Independent Validation of the Polarimetric Radio Occultation Profiles from Spire's Nanosatellite Constellation, and their Potential Applications

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(1) Abstract

In early 2023, **Spire launched the first three nanosatellites capable of collecting PRO measurements** from low-earth orbit. This study, performed independently from the data providers, assesses the validation and co-location of Spire PRO observations with ancillary information from global precipitation missions. **The results are compared with those obtained from the ROHP-PAZ instrument, showing a good agreement between the three Spire nanosatellites and PAZ.** Furthermore, unlike PAZ, Spire nanosatellites are able to collect measurements from the 4 major GNSS constellations, and are placed in orbits that are convenient for obtaining coincident observations from the different nanosatellites.

A study of the potential scientific and meteorological applications of such small PRO constellation is also presented, with emphasis on the resulting **clusters of observations around interesting meteorological events**, such as Tropical Cyclones (TC) or Mesoscale Convective Systems (MCS). Examples of such clusters and their statistics are provided, highlighting the potential impact of expanding the set of quality observations over these extreme events by means of cubesat constellations.

(2) Differences between ROHP-PAZ and Spire

The proof-of-concept ROHP experiment aboard PAZ was also an opportunistic mission and therefore was not fully optimized for PRO. **These Spire nanosatellites are designed specifically for PRO**, and offer several advantages summarized below:

Differences		Implication for Spire observations
Spire PRO nano-satellites	ROHP - PAZ	
Synchronized H and V	Independent H and V	Same measurements for H and V, avoiding interpolation
Open Loop whole profile	Closed Loop until ~7km, then Open Loop	Avoids issues in the tracking mode transition
Multi GNSS (major 4 constellations)	GPS only	More observations per platform
Small constellation	One single satellite	Simultaneous coincident measurement, more observations overall
Clear antenna FoV	FoV partially blocked	No local multipath for Spire satellites, calibration not needed

