Ph.D Final Exam

Simulation of Space-Based Radar Observations of Precipitation

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Outline

- Research Goal
- Background and Theoretical framework
- Space-based radar observations characteristics and analysis
- Microphysical model development
- Simulation of space-based radar observation
- Study and simulation of tropical storms
- Summary, conclusions, and suggestions for future work

Research Goal

" To develop methodologies for simulating space-based radar observations of precipitation using current space-based precipitation radar observations and earth-based radar measurements"

Background on space-based radar observations of precipitation

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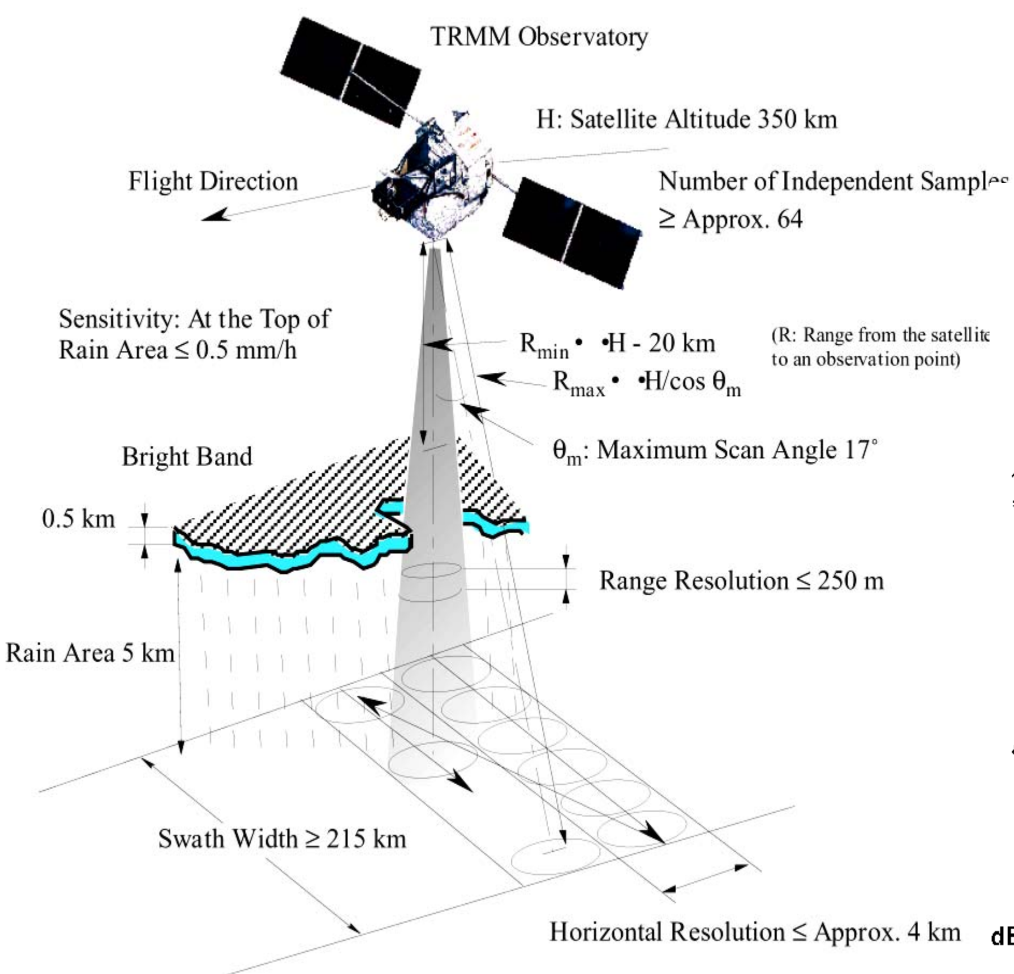
1997 Current	Future
Tropical Rainfall Measurement Mission (TRMM) satellite	**Global Precipitation Measurement (GPM) satellite**
➢ Joint mission between NASA (US) and JAXA (Japan)	➢ Joint mission between NASA (US) and JAXA (Japan)
<u>Instruments on board TRMM</u>	**<u>Instruments on board GPM</u>**
• **Precipitation radar (PR)**	• **Dual-frequency precipitation radar (DPR)**
• TRMM Microwave Imager (TMI)	• GPM Microwave Imager (GMI)
• Visible and Infrared Scanner (VIRS)	• Additional 8 constellation satellites carrying passive microwave rain radiometer
• Clouds and the Earth's Radiant Energy System (CERES)	
• Lightning Imaging Sensor (LIS)	

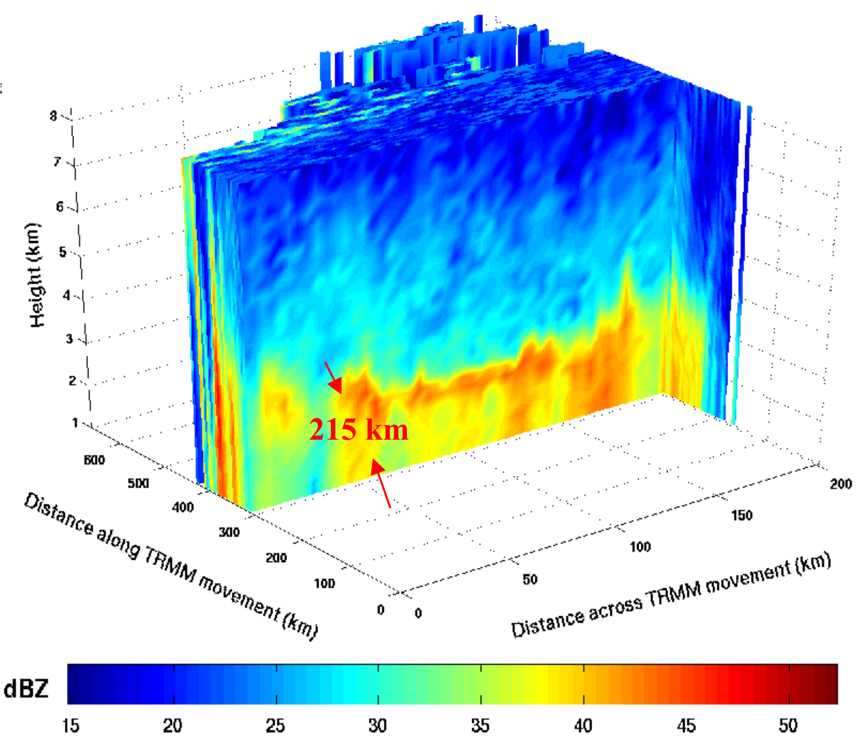
Background : TRMM- PR (Currently operating)

- Coverage area : 37º S - 37º N



- PR

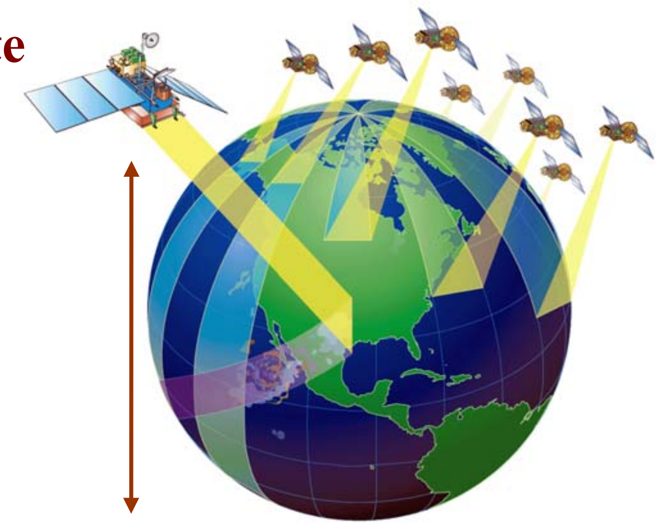
- 13.8 GHz Ku-band radar (2.17 cm. wavelength)
- Horizontal res. at nadir : 4.3 km. (5 km. postboost)
- Range res. : 250 m.
- Swath width : 215 km. (245 km postboost)
- Altitude : 350 km. (402.5 km postboost)



Background : GPM-DPR

Global Precipitation Measurement (GPM) Satellite

- Coverage area 65ºS – 65º N

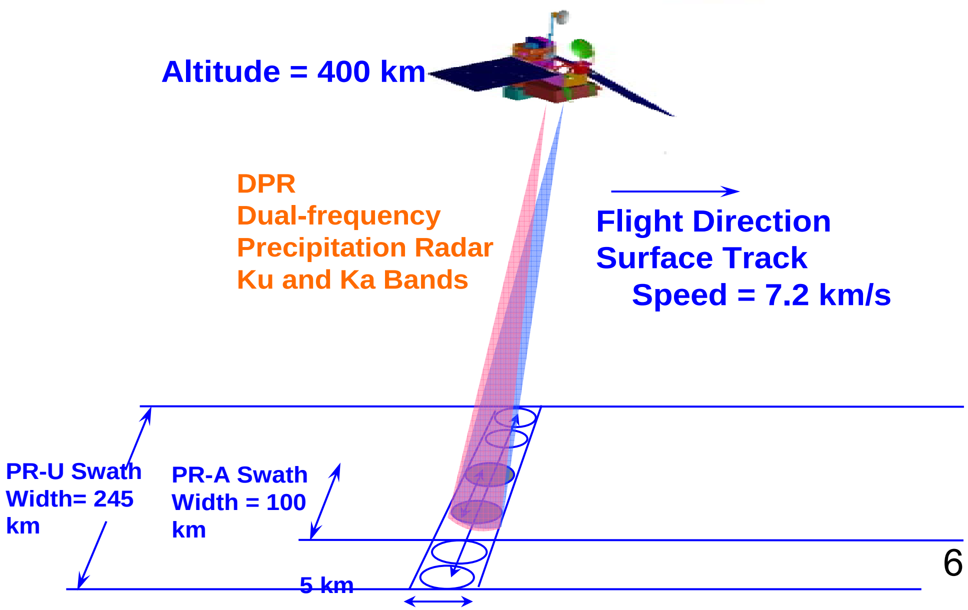


Dual-frequency Precipitation Radar (DPR)

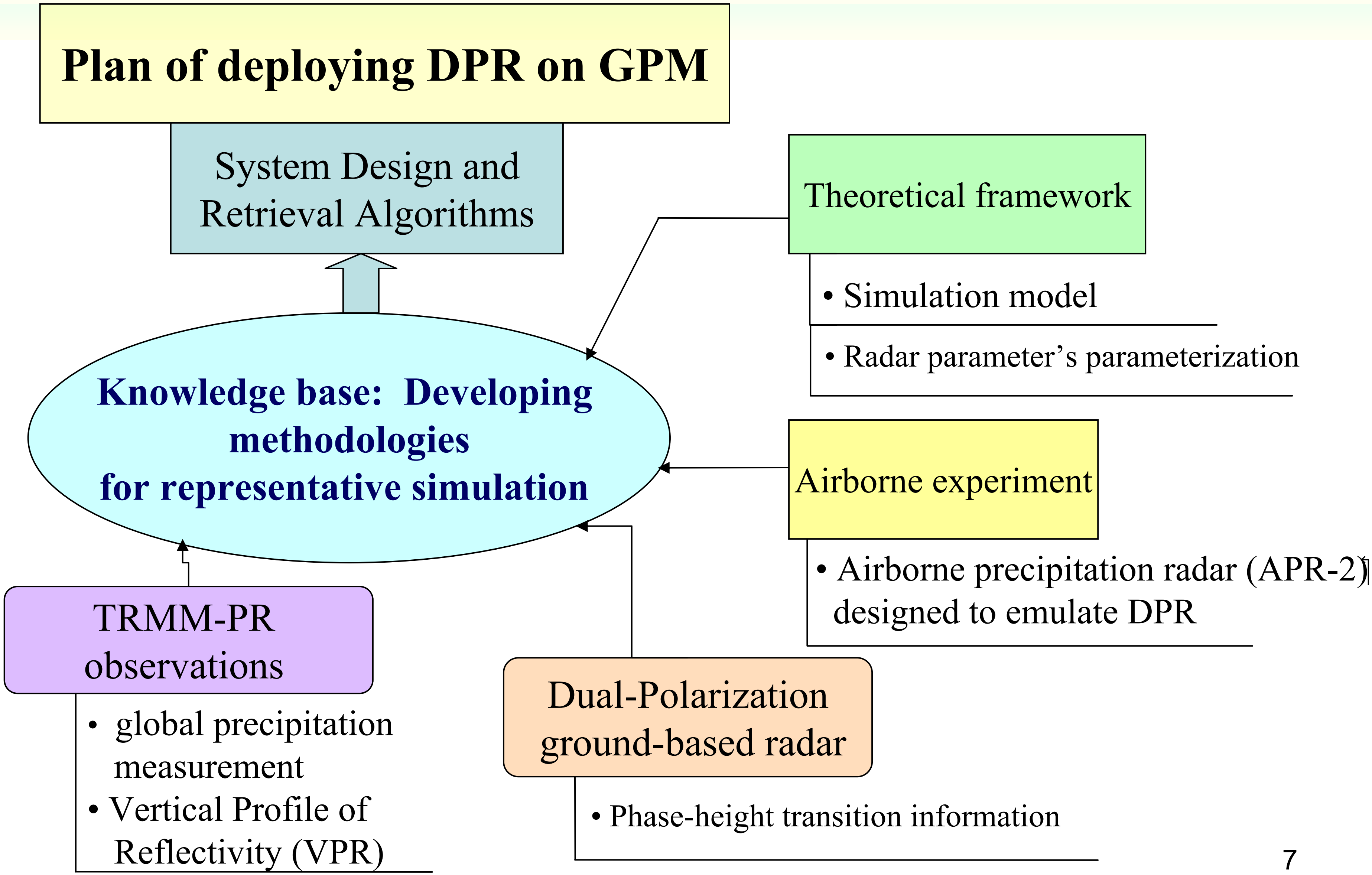
- Ku-band (13.6 GHz) similar to TRMM-PR
- Ka-band (35.6 GHz) –0.87 cm. wavelength

Key benefits of GPM-DPR

- Improve accuracy of rainfall rate estimate via accurate estimate of DSD parameters.
- Be able to discriminate between rain and frozen precipitation



Motivation


Plan of deploying DPR on GPM
System Design and Retrieval Algorithms
Knowledge base: Developing methodologies for representative simulation
Theoretical framework
• Simulation model
• Radar parameter's parameterization
Airborne experiment
• Airborne precipitation radar (APR-2) designed to emulate DPR
TRMM-PR observations
• global precipitation measurement
• Vertical Profile of Reflectivity (VPR)
Dual-Polarization ground-based radar
• Phase-height transition information

Theoretical Framework:
Electromagnetic & Microphysics

- Radar reflectivity from precipitation particles

$$Z = \frac{\lambda^4}{\pi^5 |K_p|^2} \int \sigma_b(D) N(D) dD$$

$$where \quad |K_p| = \left| \frac{\varepsilon_r - 1}{\varepsilon_r - 2} \right|^2 \text{ is dielectric factor of pricipitat ion particles}$$

ε_r is complex dielectric constant

- Radar cross-section of precipitation particles

$$\sigma_b(-\hat{i}, \hat{i}) = 4\pi \left| \vec{f}(-\hat{i}, \hat{i}) \right|^2$$

$\vec{f}$ is the scattering amplitude

$\hat{i}$ is incident wave direction

Theoretical Framework:
Electromagnetic & Microphysics

- Specific attenuation (k) of wave propagating through precipitation defined as

$$k = 4.343 \times 10^3 \int \sigma_{ext}(D) N(D) dD \quad \text{dB/km}$$

- Extinction cross-section of precipitation particles

$$\sigma_{ext} = \frac{-4\pi}{k_o} \operatorname{Im} \vec{f}(\hat{i}, \hat{i}) \cdot \hat{e}_i$$

where

$\vec{f}$ is the scattering amplitude,

$k_o = 2\pi/\lambda$

$\hat{e}_i$ is polarization state of incident wave

- Measured reflectivity (Zm) is defined as

$$Zm(r) = Ze(r) \exp\left[-0.2 \ln 10 \int_0^r k(s) ds\right] = Ze(r) A(r)$$

Theoretical Framework:
Electromagnetic & Microphysics

- The particle size distribution (PSD) is based on the normalized gamma model:

$$N(D) = N_W f(\mu)\left(\frac{D}{D_o}\right)^{\mu} e^{-\left(\frac{3.67+\mu}{D_o}\right)D} dD$$

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

where μ is shape parameter.

D_o is the median volume diameter in mm.

N_w is intercept parameter ($mm^{-1}mm^{-3}$)

➢ If μ is fixed. *N(D)* is controlled by D_o and N_w

Reflectivity (*Ze*) and specific attenuation (*k*) computation

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- *Ze* and *k* of various type of precipitation particles are computed based on 1000 pairs of PSD parameters (Do and Nw)

- At 3 radar frequencies : 1) 2.7 GHz (S-band)
  2) 13.6 GHz (Ku-band)
  3) 35.6 GHz (Ka-band)

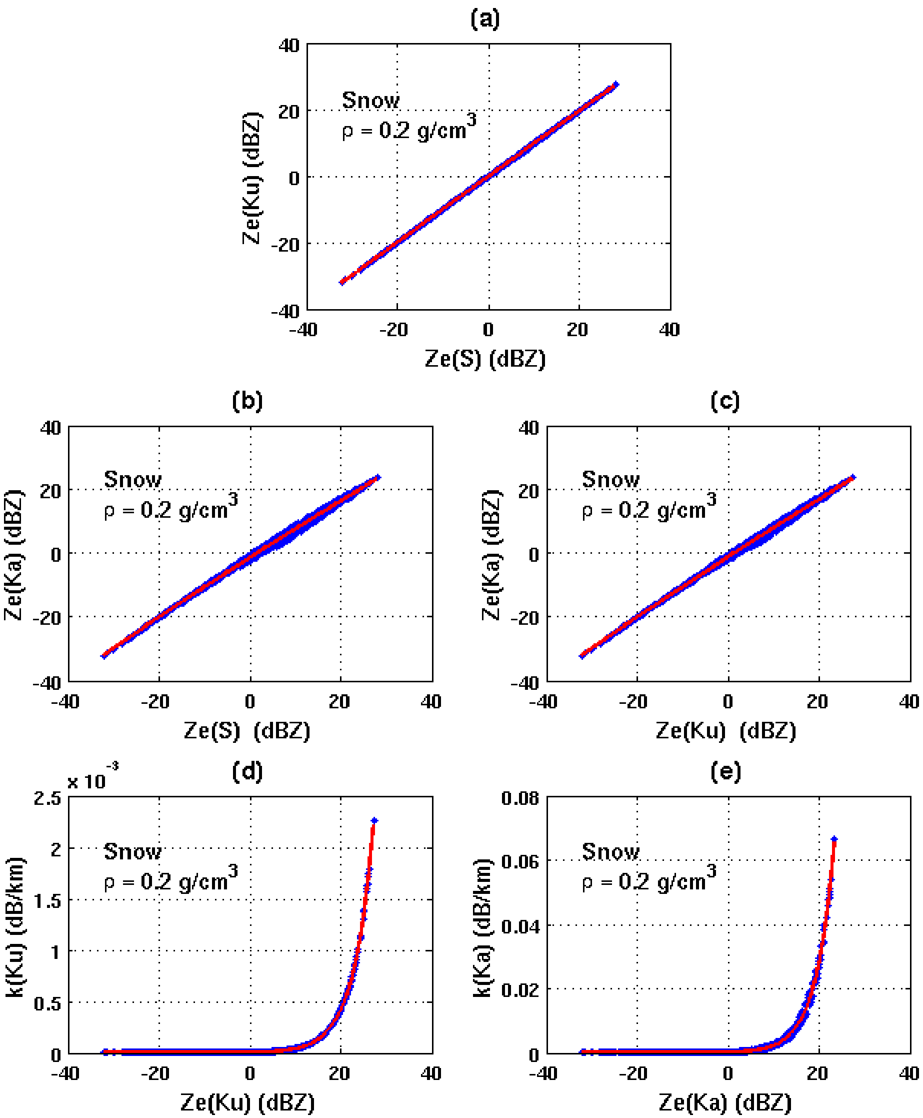
Note : log = log10

Precipitation Particle	D_o (mm)	N_w ($mm^{-1}m^{-3}$)	μ
Rain	$0.5 \le D_o \le 2.5$	$3.0 \le \log N_w \le 5.0$	$-1 \le \mu \le 4.0$
Melted particles	$1.0 \le D_o \le 3.0$	$2.0 \le \log N_w \le 4.0$	0
Aggregation of ice crystal (snow/graupel)	$0.5 \le D_o \le 2.0$	$2.0 \le \log N_w \le 4.0$	0

