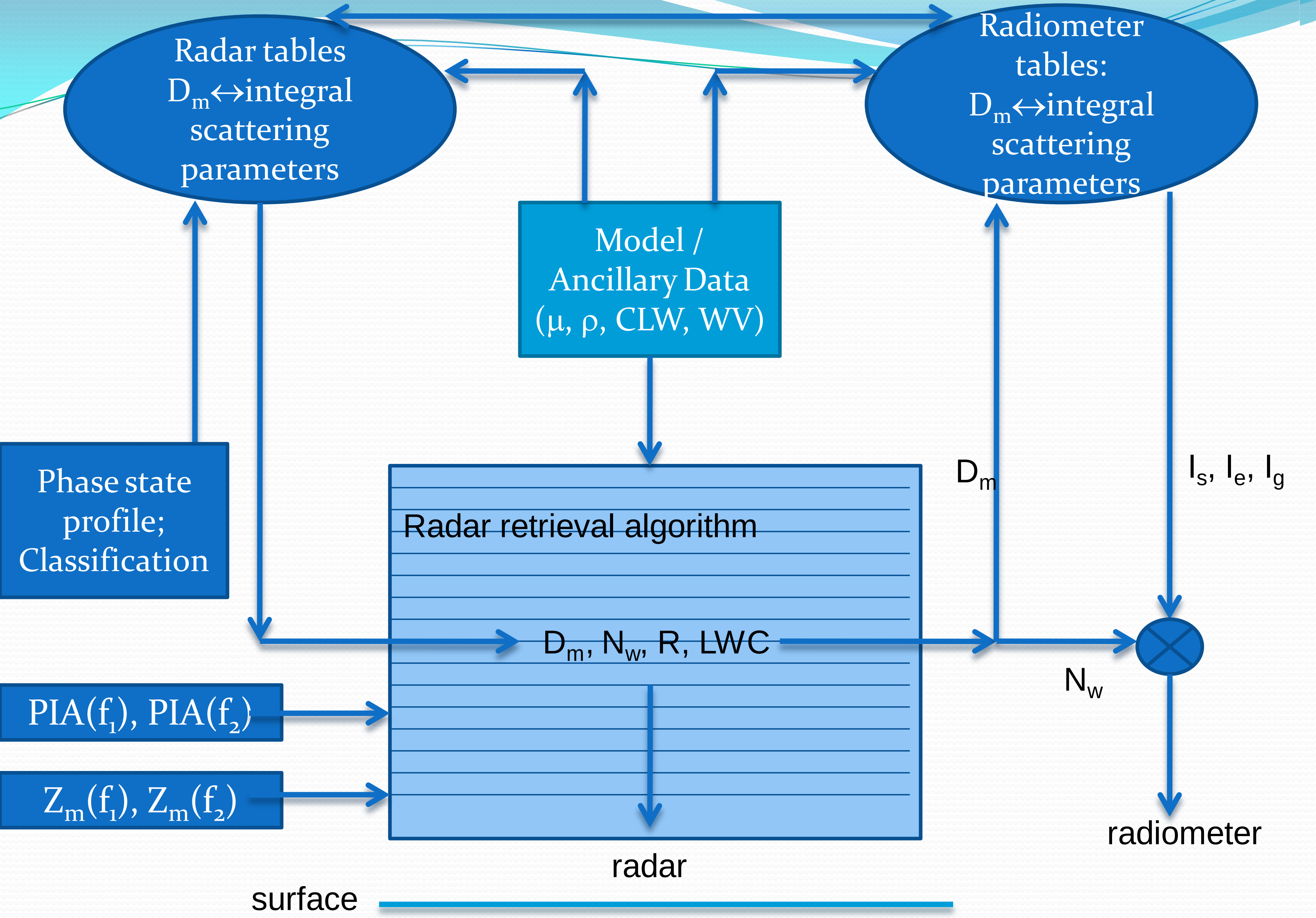
Outline

- U.S. DPR Activities
- Integral Scattering Tables
- Surface Reference Technique



Radar tables $D_m \leftrightarrow$ integral scattering parameters

Radiometer tables: $D_m \leftrightarrow$ integral scattering parameters

Model / Ancillary Data (μ, ρ, CLW, WV)

Phase state profile; Classification

Radar retrieval algorithm

D_m, N_w, R, LWC

$PIA(f_1)$, $PIA(f_2)$

$Z_m(f_1)$, $Z_m(f_2)$

D_m

I_s, I_e, I_g

N_w

radiometer

radar

surface

DPR Activities

- DPR Solver Module (Seto & Iguchi)
  - Scattering tables (Seto; Liao; DSDWG (Williams); Kuo; et al.)

- Classification Module (Awaka)
  - Hydrometeor ID (Chandra & Le; Liao & Meneghini)

- Surface Reference Module (Meneghini)
  - Land classification (Durden & Tanelli)
  - Weak-rain reference (Seto)
  - NUBF (Durden & Tanelli; Takahashi & Iguchi; Short et al.)
  - Radiometric processing (Iguchi)

DPR Activities

- Radar/(Radiometer) Simulator
  - Kubota (synthetic; model data input; PR-derived)
  - Tanelli (model data from Tao, Matsui)
  - Kwiatkowski (PR-derived with TMI)
  - Kim & Meneghini (model data from Tao, Matsui)

- Airborne Radar Data for Algorithm Testing
  - APR-2 (Tanelli, Durden)
  - HiWRAP (Heymsfield, Tian)

DPR Activities

- Integration/Testing at GSFC
  - Kwiatkowski, Seto
- Linkages with Combined team
  - Scattering tables
  - Simulators
  - Output products from DPR algorithm
- Level 3 DPR Products

