Radar Algorithm Team/ U.S.

Chandra:	CSU
Durden, Steve:	JPL
Kwiatkowski, John:	GSFC/George Mason
Liao, Liang:	GSFC/Morgan State
Meneghini, Bob	GSFC
Tanelli, Simone	JPL

Outline

- Summary of U.S. participation in DPR algorithm development
- SRT Status
- NUBF Studies

Background

- Over 15 years of experience for Ku-band radar alg
- Extension from Ku- to Ka-band is a well-defined problem; nevertheless
  - Attenuation at Ka-band is about 6x larger than at Ku-band (SNR issues)
  - Non-Rayleigh scattering effects much larger at Ka-band (e.g., BB isn't so clearly delineated)
  - Algorithm architecture is more flexible but more complex
- The central science challenge is to develop & test dual-freq algorithms

Classification Module

- Objective is to classify into rain-type and ID predominant phase state along radar range
  - Extension of 2a23 (J. Awaka)
- Chandra/Le are working closely w/ Prof Awaka on a dual-freq classification algorithm
  - Based on an examination of DFR_m profiles & 1st derivative ($DFR_m = dBZ_m(Ku) - dBZ_m(Ka)$)
  - Ideally will work seamlessly with single-freq method across inner/outer swath bndy (in most cases)

Solver Module

- Objective is to estimate rain rate and DSD parameters
  - Extension of 2a25 (Iguchi -> Seto/Iguchi)
- Algorithm covers both single & dual-freq data
- Algorithm uses an iterative method that can either use or dispense with SRT-PIA
- Makes use of scattering tables

Utility of Scattering Tables

- Applicable to most radar & radar-radiometer methods
- Encapsulates microphysical assumptions of particle models
- Provides sensitivity tests of algorithms
- Allows a separation between the mechanics of the algorithm and the particle microphysics assumptions
- Establishes a linkage between the algorithm & microphysics/GV communities

Solver Module (scattering tables)

- Both Japan & U.S. are working on scattering table generation
- General agreement as to basic structure/content
  - Gamma DSD with μ constant or function of Λ
  - Scattering parameters normalized by a number concentration parameter & provided as function of a characteristic size parameter
  - e.g., (N_w, D_m) or (N_T, D_0)
- Liao and Williams have generated a number of tables for snow, mixed-phase and rain
- Kuo and Johnson working on physically-based, computer-generated dry & wet snow particle models

Surface Reference Technique Module

- Objective is to estimate the path-integrated attenuation (PIA)
- Improvements in the basic SRT
  - Forward/backward; along/X-track; temporal (2a21, v7)
  - Land classification (Durden, Tanelli)
  - Weak-rain/wet-surface reference (Seto)

Surface Reference Technique Module

- Extensions of the basic method
  - PIA ratio (PIA(Ka)/PIA(Ku)) for NUBF (Tanelli, Durden)
  - PIA estimates at sub-beam resolution for NUBF (Takahashi, Hanado, Iguchi)
  - Correlation properties of $\sigma^0(f_1)$, $\sigma^0(f_2)$ (GSFC)

Correlation properties of $\sigma^0(f_1)$, $\sigma^0(f_2)$: DSRT

SRT

$$PIA(f_i) \equiv 2\int_0^{r_s} k(f_i, s)\,ds = \sigma^0_{NR}(f_i) - \sigma^0_R(f_i)$$

$$\mathrm{var}(PIA(f_i)) \approx \mathrm{var}(\sigma^0_{NR}(f_i))$$

$DSRT$

$$\delta PIA \equiv PIA(f_2) - PIA(f_1) \equiv 2\int_0^{r_s} [k(f_2, s) - k(f_1, s)]\,ds$$

$$= [\sigma^0_{NR}(f_2) - \sigma^0_{NR}(f_1)] - [\sigma^0_R(f_2) - \sigma^0_R(f_1)]$$

$$\mathrm{var}(\delta PIA) \approx 2\,\mathrm{var}(\sigma^0_{NR}(f))\{1 - \rho[\sigma^0_{NR}(f_2), \sigma^0_{NR}(f_1)]\}$$

$$\rho \longrightarrow 1,\ \mathrm{var}(\delta PIA) \longrightarrow 0$$

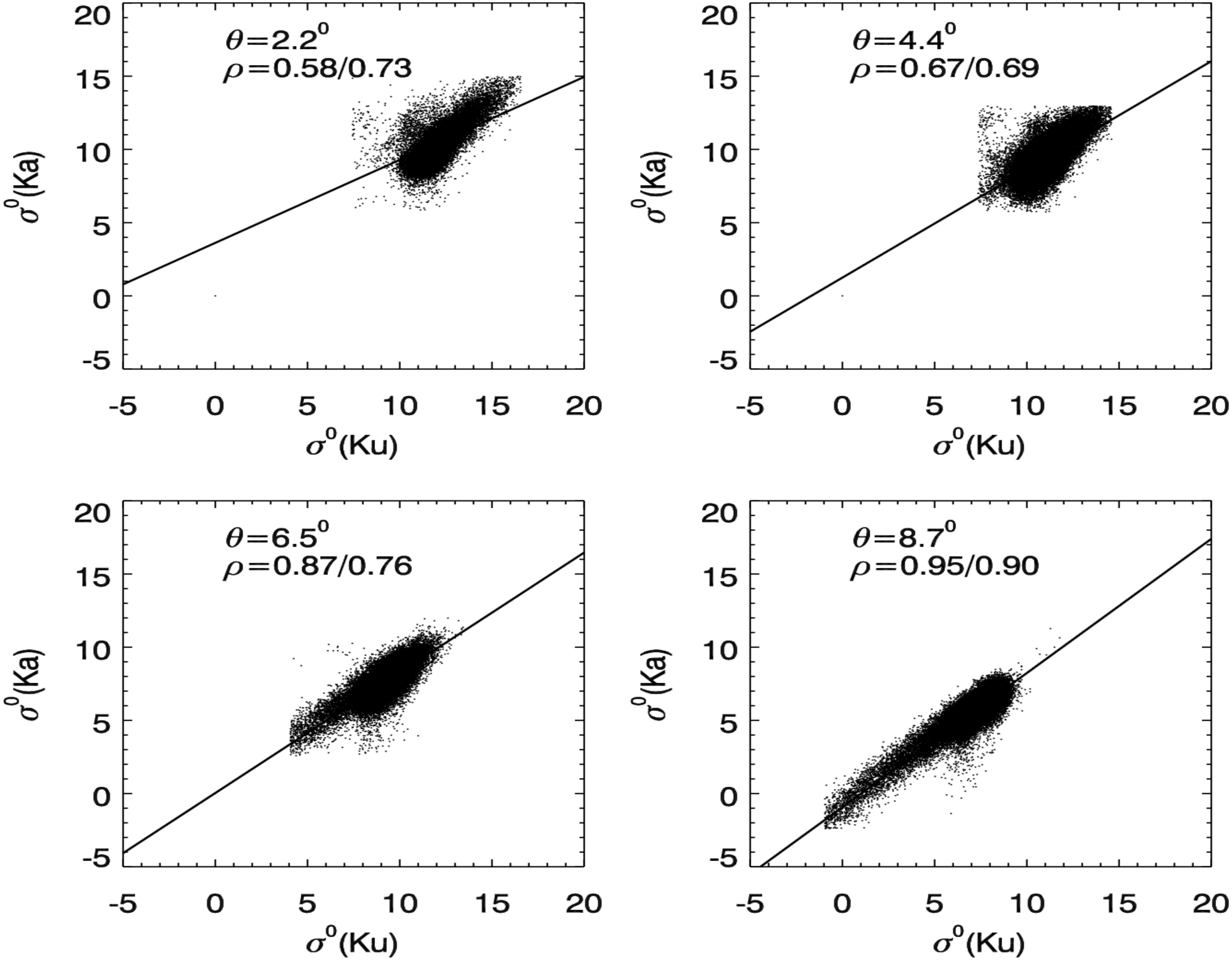
Error Sources

- DSRT
  - Errors in δPIA estimation
  - Errors in estimating PIA from δPIA
  - 'saturation' error – loss of surface signal at either Ka or Ku-band

- SRT
  - Errors in PIA estimation
  - No comparable error: direct estimation of PIA
  - 'saturation' error – loss of surface signal at the particular freq of interest