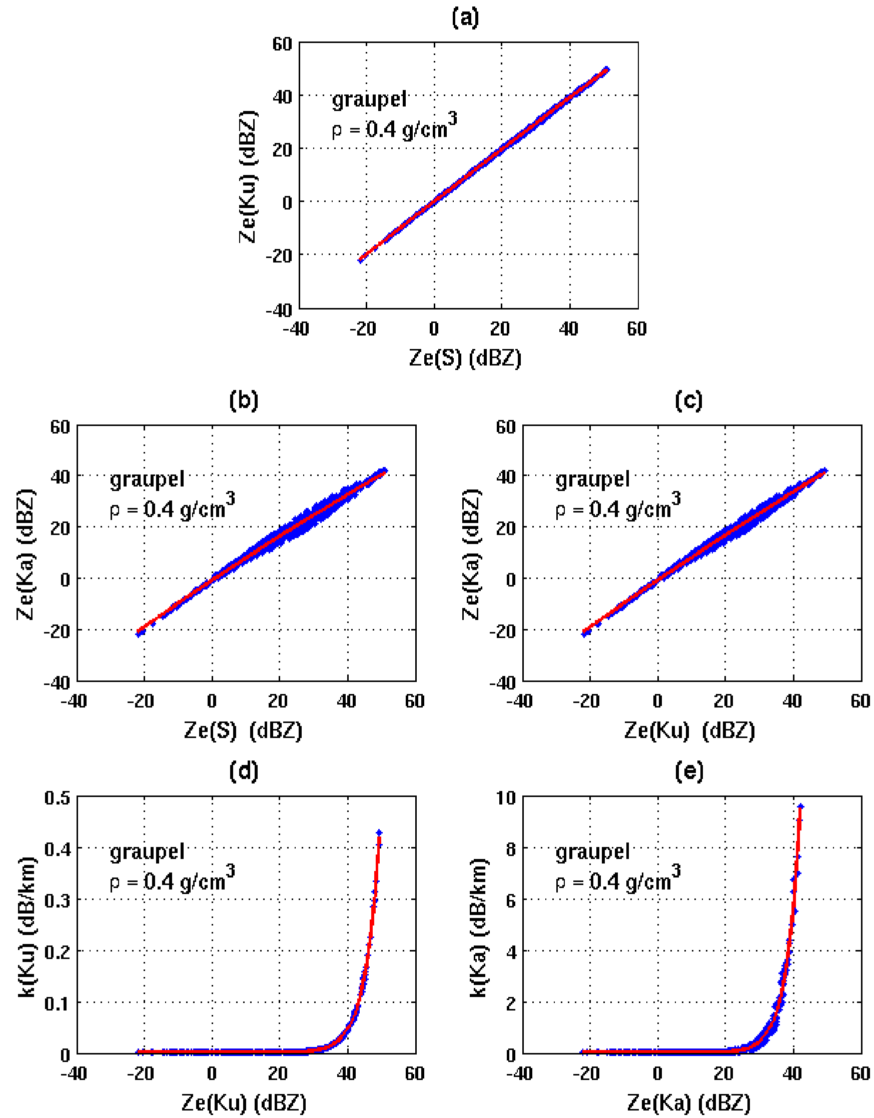
Precipitation Particle	Density (g/cm^{-3})	Water Fraction (WF)
Rain	1.0	1.0
Melted particles	Vary with WF	0.01 – 0.85
Aggregation of ice crystal (snow/graupel)	0.1 – 0.4	0.0

k-Ze Relation and variability of *Ze* with frequency

Dry Snow

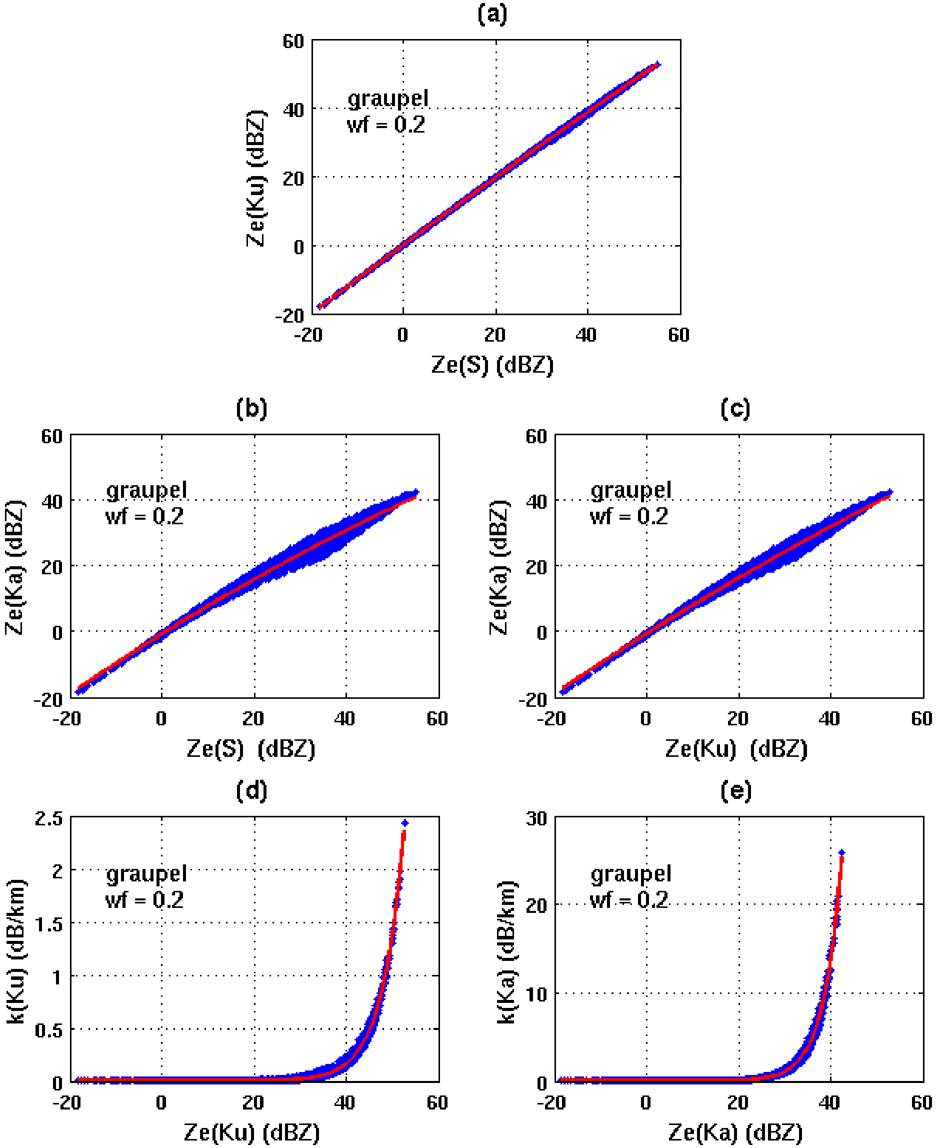


Dry Graupel

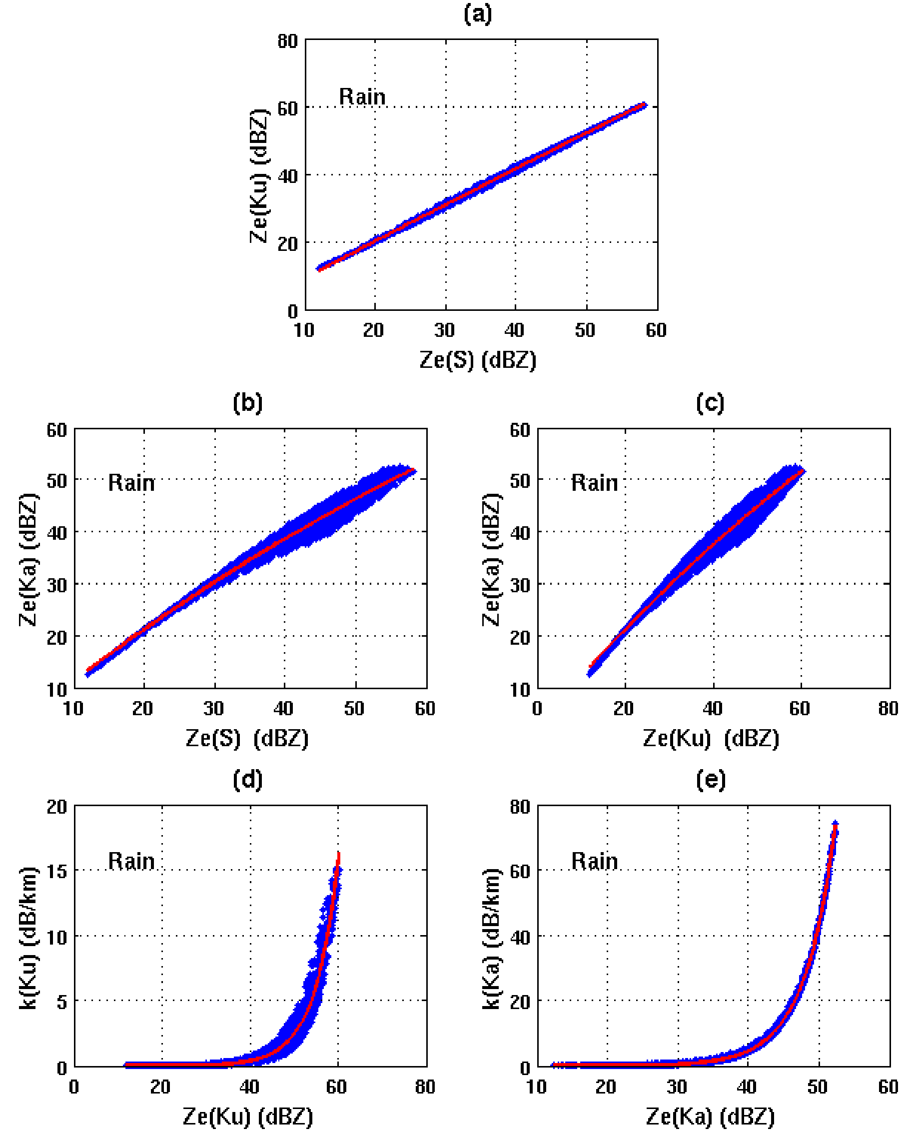


k-Ze Relation and variability of Ze with frequency

Partially-melted paritcles



Rain



k-Ze Relation and variability of Ze with frequency

Coefficients

Ze(Ka) = a + b*Ze(S)

k(Ka) = α*Ze(Ka)$^{\beta}$

Ze(Ku) = a + b*Ze(S)

k(Ku) = α*Ze(Ku)$^{\beta}$

Ze(Ka) = a + b*Ze(Ku)

	$Z_e(Ka) = a + bZ_e(S)$		$k(Ka) = \alpha Z_e(Ka)^{\beta}$	
Particle types	a	b	α	β
Snow/graupel				
$\rho = 0.05$ g cm^{-3}	-3.2575	0.87242	0.0002538	1.0764
$\rho = 0.10$ g cm^{-3}	-2.4729	0.88633	0.0002273	1.0792
$\rho = 0.15$ g cm^{-3}	-2.0339	0.89496	0.0002135	1.0805
$\rho = 0.20$ g cm^{-3}	-1.7291	0.90146	0.000204	1.0819
$\rho = 0.25$ g cm^{-3}	-1.4955	0.90678	0.000197	1.0835
$\rho = 0.30$ g cm^{-3}	-1.3061	0.91135	0.0001912	1.0852
$\rho = 0.35$ g cm^{-3}	-1.147	0.9154	0.0001868	1.0865
$\rho = 0.40$ g cm^{-3}	-1.0098	0.91906	0.0001828	1.0883
Melted particles				
wf = 0.1	-0.73694	0.88112	0.0004432	1.1028
wf = 0.2	-0.37998	0.88791	0.0004204	1.1206
wf = 0.3	-0.048003	0.88364	0.0005359	1.1021
wf = 0.4	0.23254	0.86874	0.0009077	1.0423
wf = 0.5	0.34781	0.87103	0.0007553	1.0536
wf = 0.6	0.29574	0.89583	0.0003683	1.1151
wf = 0.7	0.35682	0.91158	0.0008656	1.0064
wf = 0.8	0.49717	0.94157	0.0006854	1.0056
Rain				
$\mu = 0$	0.75765	1.0881	0.0005468	0.97905
$\mu = 1$	-0.18462	1.1379	0.0005801	0.97163
$\mu = 2$	-0.83483	1.1721	0.0006141	0.96492
$\mu = 3$	-1.2763	1.1945	0.0006446	0.95933

	$Z_e(Ku) = a + bZ_e(S)$		$k(Ku) = \alpha Z_e(Ku)^{\beta}$	
Particle types	a	b	α	β
Snow/graupel				
$\rho = 0.05$ g cm^{-3}	-0.50831	0.97897	5e-06	0.98144
$\rho = 0.10$ g cm^{-3}	-0.37263	0.98202	4.5e-06	0.99343
$\rho = 0.15$ g cm^{-3}	-0.29767	0.98399	4.3e-06	0.99981
$\rho = 0.20$ g cm^{-3}	-0.24631	0.98551	4.2e-06	1.0025
$\rho = 0.25$ g cm^{-3}	-0.20752	0.98676	4.1e-06	1.0044
$\rho = 0.30$ g cm^{-3}	-0.17651	0.98785	4e-06	1.0061
$\rho = 0.35$ g cm^{-3}	-0.15086	0.98882	4e-06	1.0073
$\rho = 0.40$ g cm^{-3}	-0.12904	0.98969	4e-06	1.0083
Melted particles				
wf = 0.1	-0.070347	0.99508	2.23e-05	0.9402
wf = 0.2	-0.048824	1.0021	1.98e-05	0.953
wf = 0.3	-0.046588	1.0095	1.5e-05	0.97756
wf = 0.4	-0.059505	1.0168	1.13e-05	1.0055
wf = 0.5	-0.069584	1.0221	9.9e-06	1.0247
wf = 0.6	-0.01878	1.0155	1.23e-05	1.0162
wf = 0.7	0.08087	0.99349	1.53e-05	1
wf = 0.8	0.01645	0.97903	3.05e-05	0.93829
Rain				
$\mu = 0$	-1.8792	1.1099	0.0002159	0.80897
$\mu = 1$	-1.3599	1.0669	0.0002757	0.79688
$\mu = 2$	-0.92941	1.0329	0.0003321	0.78806
$\mu = 3$	-0.58841	1.007	0.0003755	0.78335

	$Z_e(Ka) = a + bZ_e(Ku)$	
Particle types	a	b
Snow/graupel		
$\rho = 0.05$ g cm^{-3}	-2.8102	0.91275
$\rho = 0.10$ g cm^{-3}	-2.2474	0.91314
$\rho = 0.15$ g cm^{-3}	-1.9064	0.91348
$\rho = 0.20$ g cm^{-3}	-1.6569	0.91375
$\rho = 0.25$ g cm^{-3}	-1.4578	0.91396
$\rho = 0.30$ g cm^{-3}	-1.2383	0.91898
$\rho = 0.35$ g cm^{-3}	-1.0945	0.91903
$\rho = 0.40$ g cm^{-3}	-0.96614	0.91893
Melted particles		
wf = 0.1	-0.78052	0.90717
wf = 0.2	-0.51698	0.90564
wf = 0.3	-0.27278	0.9006
wf = 0.4	-0.078396	0.89207
wf = 0.5	0.062791	0.88521
wf = 0.6	0.15406	0.88269
wf = 0.7	0.14174	0.90459
wf = 0.8	0.12439	0.96332
Rain		
$\mu = 0$	2.2861	0.99926
$\mu = 1$	0.95818	1.0808
$\mu = 2$	-0.023823	1.1414
$\mu = 3$	-0.75494	1.186

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- Microphysical model development
- Simulation of space-based radar observation
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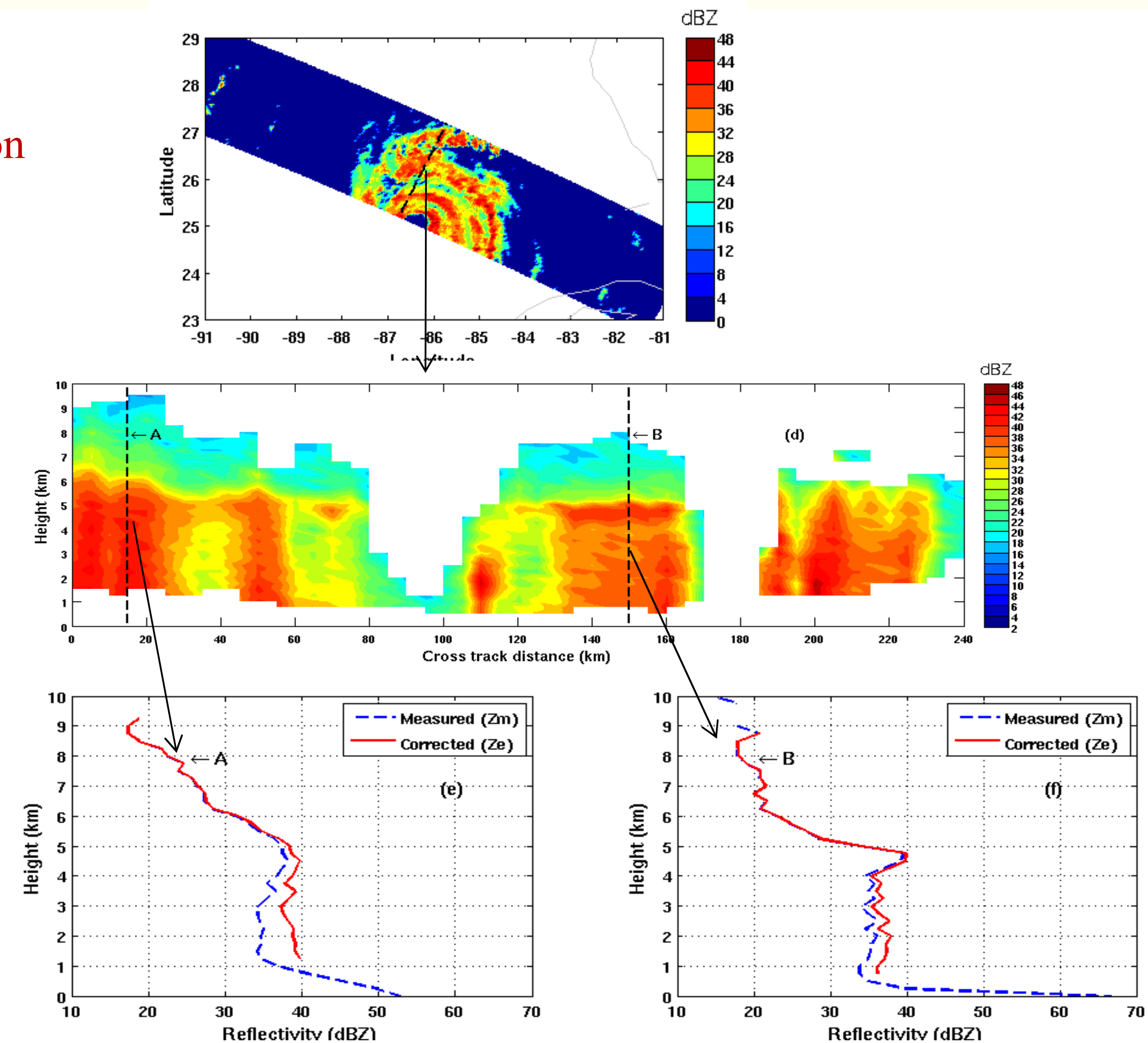
Observation Characteristics of TRMM-PR

Horizontal cross-section
Of reflectivity

Vertical cross-section
Of reflectivity

Vertical profile
of reflectivity



TRMM-PR attenuation-correction algorithm

$$Z_m(r) = Z_e(r)A(r)$$

Attenuation factor defined as

$$A(r) = \exp\left[-0.2\ln(10)\int_0^r k(s)ds\right]$$

Using k and Ze relaton ($k = \alpha Ze^{\beta}$)
Hitchfeld Bordan solution in integral form of Z_m

$$A_{HB}(r) = \left[1 - q\beta\int_0^r \alpha(s)Z_m^{\beta}(s)ds\right]^{1/\beta}$$

In dB unit

$$PIA_{HB} = -\frac{10}{\beta}\log(1-\zeta)$$

where

$$\zeta = q\beta\int_0^{r_s}\alpha(s)Z_m^{\beta}(s)ds$$

HB solution is unstable when PIA is large

Surface reference (SR) technique is used as a constraint, defined as

$$PIA_{SR} = \Delta\sigma^0 = \left\langle \sigma^0_{no-rain}\right\rangle - \left\langle \sigma^0_{rain}\right\rangle$$

Estimate most probable PIA (***PIA_e***)
for given ζ and $\Delta\sigma^o$

$$PIA_e = -\frac{10}{\beta}\log(1-\varepsilon\zeta)$$

ε is correction factor, defined in a form as

$$\varepsilon = \frac{1-10^{-0.1\beta\Delta\sigma^0}}{\zeta}$$

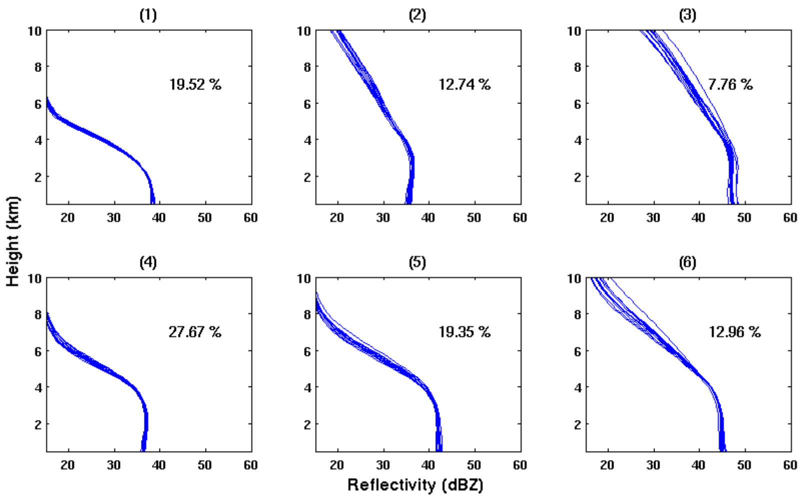
ε is used to adjust α coefficient of $k = \alpha Ze\beta$. Then
It is also called "α adjustment" method.

