Reconciling CloudSat and GPM Estimates of Falling Snow

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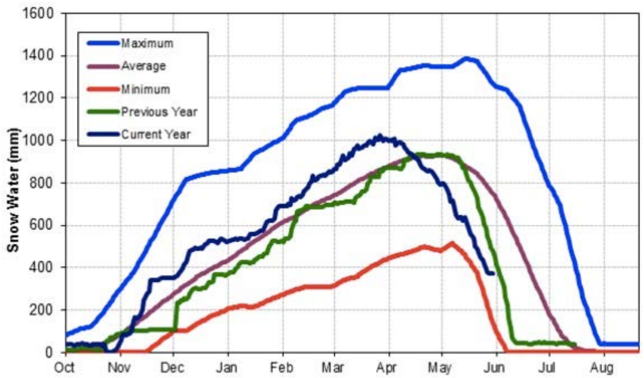
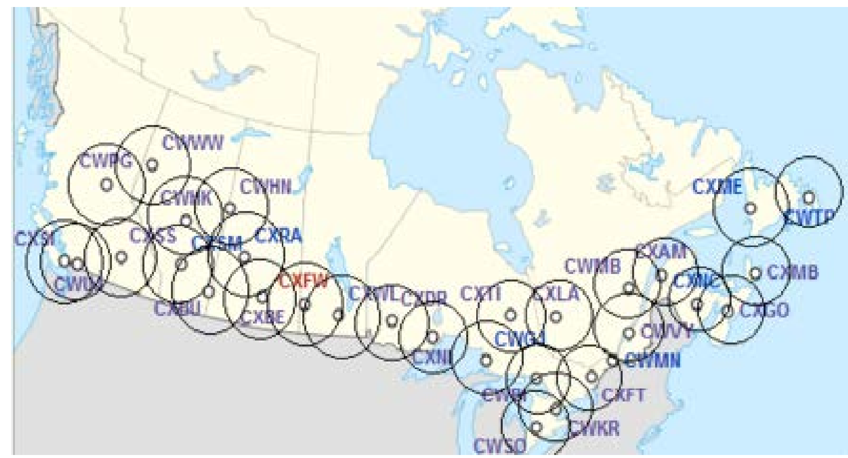
Outline

- Why measure snow from space?
- How have we measured snow from space?
- Fundamentals of snowfall estimation from radar measurements
- Comparing the CloudSat and GPM datasets
- Reconciling the CloudSat and GPM datasets

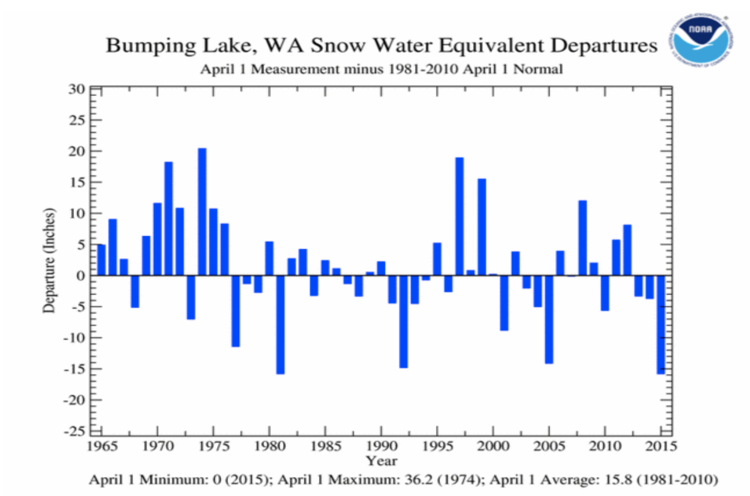
Why measure snow from space?



Importance of snow for water supply, albedo feedback



Low population where most snow falls, sparse ground instrumentation and radars



Polar regions where climate changing most rapidly; how is the relationship between snowfall and snowpack changing?

How have we measured snow from space?

- Passive microwave radiometers (SSMI, AMSR-E/2, MHS, …)
- TRMM (1997-2015) Ku-band radar + TMI
- **CloudSat** (2006-present) W-band radar
- **GPM** (2014-present) Ku+Ka band radar + GMI

How do we measure snowfall rate with radar?

- Radar equation for distributed targets:

$$\overline{P_R} = \frac{c\pi^3}{1024\ln(2)} \frac{\overline{P_T}\tau G^2\Phi^2}{\lambda^2} \frac{|K|^2 Z_e}{r^2}$$

