PlanetiQ

PlanetiQ dual linear polarization GNSS measurements in 2024 for PRO and surface reflections

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Outline

- Summary of PlanetiQ present and near-future capabilities
  - 4th spacecraft was to launch today (delayed to Friday)
- SNR and antennas
- Value of polarized RO measurements
- Sources of PRO measurement error
- A few comments
- NASA CSDA evaluation RFP

Summary of PlanetiQ capabilities

- Summary table

	GNOMES-2	GNOMES-3	GNOMES-4	Spacecraft 5	Spacecraft 6
Launch date	30-Jun-2021	01-Apr-2022	1-Dec-2023	June 2024	Oct 2024
Operational since	1-Oct-2021	15-May-2022	06-Dec-2023?	Soon after	Soon after
End of life		01-Sep-2023			
Current altitude (km)	525 => 435	641	559	525-600	525-600
SSO LTDN	2 pm	11 am	10:30 am	TBD	TBD
Payload duty cycle (%)	100	100	100	100	100
Payload(s)	Pyxis			Pyxis	
RO antenna configuration	Fore: 2 RCP columns Aft: 2 RCP columns			Fore/Aft: 2 RCP columns, Aft/Fore: 1 dual linear-pol col	
Neutral atmo. occ/day	1200-1400	2100+	2100+	Total: 2100+ incl PRO: 1050+	
Ionosphere occ/day	2700	2700	2700	2700	2700
DDMs/day				>100	>100

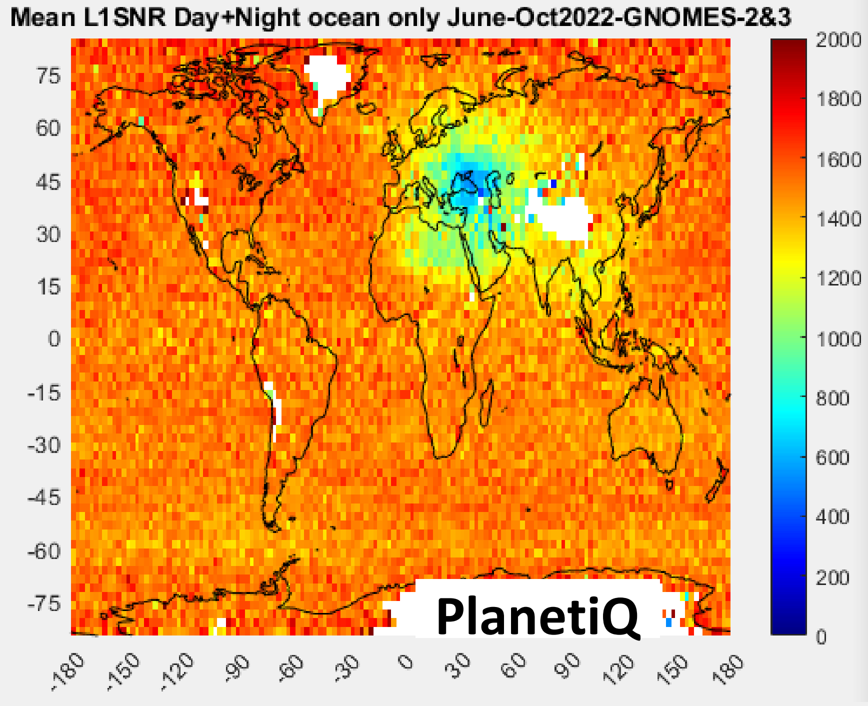
Summary of PlanetiQ capabilities cont'd

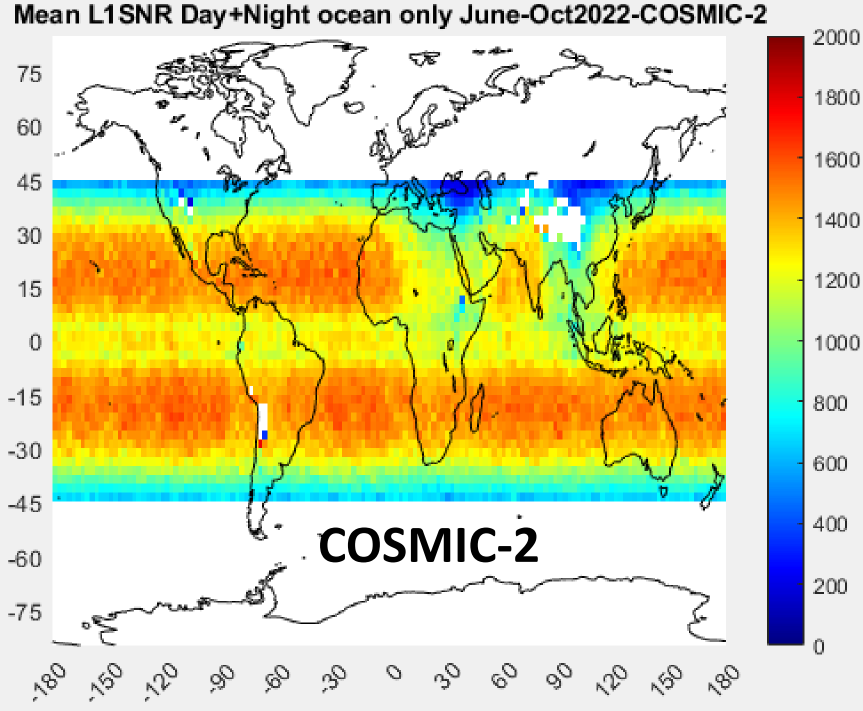
- Pole to pole coverage with very high SNRs
- Neutral atmosphere RO processed at AER using SatDAAC (version of CDAAC) run on AWS cloud with low latency
- External validation of PlanetIQ data by many users
- On NOAA RODB2 contract, delivering data to NOAA under DO-2 and hopefully DO-3 beginning Jan 18, 2024
- On NASA CSDA contract, NASA RFP to evaluate our data coming out soon