$$Z_e(r) = \frac{Z_m(r)}{\left[1 - \varepsilon q\beta\int_0^r \alpha(s)Z_m^{\beta}(s)ds\right]^{1/\beta}}$$

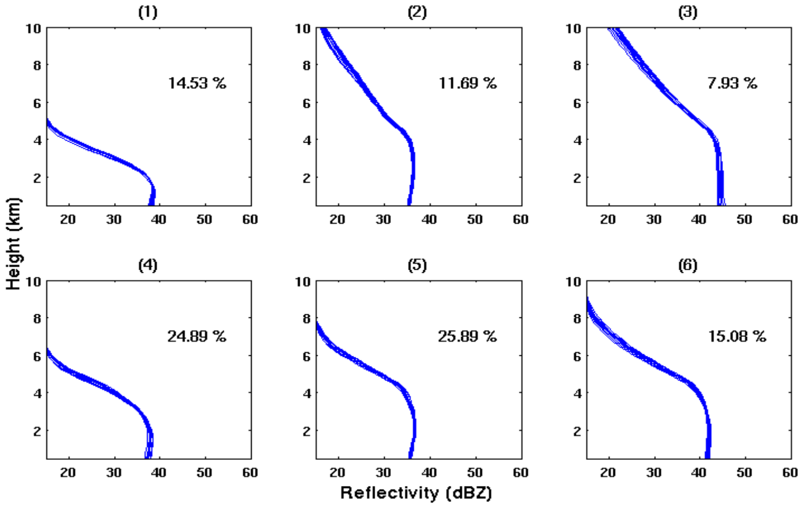
Characterization of vertical profile of reflectivity (VPR): Self-organizing map

Convective rain profiles

Land

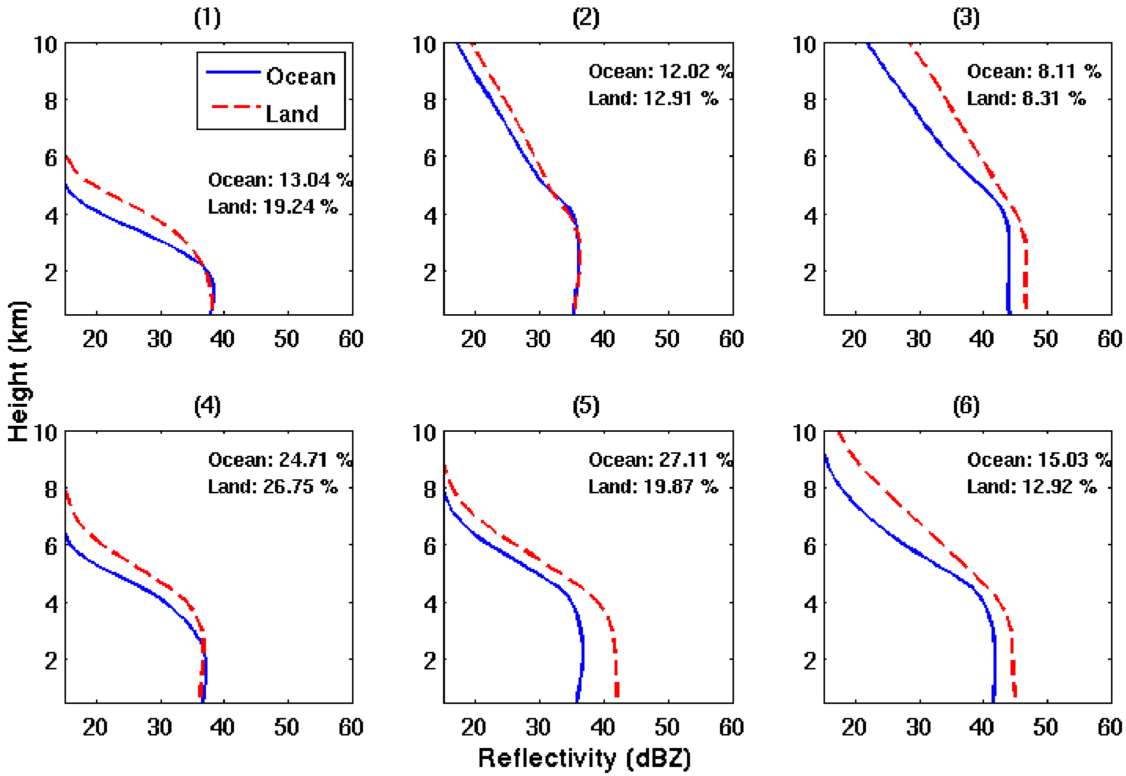


Ocean



Characterization of vertical profile of reflectivity (VPR): Self-organizing map

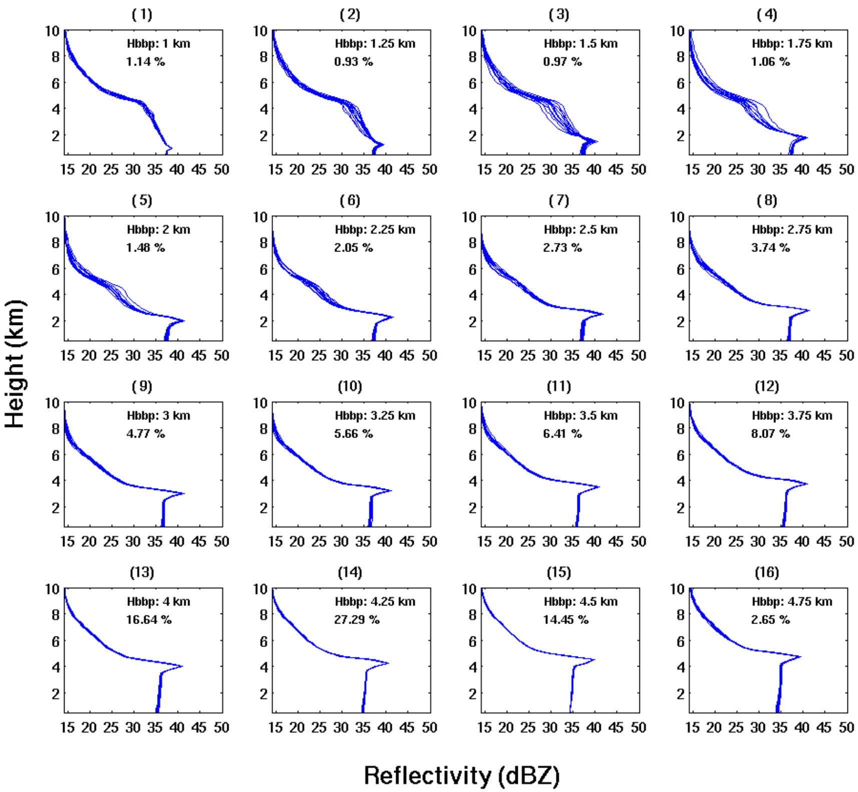
Convective profiles
Land vs. Ocean



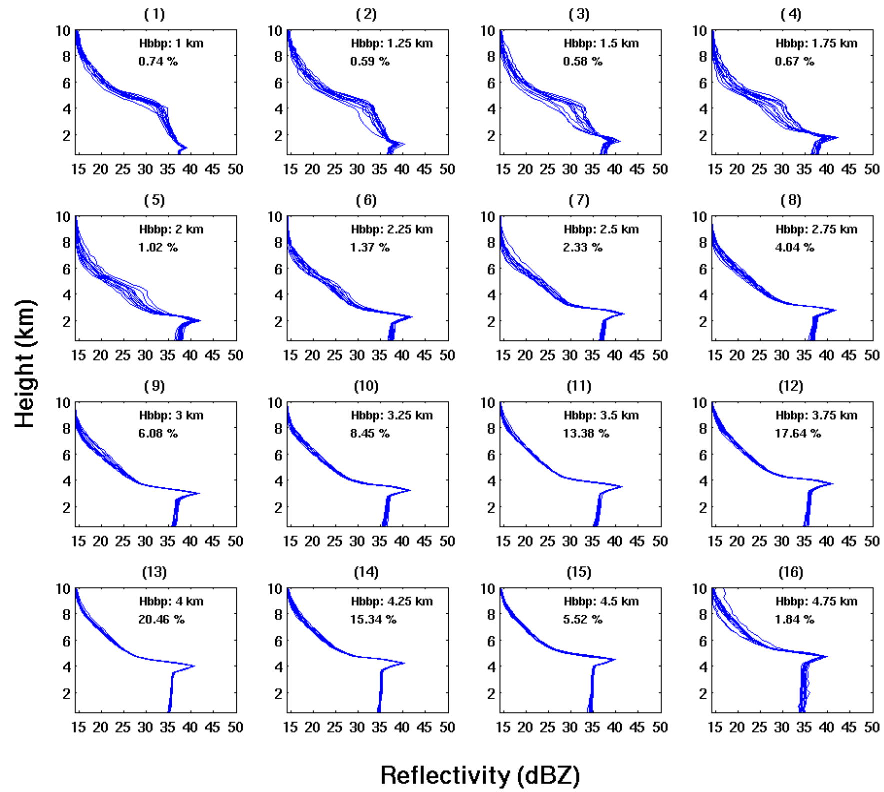
Characterization of vertical profile of reflectivity (VPR): Self-organizing map

Stratiform rain with bright band

Ocean

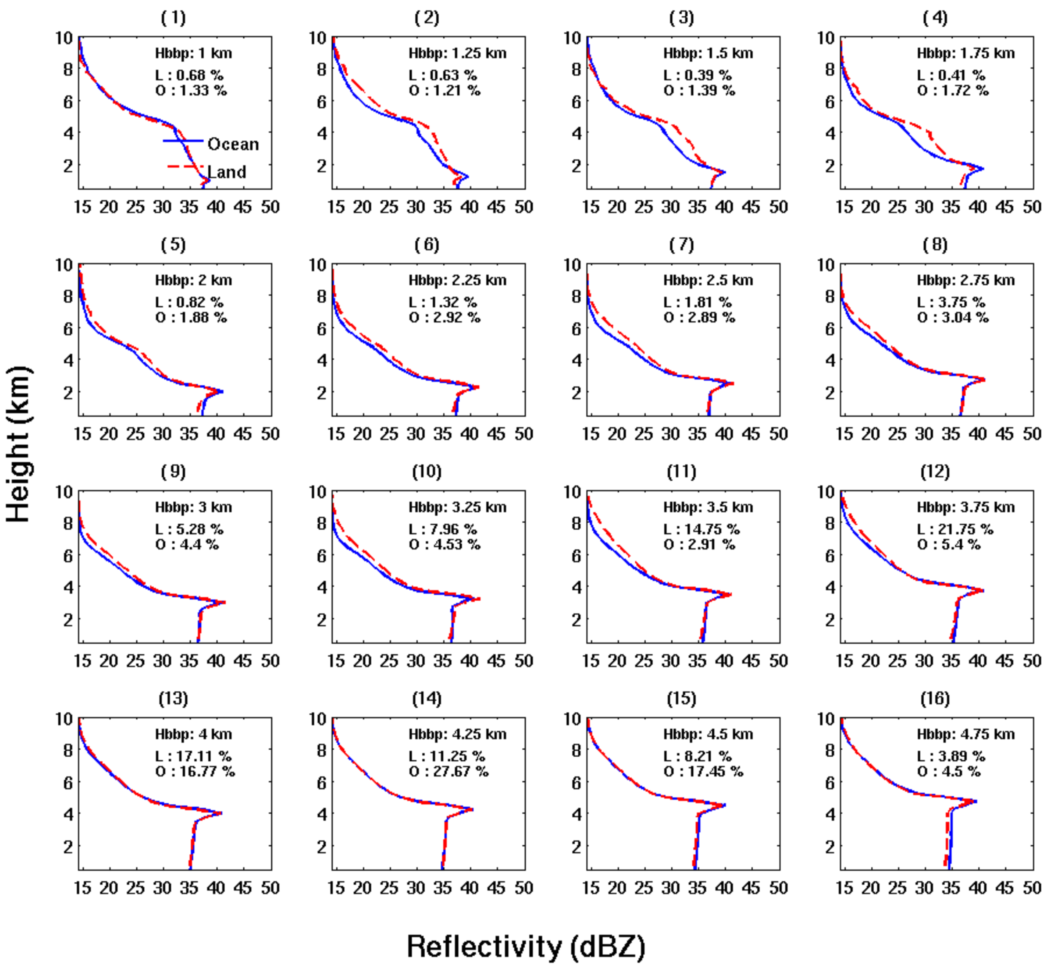


Land



Characterization of vertical profile of reflectivity (VPR): Self-organizing map

Stratiform rain with bright band



Do and Nw estimation using TRMM-PR observations

The drop-size-distribution (DSD) is based on the normalized gamma model:

$$N(D) = N_W f(\mu)\left(\frac{D}{D_o}\right)^{\mu} e^{-\left(\frac{3.67+\mu}{D_o}\right)D} dD$$

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

D_o and N_w estimate using TRMM-PR observations

$$k = \alpha Z^{\beta}$$

Normalized by Nw and get new coefficient

$$\left(\frac{k}{N_w}\right) = \tilde{\alpha}\left(\frac{Z}{N_w}\right)^{\beta}$$

$$k = \tilde{\alpha}(N_w)^{1-\beta} Z^{\beta} = \alpha Z^{\beta}$$

$$\alpha = \tilde{\alpha}(N_w)^{1-\beta} \Rightarrow N_w = \left(\frac{\alpha}{\tilde{\alpha}}\right)^{\frac{1}{1-\beta}}$$

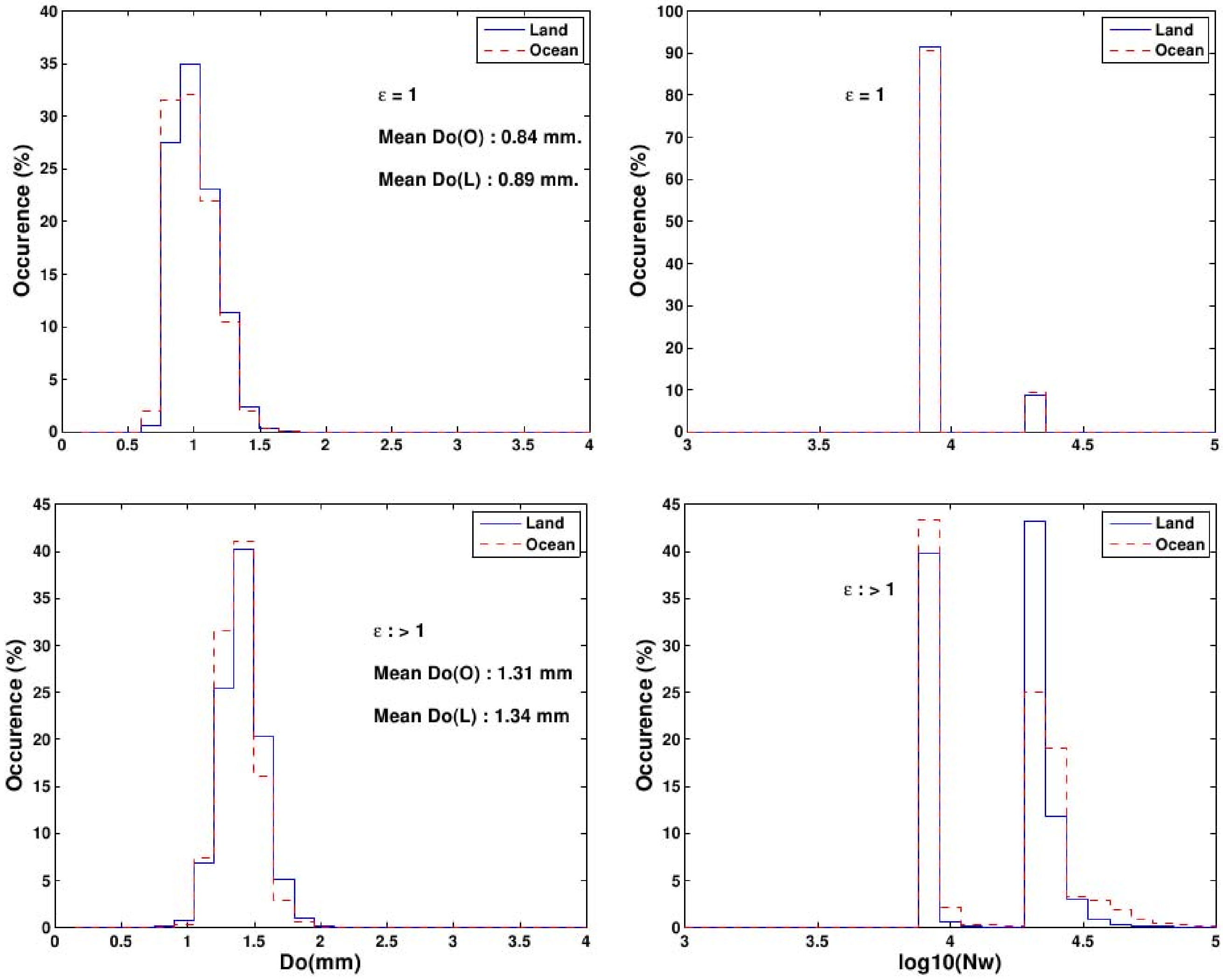
where $\alpha = \alpha_{ini}\varepsilon$

ε is correction factor

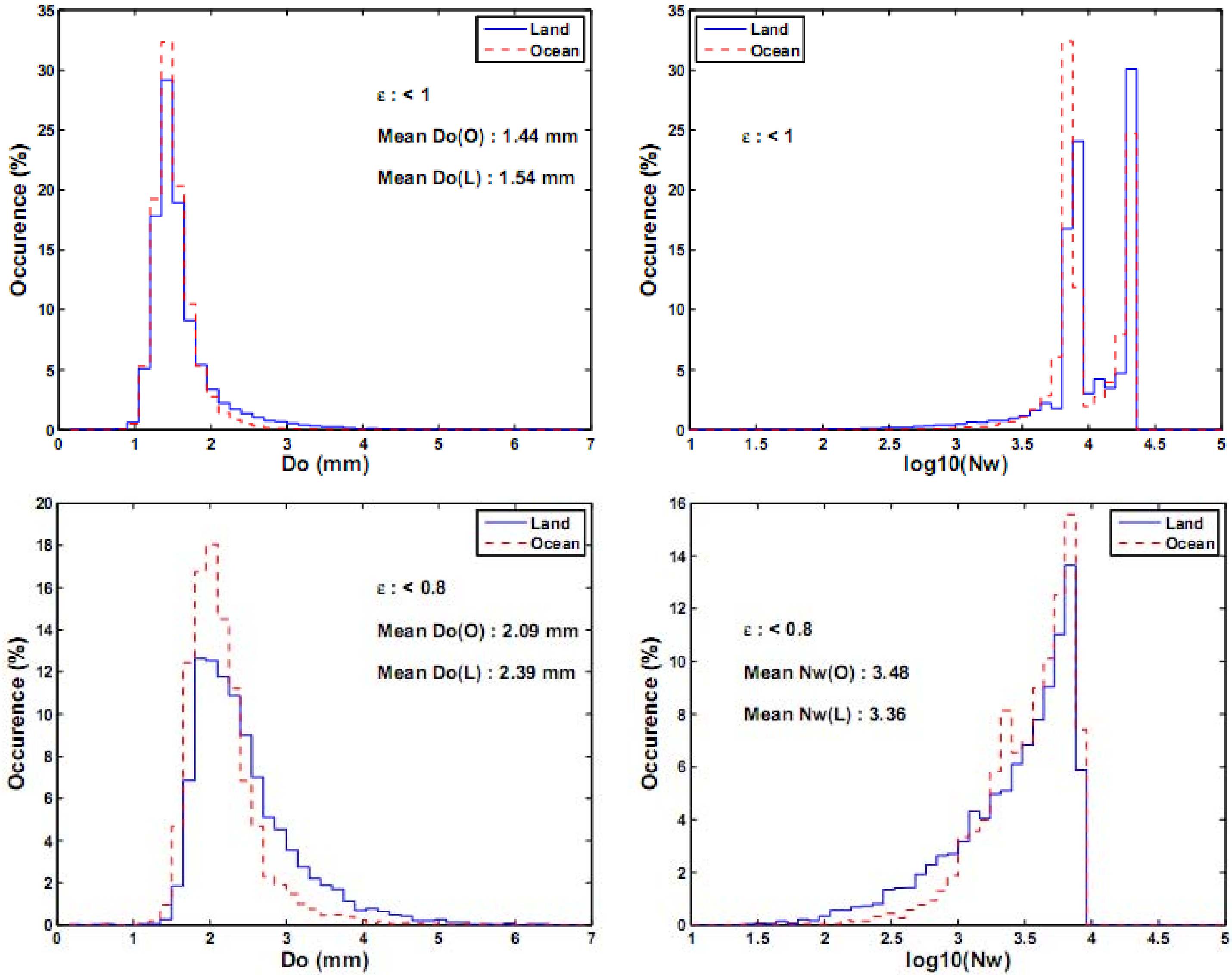
$$D_0 \approx \left[\frac{Z}{N_w C}\right]^{\frac{1}{7}} \qquad C = \frac{f(\mu)\Gamma(7+\mu)}{(3.67+\mu)^{7+\mu}}$$

(Chandrasekar et al., 2005)