(3) Validation

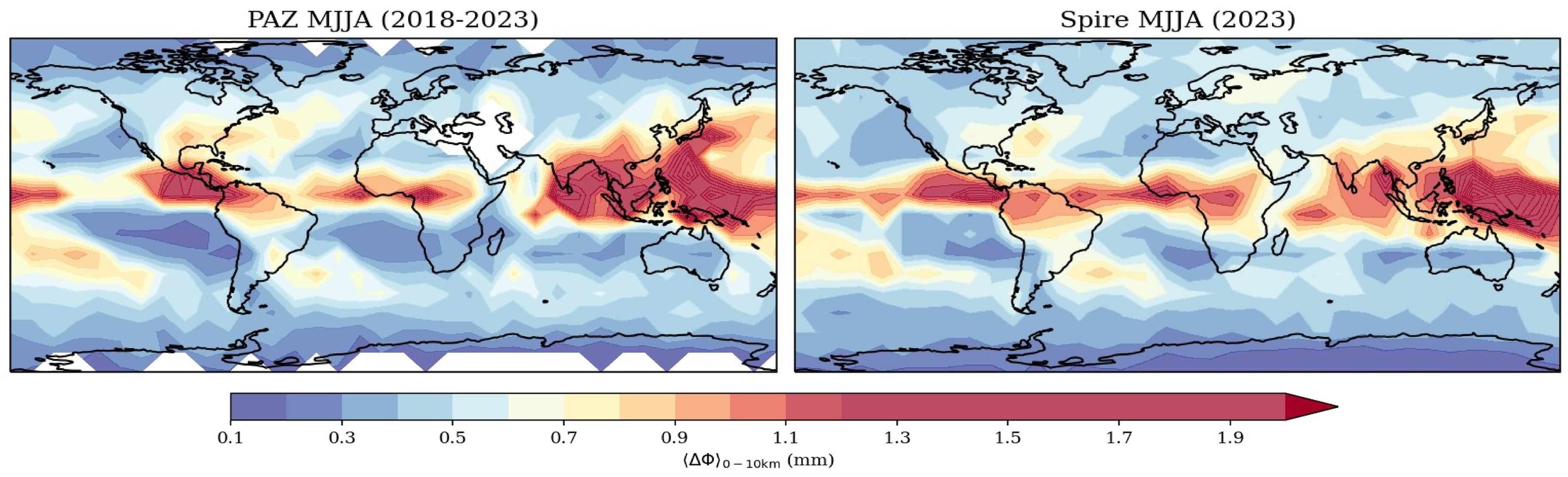


Figure 1. General pattern of Δϕ for PAZ (left) and Spire (right) for the mean Δϕ averaged between 0 and 10km at each 10°x10° bin using data between May and August.

The spatial patterns of Δϕ obtained from Spire nanosatellites are compared with those from PAZ. It can be seen how the **patterns agree, and how these resemble known global precipitation patterns** (e.g. tropical and extratropical precipitation, the Inter Tropical Convergence Zone (ITCZ), etc.).

All observations have been grouped by their co-located IMERG surface rain rate, and the mean Δϕ(*h*) for each group is shown below. Δϕ(*h*) profiles agree among the different nanosatellites and also with PAZ data, exhibiting **increased Δϕ when increasing precipitation**, with levels of noise within the expected values.