- Goal continues to be 20+ satellites delivering 50K+ RO/day including PRO and surface reflections

Pyxis GNSS receiver and antenna instrument

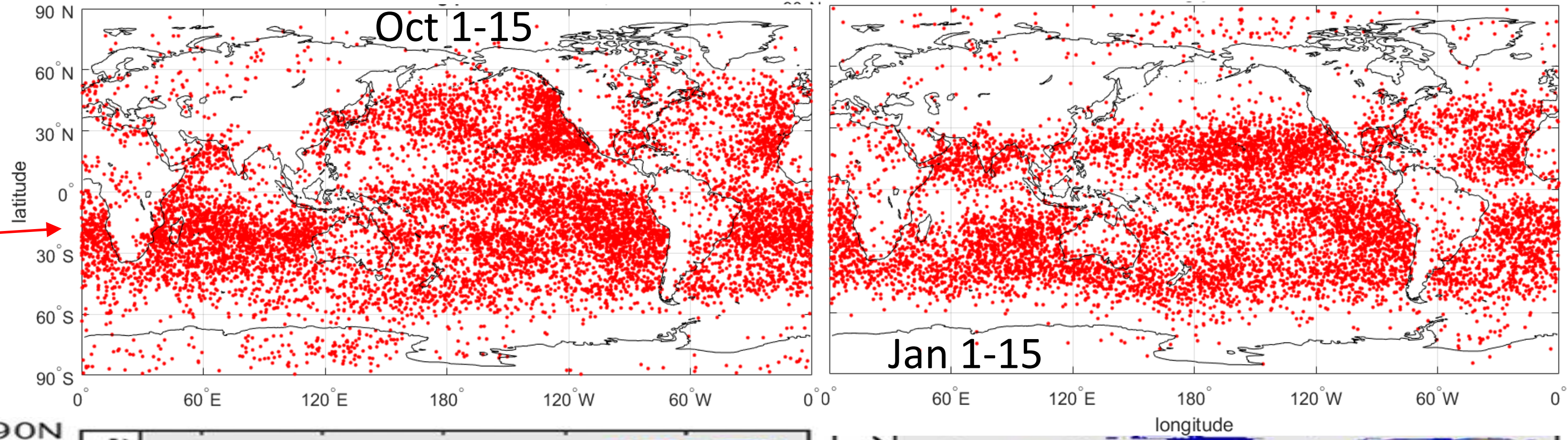
- Tracks 4 GNSS constellations: GPS, GLONASS, Galileo and Beidou
  => 2100 RO/satellite
- High gain RCP antennas provide very high, uniform SNR across the globe (except Ukraine due to jamming).
  - Mean SNR: ~1500 v/v
- Our 5th and 6th satellites will each carry one high gain, dual linear polarization antenna
  => 2100 PRO/day late next year