Distribution of D_o and N_w

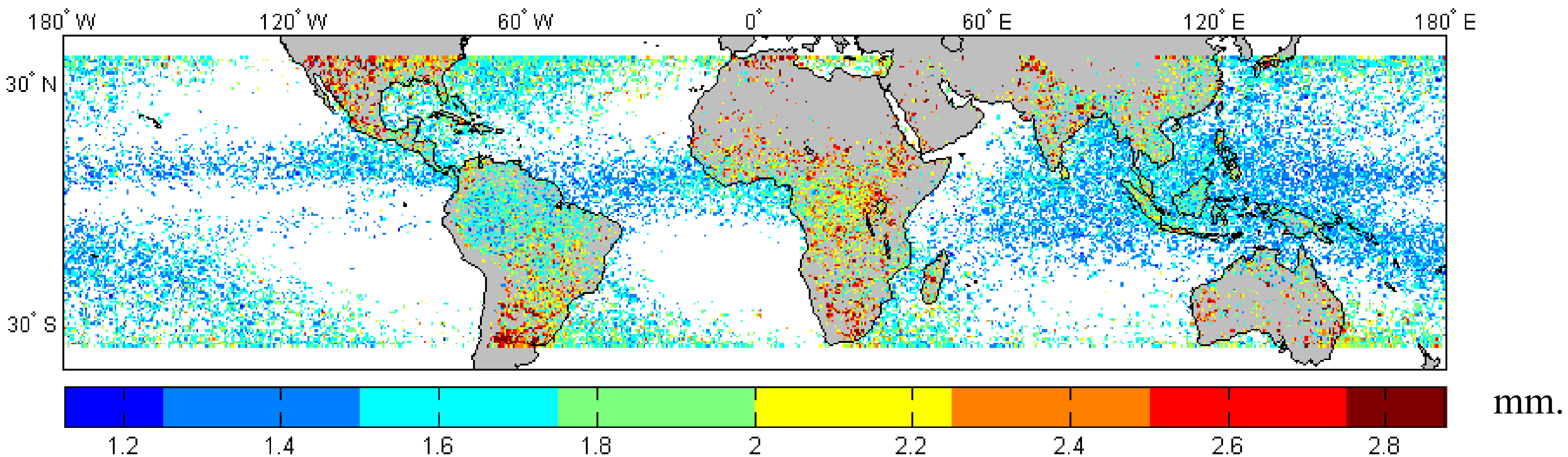


Distribution of D_o and N_w

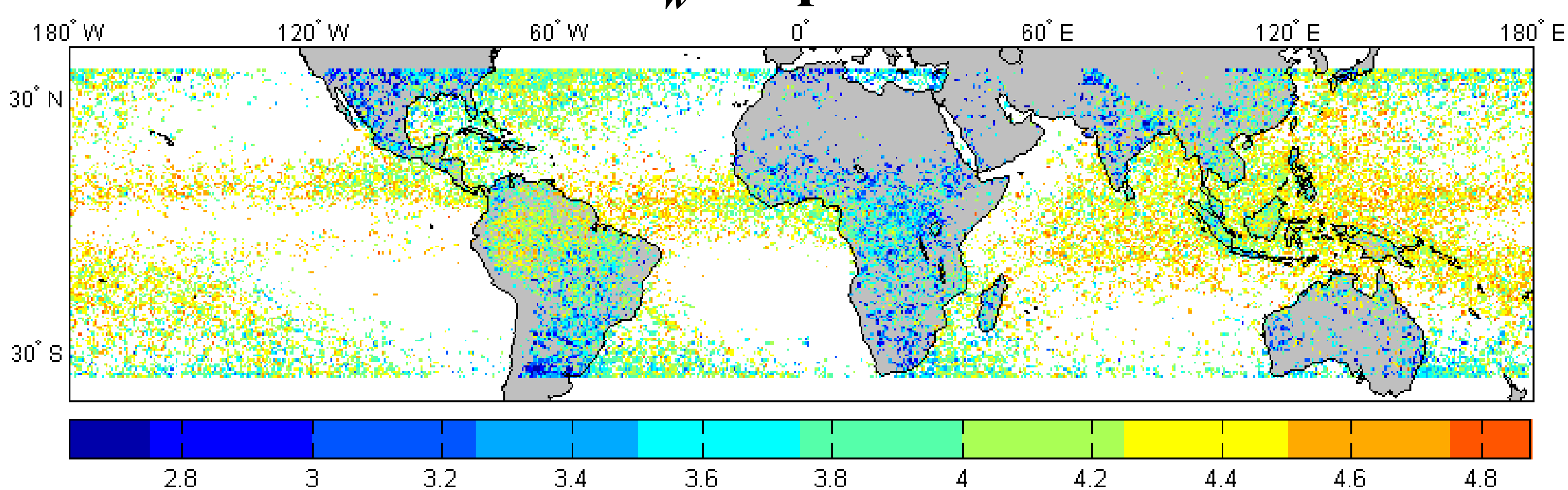


Global Map of D_o and N_w

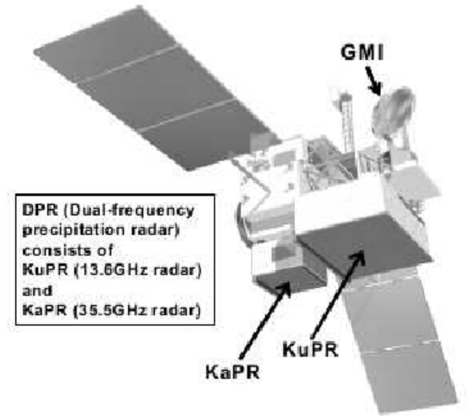
D_o Map

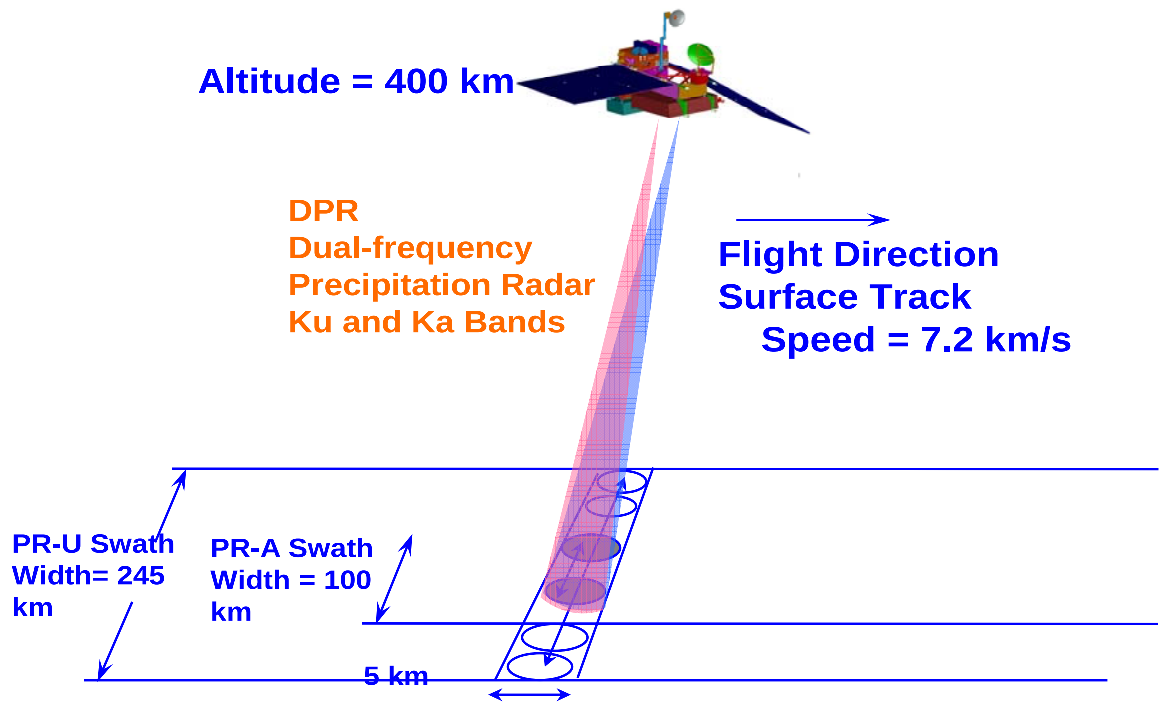


N_w Map



GPM-DPR Observations Characteristics





Dual-frequency retrieval techniques

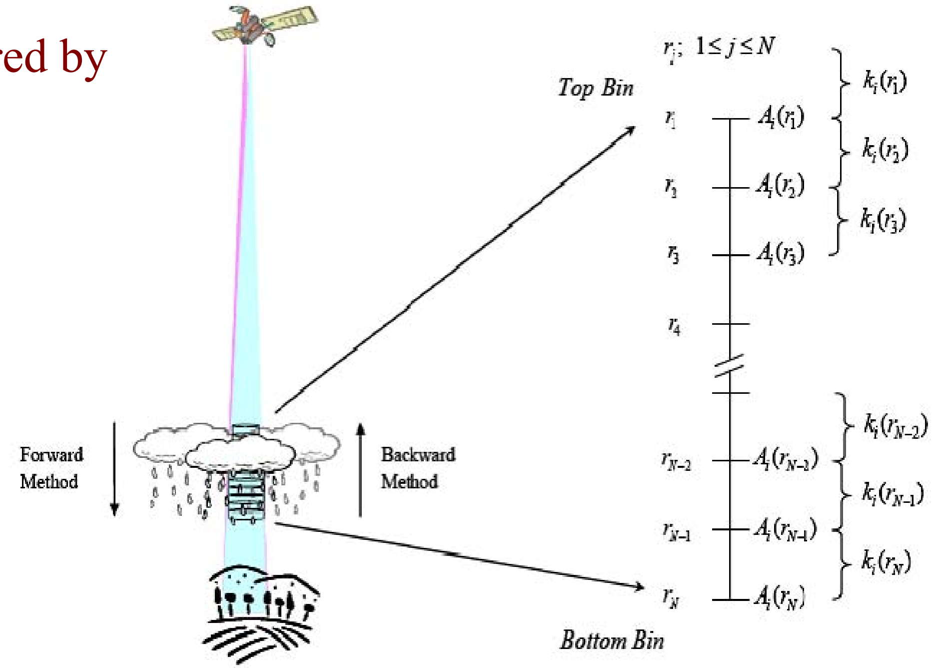
1. **Attenuation-corrected-reflectivity-based**:

- Two PSD parameters (Nw, Do) are inferred by non-Rayleigh scattering
- Integral or differential equations.

  - Solve forward or backward

➢ Backward : Stable but require SRT.

➢ Forward : SRT is not required but not stable when attenuation is large



2. Attenuation-based : Differential Attenuation Difference (DAD)

- Attenuation convert to rain rate directly using k-R relation

Integral equations for Dual-frequency retrieval

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$$Z_{mi}(r_j) = Z_{ei}(r_j)\, A_i(r_j)$$

$$Z_{ei}(r) = C_{Zi} \int_D \sigma_{bi}\, N(D)\, dD$$

$$= N_W\, f(\mu)\, D_o^{-\mu}\, C_{Zi} \int_D \sigma_{bi}\, D^{\mu}\, e^{-\Lambda D}\, dD$$

$$= N_W\, f(\mu)\, D_o^{-\mu}\, I_{bi}(D_o(r_j))$$

$$\frac{Z_{e1}(r)}{Z_{e2}(r)} = \frac{\int_D \sigma_{b1}\, D^{-\mu}\, e^{-\Lambda D}\, dD}{\int_D \sigma_{b2}\, D^{-\mu}\, e^{-\Lambda D}\, dD}$$

$$\frac{Z_{e1}(r)}{Z_{e2}(r)} = \frac{\int_D \sigma_{b1}\, D^{-\mu}\, e^{-\Lambda D}\, dD}{\int_D \sigma_{b2}\, D^{-\mu}\, e^{-\Lambda D}\, dD}$$

$$= \frac{I_{b1}(D_o(r_j))}{I_{b2}(D_o(r_j))}$$

$$= f_2(D_o(r))$$

$$10\log(Z_{e1}(r)) - 10\log(Z_{e2}(r)) = 10\log(f_2(D_o(r)))$$

$$DFR = f_3(D_o(r))$$

The specific attenuation, *ki*(*r*), at a particular range bin can also be derived as,

$$k_i(r) = C_{ki} \int_D \sigma_{ti}(D)\, N(D)\, dD$$

$$= C_{ki}\, N_W\, f(\mu)\, D_o^{-\mu} \int_D \sigma_{ti}(D)\, D^{\mu}\, e^{-\Lambda D}\, dD$$

$$= N_W\, f(\mu)\, D^{-\mu}\, I_{ti}(D_o(r))$$

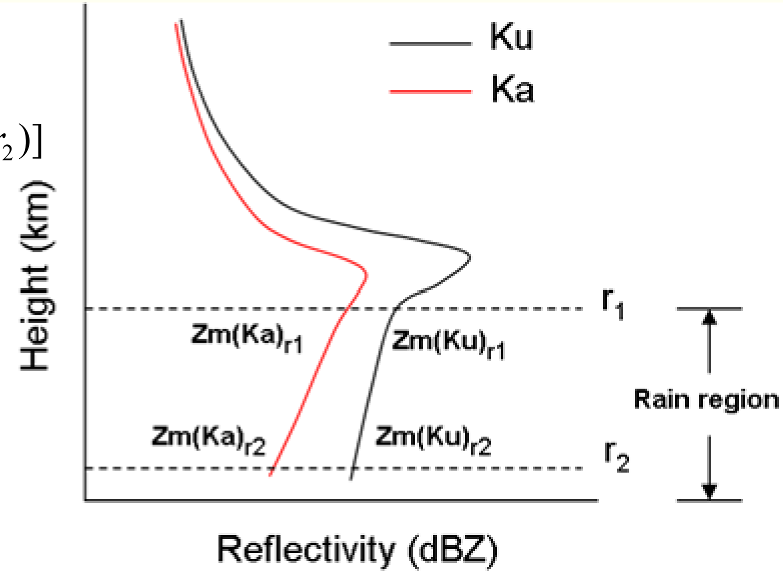
$$Z_{mi}(r_j) = N_W f(\mu) D_o^{-\mu}\, I_{bi}(D_o(r_j))\, A_i(r_j)$$

$$N_W(r_j) = \frac{Z_{mi}(r)}{f(\mu)\, D_o^{-\mu}\, I_{bi}(D_o(r_j))\, A_i(r_j)}$$

DAD equations for Dual-frequency retrieval

$$[dBZ_{m1}(r_1) - dBZ_{m1}(r_2)] - [dBZ_{m2}(r_1) - dBZ_{m1}(r_2)]$$ **=> DAD**

$$= 10\log_{10}\left(\frac{I_{b1}(D_o(r_1))I_{b2}(D_o(r_2))}{I_{b1}(D_o(r_2))I_{b2}(D_o(r_1))}\right) - [A_1(r_1) - A_1(r_2)] + [A_2(r_1) - A_2(r_2)]$$



Let $M = \frac{I_{b1}(D_o(r_1))I_{b2}(D_o(r_2))}{I_{b1}(D_o(r_2))I_{b2}(D_o(r_1))}$

If M = 1 (Rayleigh scattering)

Then $[dBZ_{m1}(r_1) - dBZ_{m1}(r_2)] - [dBZ_{m2}(r_1) - dBZ_{m1}(r_2)]$

$$= -\left[\int_0^{r_1} k_1(s)ds - \int_0^{r_2} k_1(s)ds\right] + \left[\int_0^{r_1} k_2(s)ds - \int_0^{r_2} k_2(s)ds\right]$$

$$= \left[\int_0^{r_2} a_1 R^{b_1}(s)ds - \int_0^{r_1} a_1 R^{b_1}(s)ds\right] + \left[\int_0^{r_2} a_2 R^{b_2}(s)ds - \int_0^{r_1} a_2 R^{b_2}(s)ds\right]$$

$$= 2\int_{r_1}^{r_2} (a_1 R^{b_1}(s) - a_2 R^{b2}(s))ds$$

$$\approx 2(r_2 - r_1)(a_1 \overline{R}^{b_1} - a_2 \overline{R}^{b_2})$$

$$\overline{R} = \left(\frac{DAD}{2(a_1 - a_2)(r_2 - r_1)}\right)^{1/b_1}$$

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- Research Goal
- Background and Theoretical framework
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- **Microphysical model development for simulations**
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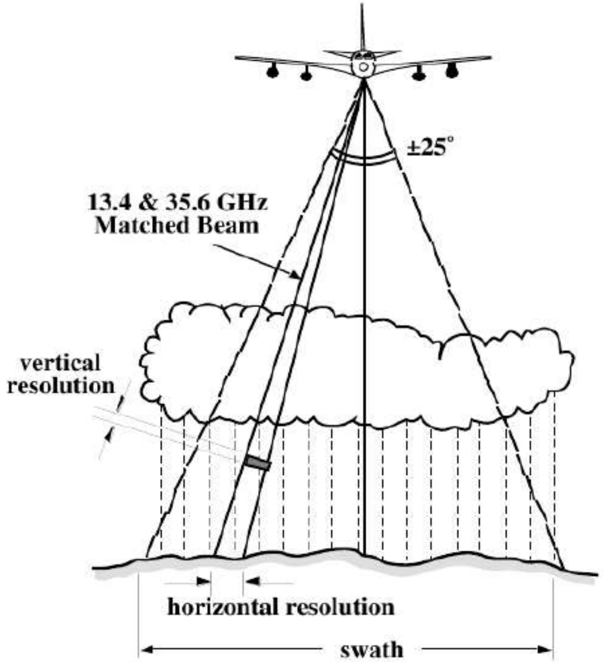
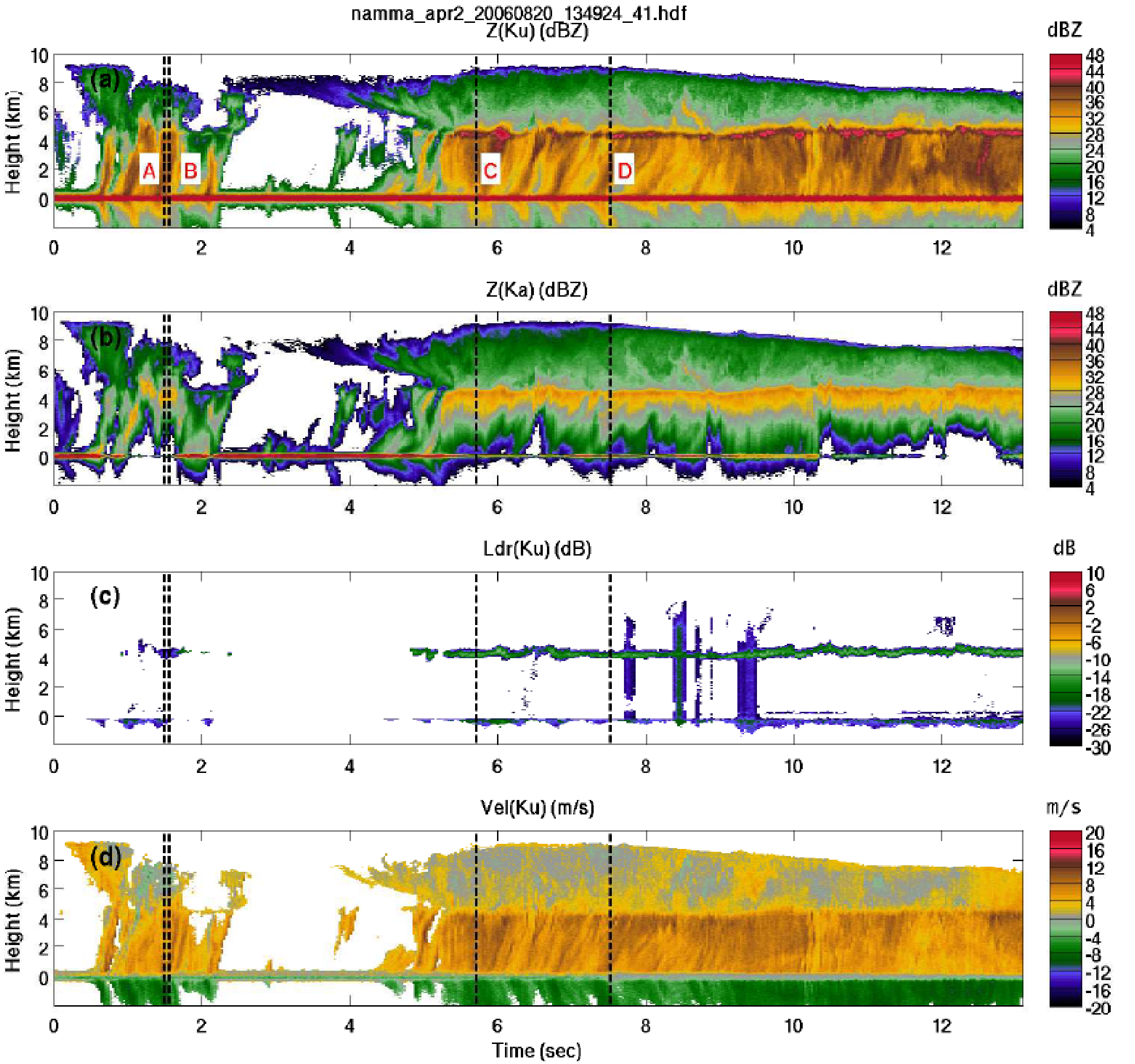
Microphysical Model development for simulations

Airborne Precipitation Radar (APR-2)

