Methods of Attenuation Correction for the DPR

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Outline

- Changes in SRT from V4 to V5
- General performance of the SRT algorithm
- Global behavior of attenuation correction
  - Z_m versus Z_e at Ku- and Ka-band
- Statistical Methods for space-time estimates of rain rate

V4 to V5 (V7 to V8) changes in SRT code

- Add snow and sea-ice surface categories (DPR)
- Re-compute databases (modified DPR calibration) and update to 3-year seasonal averages
- Re-compute databases for TRMM-PR over 17 years
- Investigate improvements in the temporal reference database (not fully implemented)
  - Fixed grid
  - Variable spatial averaging
  - Overlay/coincident track

Surface Reference Technique (SRT)

- Most unconstrained single- and dual-frequency radar retrieval methods become unstable as the path-attenuation increases
- Path Integrated Attenuation (PIA) is one such constraint & if accurate estimates of this can be made, the retrievals of rain rate & DSD parameters become more robust
- Retrieval of the PIA from the single-frequency SRT, however, is limited in accuracy by the inherent fluctuations in the surface cross section (NRCS)
- Improvement in accuracy can be made by using dual-frequency data if the surface cross sections at the 2 freq's are well correlated

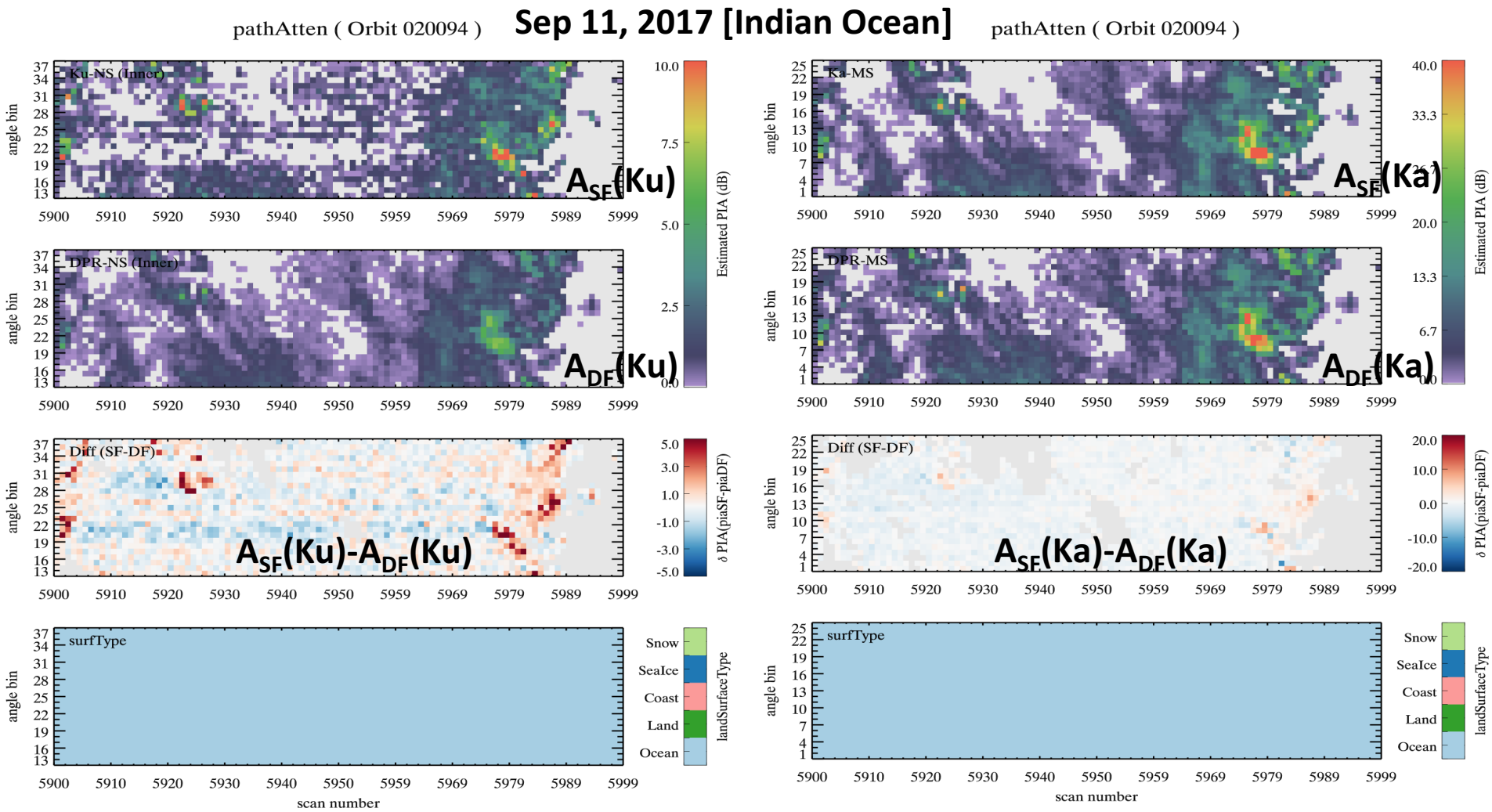
… from analysis of DPR data

- At low to moderate rain rates, DSRT shows improvement over the SRT
  - Better consistency among the different estimators
  - Less noise, fewer negative PIA's, better coherence
  - Improvement most significant at Ku-band

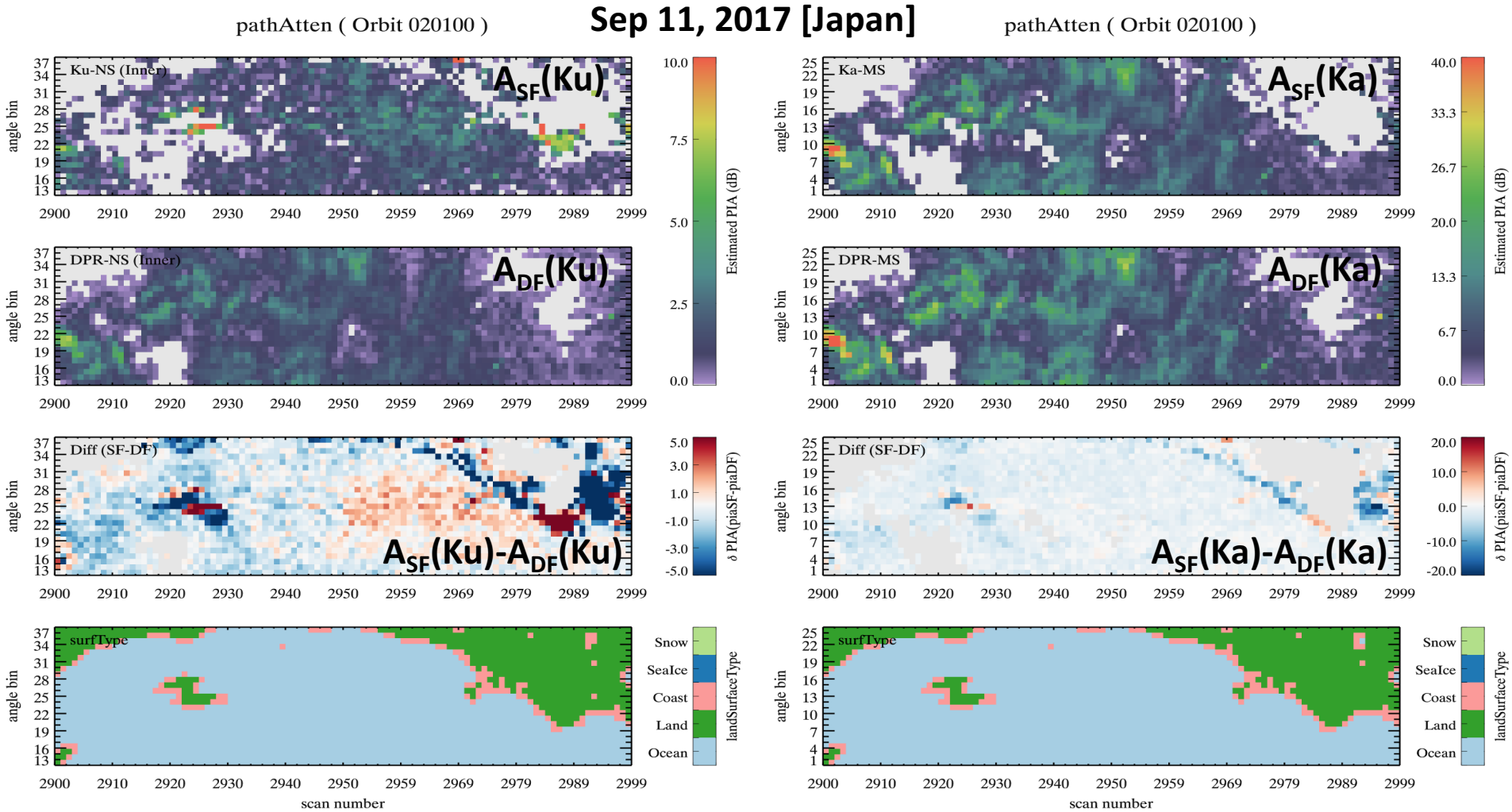
- At high rain rates, however, we sometimes lose the surface return at Ka-band
  - At Ku-band, we can revert to the single-freq. SRT
  - At Ka-band, not many options because of loss of rain signal as well