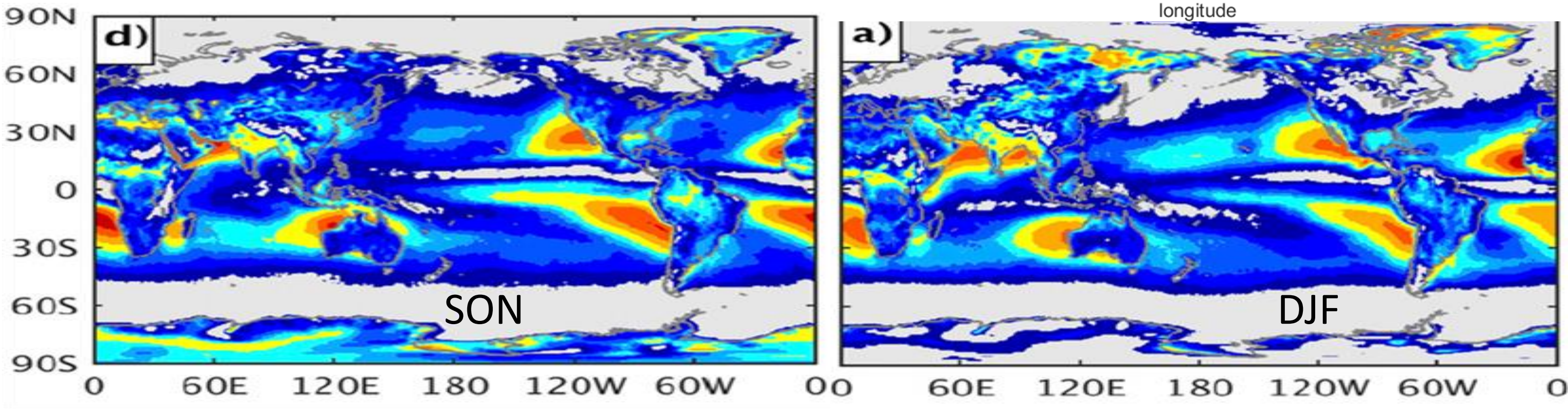




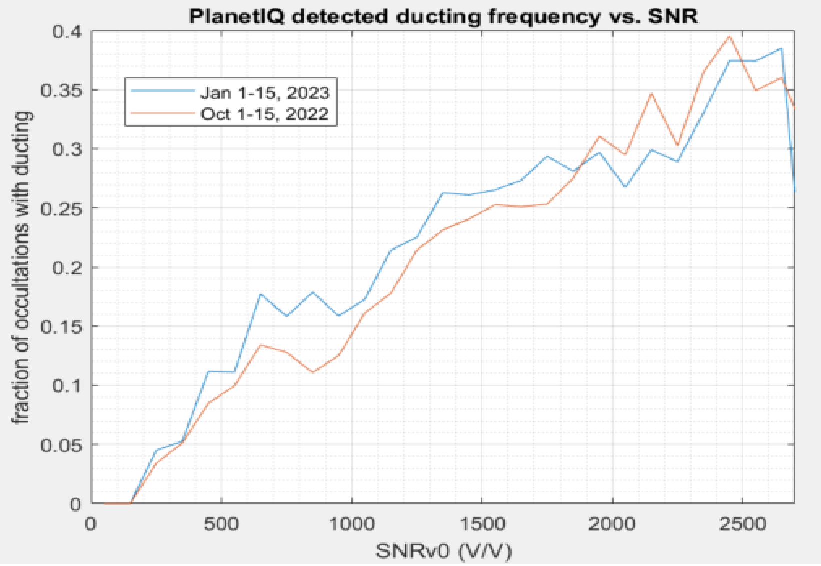
Ducting frequency

- Occultations with ducting detected in our data
- Prediction by Feng et al. 2020 based on ERA Interim
- Frequency in ERAI is likely underestimated due to limited vertical resolution
- Mostly over oceans and associated with vertical moisture gradients
- Occurs most often in subtropical marine cloud regions critical for climate
- Ducting important for TC forecasting
- Ducting over Antarctica is due to strong surface thermal inversions dT/dz $\geq$ +140K/km(!)



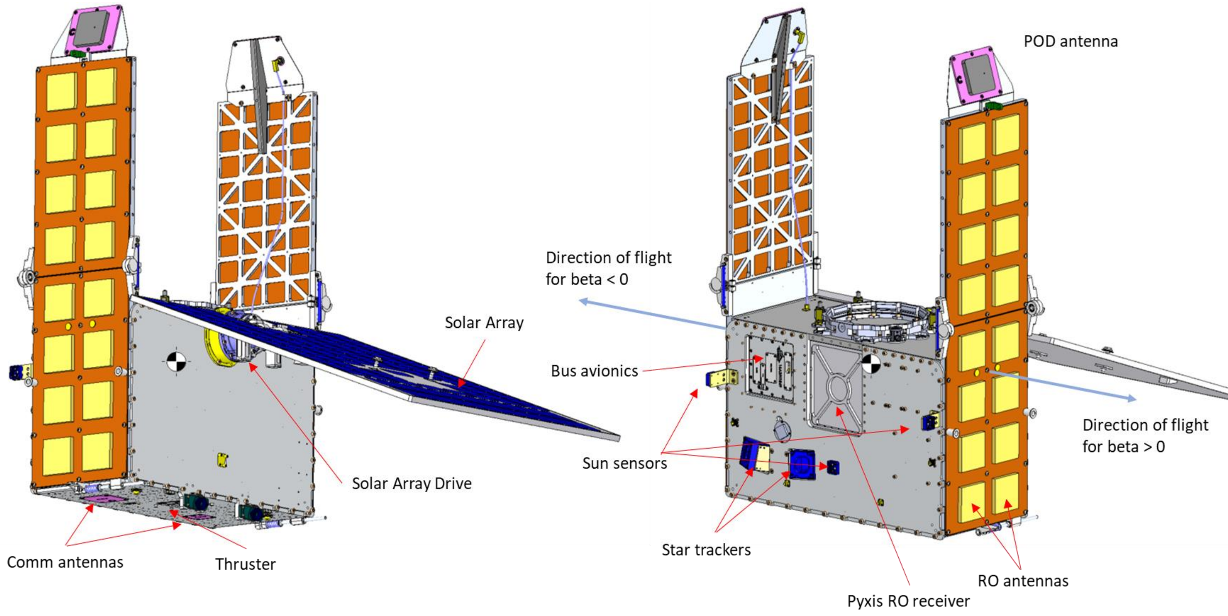


- Determined ducting % vs SNR
  - Very high SNR required to detect ducting
  - Ducting likely occurs in ~1/3 of occultations

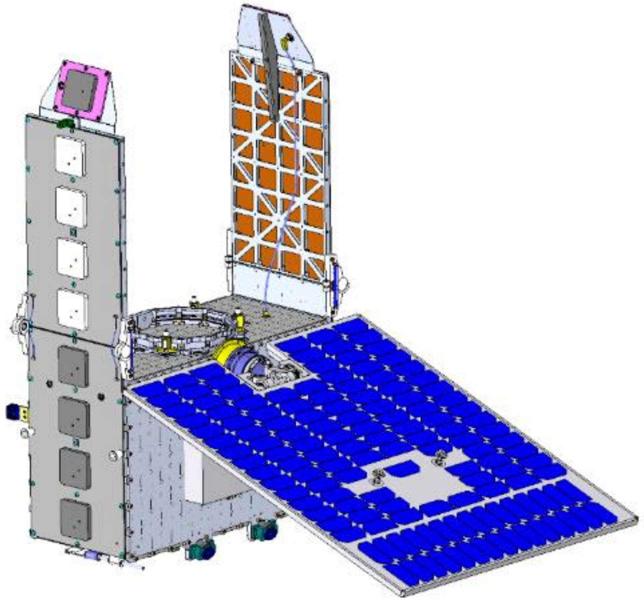


Antennas

- RHCP (Satellites 1-4)
  - 6 antennas per spacecraft
  - OL track each of the 2 RO columns separately
  - Then combine them to maximize SNR