- 2 Channels: 13.6 GHz
  35.6 GHz



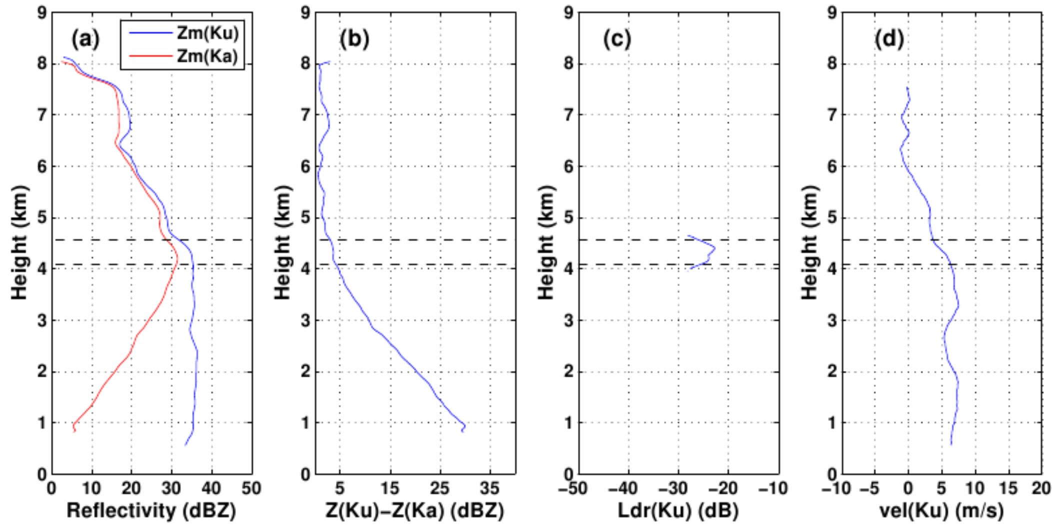


Microphysical Model development for simulations

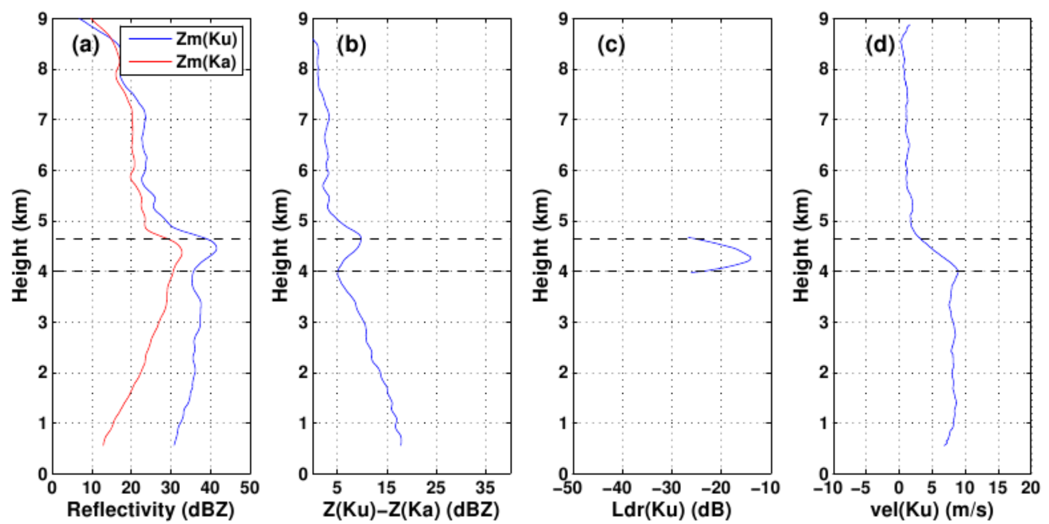
Colorado State University

Example profiles from the airborne experiment

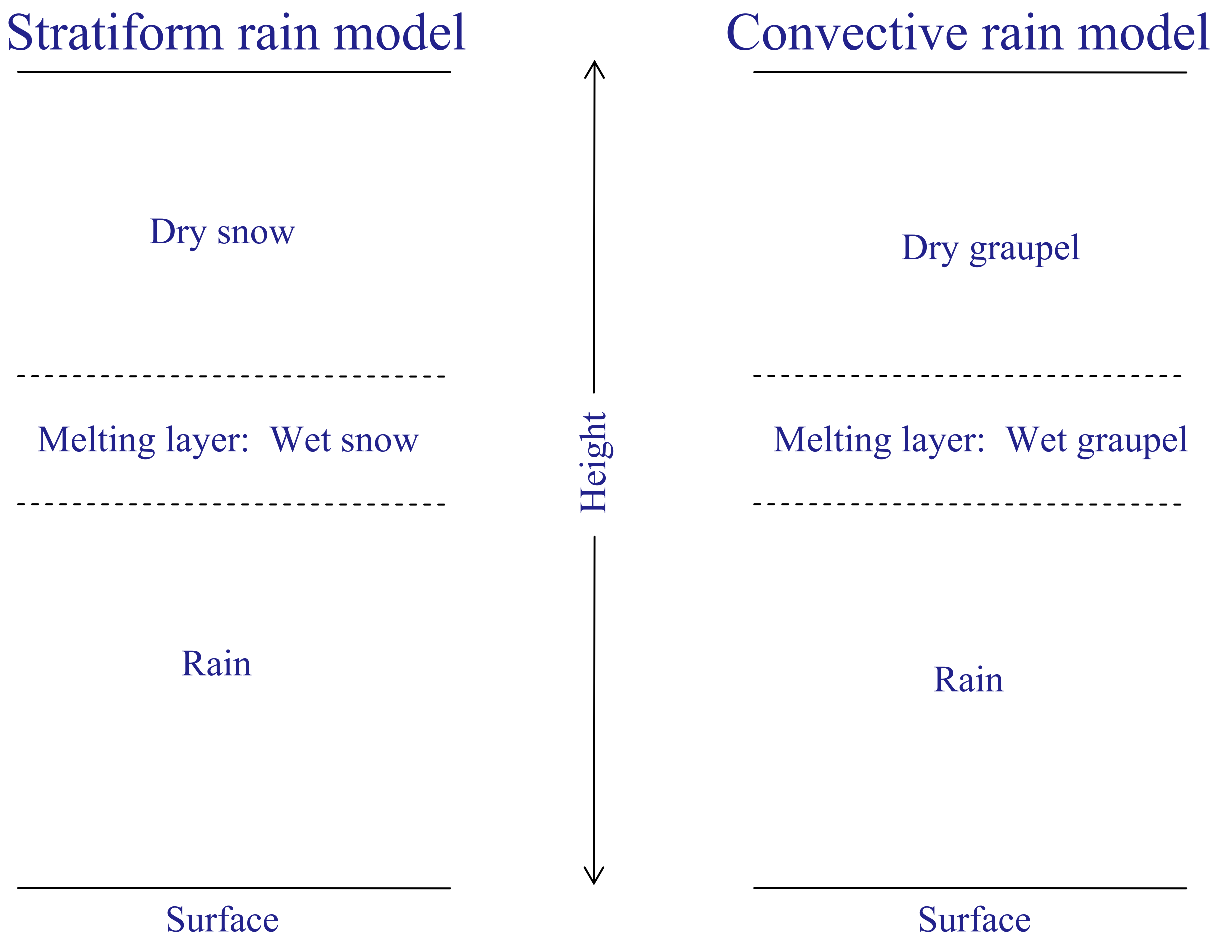
Convective Rain



Stratiform Rain
With bright band



Microphysical Model development for simulations

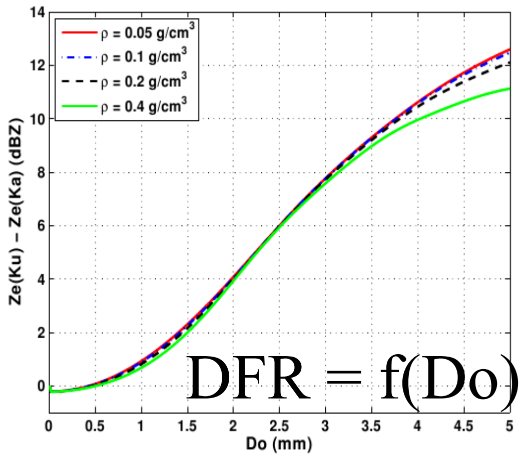


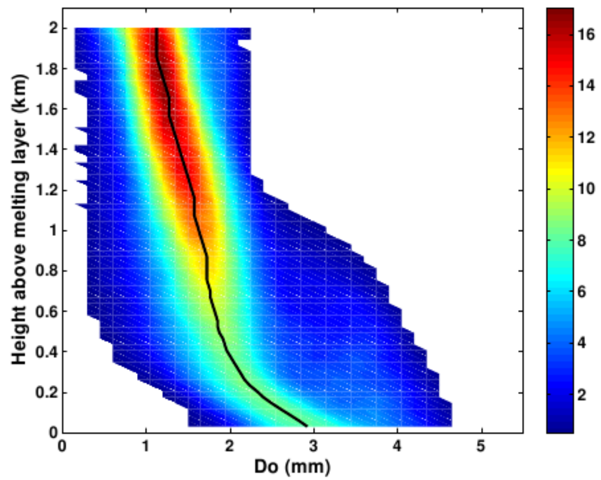
Microphysical model development for simulations

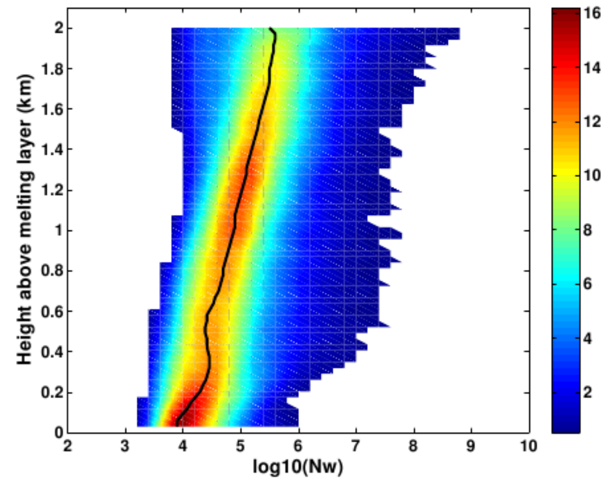
Colorado State University

Stratiform rain with bright band

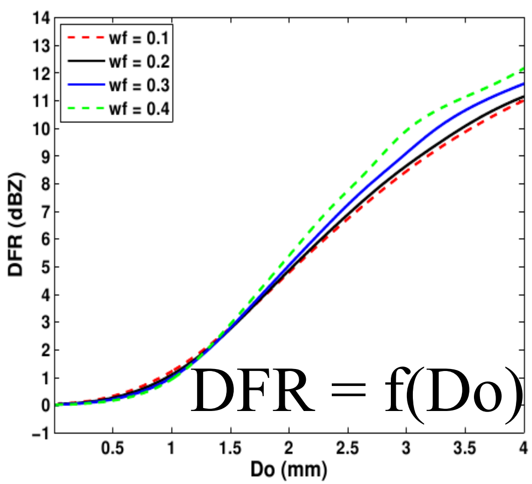
Dry snow D_o N_w

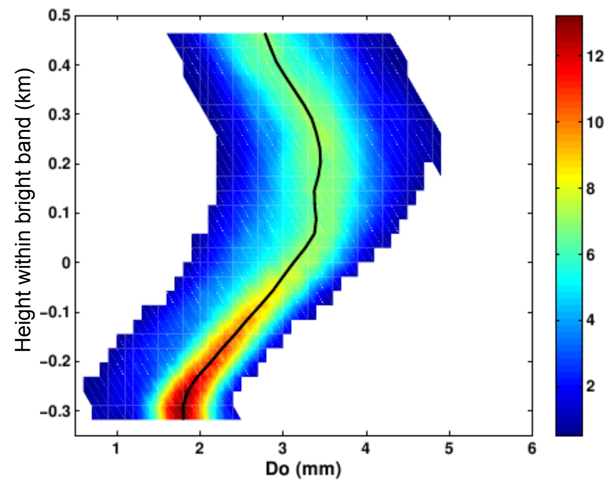


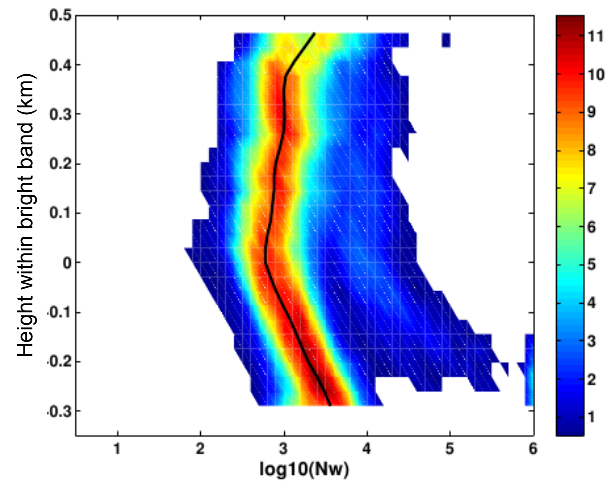




Wet snow

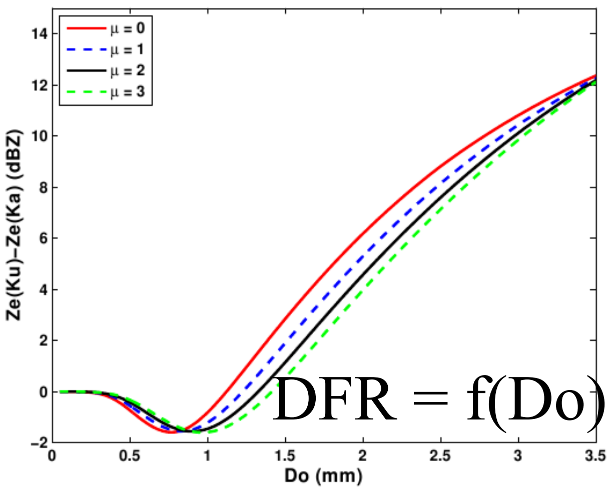




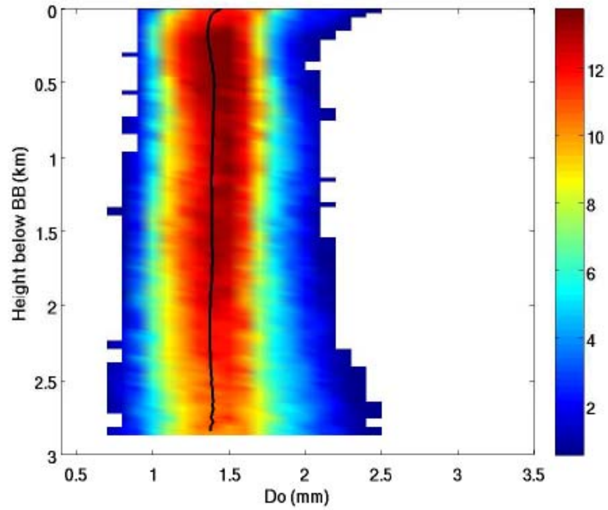


Microphysical Model development for simulations

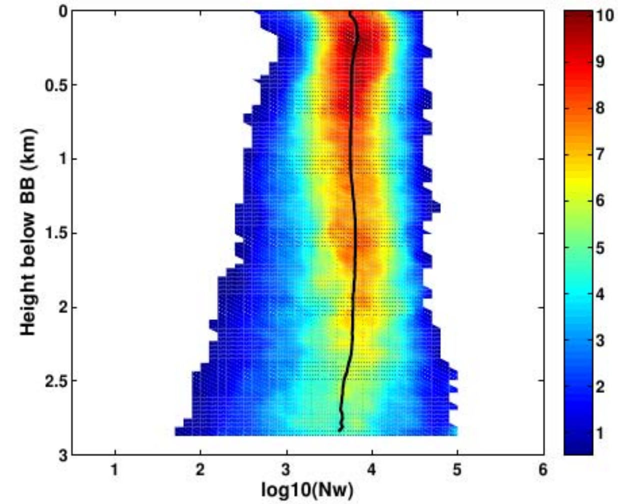
Rain



D_o



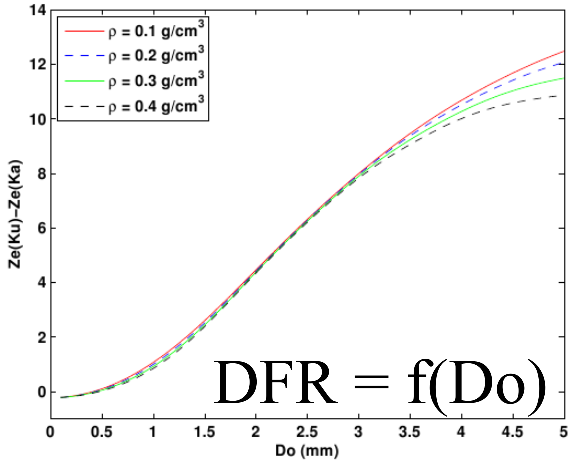
N_w



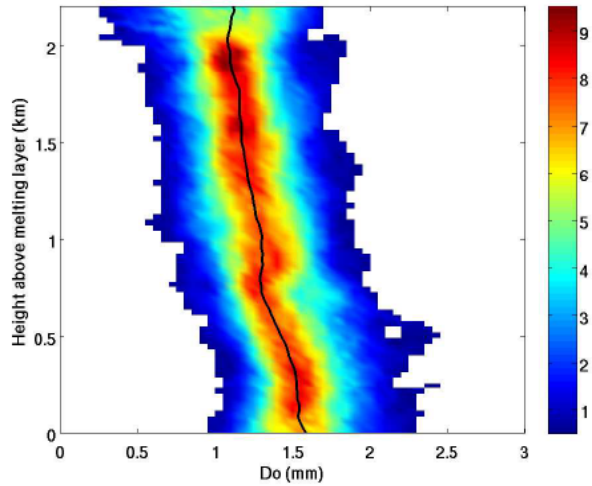
Microphysical Model development for simulations