Integral Scattering Tables

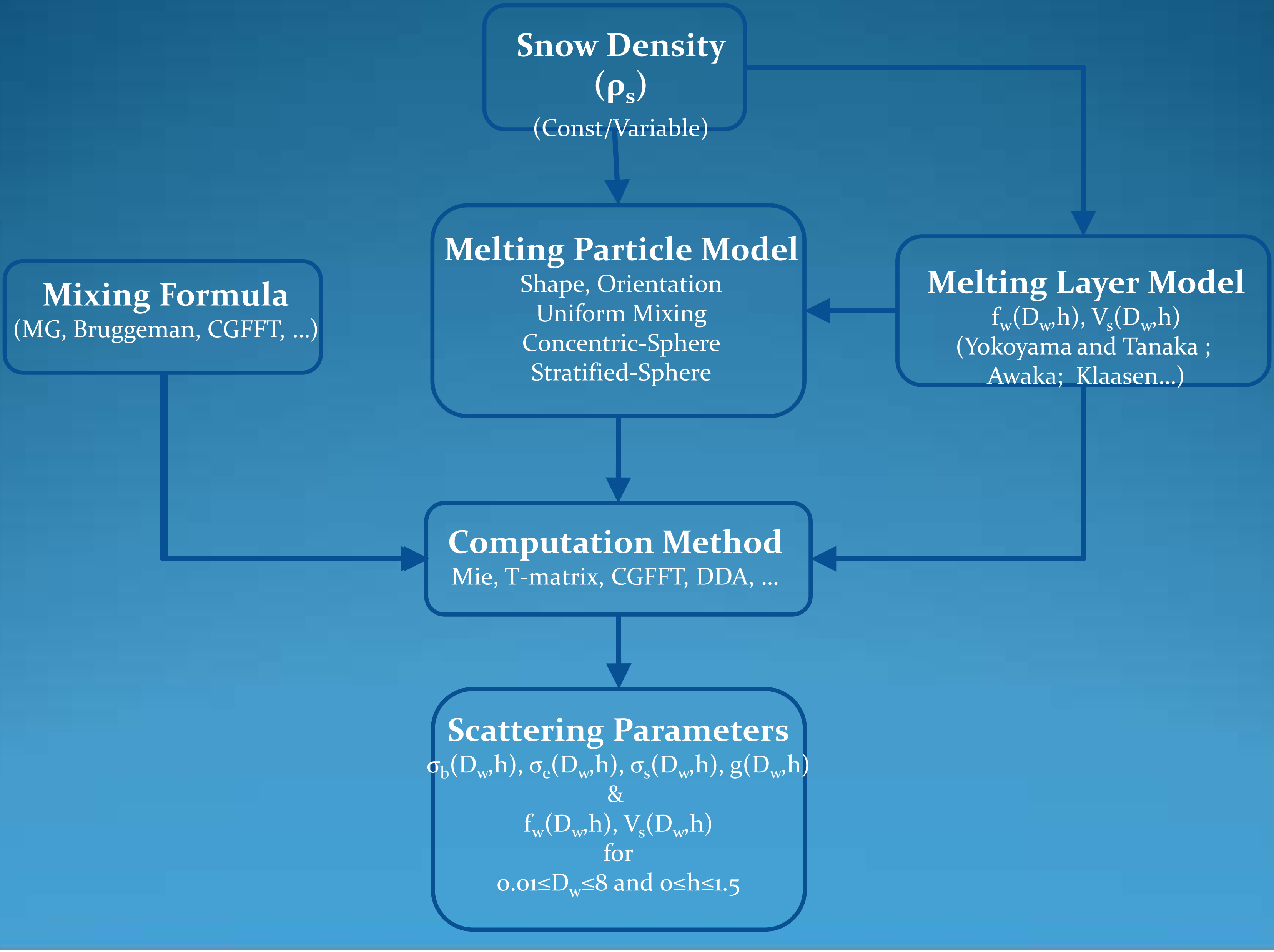
- Motivation

  - Separate method from microphysical assumptions
  - Represent microphysics by look-up tables via ‘particle model’ & EM scattering code
  - Trace microphysical assumptions used in radar and combined solutions
  - Provide a means to change the microphysics w/o modifying the method: sensitivity studies
  - Allow anyone with a particle model (& scattering code) to generate a look-up table

Integral Scattering Tables

- To do this, need to agree on certain conventions
  - Gamma size distribution, with (N_w, D_m, μ) as parameters
  - All scattering parameters in the table are normalized by N_w
  - Integrations are to be done over any shape, orientation parameters so all tables are of the form: D_m versus scattering parameters
  - Different μ, ρ values (or μ-Λ, ρ-D relations) can be represented by different tables
  - Mixed phase models require additional specifications
    - Fractional melt water as function of: distance below 0^o level, density & size
    - Specification of Dielectric Mixing formula or shell model

Single Scattering Table for Mixed-Phase (Liao)



Snow Density
(ρ_s)
(Const/Variable)

Mixing Formula
(MG, Bruggeman, CGFFT, …)