- Dual linear polarization (Satellites 5-6)
  - 6 antennas per spacecraft
  - OL track H and V polarizations separately
  - Combine H & V to increase SNR for normal RO
  - Calculate differential H-V phase to determine $\Delta\phi_{precip}$



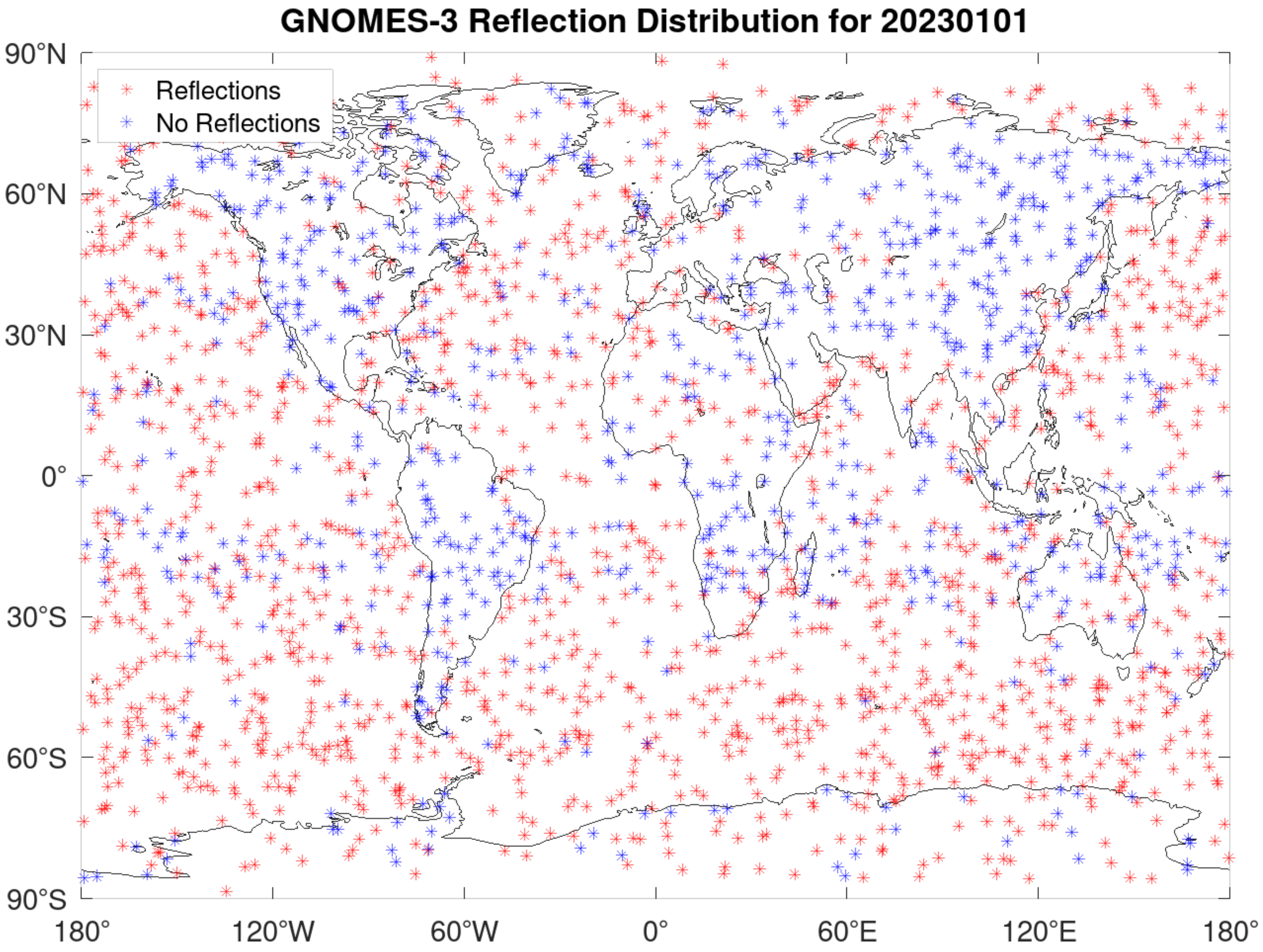
Dual polarization rationale and applications

- Surface reflections:
  - Ocean wind speeds,
  - Inland water bodies and flooding,
  - Soil moisture,
  - Sea ice,
  - Freeze/thaw detection.