Convective rain

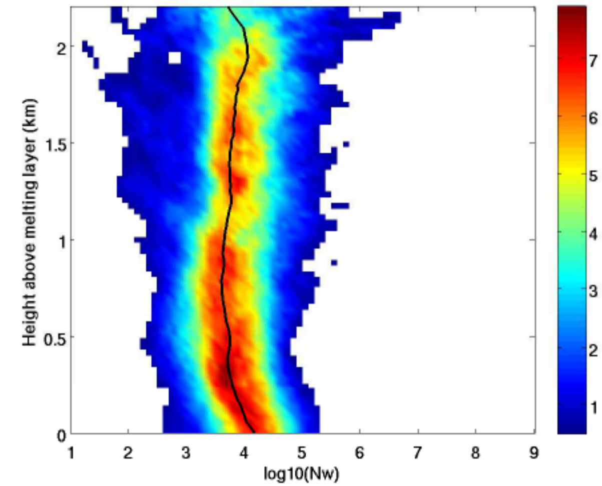
Dry graupel



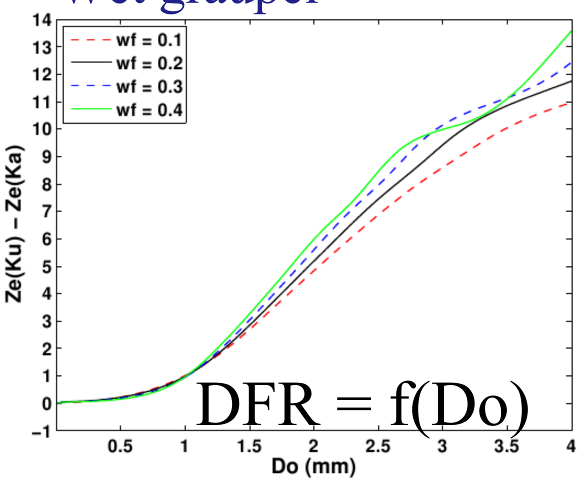
D_o

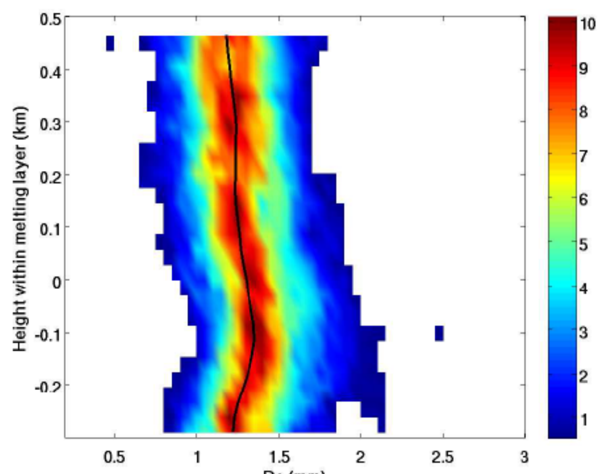


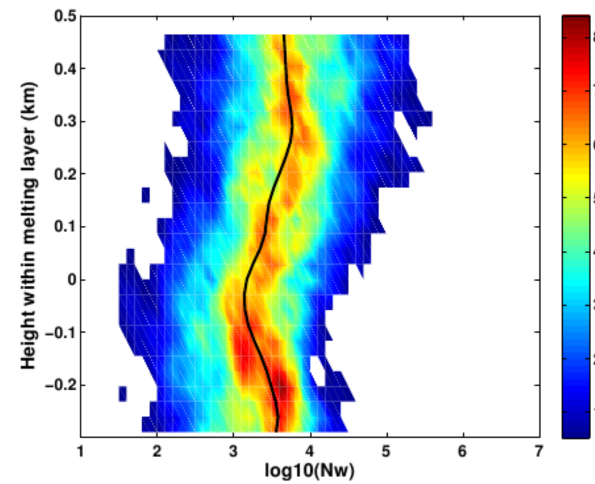
N_w



Wet graupel

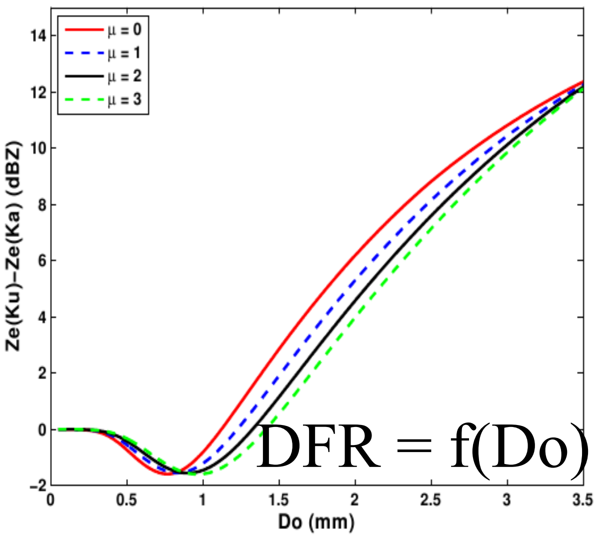




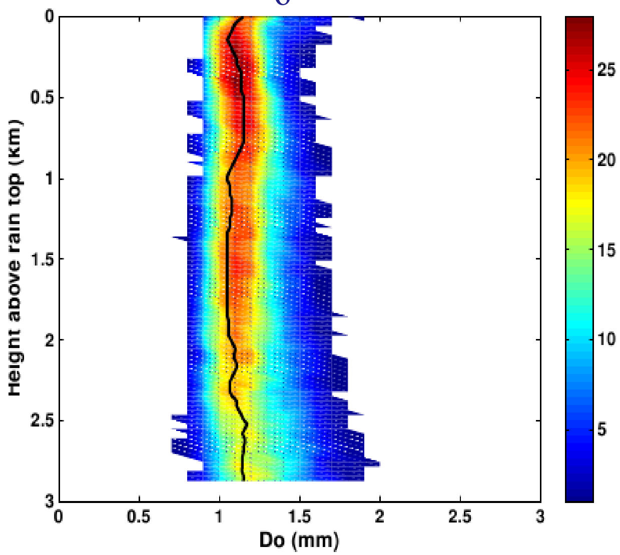


Microphysical Model development for simulations

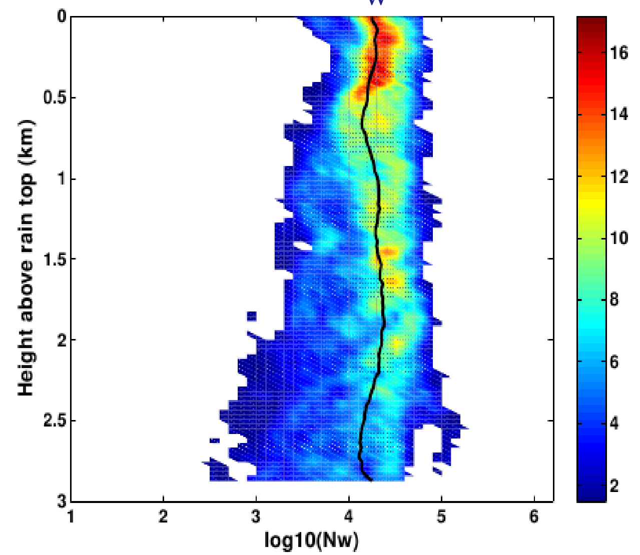
Rain



D_o



N_w



Microphysical Model development for simulations

Colorado State University

$$Ze(Ku) = a + b*Ze(S)$$

$$k(Ku) = \alpha*Ze(Ku)^{\beta}$$

	$Z_e(Ku)$ = a + b* $Z_e(S)$		$k(Ku) = \alpha * Z_e(Ku)^{\beta}$	
Height (km)	a	b	α	β
0.25	-0.74366	1.0497	0.0001645	0.85542
0.5	-0.85534	1.052	0.0001666	0.85304
0.75	-0.7614	1.05	0.0001449	0.86463
1	-0.74952	1.0493	0.0001512	0.86247
1.25	-0.81846	1.0517	0.000155	0.8603
1.5	-0.75944	1.0501	0.0001198	0.88143
1.75	-0.76781	1.0504	0.0001514	0.86103
2	-0.7179	1.0493	0.0001349	0.87198
2.25	-0.79386	1.0513	0.0001379	0.86896
2.5	-0.84385	1.0528	0.0001662	0.85255
2.75	-0.85484	1.0524	0.0001272	0.87239
3	-0.7993	1.0519	0.0001534	0.85822
3.25	-0.82464	1.0533	0.0001316	0.86955
3.5	-0.80773	1.0525	0.0001337	0.8676
3.75	-0.81402	1.0529	0.0001505	0.85876
4	-0.81231	1.0514	0.0001766	0.84625

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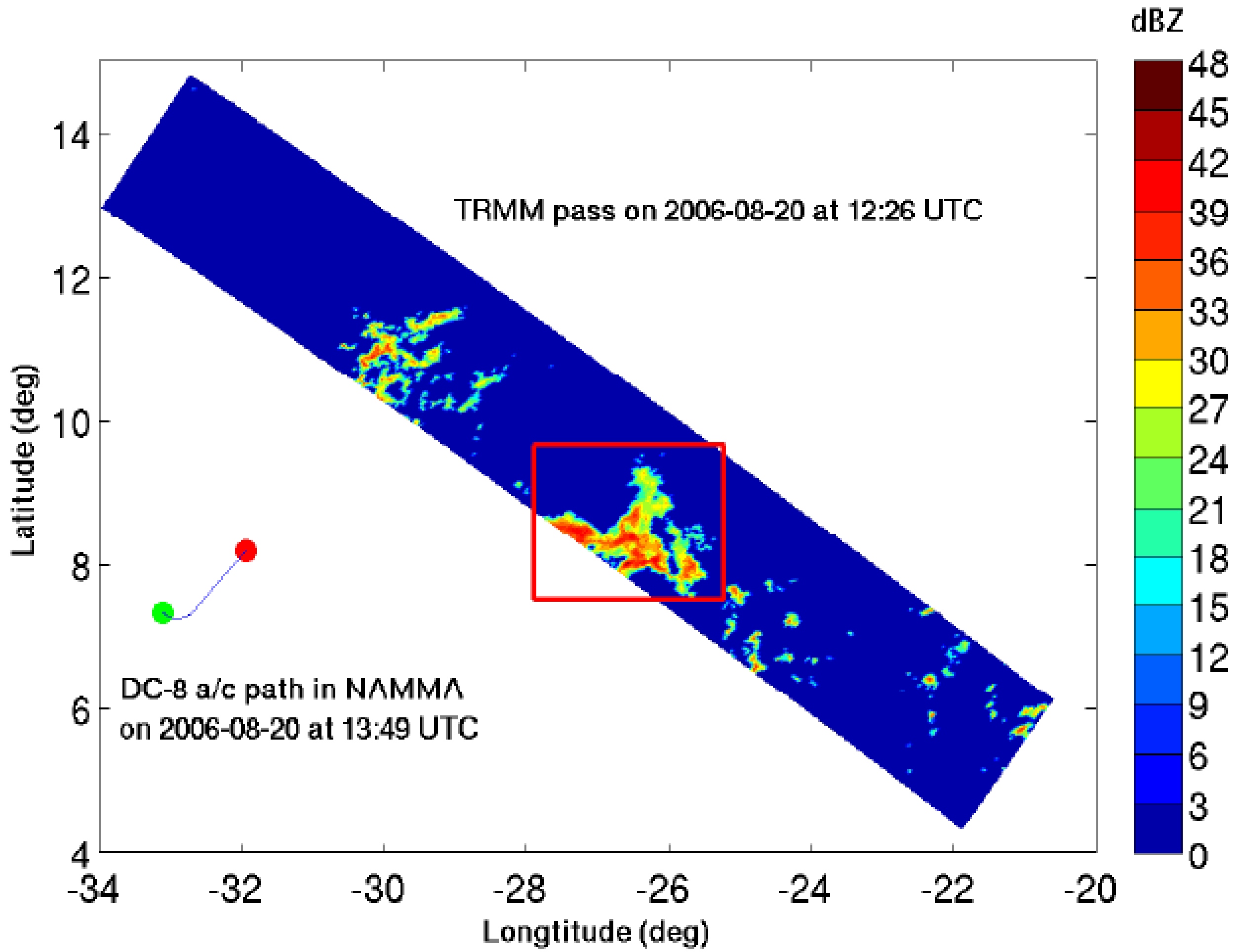
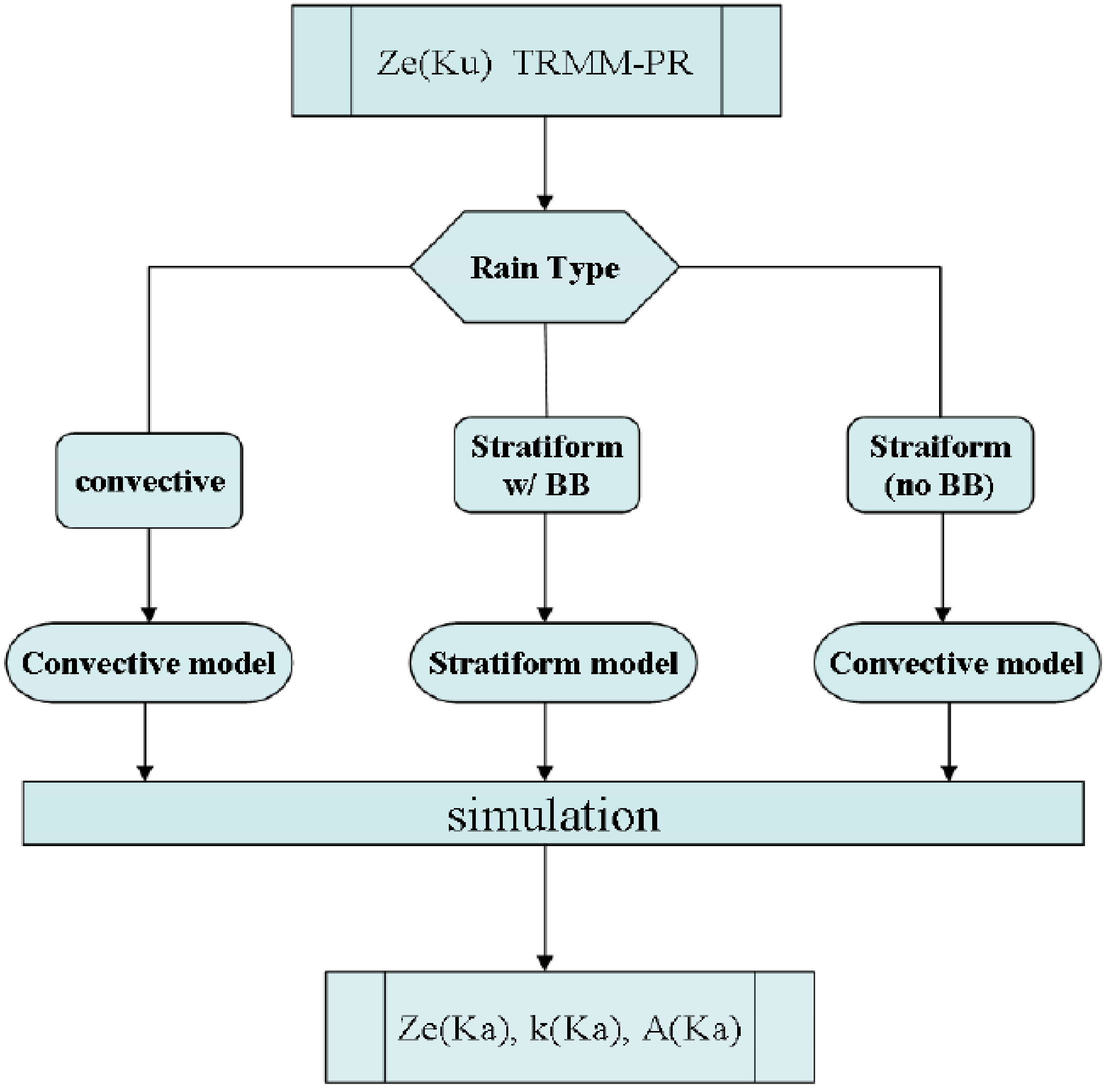
Simulation of Ka-band radar observations using Ku-band radar observations (PR)



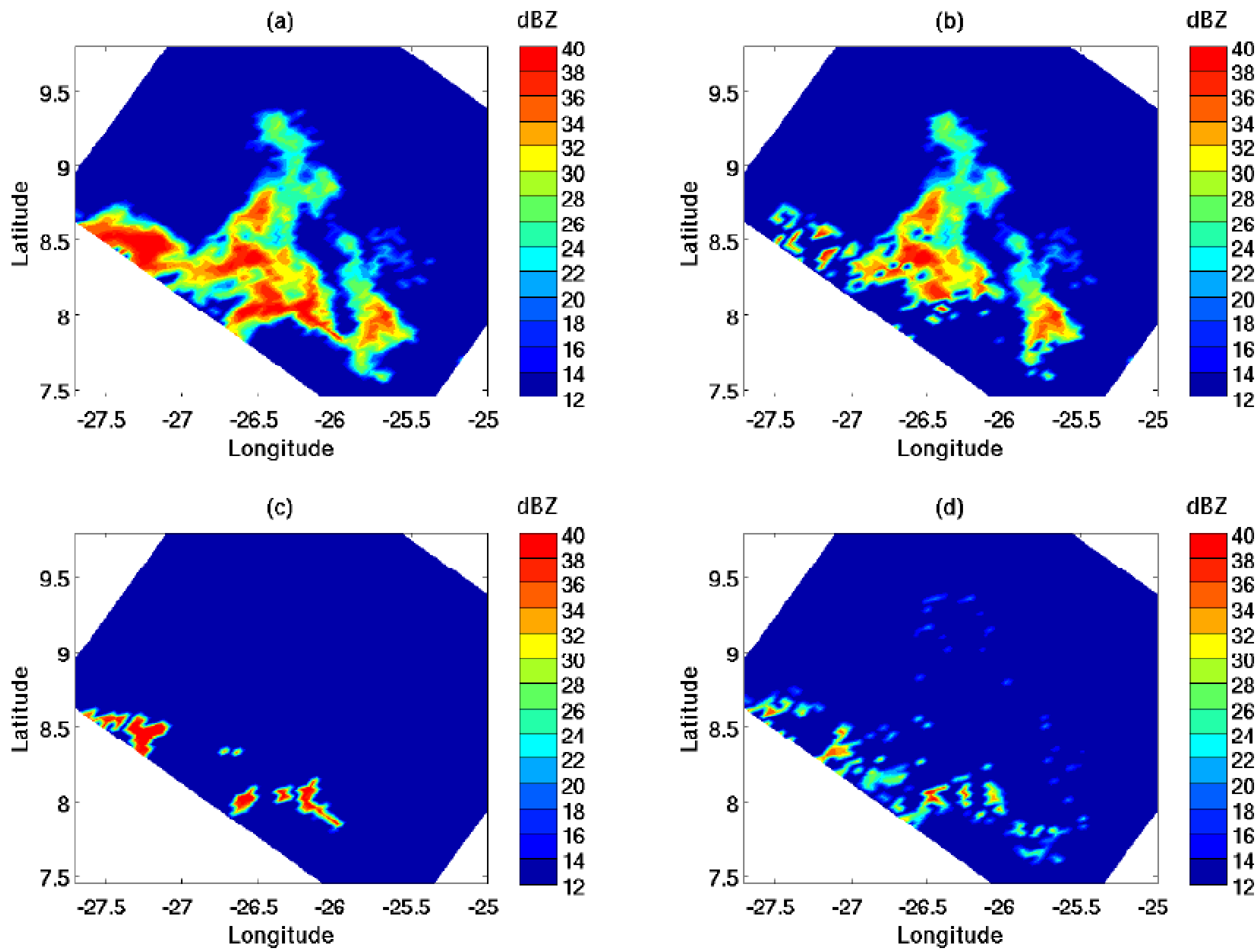
Simulation of Ka-band radar observations using Ku-band radar observations (PR)



Simulation of Ka-band radar observations using Ku-band radar observations (PR)

All rain types

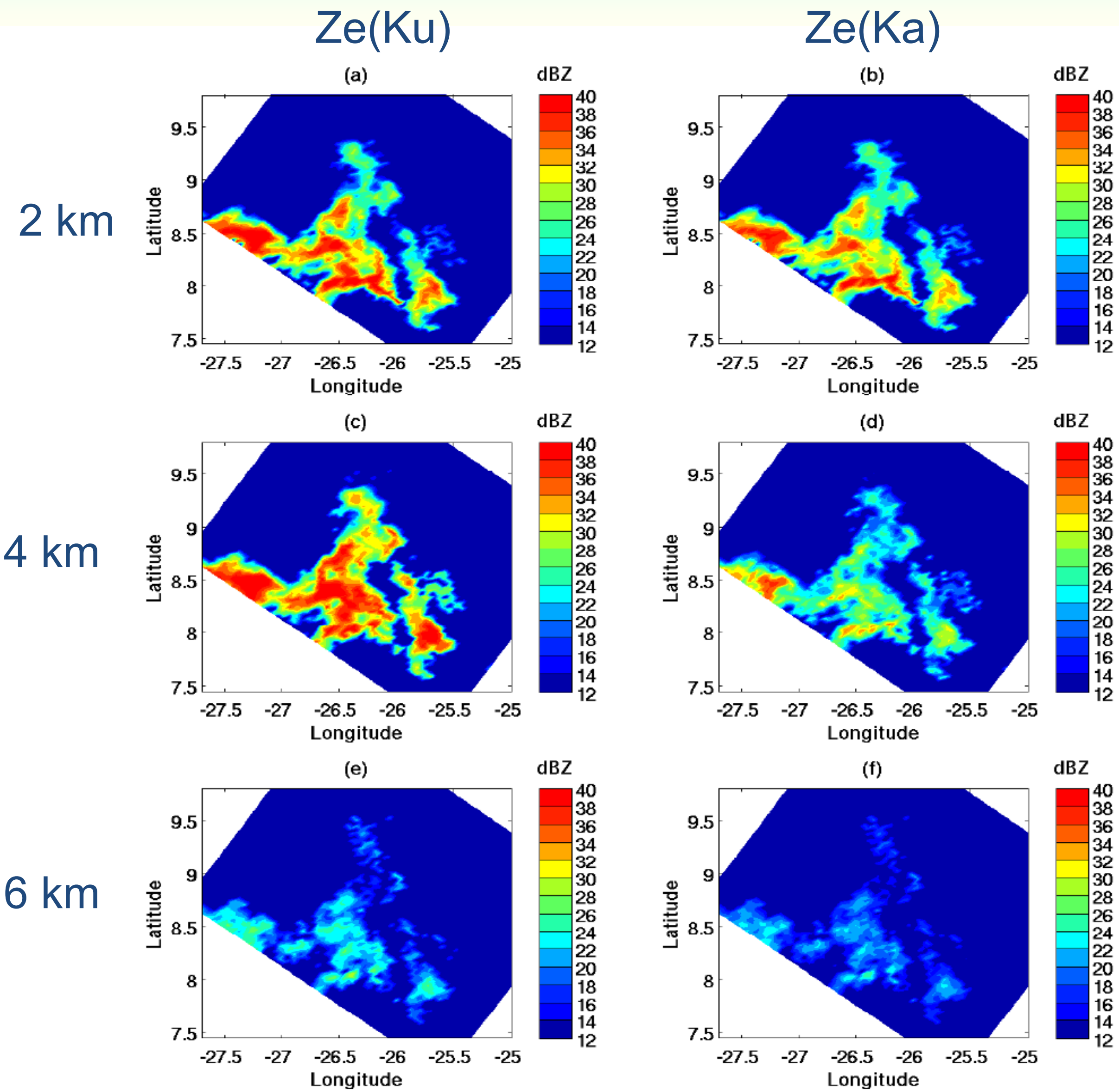
Stratiform with BB



Convective

Stratiform with no BB

Simulation of Ka-band radar observations using Ku-band radar observations (PR)



Simulation of Ka-band radar observations using Ku-band radar observations (PR)

