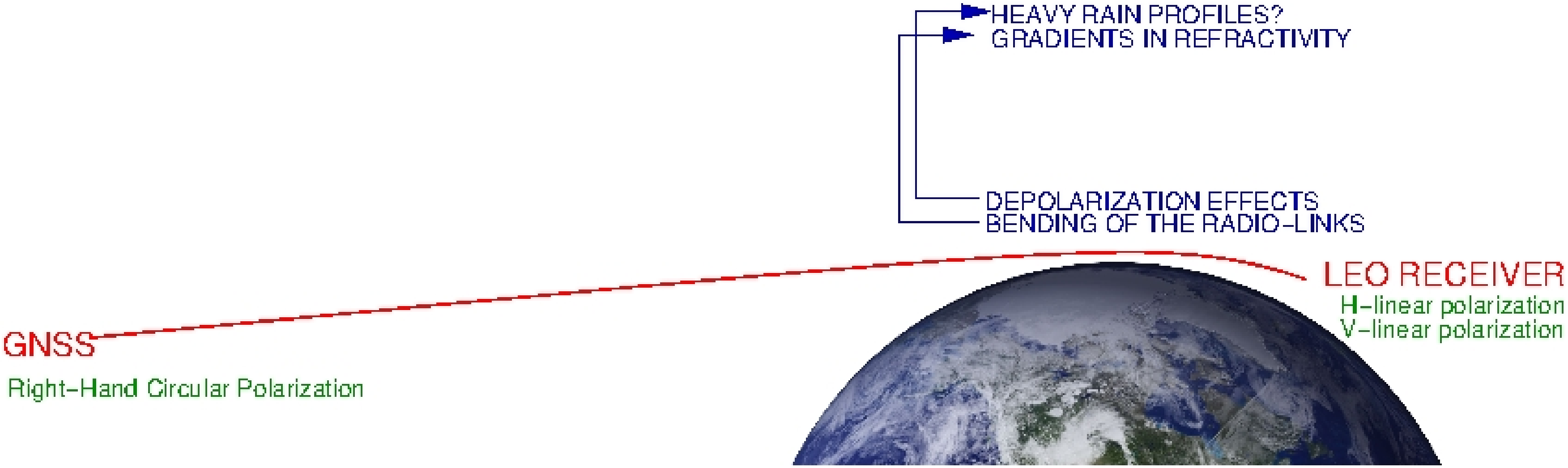
- A better u ng climate models and **quantifying the impact of climate variability** on precipitation

POTENTIAL TO CONTRIBUTE ANSWERING SCIENTIFIC QUESTIONS OF RELEVANT SOCIETAL IMPACT!

Contents:



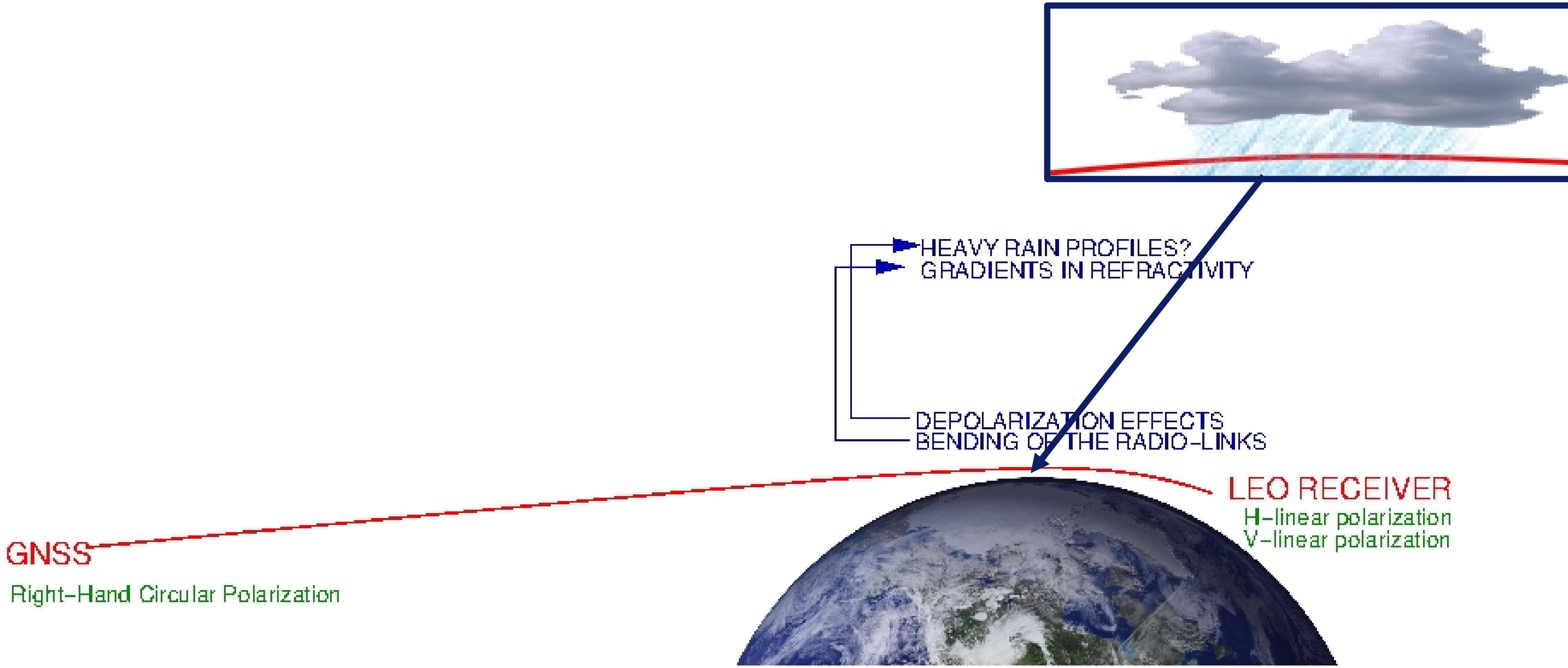
‘TYPICAL’ GNSS RO PRODUCTS: VERTICAL PROFILES OF THERMODYNAMIC VARIABLES at the tangent point (typically temperature, pressure, humidity)



'NEW' GNSS-PRO PRODUCTS:

VERTICAL PROFILES OF THERMODYNAMIC VARIABLES (typically temperature, pressure, water vapor)

+ **VERTICAL PROFILES OF INTENSE RAIN**



'NEW' GNSS-PRO PRODUCTS:

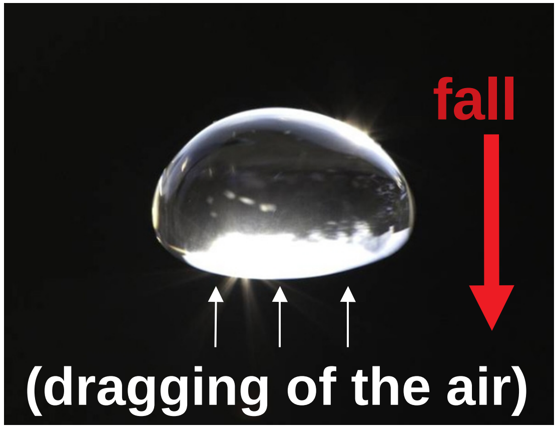
VERTICAL PROFILES OF THERMODYNAMIC VARIABLES (typically temperature, pressure, water vapor)

+ **VERTICAL PROFILES OF INTENSE RAIN**

To understand this concept it is important to keep in mind that the big falling rain drops ARE NOT like this

To understand this concept it is important to keep in mind that the big falling rain drops ARE NOT like this