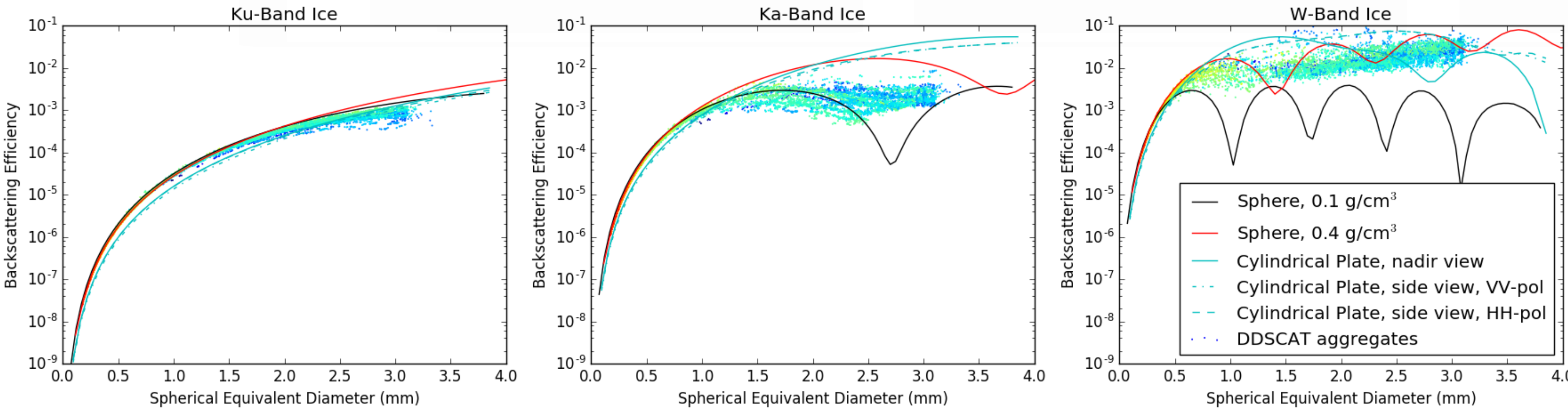
constants — Radar properties — Target properties

- Equivalent reflectivity factor Z_e is defined as:

$$Z_e = \frac{\lambda^4}{\pi^5 |K|^2} \int_{D_{min}}^{D_{max}} N(D,s)\sigma_b(D,s,\lambda)dD$$

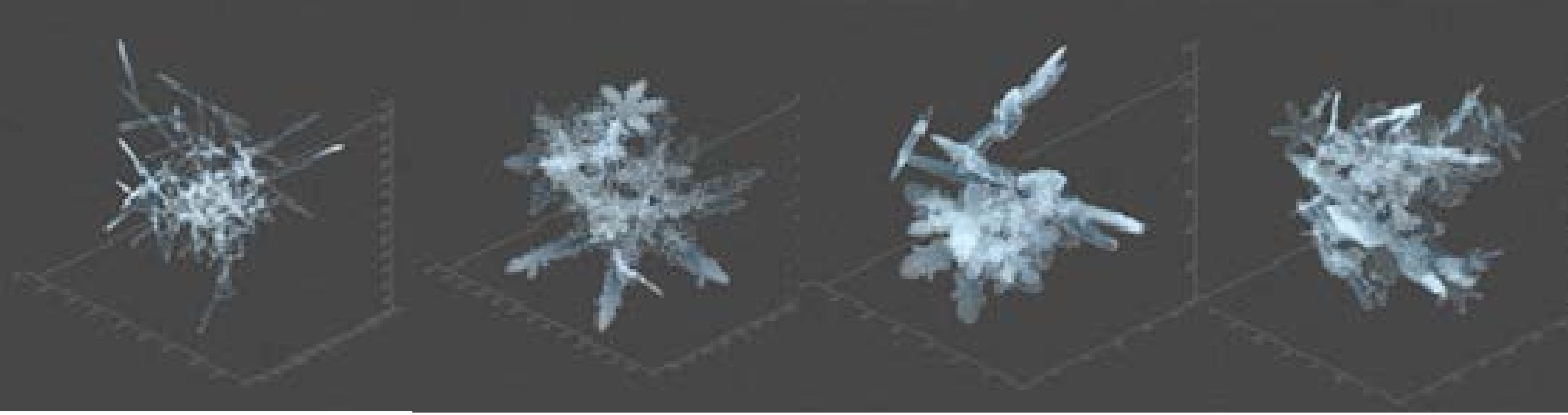
Relating Reflectivity to Snowfall Rate

$$Z_e = \frac{\lambda^4}{\pi^5 |K|^2} \int_{D_{min}}^{D_{max}} N(D,s)\sigma_b(D,s,\lambda)dD$$



