Detection and use of Multiple Scattering and Non-Uniform Beam Filling in DPR data

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Overview

- Detect Multiple Scattering (MS)
  - Detect the DWR Knee
  - Detect the MS Tail
- Detect Non-Uniform Beam Filling (NUBF)
  - Detect PIA ratio departure
  - Detect horizontal variability of neighboring profiles
  - Detect multi-beam signatures on off-nadir surface echoes
- COMBINE these two diagnoses and decide what to do about solving the profile
- Solve

- The primary goal of this detection is to identify which DPR profiles are NOT AFFECTED by significant MS & NUBF.
  - Enable use of DFR_m in the standard solver
- Second purpose:
  - Provide the standard solver with a measure of NUBF when only NUBF is present

- The primary purpose of a MS-based retrieval module is to retrieve available information contained in MS-affected profiles and the associated uncertainty

Ka-band structure observed by RainCube during PECAN (June 28, July 15 2015)

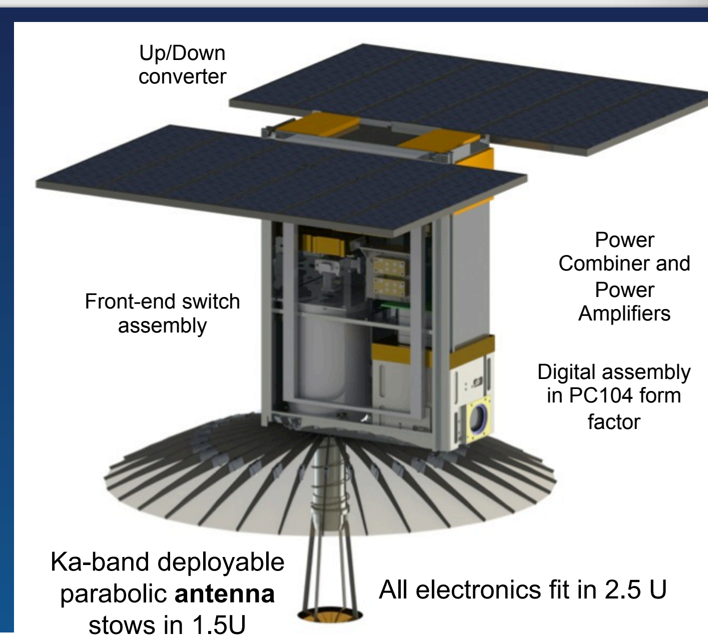
RainCube is a Ka band vertical profiler of precipitation for 6U cubesats (E. Peral, PI)

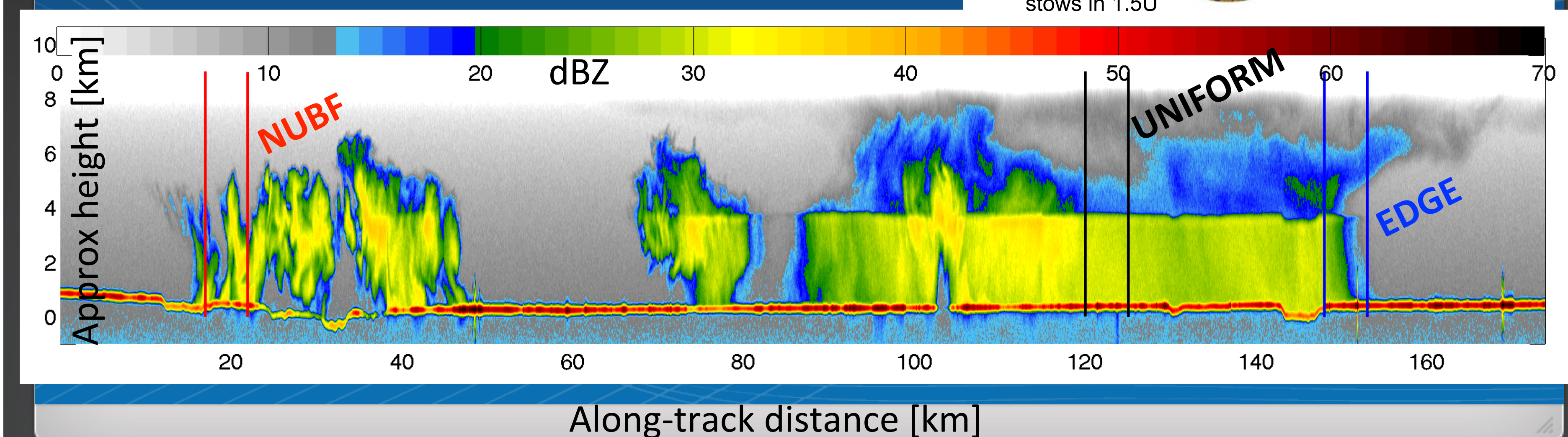
Maiden experiment demonstrated :

- Overall performance of all electronics – no failures or performance degradations during the entire experiment.
- Pulse Compression with better than 70 dB sidelobe level.

Preliminary calibration shows expected radar reflectivity structures.

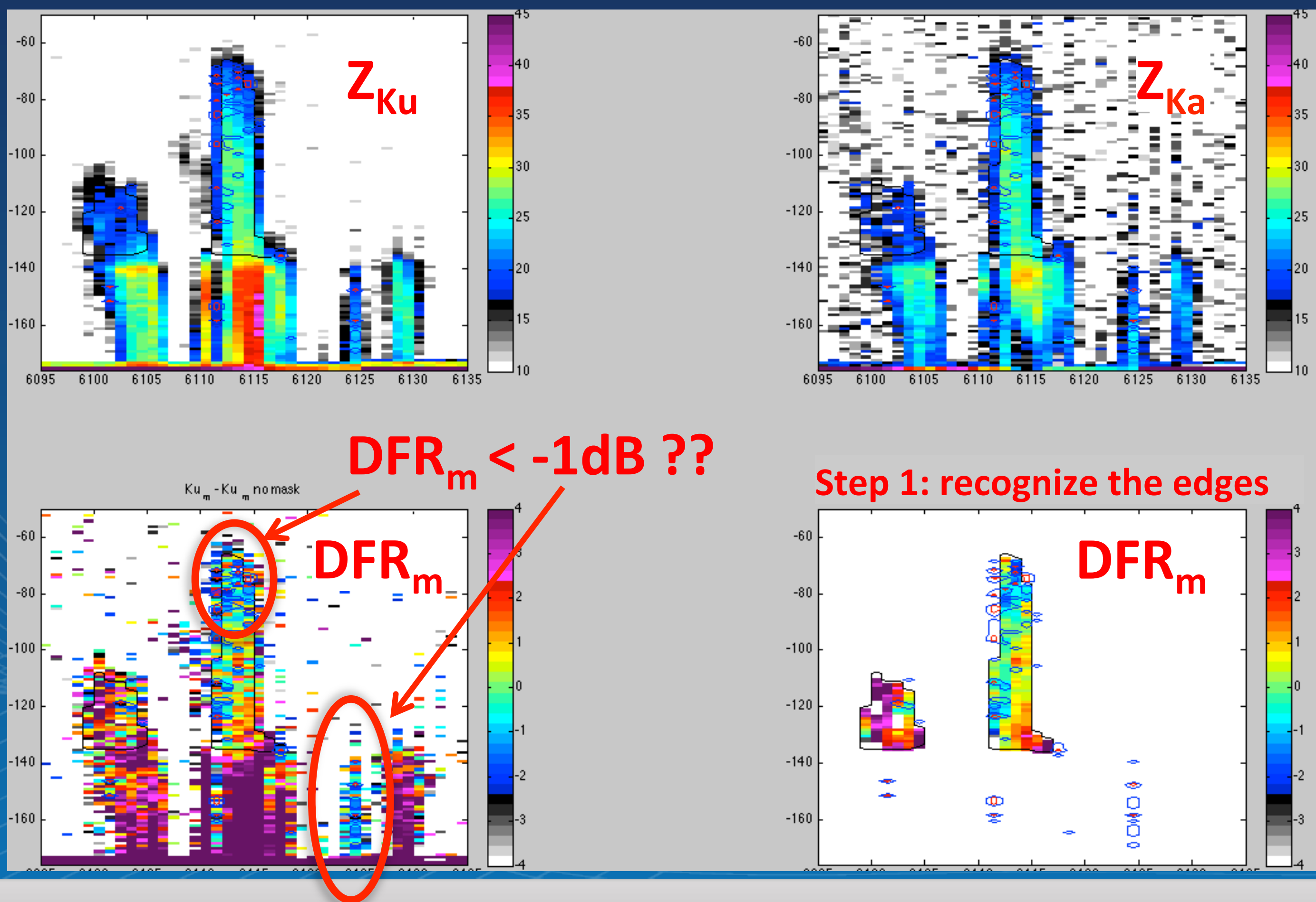
Collaboration with OU enabled acquisition of collocated ground radar data for validation.





High-Priority: enable use of DFRm wherever possible

- Anomalously large occurrence of negative DFRm doesn't reconcile with basic scattering principles. Is it calibration, is it processing, … ?