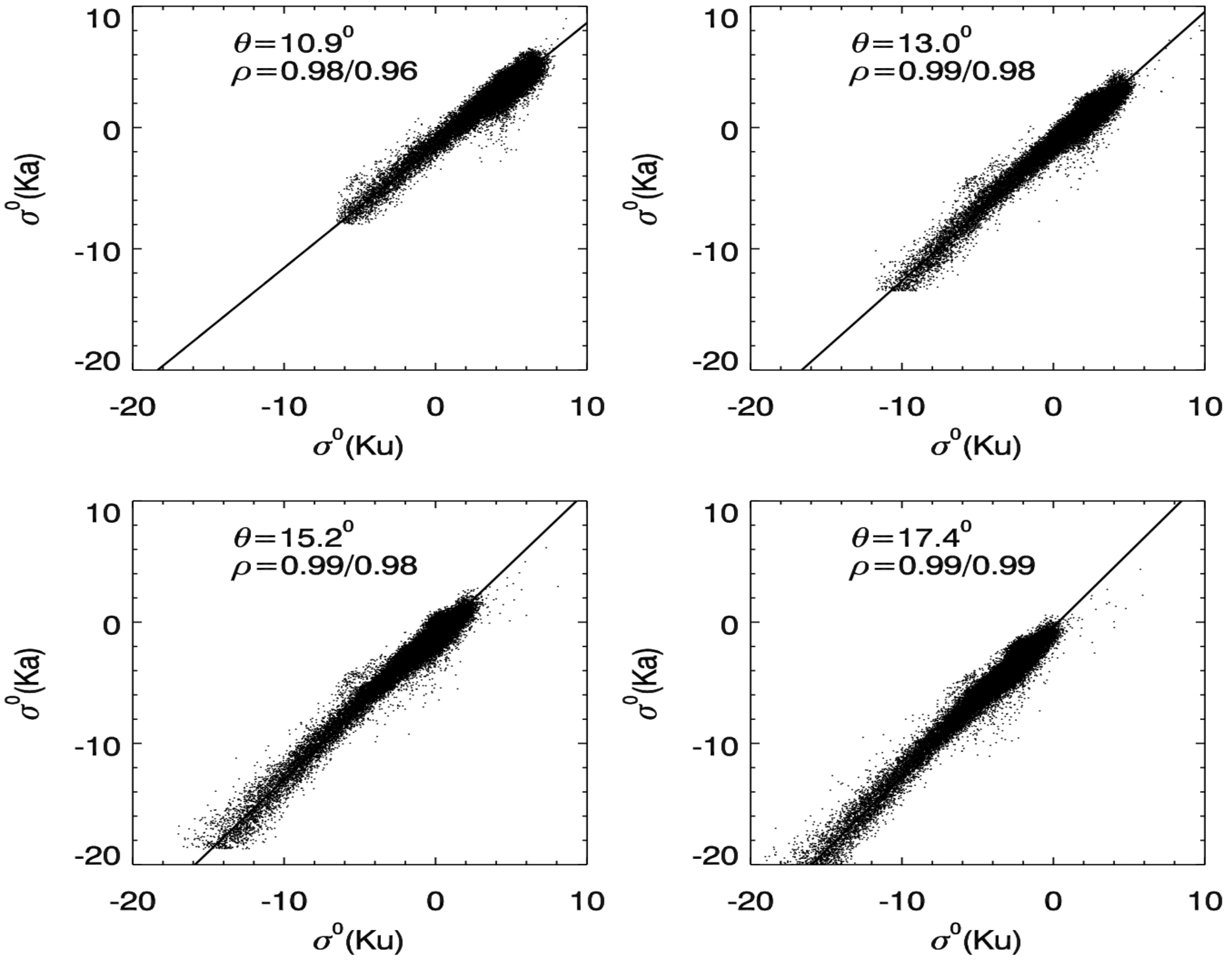
JPL APR-2

OCEAN: TC4

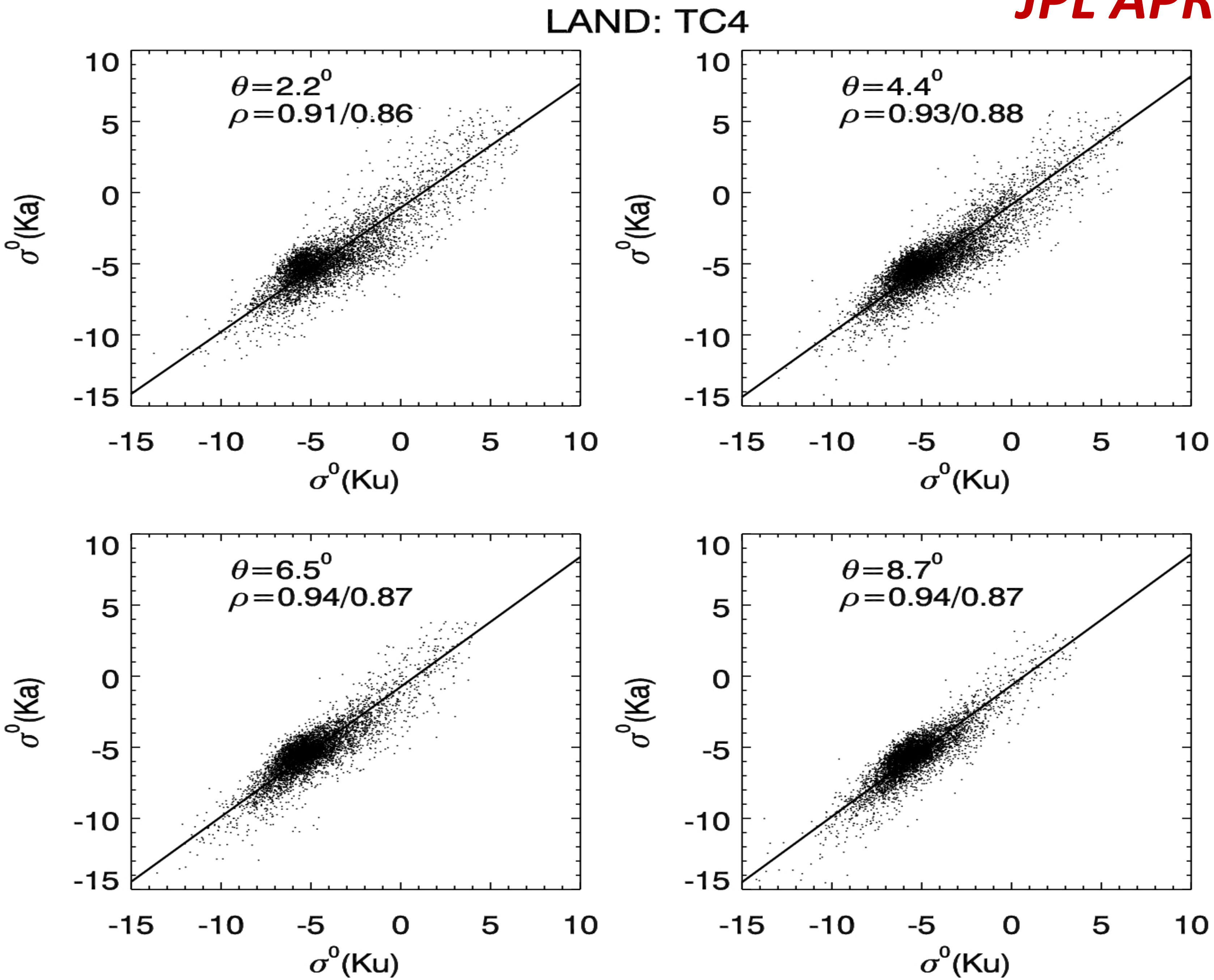


JPL APR-2

OCEAN: TC4



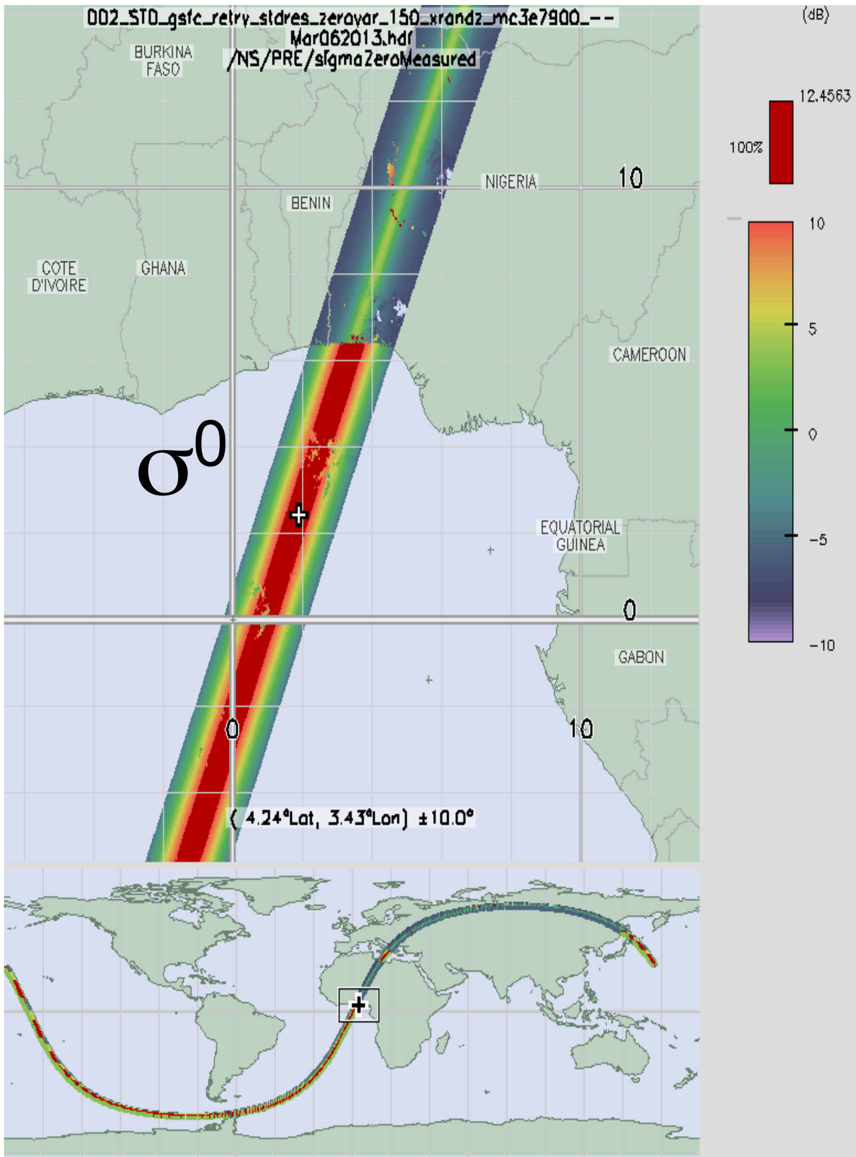
JPL APR-2

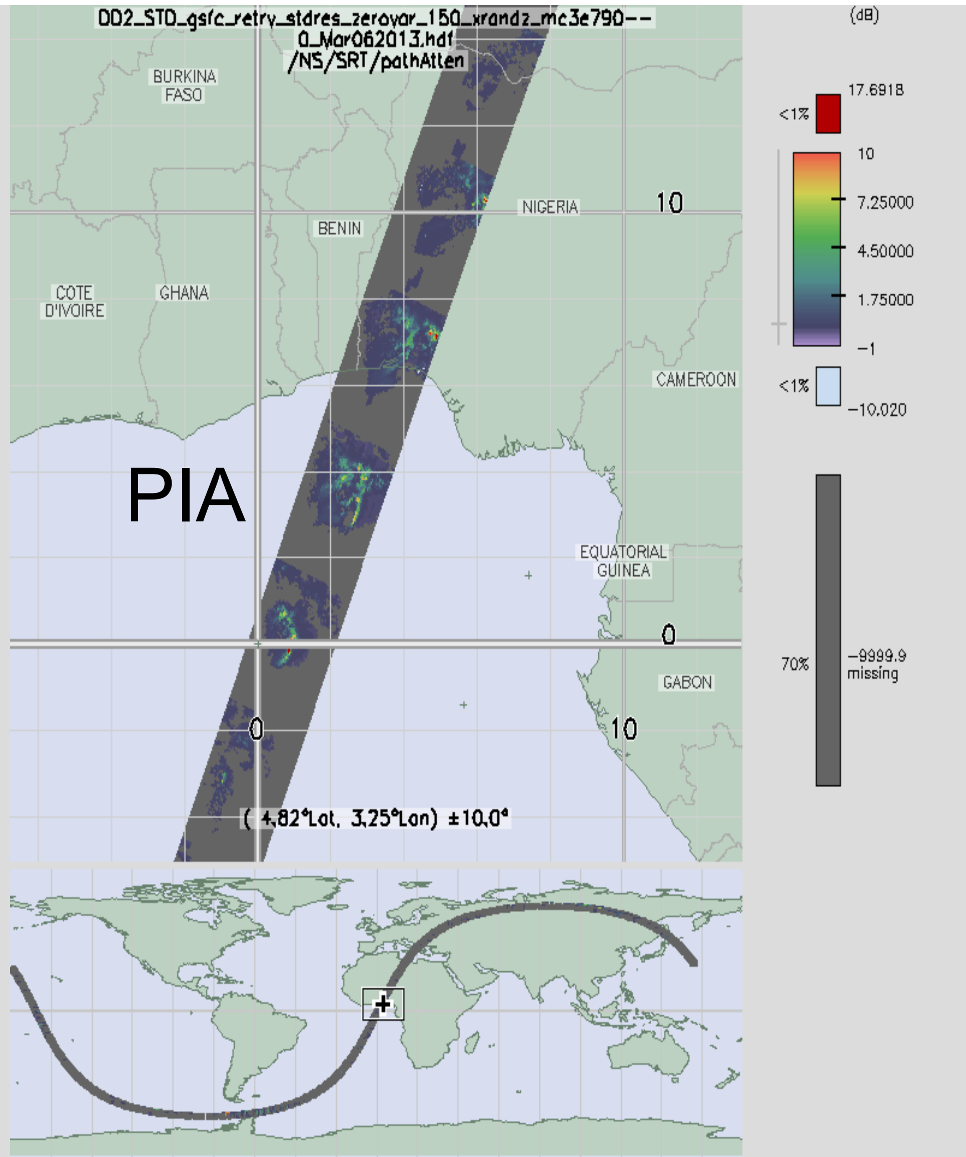

LAND: TC4
$\theta=2.2^0$
$\rho=0.91/0.86$
$\theta=4.4^0$
$\rho=0.93/0.88$
$\theta=6.5^0$
$\rho=0.94/0.87$
$\theta=8.7^0$
$\rho=0.94/0.87$
σ^0(Ka)
σ^0(Ku)
10
5
0
-5
-10
-15

Test Environment

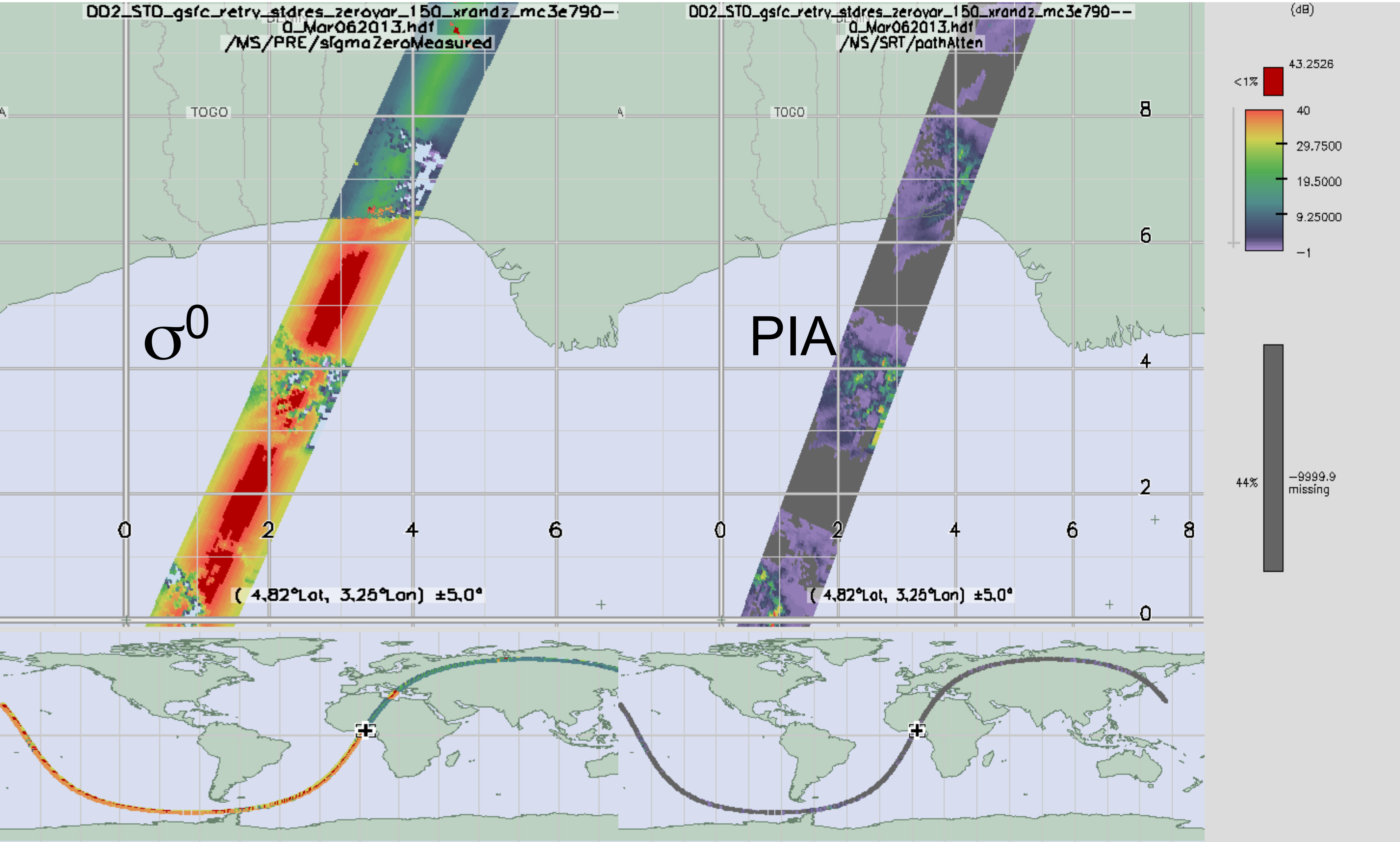
- Goddard Test & Validation data
  - MC3E_150 and _300 & LPVEX (Matsui)
  - Generate L1 data sets using JAXA template and radar simulator (Kim)
  - Run L2 modules: Ku, Ka/Ka-HS, and DPR
  - Compare 'true' PIA with retrieved PIA's
    - Single & dual-freq methods
    - Baseline: σ^0 statistics derived from the JPL APR-2 data