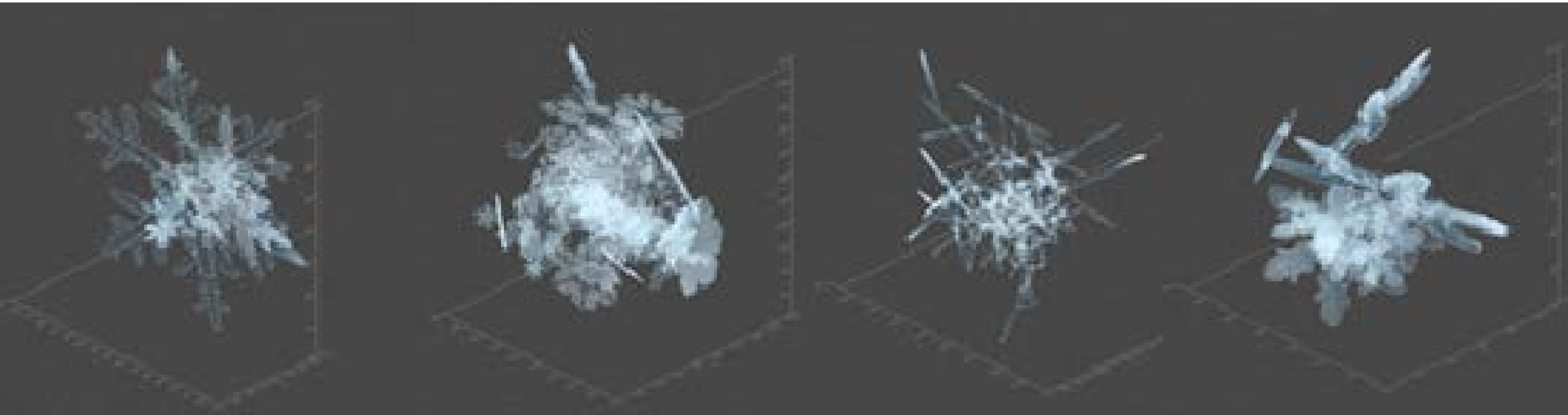
When D << , σ_b proportional to D6 (Rayleigh scattering).
When D ≈ λ, σ_b depends on shape and roughly proportional to D^2.

$$S = \frac{\pi\rho_i}{6} \int_{D_{min}}^{D_{max}} N(D,s)D^3 v_t(D,s)dD$$



In summary, relationship between Z and S is ambiguous because of:
-Different dependence on particle size
-Different dependence on particle shape

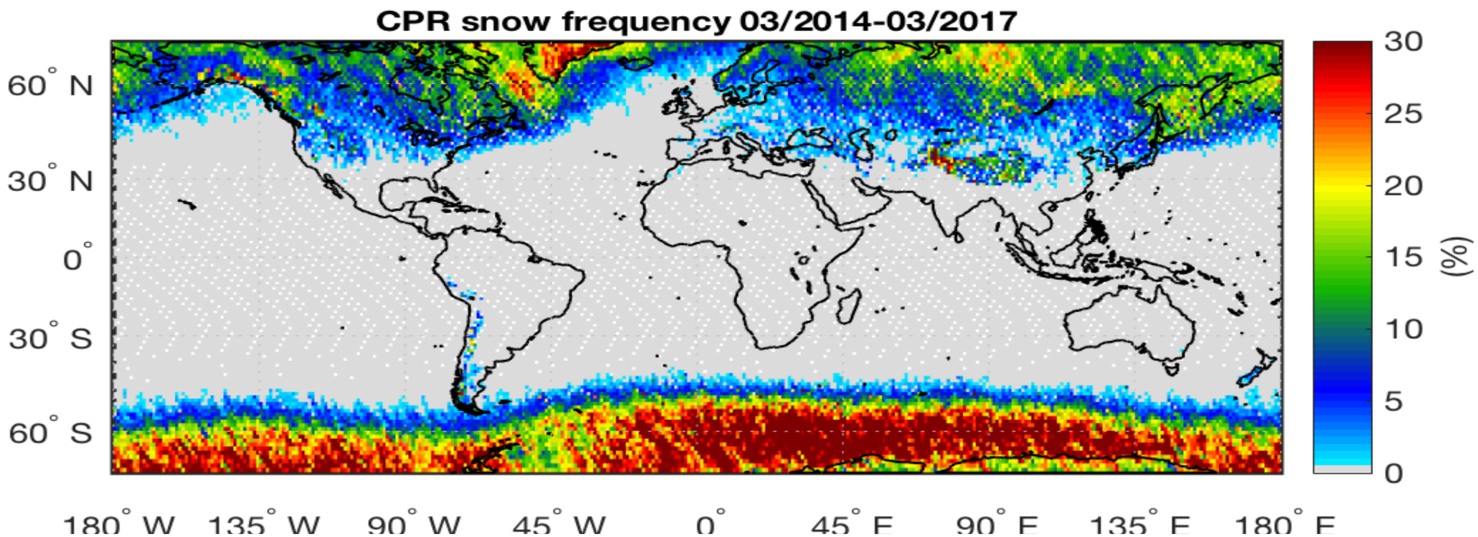
Multi-frequency measurements can provide further constraints on size/shape, and passive microwave radiometry can constrain column-integrated ice mass.