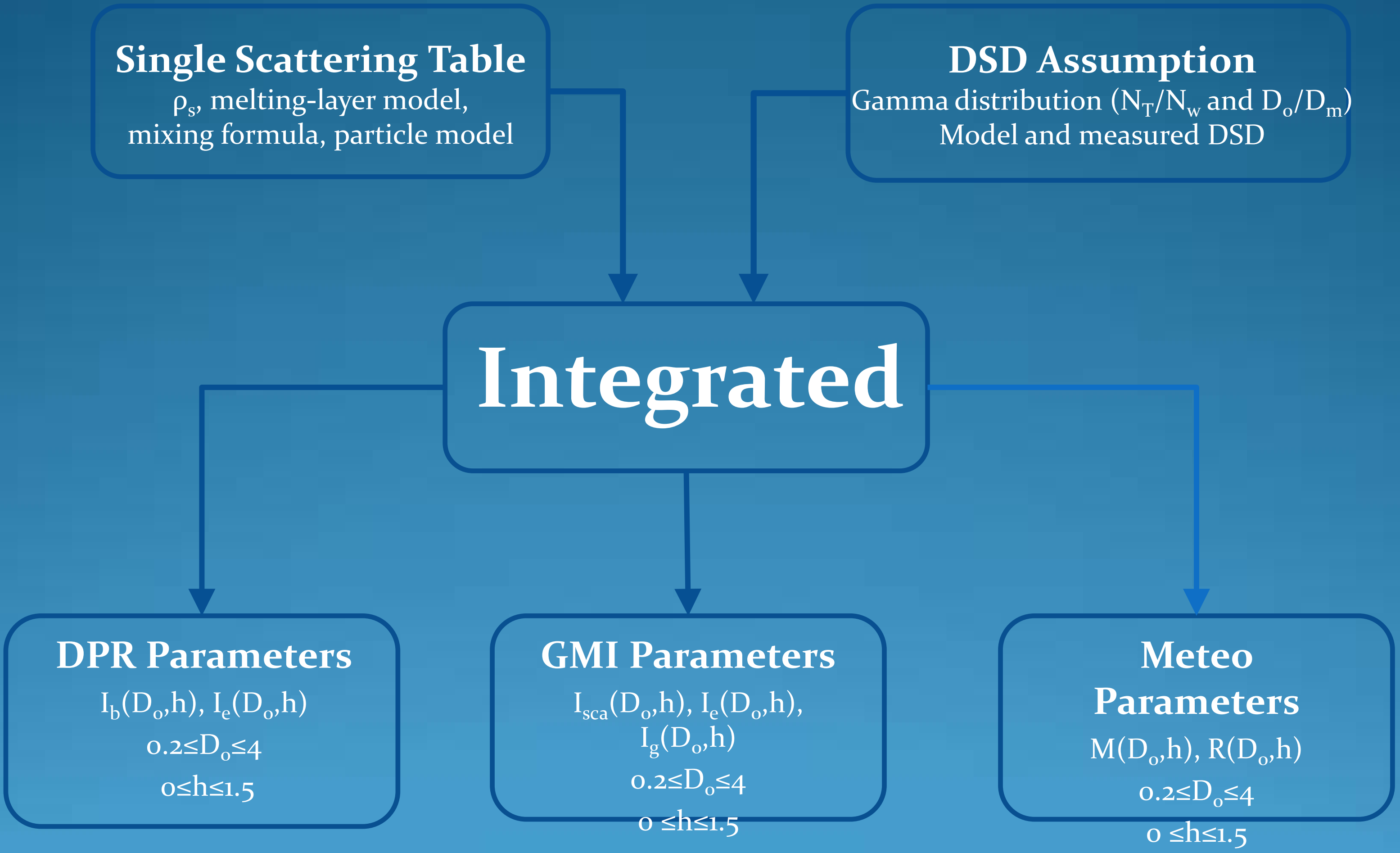
Melting Particle Model
Shape, Orientation
Uniform Mixing
Concentric-Sphere
Stratified-Sphere

Melting Layer Model
$f_w(D_w,h)$, $V_s(D_w,h)$
(Yokoyama and Tanaka ;
Awaka; Klaasen…)

Computation Method
Mie, T-matrix, CGFFT, DDA, …

Scattering Parameters
$\sigma_b(D_w,h)$, $\sigma_e(D_w,h)$, $\sigma_s(D_w,h)$, $g(D_w,h)$
&
$f_w(D_w,h)$, $V_s(D_w,h)$
for
$0.01 \le D_w \le 8$ and $0 \le h \le 1.5$

DSD Integrated Scattering Table (Liao)



Single Scattering Table

ρ_s, melting-layer model,
mixing formula, particle model

DSD Assumption

Gamma distribution (N_T/N_w and D_o/D_m)
Model and measured DSD

Integrated

DPR Parameters

$I_b(D_o,h)$, $I_e(D_o,h)$
$0.2 \leq D_o \leq 4$
$0 \leq h \leq 1.5$

GMI Parameters

$I_{sca}(D_o,h)$, $I_e(D_o,h)$,
$I_g(D_o,h)$
$0.2 \leq D_o \leq 4$
$0 \leq h \leq 1.5$

Meteo Parameters

$M(D_o,h)$, $R(D_o,h)$
$0.2 \leq D_o \leq 4$
$0 \leq h \leq 1.5$

N_W-normalized scattering parameters (N_W=1 mm^{-1}m^{-3})

$$N(D) = N_w f(\mu)\left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D), \qquad f(\mu) = \frac{6(3.67+\mu)^{\mu+4}}{3.67^4\Gamma(\mu+4)}$$

Radar:

$$I_b(D_0,\mu,\lambda) = 10\log_{10}\left(\frac{\lambda^4}{\pi^5|K_w|^2}\int_{D_{min}}^{D_{max}} f(\mu)\left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D)\cdot\sigma_b(D,\lambda)dD\right), \quad \text{dBZ}$$

$$I_e(D_0,\mu,\lambda) = 4.343\times 10^{-3}\int_{D_{min}}^{D_{max}} f(\mu)\left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D)\cdot\sigma_e(D,\lambda)dD\,, \quad \text{dB/km}$$

Radiometer:

$$I_{sca}(D_0,\mu,\lambda) = 10^{-6}\int_{D_{min}}^{D_{max}} f(\mu)\left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D)\cdot\sigma_s(D,\lambda)dD\,, \qquad \text{m}^{-1}$$

$$I_e(D_0,\mu,\lambda) = 10^{-6}\int_{D_{min}}^{D_{max}} f(\mu)\left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D)\cdot\sigma_e(D,\lambda)dD\,, \qquad \text{m}^{-1}$$

$$I_g(D_0,\mu,\lambda) = \frac{\int_{D_{min}}^{D_{max}} f(\mu)\left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D)\cdot g(D,\lambda)\sigma_s(D,\lambda)dD}{\int_{D_{min}}^{D_{max}} f(\mu)\left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D)\cdot\sigma_s(D,\lambda)dD}$$

- N_w ($mm^{-1}m^{-3}$)-normalized mass content (I_M) and precipitation rate (I_R):

$$I_M = \frac{\pi}{6} \times 10^{-6} \int_{D_{min}}^{D_{max}} f(\mu) \left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D) \cdot D^3 dD \,, \ g/m^3$$

$$I_R = 6\pi \times 10^{-4} \int_{D_{min}}^{D_{max}} N_w f(\mu) \left(\frac{D}{D_0}\right)^{\mu} \exp(-\Lambda D) \cdot D^3 V(D) dD \,, \ mm/h$$

$$f(\mu) = \frac{6(3.67+\mu)^{\mu+4}}{3.67^4 \Gamma(\mu+4)}$$

Water content: $M = N_w I_M \,, \quad g/m^3 \quad ;$

Precipitation rate: $R = N_w I_R \,, \quad mm/h$

- N_T (m^{-3})-normalized mass content (I_M) and precipitation rate (I_R):

$$I_M = \frac{\pi}{6} \times 10^{-6} \int_{D_{min}}^{D_{max}} \frac{\Lambda^{\mu+1}}{\Gamma(\mu+1)} D^{\mu} \exp(-\Lambda D) \cdot D^3 dD \,, \ g/m^3$$

$$I_R = 6\pi \times 10^{-4} \int_{D_{min}}^{D_{max}} \frac{\Lambda^{\mu+1}}{\Gamma(\mu+1)} D^{\mu} \exp(-\Lambda D) \cdot D^3 V(D) dD \,, \ mm/h$$