- PRO:
  - Heavy rain
  - Snowfall
  - Other solid and mixed phase hydrometeors

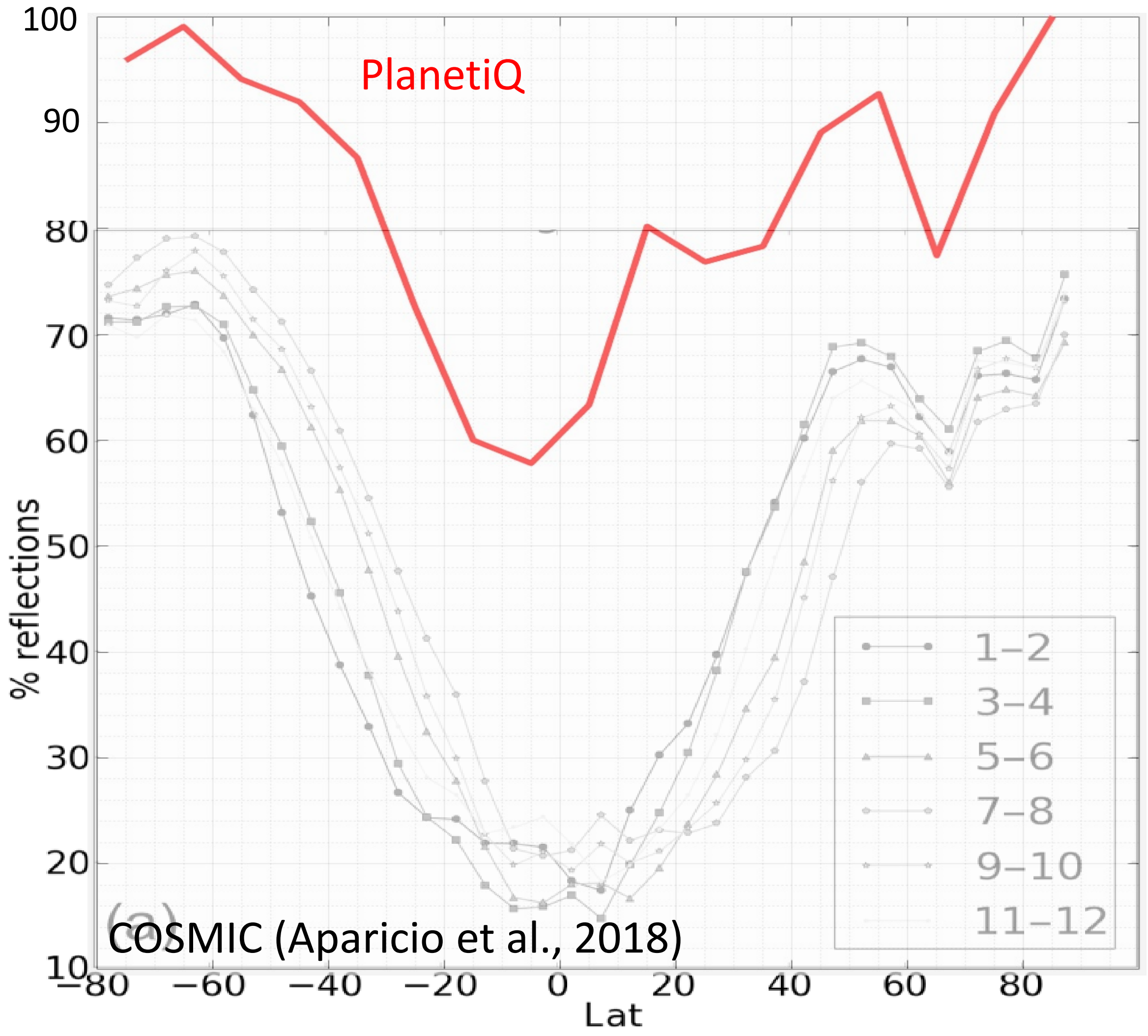
Grazing surface reflections

- GNOMES-3 occultations from Jan 1, 2023 and which occultations also have grazing surface reflections and which do not.
- Many more reflections over the oceans as expected.
- Some interesting reflections over land



PlanetiQ Fraction of occ's over oceans with grazing surface reflections

- Black lines are % COSMIC occultations over oceans where grazing reflections were observed (Aparicio et al., 2018)
- Red line is % of GNOMES-3 occultations over oceans in Jan 2023 where grazing reflections were observed
- GNOMES-3 observes a significantly higher % of occultations with ocean reflections than observed with COSMIC
  - Particularly at low latitudes
- The higher % is presumably due to the significantly higher SNR of PlanetiQ RO observations



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PAZ PRO measurements of snowfall

- Cardellach et al. results from 2022 IROWG “*A Multi-center exercise on the sensitivity of PAZ GNSS Polarimetric RO for NWP modeling*”
- Compared $\Delta\phi$ measured by PAZ with forward calculated, slant delays through ERA-5 water content, in particular, snow water content (SWC)

Preliminary Results

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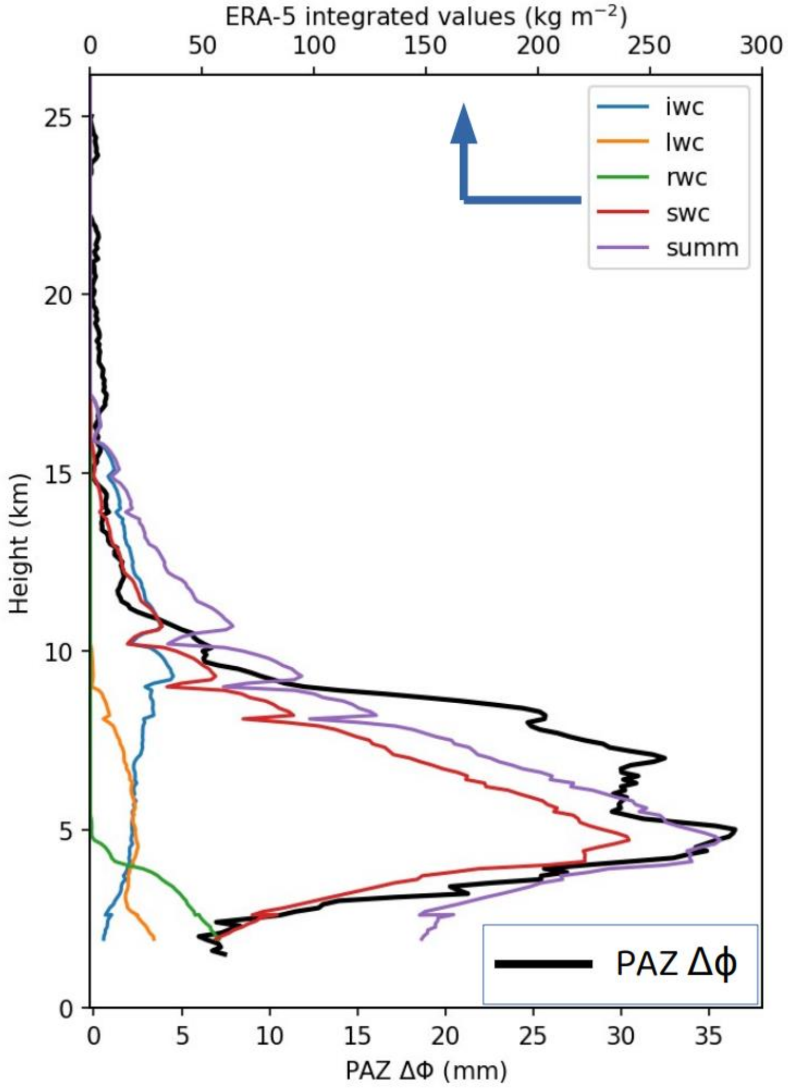
Integration of ERA-5 fields along RO rays