DFR_m statistics in different conditions

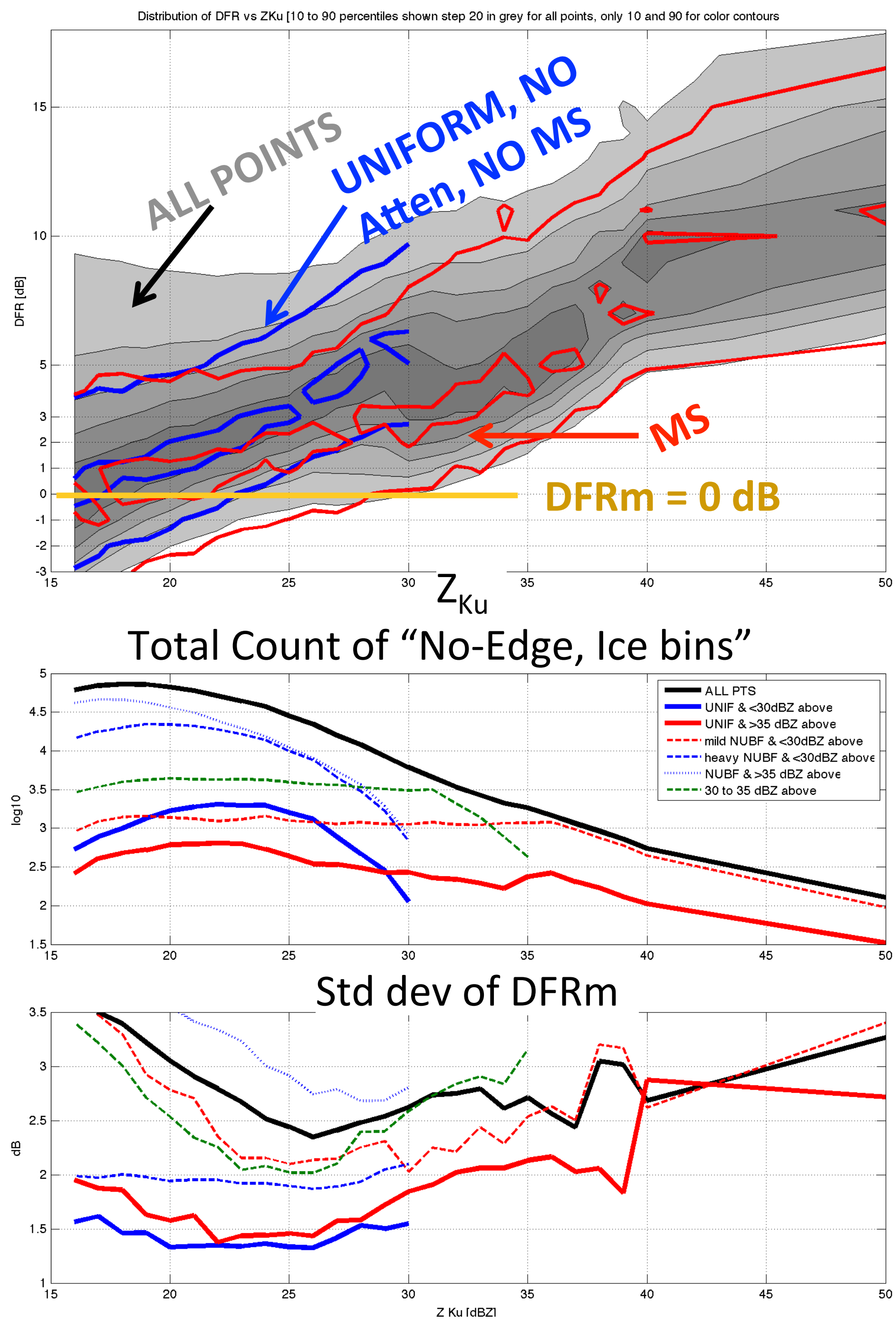
Black/grey: All points are the grey histogram in top plot. Each column is normalized by its max.

Blue: points where all the 8 Ka band neighbors at the same range do not differ by more than 3 dB (i.e., |dZKa| < 3 dB), and no MS is detected. These are uniformly distributed, not multiply scattered echoes from low density aggregates.

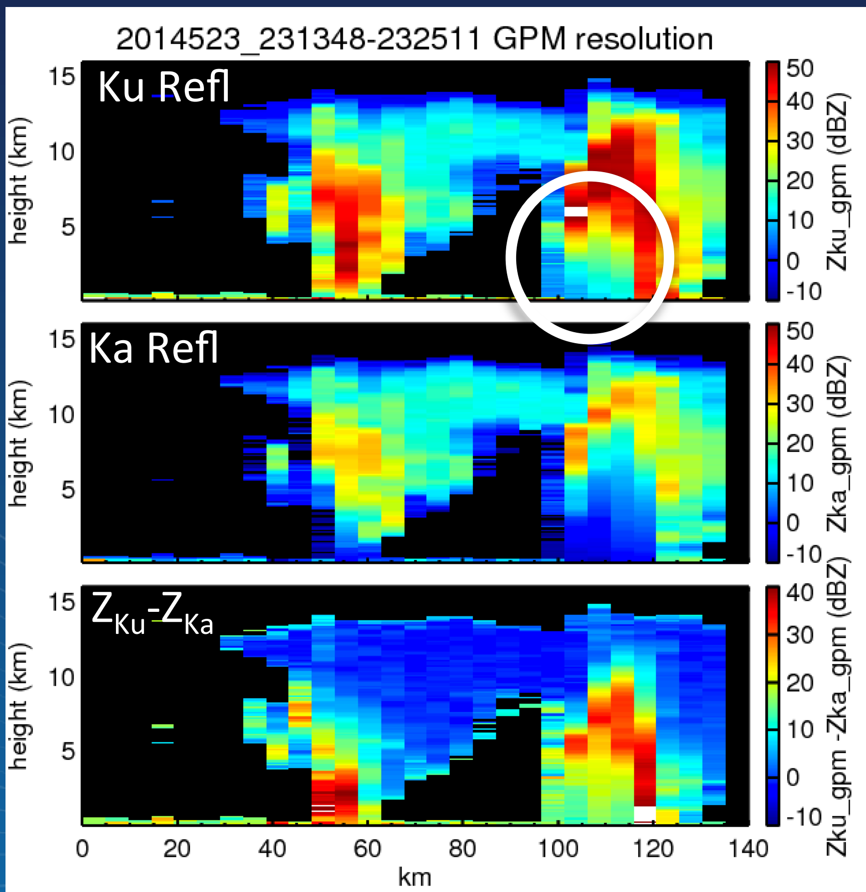
Note the lowest std dev, and highest occurrence between 20 and 26 dBZ. The dash blue curves in the lowest plots show points where 3 < |dZKa| < 6 dB (moderate NUBF) and dot where |dZKa| > 6 dB (heavy NUBF).

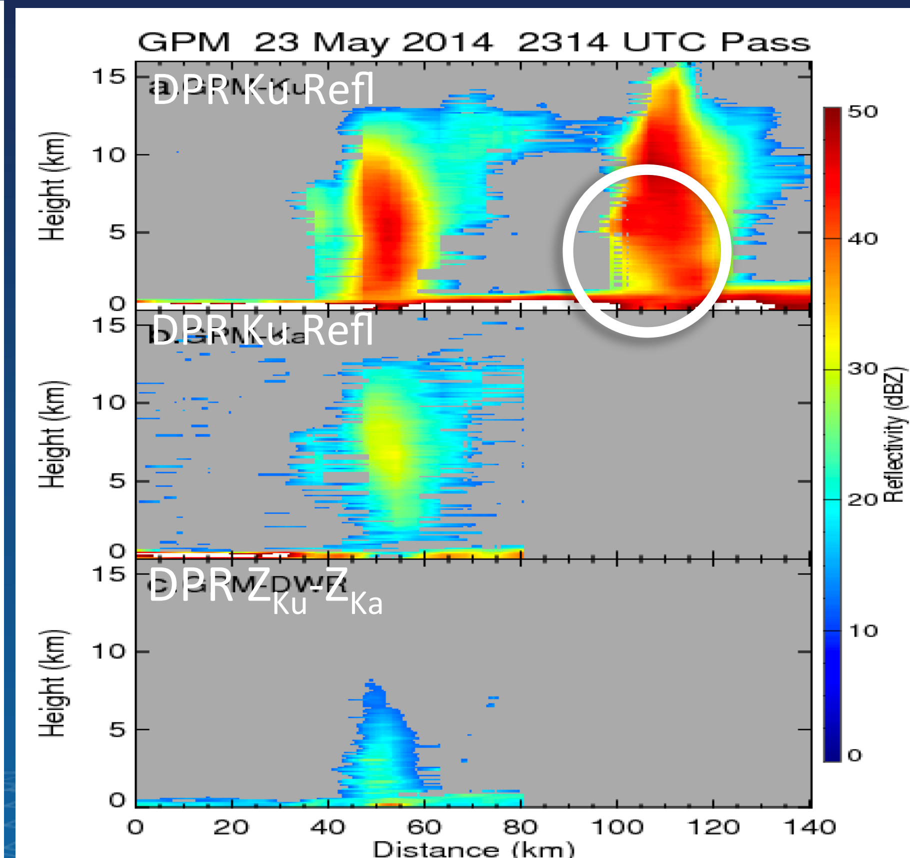
Red: subset of points where max Z_{Ku} in the profile was in excess of 35 dBZ. Solid is |dZKa| < 6 dB, dash is for |dZKa| > 6 dB. These are not many, but they create that second mode visible in the top plot that dominates the high end. It is shifted down probably because of MS: MS Ka increases Z_{Ka} more than Z_{ku} and therefore biases DFRm negatively.

Green: the rest of the points, no man land between likely MS and surely no MS.