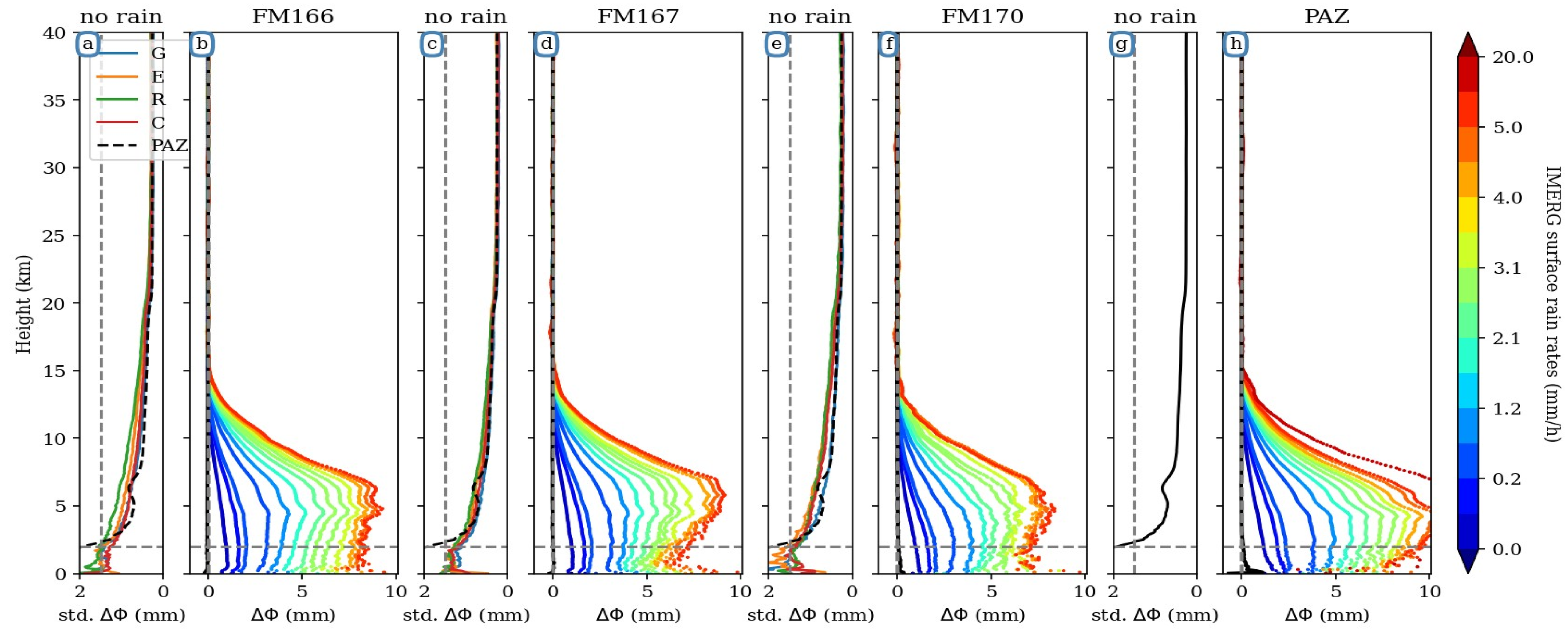
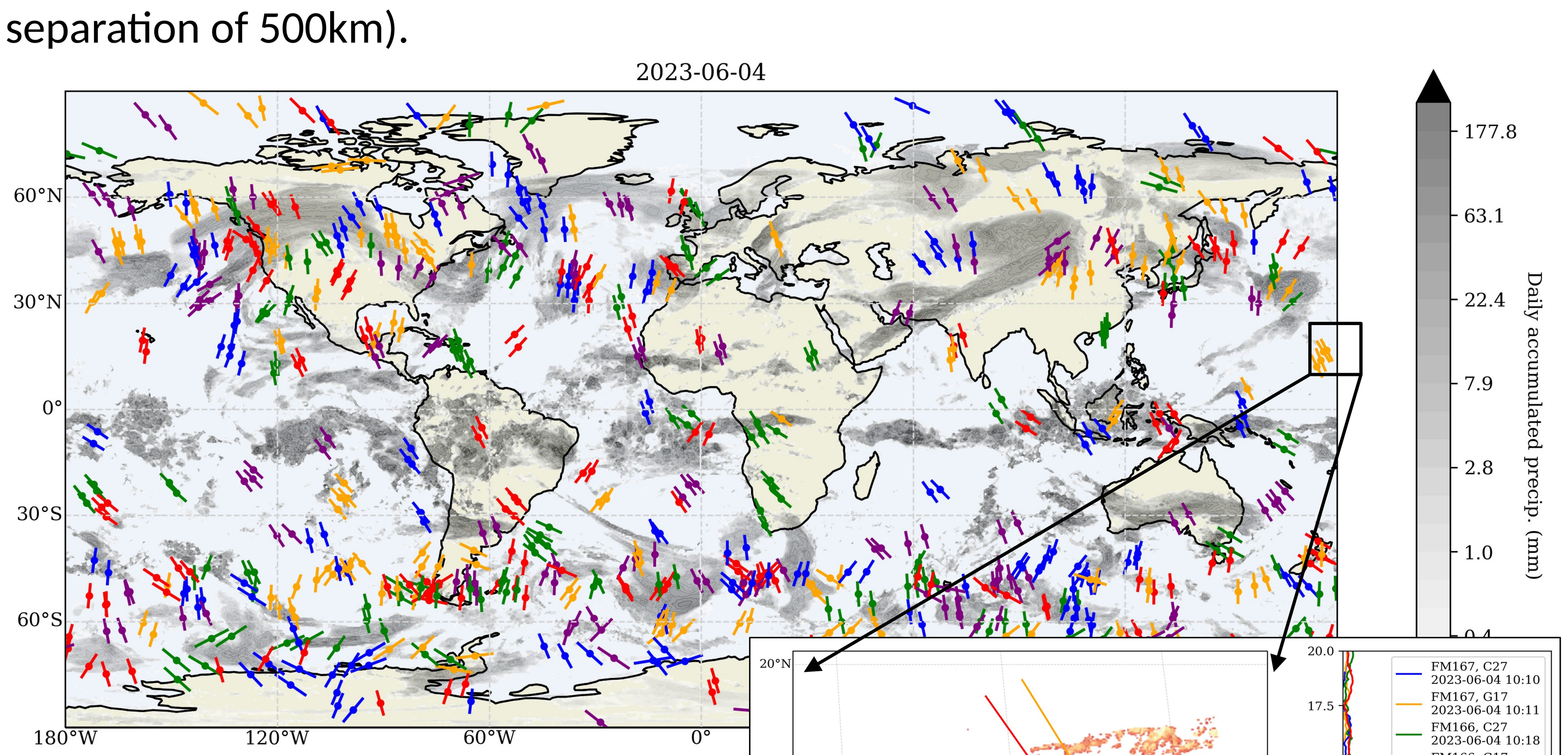


