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EXCELENCIA MARÍA DE MAEZTU

# Advances in Remote Sensing Using the Polarimetric RO Technique

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# Advances in Remote Sensing Using the Polarimetric RO Technique



- **The Polarimetric RO technique**
  - Basics
  - Processing, production and products
- **Status: what do we know?**
- **Current work on forward operator**

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**Next talk by Estel Cardellach:**

**Roadmap towards full exploitation of PRO observations**

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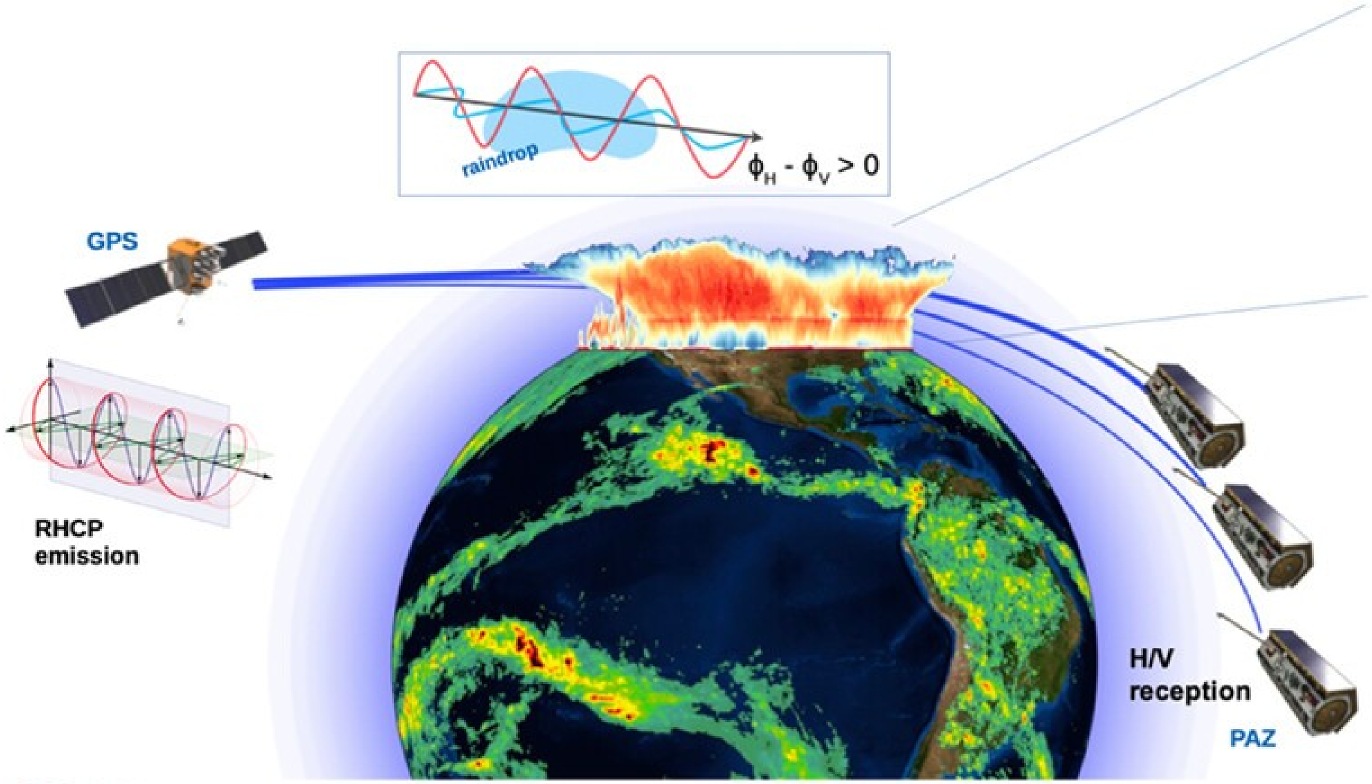
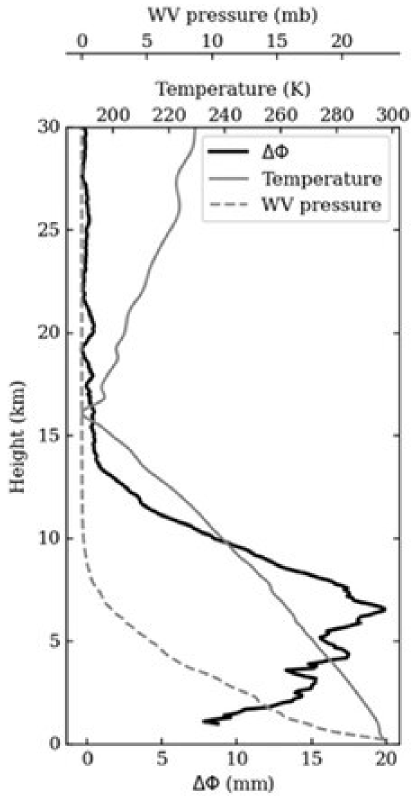
# Polarimetric RO Technique



- To collect the RO rays 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

$\phi$: excess phase




Simultaneous retrieval of vertical profiles of thermodynamics (standard products) and differential phase shift (Δϕ, polarimetric products)

# Polarimetric RO Technique

**ROHP-PAZ experiment:** proof of concept experiment aboard PAZ satellite (launched in 2018)


- 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 standard RO profiles be recovered from GNSS PRO data?

# Polarimetric RO Technique



**ROHP-PAZ experiment:** proof of concept experiment aboard PAZ satellite (launched in 2018)


Soon after the launch

- ✓ Is it technologically possible to measure the polarimetric RO?
- ✓ Are the GNSS PRO signatures sufficiently large to be measured?
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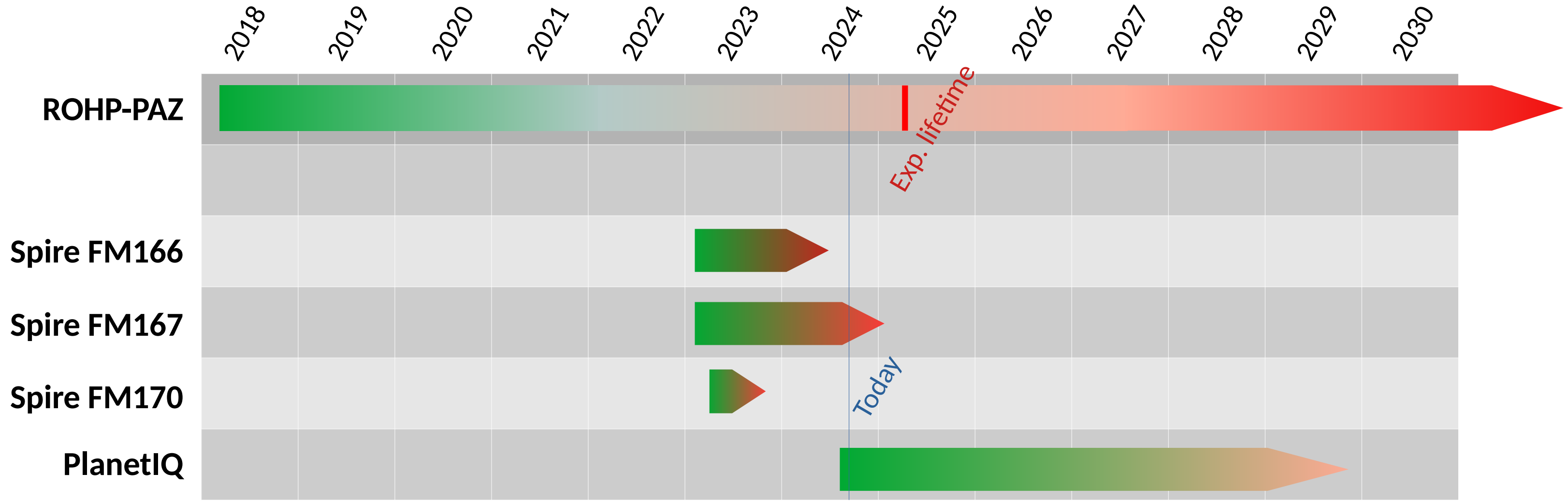
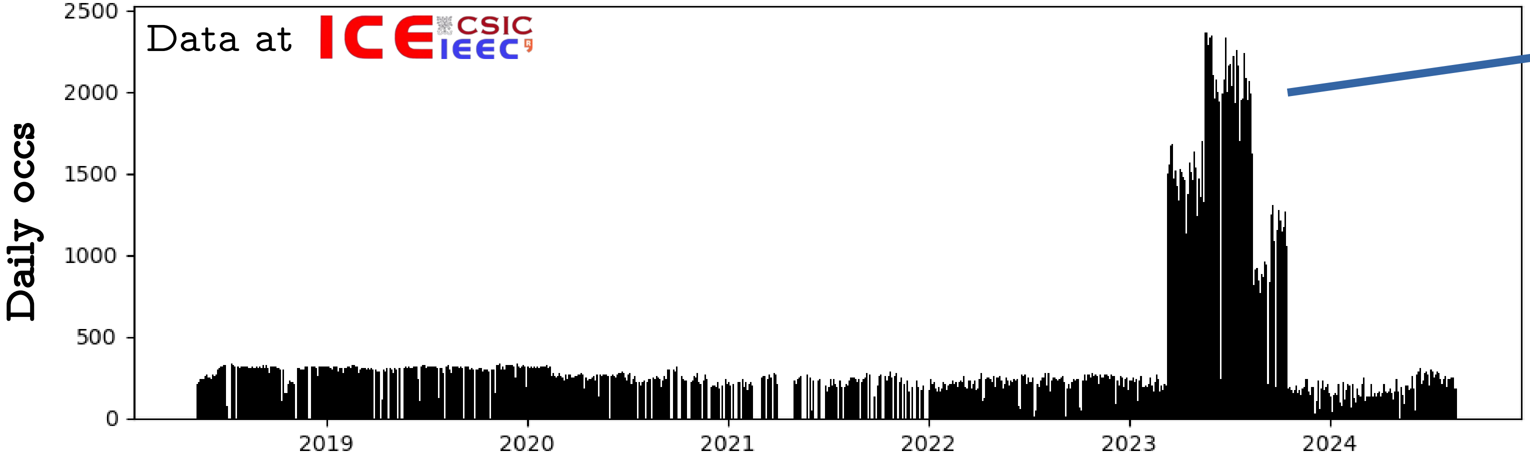
# Polarimetric RO Technique