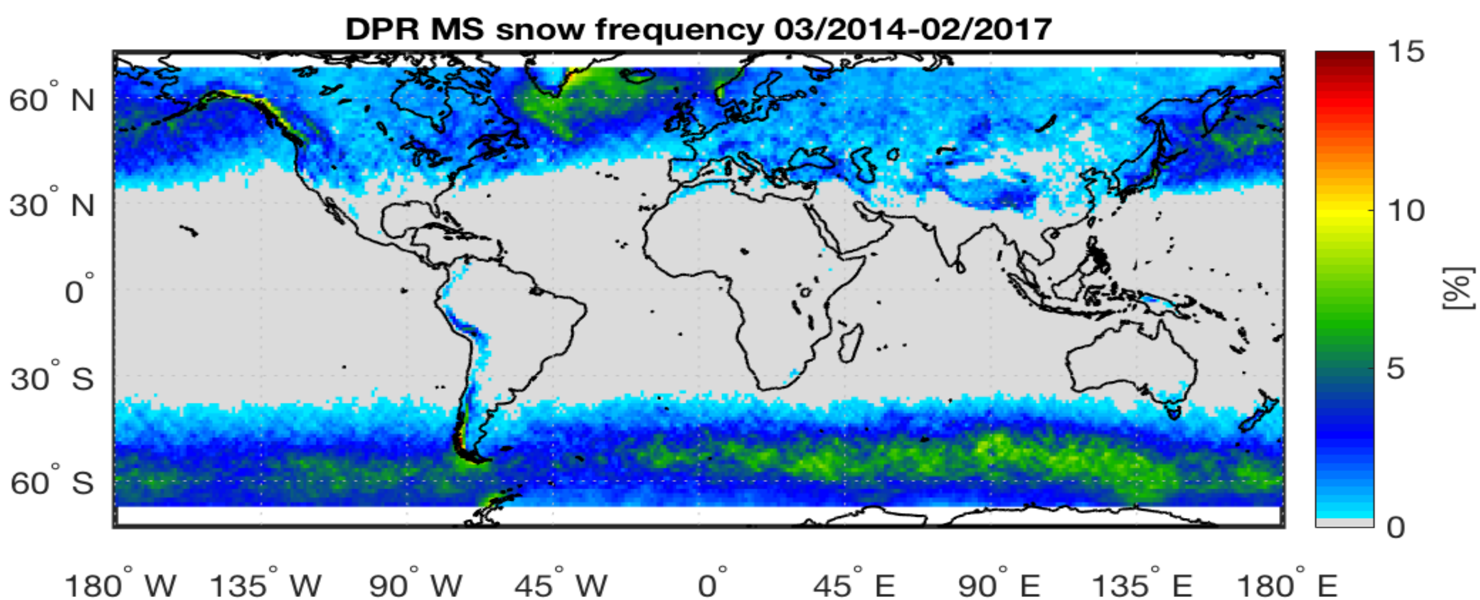


Comparing the CloudSat CPR and GPM DPR

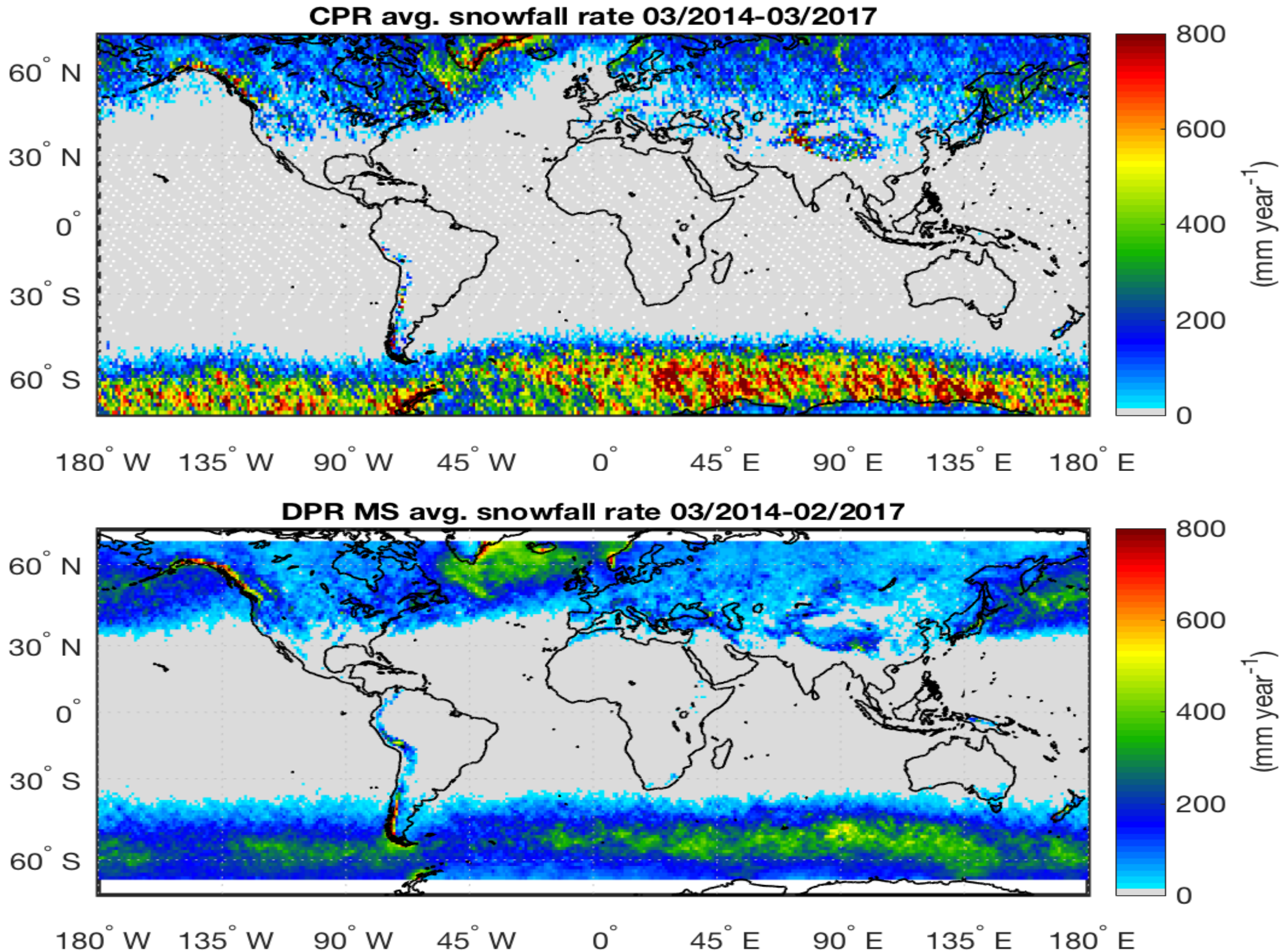
	CPR	DPR	
		KuPR	KaPR
Frequency	94 GHz	13.6 GHz	35.5 GHz
Footprint size	~ 1.7 x 1.4 km^2	5.05 – 5.60 km of diameter	
Near surf. bin	~ 720 - 1200 m	~ 750 - 2500 m	
Sensitivity	~ - 29 dBZ	~12-13 dBZ	~12-13 dBZ HS ~17-18 dBZ MS
Snowfall retrieval products	2C-SNOW-PROFILE R04	2A DPR V05 (ITE114)	
Scanning mode	Nadir pointing	Cross track	