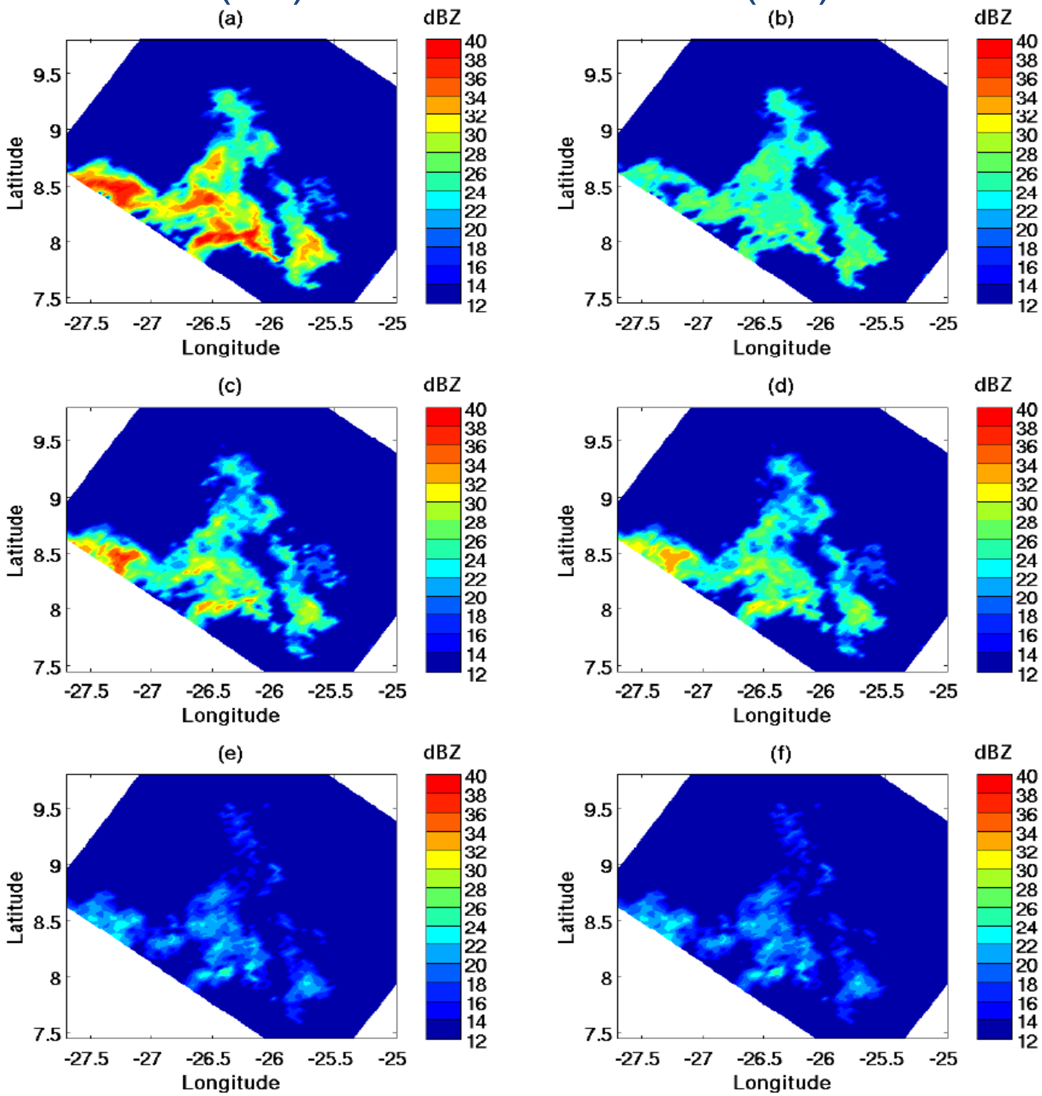
Ze(Ka)

Zm(Ka)

2 km

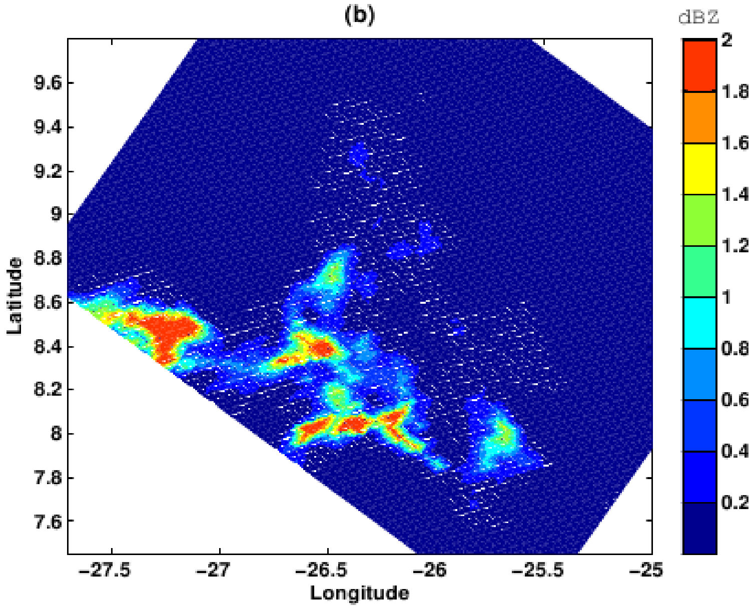
4 km

6 km

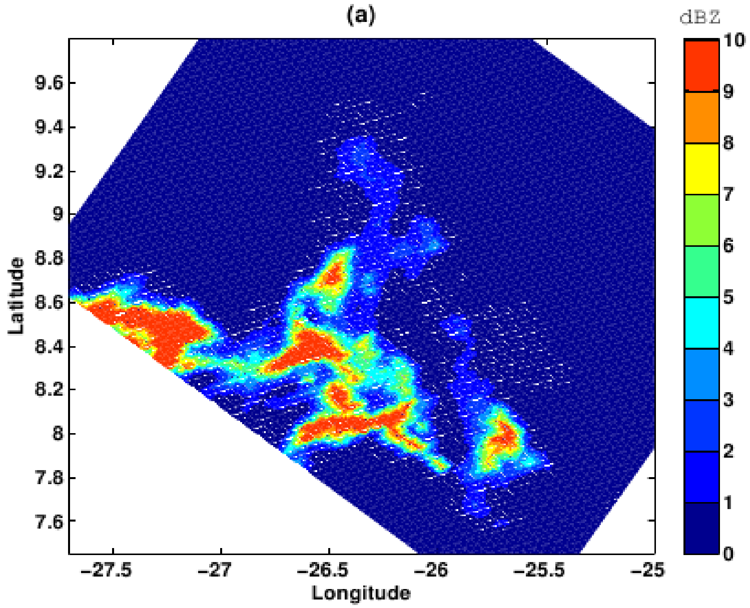


Simulation of Ka-band radar observations using Ku-band radar observations (PR)

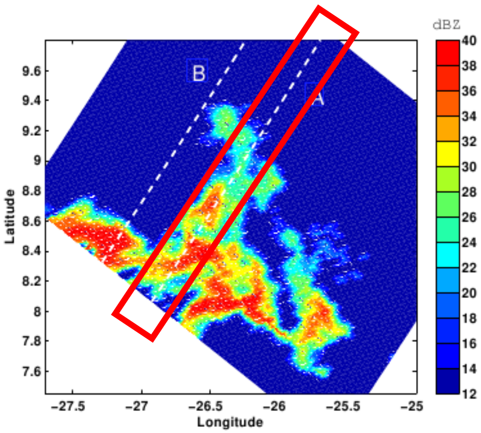
PIA(Ku)



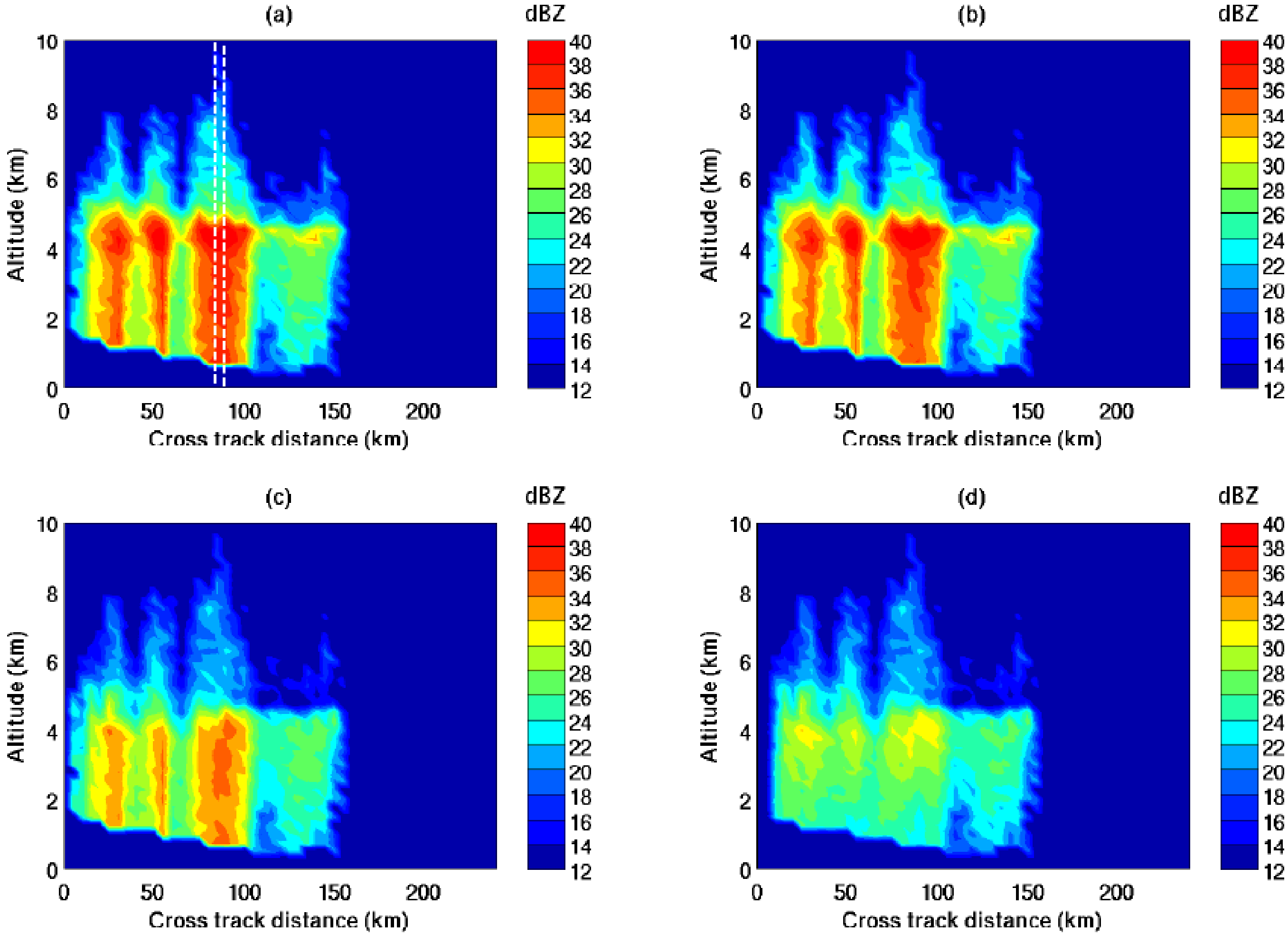
PIA(Ka)



Simulation of Ka-band radar observations using Ku-band radar observations (PR)

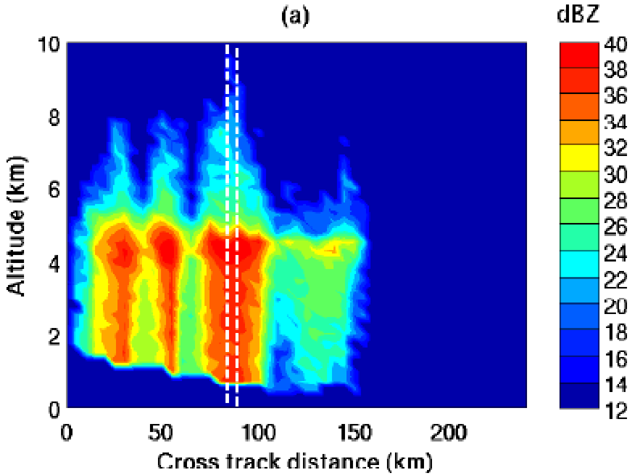


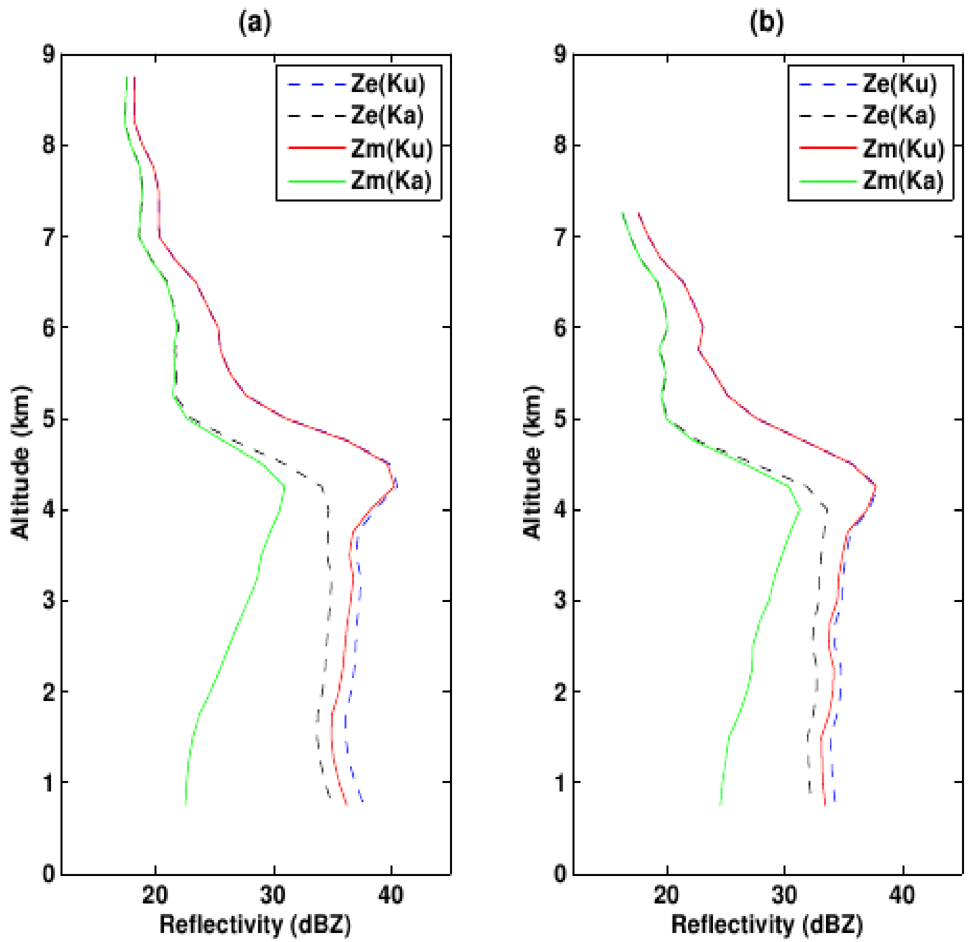
Ze(Ku) Ze(Ka)



Zm(Ku) Zm(Ka)

Simulation of Ka-band radar observations using Ku-band radar observations (PR)





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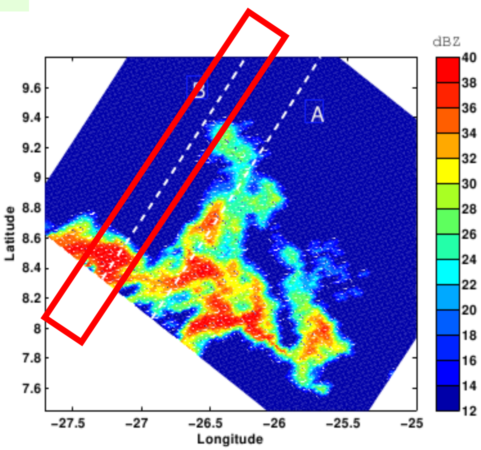
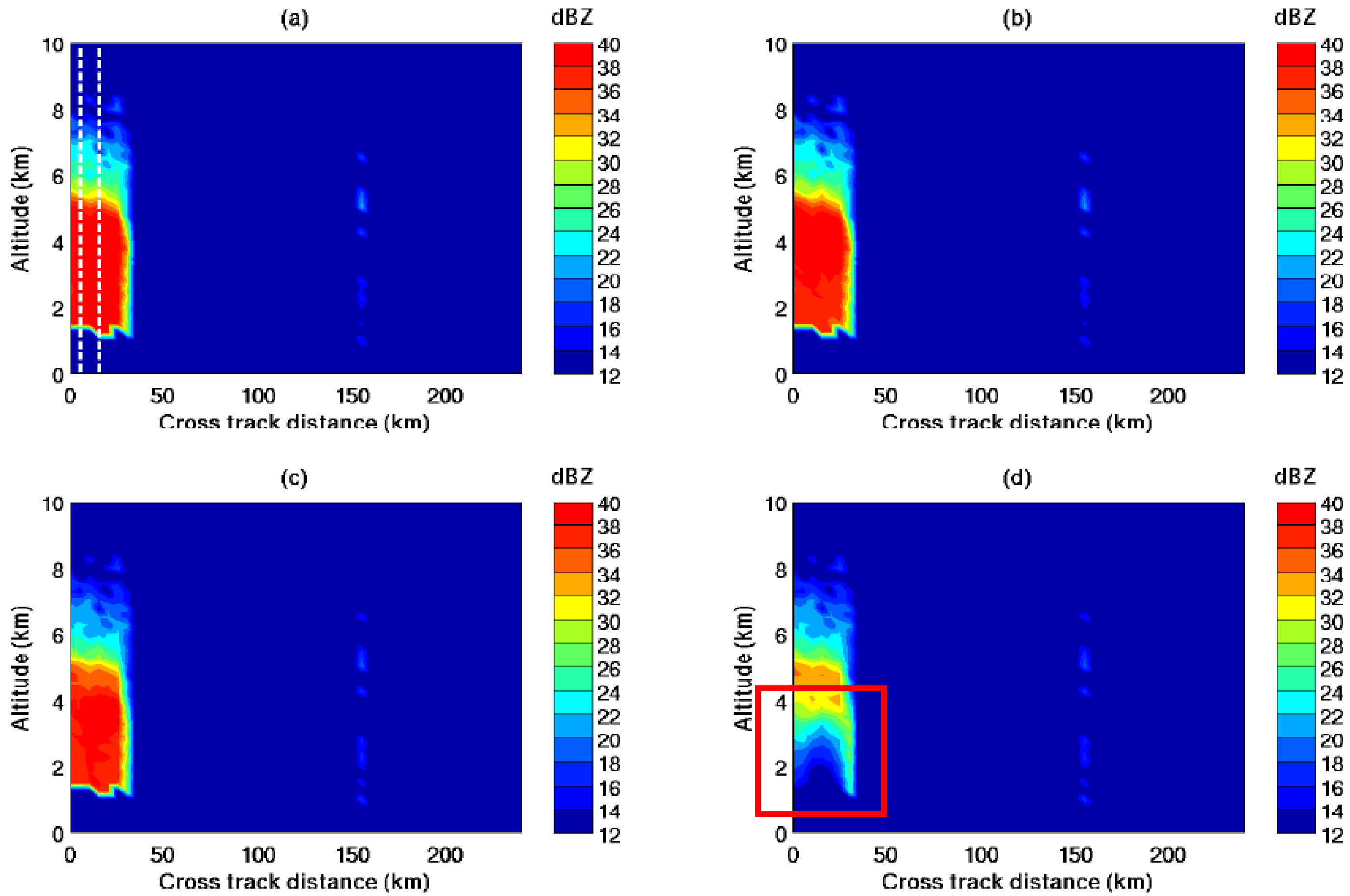
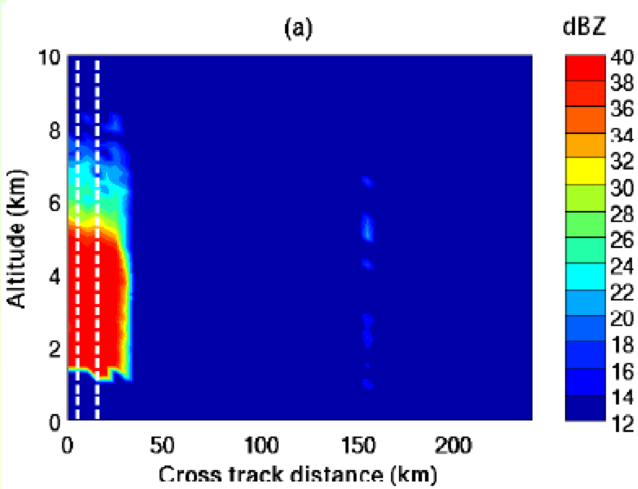