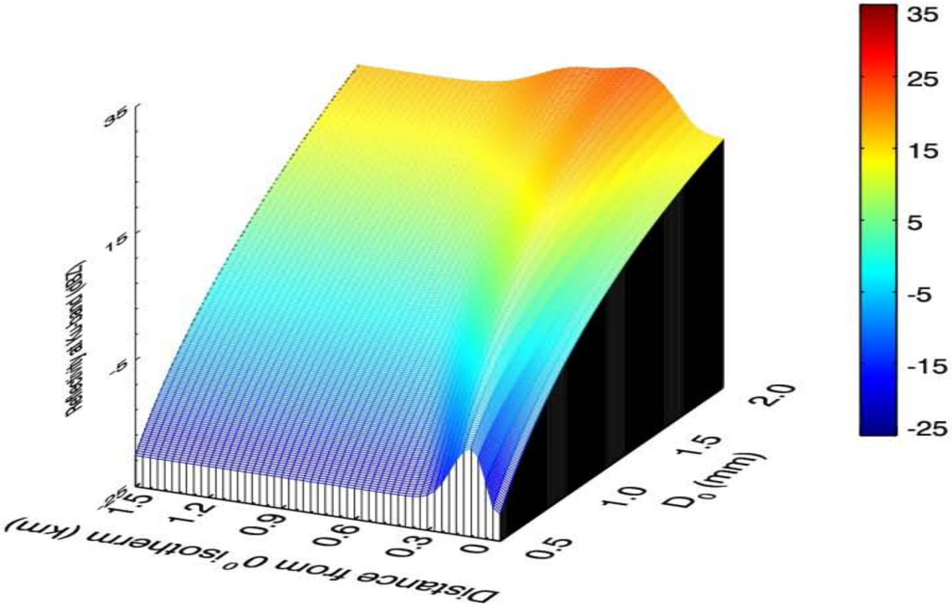
Water content: $M = N_T I_M \,, \quad g/m^3$

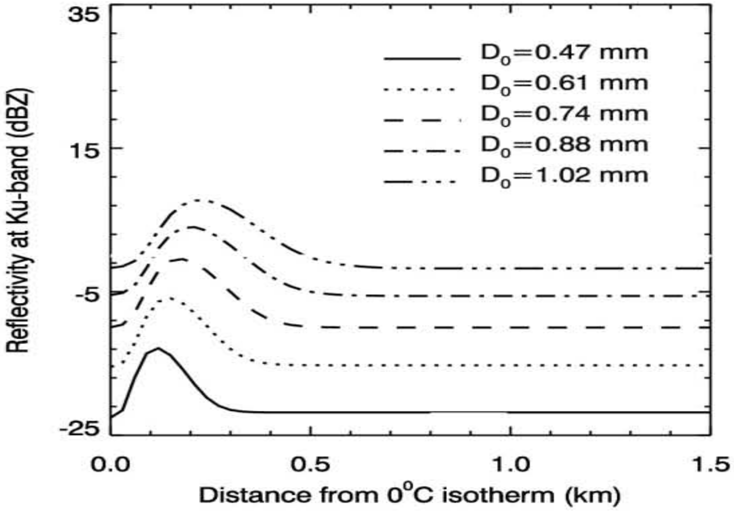
Precipitation rate: $R = N_T I_R \,, \quad mm/h$

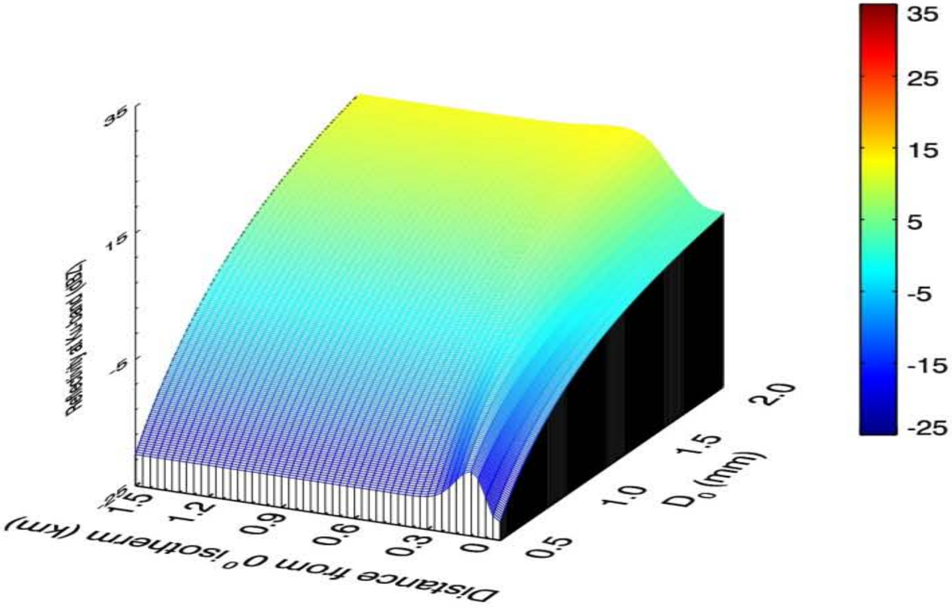
Radar Scattering Parameters Scaled by N_w and N_T