Spire data
(available to European researchers
through ESA third party mission (TPM))
(May – Nov 2023)

**PAZ : ~200 occs/day**
**PAZ + 3 Spire nano-sats : ~2400 occs/day**

# Polarimetric RO Technique

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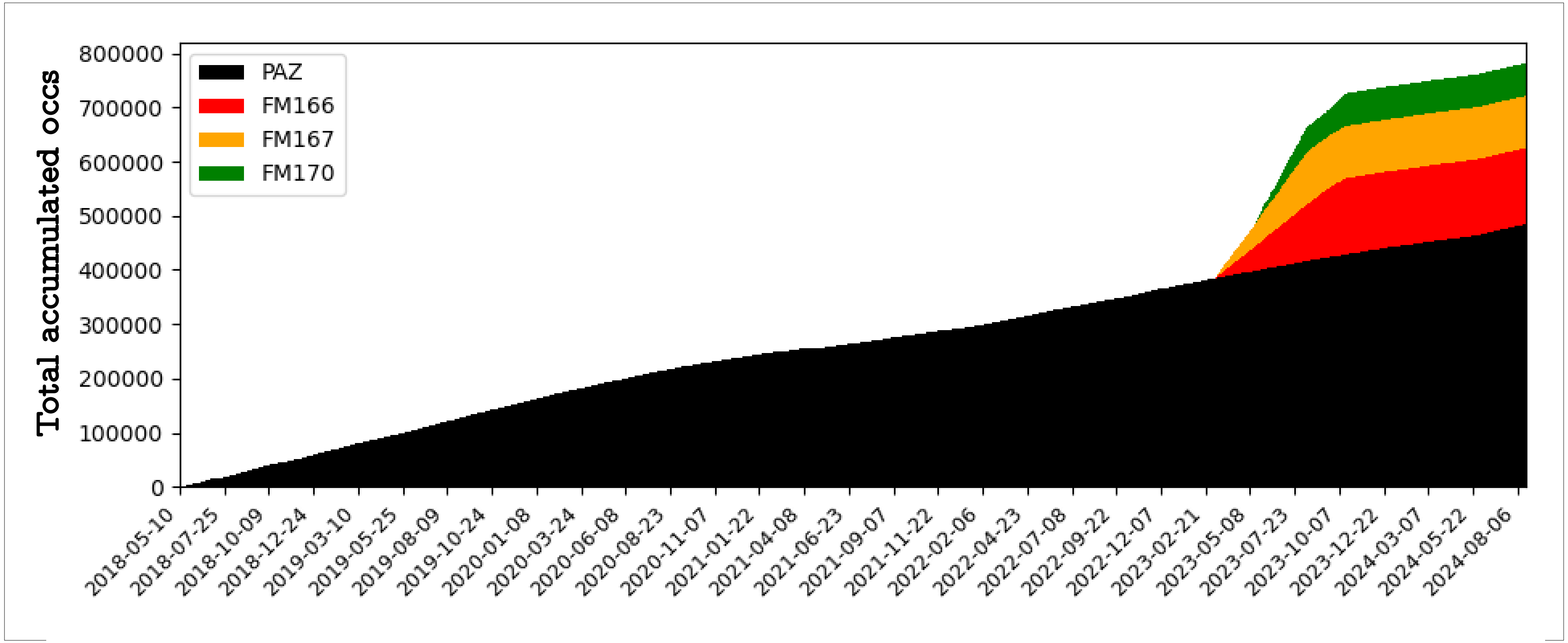


Spire
>300.000 occs

ROHP-PAZ
~500.000 occs

>800.000
pro obs

# ROHP-PAZ data flow

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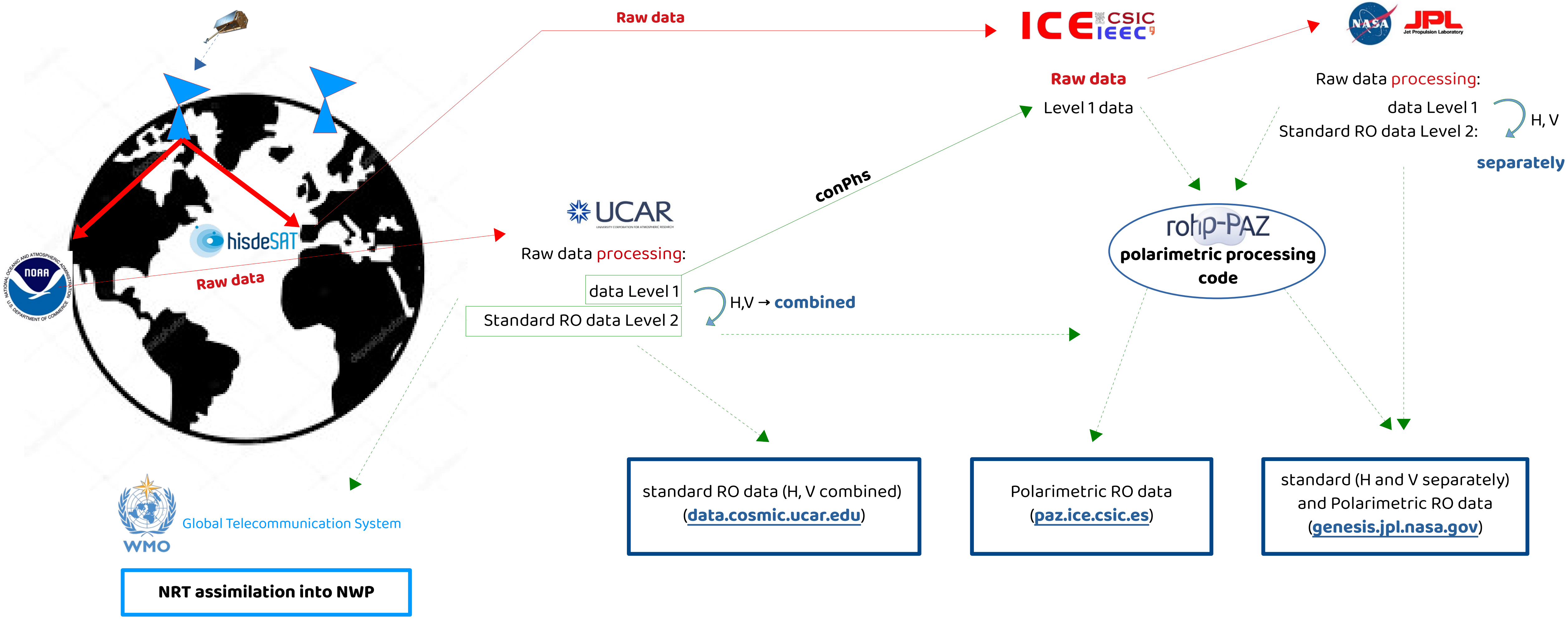

# Polarimetric RO processing ICE-CSIC

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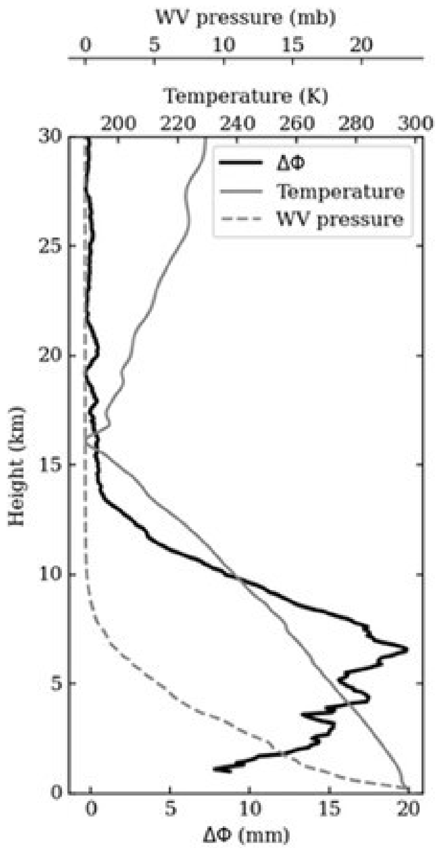
Filetype: resPrf
Processing version: V07
Available at *paz.ice.csic.es*.
DOI: https://doi.org/10.20350/digitalCSIC/16137

```
resPrf_PAZ1.YYYY.DOY.HH.MM.GXX_proc.vers_V07 {
	group: profiles
		variables: height, dphi, temp, pres, vp, ref
	group: rays
		variables: lat, lon, hei
	group: coll
		group: precipitation
			variables: precipitation
		group: irtb
			variables: irtemp
		group: GPM radiometer
			group Swaths
				variables: channels
```

