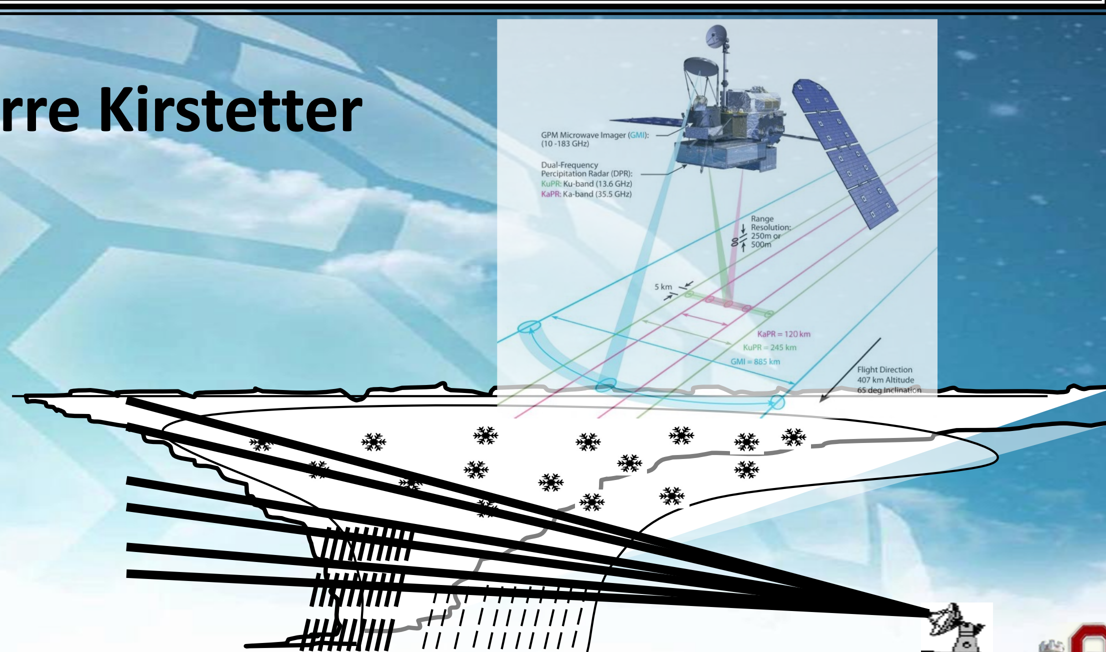
Probabilistic Quantitative Precipitation Estimation With Space-Based Radars

Pierre Kirstetter

with contributions from:
N. Liu



International Precipitation Working Group – 9 July 2026

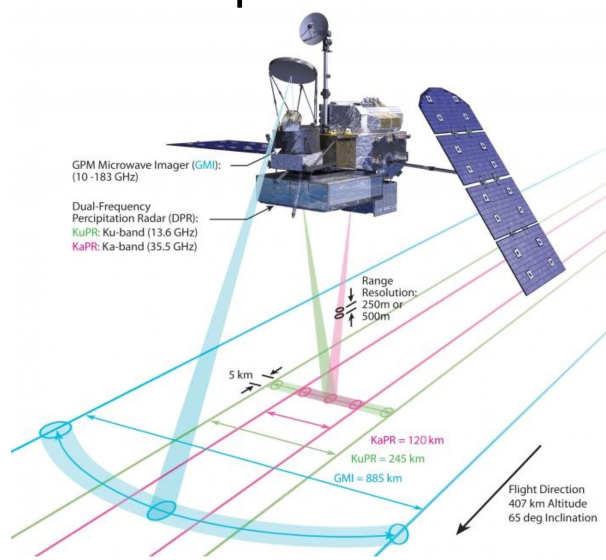
Global Precipitation Measurement mission