23 May 2014 HIWRAP: DPR Resolution & DPR: 2321UTC (courtesy of G. Heymsfield, GSFC)



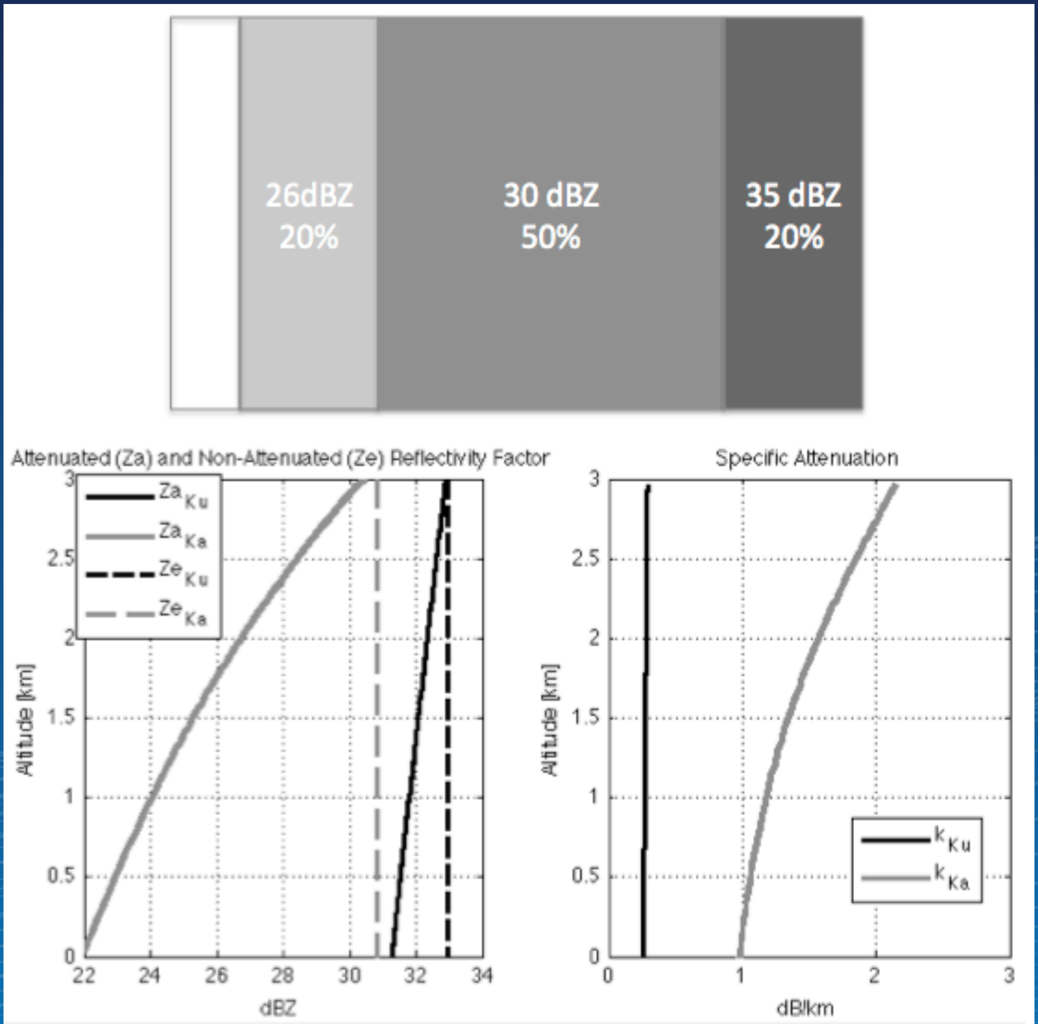


- DPR Data: Special level-2 products provided by Drs. Kubota and Iguchi due to DPR sidelobe reduction test period.

Non-Uniform Beam Filling

The 'column model'

- Non-Uniform Beam Filling = inhomogeneity in the field of reflectivity across the radar beam
- Column Model = the pattern of NUBF is completely correlated along range
- This model was adopted since the first studies (e.g., Nakamura et al. 1991) and is well suited to explain the nature of the problem.
- The higher the specific attenuation the stringer the impact of NUBF➔ higher frequencies are more affected.

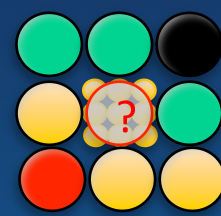


Theoretical Framework

The coefficient of variation

- Key parameter describing the degree of NUBF was defined in Iguchi et al. (2000, 2000, 2009).
- In single-frequency systems (TRMM/PR) an estimate of σ_n within the FOV was obtained from the observable σ_n over an 9-neighborhood of FOVs.
- The σ_n is then used to calculate correction factors in the retrieval.
- Alternative approaches for off-nadir beams rely on the range-resolved returns (Meneghini et al. 2012).
- Additional statistical studies provide the means to apply this parameter also to non-column NUBF (Short et al. 2012)

$$\sigma_n = \frac{\sigma_{PIA}}{PIA}$$



$\sigma_{n,ext}$

$$C'_{SR} = 1 + \frac{\sigma_n^2}{\beta}$$

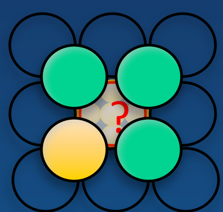
Our question:

Can co-located multi-frequency measures of NRCS provide a measure of σ_n?

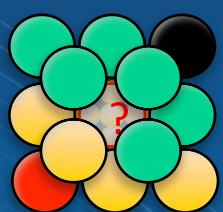
Theoretical Framework

The coefficient of variation

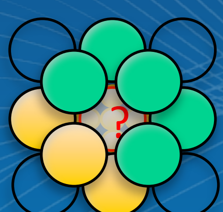
TRMM/PR approach — <0.5



GPM/DPR HS Only — ~0.6



GPM/DPR HS & MS — ~0.65

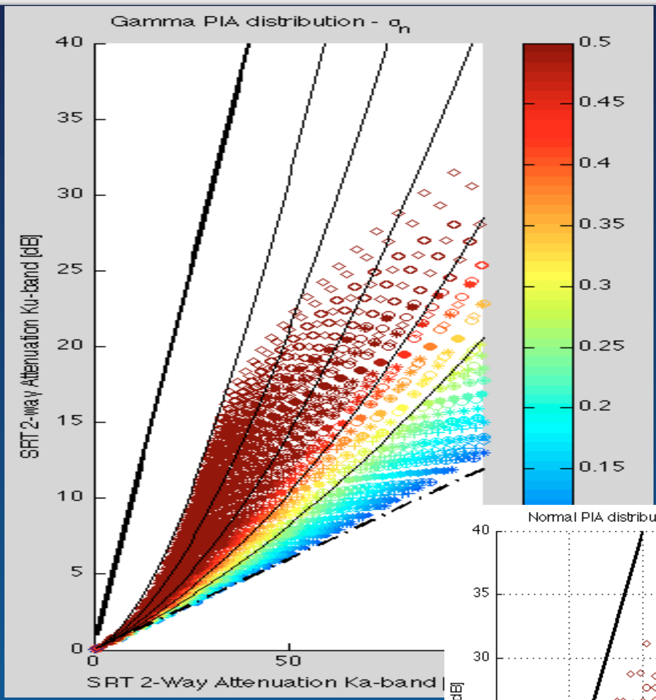


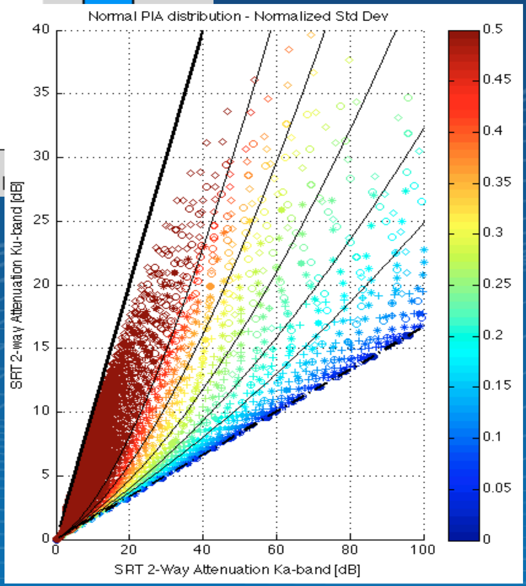
Best performer — ~0.7

Theoretical Framework

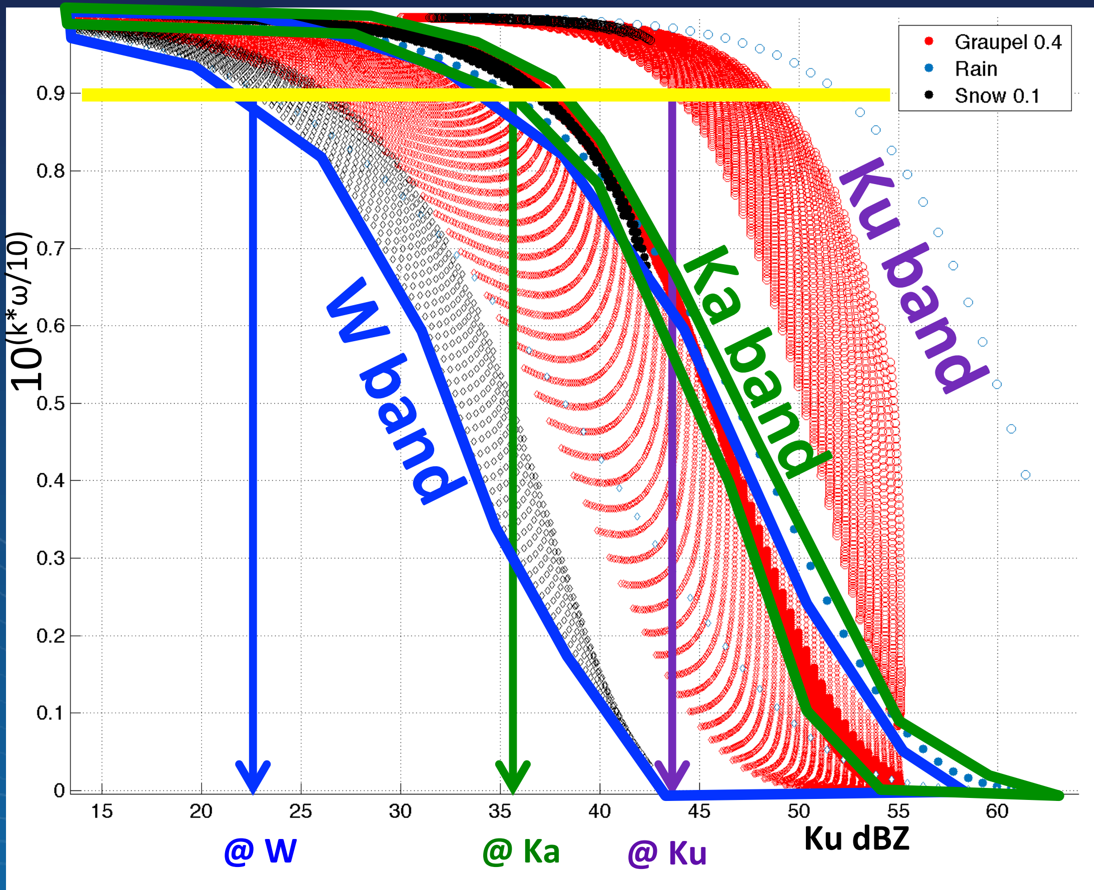
Coefficient of variation vs. multi-frequency PIA

- In the TRMM operational algorithm two shapes have been considered (Iguchi et al. '00, '09):
  - Gamma
  - Log Normal
- The corresponding correction terms have been shown to be comparable.
- They enable elegant analytical solutions.
- How well do these classical monomodal distributions capture the actual distribution of PIA within a 5 km FOV?
- A 'Delta-clear + Gaussian-Rain' simple model is also explored in this paper.