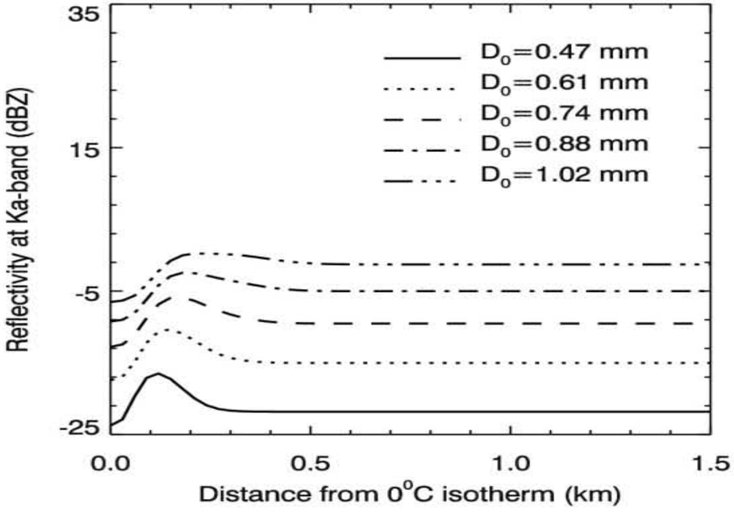
N_w scale factor	N_T scale factor
$DFR(dB) = I_b(D_0, \mu, \lambda_1) - I_b(D_0, \mu, \lambda_2)$	$DFR(dB) = I_b(D_0, \mu, \lambda_1) - I_b(D_0, \mu, \lambda_2)$
$Z_\lambda(dB) = 10\log_{10} N_w + I_b(D_0, \mu, \lambda)$	$Z_\lambda(dB) = 10\log_{10} N_T + I_b(D_0, \mu, \lambda)$
$k_\lambda(dB/km) = N_w I_e((D_0, \mu, \lambda)$	$k_\lambda(dB/km) = N_T I_e((D_0, \mu, \lambda)$

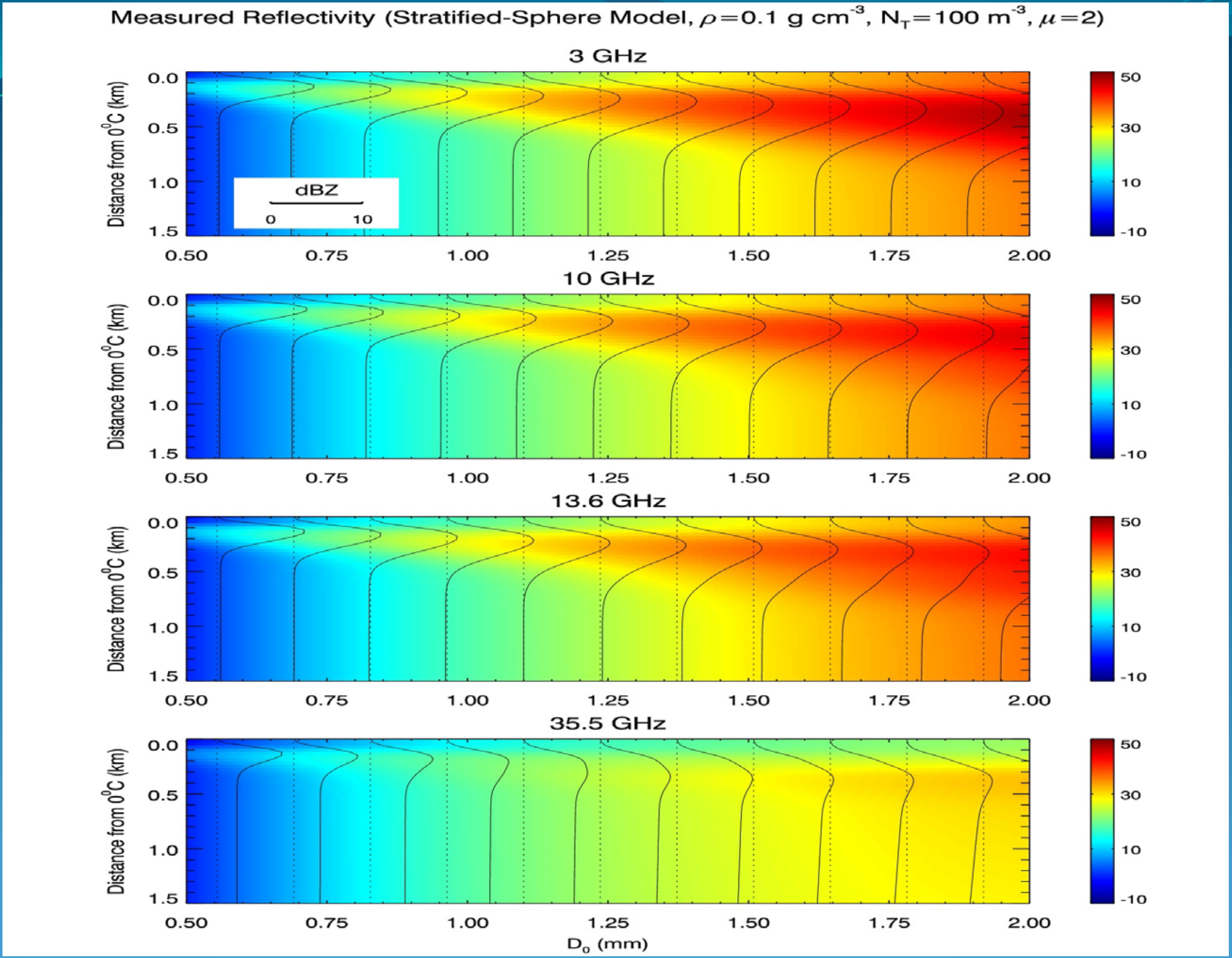
ML Simulation Table (Stratified-Sphere Model, ρ=0.1 g cm^{-3}, μ=2, N$_T$=1 m^{-3})










Measured Reflectivity (Stratified-Sphere Model, ρ=0.1 g cm⁻³, N_T=100 m⁻³, μ=2)
3 GHz
10 GHz
13.6 GHz
35.5 GHz
Distance from 0°C (km)
0.0
0.5
1.0
1.5
0.50
0.75
1.00
1.25
1.50
1.75
2.00
D₀ (mm)
dBZ
0
10
50
30
10
-10

Integral Scattering Tables-Summary

- Integral scattering tables provide transparency to microphysical assumptions being used by radar & combined algorithms