CloudSat vs. GPM: Snow occurrence

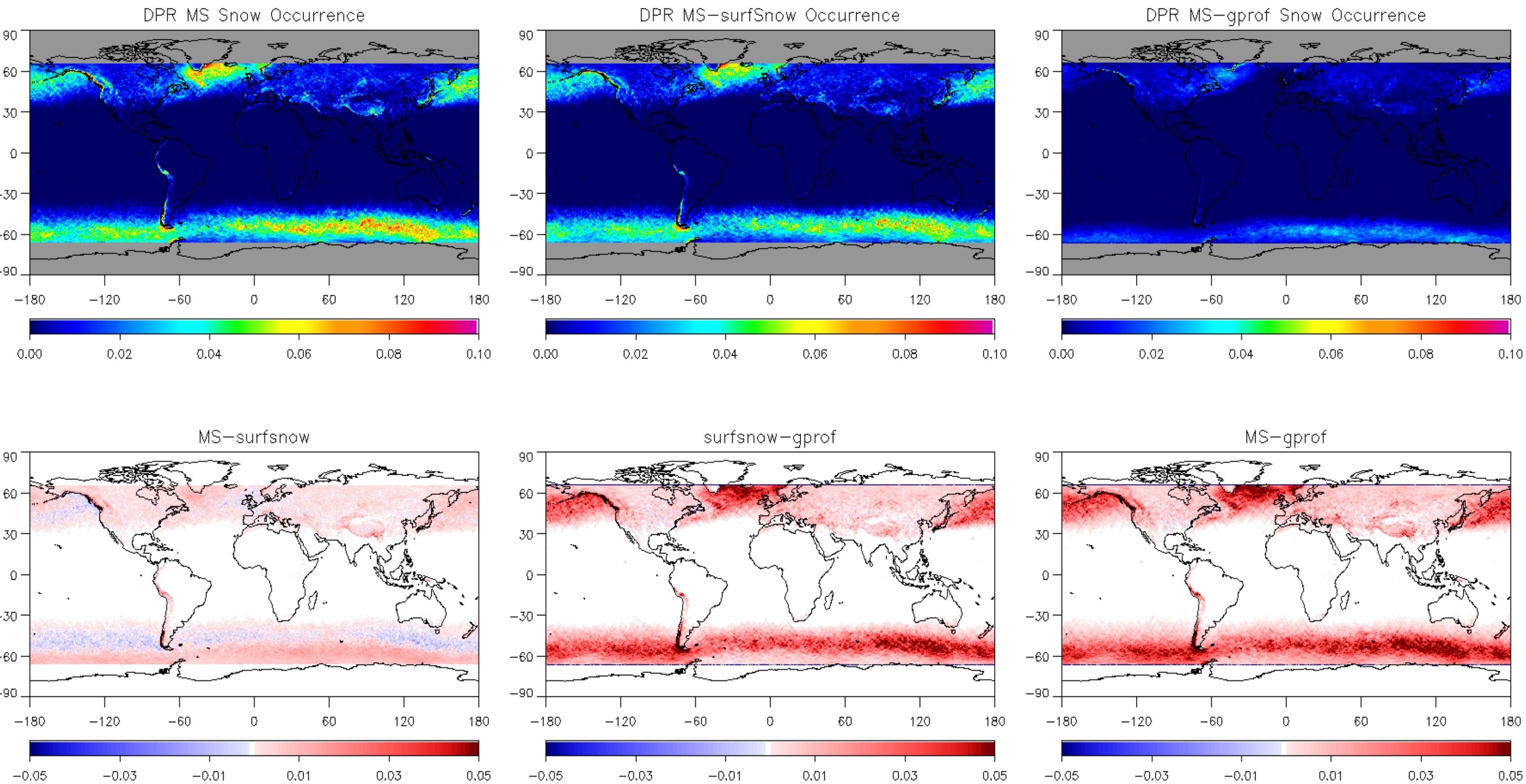




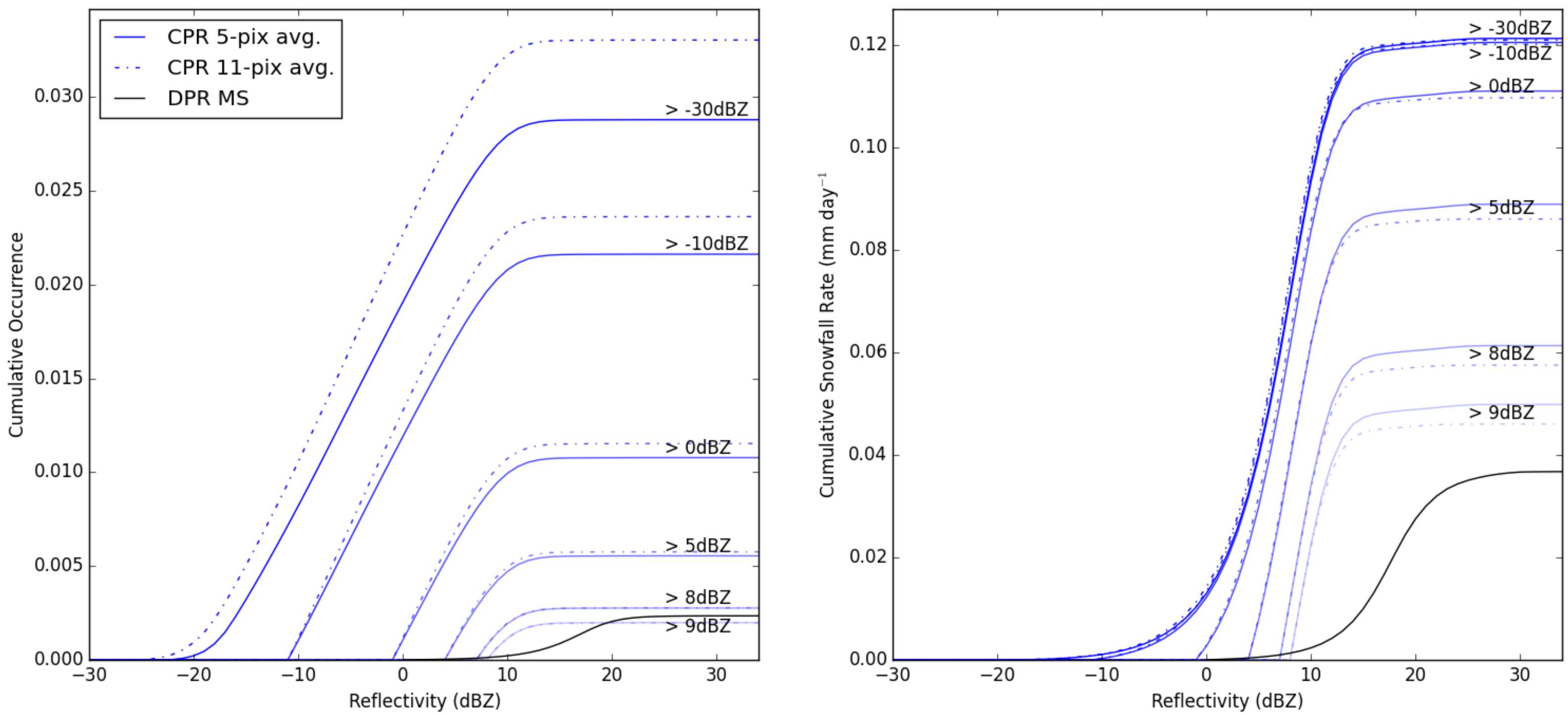
CloudSat vs. GPM: Snow amount



Accounting for differences in phase discrimination