- Although several methods for correcting NUBF have been proposed, the problem continues to be a significant source of error, esp at Ka

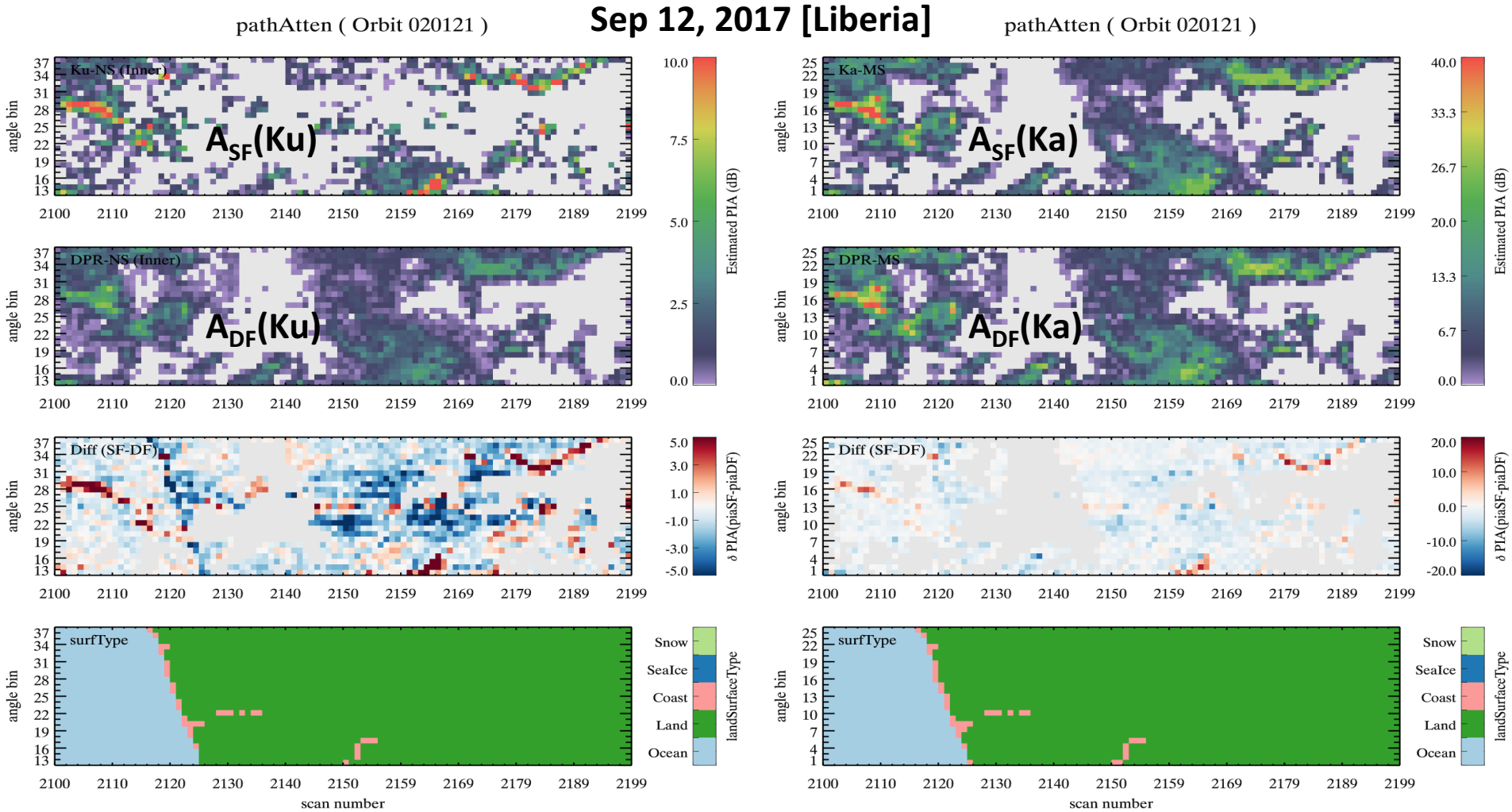
Sep 11, 2017 [Indian Ocean]



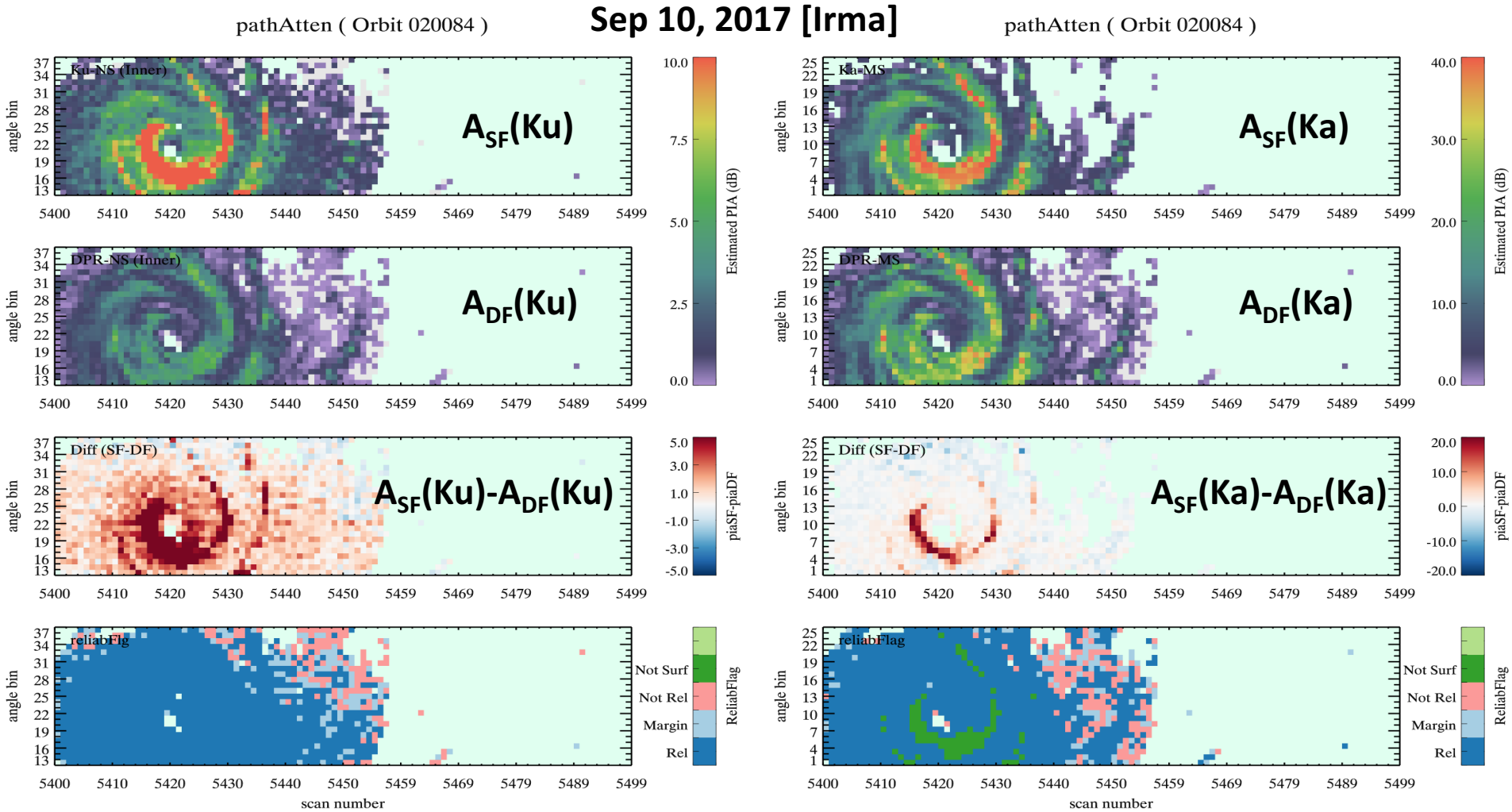
Sep 11, 2017 [Japan]



Sep 12, 2017 [Liberia]