GPM constellation

➔ estimates precipitation every 3h

- challenge: unify estimation

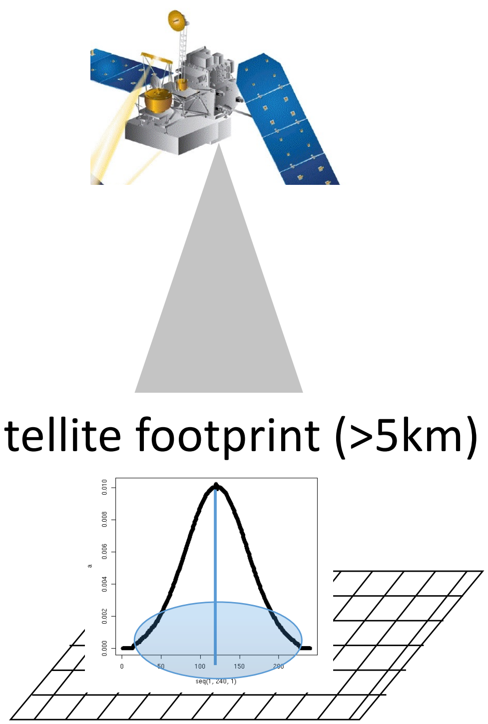
GPM Dual-frequency Precipitation Radar



➔ calibrate other platforms

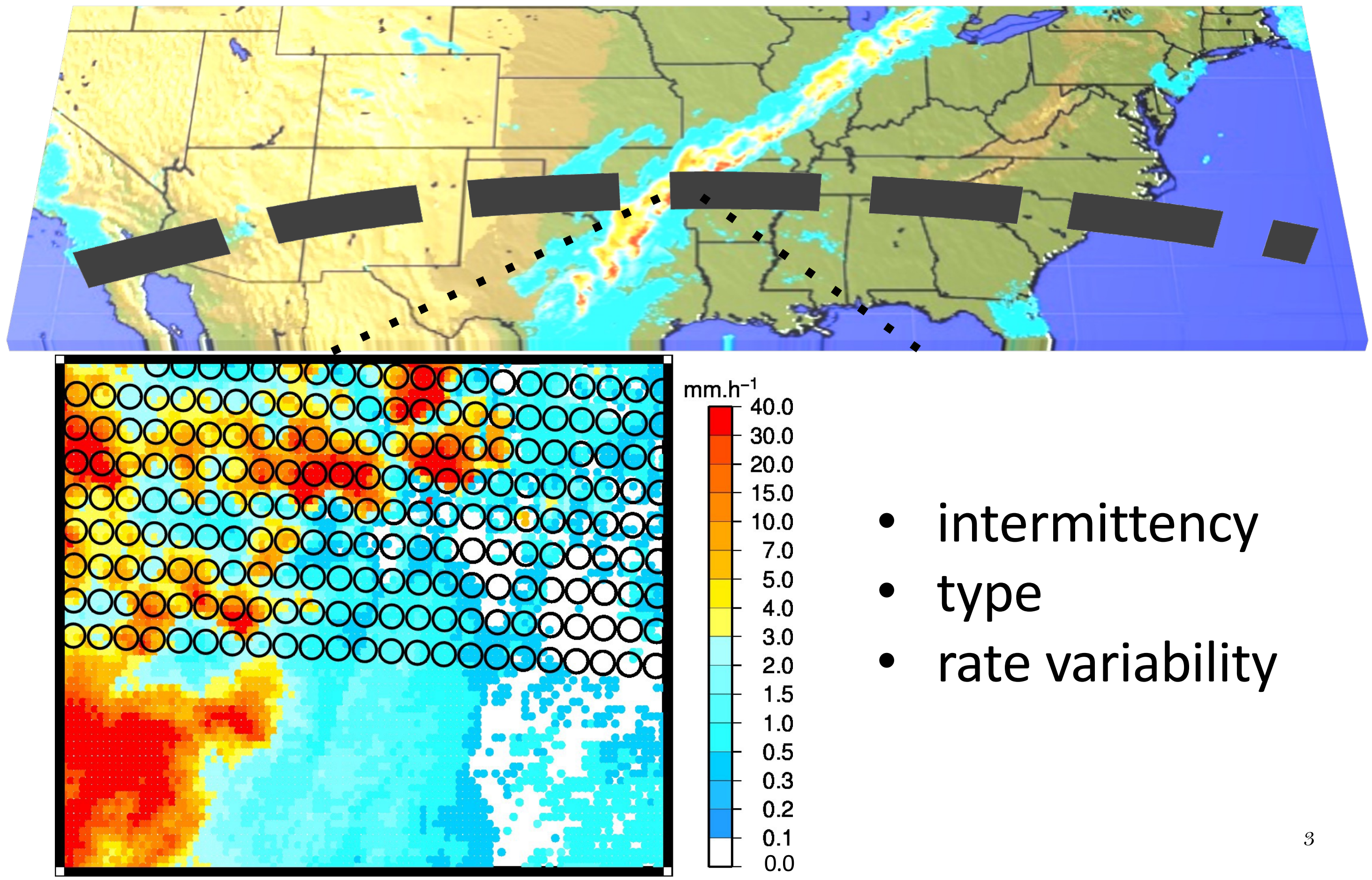
- challenge: precipitation processes (PSD)
- challenge: precipitation variability (NUBF)

A cornerstone for understanding global water fluxes… with observation challenges



satellite footprint (>5km)

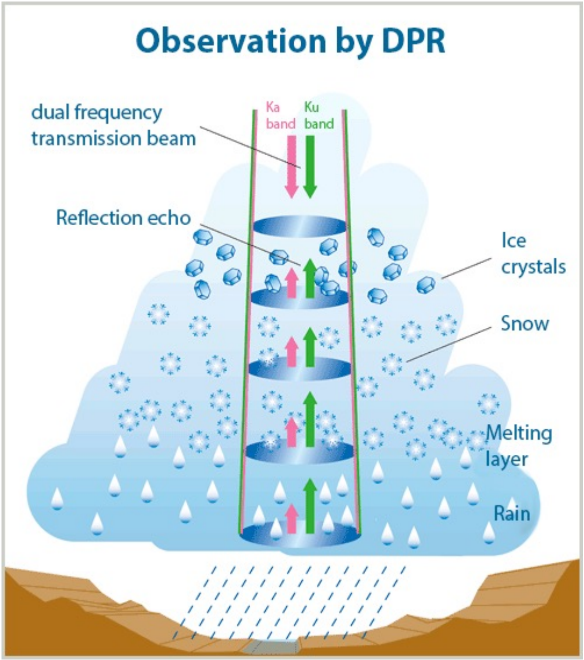
ground radar grid (~1km resolution)



- intermittency
- type
- rate variability

Challenge: mixture of observed processes

Space radar algorithm estimates the profile of microphysics (PSD) at each gate and the surface precipitation rate



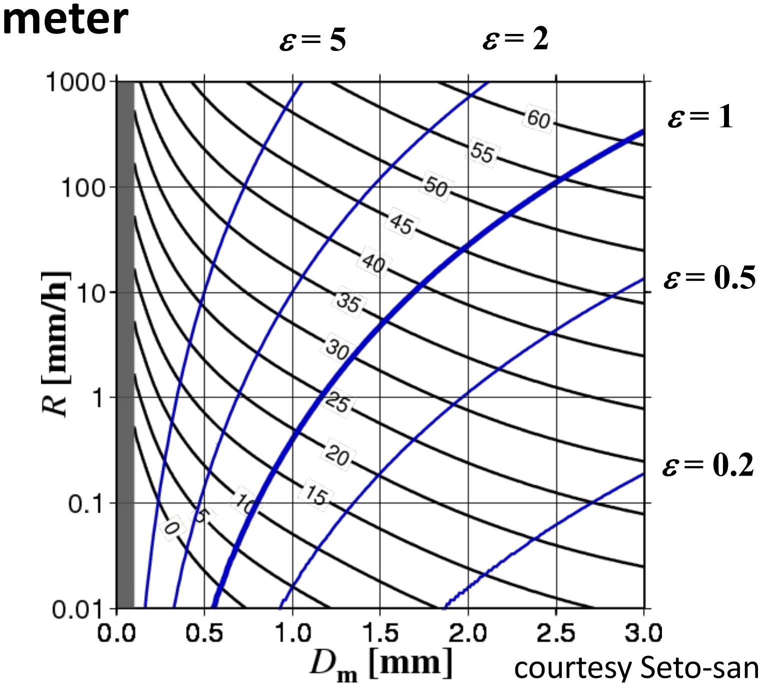
- Space radar algorithm fits 1D vertical model of precipitation microphysics to the observed profile(s) of reflectivity

- Assumes microphysics: convective / stratiform
- Assumes primarily uniform precipitation in the field of view

- Challenge: get the microphysics right
- Challenge: deal with unresolved variability

Dual-frequency Precipitation Radar QPE relations

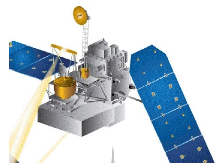
- **Rainfall – mass weighted mean diameter relation: R-Dm**
  - **stratiform: $R_{DPR} = 0.401\ \varepsilon^{4.649}\ D_m^{6.131}$ ε : adjustment parameter**
  - **convective: $R_{DPR} = 1.370\ \varepsilon^{4.258}\ D_m^{5.420}$ Dm: mean diameter**

