Towards Understanding the Uncertainties of PMW-derived Precipitation Regime Trends

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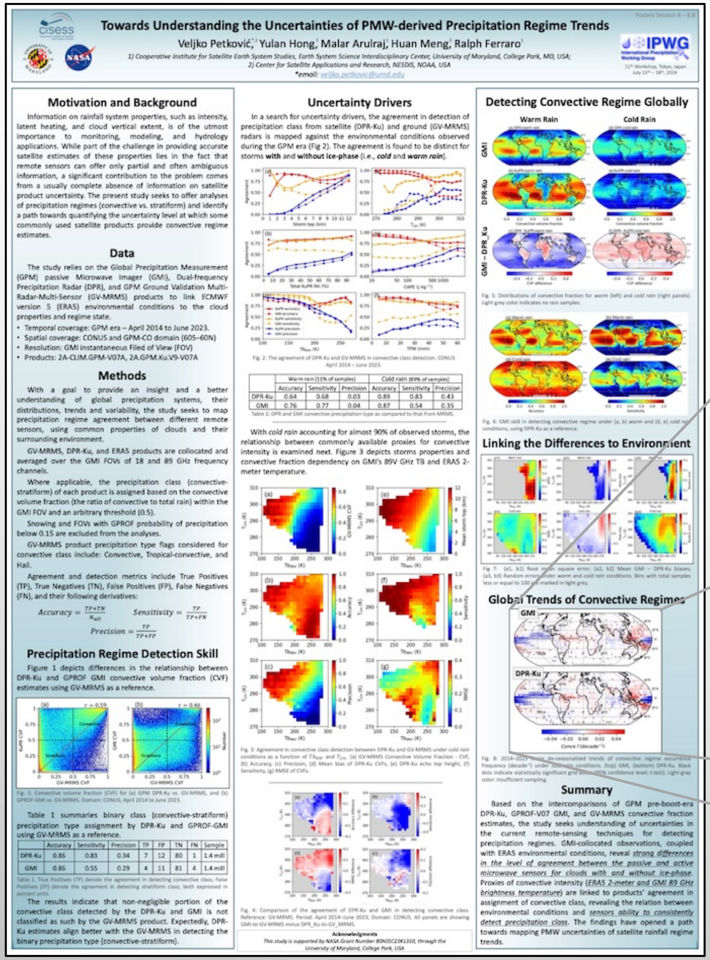

Posters Session A – 6.8

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Motivation and Background

Information on rainfall system properties, such as intensity, latent heating, and cloud vertical extent, is of the utmost importance to monitoring, modeling, and hydrology applications. While part of the challenge in providing accurate satellite estimates of these properties lies in the fact that remote sensors can offer only partial and often ambiguous information, a significant contribution to the problem comes from a usually complete absence of information on satellite product uncertainty. The present study seeks to offer analyses of precipitation regimes (convective vs. stratiform) and identify a path towards quantifying the uncertainty level at which some commonly used satellite products provide convective regime estimates.

Data

The study relies on the Global Precipitation Measurement (GPM) passive Microwave Imager (GMI), Dual-frequency Precipitation Radar (DPR), and GPM Ground Validation Multi-Radar-Multi-Sensor (GV-MRMS) products to link ECMWF version 5 (ERA5) environmental conditions to the cloud properties and regime state.

- Temporal coverage: GPM era – April 2014 to June 2023.
- Spatial coverage: CONUS and GPM-CO domain (60S–60N)
- Resolution: GMI instantaneous Filed of View (FOV)
- Products: 2A-CLIM.GPM-V07A, 2A.GPM.Ku.V9-V07A

Methods

With a goal to provide an insight and a better understanding of global precipitation systems, their distributions, trends and variability, the study seeks to map precipitation regime agreement between different remote sensors, using common properties of clouds and their surrounding environment.

GV-MRMS, DPR-Ku, and ERA5 products are collocated and averaged over the GMI FOVs of 18 and 89 GHz frequency channels.

Where applicable, the precipitation class (convective-stratiform) of each product is assigned based on the convective volume fraction (the ratio of convective to total rain) within the GMI FOV and an arbitrary threshold (0.5).

Snowing and FOVs with GPROF probability of precipitation below 0.15 are excluded from the analyses.

GV-MRMS product precipitation type flags considered for convective class include: Convective, Tropical-convective, and Hail.

Agreement and detection metrics include True Positives (TP), True Negatives (TN), False Positives (FP), False Negatives (FN), and their following derivatives:

$$Accuracy = \frac{TP+TN}{N_{all}} \qquad Sensitivity = \frac{TP}{TP+FN}$$

$$Precision = \frac{TP}{TP+FP}$$

Precipitation Regime Detection Skill

Figure 1 depicts differences in the relationship between DPR-Ku and GPROF GMI convective volume fraction (CVF) estimates using GV-MRMS as a reference.