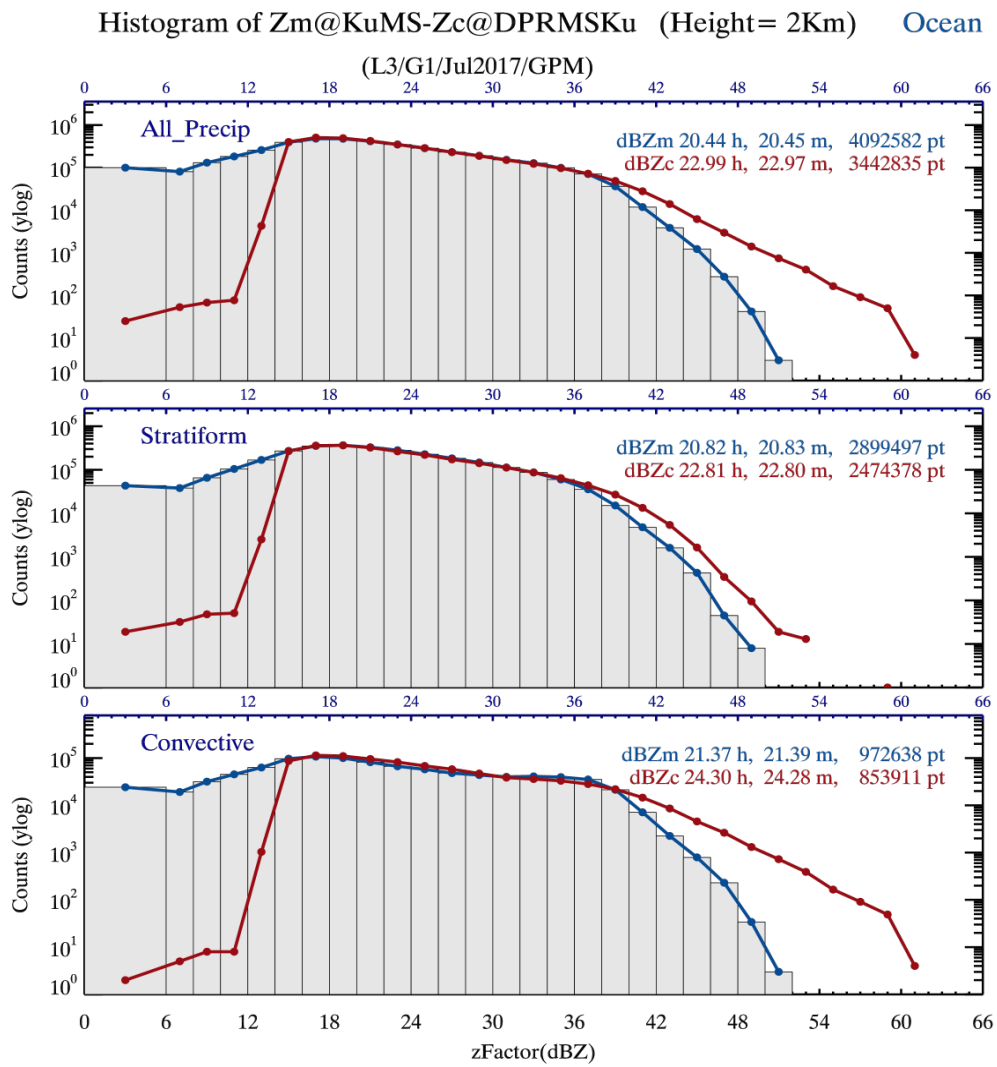
Sep 10, 2017 [Irma]

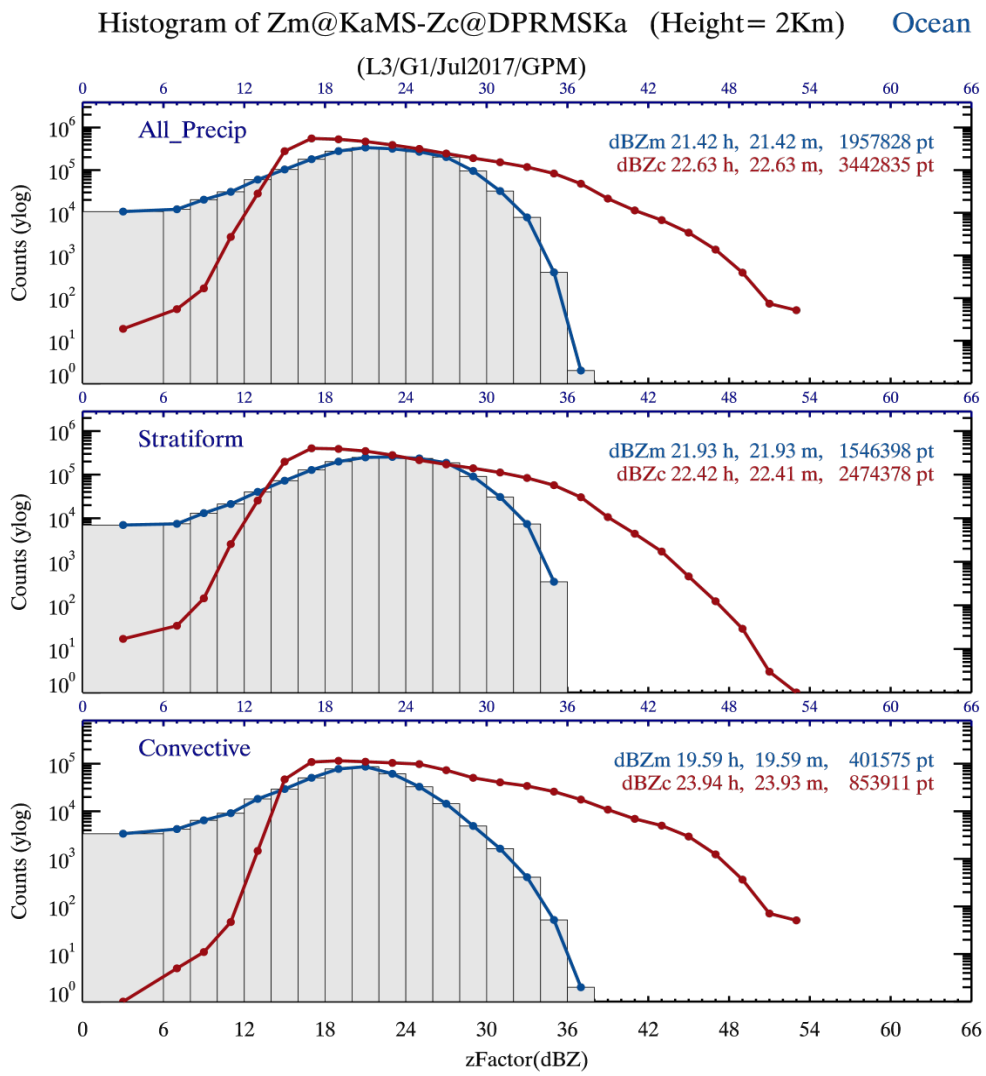


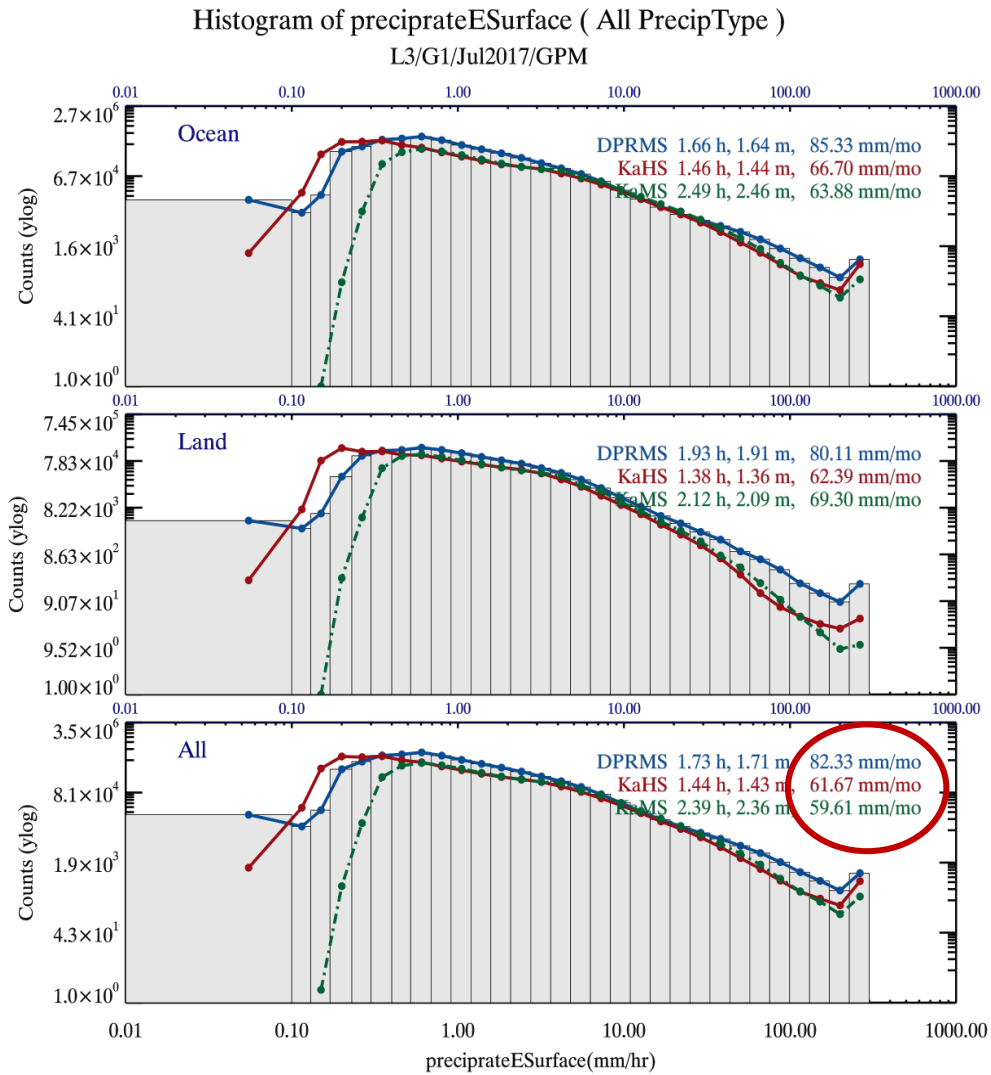
Local to global

- to gauge the effects of attenuation correction, and the problem at Ka-band, it's useful to look at the level 3 products