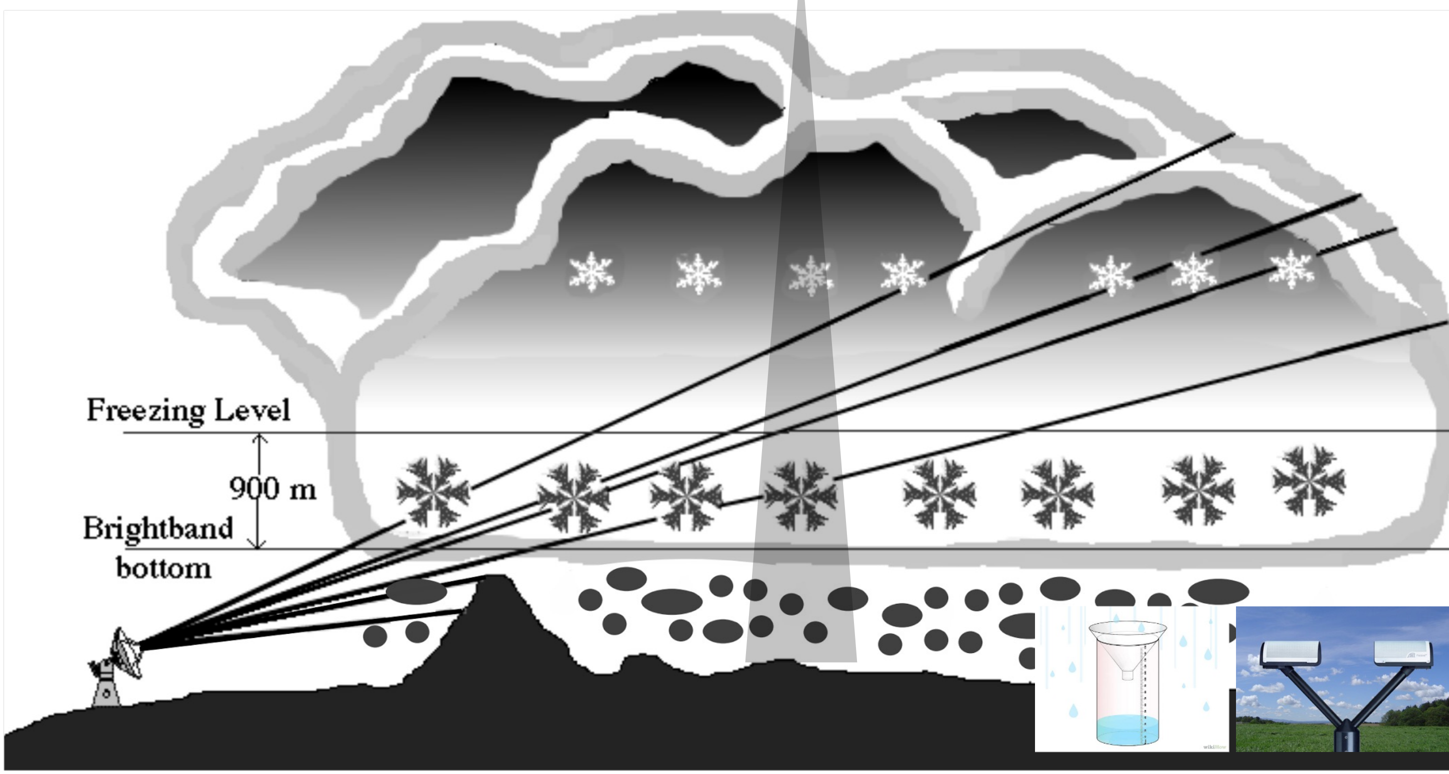


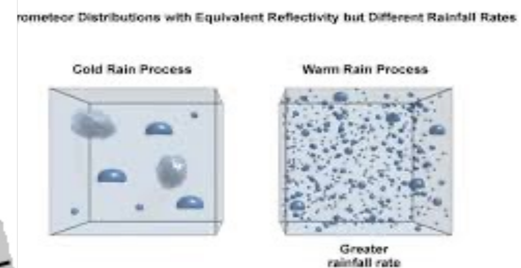
courtesy Seto-san

Uncertainties in radar hydrometeorology

Deterministic QPE … but **indirect and often underdetermined relationship** between observations and precipitation







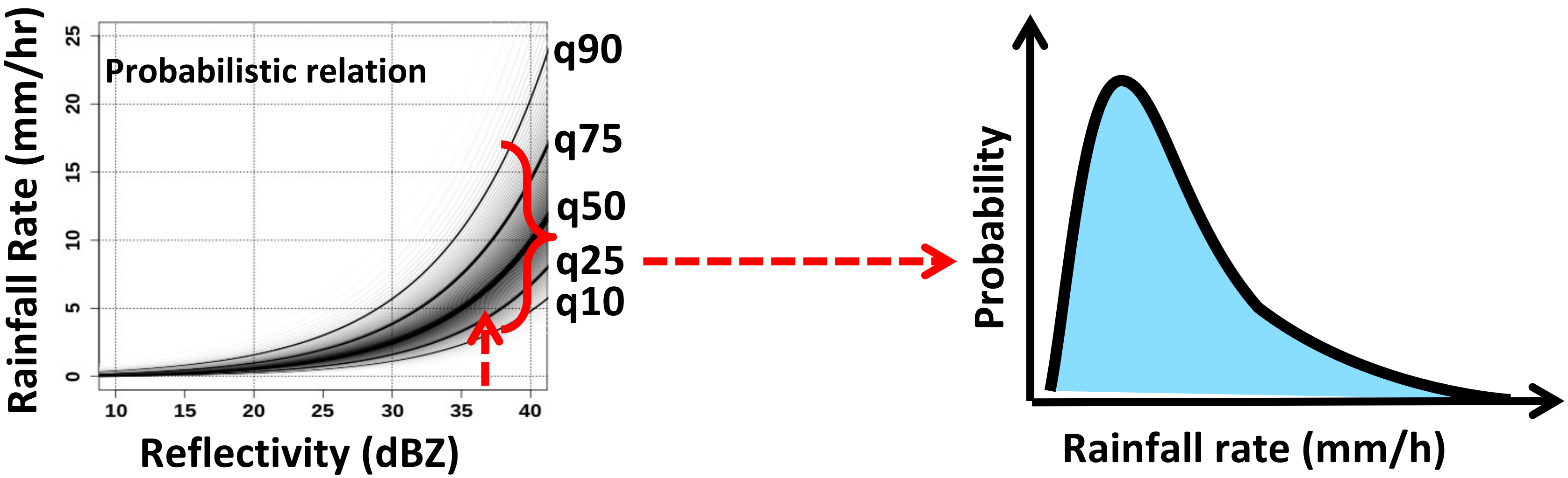
Uncertainties in radar hydrometeorology

- **Remote sensing, atmospheric sciences, and hydrology:**
  - precipitation variability is ignored;
  - partially resolved / mixtures of precipitation processes;
  - limited characterization of extremes;
  - impacts hazard applications.
- **Classical parameterization approach is insufficient: deterministic, based on averaged properties.**