L2 output data (Ku-band)

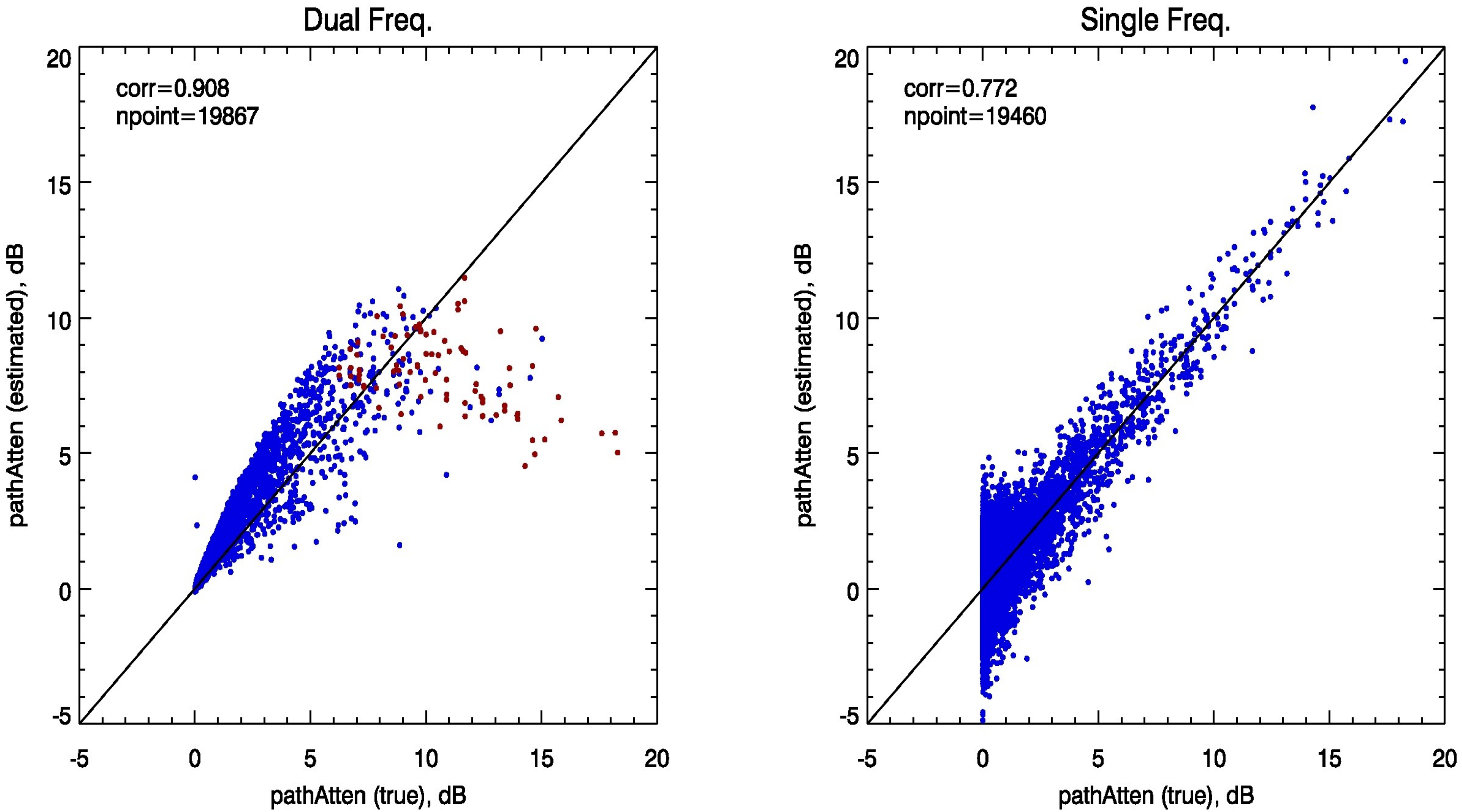




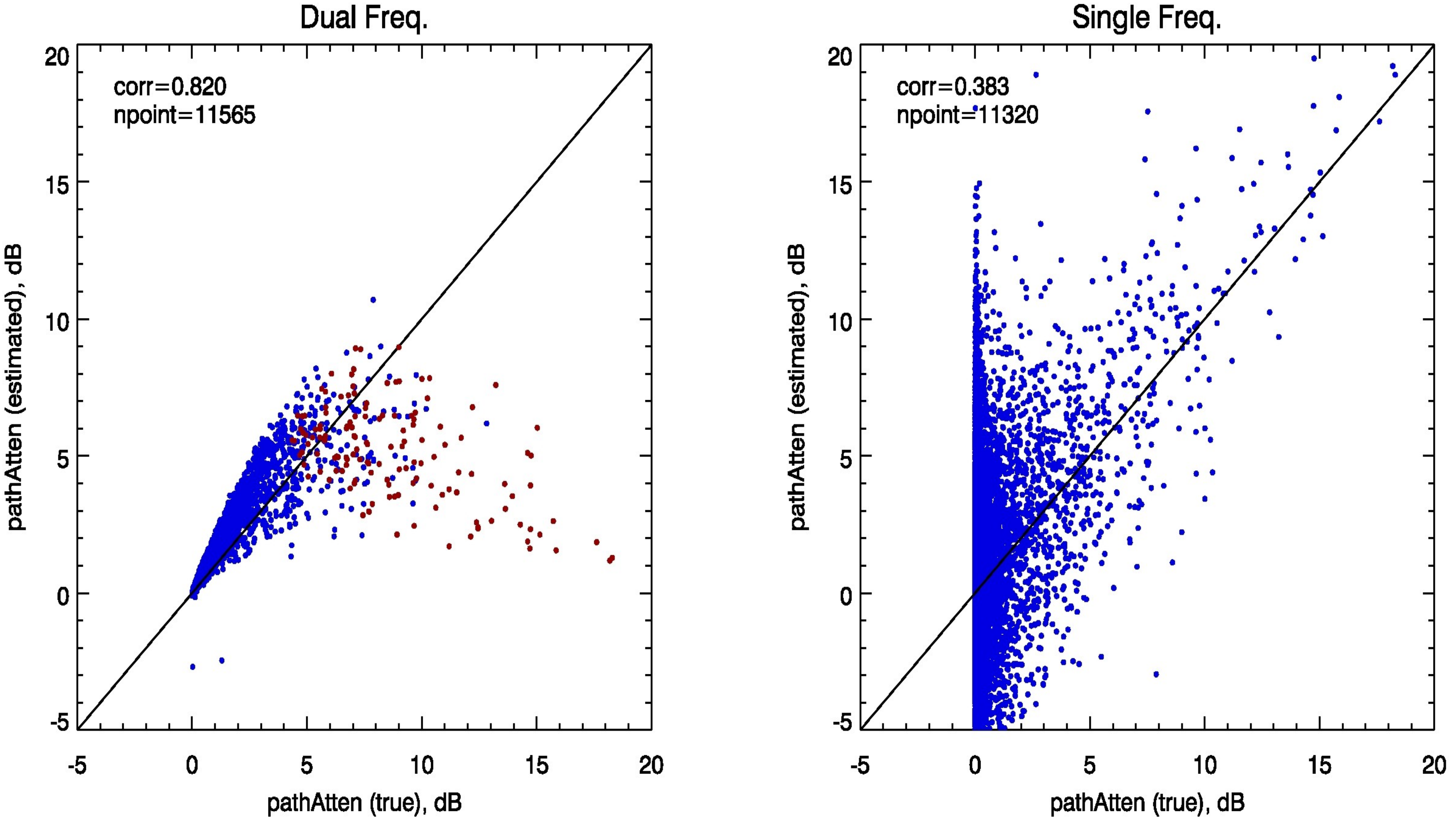
L2 output data (Ka-band)



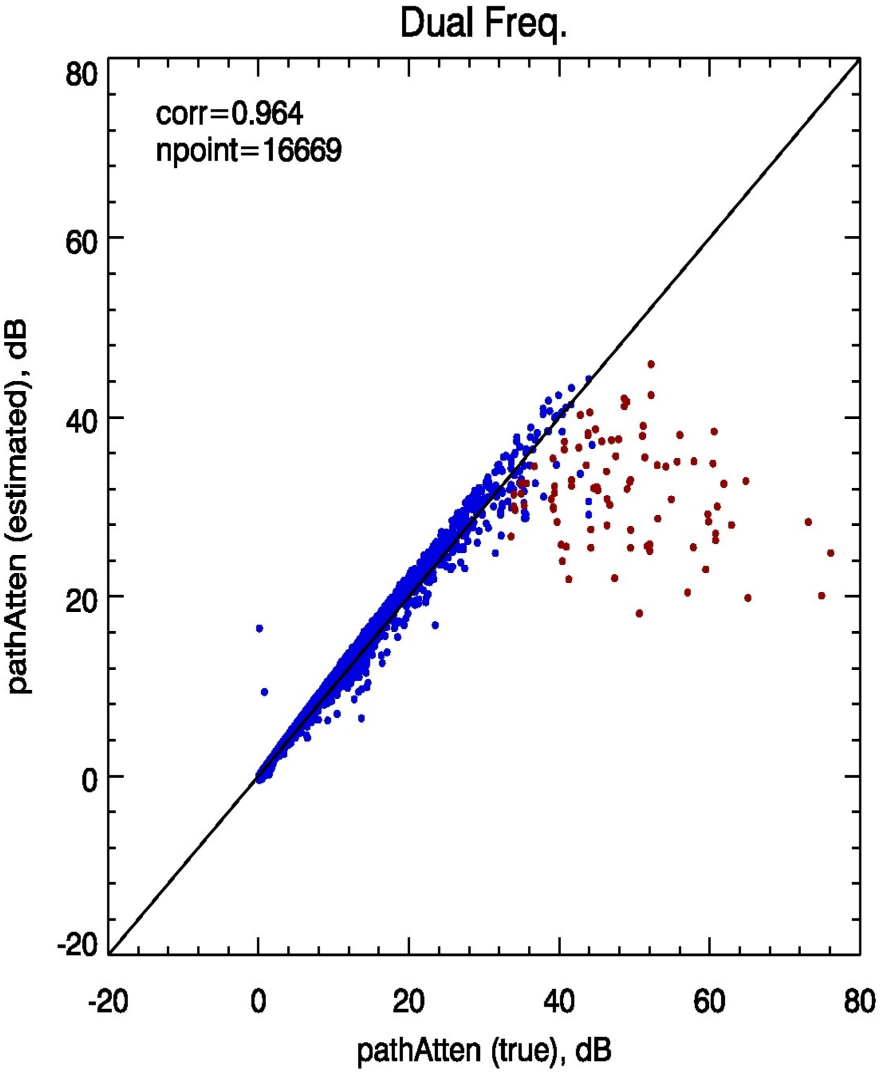
High correlation,
0^0-9^0
Ocean, PIA(Ku)

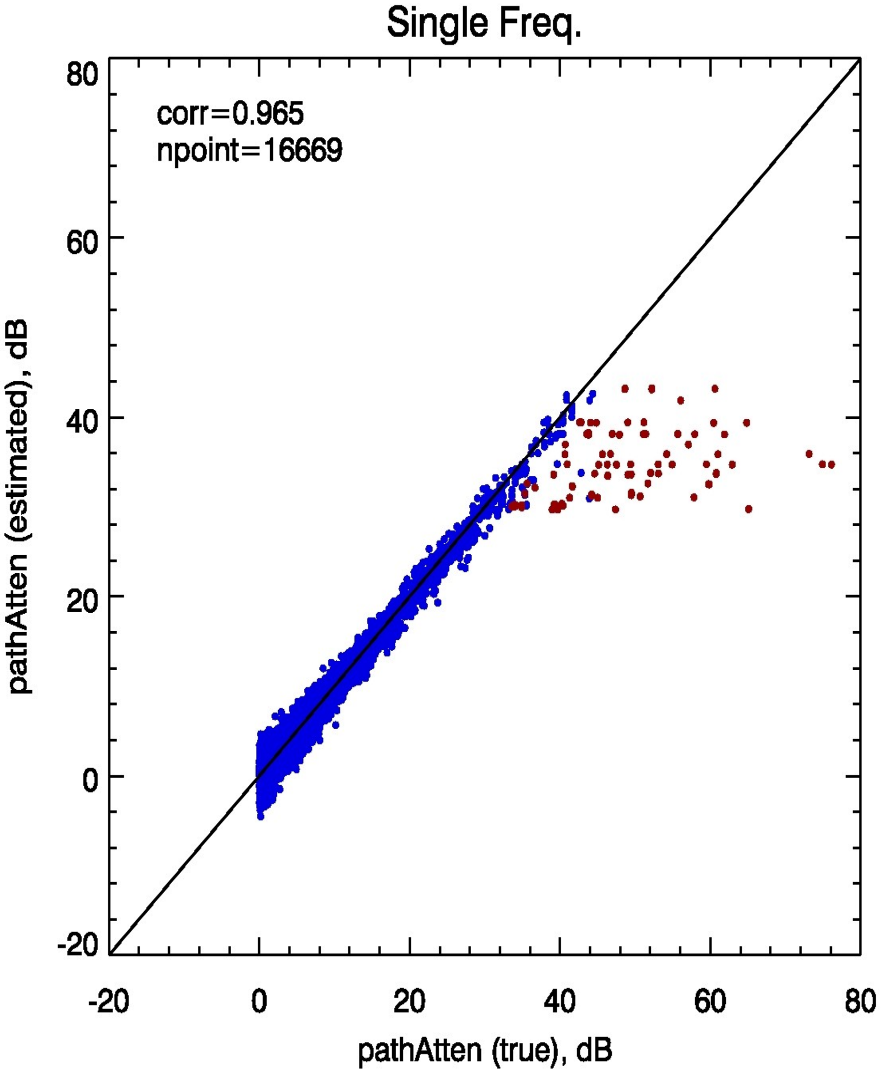


High correlation,
0^0-9^0
Land, PIA(Ku)