- Qualitatively, $\Delta\phi$ agrees well with the integrated SWC along the rays
- Order of magnitude of integrated WC values agrees with study using Cloudsat (*ACPD, under review*)
- Next step: to convert the WC fields into K_{dp}
  - Point by point (more or less complex)
  - Integrated quantities → directly to $\Delta\phi$



Preliminary Results

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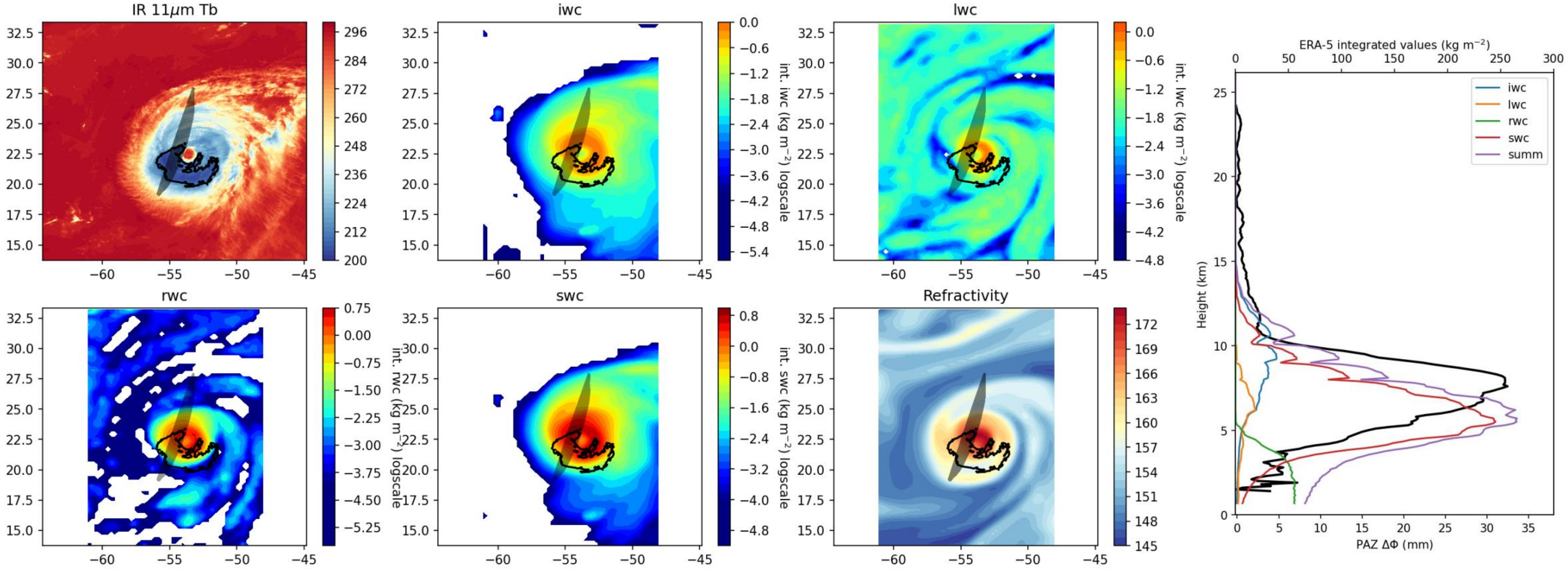
Integration of ERA-5 fields along RO rays

Example of Tropical Cyclone



PAZ PRO measurements of snowfall

- The high correlation between $\Delta\phi$ measured by PAZ and forward calculated slant delays through ERA-5 snow water content (SWC) is really impressive given that the two data sets, PAZ & ERA5, are completely independent
- Strongly suggests that in the general vicinity of the freezing level, PRO is measuring snowfall
- Perhaps these also suggest ERA5 may have a systematic error in not generating enough snowfall at higher altitudes. Certainly valuable information for modelers.