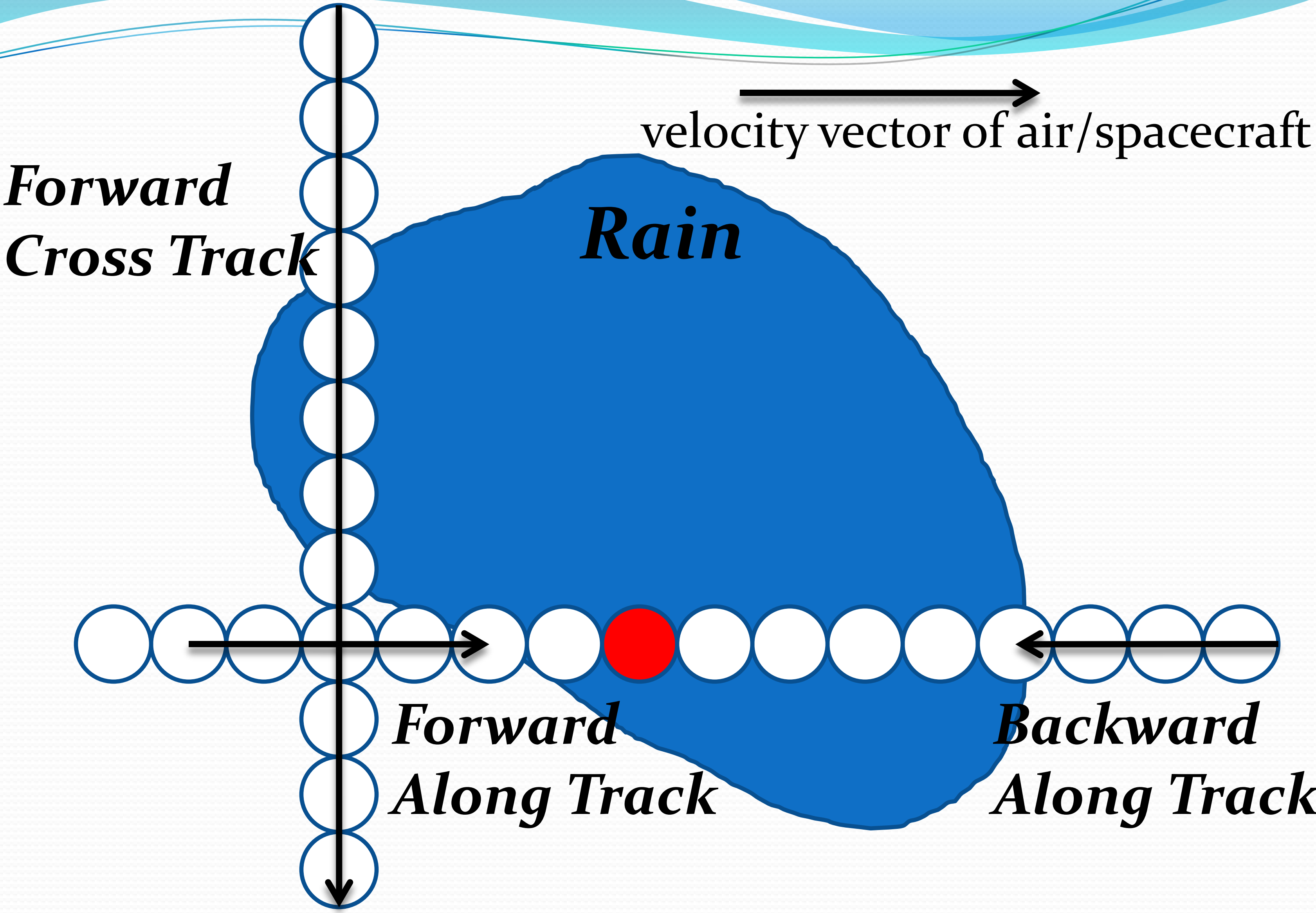
- Address the goal of common and traceable microphysical assumptions among the various methods

- Provide a means by which the community can contribute to algorithm development & implementation

- Making the tables general enough to suit the needs of the algorithm developers requires further work

Surface Reference Technique

- Most unconstrained retrieval methods become unstable as the path-attenuation increases
- If accurate estimates of path-attenuation can be made, the retrievals of rain rate & DSD parameters become more robust
- The single-frequency SRT, however, is limited in accuracy by the inherent fluctuations in the normalized radar cross section (NRCS) of the surface
- Some improvement can be made by considering multiple reference measurements



velocity vector of air/spacecraft

Forward Cross Track

Rain

Forward Along Track

Backward Along Track

Surface Reference Technique

- To a first approximation, the variance of the single-freq SRT PIA is proportional to the variance of the NRCS