temp, pres, vp, ref: wetPf2 UCAR

## Collocated vertical profiles of $\triangle\phi$ and thermodynamics



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            variables: irtemp
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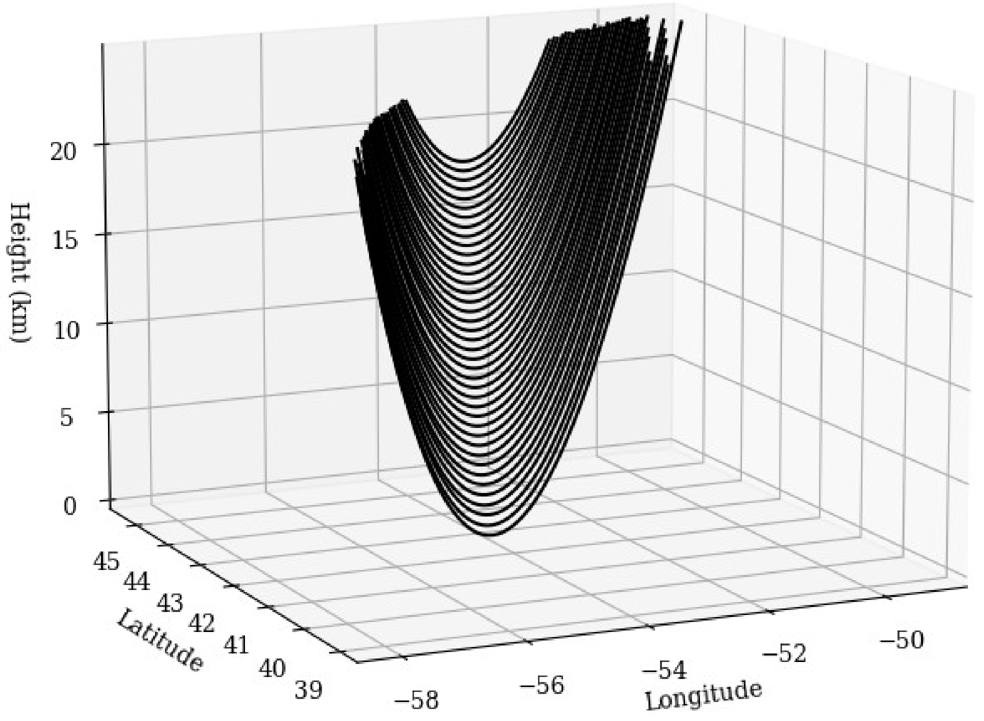
                variables: channels
```

**Ray trajectories obtained using ray-tracing technique**



# Polarimetric RO processing ICE-CSIC

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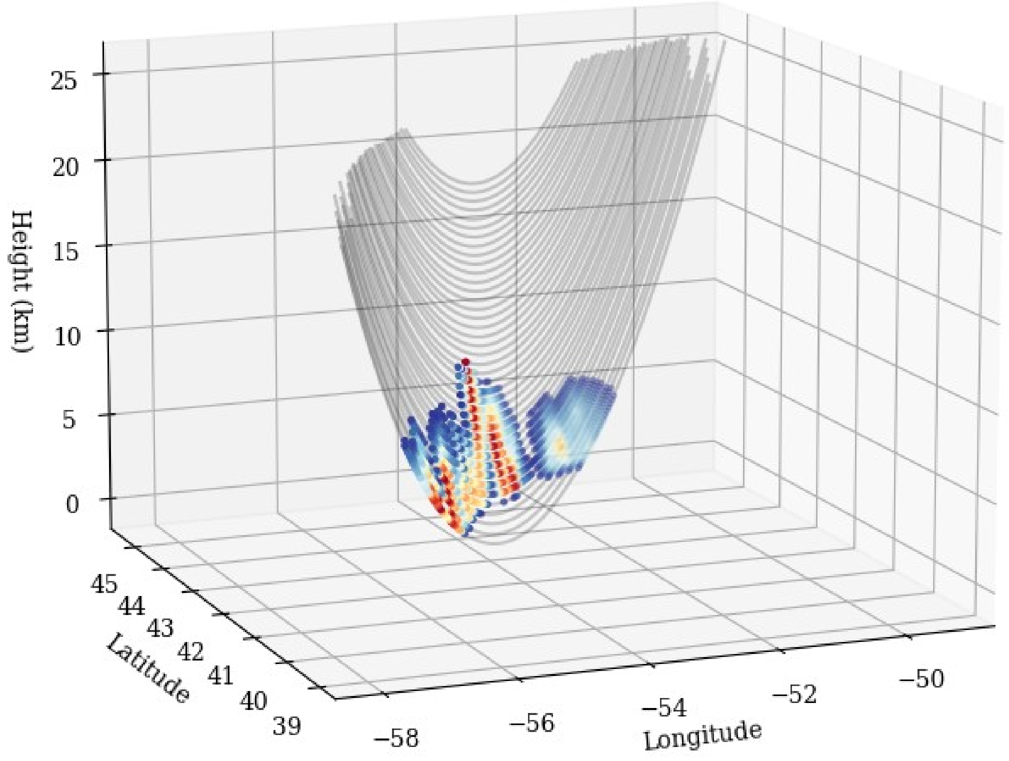
  - group: irtb
    - variables: irtemp
  - group: GPM radiometer
    - group Swaths
      - variables: channels

## Ray trajectories obtained using ray-tracing technique




Interpolation of 3D model fields

# Polarimetric RO processing ICE-CSIC

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    group: coll
        group: precipitation
            variables: precipitation
        group: irtb
            variables: irtemp
        group: GPM radiometer
            group Swaths
                variables: channels
```
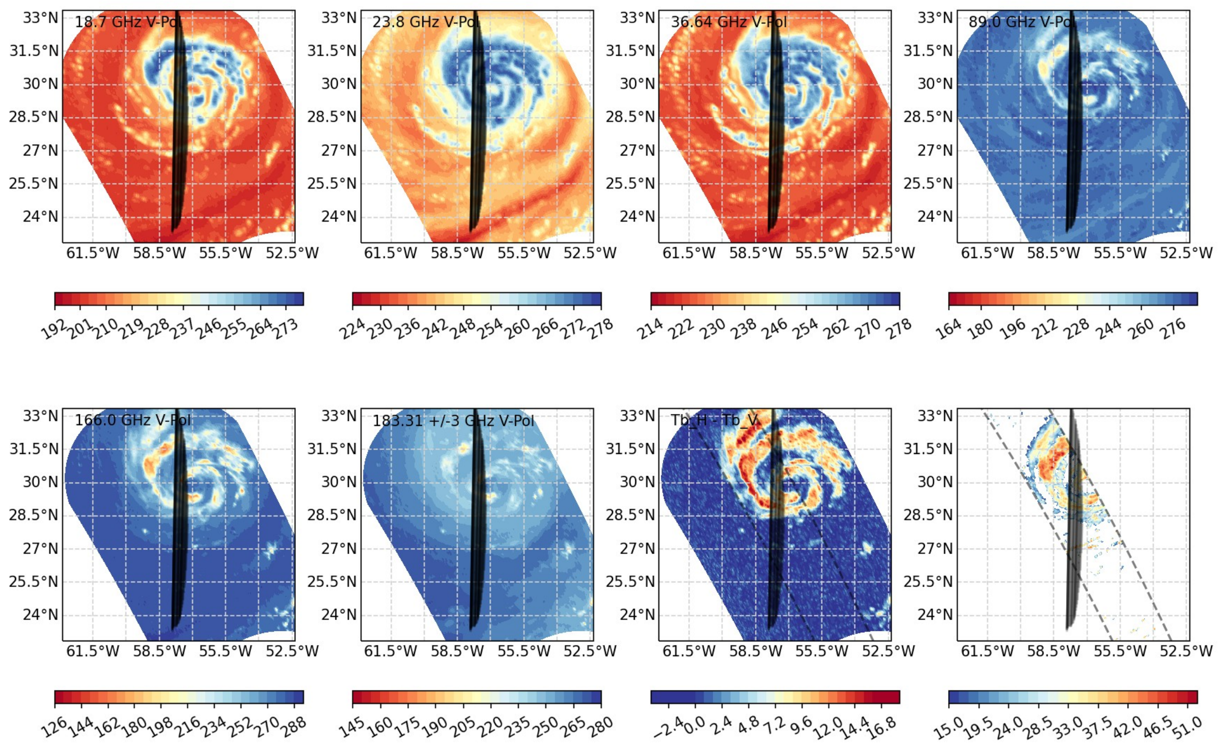