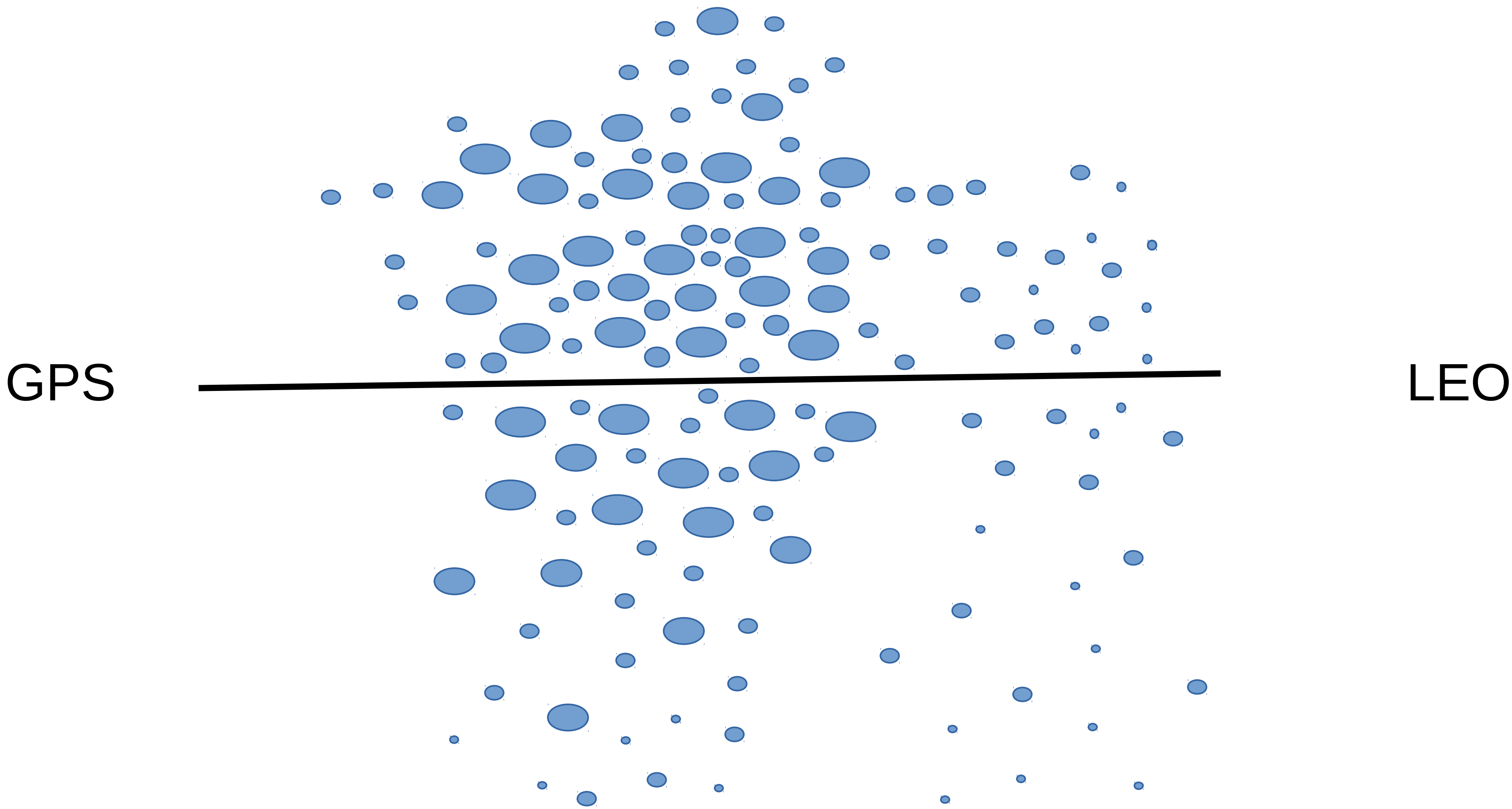
but rather LIKE



The bigger the drop, the larger the asymmetry effect

More large drops in heavier rain

precipitation cell



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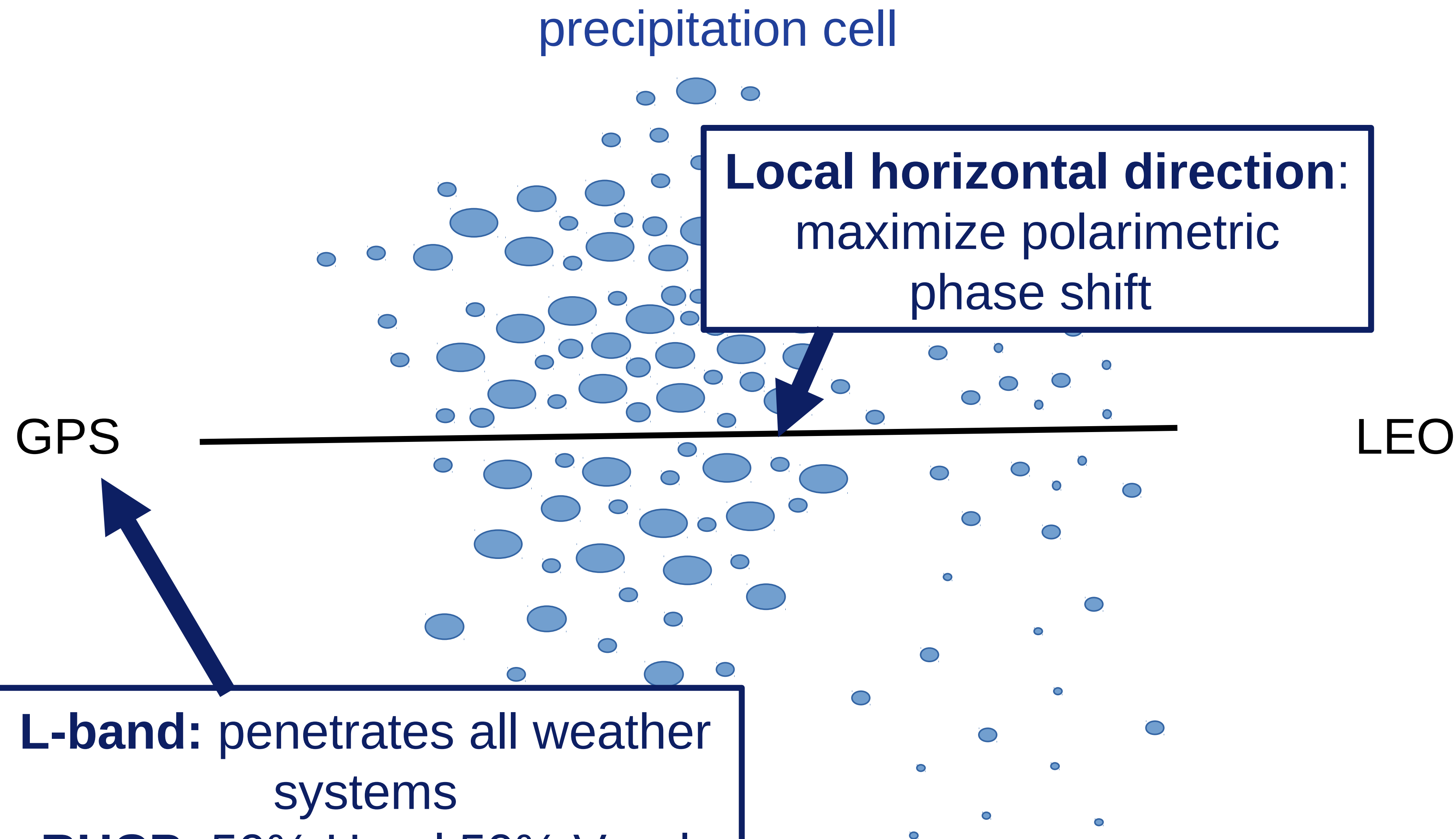

Local horizontal direction: maximize polarimetric phase shift

L-band: penetrates all weather systems
RHCP: 50% H-pol 50% V-pol
Robust to Faraday rotations

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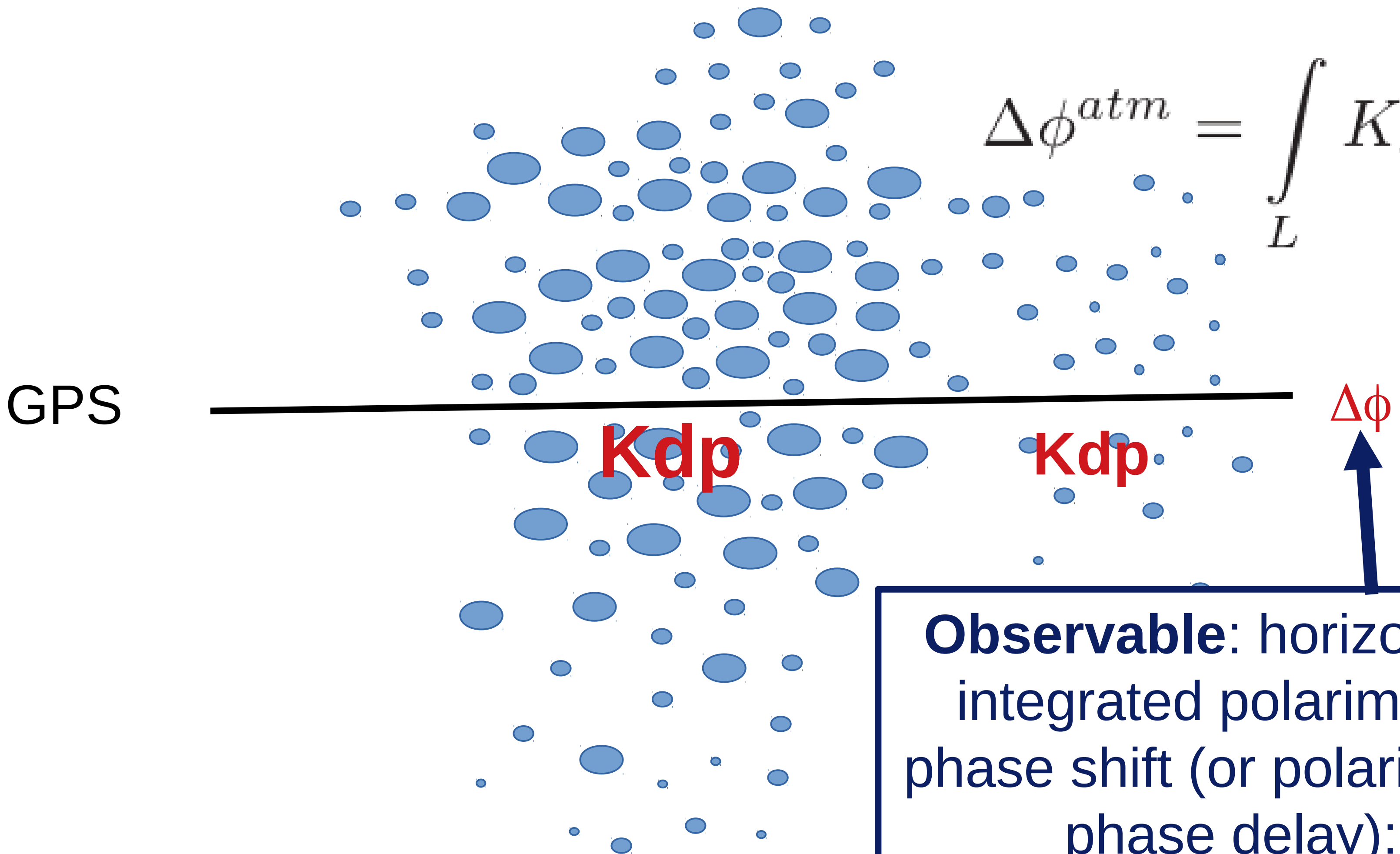
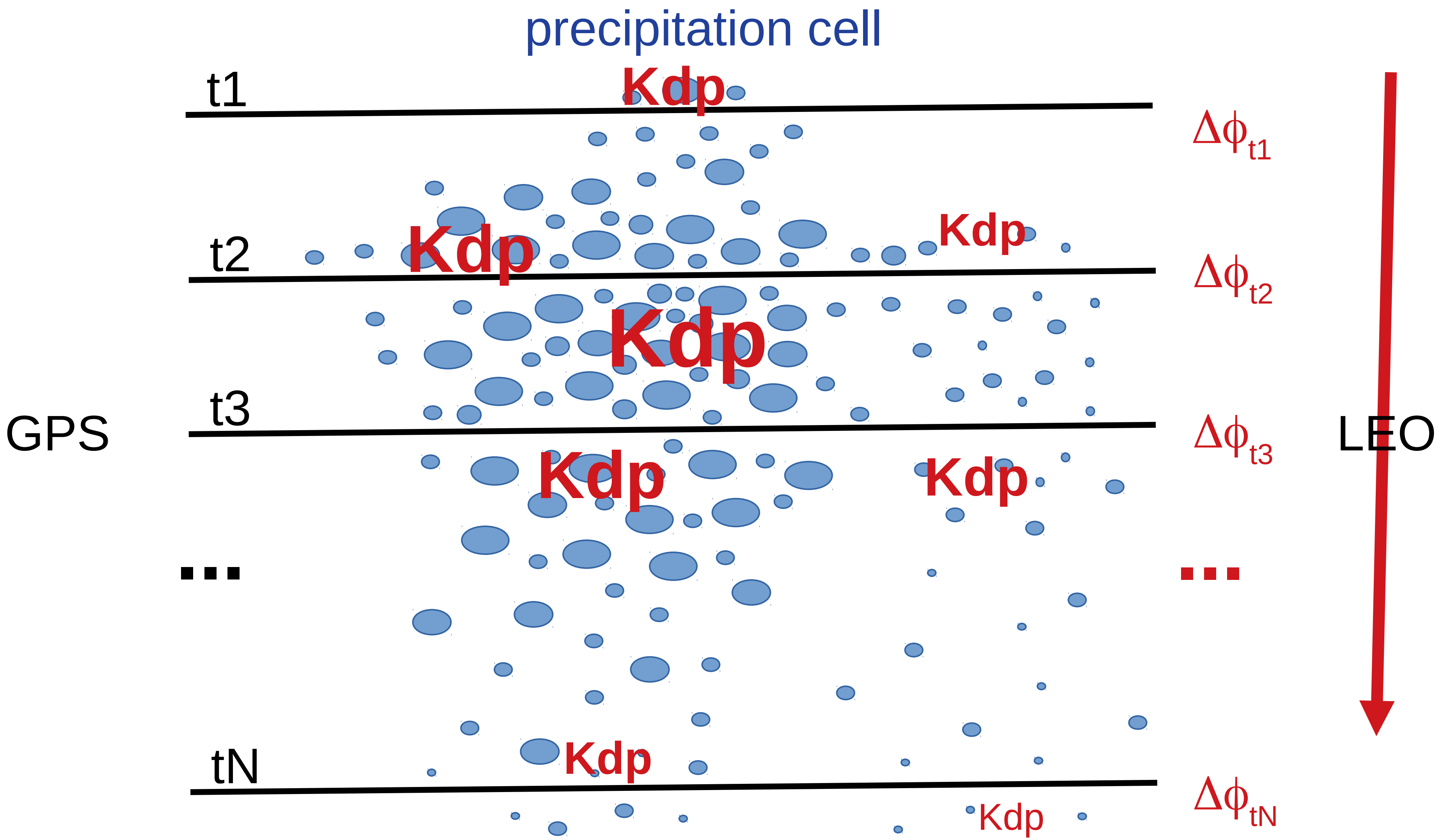
precipitation cell



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

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

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



Vertical scanning

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IEEC

This new measurement concept is being proved aboard the Spanish PAZ LEO

→ the Radio Occultation and Heavy Precipitation aboard PAZ experiment

(ROHP-PAZ)

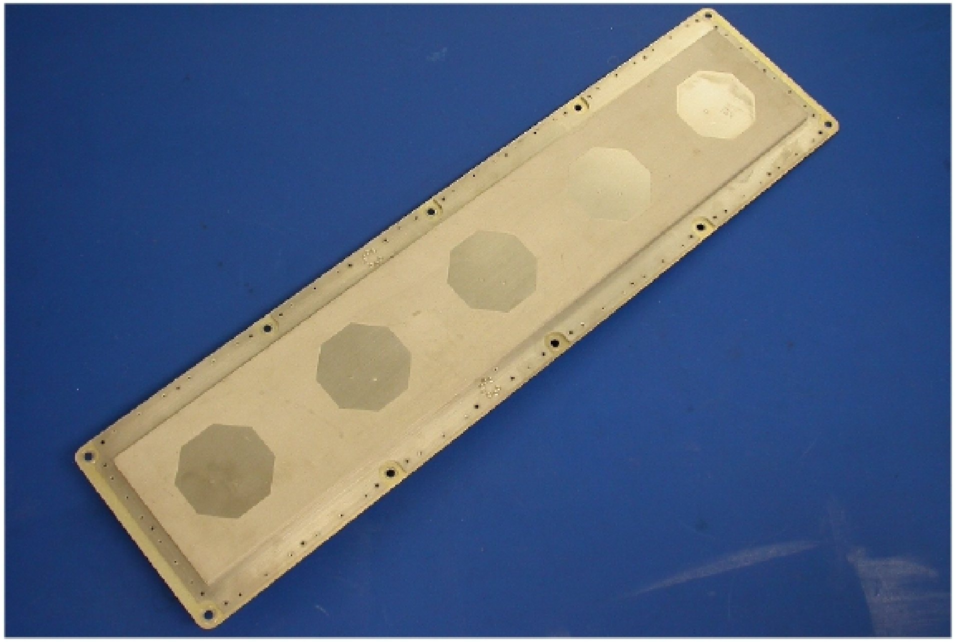
https://paz.ice.csic.es

rohp-PAZ

Contents:

Spanish PAZ satellite:

- Main payload, X-band SAR
- Polar orbit (97.4 deg) at ~514 km altitude, sun-synchronous dusk/dawn
- GPS receiver
- One 2-pol (H/V) RO antenna



The ROHP-PAZ experiment is led by ICE-CSIC IEEC: concept, experiment design, technological requirements, funding responsibilities…

But it has only been possible because of the committed support, collaboration and agreements with:

- **Hisdesat**: company owner of PAZ
- **NASA/Jet Propulsion Laboratory**: scientific interest in products and post-processing algorithms, NASA grants for their participation
- **NOAA**: near-real time ground-segment operations, NRT data dissemination of the 'standard' products to weather services worldwide
- **UCAR**: generation of the NRT 'standard' products for NOAA

Sucessful launch on **February 22, 2018**, by SpaceX (Falcon9).
GNSS RO experiment **activated on May 10**, 2018.