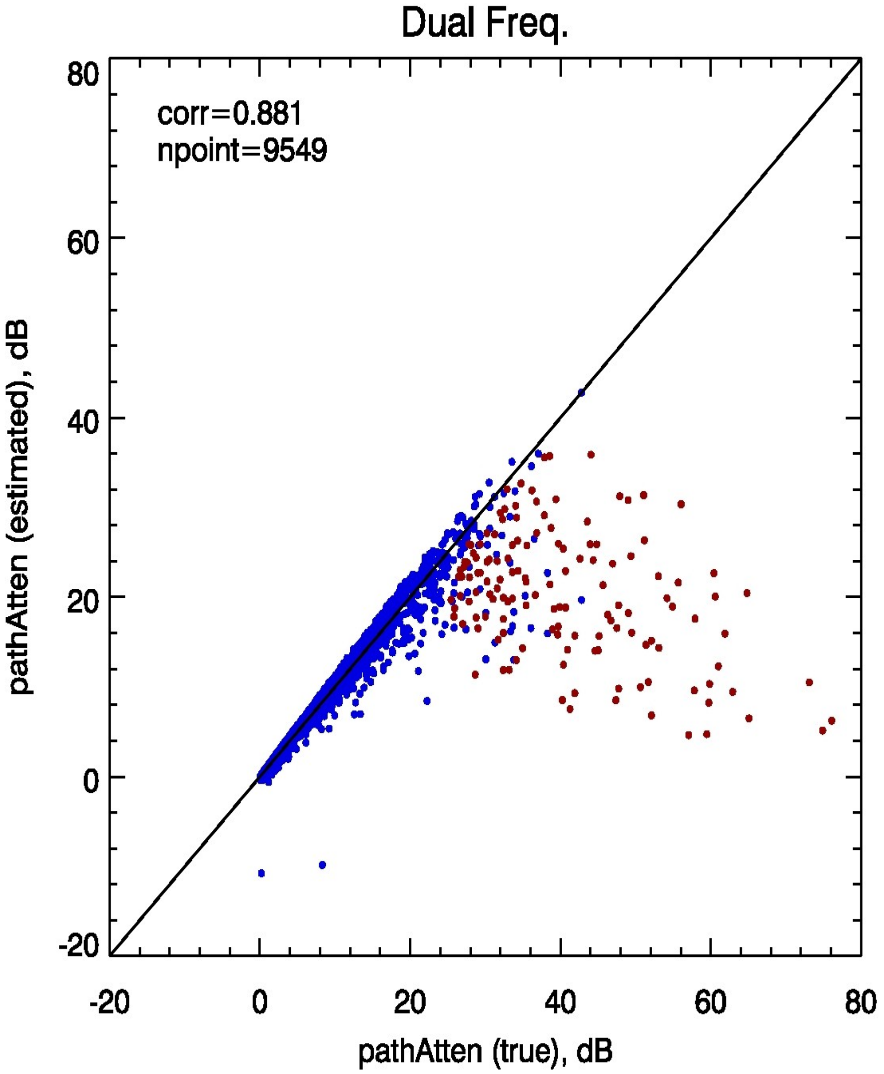


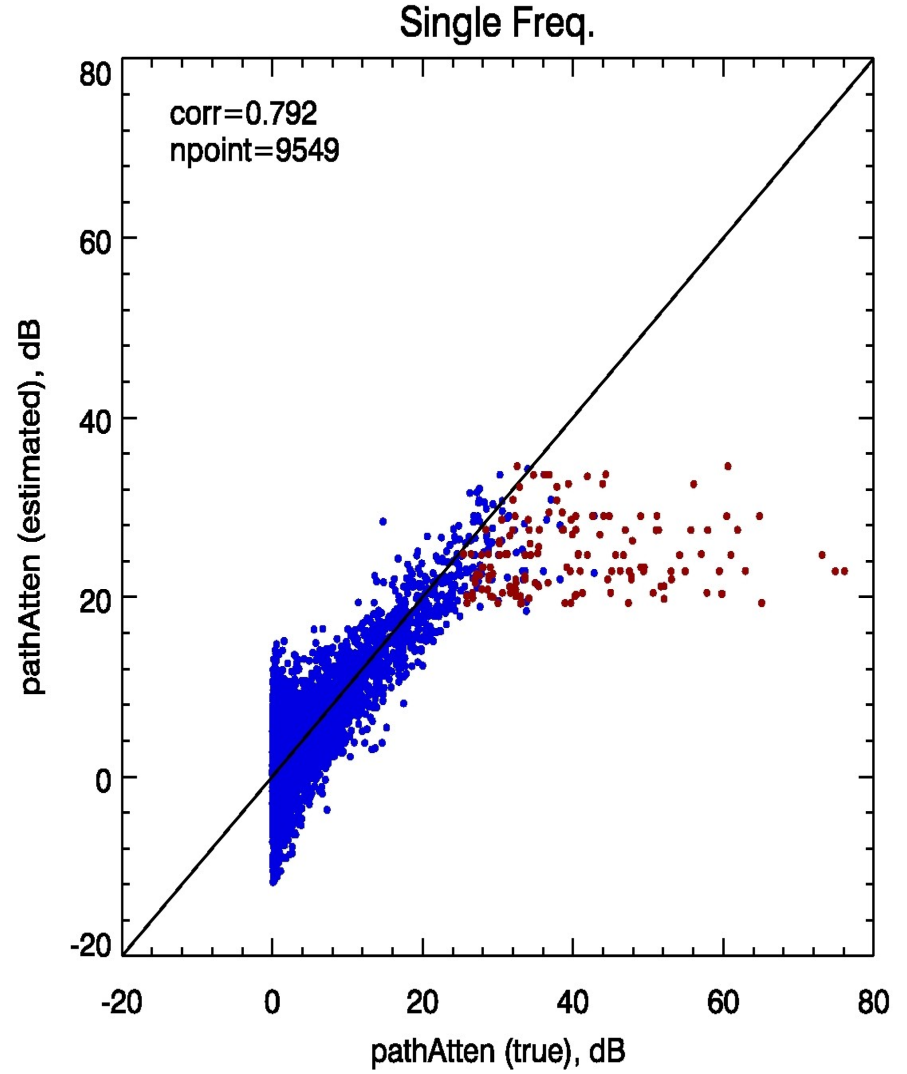
High correlation,
0^0-9^0
Ocean, PIA(Ka)

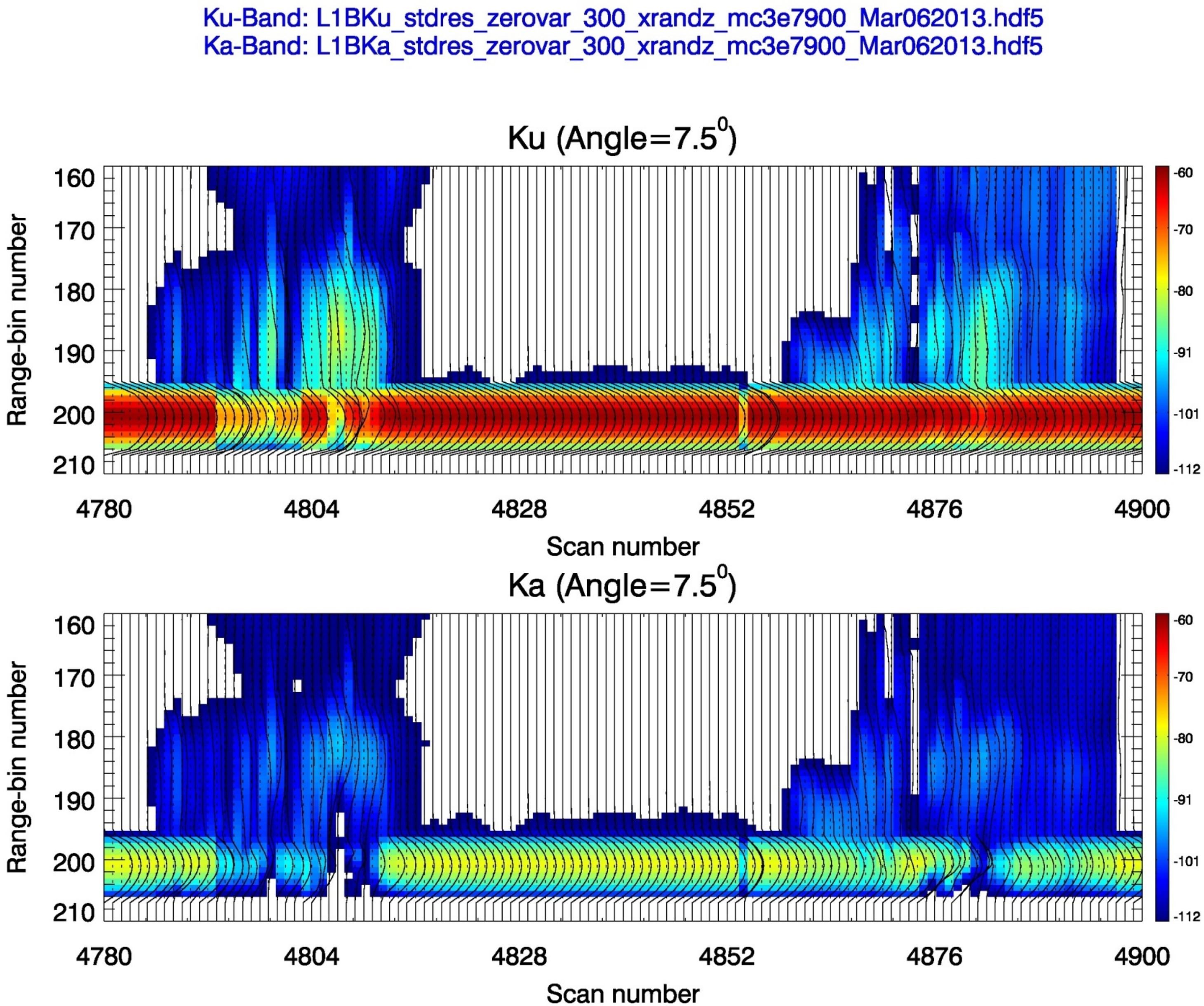




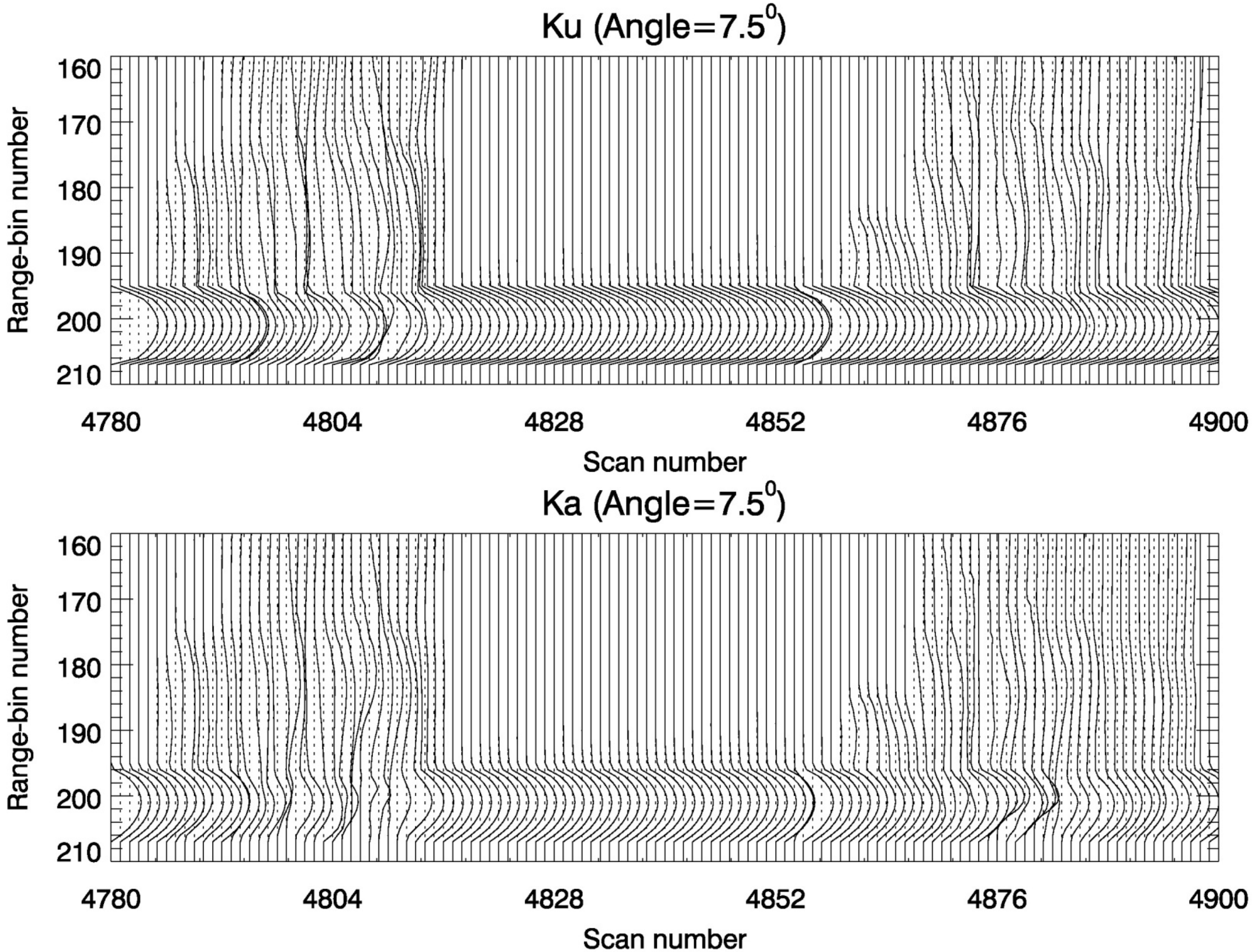
High correlation,
0^0-9^0
Land, PIA(Ka)