Moving forward: increase QPE information content

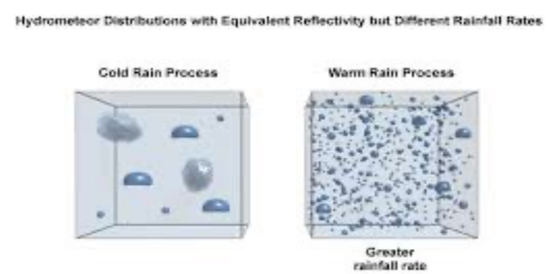
- ➔ **Use uncertainty as an integral part of precipitation estimation**
  - ➔ data fusion
  - ➔ data assimilation
- ➔ **Quantify the likelihood of weather and water extremes**
  - ➔ hazard information
  - ➔ risk analysis

Estimating distributions of possible precipitation rates



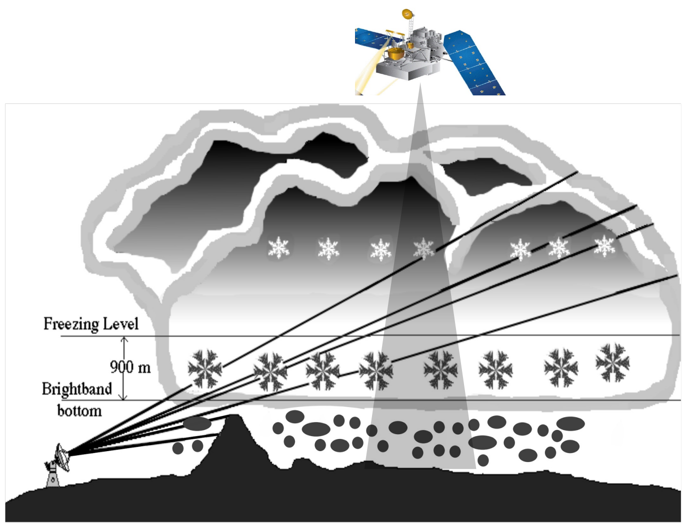
Same reflectivity $$Z_\infty = \int_0^\infty D^6 N(D)\,dD$$

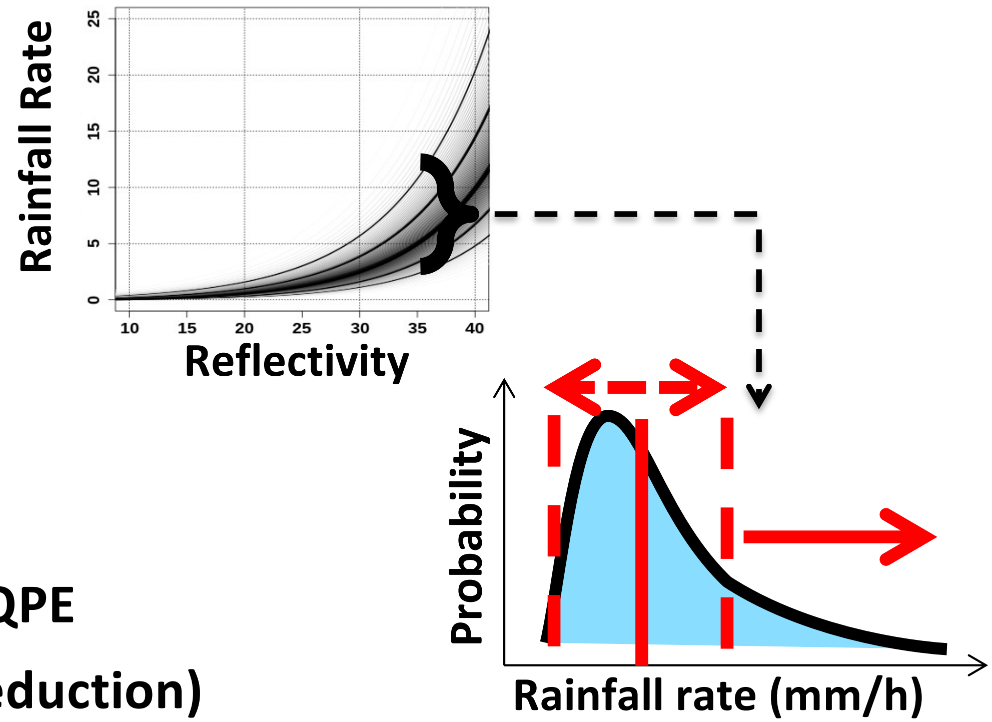
2 different rain rates $$R_\infty = \frac{\pi}{6}\int_0^\infty w_t D^3 N(D)\,dD$$



Kirstetter, P.E., et al. , 2015: Probabilistic Precipitation Rate Estimates with Ground-based Radar Networks. *Water Resources Research*, 51, 1422–1442. doi:10.1002/2014WR015672

PQPE Summary





- **Uses uncertainty as an integral part of QPE**
- **Depicts the most likely value (➔ bias reduction)**
- **Quantifies certainty bounds (➔ data fusion & assimilation)**
- **Quantifies the likelihood of extreme cases (➔ risk analysis)**

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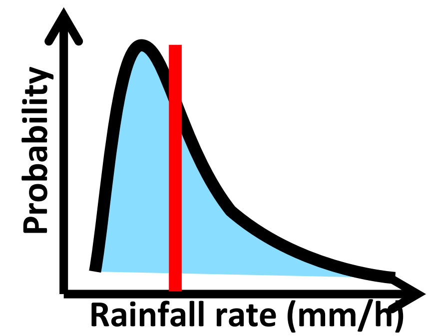
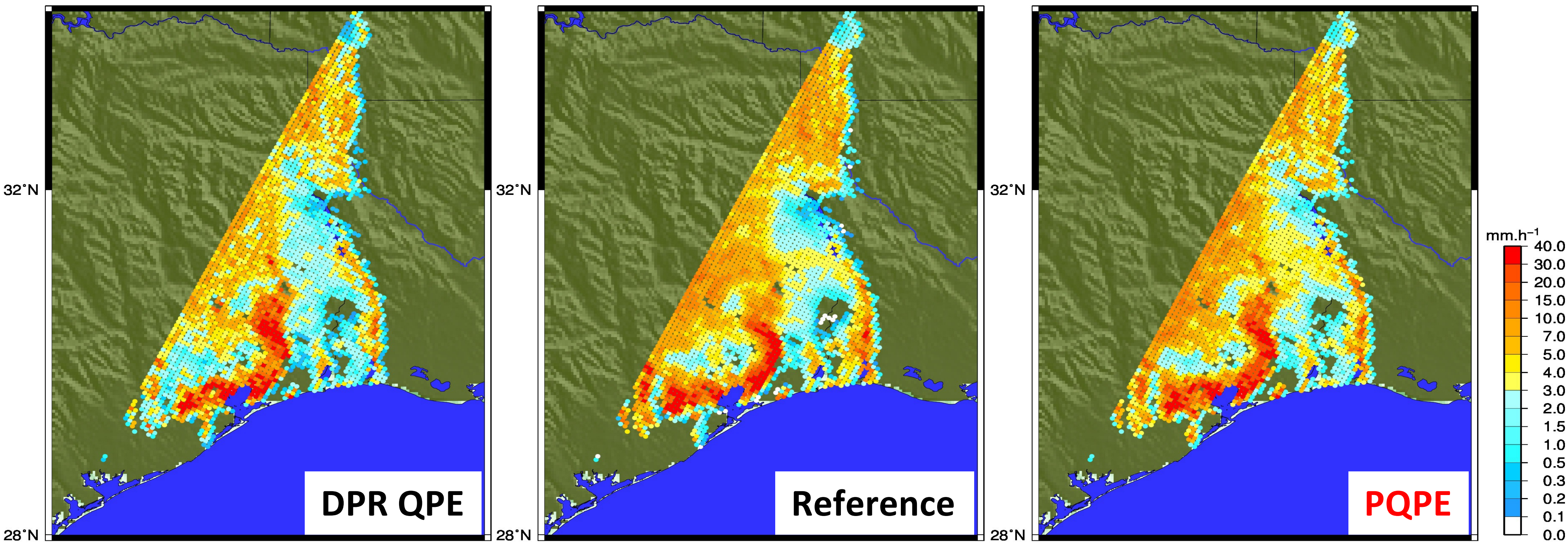
Space-based Precipitation Radar