Contents:

PRO PROCESSING:

- The IGOR receiver provides amplitudes and phases of each polarization channel.
- UCAR and JPL process at level-1: SNR, **excess phase ϕ, at each polarization**: ϕH, ϕV → suitable to play with polarimetry.
- Ideally, the **only difference between ϕH and ϕV** would be the larger delay induced by **hydrometeors** at H-pol than V-pol (and a constant 90º shift).
- However, other systematic effects do not cancel out. Largely the antenna phase pattern.

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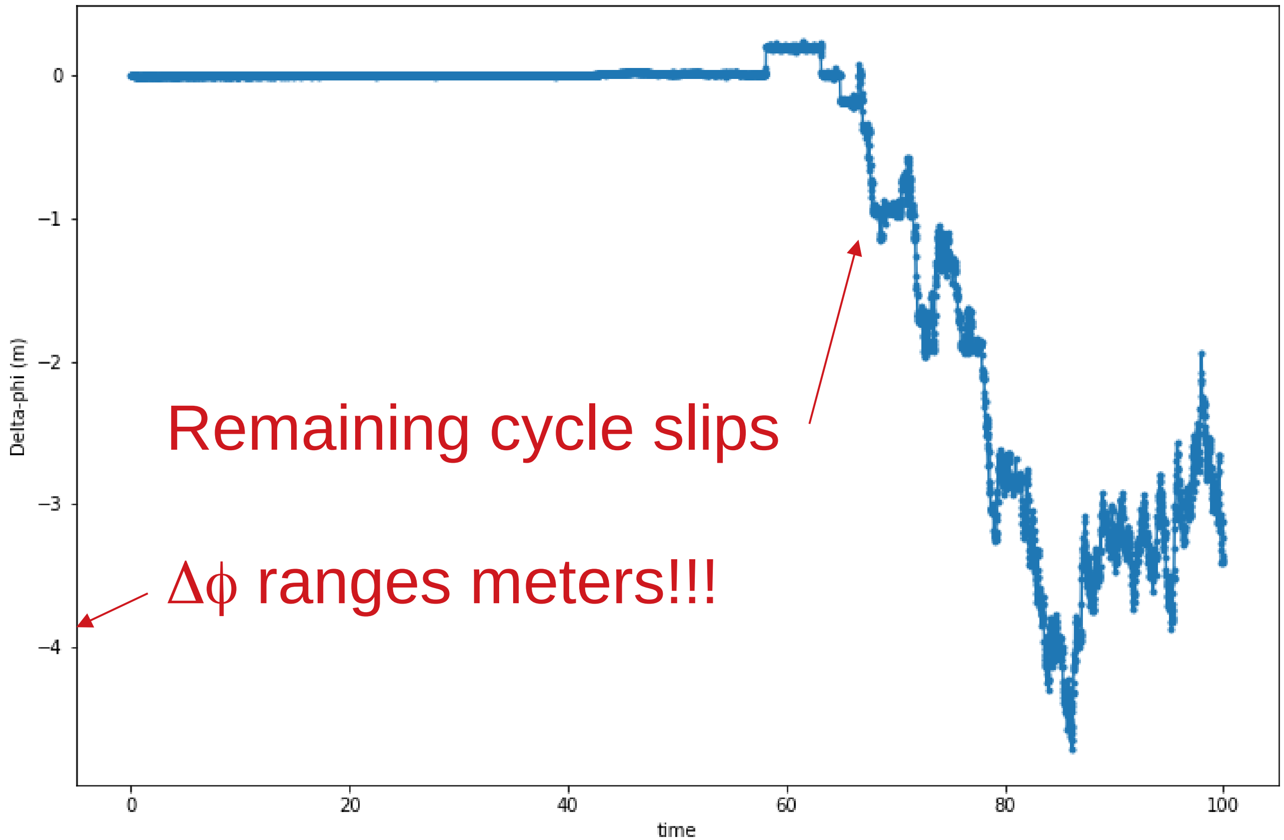
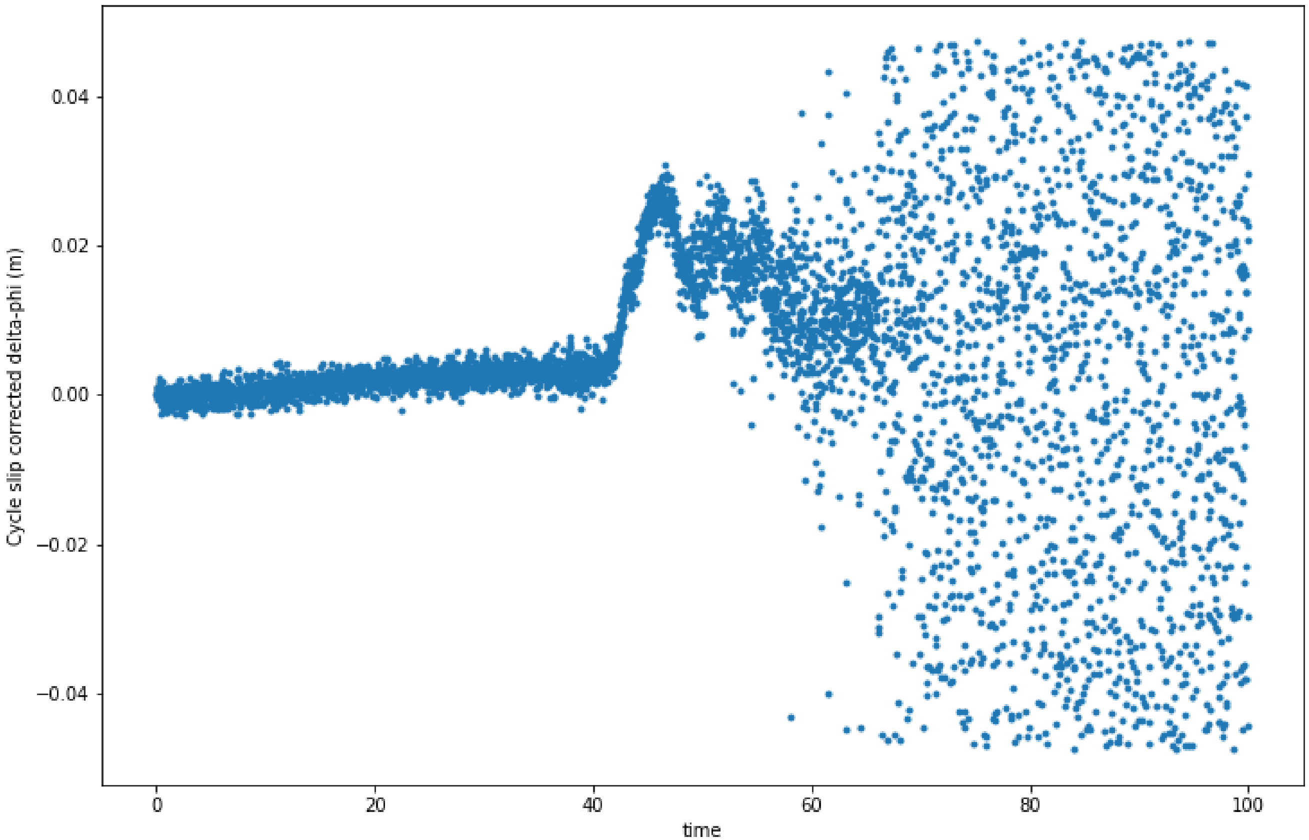
ϕH-ϕV without further processing looks wrong (h_exL1 - v_exL1):



ϕH-ϕV without further processing looks wrong:



1) correct residual cycle-slips!!

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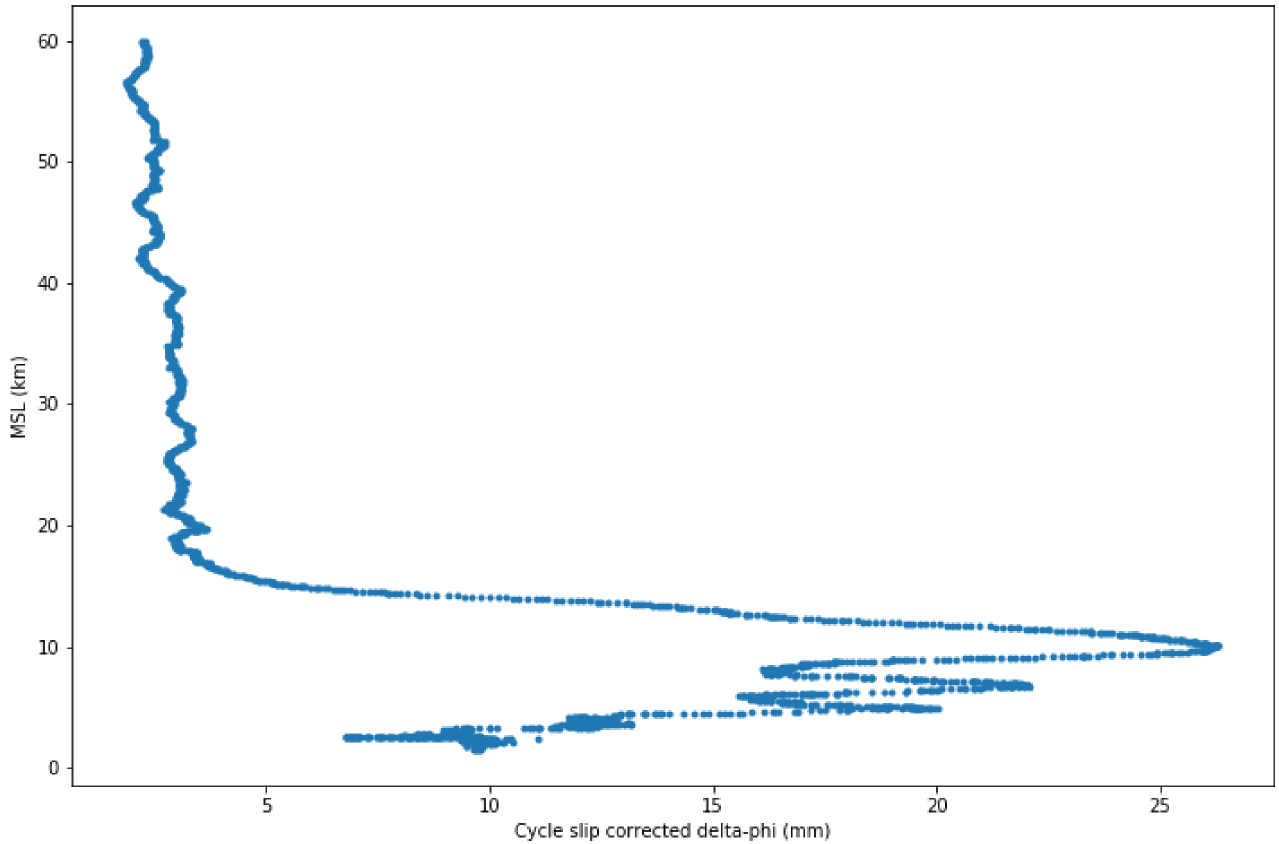
ϕH-ϕV without further processing looks wrong:



2) function of altitude and smooth (1-sec filter)