- Work obviously remains to derive K_{dp} and snow amounts from $\Delta\phi$ but clearly a strong, unique, and useful geophysical signal has been demonstrated

PlanetiQ Sources of $\Delta\phi$ measurement error

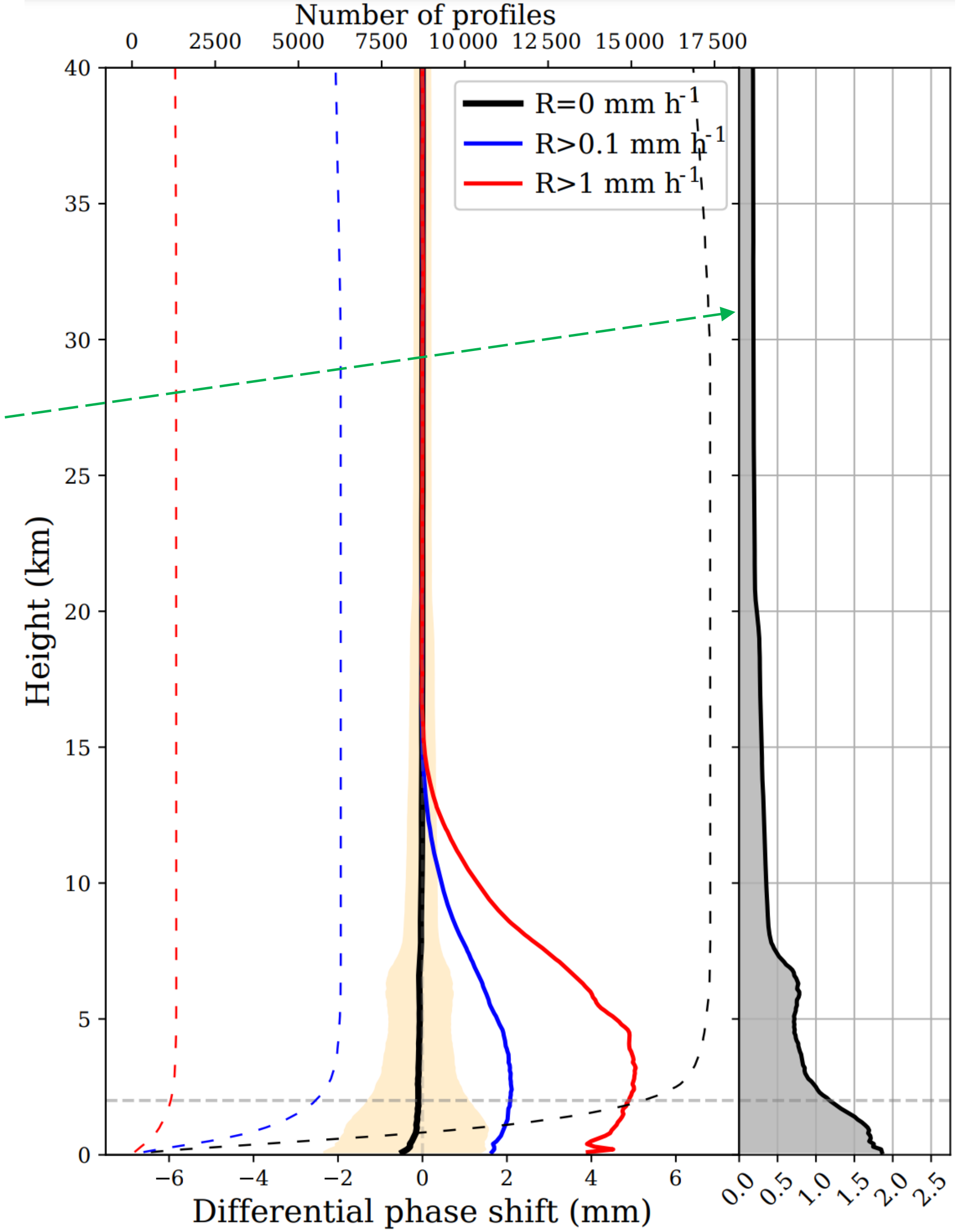
- SNR and thermal noise
- Cross polarization isolation
- Local msultipath
- Faraday rotation (negligible?)
- Others?

- Dual frequency measurements to cross check and further reduce noise?

PlanetiQ SNR and sensitivity

- PlanetiQ SNRs average ~1500 v/v using 2 RCP antenna columns.
- Using 1 column of H and V will decrease the SNR's to ~750 v/v
  - Half the antenna gain x half the signal power = half the **voltage** SNR
- $\sigma_{\Delta\phi}$ ~ 0.06 mm which is 3-4 times better than PAZ
- When phase error or uncertainty is limited by thermal noise, sensitivity will increase by factors of 3-4