DPR QPE = f (ε, $D_{m.}$ precipitation type, …)

PDF(R_{ref}) = f (ε, $D_{m,}$ precipitation type, …)



Storm system at 12:30 UTC on 18 April 2016 near Houston

Space-based Precipitation Radar

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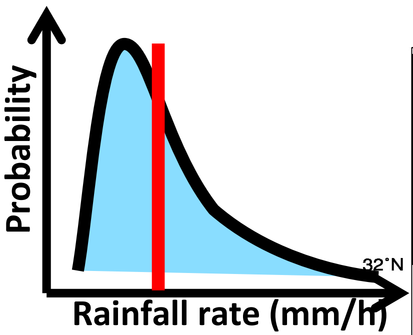

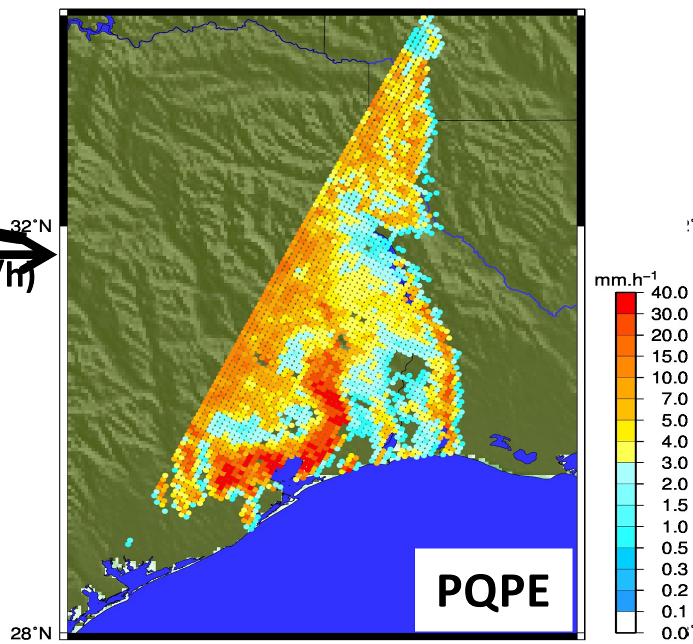

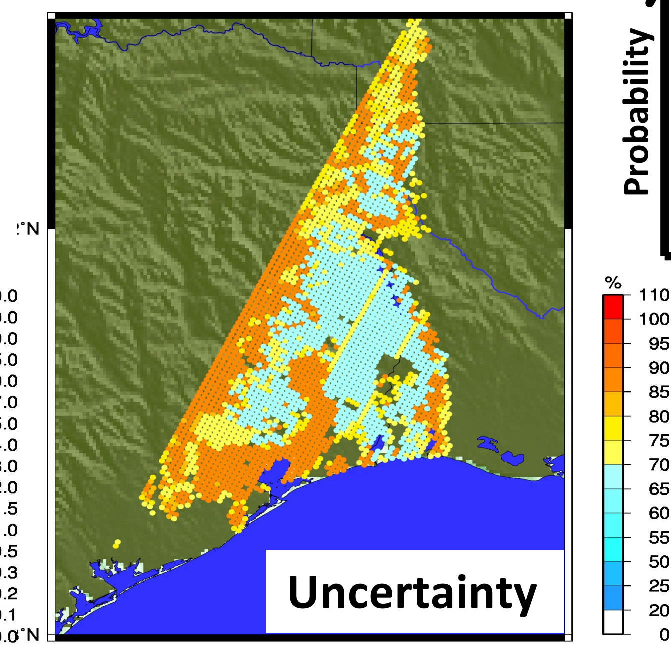

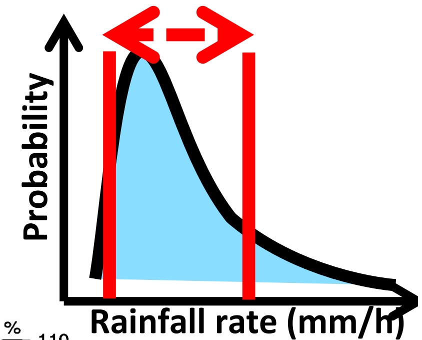

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Dual-frequency Precipitation Radar QPE relations

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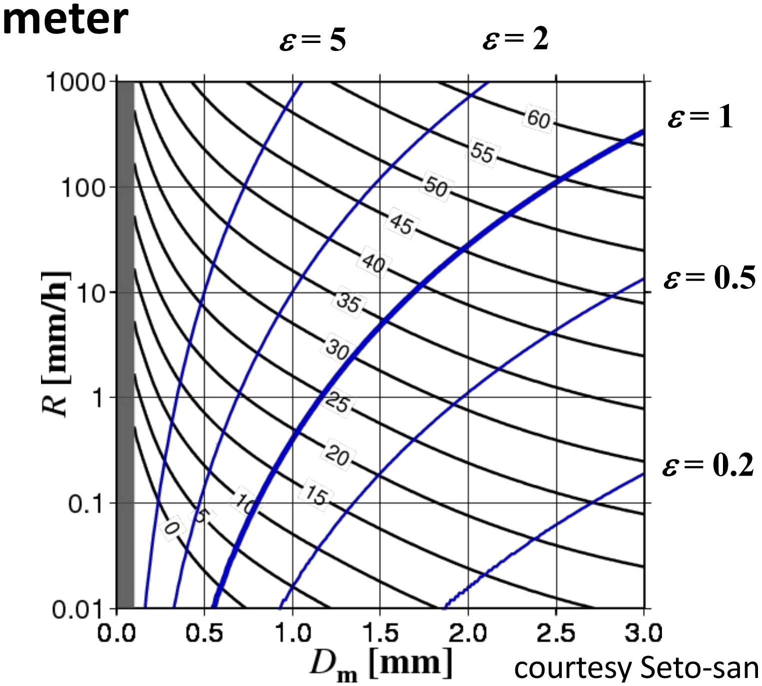
- **Questions:**
  - **Does this parameterization impact QPE?**
  - **What is the room for improvement?**
- **Methodology**
  - **stratiform: $R_{ref} \Leftrightarrow 0.401\ \varepsilon^{4.649}\ D_m^{6.131}$**
  - **convective: $R_{ref} \Leftrightarrow 1.370\ \varepsilon^{4.258}\ D_m^{5.420}$**