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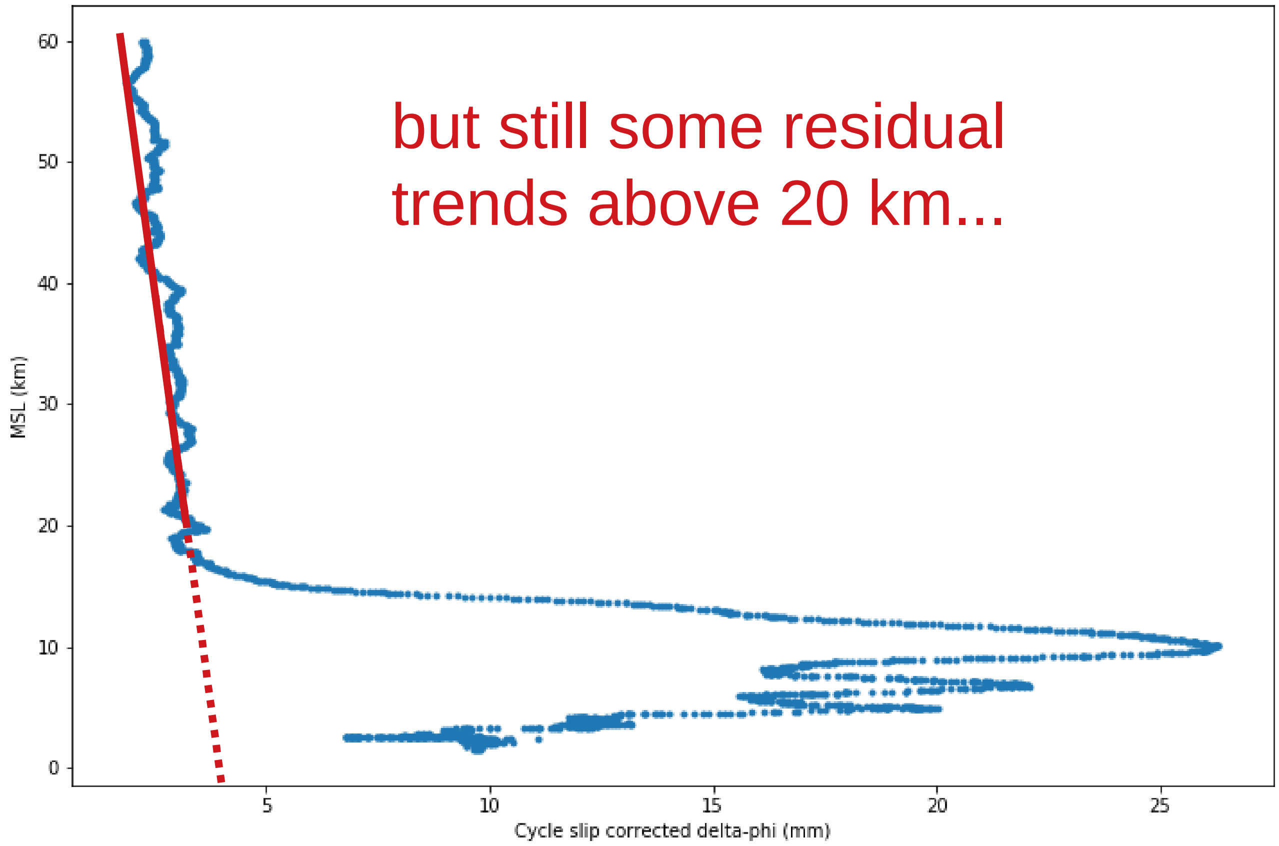
ϕH-ϕV without further processing looks wrong:



2) function of altitude and smooth (1-sec filter)

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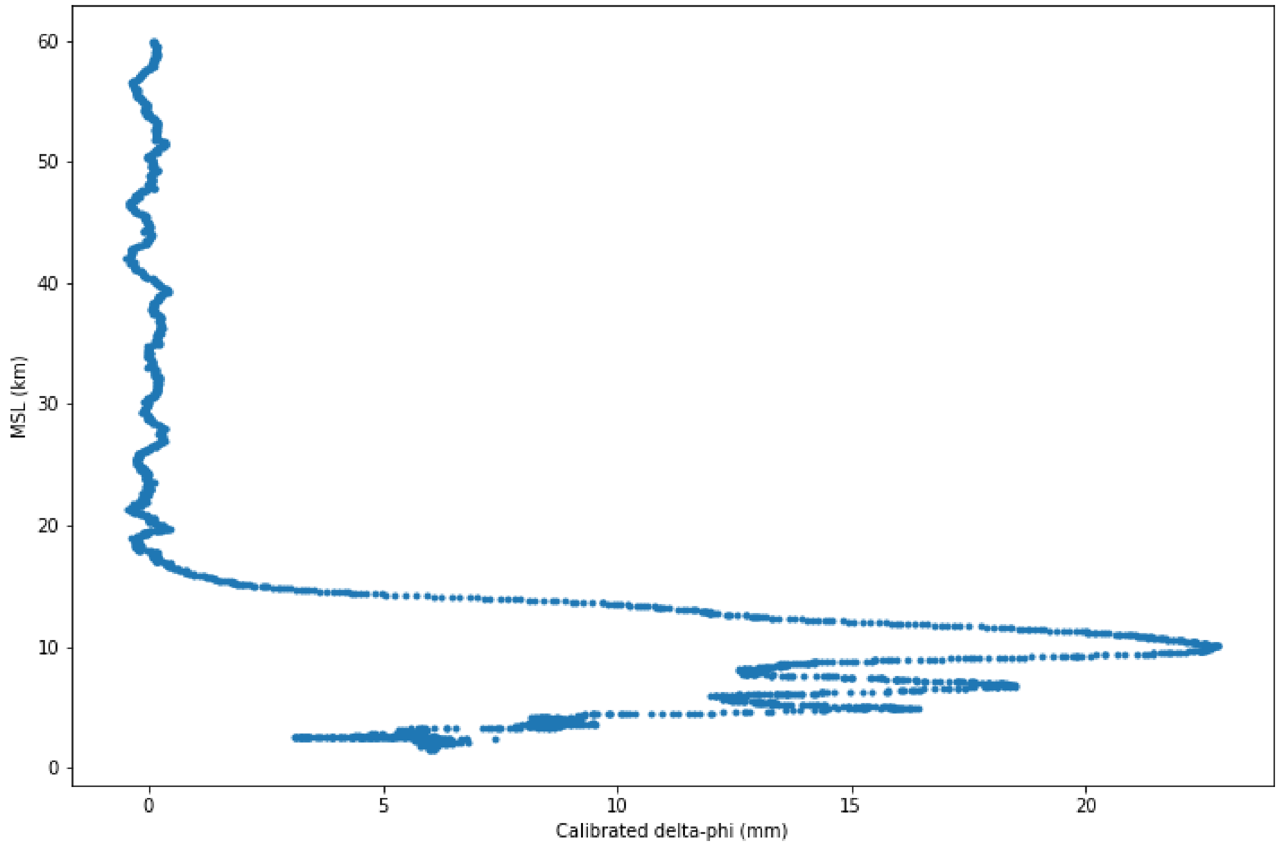
φH-φV now calibrated!



3) linear fit above 20km, then subtracted to the whole profile

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- After simple calibration:

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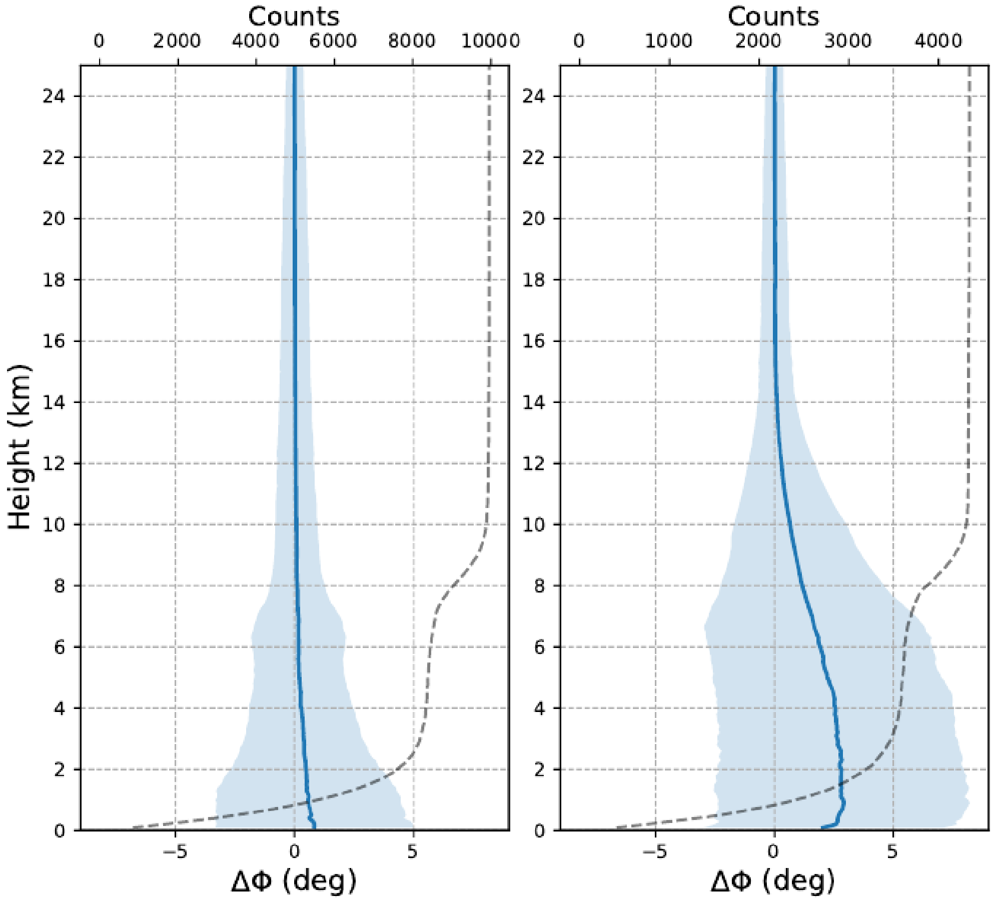
RAIN FREE:
- average → 0
- bias ~ 1º (bottom)
- dispersion:
  <2º @ h>4.5km
  <4º @ surface

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

Rain-free: Rain:



Improved calibration strategy, accounting for antenna pattern:

Calibration and Validation of the Polarimetric Radio Occultation and Heavy Precipitation experiment Aboard the PAZ Satellite

Ramon Padullés[1], **Chi O. Ao**[1], **F. Joseph Turk**[1], **Manuel de la Torre Juárez**[1], **Byron Iijima**[1], **Kuo Nung Wang**[2,1], **and Estel Cardellach**[3]

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[2]Scripps Institution of Oceanography, La Jolla, San Diego, CA
[3]Institut de Ci'encies de l'Espai, Consejo Superior de Investigaciones Científicas, Insitut d'Estudis Espacials de Catalunya

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Under review at *Atmospheric Measurement Techniques*

(Padullés et al., IROWG-ROM SAF 2019, next talk)

Contents:

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER

10.1029/2018GL080412

Sensing Heavy Precipitation With GNSS Polarimetric Radio Occultations

E. Cardellach[1,2], S. Oliveras[1,2], A. Rius[1,2], S. Tomás[1,2], C. O. Ao[3], G. W. Franklin[3], B. A. Iijima[3], D. Kuang[3], T. K. Meehan[3], R. Padullés[3], M. de la Torre Juárez[3], F. J. Turk[3], D. C. Hunt[4], W. S. Schreiner[4], S. V. Sokolovskiy[4], T. Van Hove [4], J. P. Weiss[4], Y. Yoon[4], Z. Zeng[4], J. Clapp[5], W. Xia-Serafino[5], and F. Cerezo[6]

[1]Institute of Space Sciences (ICE, CSIC), Barcelona, Spain, [2]Institute for Space Studies of Catalonia (IEEC), Barcelona, Spain, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4]University Corporation for Atmospheric Research, Boulder, CO, USA, [5]National Oceanic and Atmospheric Administration, Silver Spring, MD, USA, [6]Hisdesat, Madrid, Spain

Key Points:

- We present the first spaceborne GNSS radio occultation signals acquired at two polarizations
- The measured observables sense intense precipitation and capture its vertical structure
- No other technique captures both thermodynamics and hydrometeor profiling in intense rain phenomena

Jan 2019

- Results using **first 5 months** of data: May 10 to October 10 2018
- 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**

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$<\Delta\phi>_{0km\text{-}20km}$ for each individual profile → histograms:

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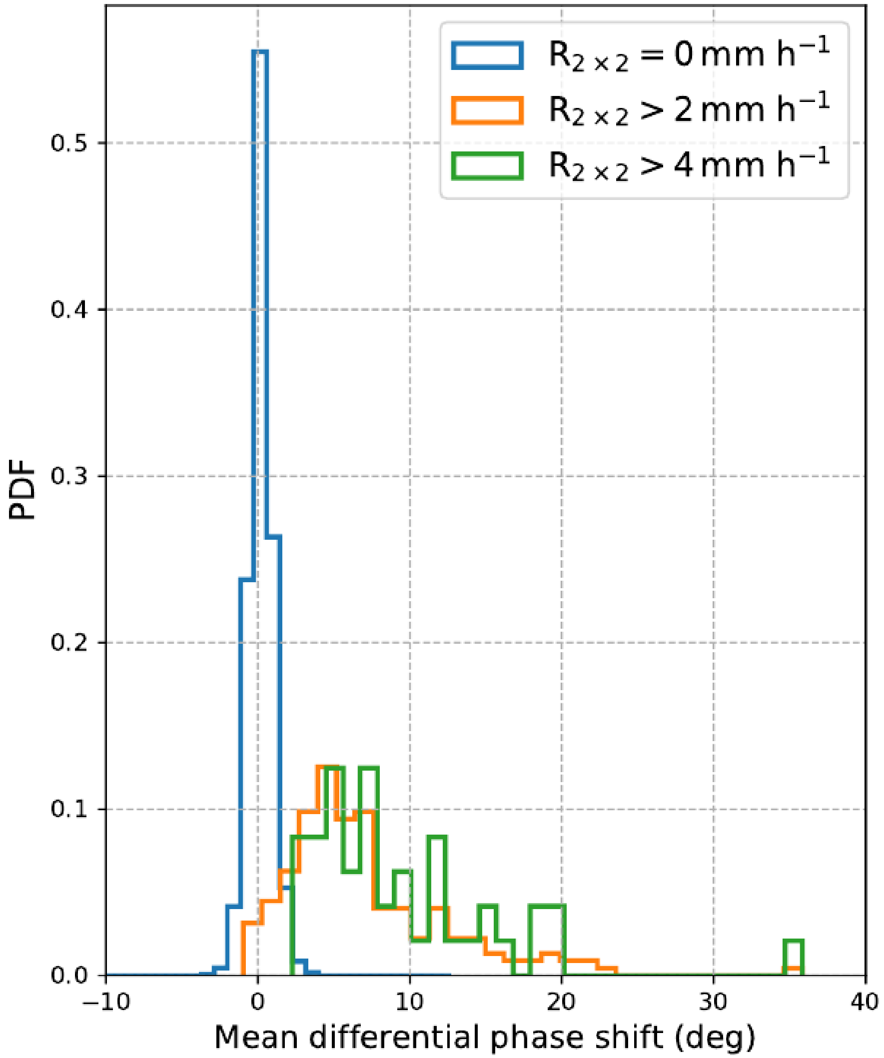


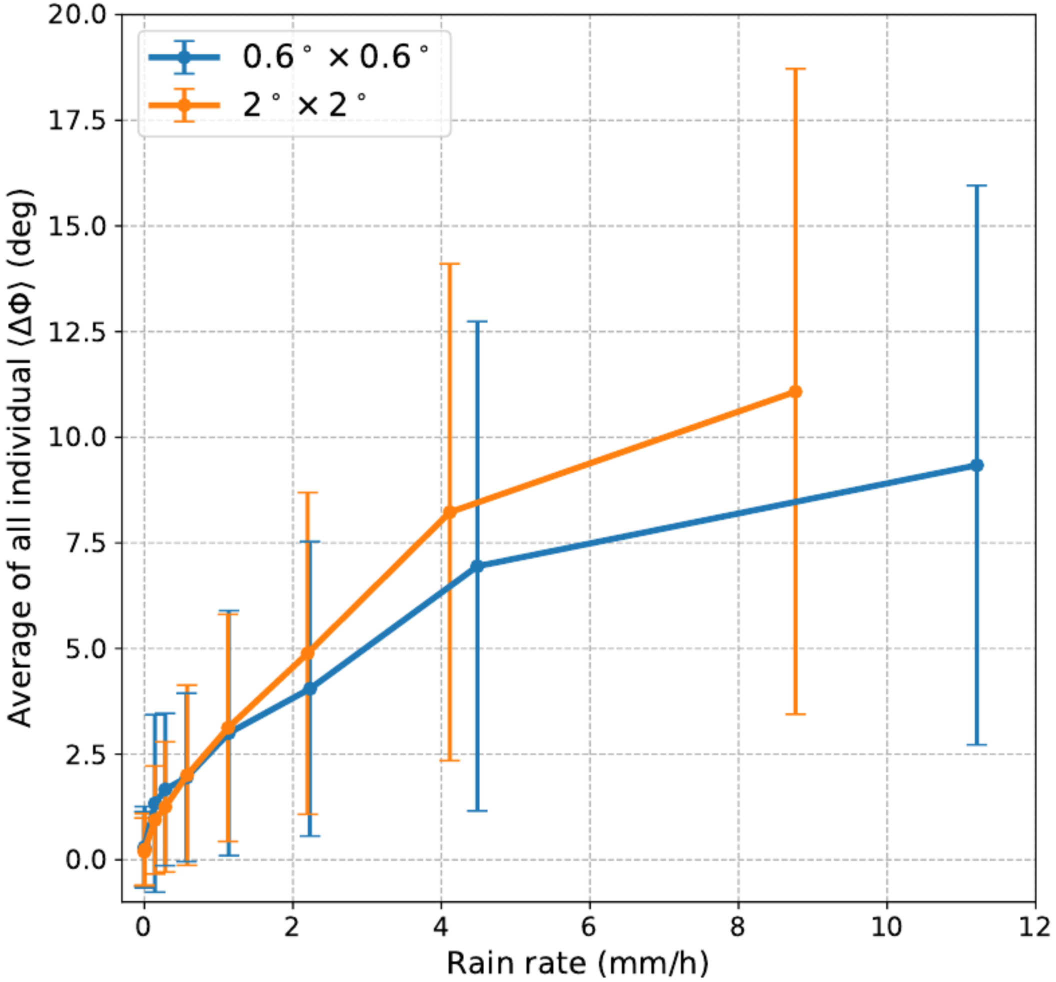
RAIN-FREE events:
98.4% with $<\Delta\phi>_{0km\text{-}20km} <2^o$
99.97% with $<\Delta\phi>_{0km\text{-}20km} <4^o$

'false intense rain positives':
for $<\Delta\phi>_{0km\text{-}20km} >4^o$ → 0.96%

NOTE: not a detection algorithm, yet
Exercise to check meaning of the signals, to understand the observables, link to hydrometeors...

$<\Delta\phi>_{0km-20km}$ for each individual profile → link to rain rate:

GRL 2019



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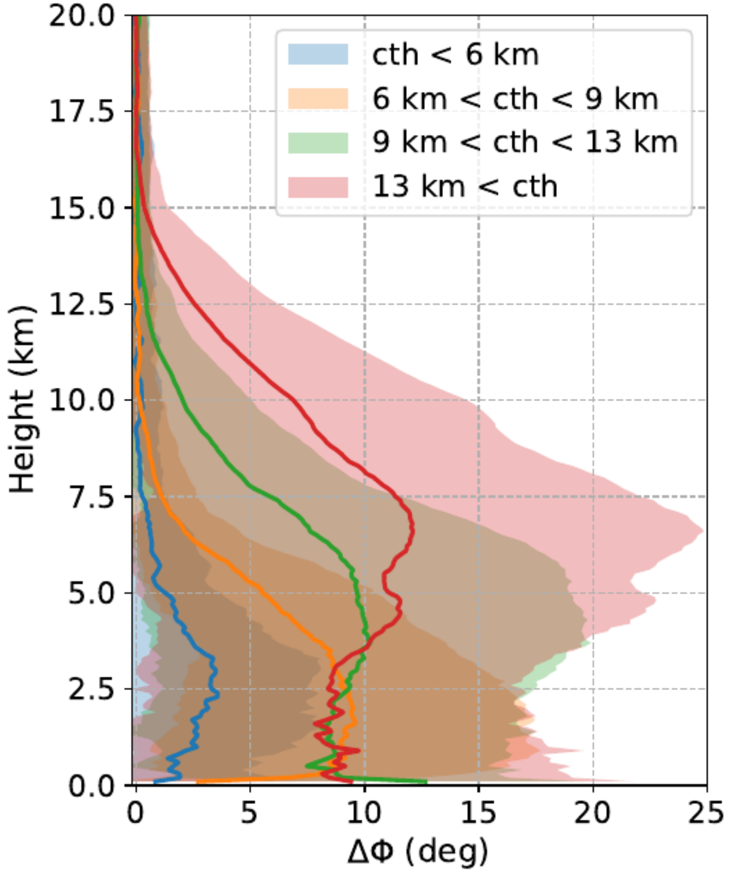
Validation of the vertical structure of $\Delta\phi(h)$:

GRL 2019



All cases with R_{2^o}>1mm/h

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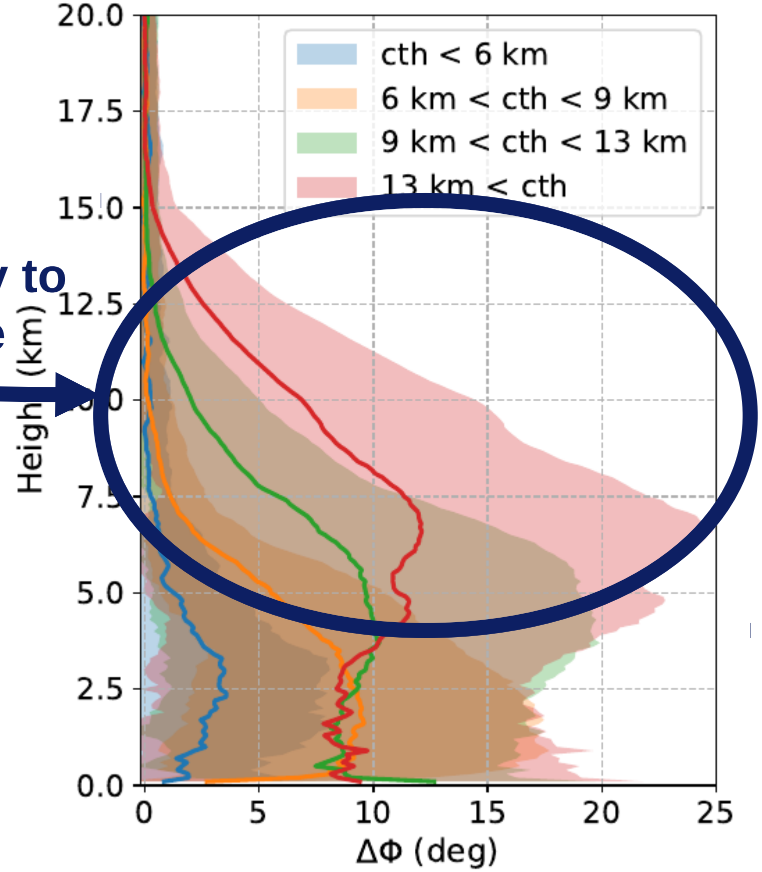
Validation of the vertical structure of $\Delta\phi(h)$:

GRL 2019

High sensitivity to mixed phase + Cloud ice



All cases with R_{2^o}>1mm/h

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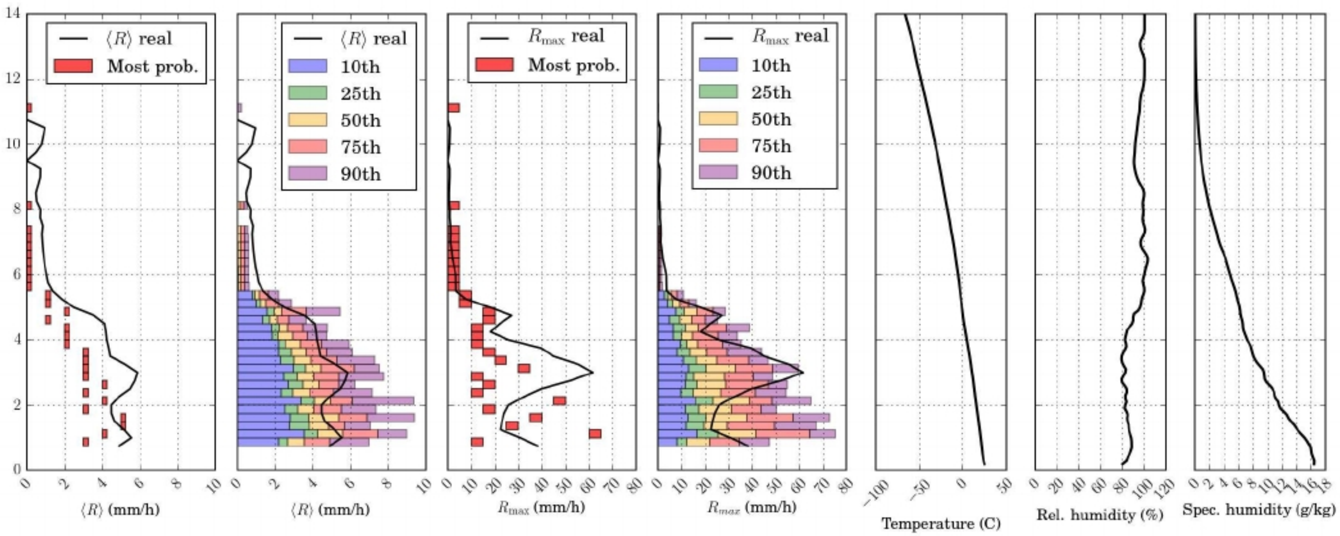
- **STRONG SIGNAL DUE TO FROZEN PARTICLES** (cloud ice, mixed phase…)
- **OPPORTUNITY**: unique new way of sensing frozen particles. Can it be used to improve micro-physic aspects? Role of these particles in extreme events?
- **CHALLENGE**: polarimetric shift mixes rain and other hydrometeors. The Look-Up Tables (LUT) prepared for the rain retrievals did not include contribution from frozen hydrometeors, so new LUTs need to be developed



QJRMS 2018

Contents:

Institute of Space Sciences CSIC Consejo Superior de Investigaciones Científicas IEEC

SCIENTIFIC INTEREST

THE POLARIMETRIC GNSS RO

THE ROHP-PAZ EXPERIMENT

POLARIMETRIC DATA PROCESSING

OVERVIEW OF STUDIES →

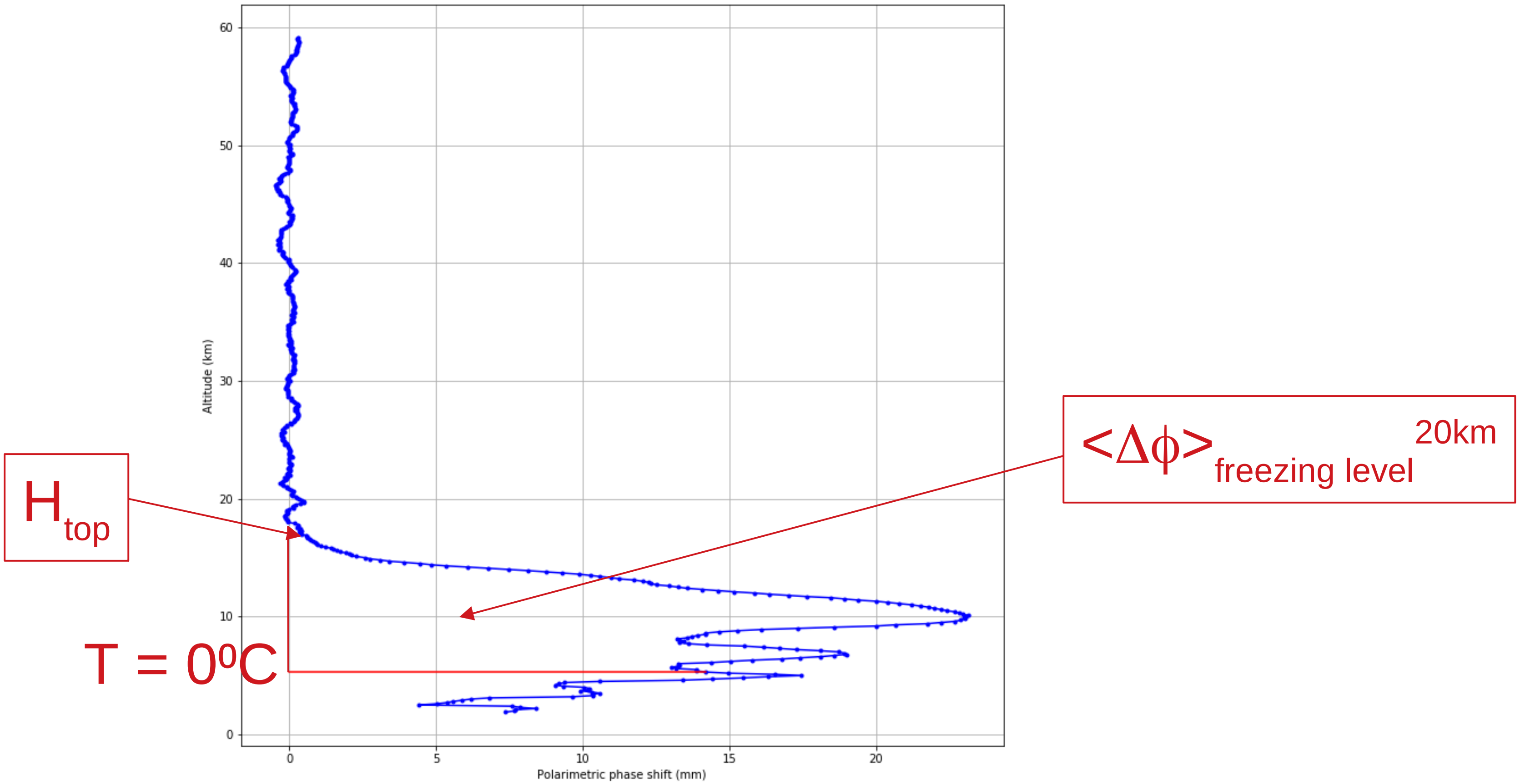
1) Sensing hydrometeors
2) **Other observables**
3) Thermodynamics of heavy precipitation
4) Polarimetric bending-impact space
5) Reflectometry

DATA STATUS

CONCLUSIONS

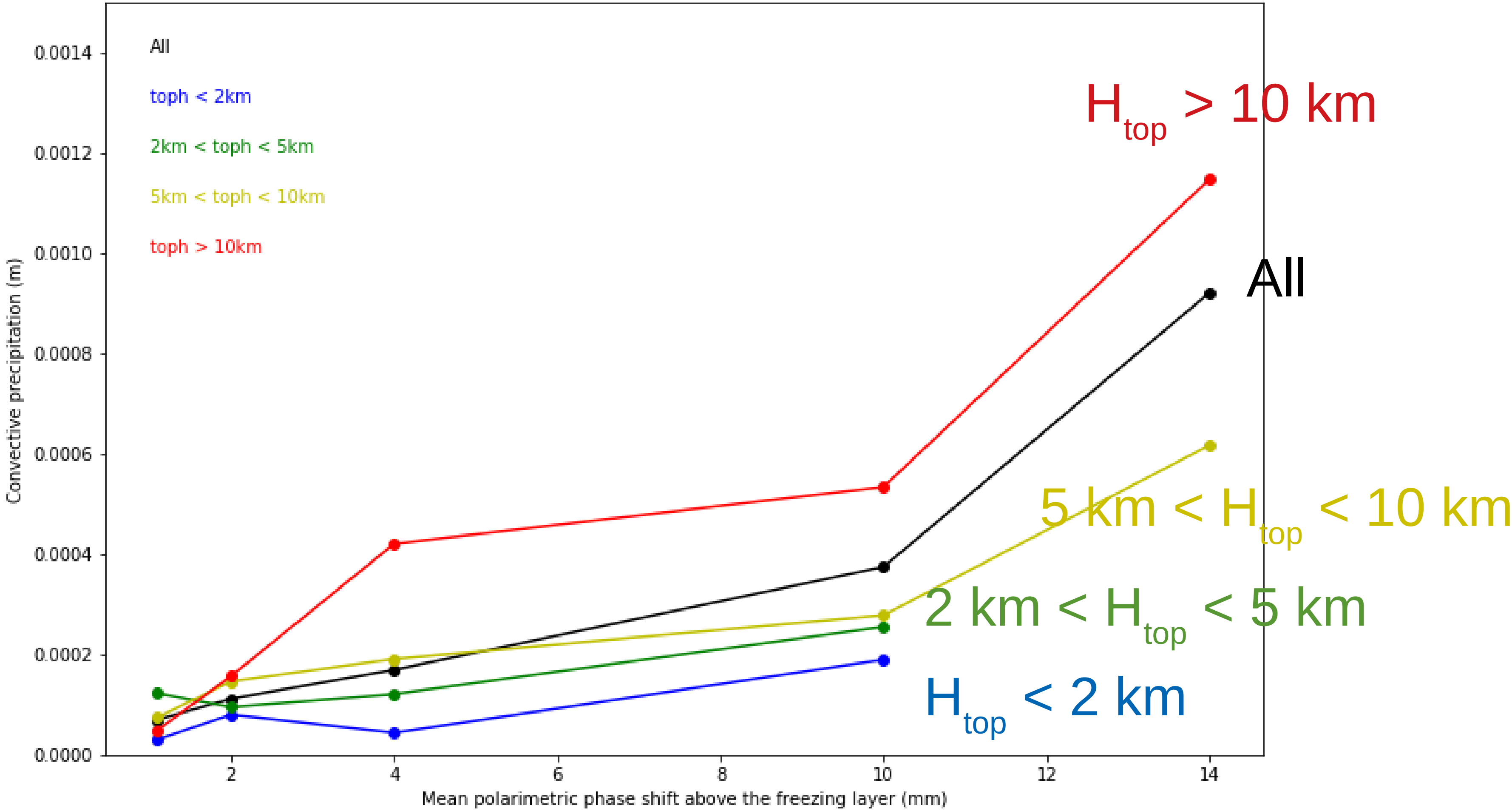
STUDIES: Other observables

- **Extraction of large scale precipitation information from intermediate observables?**



STUDIES: Other observables

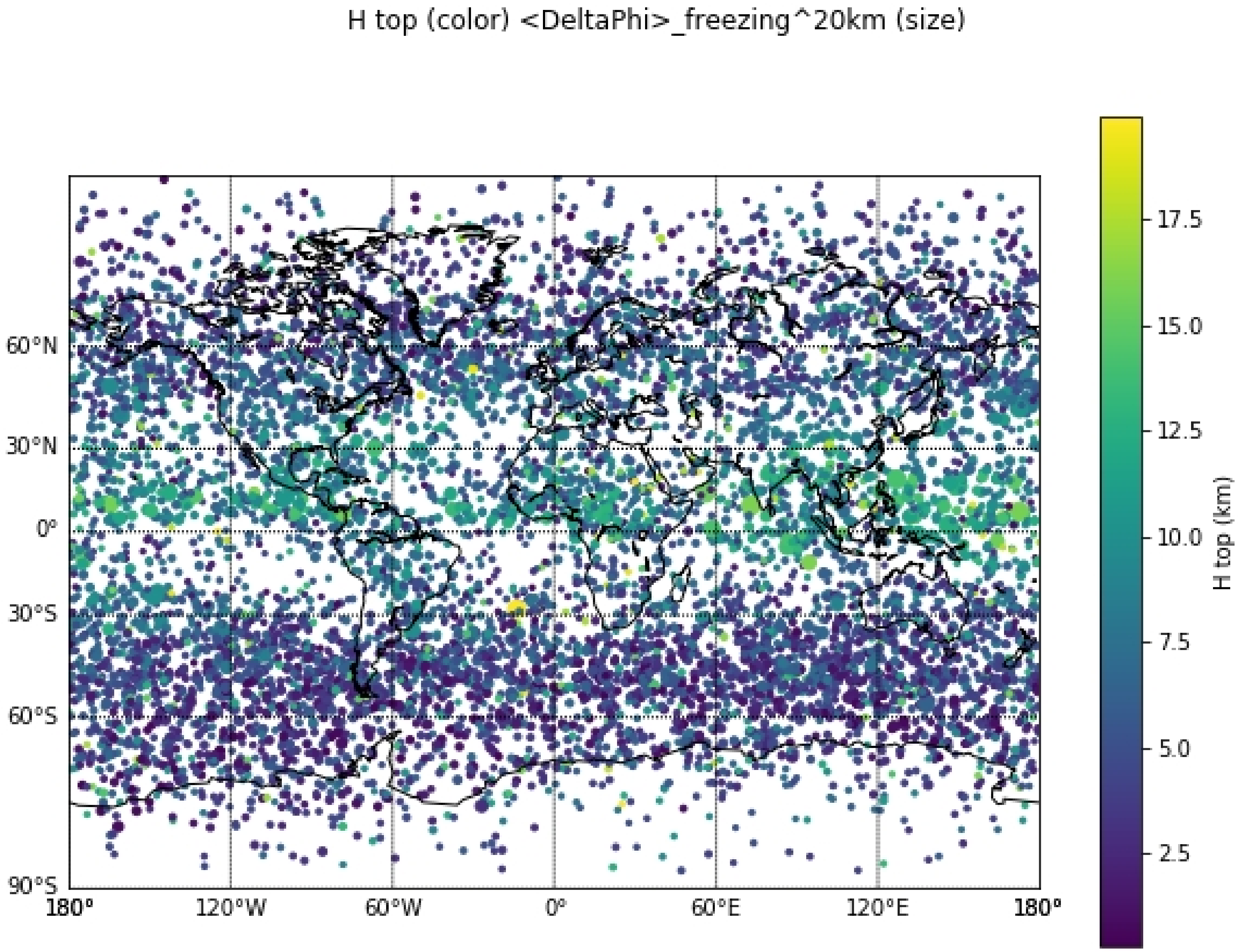
- **Convective precipitation from ERA-5:**