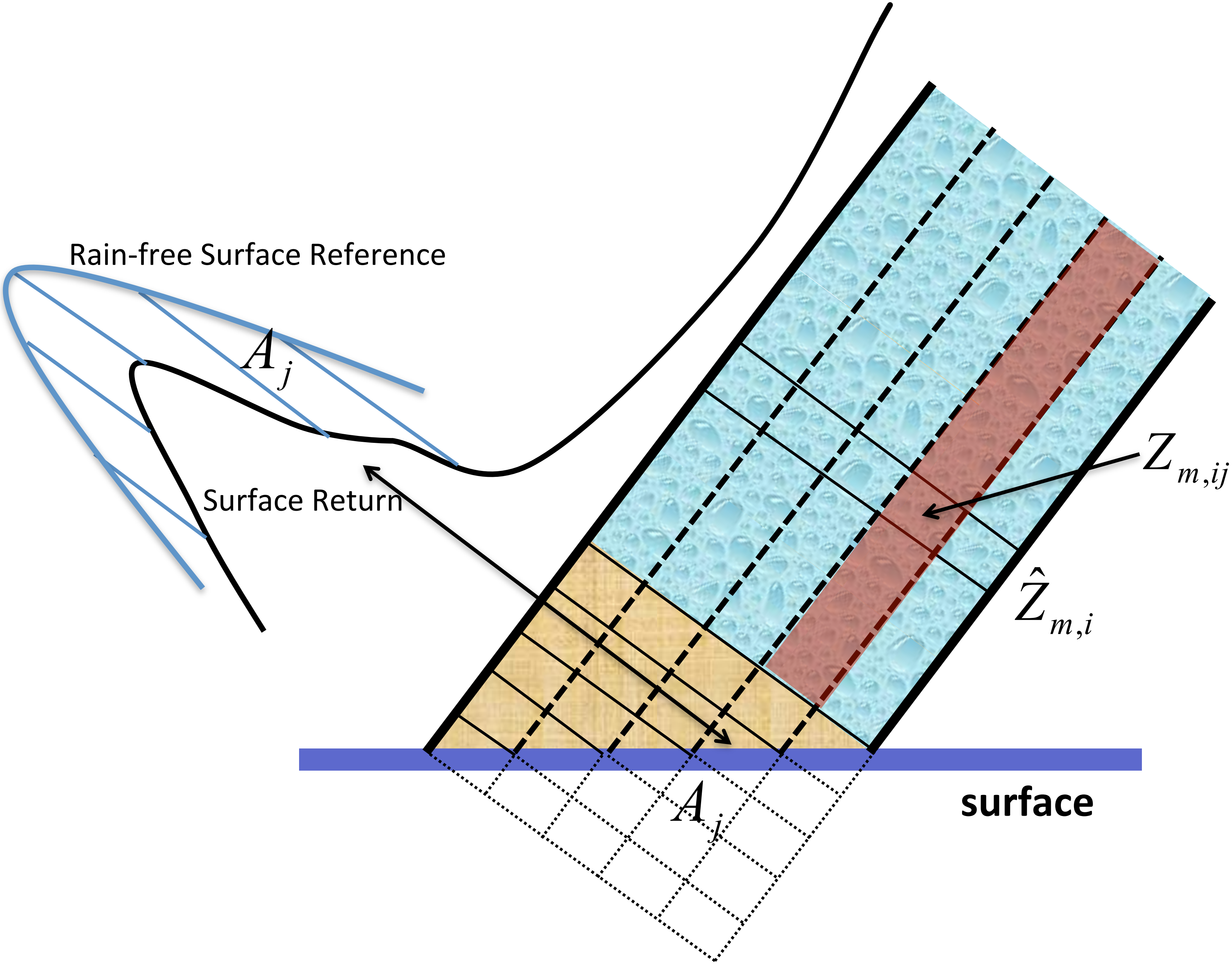





Ku-Band: L1BKu_stdres_zerovar_300_xrandz_mc3e7900_Mar062013.hdf5
Ka-Band: L1BKa_stdres_zerovar_300_xrandz_mc3e7900_Mar062013.hdf5
Ku (Angle=7.5^0)
Range-bin number
160
170
180
190
200
210
4780
4804
4828
4852
4876
4900
Scan number
-60
-70
-80
-91
-101
-112
Ka (Angle=7.5^0)
Range-bin number
160
170
180
190
200
210
4780
4804
4828
4852
4876
4900
Scan number
-60
-70
-80
-91
-101
-112

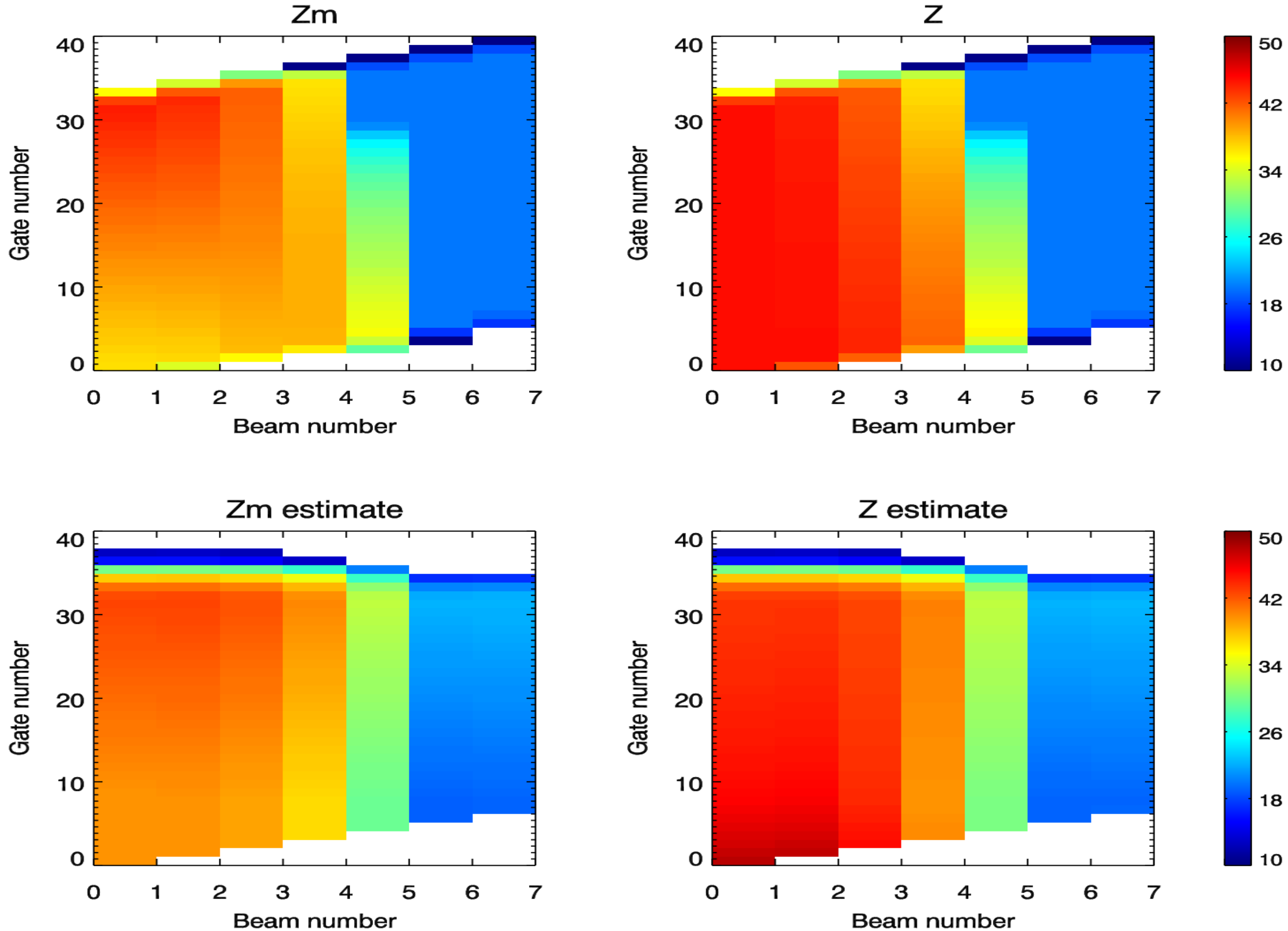
Ku-Band: L1BKu_stdres_zerovar_300_xrandz_mc3e7900_Mar062013.hdf5
Ka-Band: L1BKa_stdres_zerovar_300_xrandz_mc3e7900_Mar062013.hdf5




Rain-free Surface Reference
A_j
Surface Return
$Z_{m,ij}$
$\hat{Z}_{m,i}$
A_j
surface

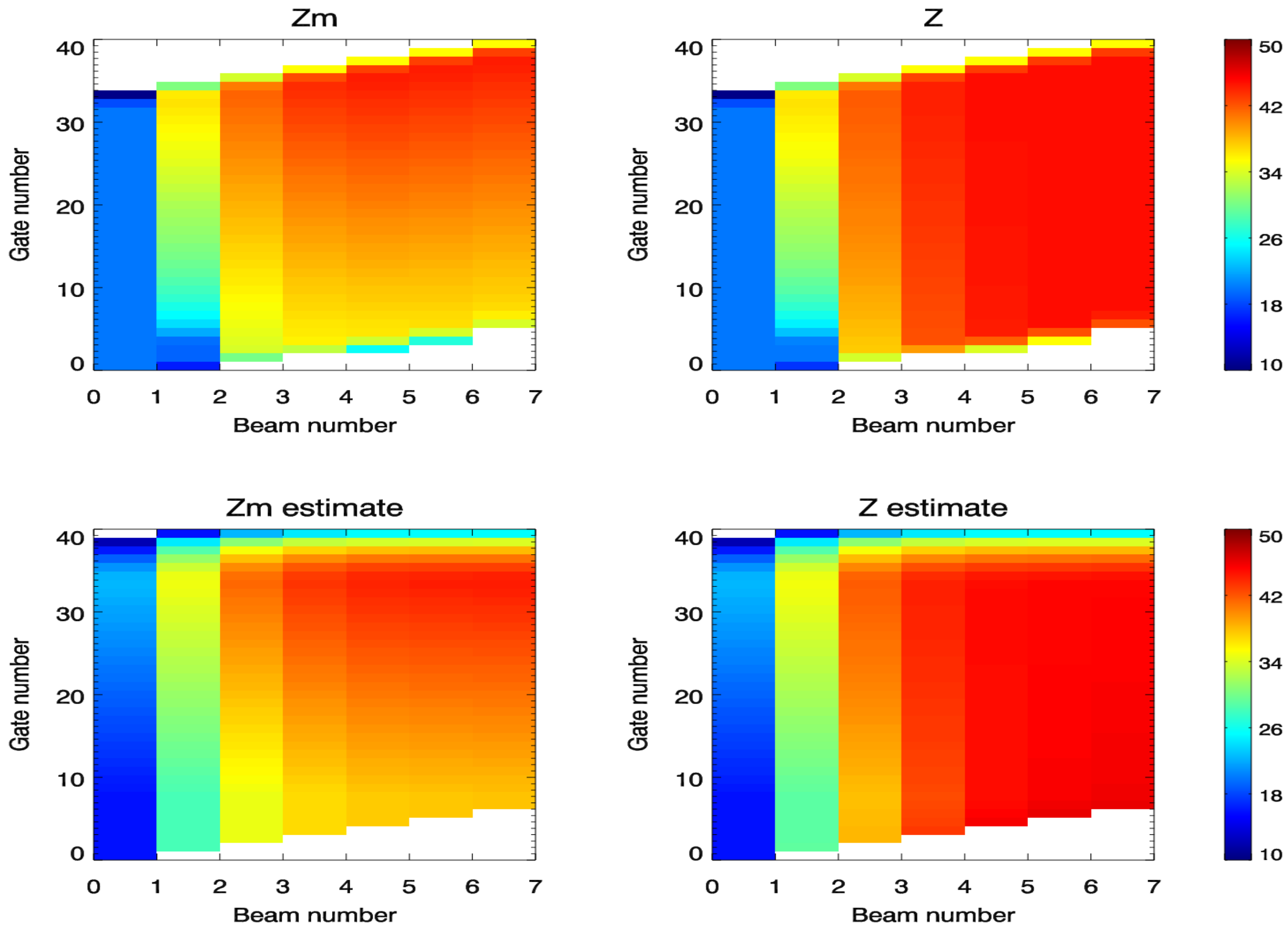
Estimation Procedure

- Along the j^{th} Column
  - Write Hitschfeld-Bordan PIA estimate for each column
  - The HB PIA, however, is a function of the high-res (not measurable) Z_m
  - Replace high-res Z_m with the product of the low-res Z_m (measurable) and a scalar factor, ε_j
  - Adjust ε_j such that $PIA_j(HB) = PIA_j(SRT)$
  - This provides high-res estimates of the atten-corr Z
  - Use R-Z relation to convert Z to R at high-res
  - Average R, Z back to the low-res