**Context!**



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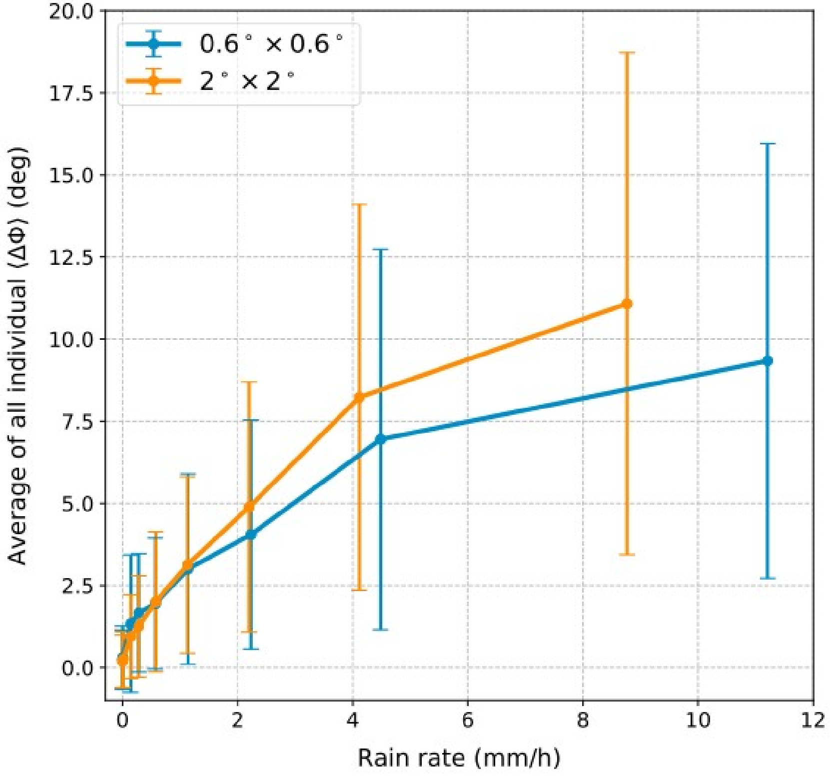
- **Status: what do we know?**
- Current work on forward operator

# Status: what do we know?



PRO is sensitive to precipitation, both presence and intensity

**PAZ Δϕ increases with increasing R**




*Cardellach et al. 2019, GRL, https://doi.org/10.1029/2018GL080412*

# Status: what do we know?

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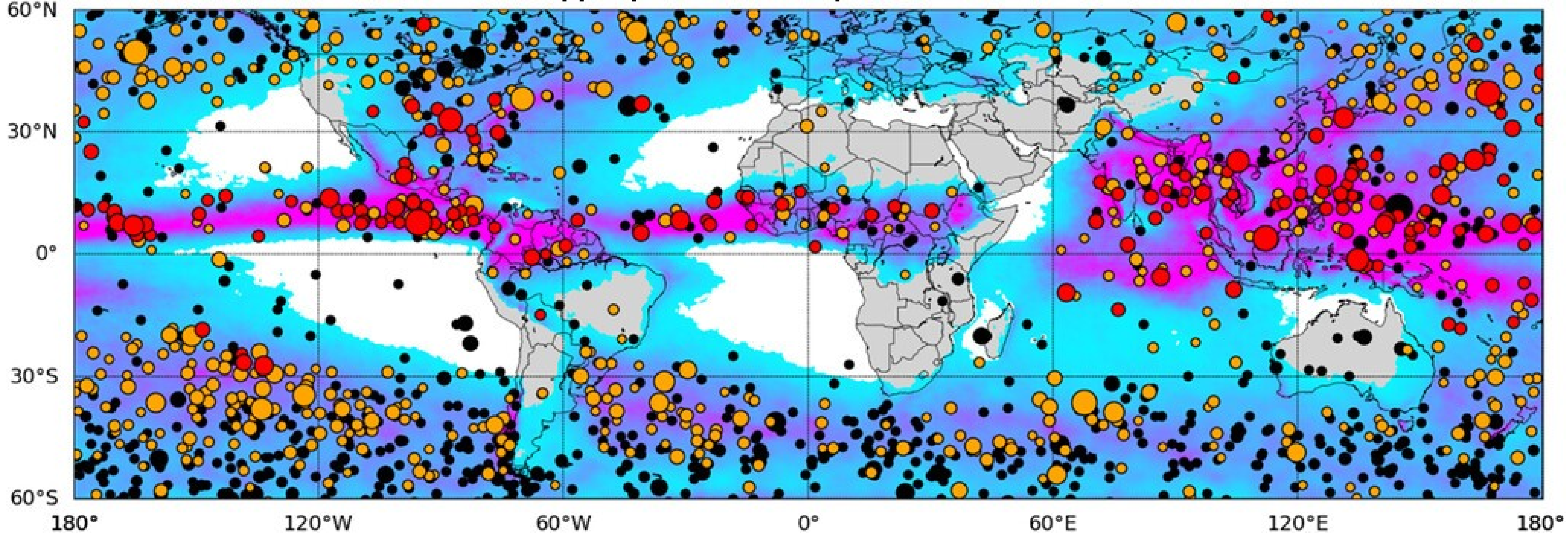
PRO captures **precipitation** patterns very well

**Upper percentile of Δϕ measurements**




$\langle\Delta\phi\rangle_{0\text{-}5km}$ $\langle\Delta\phi\rangle_{5\text{-}10km}$ $\langle\Delta\phi\rangle_{10\text{-}15km}$ **IMERG surface precipitation**

*Turk et al. 2024, BAMS, https://doi.org/10.1175/BAMS-D-24-0050.1*

# Status: what do we know?

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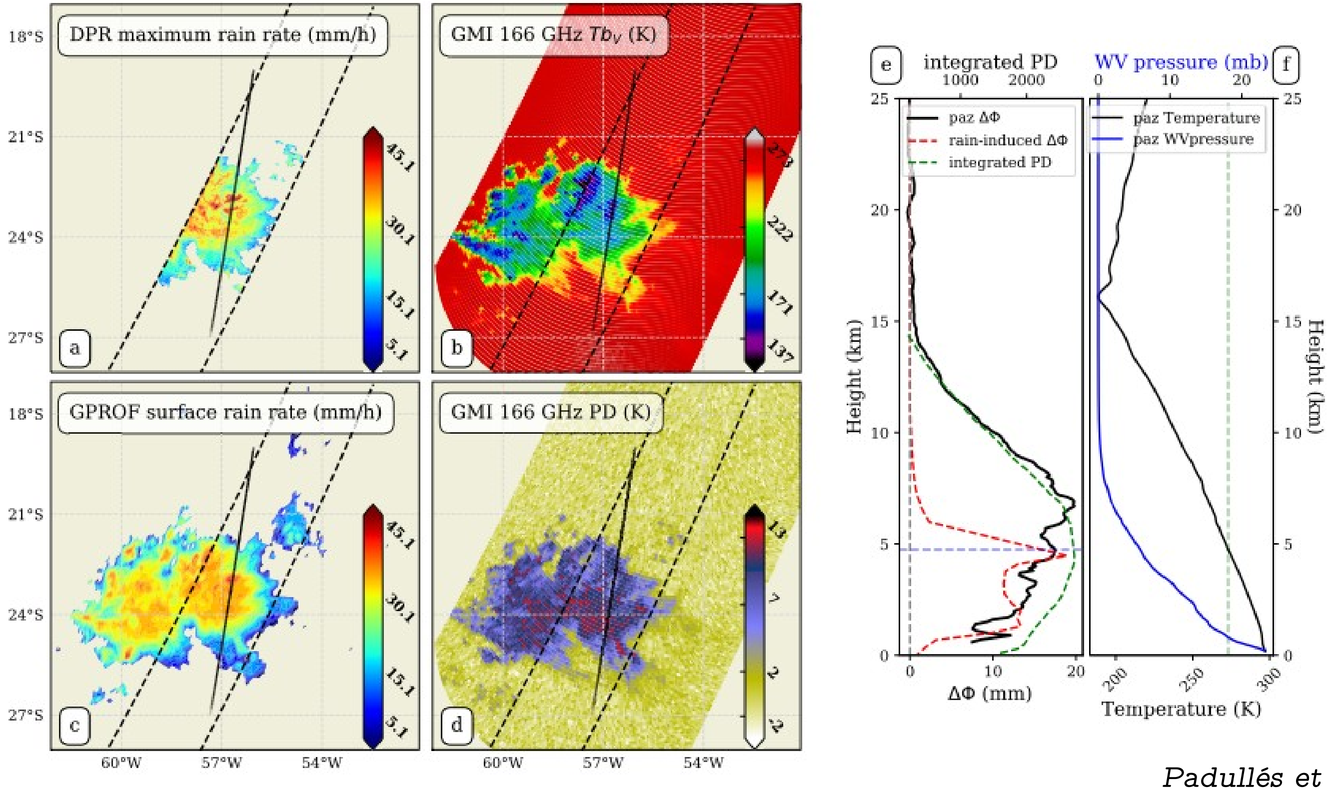
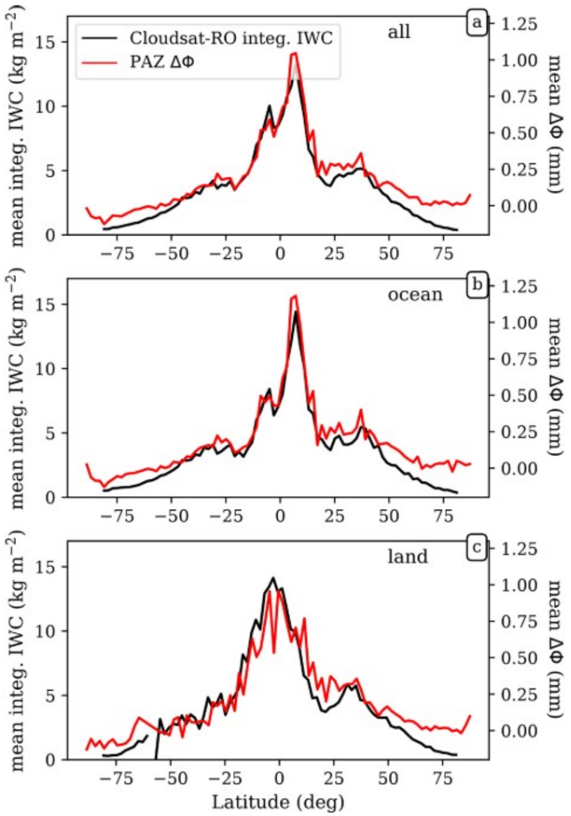
PRO is sensitive to **frozen hydrometeors** above freezing level