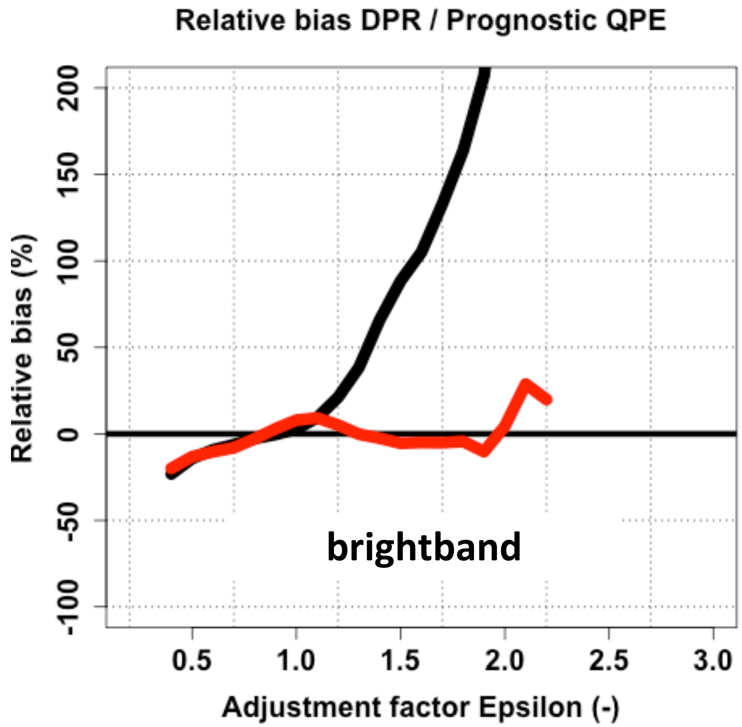


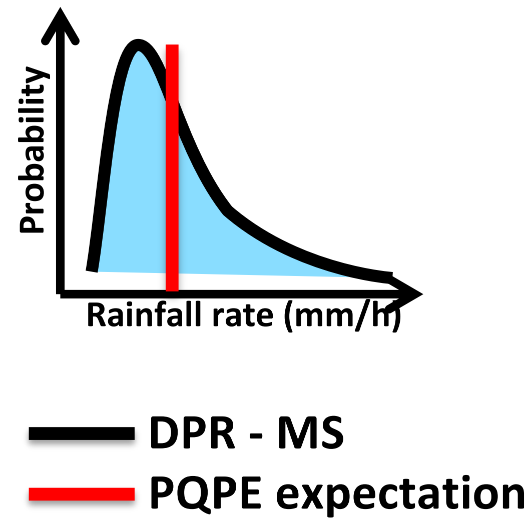
courtesy Seto-san

Dual-frequency Precipitation Radar Conditional biases with ε and Dm

DPR QPE = f (ε, $D_{m,}$ precipitation type, …) **PDF(R_{ref}) = f (ε, $D_{m,}$ precipitation type, …)**

ε





- **Data sample: sample size 2M+ matched DPR-MS & MRMS pairs over period [06/14-09/16]**

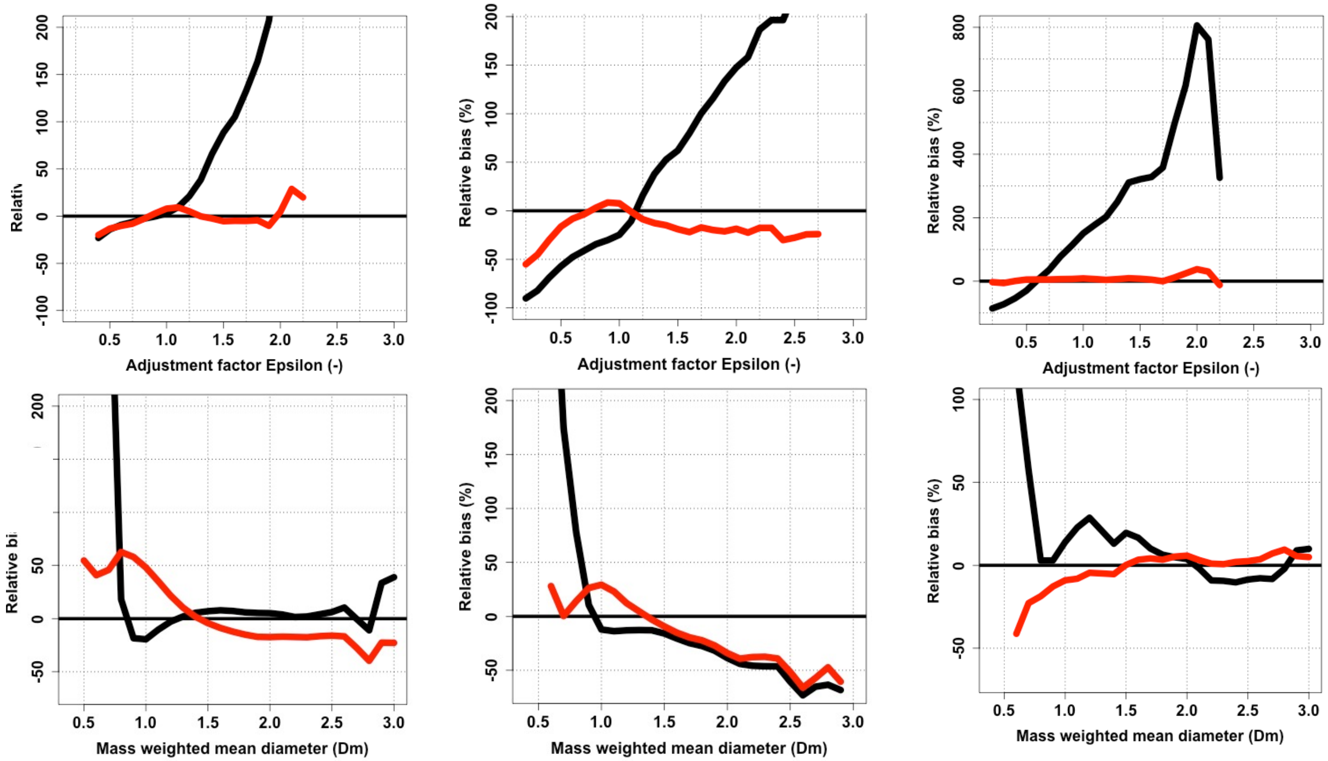
Dual-frequency Precipitation Radar Conditional biases with ε and Dm