$\langle\Delta\phi\rangle^{20km}_{\text{freezing level}}$

4.5 months of PAZ data

STUDIES: Other observables



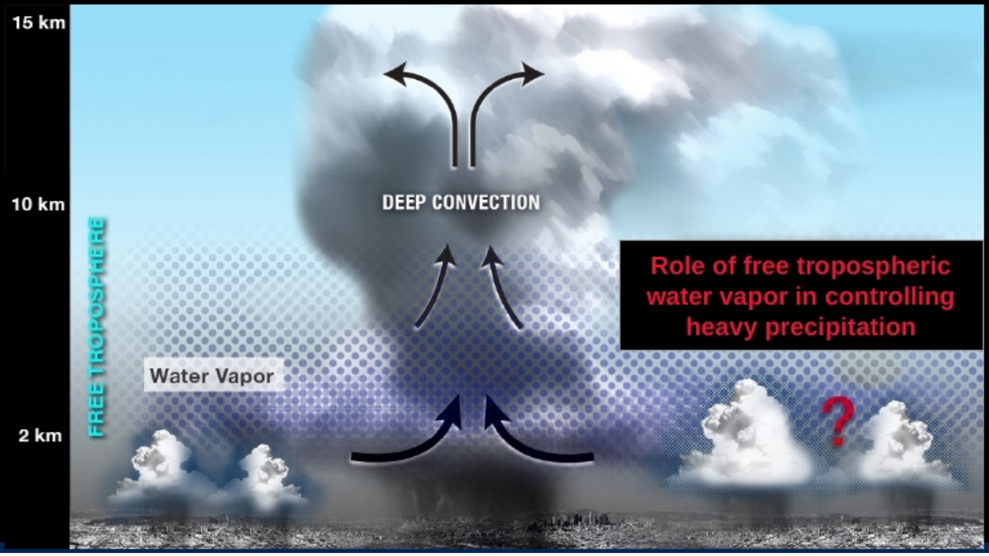
May 10 – Sep 30, 2018

Contents:

Padullés et al., AGU 2018:

Vertical Thermodynamic Structure of Precipitation

- Convection drives the most intense precipitation events
- There is a lack of observations in deep convection
- This results in uncertainties in modeling and predicting precipitation



- Increasing evidence points to control of convection by the free tropospheric water vapor

We need more globally distributed and vertically resolved observations

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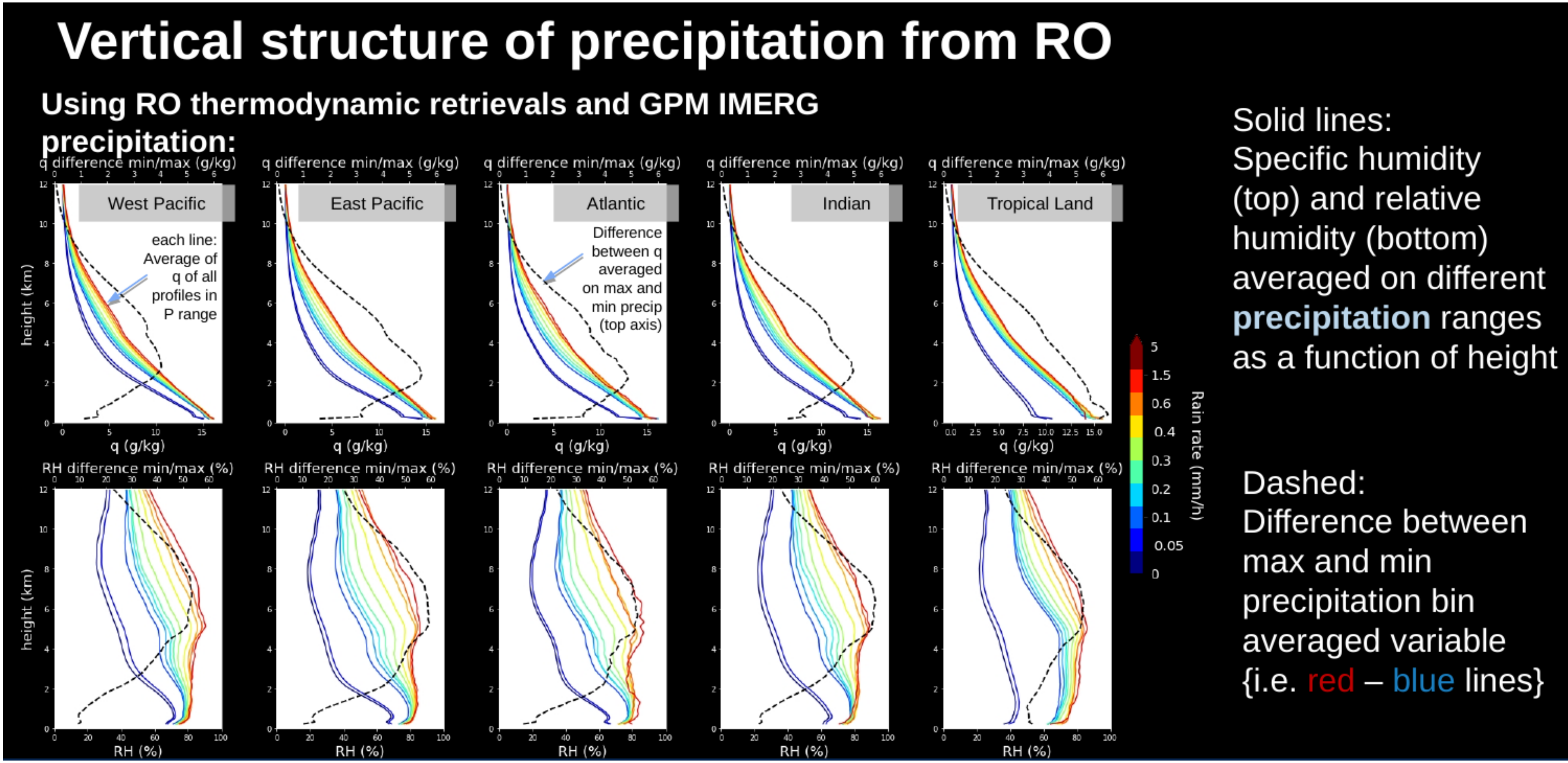
Padullés et al., AGU 2018:



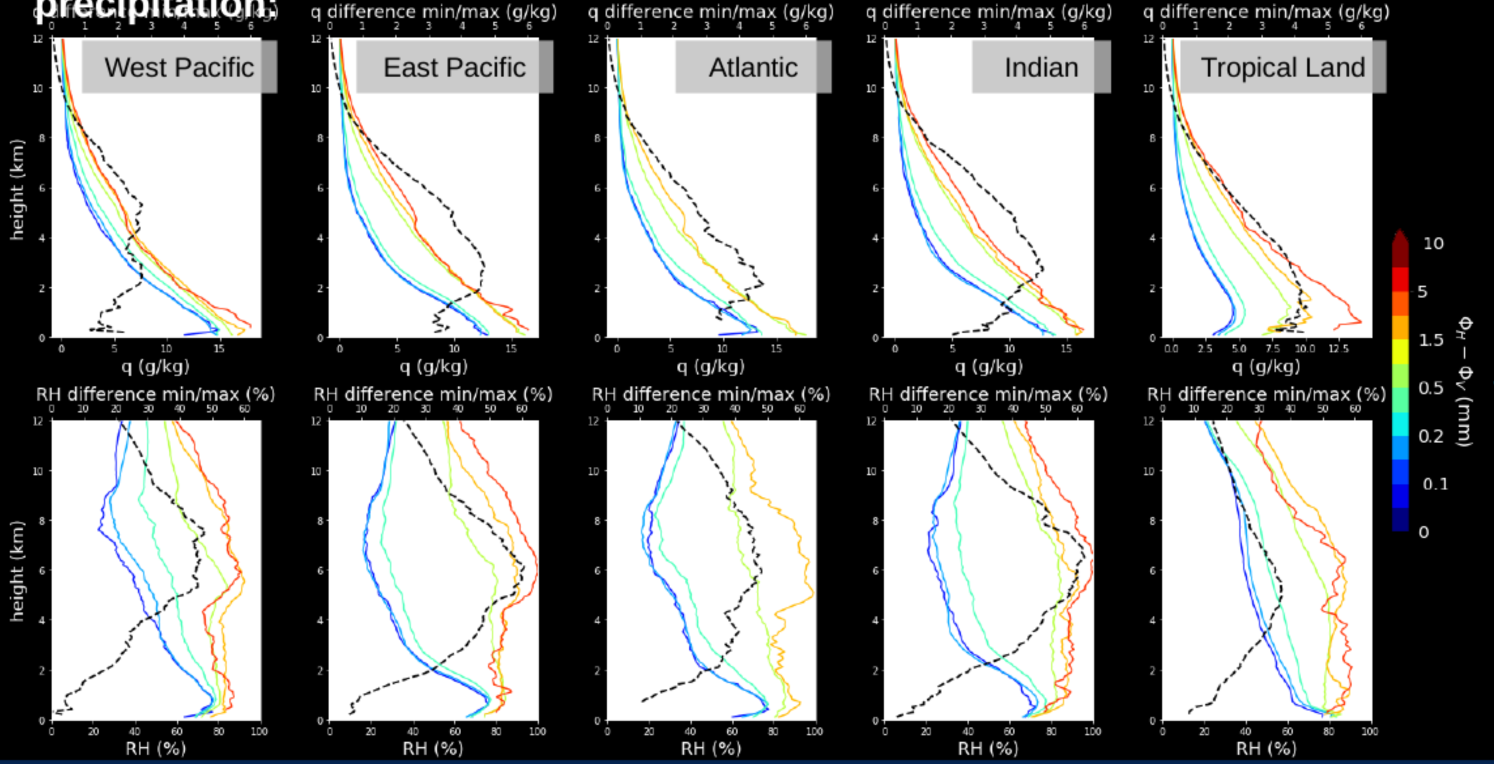
Co-location COSMIC – IMERG precipitation

Padullés et al., AGU 2018:

Vertical structure of precipitation using PRO

Using PRO thermodynamic retrievals and ⟨ $\phi_H - \phi_V$ ⟩ as a proxy for precipitation:

Preliminary results



⟨ $\phi_H - \phi_V$ ⟩ as a proxy for precipitation

PAZ data (no co-location)