Accounting for differences in instrument sensitivity

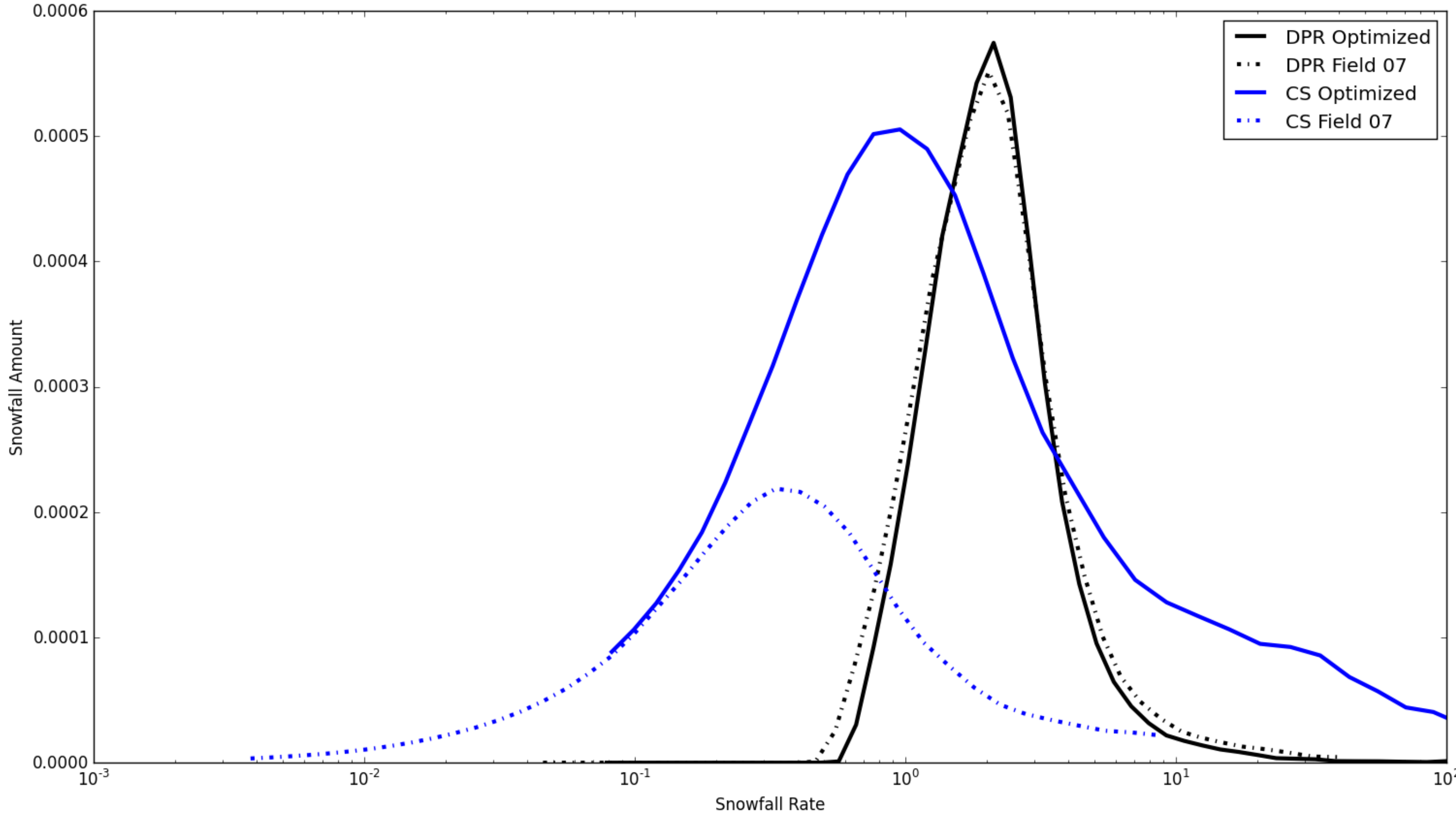


DPR and CloudSat algorithms use different scattering models and PSD assumptions. What happens when we use the same ones for both datasets?