- In additional to the usual list of potential benefits of DPR, the data allow us to assess the potential of a Ka-band radar
  - Can Ka-band radar be used as a stand-alone instrument for global PE ?
  - How important is attenuation correction: differences between Z_m & Z_e ?
  - How well/poorly do the pdf's of R(Ku) & R(Ka) match-up ?


Histogram of Zm@KuMS-Zc@DPRMSKu (Height= 2Km) Ocean
(L3/G1/Jul2017/GPM)
All_Precip
dBZm 20.44 h, 20.45 m, 4092582 pt
dBZc 22.99 h, 22.97 m, 3442835 pt
Stratiform
dBZm 20.82 h, 20.83 m, 2899497 pt
dBZc 22.81 h, 22.80 m, 2474378 pt
Convective
dBZm 21.37 h, 21.39 m, 972638 pt
dBZc 24.30 h, 24.28 m, 853911 pt
Counts (ylog)
zFactor(dBZ)


Histogram of Zm@KaMS-Zc@DPRMSKa (Height= 2Km) Ocean
(L3/G1/Jul2017/GPM)
All_Precip
dBZm 21.42 h, 21.42 m, 1957828 pt
dBZc 22.63 h, 22.63 m, 3442835 pt
Stratiform
dBZm 21.93 h, 21.93 m, 1546398 pt
dBZc 22.42 h, 22.41 m, 2474378 pt
Convective
dBZm 19.59 h, 19.59 m, 401575 pt
dBZc 23.94 h, 23.93 m, 853911 pt
Counts (ylog)
zFactor(dBZ)



R(Ka) ~ 27% smaller than R(DPR) [or R(Ku)]

take home

- Ku & KaHS have comparable sensitivities at the light rain/snow rates
- For KaMS & KaHS attenuation correction is important above ~30 dBZ; for Ku, above ~40 dBZ
- Rain Rate histograms suggest that, relative to Ku-band, Ka-band estimates have too few counts at high rain rates
- This is probably caused by a combination of
  - Loss of surface return at Ka-band
  - NUBF errors in SRT, DSRT
- Can this problem be ameliorated, at least in a space-time averaged sense?

Statistical Methods of Rain Estimation

- Statistical Methods of Rain Rate Estimation applied to DPR measurements
- Two Approaches have been studied with TRMM PR data
  - Use the correlation between fractional area above/below a particular rain rate threshold and area-time averaged rain rate
  - Estimate of the probability distribution (cdf) of R from filtered database
- Primary objective is to assess how these methods perform at Ka-band
  - In particular, can we achieve an unbiased mean R

Statistical Methods

- Standard Statistical methods must be modified for attenuating-wavelength radar data because the measured reflectivities, Z_m, do not provide an accurate estimates of rainfall rate
- To test the methods, we assume that we cannot accurately correct for attenuation; instead we try to filter out data that are affected by it

Schematic Eq's

Standard & Statistical Approaches

$$P_r \xrightarrow{radar\ eq} Z_m \xrightarrow{atten\ corr} Z \xrightarrow{R-Z}$$

$$R \xrightarrow{accumulate} \langle R \rangle_{sample\ mean}$$

$$P_r \xrightarrow{radar\ eq} Z_m \xrightarrow{R-Z} R_a \xrightarrow{filter\ \&\ accumulate}$$

$$\{R_a\} \xrightarrow{statistical\ method} \langle R \rangle_{Threshold} \ \ or\ \langle R \rangle_{cdf}$$

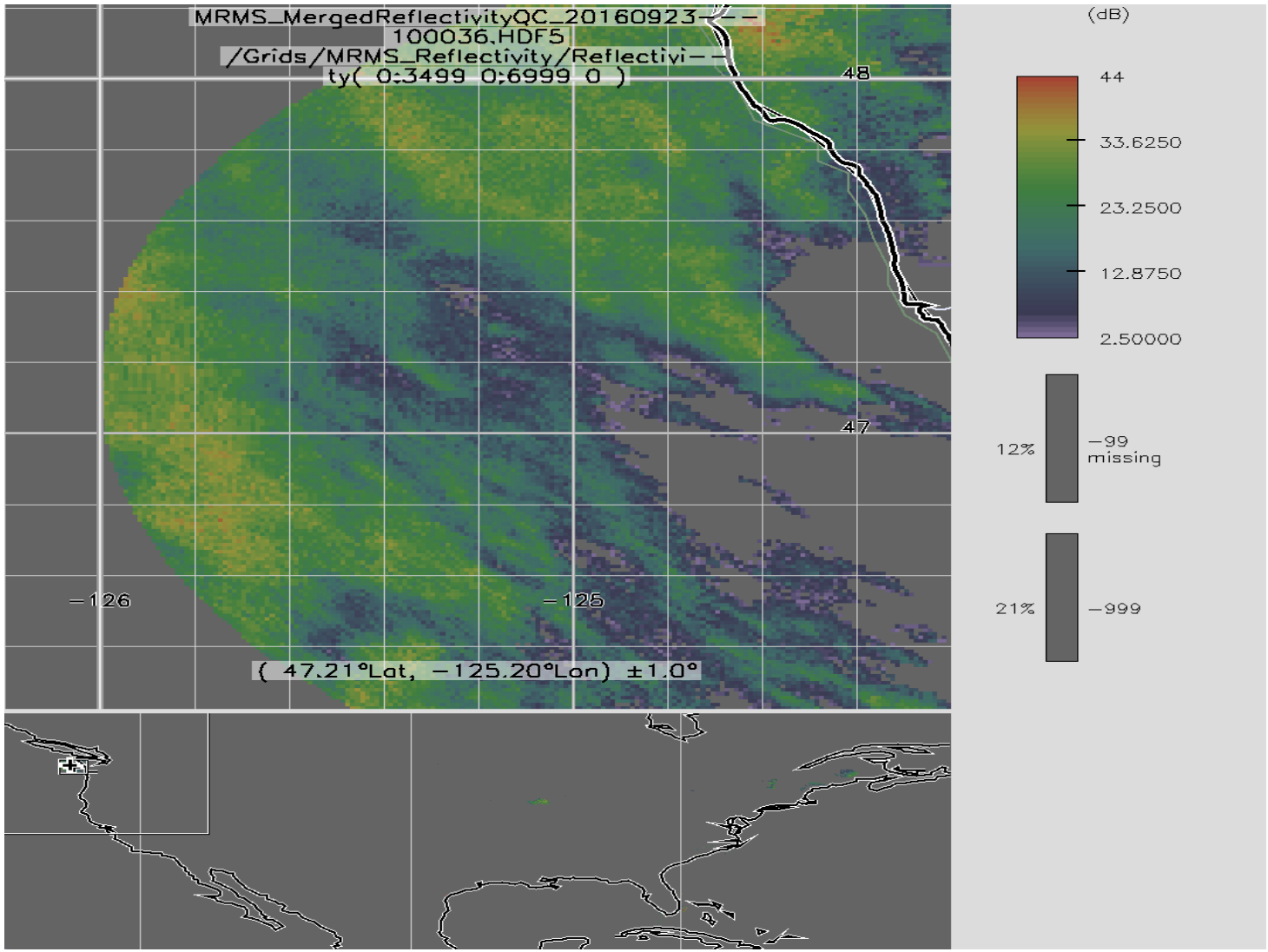
Statistical Methods

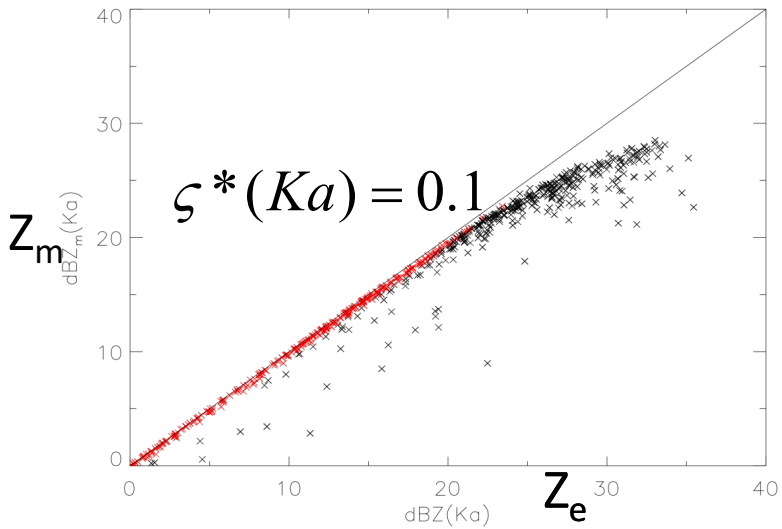
- One such filtering function is the quantity ς from the Hitschfeld-Bordan equation, where