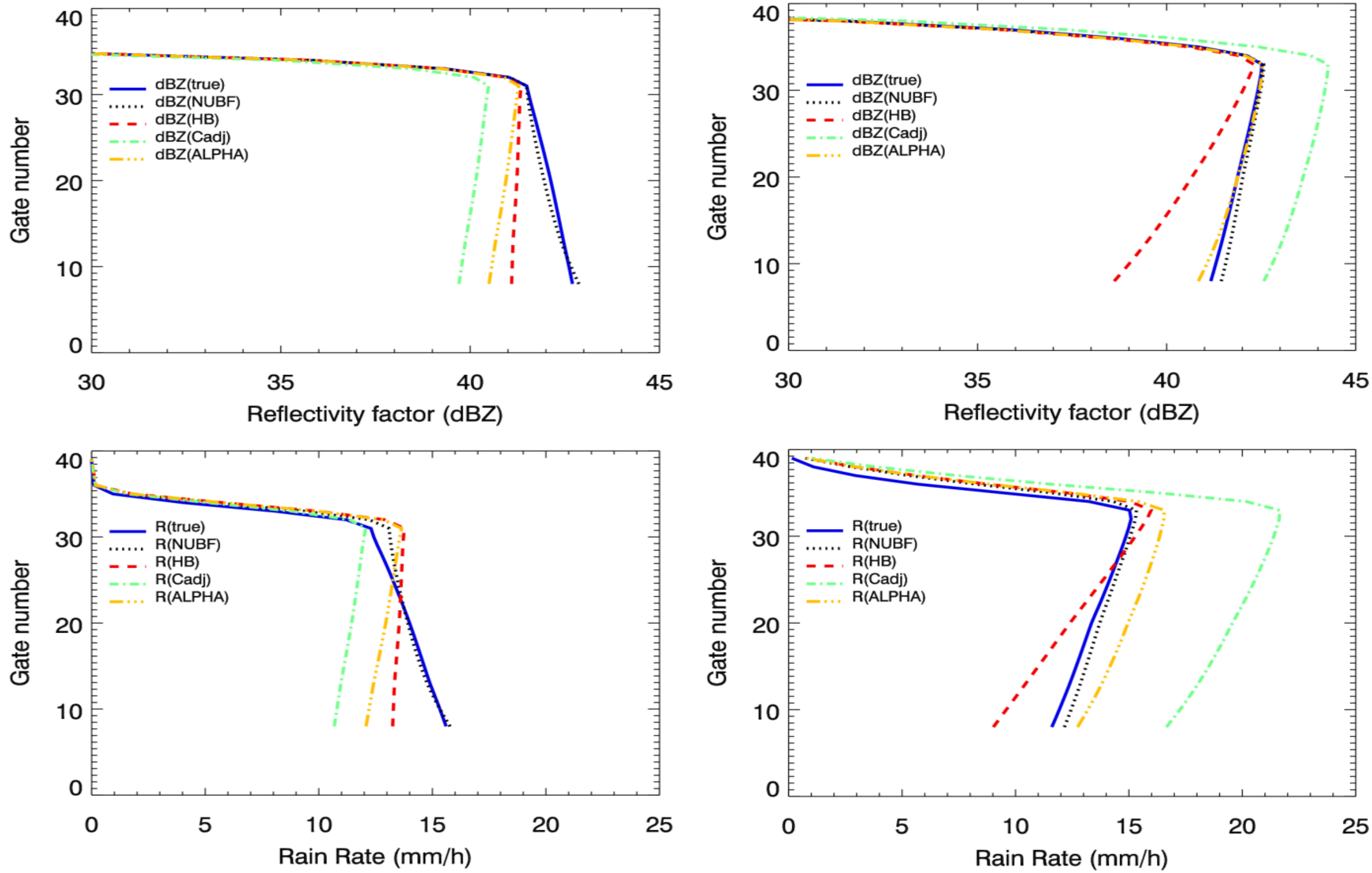
Top: High resolution true/input vales of Z_m and Z for an incidence angle of 10^0 negative gradient in Z in X-track direction

Bottom: High resolution estimates of Z_m and Z using NUBF solution

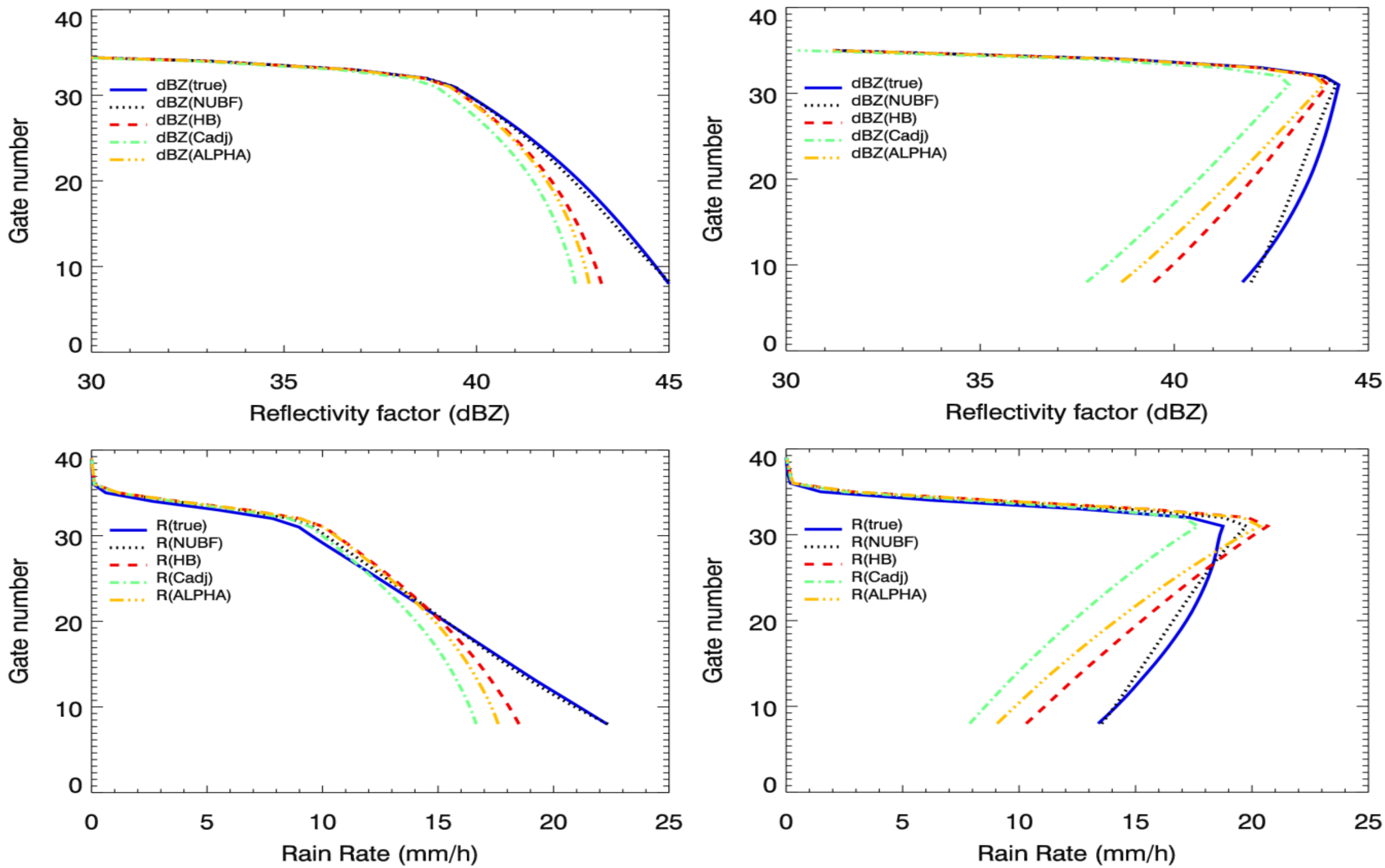


Top: High resolution true/input vales of Z_m and Z for an incidence angle of 10^0 positive gradient in Z in X-track direction

Bottom: High resolution estimates of Z_m and Z using NUBF solution



Left: negative X-track gradient ; Right: positive X-track gradient
Solid: True; Dotted: NUBF solution; Others: standard solutions w/o NUBF



Left: negative X-track gradient, negative vertical gradient
Right: negative X-track gradient, positive vertical gradient
Solid: True; Dotted: NUBF solution; Others: standard solutions w/o NUBF

NUBF- comments

- For the simple cases considered, the NUBF algorithm (Ku-band) almost always does better than the standard algorithm in both R & Z
- We have assumed, however, perfect measurements of the multiple PIA's needed in the solution
- Improvements are not a strong function of incidence angle (10^0 and 15^0)
- More realistic tests of the approach are needed
  - Use TRMM data
  - Use airborne data & radar simulator
- If results are positive, we may want to upgrade operational SRT to estimate multiple PIA's

Summary of SRT

- Dual-frequency radar may provide a way to improve estimates of path-integrated attenuation, which should lead to improvements in retrieval accuracy of R & DSD parameters

- However, errors caused by conversion of δA to A *and* the surface 'saturation' problem may reduce the effectiveness of the dual-freq approach

- Use of surface return might also be important in deducing the NUBF but these methods have not been demonstrated at an operational level

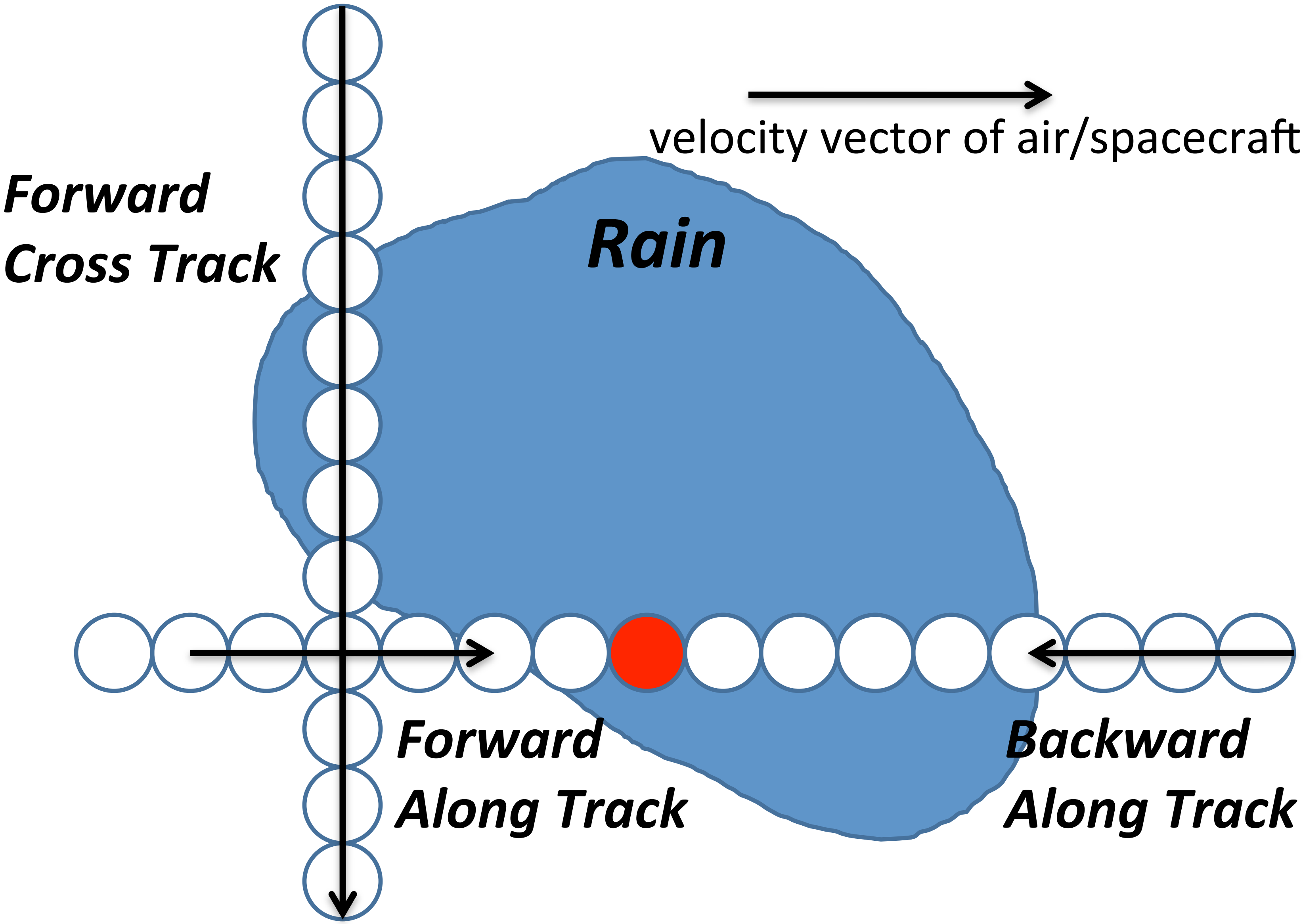
- Improvements in the land application of the SRT might be possible using work done in Japan & at JPL

Summary

- U.S. radar team members are working closely with Japanese counterparts in the writing/testing of algorithms

- Airborne radar data from JPL & GSFC will continue to be used for testing retrieval methods, improving σ^0 models, devising/testing new methods