**Coincidences with K-band radar cannot explain Δϕ measurements. Agreement is possible when we include ice/snow information**




**Agreement between Cloudsat IWC climatology and PAZ**

**@ 7km**




*Padullés et al. 2021, IEEE-TGRS, https://doi.org/10.1109/TGRS.2021.3065119*

*Padullés et al. 2023, ACP, https://doi.org/10.5194/acp-23-2199-2023*

# Status: what do we know?

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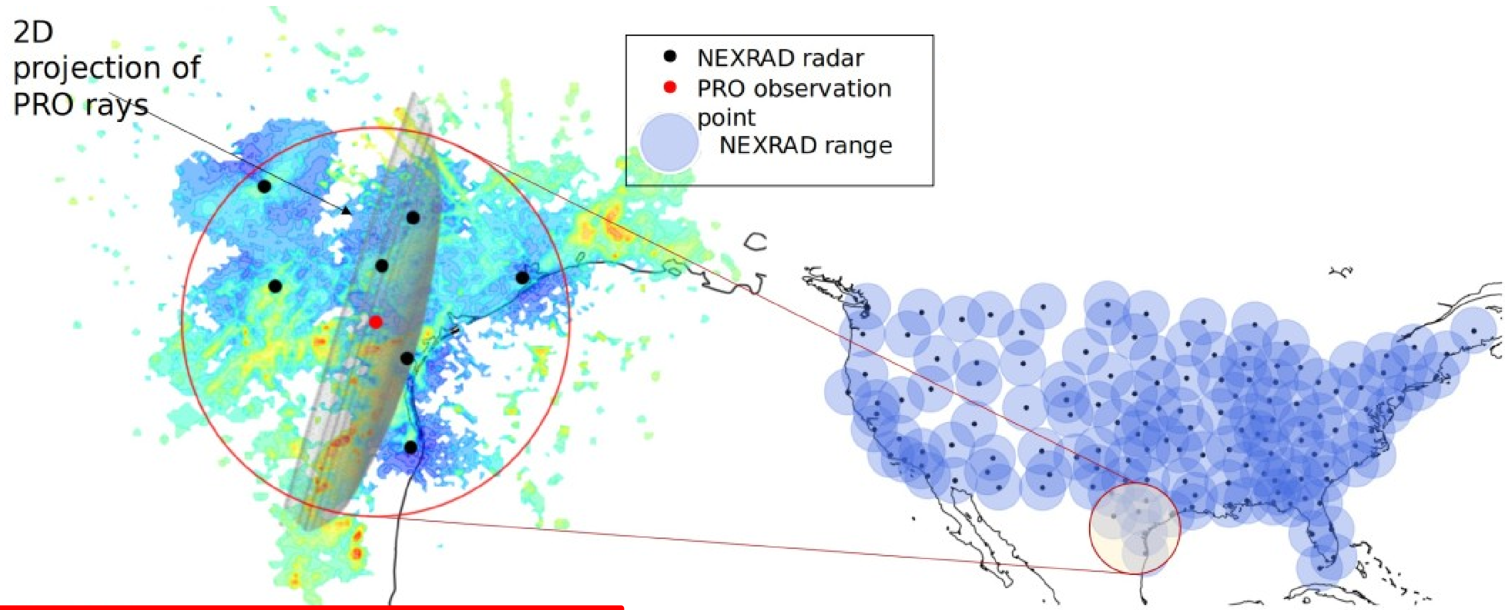
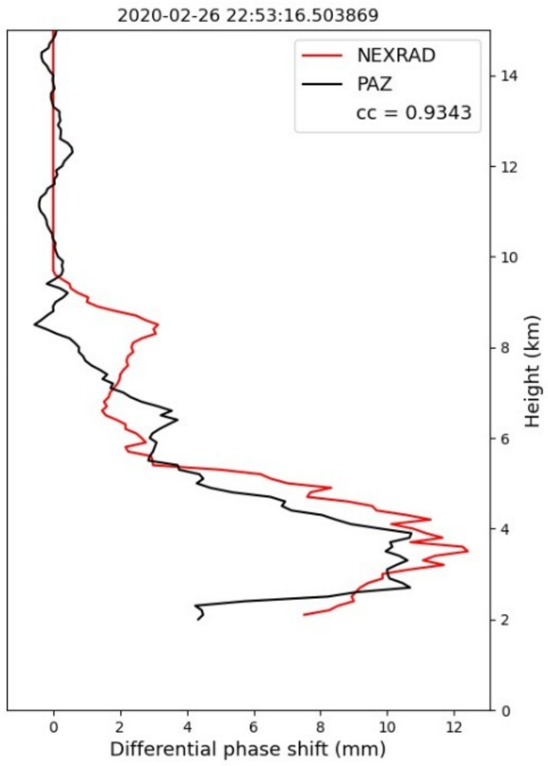
Validation of **PRO vertical structure** using NEXRAD polarimetric radars

**Agreement between vertical profiles of Δϕ obtained with PAZ and Δϕ recreated from $K_{dp}$ measurements from NEXRAD polarimetric radars**




*Poster by **Antía Paz**, #20-A:*
*Validation and sensitivity analysis of the Polarimetric Radio Occultation technique*

*Paz et al. 2024, Remote Sensing, https://doi.org/10.3390/rs16071118*

# Status: what do we know?

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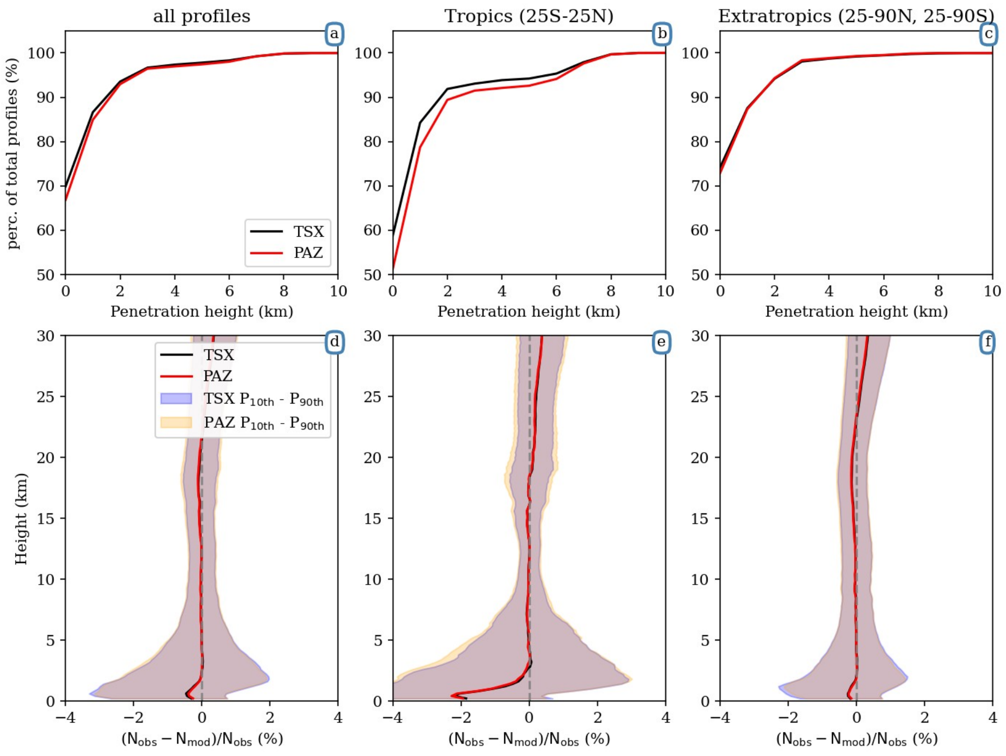
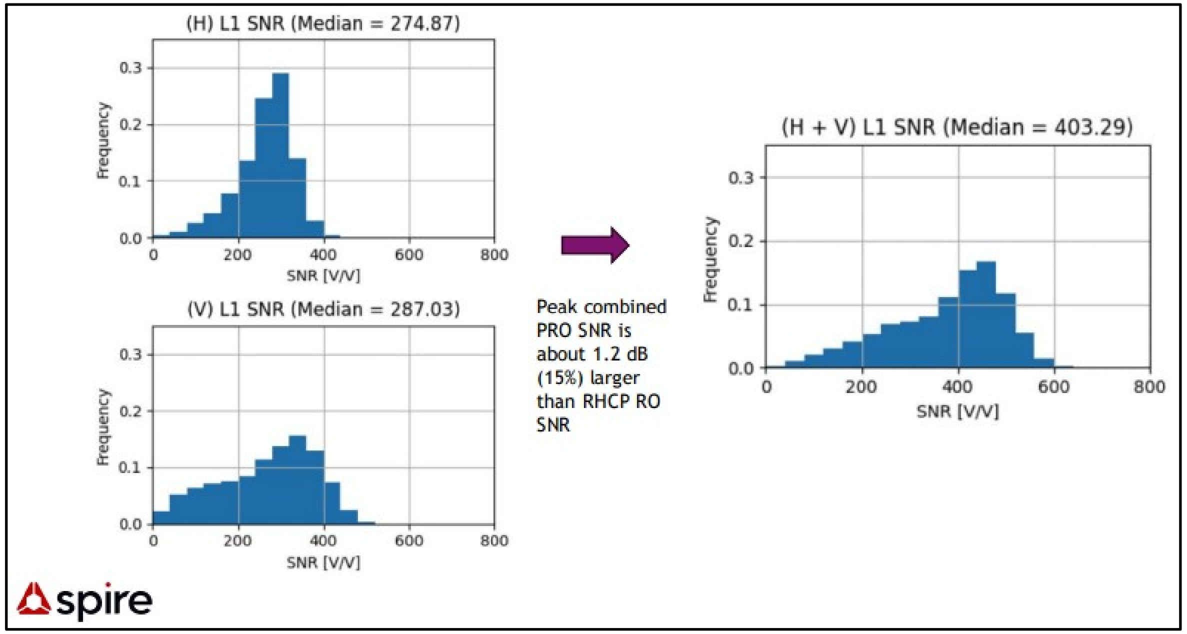
Standard RO products from PRO antennae are of **equivalent quality**