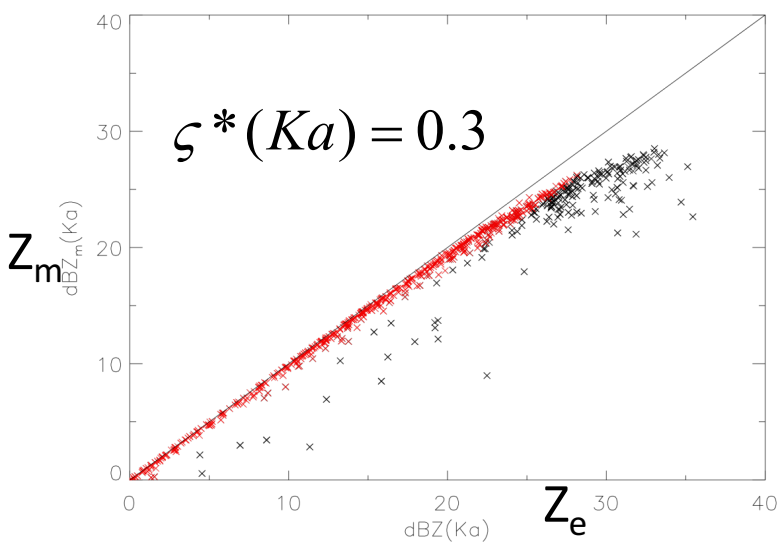
$$Z_{HB}(r) = Z_m(r)/[1-\varsigma(r)]^{1/\beta}$$

$$\varsigma(r) = 0.46\beta\int_0^r \alpha(s) Z_m^{\beta}\, ds$$

$$k = \alpha Z^{\beta};\ P(r) = C\,|\,K\,|^2\ Z_m(r)/r^2$$


MRMS_MergedReflectivityQC_20160923---
100036.HDF5
/Grids/MRMS_Reflectivity/Reflectivi--
ty(0:3499 0:6999 0)
48
47
-126
-125
(47.21°Lat, -125.20°Lon) ±1.0°
(dB)
44
33.6250
23.2500
12.8750
2.50000
12%
-99
missing
21%
-999



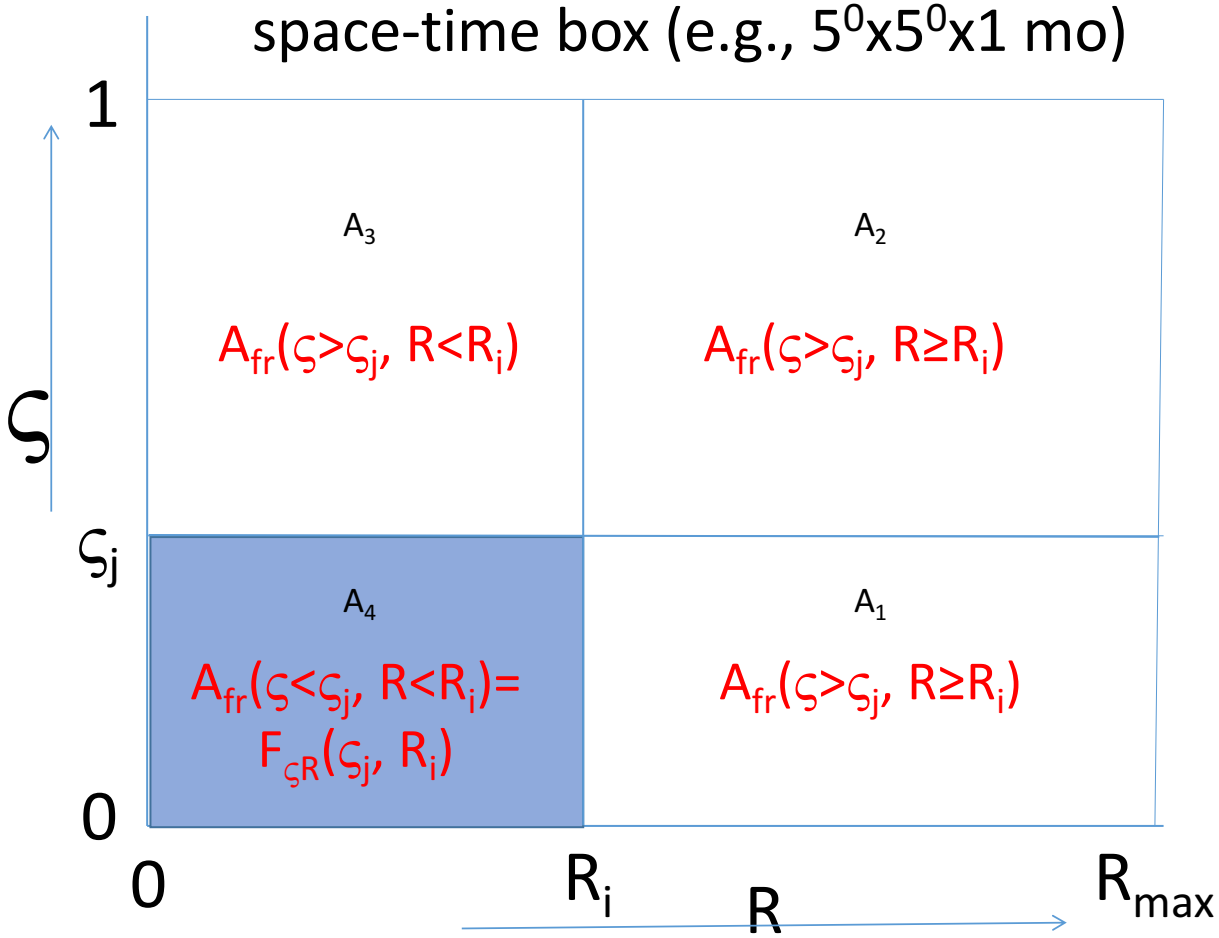


- MRMS data from stratiform rain off Olympic Peninsula, 27 Sept, 2016
- Simulated Ka-band measurements using a 5-km field of view (DPR-Ka)
- S-band converted to Ka: Z(Ka)=f[Z(S)]
- Data points in red satisfy the condition that $\varsigma < \varsigma^*$.

Some details

- In most thresholding methods, we have the fractional area associated with a single threshold (e.g., R or T_B)
- In the case of attenuating-frequency radars, we have two thresholds (R_i, ζ_j), which corresponds to the fraction of data in (R, ζ) space
- The goal is to find, for a particular channel (Ku, KaMS or KaHS), the 'fractional area' that is most highly correlated with the 'true' mean R
  - If $\langle R \rangle = \eta$ FrA, then η should be constant from month to month
- The true mean R is taken to be the sample mean of the high-resolution estimates at Ku-band

Consider the (ζ, R_a) data within a space-time box (e.g., 5^0x5^0x1 mo)



Fractional area associated with the probability that that $\zeta<\zeta_j$ and $R>R_i$ is