- Several new ideas/methods have been proposed that might have an impact on the Day-2 algorithms


velocity vector of air/spacecraft
Forward
Cross Track
Rain
Forward
Along Track
Backward
Along Track

NUBF

Hitschfeld – Bordan Eq. for ith gate of jth column

$$Z_{ij} = Z_{m,ij} / [1 - qh \sum_{k=1}^{i} \alpha_{kj} Z_{m,kj}^{\beta}]^{1/\beta} \qquad (1) \ where: \ k = \alpha Z^{\beta}$$

$$A_j = 10^{-0.1\beta PIA_j} \cong 1 - qh \sum_{i=1}^{n_j} \alpha_{kj} Z_{m,kj}^{\beta} \qquad (2) \ where: PIA = 2\int_0^{r_s} k(s)ds$$

Express high resolution Z_m in terms low resolution data (row × column)

$$Z_{m,ij} = \varepsilon_j^{1/\beta} \hat{Z}_{m,i} \qquad (3)$$

$$\alpha_{ij} = \alpha_i \qquad (3')$$

(3) → (2), *solving for* ε_j

$$\varepsilon_j = [1 - A_j] / qh \sum_{k=1}^{n_j} \alpha_k \hat{Z}_{m,k}^{\beta} \qquad (4)$$

NUBF

$(4) \rightarrow (3),\ (3) \rightarrow (1):$

$$Z_{ij}^{\beta} = \hat{Z}_{m,i}^{\beta}[1 - A_j] / \{qh[\sum_{k=1}^{n_j} \alpha_k \hat{Z}_{m,k}^{\beta} - (1 - A_j) \sum_{k=1}^{i} \alpha_k \hat{Z}_{m,k}^{\beta}]\} \qquad (5)$$

where n_j *is the number of range gates in jth column*

at the surface $(i = n_j)$,

$$Z_{n_j j}^{\beta} = \hat{Z}_{m,n_j}^{\beta} / A_j = \hat{Z}_{m,n_j}^{\beta}\, 10^{0.2\beta \int_0^{n_j} k(s)ds} \qquad (6)$$

high resolution rain rates:

$$R_{ij} = aZ_{ij}^{b} \qquad (7)$$

NUBF

$$to\ \ estimate\ \ coarse\ \ resolution\ \ data:$$

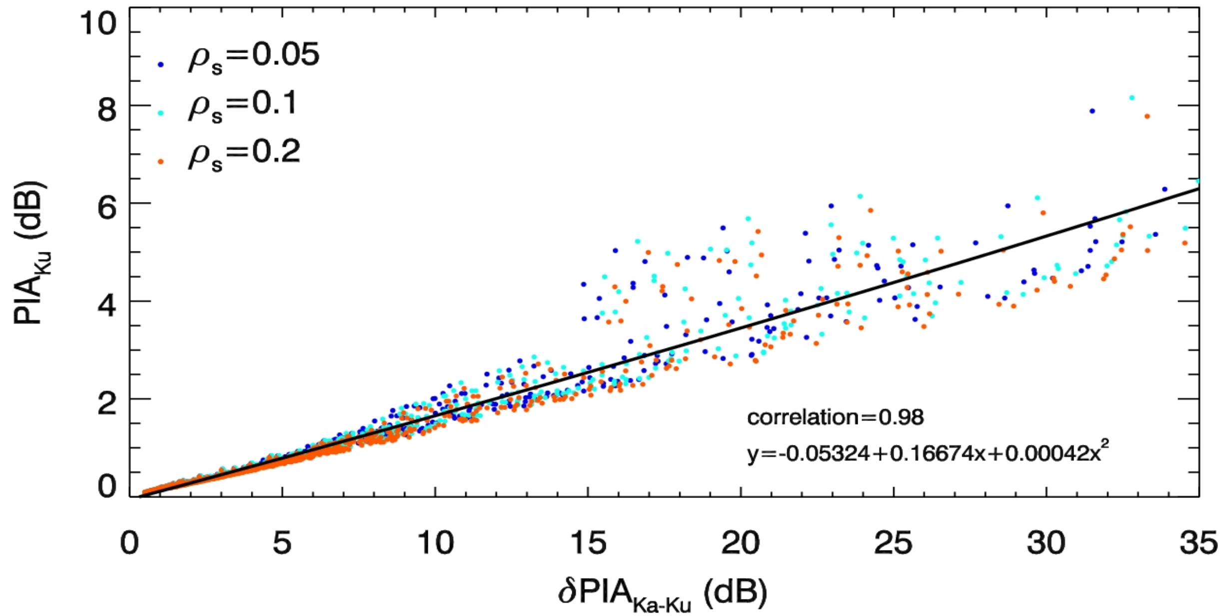
$$\hat{R}_i = \sum_j w_j R_{ij} / \sum_j w_j$$

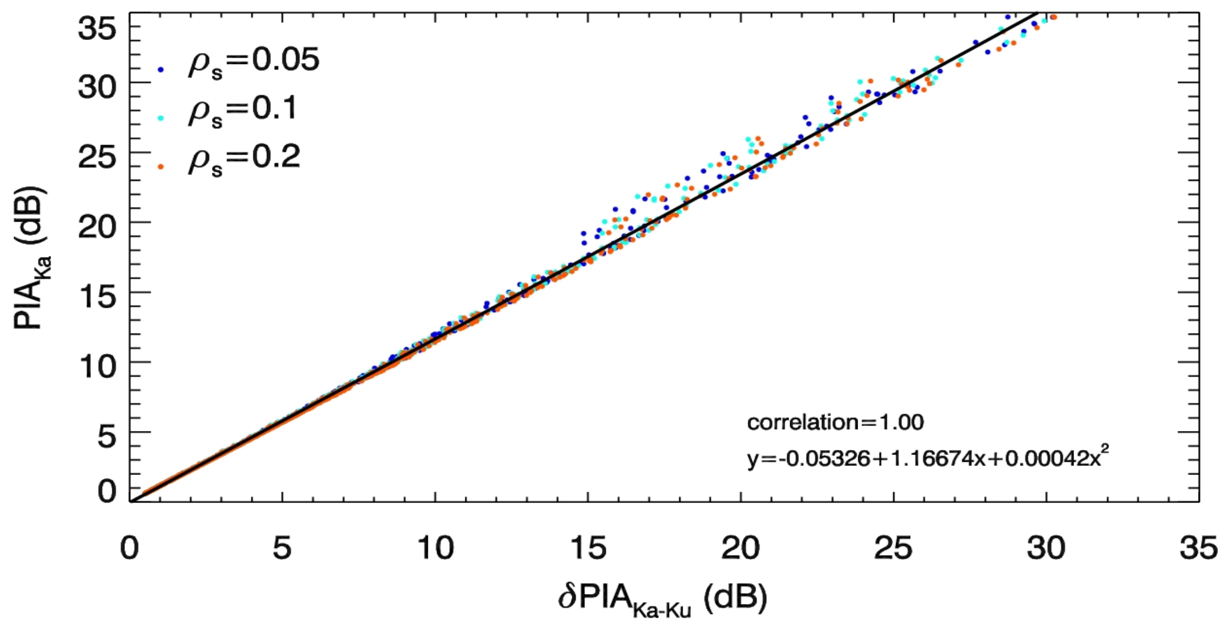
$$\hat{Z}_i = \sum_j w_j Z_{ij} / \sum w_j$$

DSRT vs SRT

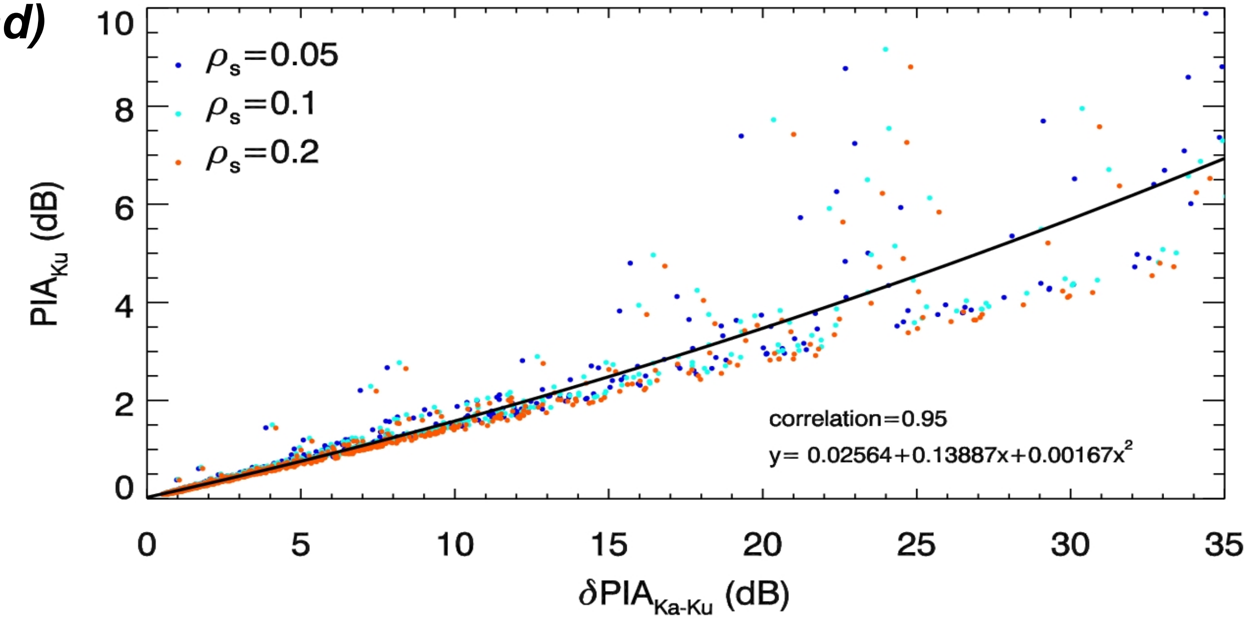
- In summary
  - If the correlation of σ^0 (with freq) is high and if surface return is detectable, then the estimate of δPIA, via the DSRT, is more accurate than the estimate of PIA at either freq, using the SRT
  - This δPIA can be used in the retrieval of the profile of the characteristic size parameter of the PSD
  - However, to estimate parameter associated with the particle number concentration, we need to estimate PIA(Ku) or PIA(Ka) from δPIA; this estimate, however, depends on the PSD along the column, introducing an additional error into the retrieval

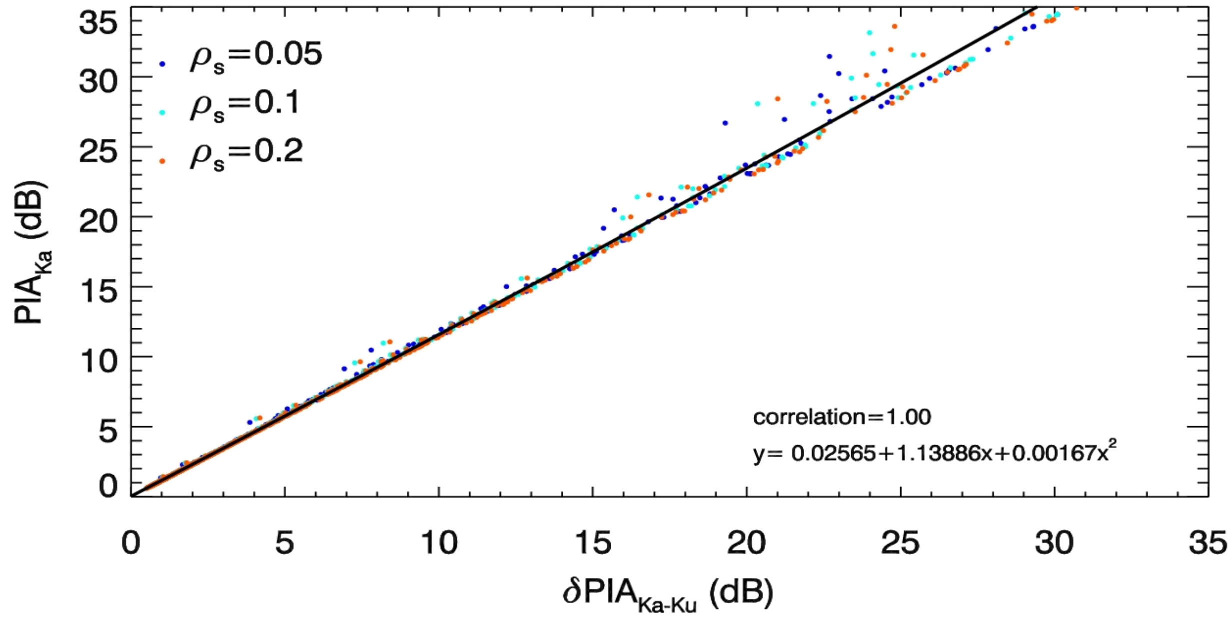
Fully correlated DSDs Along column (Wallops, VA)