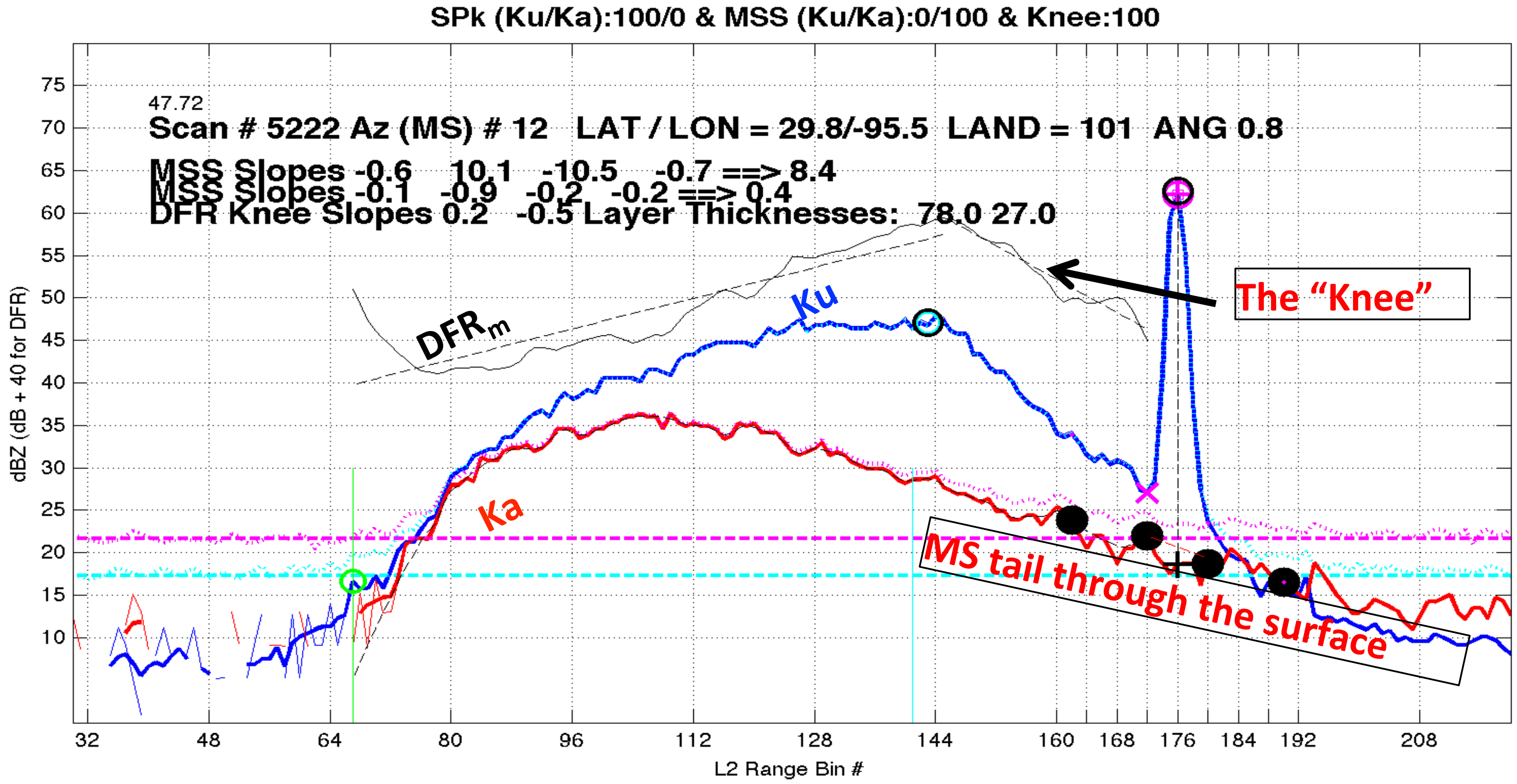


Onset of MS (a very rough rule of thumb)



W-band : almost any kind of precipitation within the TRMM PR/GPM DPR detection range
Ka-band : requires moderate precipitation, at least ~ 5 mm/hr (35 dBZ),either solid or liquid
Ku-band : requires extreme frozen or mixed-phase precipitation

The MS detection criteria



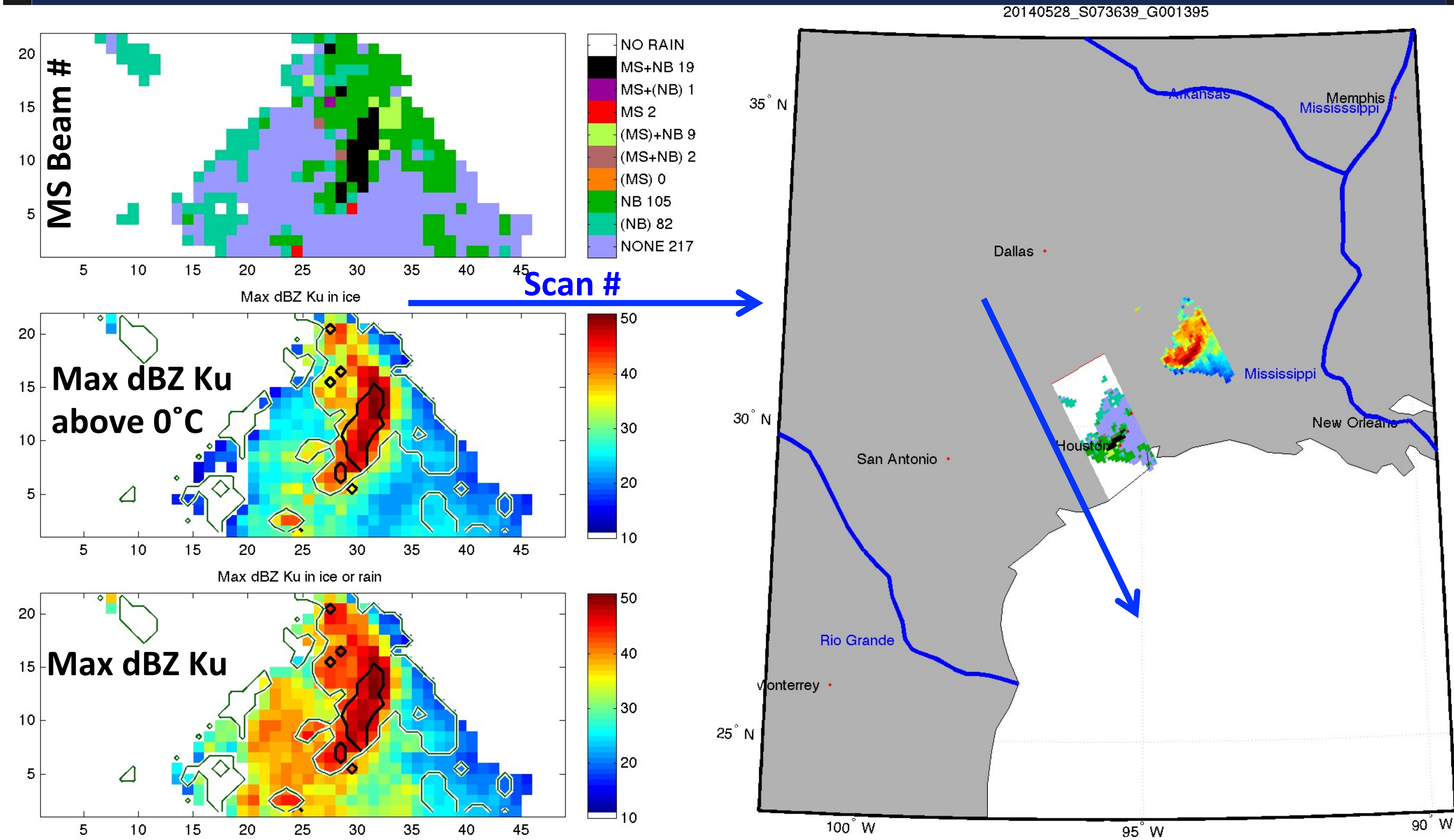
DPR's view of that storm

	NO NUBF	POSSIBLE NUBF	CERTAIN NUBF
NO MS	**"NONE"** Evidence of moderate or strong MS or NUBF is not detected. This does not imply that mild MS or NUBF are not present, or unlikely. They may very well still be present but they are not strong. A retrieval that doesn't account for NUBF or MS may produce errors with additional uncertainty, but not larger than all the standard sources of uncertainty.	**(NB)** Some features of the profile appear anomalous. Possible NUBF. No MS detected. These profiles are associated with a definitely negative check for MS, but either the HS or the PIA indicate that NUBF is possible. These profiles should be handled by a solver that is based on SS but accounts to some extent for NUBF (e.g., the new Solver by Seto). Two parameters are produced: the normalized std dev of Ka-PIA and the fraction of empty.	**NB** NUBF signatures detected. No MS detected. These profiles are associated with a definitely negative check for MS, but either the HS or the PIA indicate that NUBF is possible. These profiles should be handled by a solver that is based on SS but accounts to some extent for NUBF (e.g., the new Solver by Seto). Two parameters are produced: the normalized std dev of Ka-PIA and the fraction of empty.
POSSIBLE MS	**(MS)** Some features of the profile appear anomalous. Possible MS. No NUBF detected. These profiles may include MS effects, but poor quality of the relevant signals doesn't allow to be sure about it. Usually the most limiting factor is the Ka-sensitivity. These profiles should be handled by a solver that is based on SS and one based on MS to verify if solutions converge.	**(MS + NB)** Some features of the profile appear anomalous. No clear answer about NUBF and MS. This is the worst kind of diagnose. These profiles often exhibit features that are quite difficult to interpret even in a supervised manner. An ensemble of solvers should be used to at least characterize the overall uncertainty of the retrieved solutons.	**(MS) + NB** NUBF detected. MS possible. These profiles often exhibit features that are quite difficult to interpret even in a supervised manner. An ensemble of solvers should be used to at least characterize the overall uncertainty of the retrieved solutons.
MS	**MS** MS detected. No NUBF detected. Using an SS based solver will cause grossly erroneous retrievals. MS-based solvers have been developed and are being validated.	**MS + (NB)** Signatures of MS are present. Possible NUBF. In this case the NUBF "may modulate" the MS tail. Using an SS based solver will cause grossly erroneous retrievals. Using an MS solver without NUBF will produce occasionally biased retrievals but with uncertainties not too dissimilar from the standard product.	**MS + NB** Signatures of MS and NUBF are present. In this case the NUBF "modulates" the MS tail. Using an SS based solver will cause grossly erroneous retrievals. Using an MS solver without NUBF will produce possibly biased retrievals but with uncertainties not too dissimilar from the standard product. No NUBF+MS solver has been developed to date. Correlation between surface precipitation and ice aloft must be established with ancillary datasets (e.g., Nexrad).