**Comparison with ECMWF of refractivity profiles obtained with PAZ and those from TSX for the same time period**




**Combined H + V SNR from Spire's PRO antenna is larger than Spire's RO RHCP antenna SNR**




*Nguyen, V., et al. 2023, 2nd PAZ Polarimetric Radio Occultations User Workshop*

*Padullés et al. 2024, ESSD, https://doi.org/10.5194/essd-2024-150*

# Status: what do we know?

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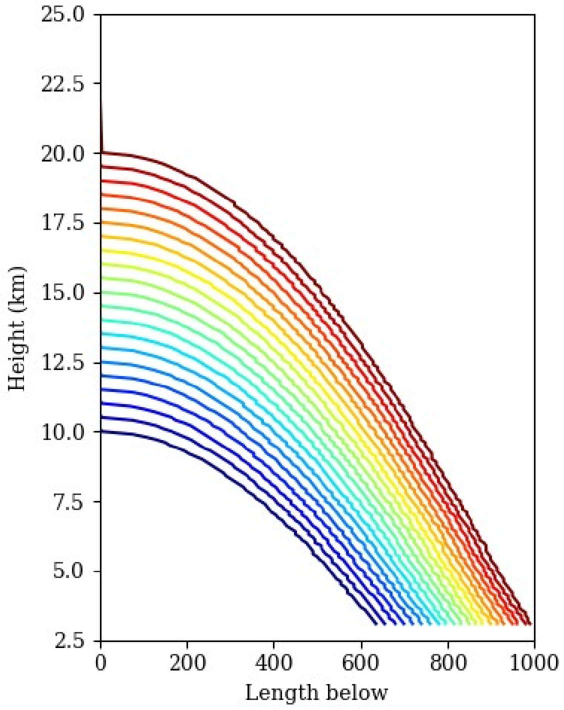
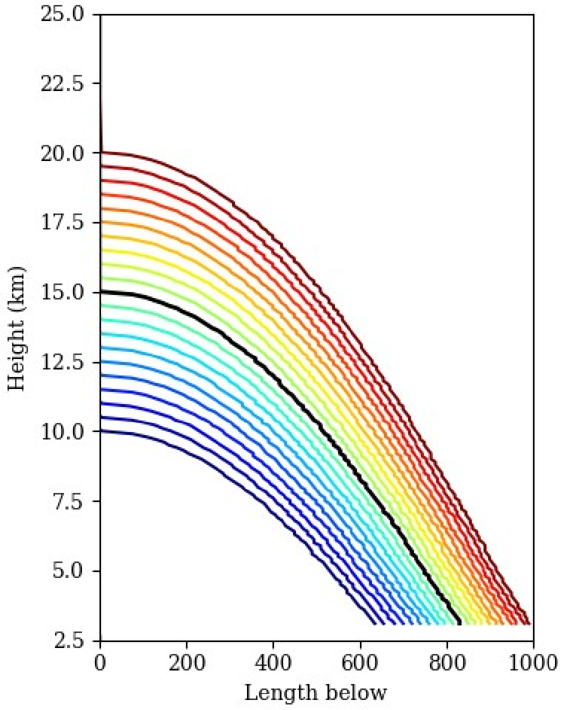
PRO Δϕ products have large along-track **horizontal resolution**

**Everything present along the ray-path contributes equally to Δϕ**




Assuming a height at which clouds may be present, we can compute the theoretical (maximum) horizontal resolution

If we can know the cloud top height (using Δϕ or external information), we can reduce the maximum horizontal resolution




*Padullés et al. 2024, ESSD, https://doi.org/10.5194/essd-2024-150*

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- Status: what do we know?
- **Current work on forward operator**

# Forward operator



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

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

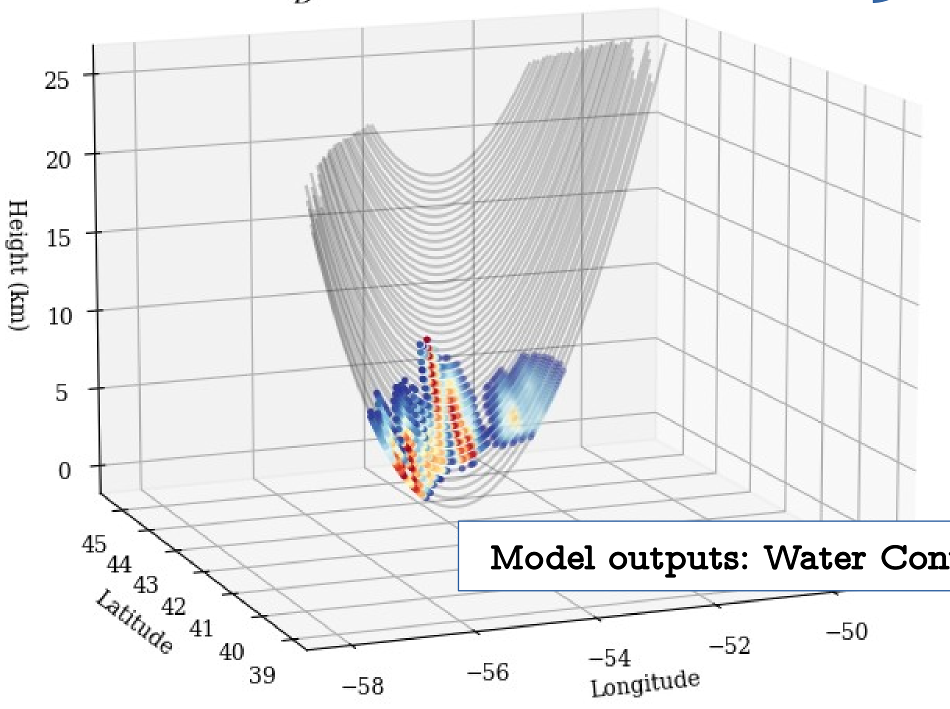
$$\mathrm{WC} = \frac{\pi}{6}\rho_{\mathrm{w,i}}\int_D D^3 N(D)\mathrm{d}D$$

**Simplified approximation:** $K_{dp} = \frac{1}{2}\, C\, \rho\, (1\text{-}ar)\, WC$

*(e.g. Padullés et al. 2021, IEEE-TGRS*
*Hotta et al. 2024, AMT)*

*Study that uses this approximation*

*Poster by* ***Shu-Ya Chen**, #18-B:*
*Comparison of WRF simulations and Polarimetric RO Data for Hydrometeors around Tropical Cyclones*




Model outputs: Water Content fields

*Padullés et al. 2021, IEEE-TGRS, https://doi.org/10.1109/TGRS.2021.3065119*
*Hotta et al. 2024, AMT, https://doi.org/10.5194/amt-17-1075-2024*