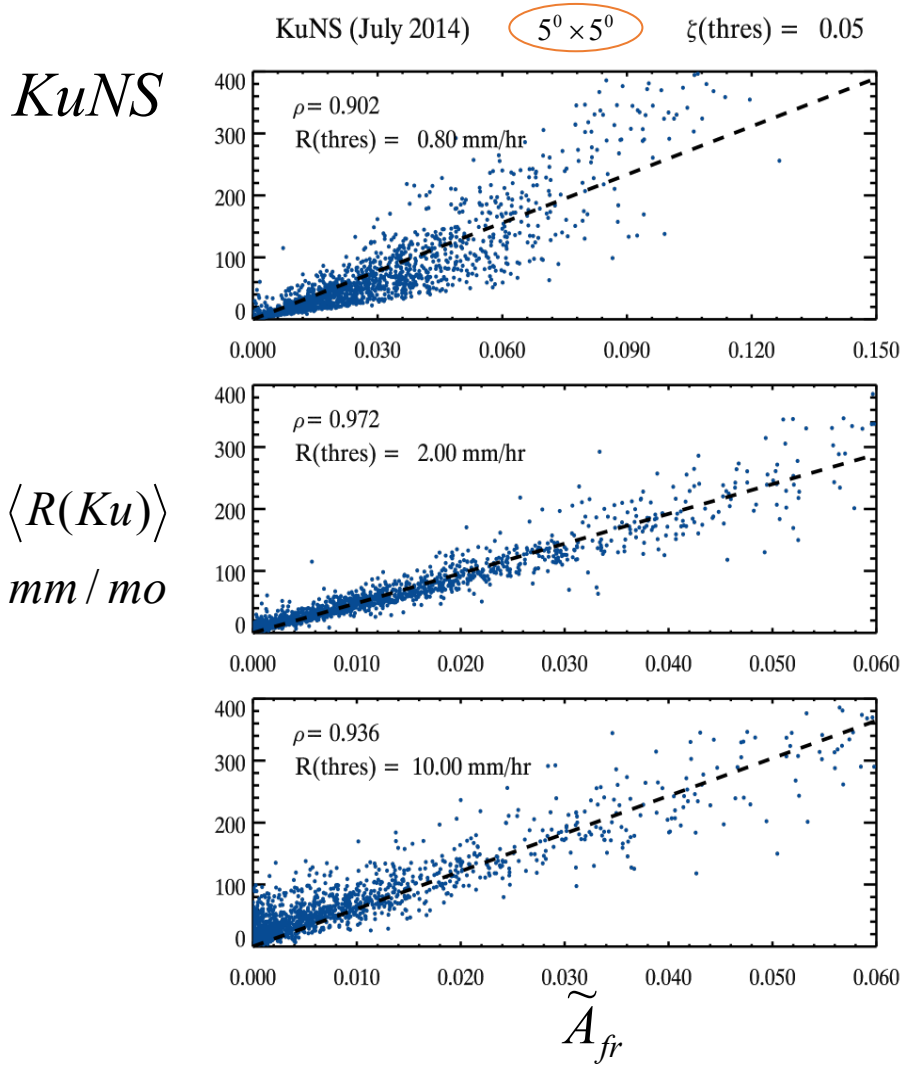
$$A_{fr} = F_{\varsigma R}(\varsigma_j, R_{\max}) - F_{\varsigma R}(\varsigma_j, R_i) = F_{\varsigma}(\varsigma_j) - F_{\varsigma R}(\varsigma_j, R_i)$$

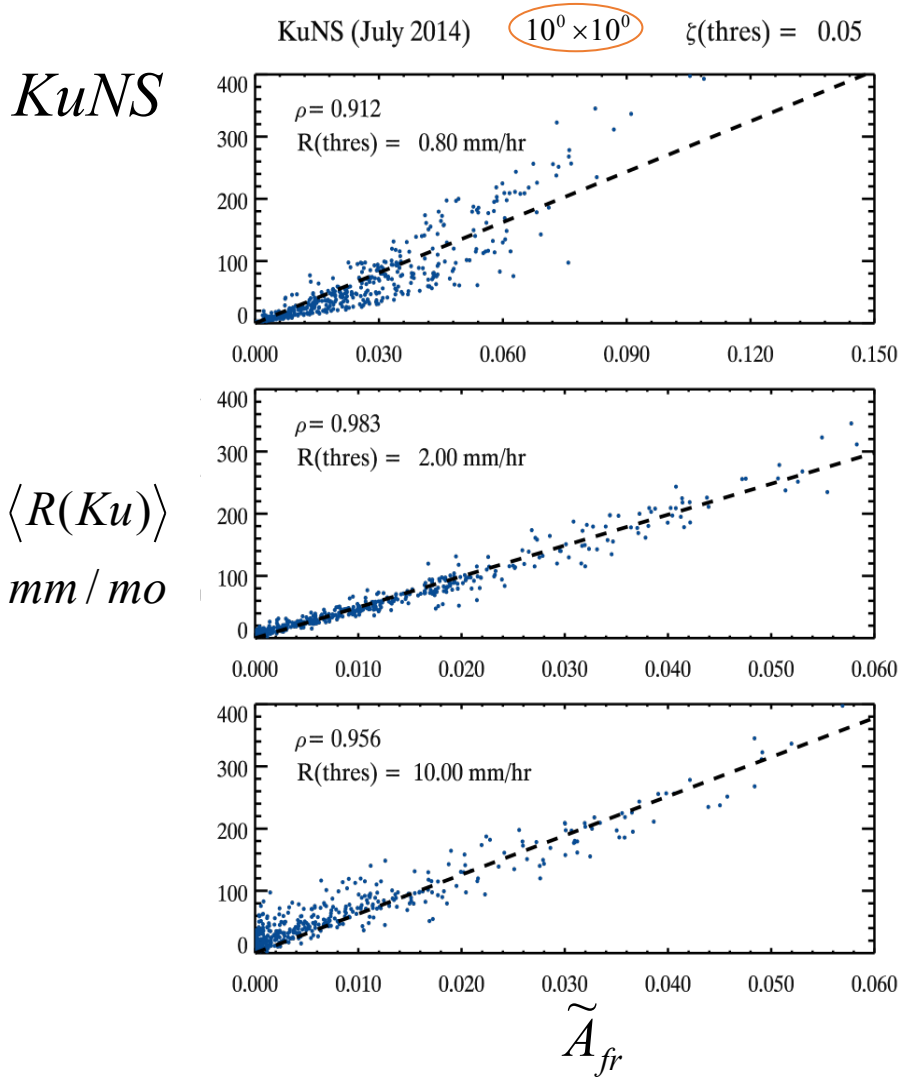
Fractional area associated with the joint probability that that $\zeta<\zeta_j$ and $R\leq R_i$ is

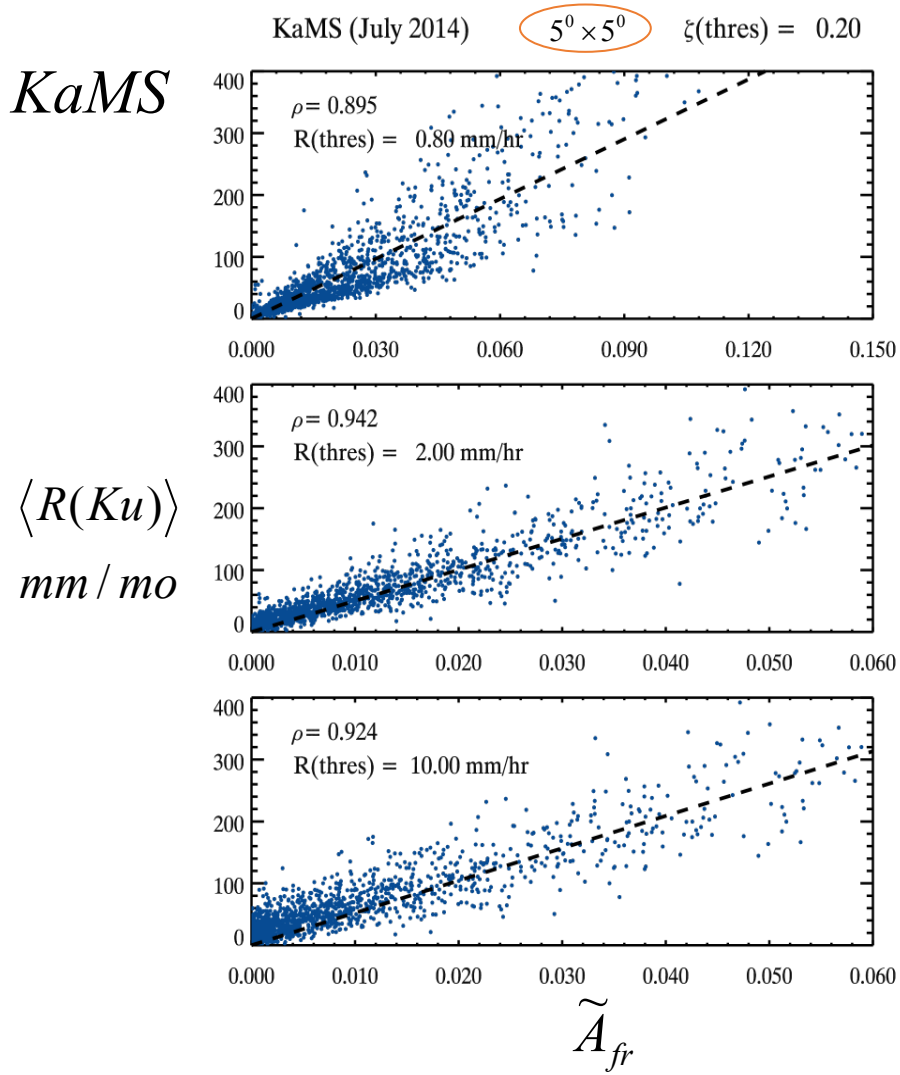
$$F_{\varsigma R}(\varsigma_j, R_i)$$

We consider a 'modified fractional area' expression that is closely related to $F_{\zeta R}$

$$\widetilde{A}_{fr} = 1 - F_{\varsigma R}(\varsigma_j, R_i)$$


KuNS (July 2014)
$5^0 \times 5^0$
ζ(thres) = 0.05
KuNS
$\langle R(Ku) \rangle$
mm / mo
ρ = 0.902
R(thres) = 0.80 mm/hr
ρ = 0.972
R(thres) = 2.00 mm/hr
ρ = 0.936
R(thres) = 10.00 mm/hr
$\tilde{A}_{fr}$