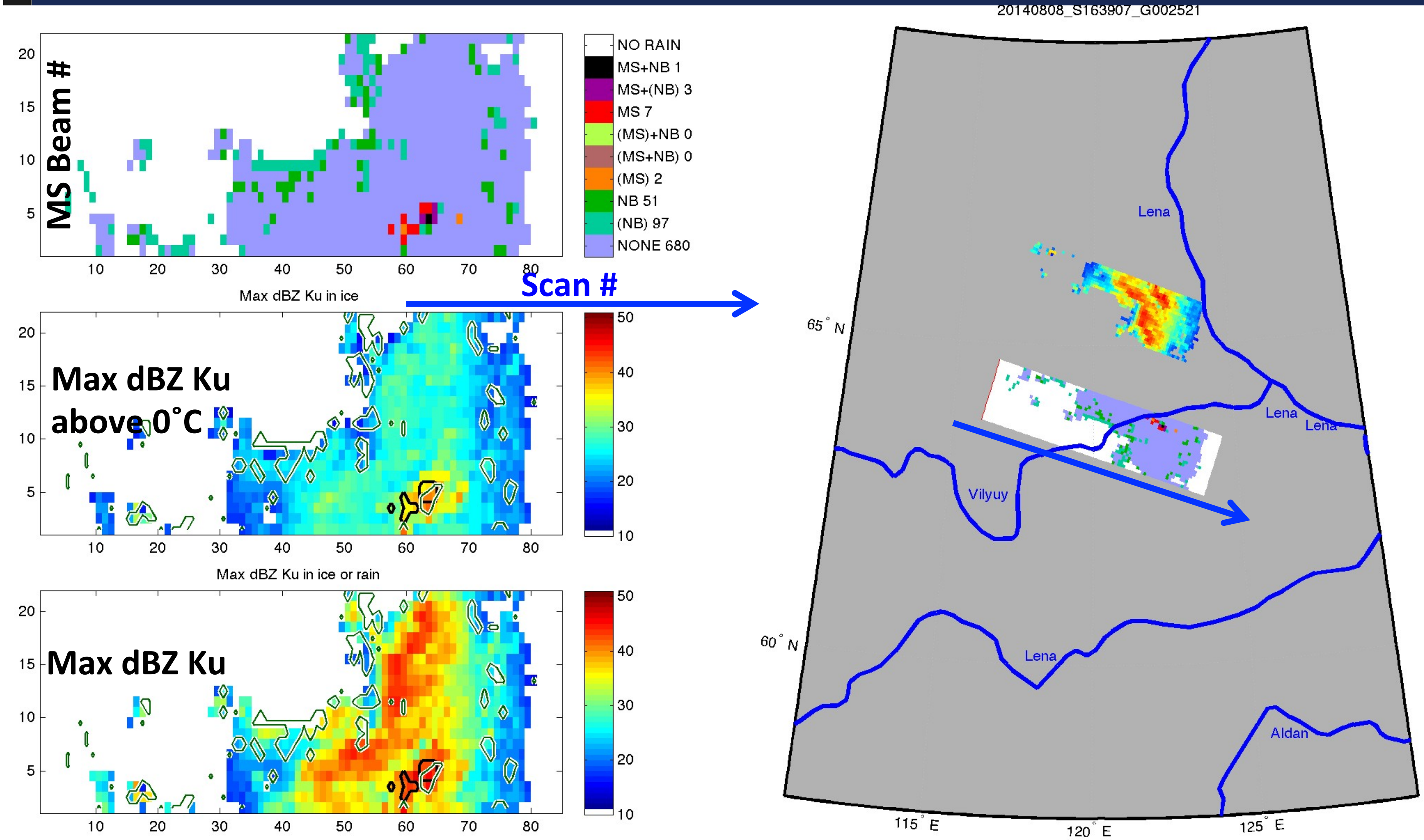
The "Trigger" algorithm applies the criteria described before and generates fuzzy probabilities of occurrence. These are compacted in 9 classes at the time of output.

The Trigger was run on all available granules between #500 and #3200 (about 6 months worth of data in 2014)

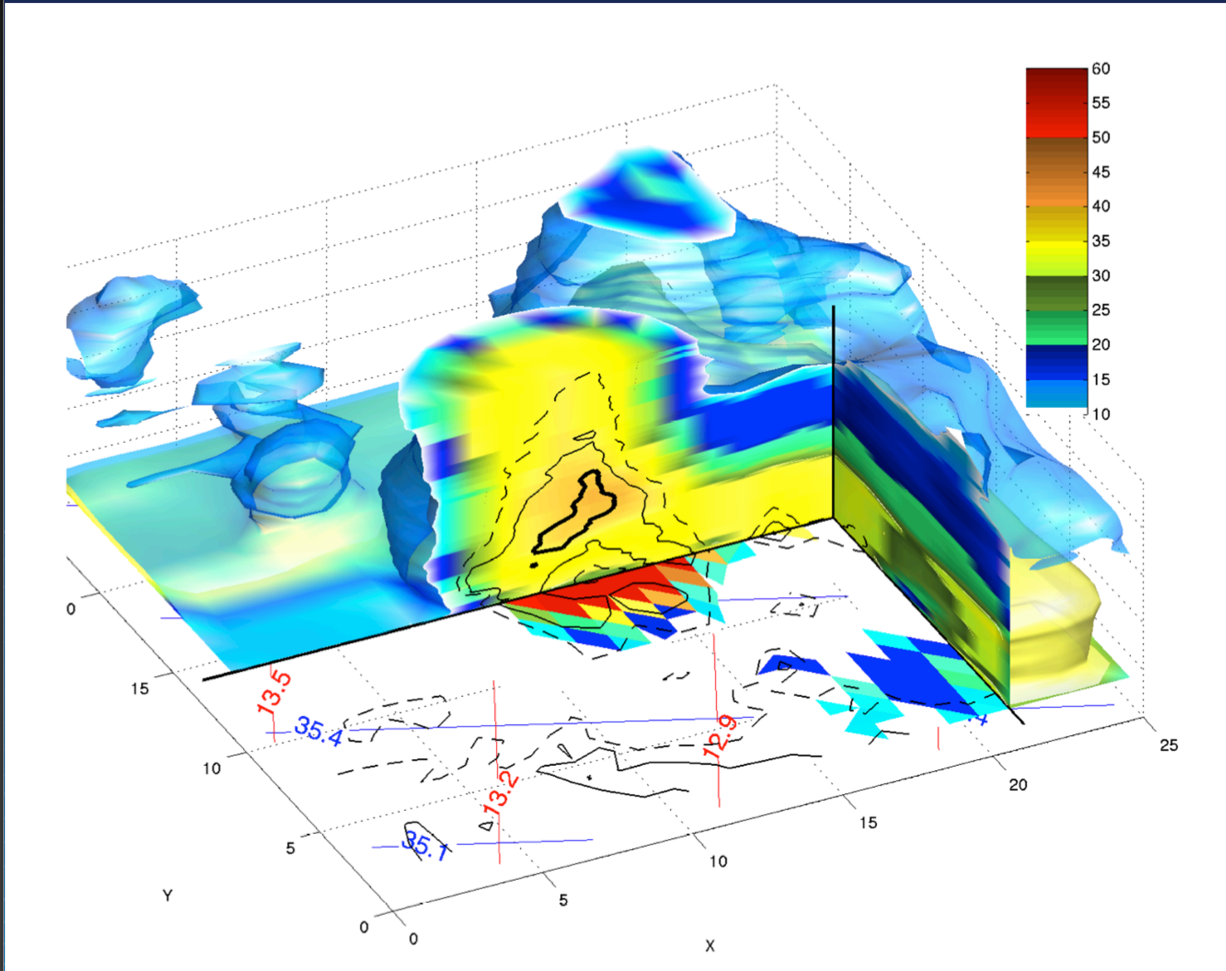
Example 1 of the Trigger algorithm output