# Forward operator



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

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

$$\mathrm{WC} = \frac{\pi}{6}\rho_{\mathrm{w,i}}\int_D D^3 N(D)\mathrm{d}D$$

**Simplified approximation:** $K_{dp} = ½\ C\ \rho\ (1\text{-}ar)\ WC$

*(e.g. Padullés et al. 2021, IEEE-TGRS*

*Hotta et al. 2024, AMT)*

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

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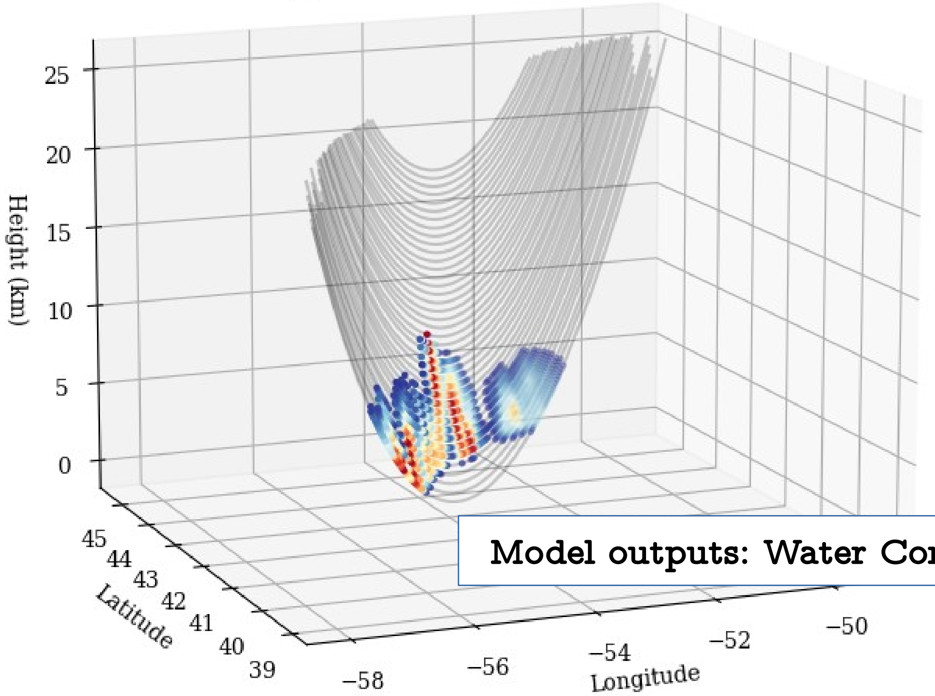
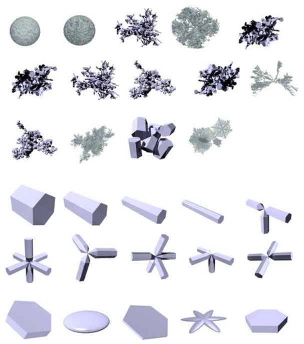



Model outputs: Water Content fields

Discrete Dipole Approximation Forward scattering

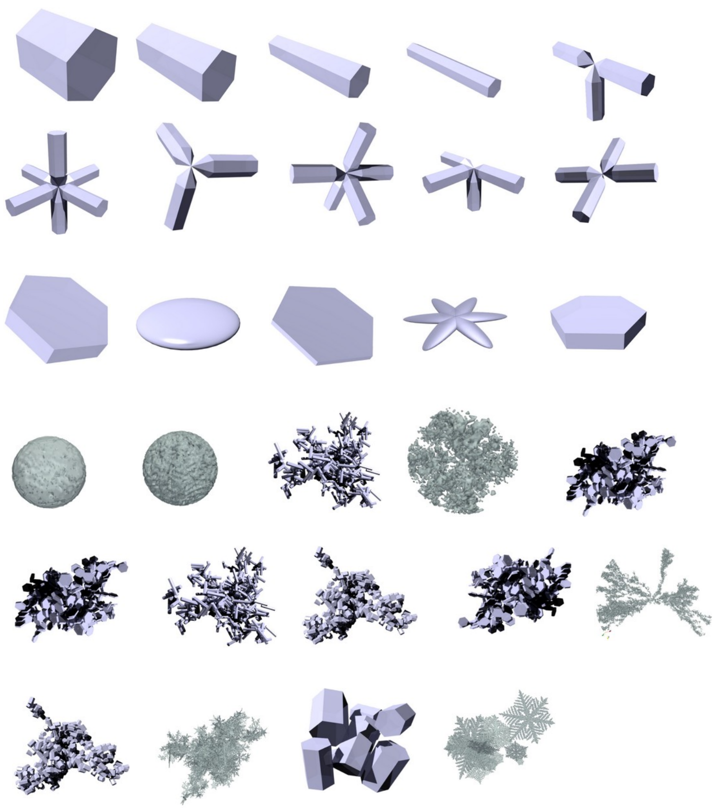


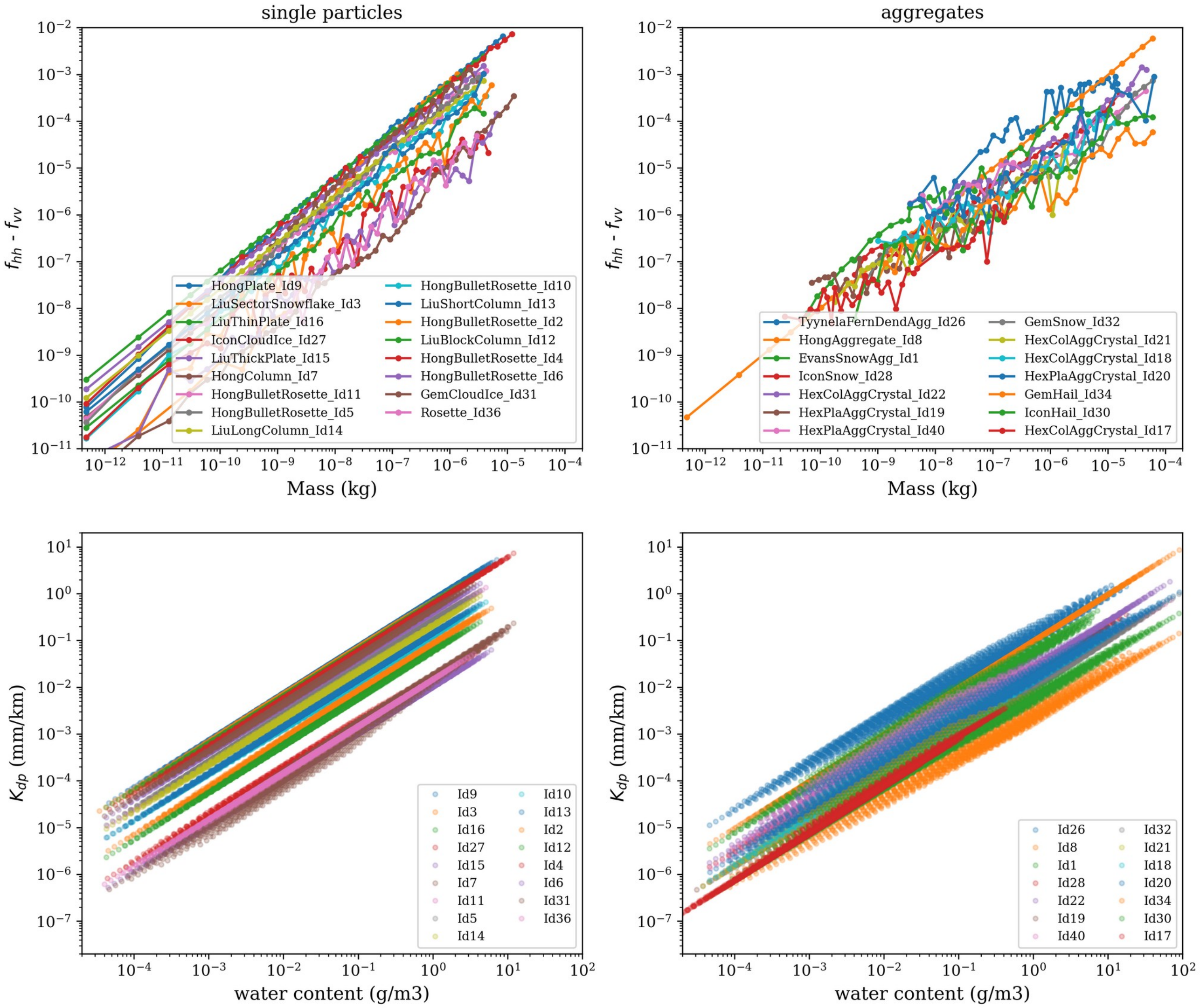
- Realistic shapes
- Consistent with Radiative Transfer approaches like RTTOV an CRTM

*Habit images from: Eriksson et al. 2018, ESSD, https://doi.org/10.5194/essd-10-1301-2018*

# Forward operator

Particles from the ARTS database






Habit images from: Eriksson et al. 2018, ESSD, https://doi.org/10.5194/essd-10-1301-2018