Figure 2. Statistics for the vertical profiles of Δϕ, grouped by according to the IMERG surface precipitation for the 3 Spire nanosatellites and PAZ. The standard deviation for the no precipitation group is shown for every tracked GNSS constellation.

(4) Applications:

The multi GNSS capability and the orbit configuration favor clustered observations, that is, observations close in space and time. Clusters of PRO observations were assessed in *Turk et al. 2019*, with the idea to use the thermodynamic retrievals and the precipitation information to study the horizontal gradients of moisture in the free troposphere, inside and outside of deep convection.

The three spire nanosatellites provide a **sampling of more than 300 clusters per day** (with maximum time difference allowed of 15min and maximum distance separation of 500km).



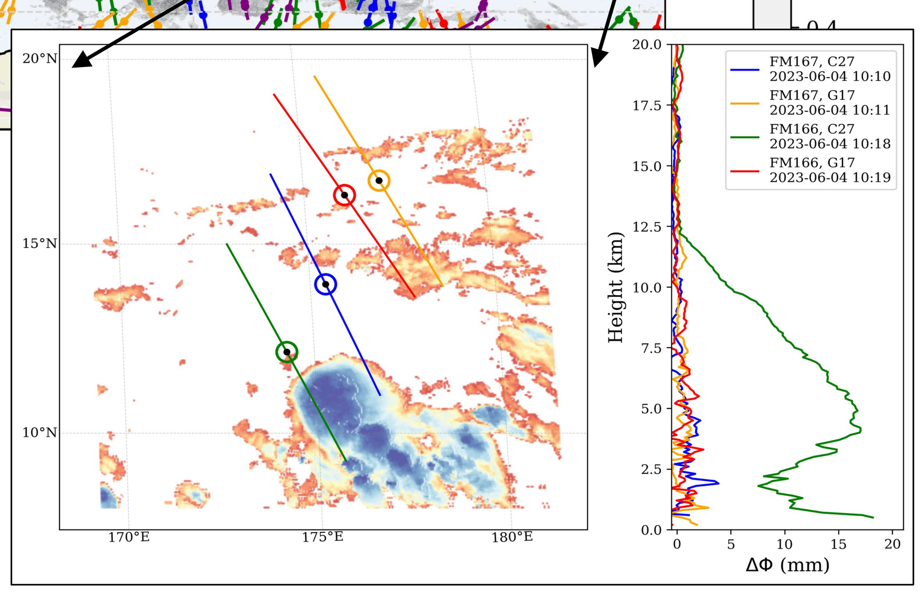


Figure 3. Clustered observations for one day corresponding to 2023-06-04, with a zoom in an interesting event – in this case, cluster nearby a mesoscale convective system in the West Pacific warm pool. Each cluster is represented in the map as same color lines indicating azimuth orientation. The zoomed in image shows the same lines with a matching color with the corresponding Δϕ profiles in the right, with IR Tb in the background.