Fig. 1: Convective volume fraction (CVF) for (a) GPM DPR-Ku vs. GV-MRMS, and (b) GPROF-GMI vs. GV-MRMS. Domain: CONUS, April 2014 to June 2023.

Table 1 summaries binary class (convective-stratiform) precipitation type assignment by DPR-Ku and GPROF-GMI using GV-MRMS as a reference.

	Accuracy	Sensitivity	Precision	TP	FP	TN	FN	Sample
DPR-Ku	0.86	0.83	0.34	7	12	80	1	1.4 mill
GMI	0.86	0.55	0.29	4	11	81	4	1.4 mill

Table 1. True Positives (TP) denote the agreement in detecting convective class; False Positives (FP) denote the agreement in detecting stratiform class; both expressed in percent units.

The results indicate that non-negligible portion of the convective class detected by the DPR-Ku and GMI is not classified as such by the GV-MRMS product. Expectedly, DPR-Ku estimates align better with the GV-MRMS in detecting the binary precipitation type (convective-stratiform).

Uncertainty Drivers

In a search for uncertainty drivers, the agreement in detection of precipitation class from satellite (DPR-Ku) and ground (GV-MRMS) radars is mapped against the environmental conditions observed during the GPM era (Fig 2). The agreement is found to be distinct for storms **with** and **without ice-phase** (i.e., ***cold*** and ***warm rain***).

Fig. 2: The agreement of DPR-Ku and GV-MRMS in convective class detection. CONUS April 2014 – June 2023.

	Warm rain (11% of samples)			Cold rain (89% of samples)		
	Accuracy	Sensitivity	Precision	Accuracy	Sensitivity	Precision
DPR-Ku	0.64	0.68	0.03	0.89	0.83	0.43
GMI	0.76	0.77	0.04	0.87	0.54	0.35

Table 2: DPR and GMI convective precipitation type as compared to that from MRMS.

With *cold rain* accounting for almost 90% of observed storms, the relationship between commonly available proxies for convective intensity is examined next. Figure 3 depicts storms properties and convective fraction dependency on GMI's 89V GHz TB and ERA5 2-meter temperature.

Fig. 3: Agreement in convective class detection between DPR-Ku and GV-MRMS under *cold rain* conditions as a function of Tb_{89V} and T_{2m}. (a) GV-MRMS Convective Volume Fraction - CVF, (b) Accuracy, (c) Precision, (d) Mean bias of DPR-Ku CVFs, (e) DPR-Ku echo top height, (f) Sensitivity, (g) RMSE of CVFs.

Fig. 4: Comparison of the agreement of DPR-Ku and GMI in detecting convective class. Reference: GV-MRMS. Period: April 2014–June 2023; Domain: CONUS. All panels are showing GMI-to-GV-MRMS minus DPR_Ku-to-GV_MRMS.

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Detecting Convective Regime Globally

Fig. 5: Distributions of convective fraction for warm (left) and *cold rain* (right panels). Light grey color indicates no rain samples.

Fig. 6: GMI skill in detecting convective regime under (a, b) warm and (d, e) *cold rain* conditions, using DPR-Ku as a reference.

Linking the Differences to Environment

Fig 7: (a1, b1) Root mean square error; (a2, b2) Mean GMI – DPR-Ku biases; (a3, b3) Random errors under warm and *cold rain* conditions. Bins with total samples less or equal to 100 are marked in light grey.

Global Trends of Convective Regimes

Fig. 8: 2014–2023 linear de-seasonalized trends of convective regime occurrence frequency (decade⁻¹) under cold rain conditions. (top) GMI, (bottom) DPR-Ku. Black dots indicate statistically significant grid boxes (95% confidence level; t-test). Light gray color: insufficient sampling.

Summary

Based on the intercomparisons of GPM pre-boost-era DPR-Ku, GPROF-V07 GMI, and GV-MRMS convective fraction estimates, the study seeks understanding of uncertainties in the current remote-sensing techniques for detecting precipitation regimes. GMI-collocated observations, coupled with ERA5 environmental conditions, reveal *strong differences in the level of agreement between the passive and active microwave sensors for clouds with and without ice-phase*. Proxies of convective intensity (*ERA5 2-meter and GMI 89 GHz brightness temperature*) are linked to products' agreement in assignment of convective class, revealing the relation between environmental conditions and *sensors ability to consistently detect precipitation class*. The findings have opened a path towards mapping PMW uncertainties of satellite rainfall regime trends.

Trends in Convective Regime Frequency of Occurrence