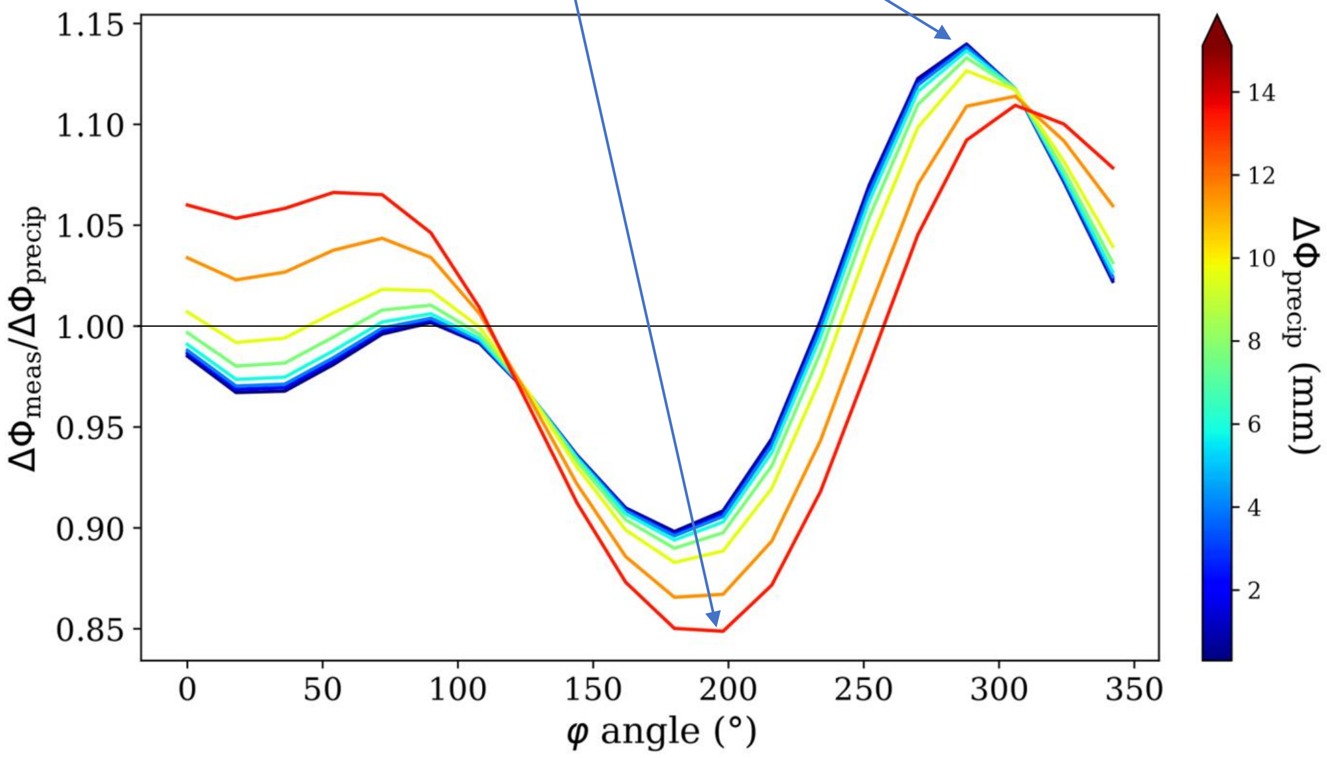
	Polarization	Typical SNRv0 v/v	σ_{ϕ} (mm)	$\sigma_{\Delta\phi}$ (mm)
PlanetiQ RO	RCP	1500	0.02	
PlanetiQ (P)RO	Combined dual linear polarizations	1100	0.028	
PlanetiQ PRO	Each lin polarization	750	0.04	0.056
PAZ PRO	Each lin polarization	200	1.4	0.2



Cross polarization noise

- Antennas have cross-polarization leakage, the impact noted Padulles at al., 2020
- For 15 dB of isolation, the peak to peak errors could reach ±15%
  - Actual results depend on specific phase difference, φ, between V and H polarized signals measured through the H antenna and the V antenna.
  - This is a systematic effect unlike thermal noise
- Our 1st dual pol antenna has ~22 dB isolation in beam center which decreases to ~8 dB at 65 deg azimuth

  => Performance ~similar to figure
- Expect φ does not vary much in time
- But φ likely depends on azimuth angle of the occultations
- We have measured the isolation and are looking to determine φ vs viewing angle



Dual Polarization Calibration

Cross polarization isolation

- Working to measure and then calibrate out the effects of finite cross-polarization isolation discussed on previous slide

Local Multipath

- Have developed and been applying local multipath calibration for TEC on our POD antennas
- Will examine PRO dual linear polarization phase and amplitude behavior to determine whether there is evidence of local multipath and then decide whether calibration is needed and, if so, what approach to use

Thoughts on yesterday's presentations/discussions

- Agree with Eric Wang: $\Delta\phi$ rather than Δ bending angle is a better quantity to utilize and forward model because more directly related to quantity of interest and less noisy.
- Agree with Estel: $\Delta\phi$ will be accurate even if there are refractivity biases because of the common mode noise cancellation which allows 1 mm differential delay effects to be measured accurately.
- Snow's big signature in PRO measurements is consistent with its large horizontal to vertical aspect ratio and implies snow is generally not randomly oriented.
  - Perhaps because turbulence associated with convection is limited in horizontal scale while snow often exists over much larger horizontal regions?
  - Does the apparent relatively stable orientation of snow particles simplify the relation between K_{dp} and the amount of snow water content?
- Does appear there is a small $\Delta\phi$ signature near 17 km from convective anvils ?
- Glad to hear JPL working on WO to establish heights of $\Delta\phi$ in lower troposphere
- How fast can a 2D PRO FO be implemented and begin to be used in NWP?

PlanetiQ

NASA CSDA Evaluation of PlanetiQ Data

- NASA CSDA about to announce RFP to evaluate PlanetiQ CSDA data
- Data types
  - Neutral atmosphere
    - Level 1B: High rate carrier phase and SNR (~ 'conPhs')
    - Level 2: Bending angle and refractivity (~ 'atmPrf')
  - Space weather/Ionosphere
    - Calibrated TEC
    - Scintillations: S4, σ_ϕ and high rate phase and amplitude
    - Sporadic E imbedded in Level 1B neutral atmosphere and ionosphere scintillation files
  - Surface reflections imbedded in Level 1B neutral atmosphere data
  - Dual polarization data will be coming starting June-Oct 2024 (separate evaluation call?)

- Will have a PlanetiQ Product Guide on ROSES shortly
- Send questions to support@planetiq.com