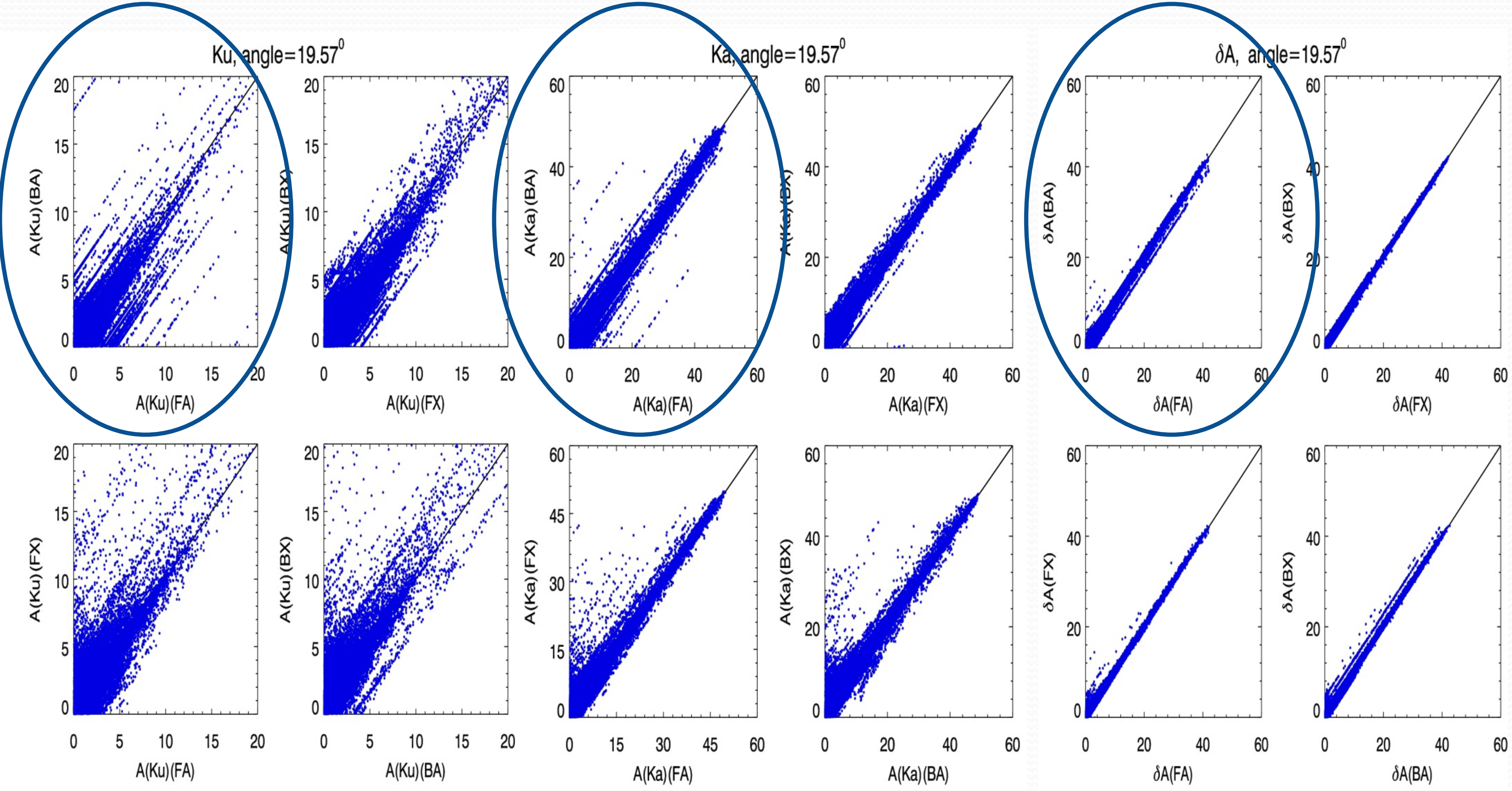
- To the same order of approximation, the variance of the dual-freq SRT is proportional to twice the variance of the NRCS multiplied the factor [1-ρ], where ρ is the correlation coeff of the NRCS at the two frequencies

- i.e., the correlation coefficient of the NRCS at the 2 frequencies is critical to the performance of the dual-wavelength SRT

- We can use the multiple-reference measurement idea to assess the relative accuracy of the dual & single-freq SRT

19.6°

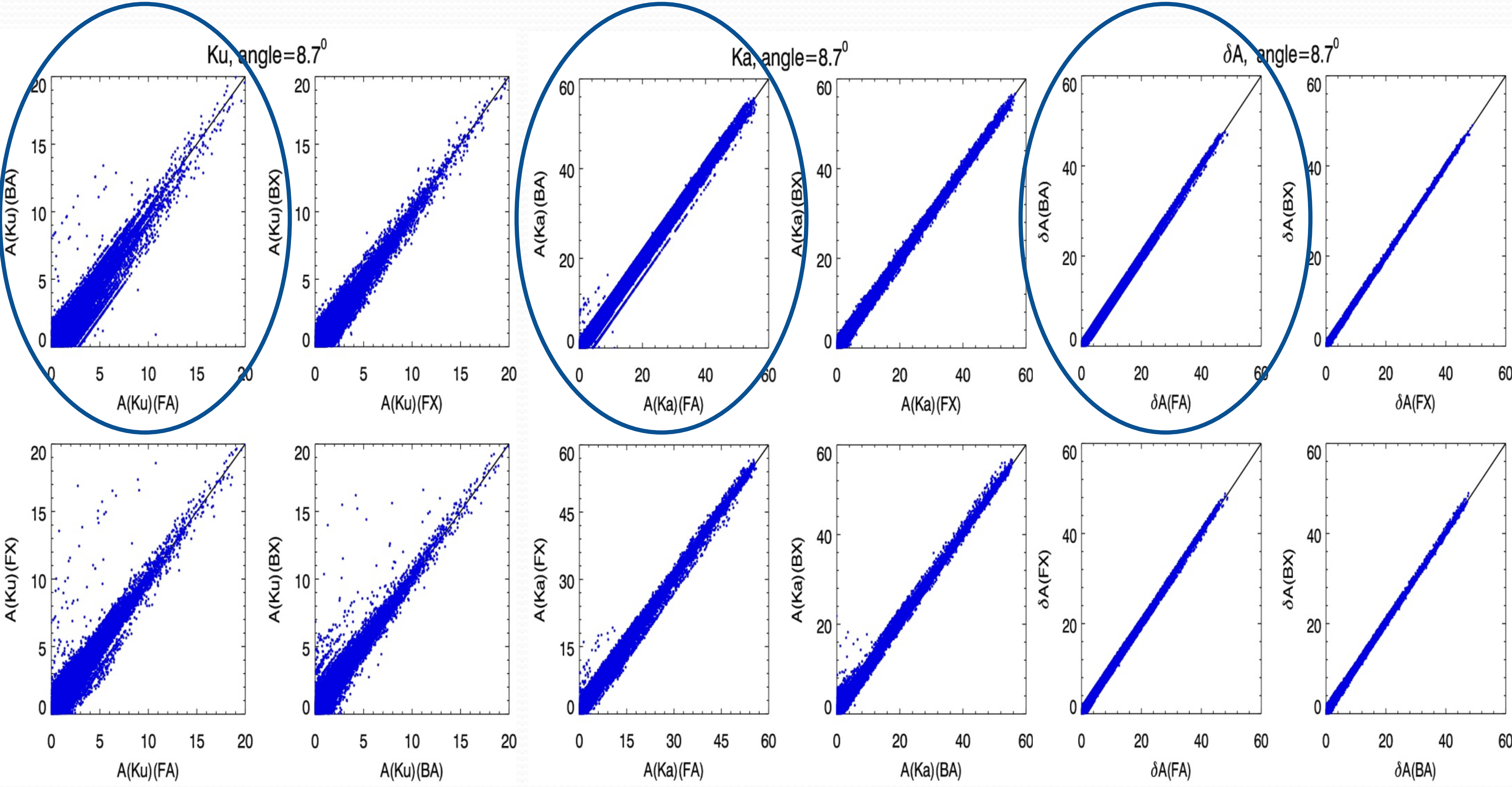
Ku **Ka** **Ka-Ku**



JPL APR2 data: GRIP (Tanelli)