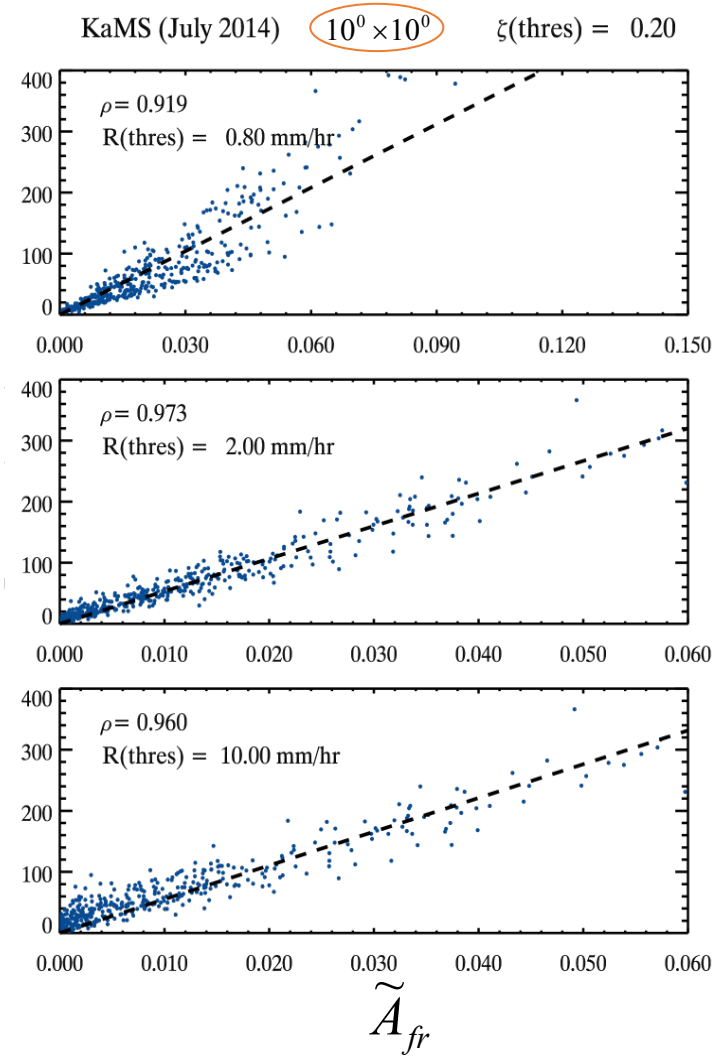

KuNS (July 2014)
$10^0 \times 10^0$
ζ(thres) = 0.05
KuNS
$\langle R(Ku) \rangle$
mm / mo
ρ = 0.912
R(thres) = 0.80 mm/hr
ρ = 0.983
R(thres) = 2.00 mm/hr
ρ = 0.956
R(thres) = 10.00 mm/hr
$\tilde{A}_{fr}$

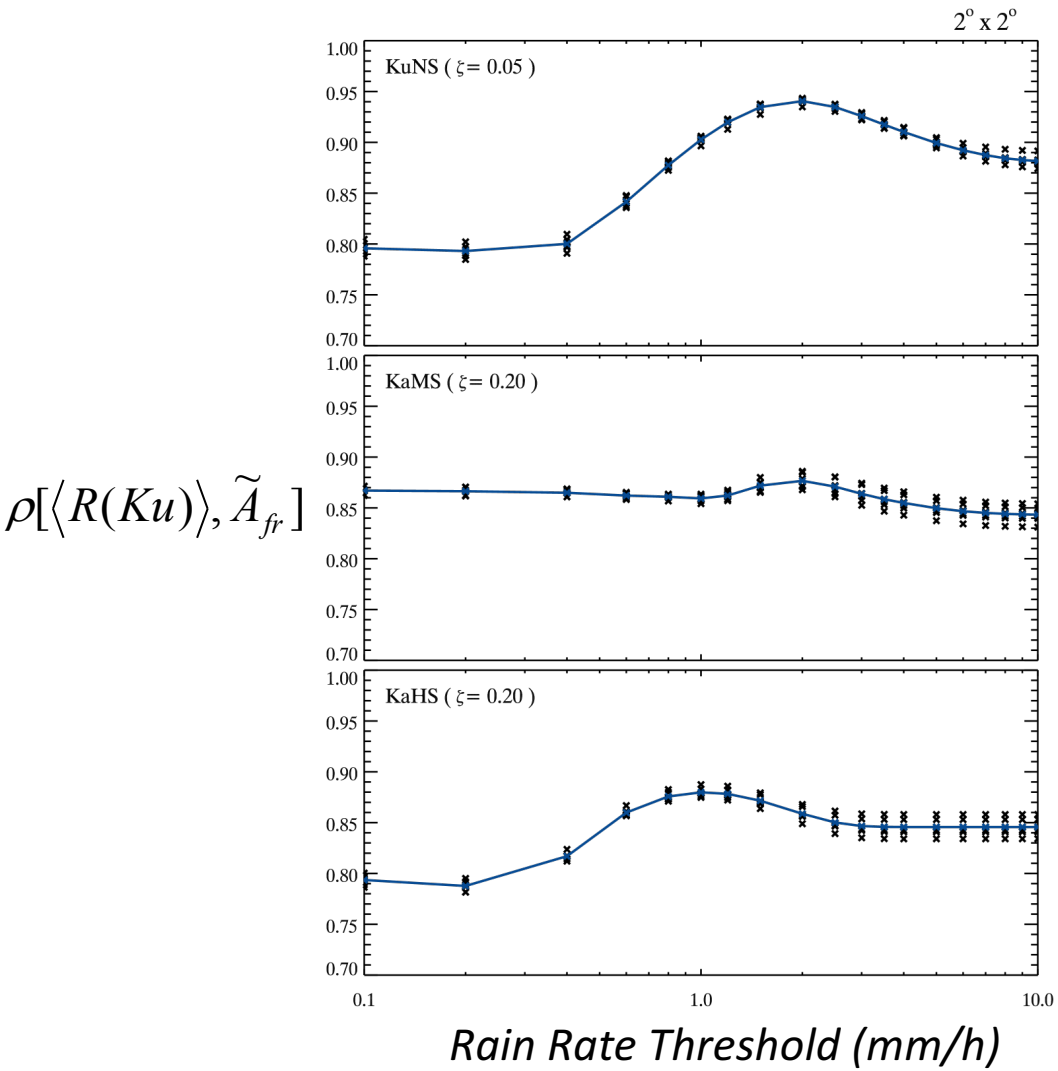

KaMS (July 2014)
$5^0 \times 5^0$
ζ(thres) = 0.20
KaMS
$\langle R(Ku) \rangle$
mm / mo
ρ = 0.895
R(thres) = 0.80 mm/hr
ρ = 0.942
R(thres) = 2.00 mm/hr
ρ = 0.924
R(thres) = 10.00 mm/hr
$\tilde{A}_{fr}$