Scattering model: Ensemble of aggregates (Kwo et al., 2016)

PSD model: a) Field et al., 2007

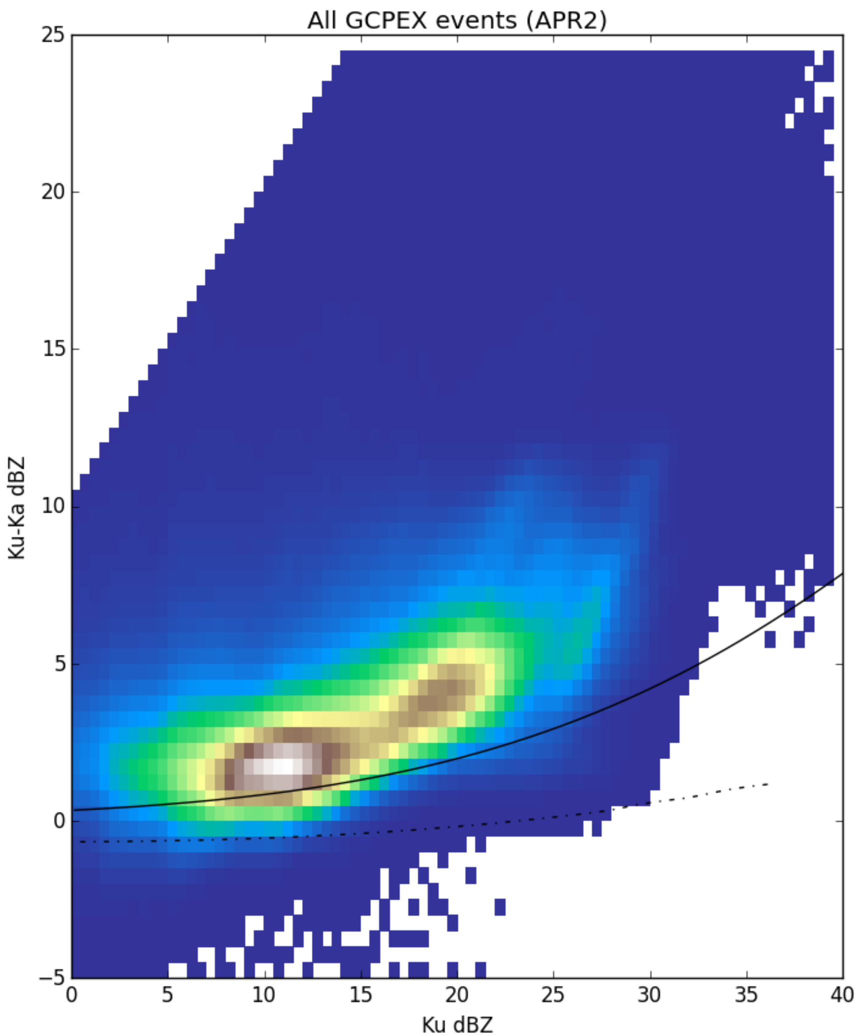
b) Gamma with constant μ=2 and optimize $N_w = f(D_m)$