Example 2 of the Trigger algorithm output

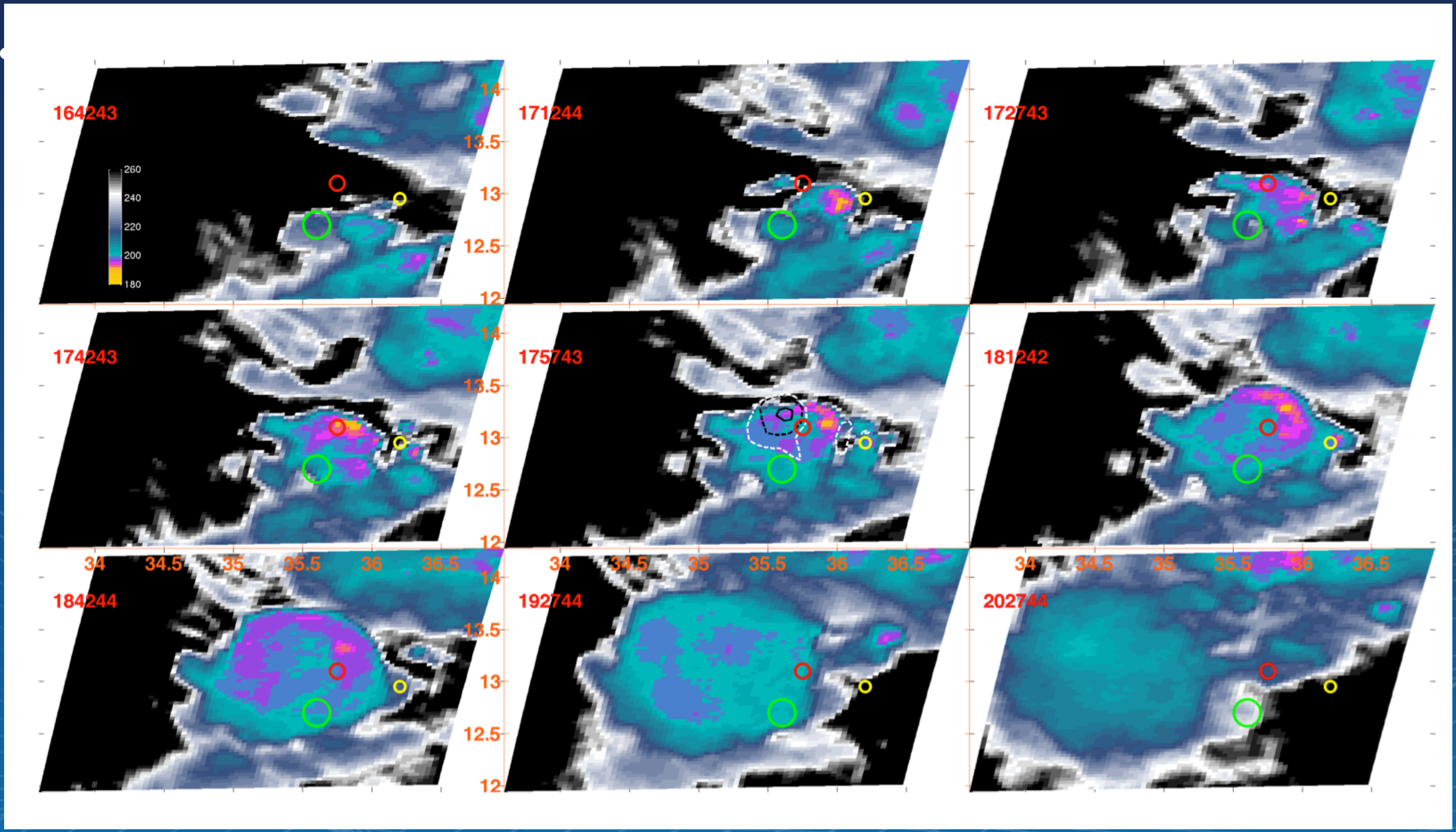


Handling of profiles affected by MS



Battaglia, A., S. Tanelli, K. Mroz, and F. Tridon (2015a), Multiple scattering in observations of the GPM dual-frequency precipitation radar: Evidence and impact on retrievals, *J. Geophys. Res. Atmos.*, *120*, 4090–4101, doi:10.1002/2014JD022866.

Context of the case study



DPR's standard retrievals

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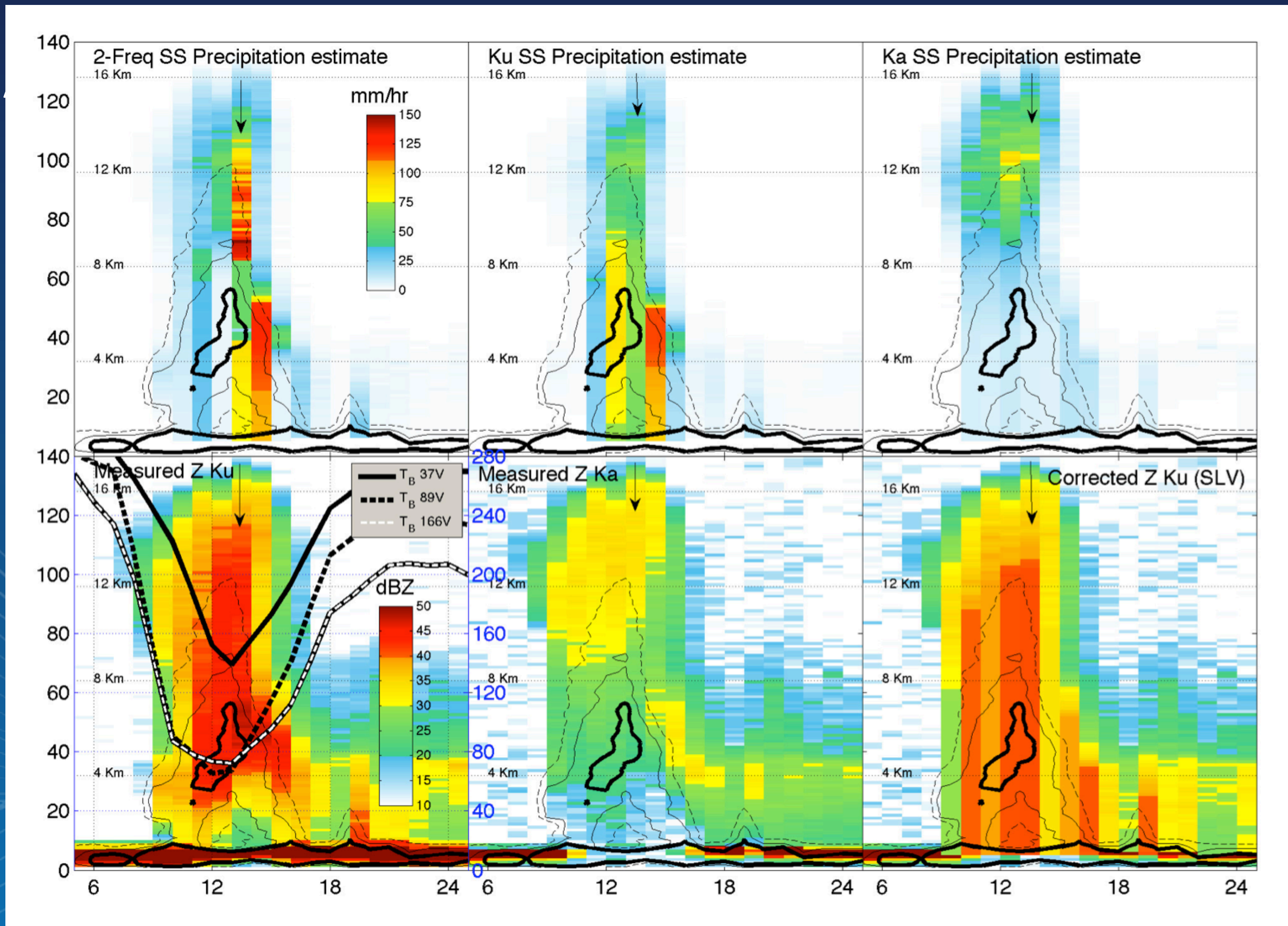
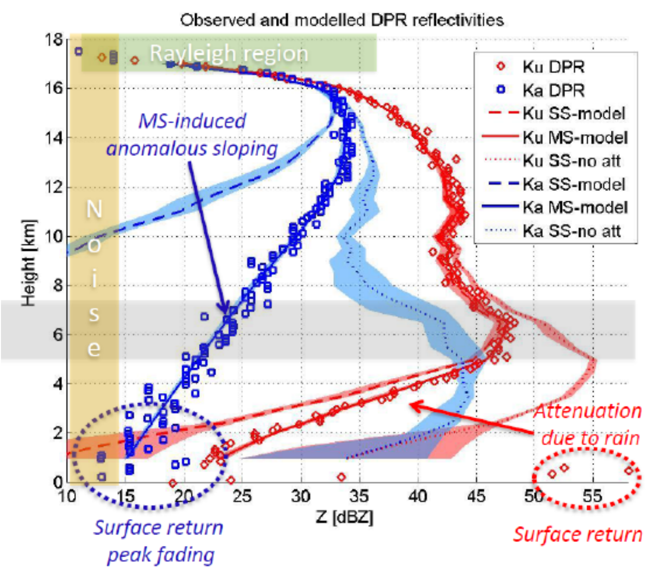