KaMS

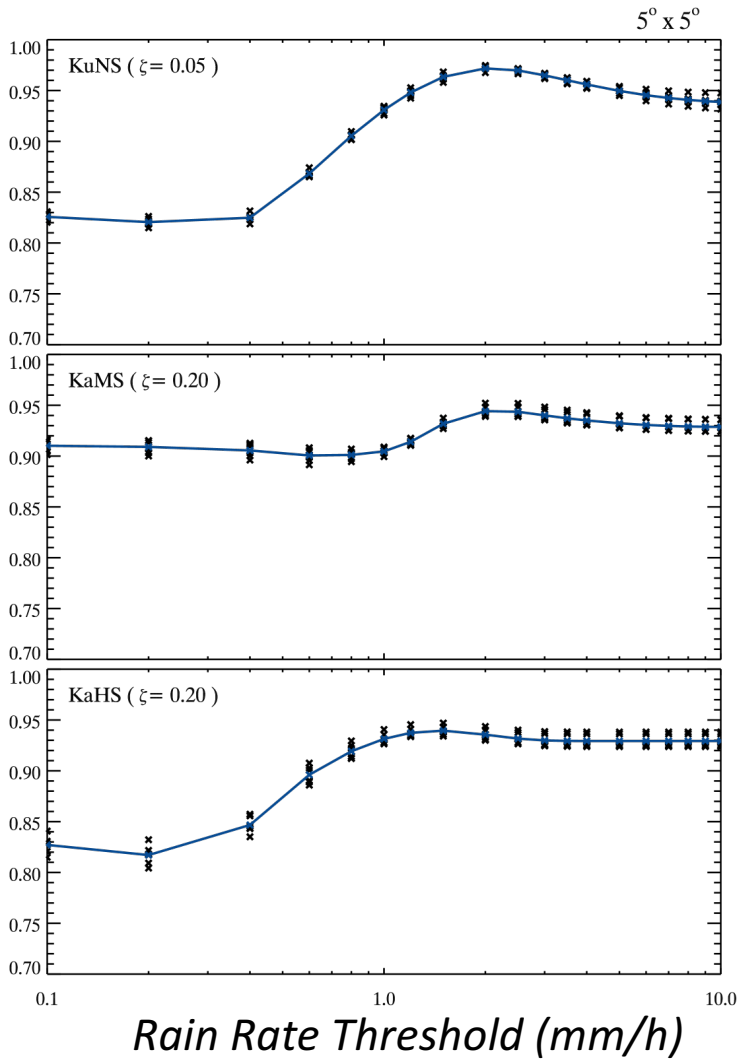
$\langle R(Ku) \rangle$

mm/mo

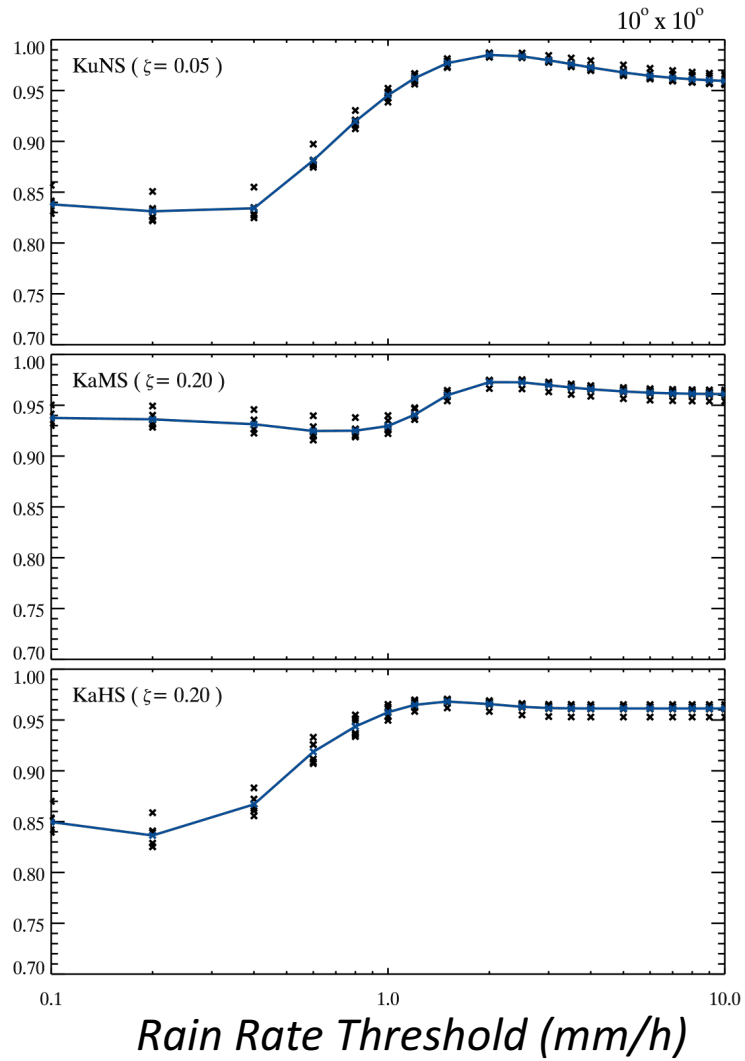



2° x 2°
KuNS (ζ= 0.05)
KaMS (ζ= 0.20)
KaHS (ζ= 0.20)
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.1
1.0
10.0
$\rho[\langle R(Ku)\rangle, \widetilde{A}_{fr}]$
Rain Rate Threshold (mm/h)

$\rho[\langle R(Ku)\rangle, \widetilde{A}_{fr}]$



$\rho[\langle R(Ku)\rangle, \widetilde{A}_{fr}]$

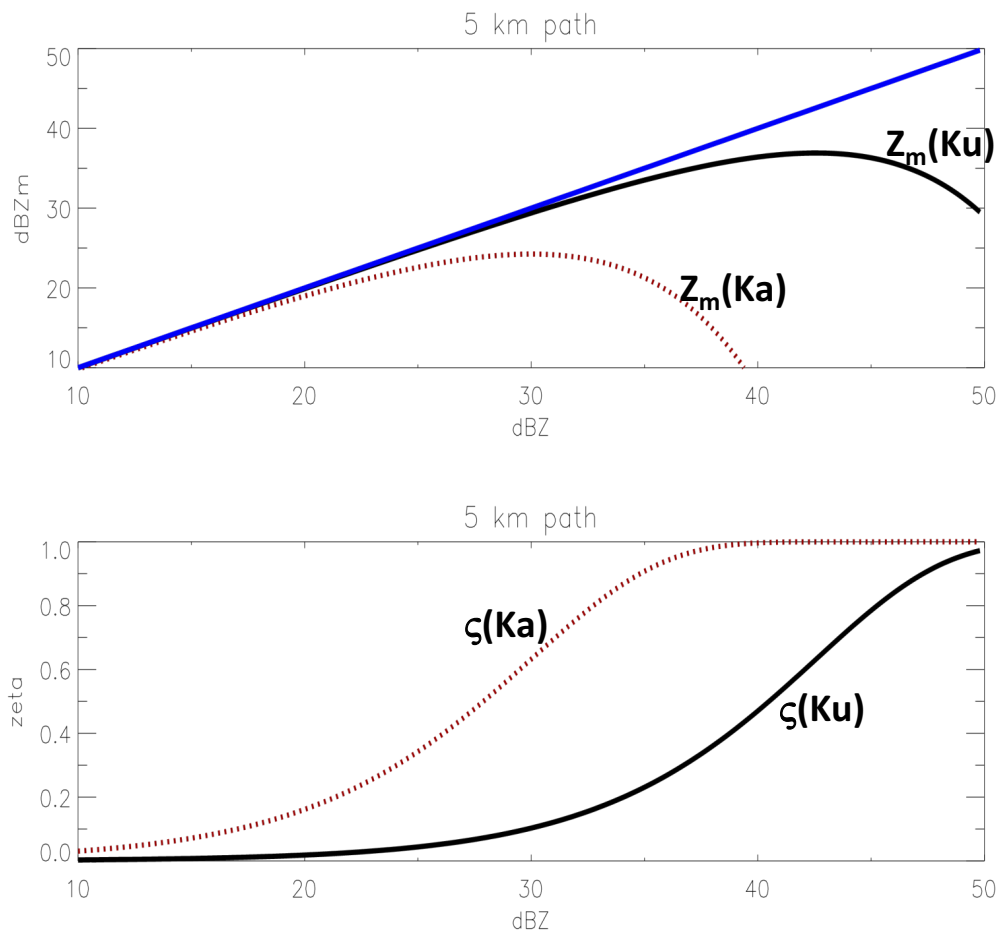


July 2015: ρ_{max} for various frequencies & cell sizes

Channel	Cell Size	ρ_{max}	ζ	R_{th}(mm/h)
KuNS	$1^0 \times 1^0$	0.914	0.1	2.0
	$2^0 \times 2^0$	0.944	0.1	2.0
	$5^0 \times 5^0$	0.972	0.05	2.0
	$10^0 \times 10^0$	0.987	0.05	2.5
	$20^0 \times 20^0$	0.990	0.05	2.0
KaMS	$1^0 \times 1^0$	0.830	0.1	0.6
	$2^0 \times 2^0$	0.872	0.1	1.5
	$5^0 \times 5^0$	0.943	0.2	2.0
	$10^0 \times 10^0$	0.975	0.2	2.0
	$20^0 \times 20^0$	0.983	0.2	2.0
KaHS	$1^0 \times 1^0$	0.833	0.2	0.8
	$2^0 \times 2^0$	0.879	0.2	1.0
	$5^0 \times 5^0$	0.940	0.3	2.0
	$10^0 \times 10^0$	0.972	0.3	2.0
	$20^0 \times 20^0$	0.978	0.3	2.0

Summary

- At Ku-band we can achieve more accurate attenuation correction than in TRMM by using single- & dual-freq methods
  - DSRT at low-moderate R
  - SRT at high R
- At Ka-band we see improvement with dual-freq
  - Problem at high R, caused by loss of surface signal
  - This may lead to underestimation of mean R
- Can we improve the situation ?
  - We can use a statistically-based estimate to reduce the bias in the mean R
  - However, we need fairly large space-time regions to achieve this


5 km path
dBZm
dBZ
Zm(Ku)
Zm(Ka)
5 km path
zeta
dBZ
ς(Ka)
ς(Ku)