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DATA STATUS

CONCLUSIONS

STUDIES: 2-pol bending angle

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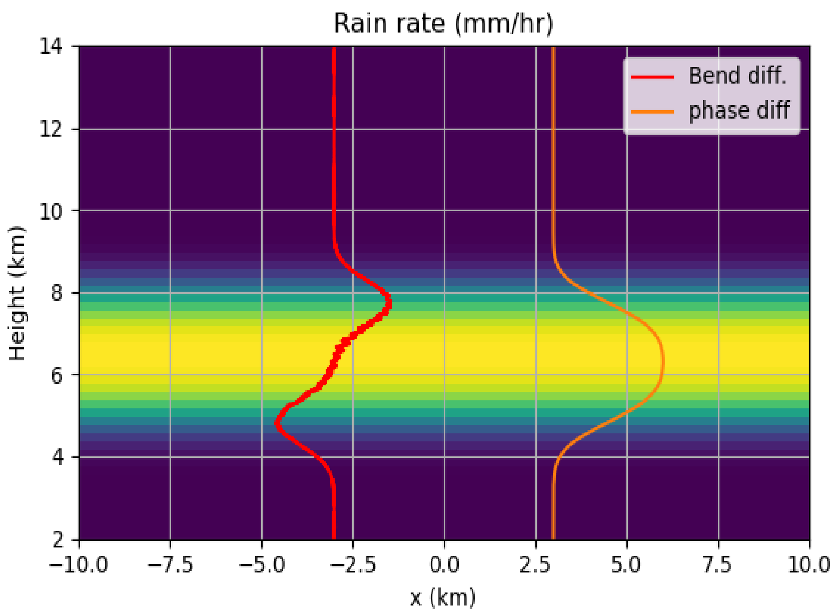
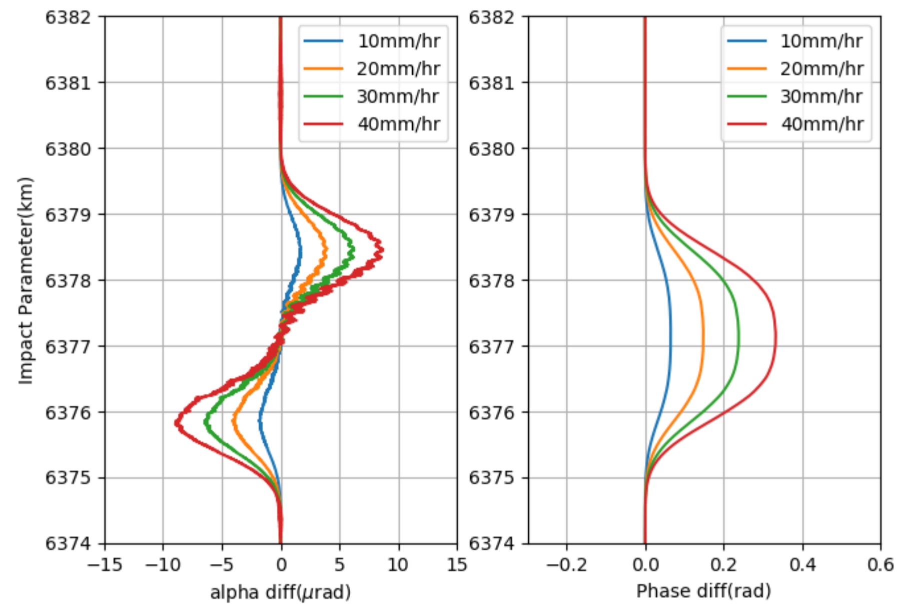
Is the differential polarimetric bending angle, $\alpha H - \alpha V$, sensitive to hydrometeors?

Wang et al., IROWG-ROMSAF 2019, poster P07





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THE ROHP-PAZ EXPERIMENT

POLARIMETRIC DATA PROCESSING

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5) **Reflectometry**

DATA STATUS

CONCLUSIONS

- As other RO missions, PAZ accidentally captures signals **reflected off the Earth** surface, too.
- Gorbunov et al., 2018 developed a 'reflection index' related to the **intensity of the reflected signal**.
- It is then possible to check the ratio between both polarizations of the reflected signal.

Is the ratio between the H-pol and V-pol components of the reflected signal providing information on the Earth surface?

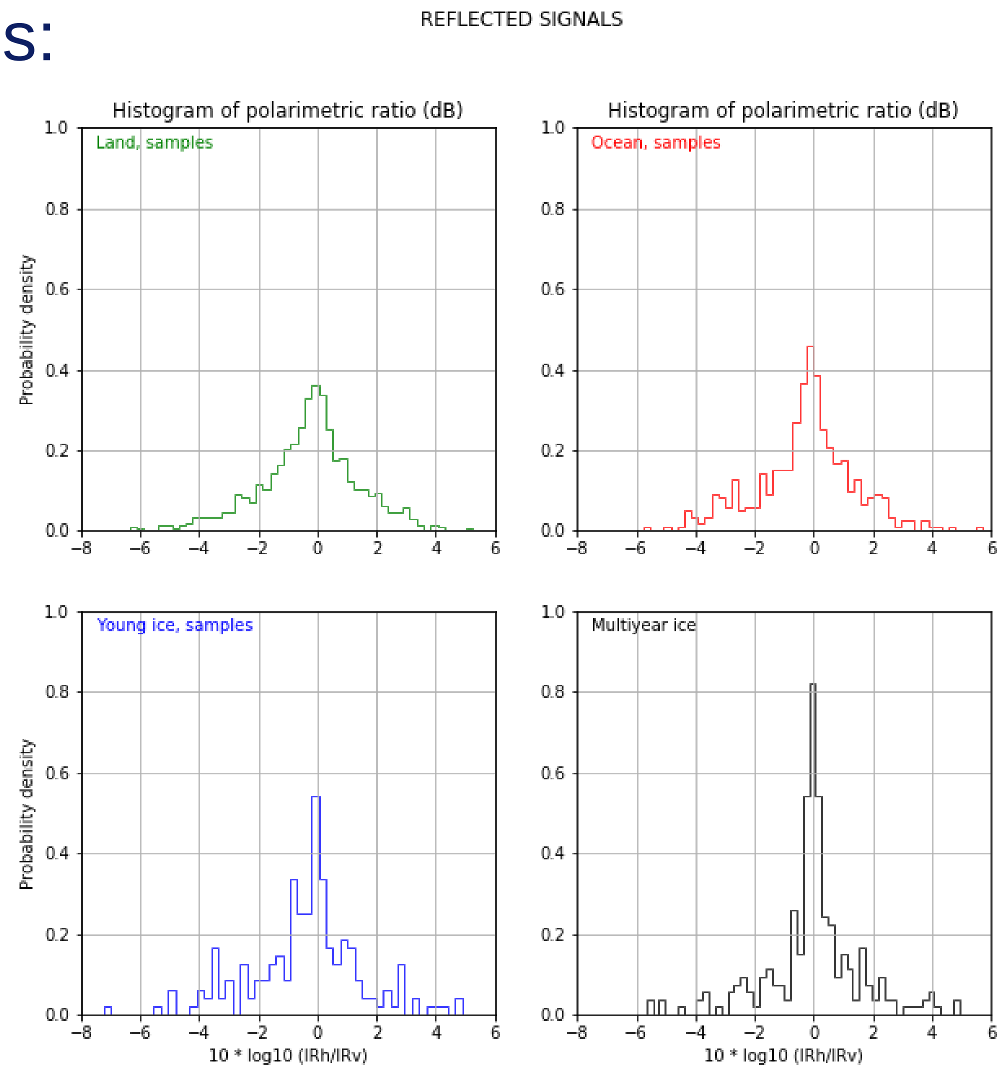
- Polarimetric ratio (in dB) of reflections off different surface types:

LAND (mostly polar)

OCEAN

YOUNG ICE

MULTIYEAR ICE

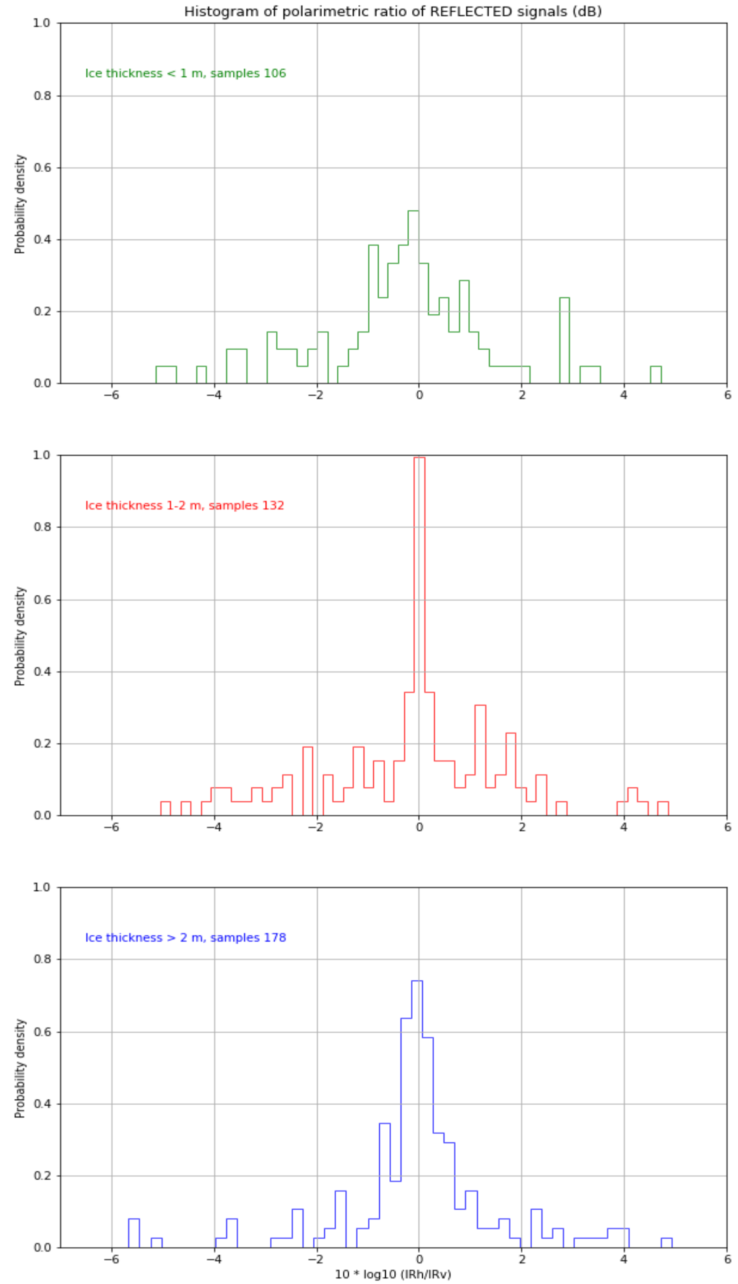


- Sea ice thickness:

Sea ice thickness < 1 m

Sea ice thickness: 1-2 m

Sea ice thickness > 2 m



Contents:

SCIENTIFIC INTEREST

THE POLARIMETRIC GNSS RO

THE ROHP-PAZ EXPERIMENT

POLARIMETRIC DATA PROCESSING

OVERVIEW OF STUDIES

DATA STATUS

CONCLUSIONS

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POLARIMETRIC SETS:

- **UCAR has released PAZ data at CDAAC** (including excess phase and SNR at both polarizations) → $\Delta\phi$ needs to be calibrated!
- IEEC plans to released calibrated $\Delta\phi$ and other derived products soon.
- JPL plans to begin releasing the PAZ data ~ November, including calibrated polarimetric $\Delta\phi$ products (Level 1b).

'USUAL' RO SETS:

- **UCAR has released PAZ data at CDAAC** (including NRT). See Doug's presentation later.
- NOAA ground segment and UCAR processing chain are opering **in NRT.** See François' presentation on Tuesday.
- NOAA working for a second ground station (Finland).
- PAZ data disseminated in **NRT through USA PDA** system.
- NRL assimilates PAZ data into NAVGEM operationally. See Ben's presentation tomorrow.
- **GTS dissemination** only requires a 'quick checkout' by NOAA (any time now?).

Contents:

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 **mixed phase/cloud ice**.
- Use of other derived-observables (top height, signal above freezing level, …) → **potential for convection products**.
- Use of PAZ $\Delta\phi$ and PAZ RO moisture profiles → Direct use of PAZ data for **better understanding of deep convection system**?
- **Polarimetric bending space** also sensitive to precipitation.
- Polarimetric **reflected** signals (?)
- DATA ALREADY PUBLICLY AVAILABLE, AND SOON DISSEMINATED IN NRT.

Conclusions:

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- PAZ carries a polarimetric RO payload, to prove the … S-PRO concept.
- New measurement concept: thermodynami…
- Launched: **Feb 22, 2018**. RO activat…
- **Polarimetric phase shift lin…** …or more intense rain.
- **Vertical featur… storms at r…**
- Stro…
- … above freezing … ts.
- U… profiles → Direct use of PAZ da… **deep convection system**?
- **Pol… ce** also sensitive to precipitation.
- Pola… **ed** signals (?)
- DATA … READY PUBLICLY AVAILABLE, AND SOON DISSEMINATED IN NRT.

- Retrieval algorithm not ready yet.
- A lot of potential studies to conduct.
- Possibilities also at high altitudes (ionospheric information?)
- A lot of data and ideas, but a little team to work on it.
- The more scientists look at the data, the quicker and better outcome.

rohp-PAZ

More info and data access:
https://paz.ice.csic.es