Multiple-Scattering Optimal Estimation algorithm retrievals



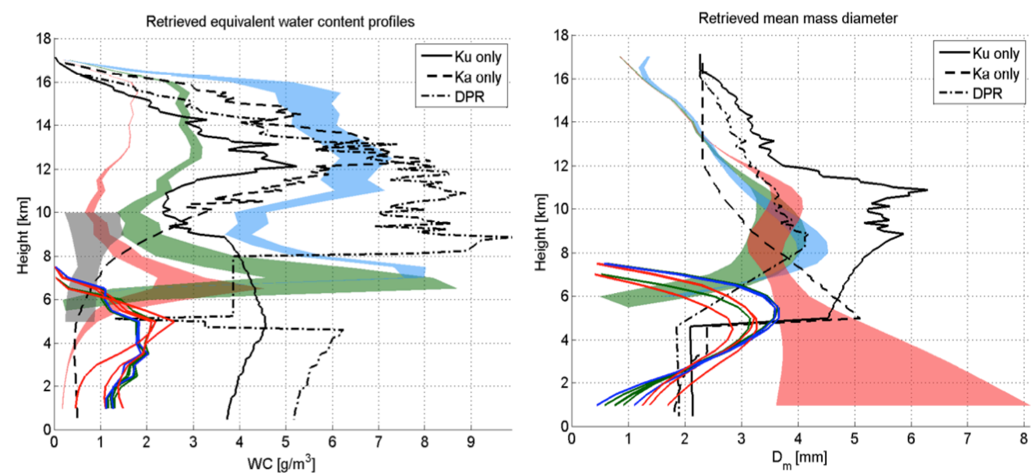
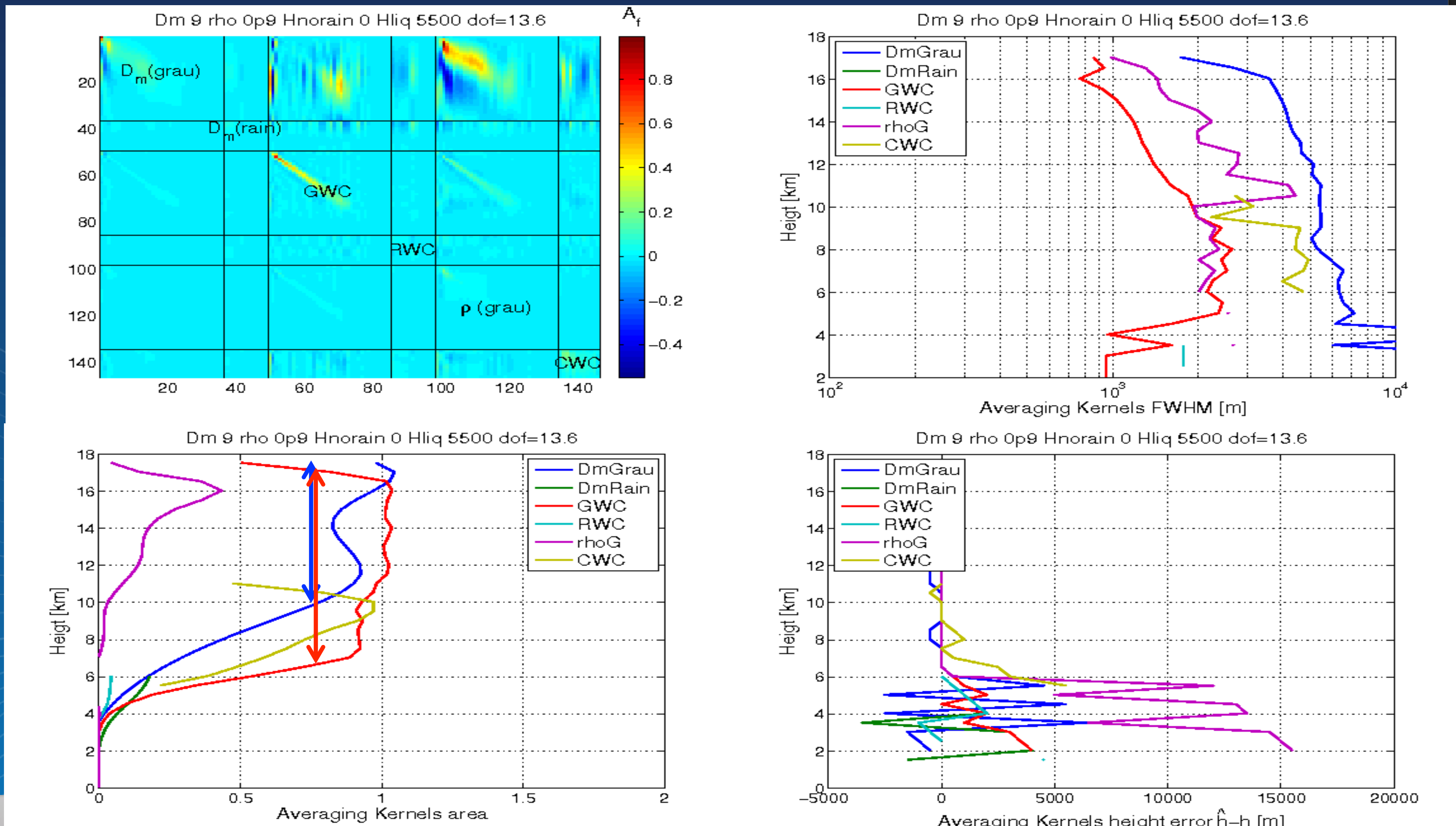


Figure 7. Retrieved profiles of equivalent water content (left) and mean mass diameter (right) for the profile shown in Fig. 4. Blue, green and red colors correspond to snow, graupel and hail a-priori assumptions for the ice density with shaded areas corresponding to the ice phase and continuous lines to the liquid phase. Cloud water contents are also retrieved and their variability is indicated by the grey-shaded area. Black lines correspond to the results of the Level 2 GPM algorithms as indicated in the legend.

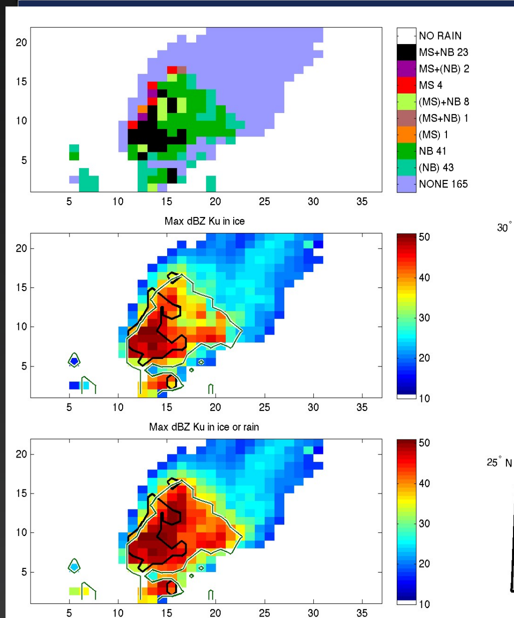
The current version employs the 1-D (plane parallel) Hogan & Battaglia Two-Stream MS model. Plans to validate with simulations from the 3-D MS model Battaglia & Tanelli (DOMUS).

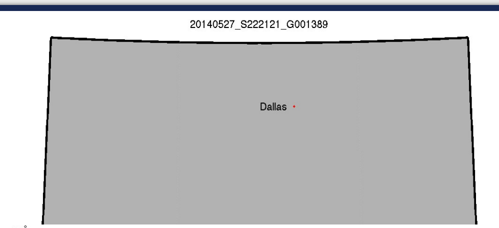
Multiple-Scattering Optimal Estimation algorithm retrievals of UNCERTAINTY