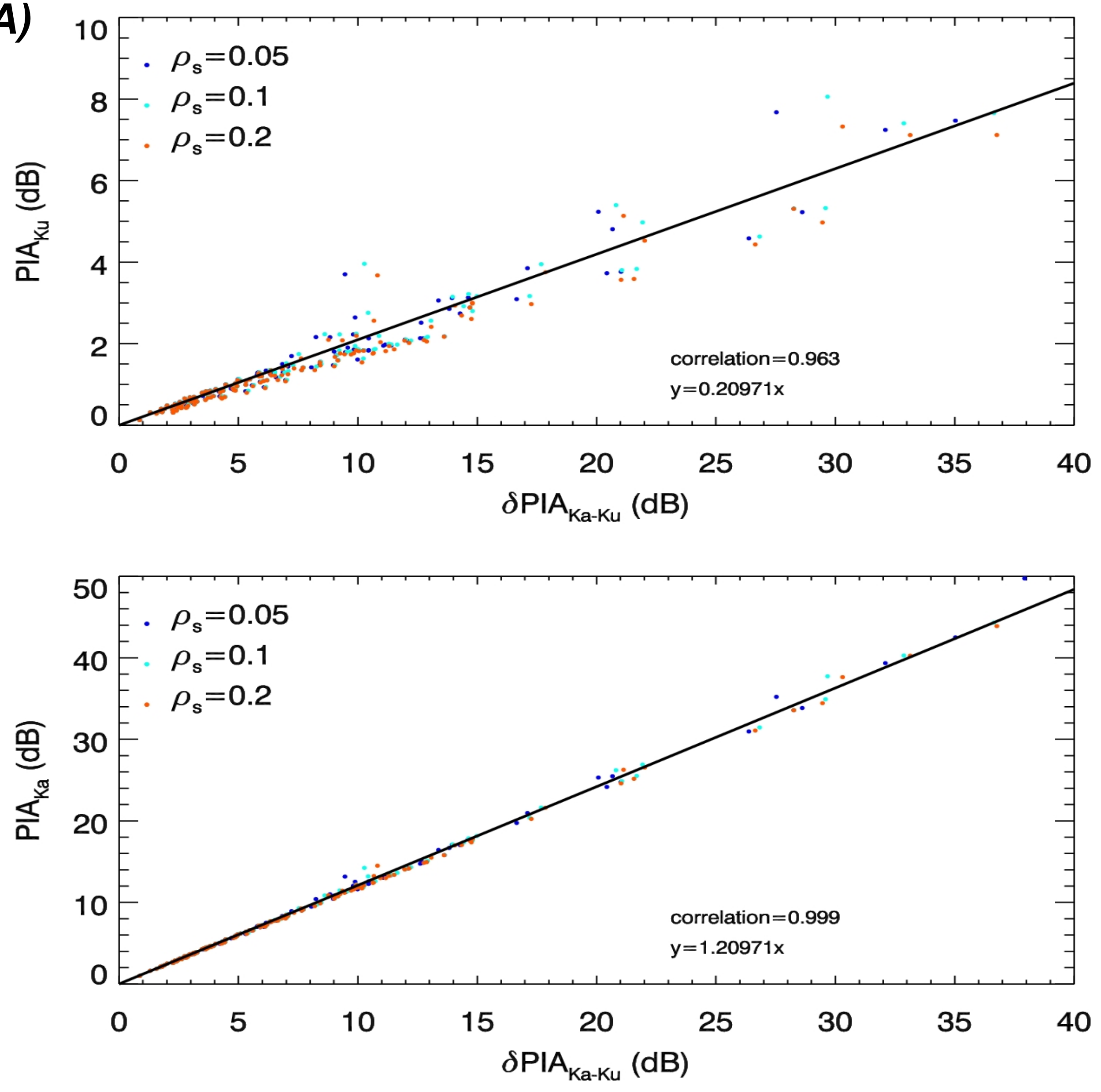


Fully correlated DSDs
Along column
(Switzerland)





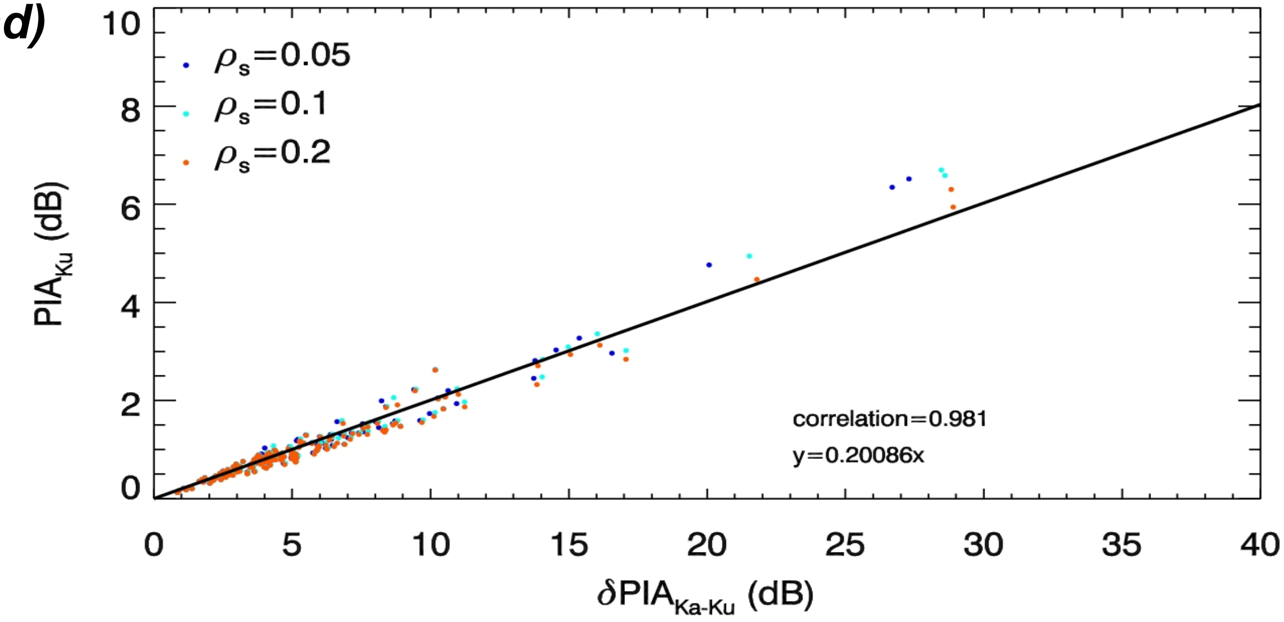
Fully uncorrelated DSDs along column (Wallops, VA)

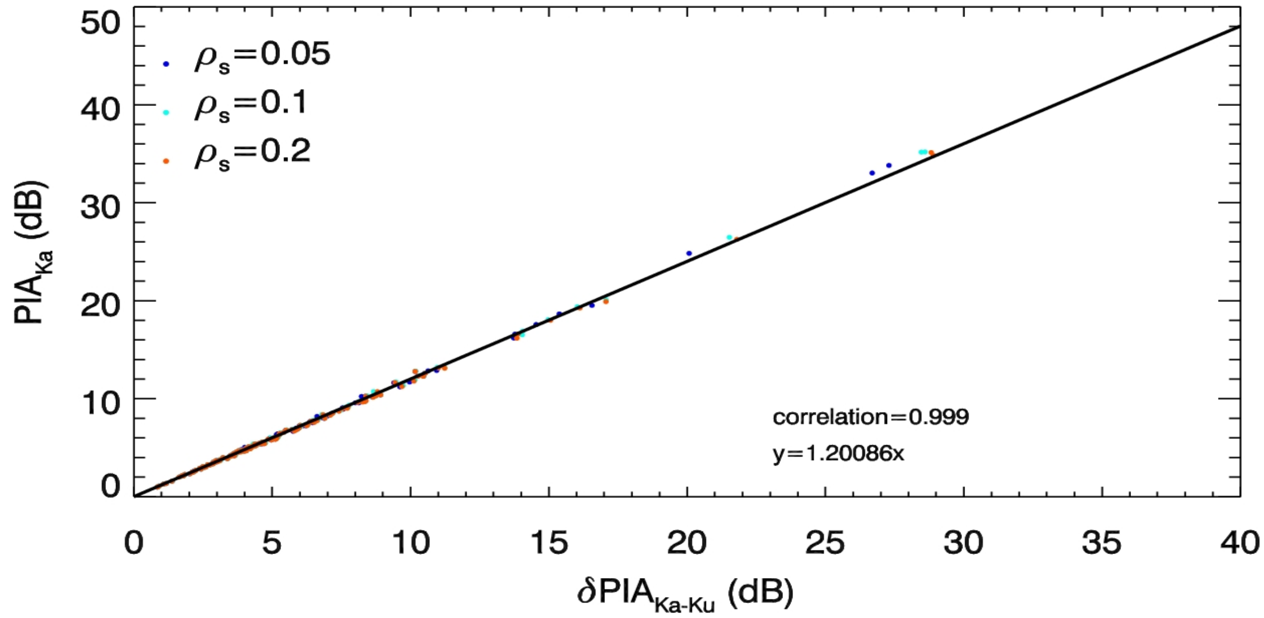


SRT – Summary

- Dual-freq version of SRT should improve estimates of path attenuation under certain circumstances
  - SNR at surface > ~3 dB at both freqs
  - High correlation between σ^0(Ku), σ^0(Ka)
  - We expect improvements over land at near-nadir incidence; over ocean off-nadir (~6^0-9^0)
- Future Work
  - Study errors in estimating PIA(Ku/Ka) from δPIA
  - Use airborne data to study statistics of σ^0
  - Examine multiple PIA's for NUBF correction

Fully uncorrelated DSDs along column (Switzerland)

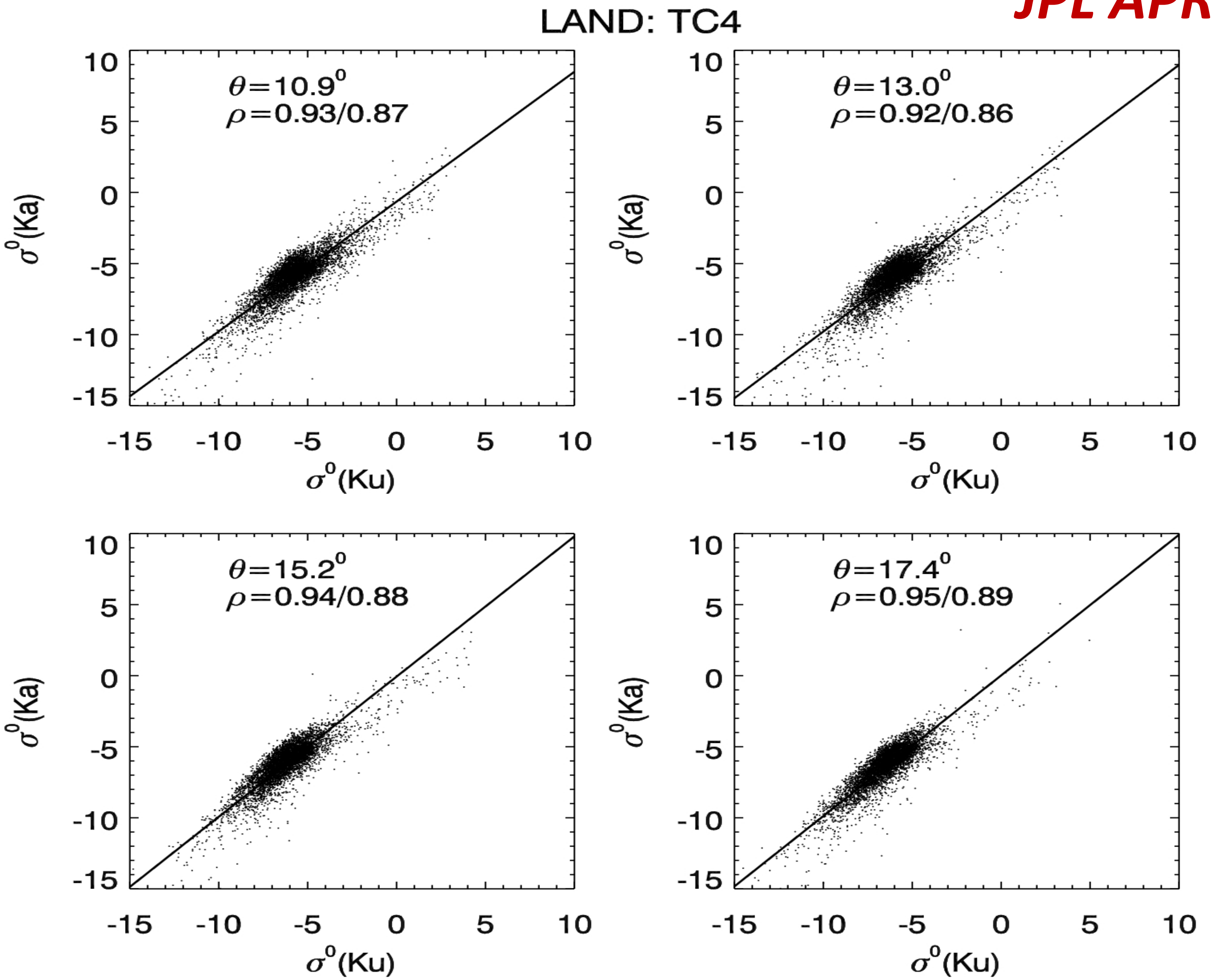




NUBF

- Non-uniform beam filling (NUBF) effects can lead to significant errors in rain estimation
- For off-nadir incidence, Takahashi et al. (2006) showed the feasibility of est. multiple path-integrated attenuations (PIA) w/i the beam
- These PIA estimates can be used to obtain high resolution attenuation-corrected Z, R
- This provides a correction to NUBF in the X-track plane

JPL APR-2


LAND: TC4
θ=10.9⁰
ρ=0.93/0.87
θ=13.0⁰
ρ=0.92/0.86
θ=15.2⁰
ρ=0.94/0.88
θ=17.4⁰
ρ=0.95/0.89
σ⁰(Ka)
σ⁰(Ku)
10
5
0
-5
-10
-15