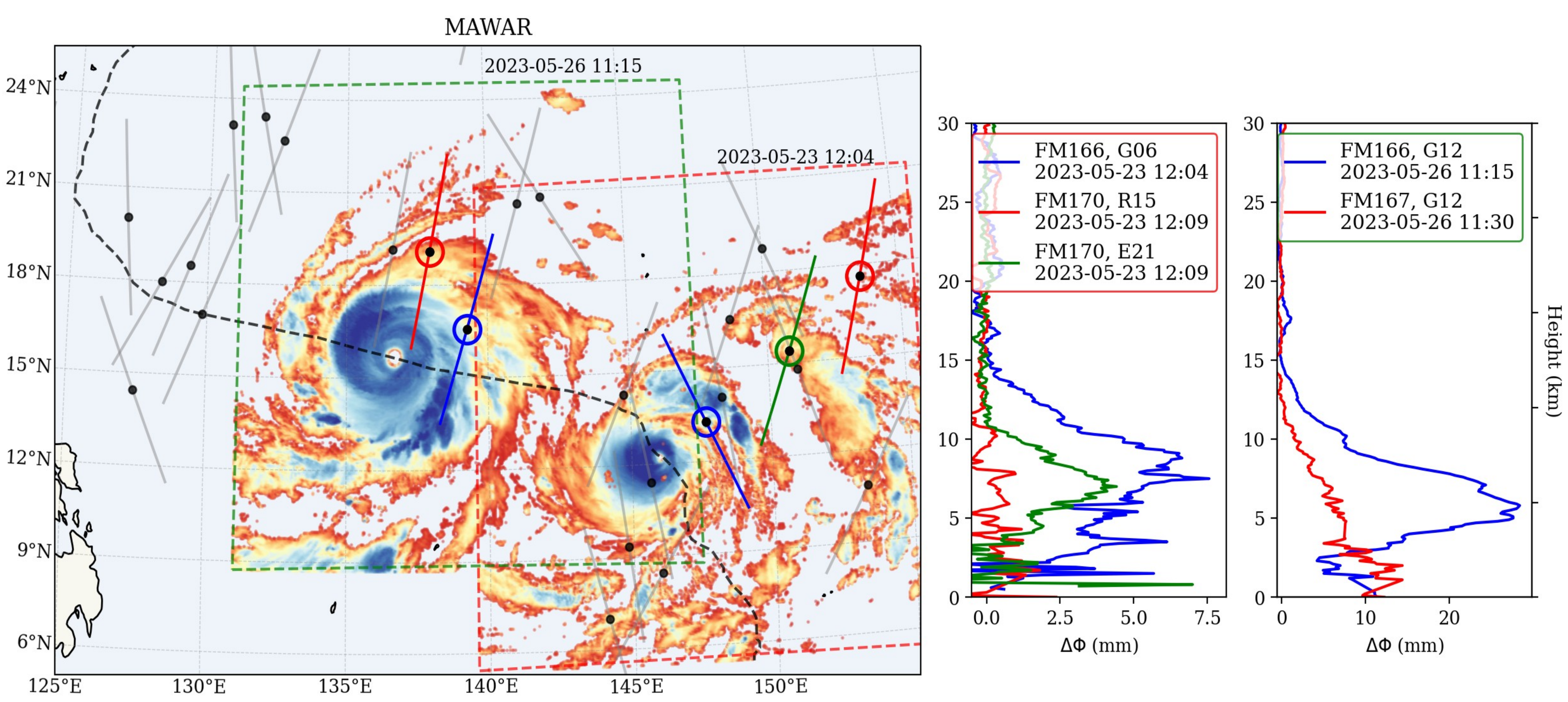


Figure 4. Example of multiple PRO observations (some clustered, some not) along the Mawar Tropical Cyclone track during its lifetime. Each black dot in the map is a PRO observation, and two clusters are highlighted, with the corresponding Δϕ profiles in the right. The background IR Tb images correspond to the observation times of the clusters of PRO that are highlighted.

Also, the large number of daily observations (**with a peak of +2000 PRO events / day**) provide enough sampling to observe events like Tropical Cyclones multiple times along its lifetime. This could enable new studies like using PRO Δϕ for model evaluation taking advantage of the different view angles of such cloud and precipitation vertical structures.

References

Padullés, R., et al., *Initial Polarimetric Radio Occultation Results from Spire's Nanosatellite Constellation: Independent validation and potential applications*, in review at BAMS, **2024**

Turk, F. J., et al., *Benefits of a closely-spaced satellite constellation of atmospheric polarimetric radio occultation measurements*, Remote Sensing, 10.3390/rs11202399, **2019**

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