# Forward operator

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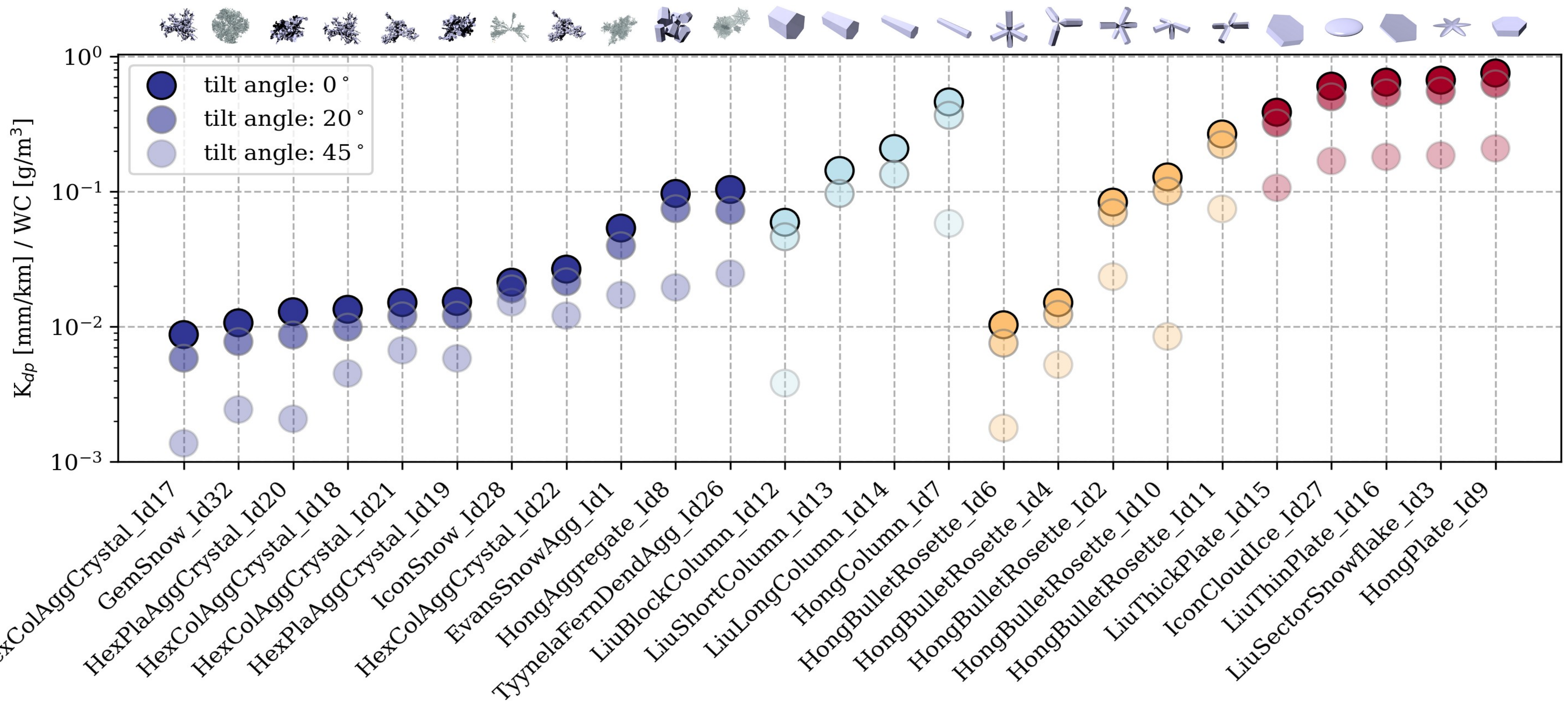


*Habit images from: Eriksson et al. 2018, ESSD, https://doi.org/10.5194/essd-10-1301-2018*

# Forward operator

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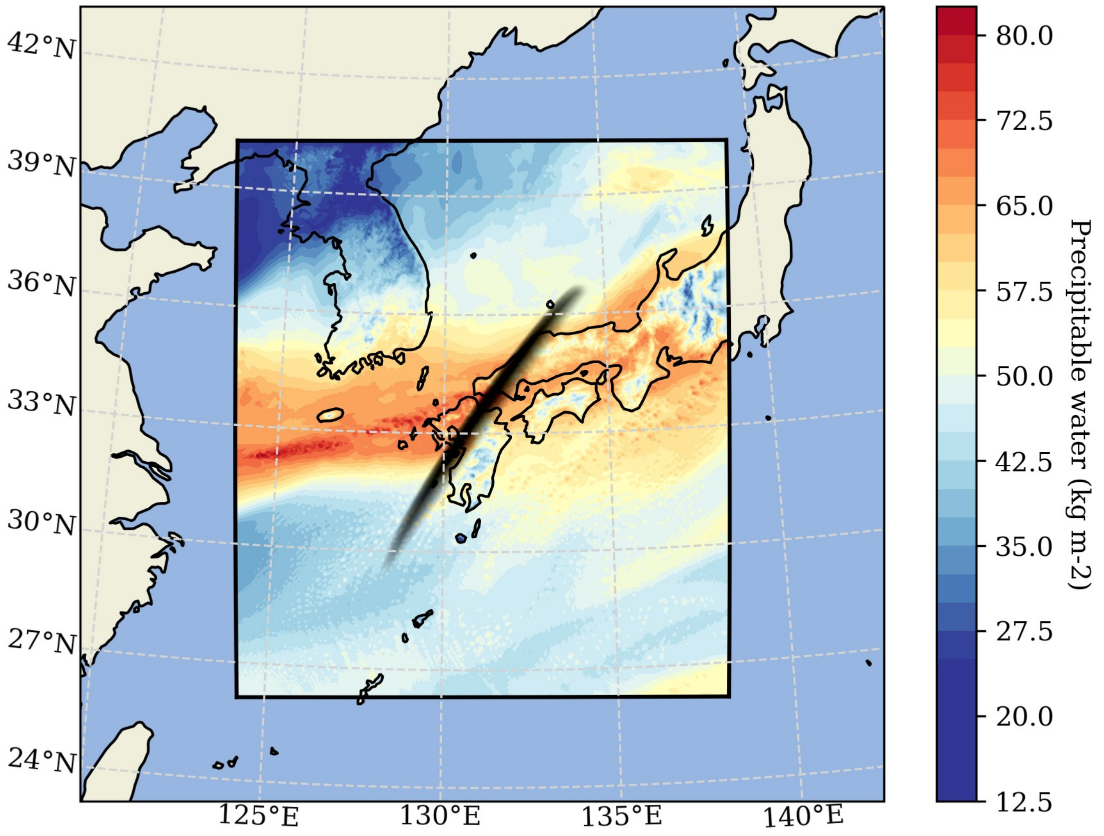
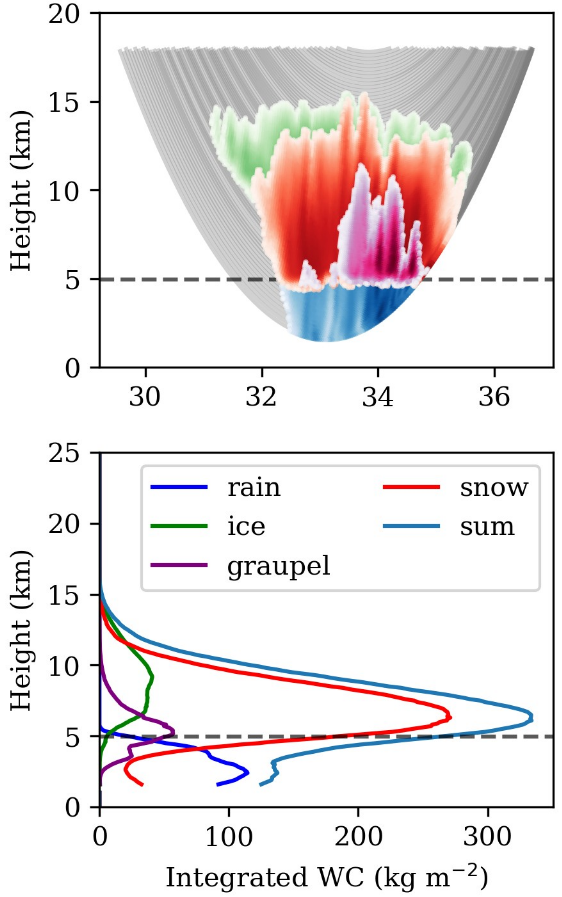
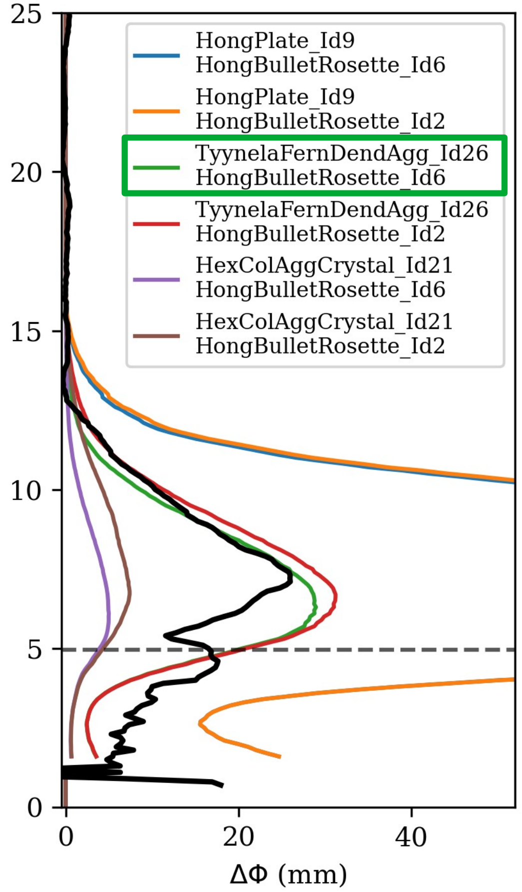
WRF simulation: inner domain
Goddard microphysics scheme, 3 km x 3 km
2019-08-27 23:00




Interpolation of WC into RO rays and integration along the rays




Simulated vs observed Δϕ



# Conclusions

- **The very basics of Polarimetric RO technique**: collect GNSS signals using two linearly polarized antennae (H, V) →

  Bending + $\Delta\phi$ → Precipitation information + thermodynamics

- **Status:**
  - PRO works, even 'better' than hypothesized
  - Sensitivity to heavy rain, to frozen hydrometeors, with no (or little) degradation of standard products
  - More missions collecting PRO, more products being released

- **Current work on forward operator:**
  - Approximations and simplifications provide reasonable results
  - More sophisticated methods should allow for consistency with other RT (e.g. PMW)

# Thanks!

padulles@ice.csic.es

*Funding: RYC2021-033309-I, PID2021-126436OB-C22, and CEX2020-001058-M from MCIN/AEI (10.13039/501100011033), and EUMETSAT ROM SAF CDOP4. The work by authors KNW, FJT, COA and MTJ was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA*

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IEEC Institut d'Estudis Espacials de Catalunya