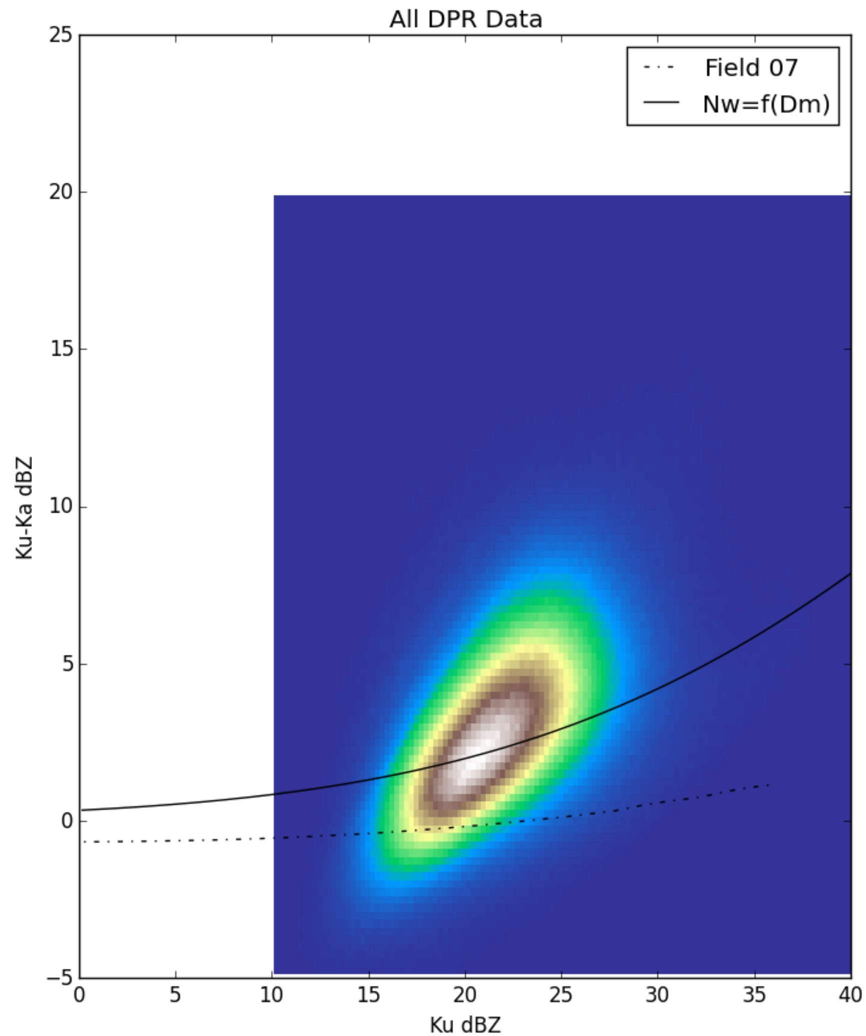


Apply to CloudSat, DPR datasets

Instrument	Global Snow Occurrence (%)	Global Snow Rate (mm/day)
CloudSat (native)	2.422	0.123
DPR (MS)	0.262	0.040
CloudSat (averaged & truncated to DPR)	0.277	0.061
DPR (Field et al., 2007)	0.262	0.110
DPR (N_w=f(D_m))	0.262	**0.115**
CloudSat (Field et al., 2007)	2.422	0.071
CloudSat (Field et al., 2007 truncated)	0.277	0.042
CloudSat (N_w=f(D_m))	2.422	0.170
CloudSat (N_w=f(D_m), truncated)	0.277	**0.115**

Check for consistency with APR-2 and DPR Ku vs. Ku-Ka measurements





Summary

- Estimation of falling snow from spaceborne radar is a difficult problem & less well-constrained than rainfall estimates
- CloudSat and GPM offer complementary radar-based snowfall products, but large discrepancies exist due to:
  - Rain/snow discrimination
  - Instrument properties
  - Scattering model and PSD assumptions
- Attempts to reconcile GPM and CloudSat require **common** & **accurate** assumptions for scattering and PSD.
  - Field et al., 2007 PSD not consistent with CloudSat and DPR data
  - A linear N_w-D_m relationship can provide consistent CloudSat and DPR global snowfall estimates, but significant variability exists
- Global triple-frequency (Ku+Ka+W) radar measurements with sensitivity <= 0 dBZ are needed to further refine global snowfall rate!