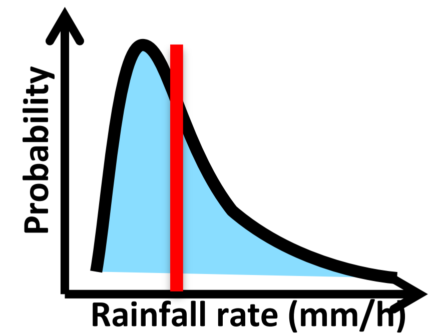
DPR QPE = f (ε, $D_{m,}$ precipitation type, …) **PDF(R_{ref}) = f (ε, $D_{m,}$ precipitation type, …)**

brightband **stratiform** **convective**

ε

D_m





DPR - MS
PQPE expectation

Dual-frequency Precipitation Radar
ε and Dm parameters

	brightband		stratiform		convective	
	ε	D_m	ε	D_m	ε	D_m
DPR	**4.65**	**6.13**	**4.65**	**6.13**	**4.26**	**5.42**
PQPE	**2.32**	**3.94**	**1.83**	**3.16**	**1.65**	**3.36**

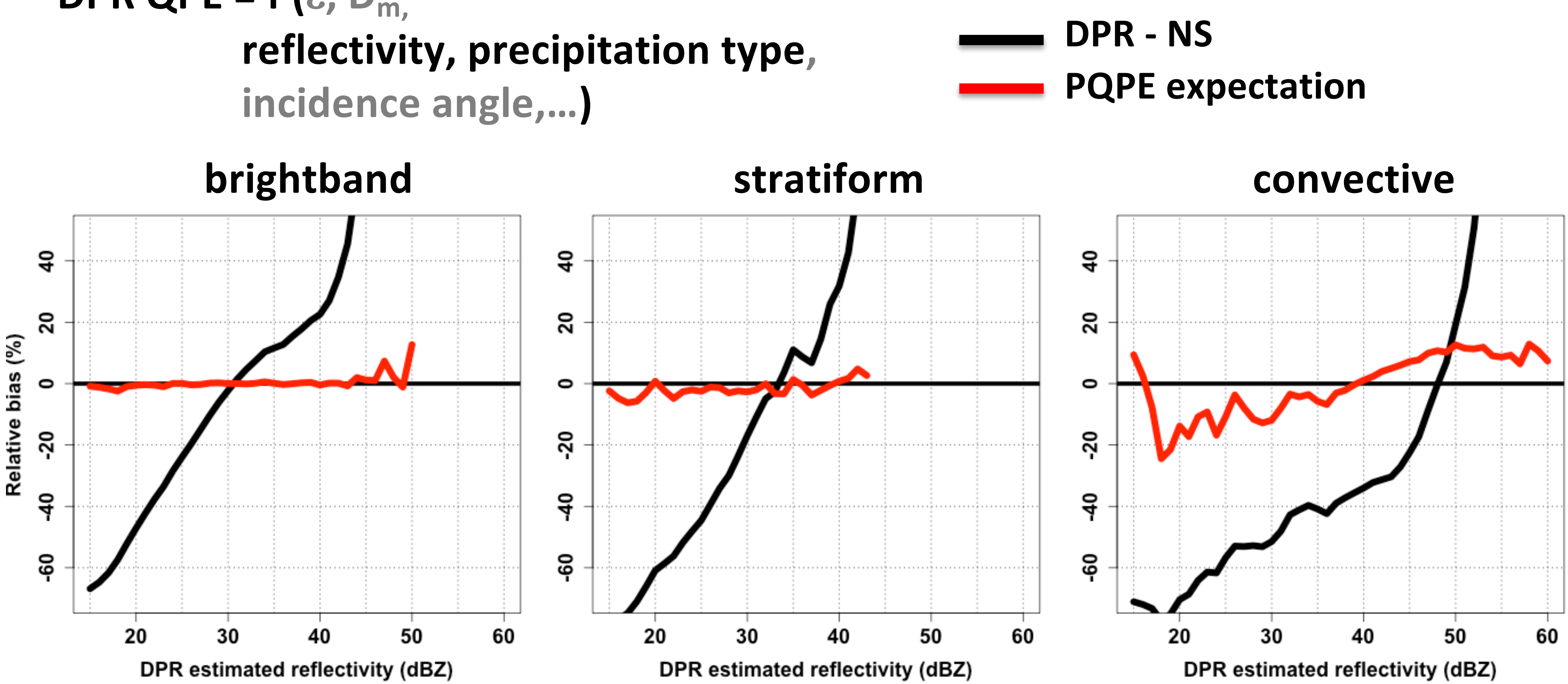
Dual-frequency Precipitation Radar scores

	brightband		stratiform		convective	
	ε	D_m	ε	D_m	ε	D_m
DPR	4.65	6.13	4.65	6.13	4.26	5.42
PQPE	2.32	3.94	1.83	3.16	1.65	3.36

	brightband		stratiform		convective	
	Bias	Correlation	Bias	Correlation	Bias	Correlation
DPR	+0.46%	0.54	-21%	0.35	-8.9%	0.37
PQPE	-0.32%	0.61	-3.3%	0.43	+2.89%	0.52