8.7°

Ku **Ka** **Ka-Ku**



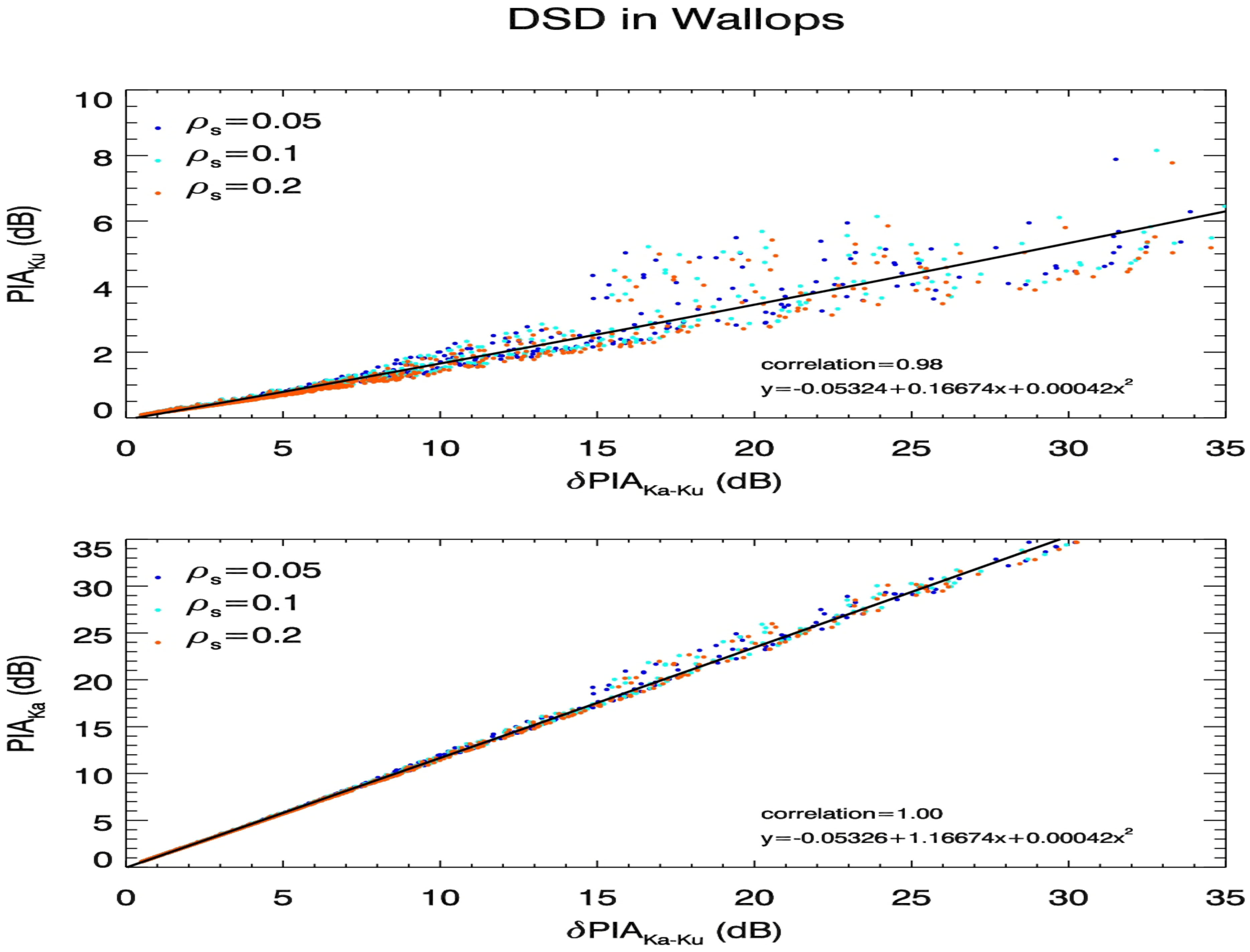
JPL APR2 data: GRIP (Tanelli)

Surface Reference Technique

- Since the estimates are independent, better agreement among the estimates is presumed to mean higher accuracy
- Improvement in DSRT over SRT generally increases as the correlation in the NRCS increases
- However, the DSRT only gives us δA (=A(Ka)-A(Ku)) and not the individual PIA's (A(Ka), A(Ku))
- Use of measured DSD's & simple vertical models with mixed phase & cloud water suggests to a good approx:

$$A(Ka) = 1.2\,\delta A$$

$$A(Ku) = 0.2\,\delta A$$


DSD in Wallops
PIA$_{Ku}$ (dB)
ρ_s=0.05
ρ_s=0.1
ρ_s=0.2
correlation=0.98
y=-0.05324+0.16674x+0.00042x^2
0
2
4
6
8
10
0
5
10
15
20
25
30
35
δPIA$_{Ka-Ku}$ (dB)
PIA$_{Ka}$ (dB)
ρ_s=0.05
ρ_s=0.1
ρ_s=0.2
correlation=1.00
y=-0.05326+1.16674x+0.00042x^2
0
5
10
15
20
25
30
35
0
5
10
15
20
25
30
35
δPIA$_{Ka-Ku}$ (dB)

Summary - 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 NUBF and conversion of δA to A may reduce the effectiveness of the dual-freq approach
- Use of surface return might 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 by work done in Japan & at JPL

Summary

- There are a number of areas where the work being done by the U.S. DPR team complements the efforts of the Japanese DPR team
  - Scattering tables
  - Hydrometeor ID/ Phase-state detection
  - SRT-related work
  - Testing: radar simulators & airborne data