PIA_{Ku}, PIA_{Ka}, TB_{Ku}, TB_{Ka}, TB_{GMI37}, TB_{GMI89}, TB_{GMI166}

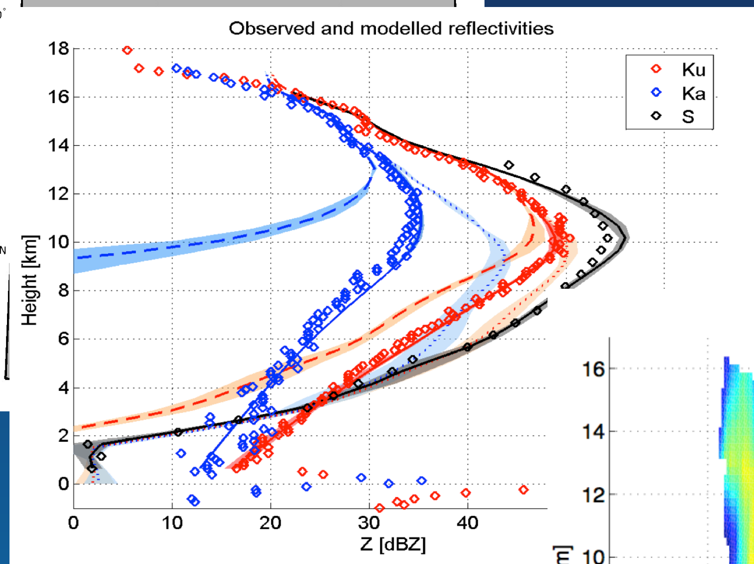


The full chain



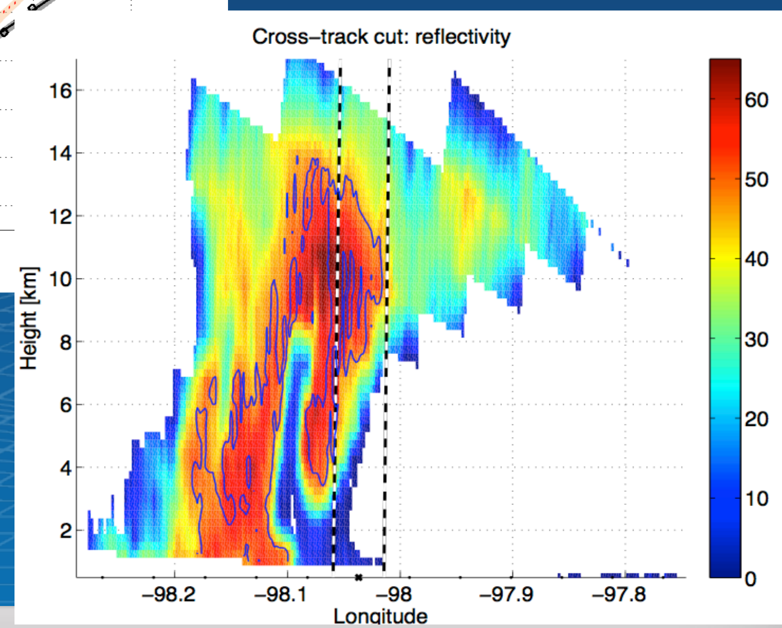


Detect



Solve

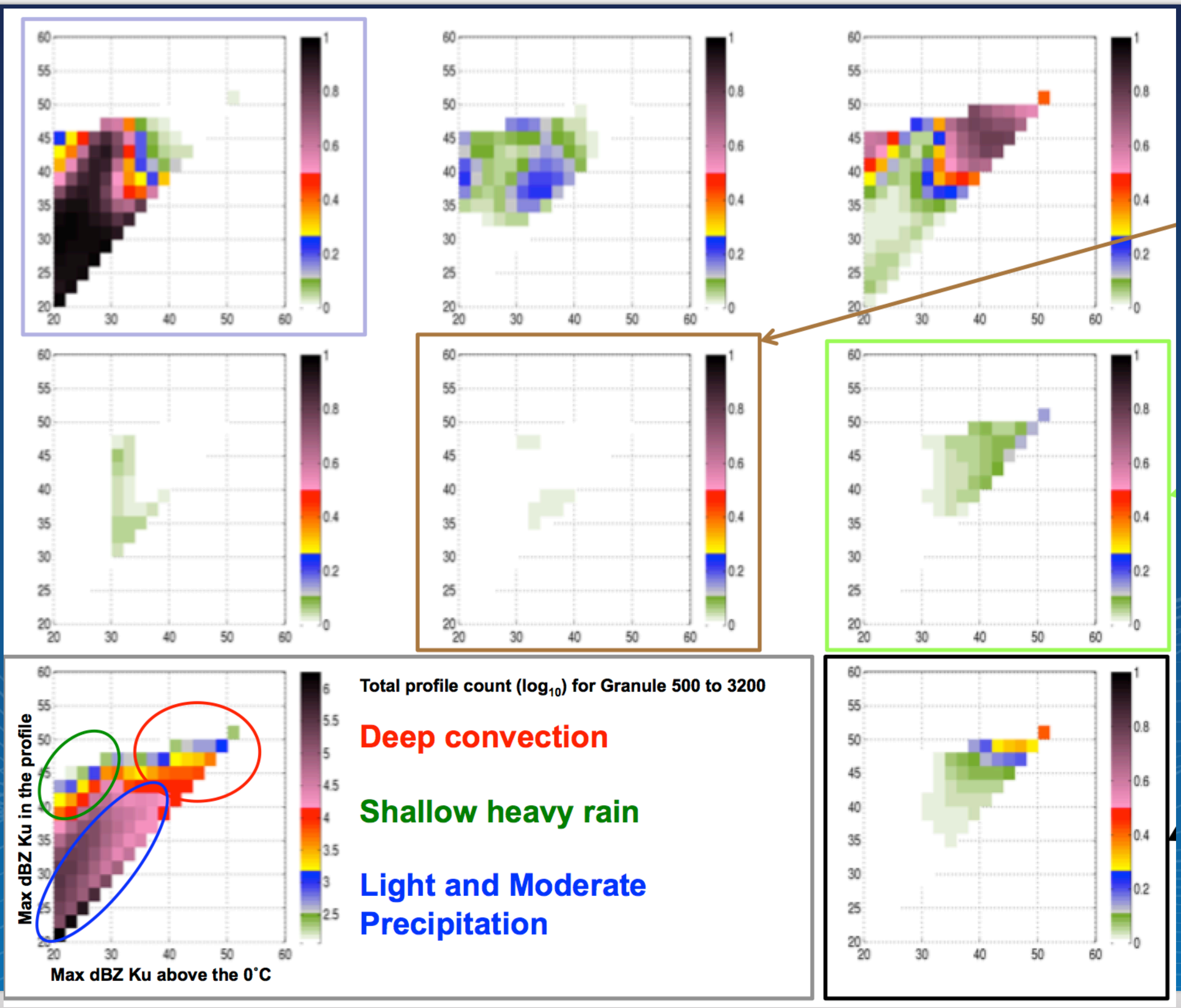
Validate



Conclusions

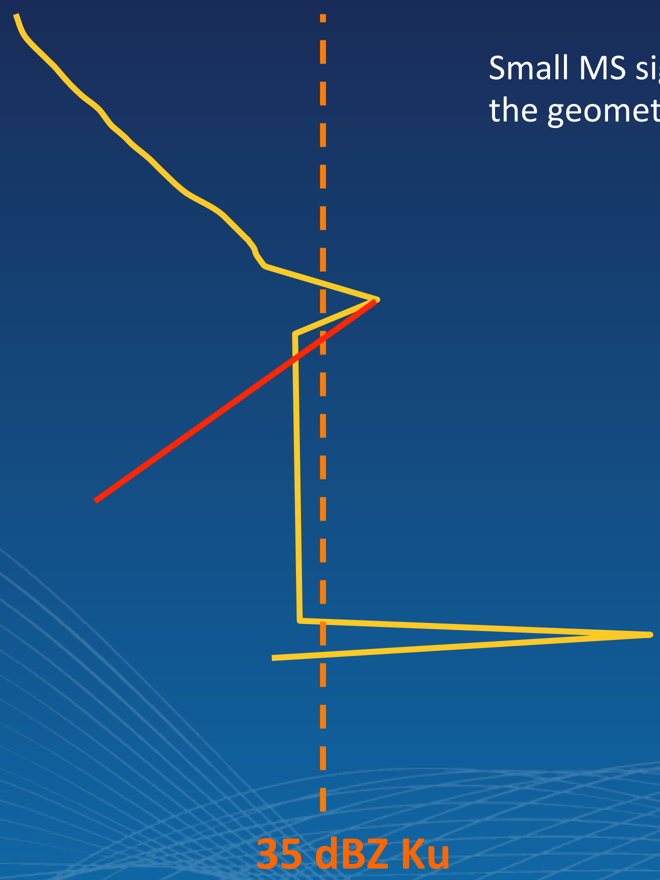
- A fast algorithm that detects occurrence of MS and / or NUBF was developed and is being refined and validated. It aims at:
  - re-enabling full use of DFRm in the DPR Solver WHEN APPROPRIATE.
  - providing a measure of NUBF to the DPR Solver
  - determining when the standard SS-based Solver is NOT APPLICABLE to a profile
- For a profile affected by MS and Optimal Estimation algorithm was developed and is being refined and validated:
  - MS essentially hides information on the lower part of the column in heavy precip BUT this doesn't mean that we should just give up because MS actually ADDS information on the UPPER part of the column
  - The MS-OE shows skill at discriminating low-density ice aloft from high-density ice aloft
  - It provides unbiased rain estimates when possible
  - It provides indication of lack of knowledge when not possible
  - Best results when combined with radiometric signatures.

Conditional Occurrence

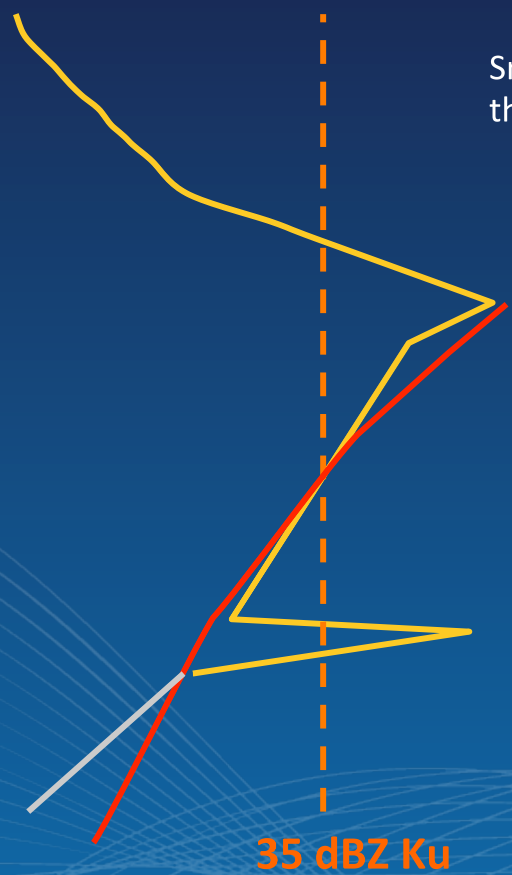


Minimal Multiple Scattering

Small MS signature, limited by
the geometrically thin layer

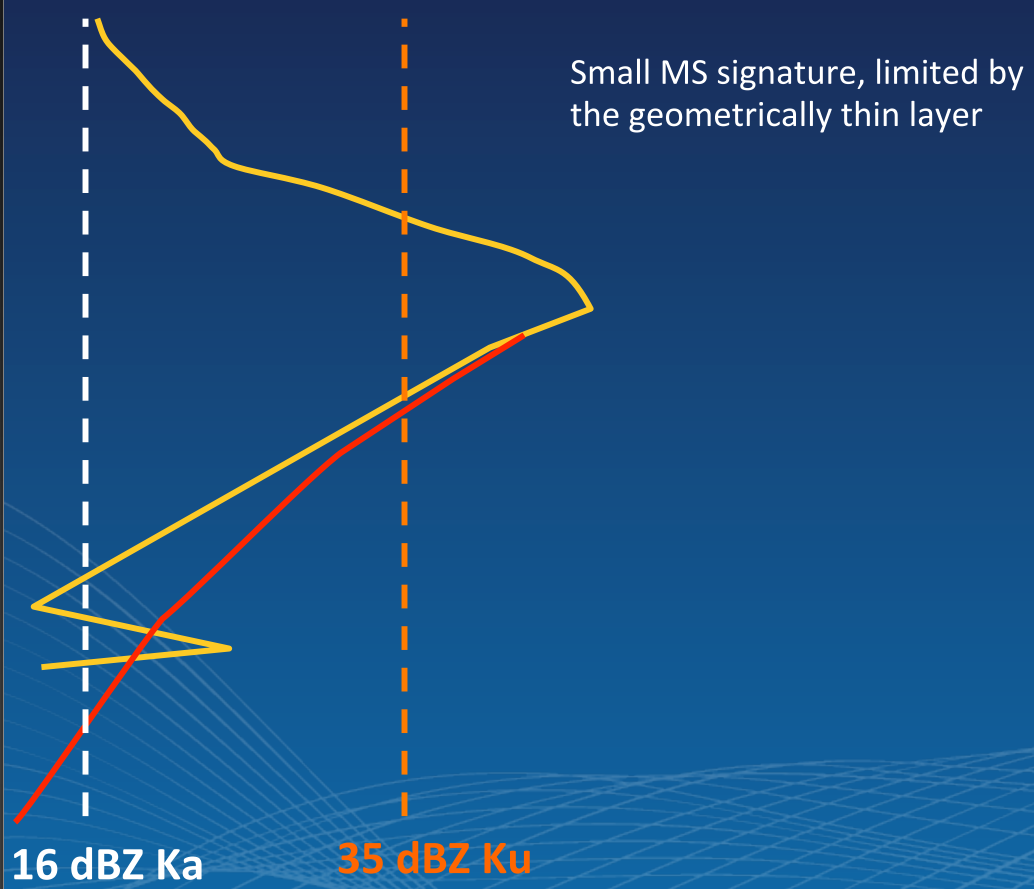


Mild MS



Small MS signature, limited by the geometrically thin layer

Moderate MS



Small MS signature, limited by the geometrically thin layer
16 dBZ Ka
35 dBZ Ku

Abstract of the paper

- This paper illustrates **how multiple scattering signatures affect Global Precipitation Measuring Mission Dual-Frequency Precipitation Radar (DPR) Ku and Ka band** reflectivity measurements, and **how they are consistent with pre-launch assessments** based on theoretical considerations and **confirmed by airborne observations**. In particular, in presence of deep convection, certain characteristics of the dual wavelength reflectivity profiles **cannot be explained with single scattering** whereas they are readily explained by multiple scattering theory. Examples of such signatures are the absence of surface reflectivity peaks and anomalously small reflectivity slopes in the lower troposphere. These findings are relevant for DPR-based rainfall retrievals and stratiform/convective classification algorithms when dealing with deep convective regions. A path to refining the rainfall inversion problem is proposed by adopting a methodology based on a forward operator which accounts for multiple scattering. **A retrieval algorithm based on this methodology is applied to a case study over Africa** and it is compared to the standard DPR-products obtained with the at-launch version of the standard algorithms.