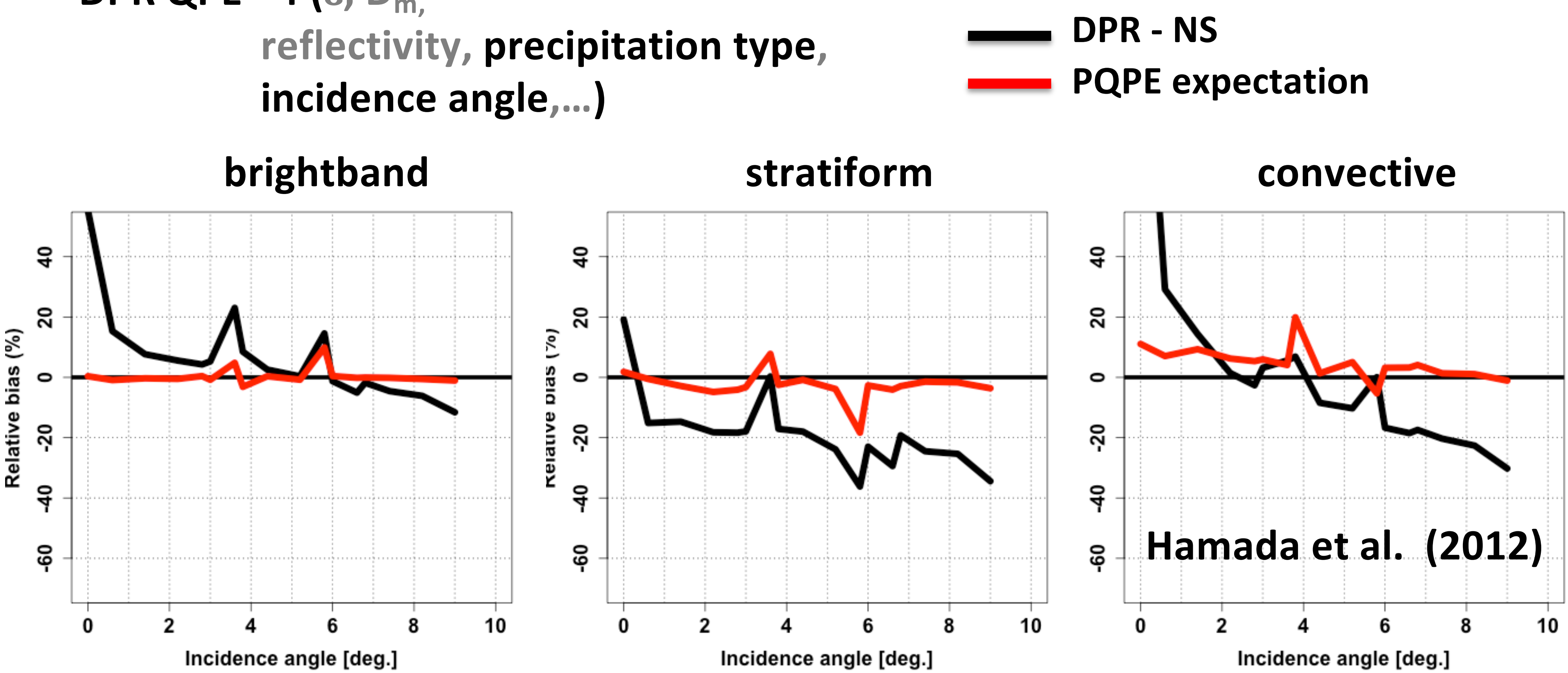
Dual-frequency Precipitation Radar Conditional biases

DPR QPE = f (ε, D_m, reflectivity, precipitation type, incidence angle,…)



Dual-frequency Precipitation Radar
Conditional biases

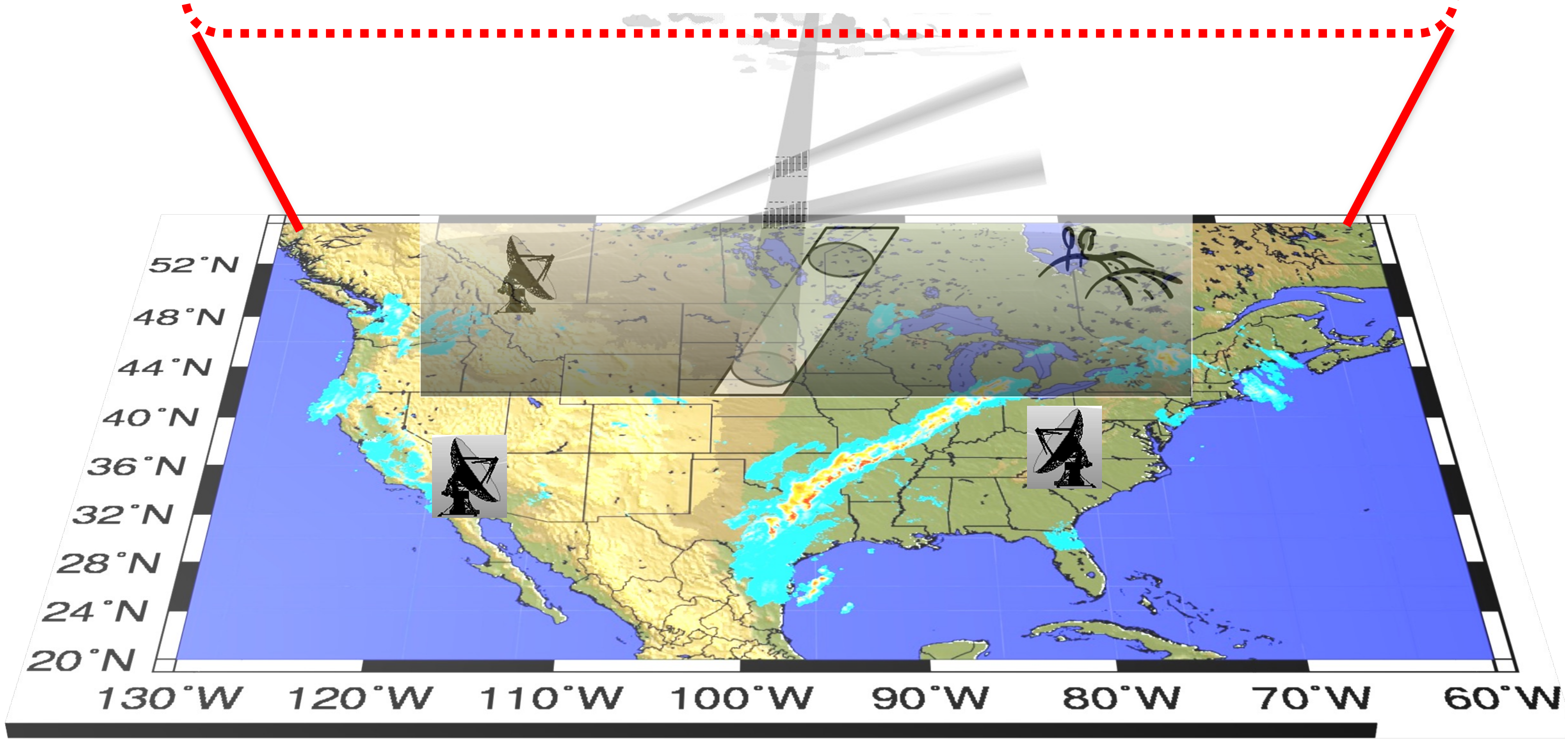
DPR QPE = f (ε, D_m, reflectivity, precipitation type, incidence angle,…)



Summary

1. **Increasing role of radar bridging across sub-orbital and orbital precipitation science and applications – cornerstone for global water fluxes.**
2. **Need to enrich QPE by explicitly integrating uncertainty and risk information through probabilistic QPE.**
3. **Preliminary results from PQPE with space-based radars:**
    1. **QPE uncertainty**
    2. **Insights into retrieval algorithm**
    3. **Algorithm parameterization adjustment**
    4. **Work with GPM-DPR version 8**

THANK YOU



- GPM Ground Validation program
- Precipitation Measuring Mission