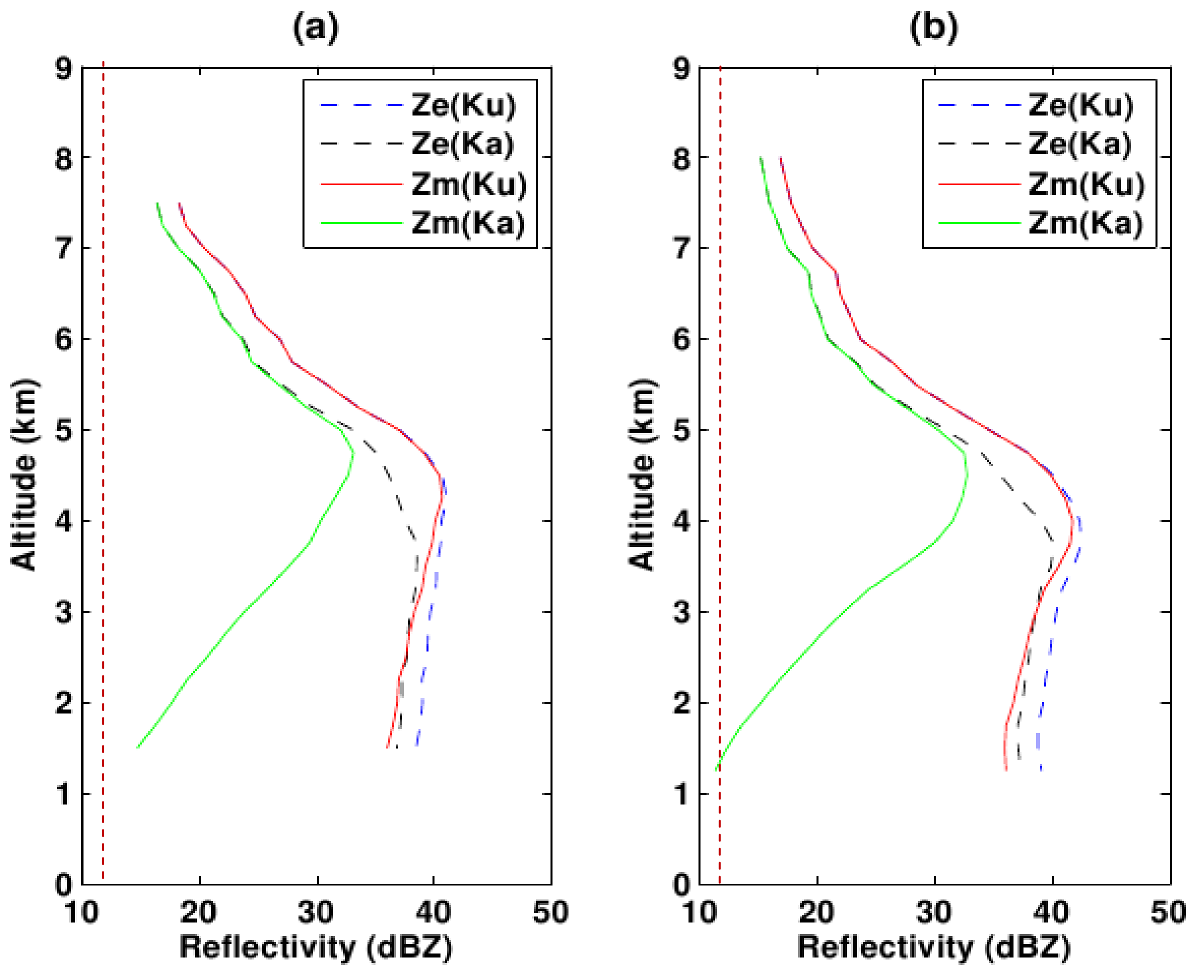
Ze(Ku) Ze(Ka)



Zm(Ku) Zm(Ka)

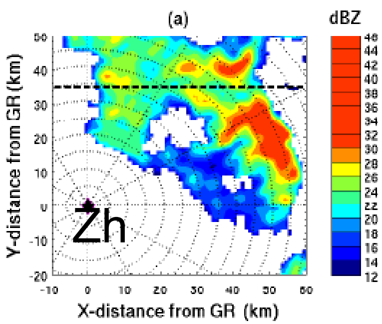
Simulation of Ka-band radar observations using Ku-band radar observations (PR)



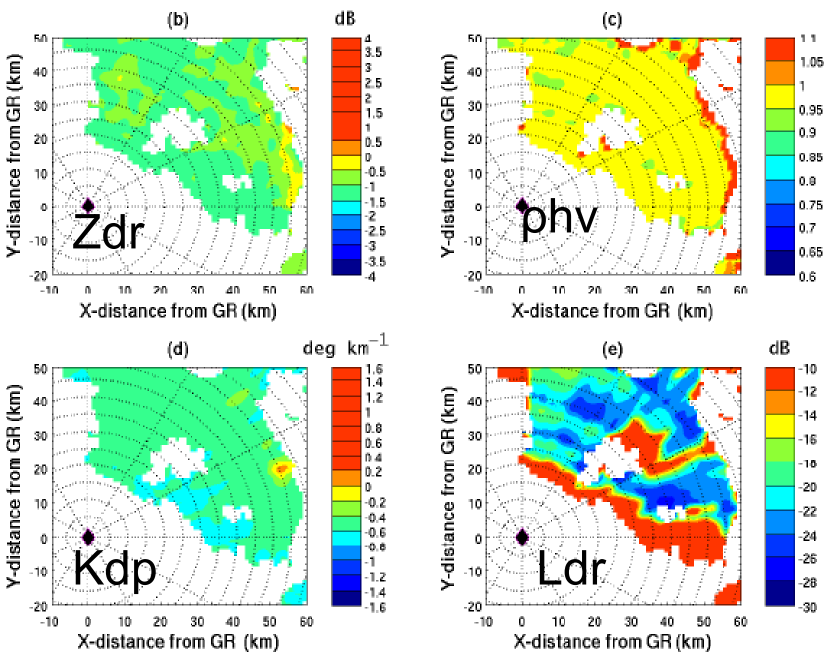


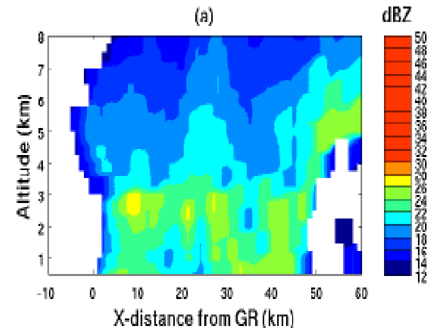
Simulation of Ku- and Ka-band radar observations using dual-polarization radar measurements

Five dual-polarization parameters:

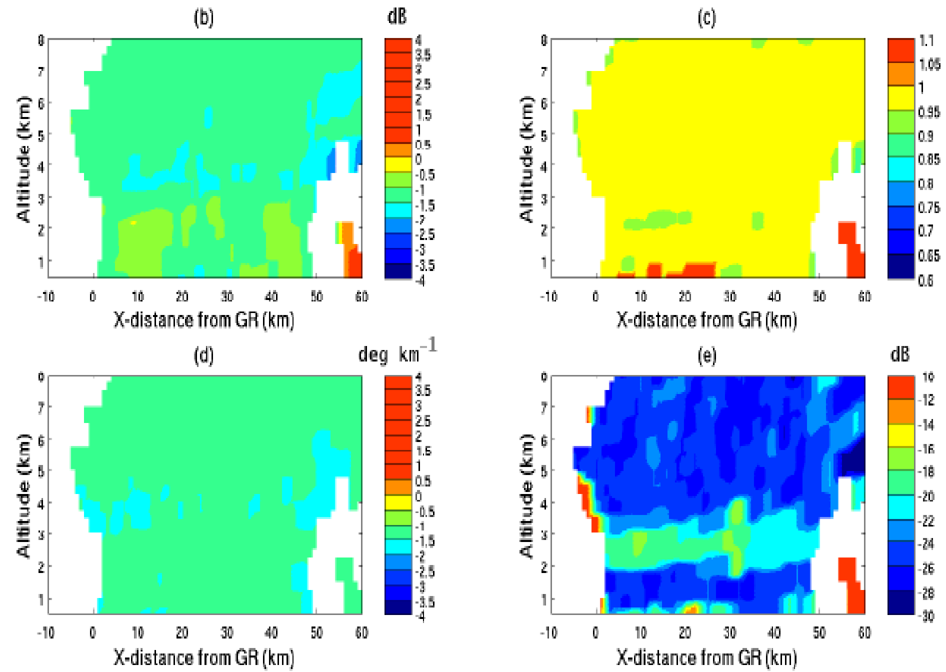


Horizontal Cross-section

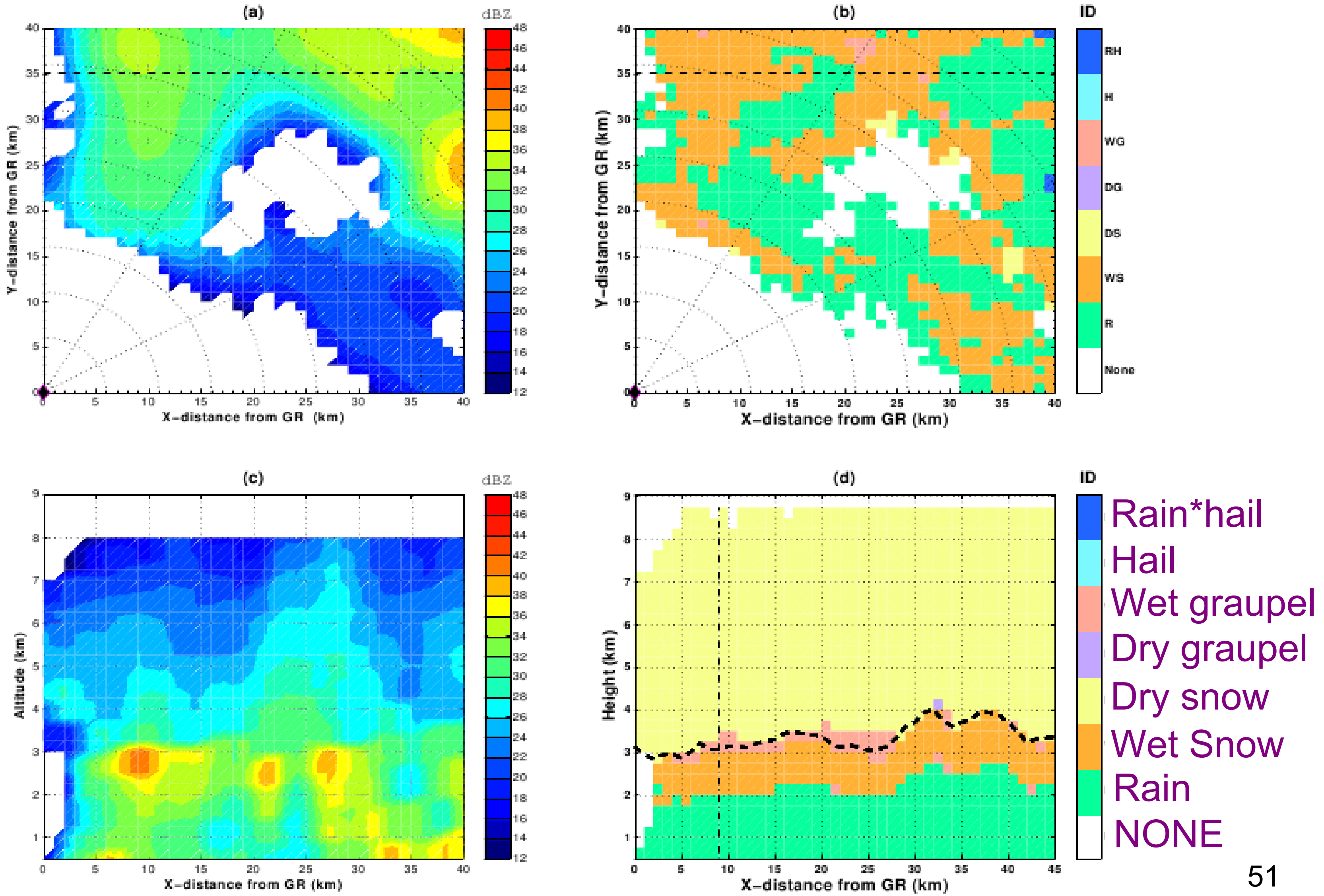




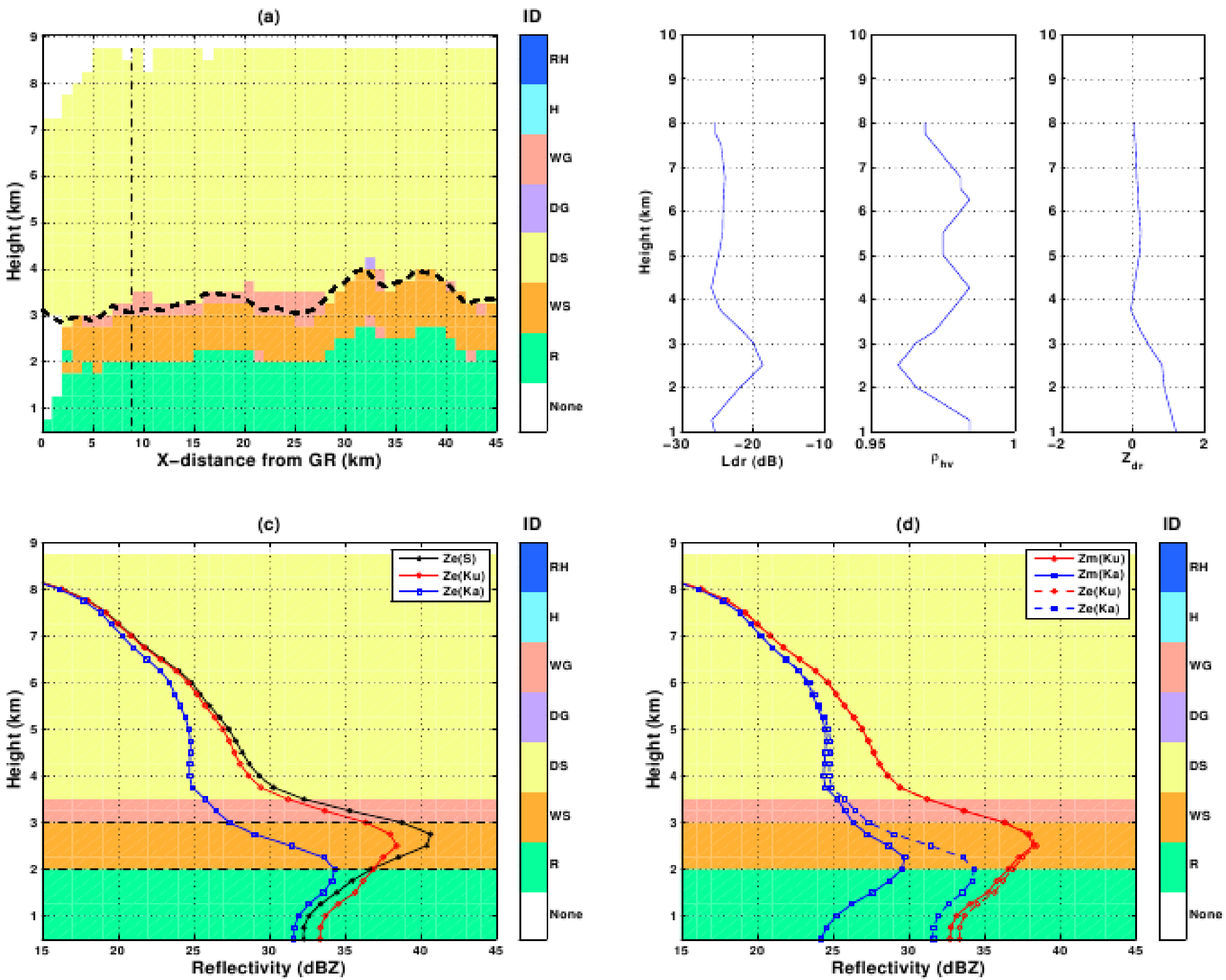
Vertical Cross-section



Simulation of Ku- and Ka-band radar observations using dual-polarization radar measurements



Simulation of Ku- and Ka-band radar observations using dual-polarization radar measurements



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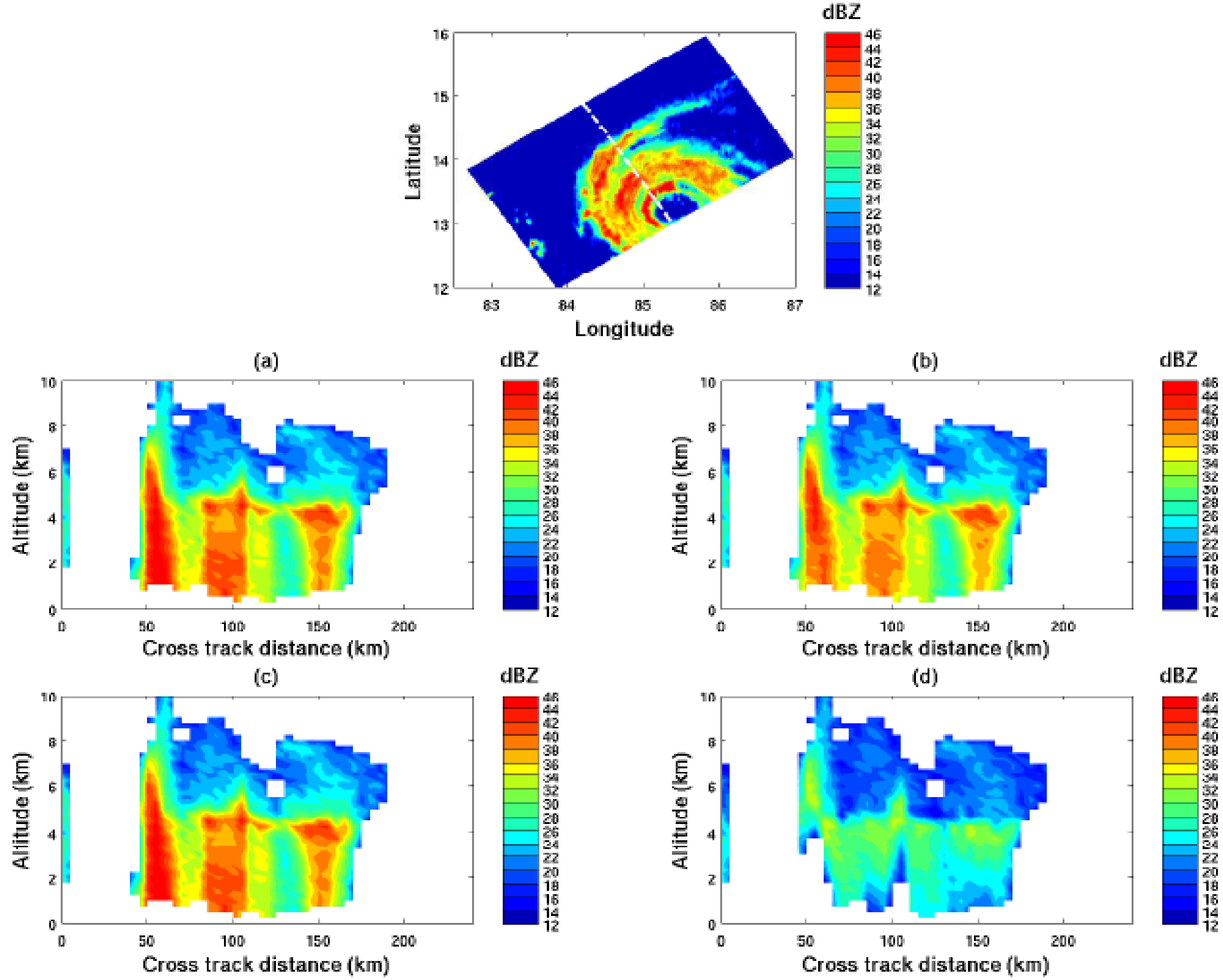
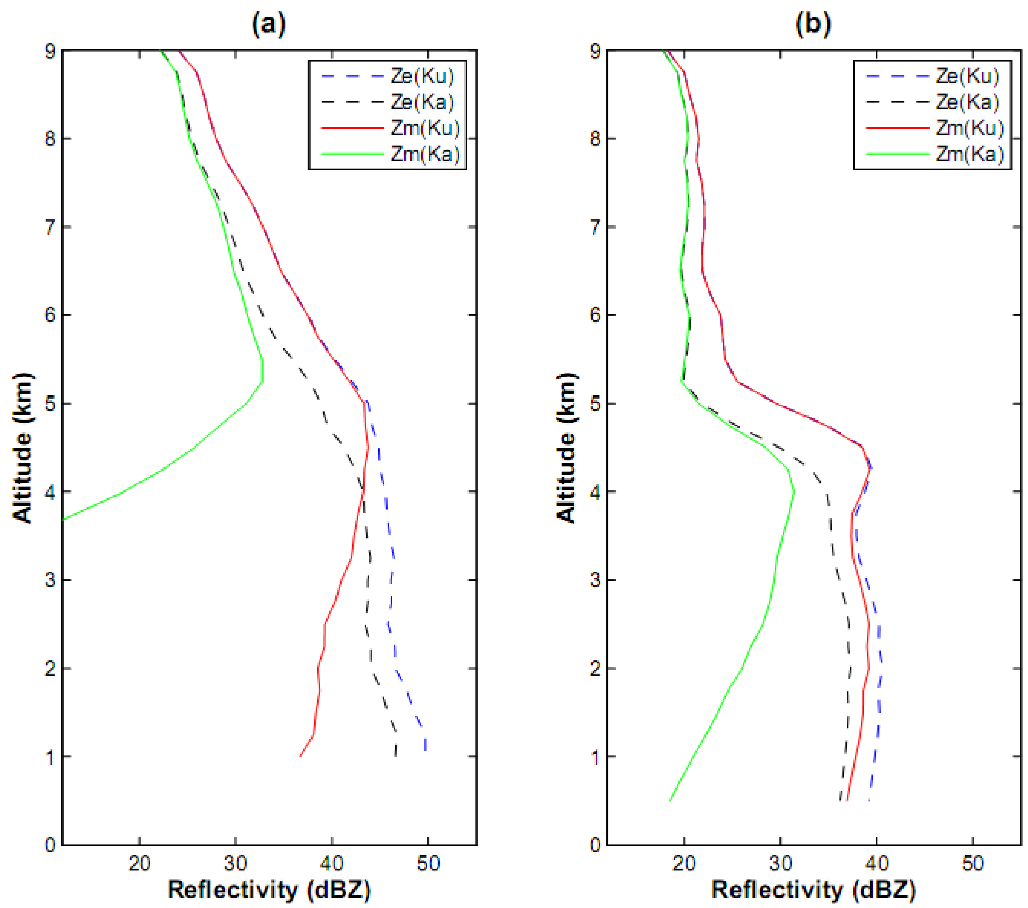
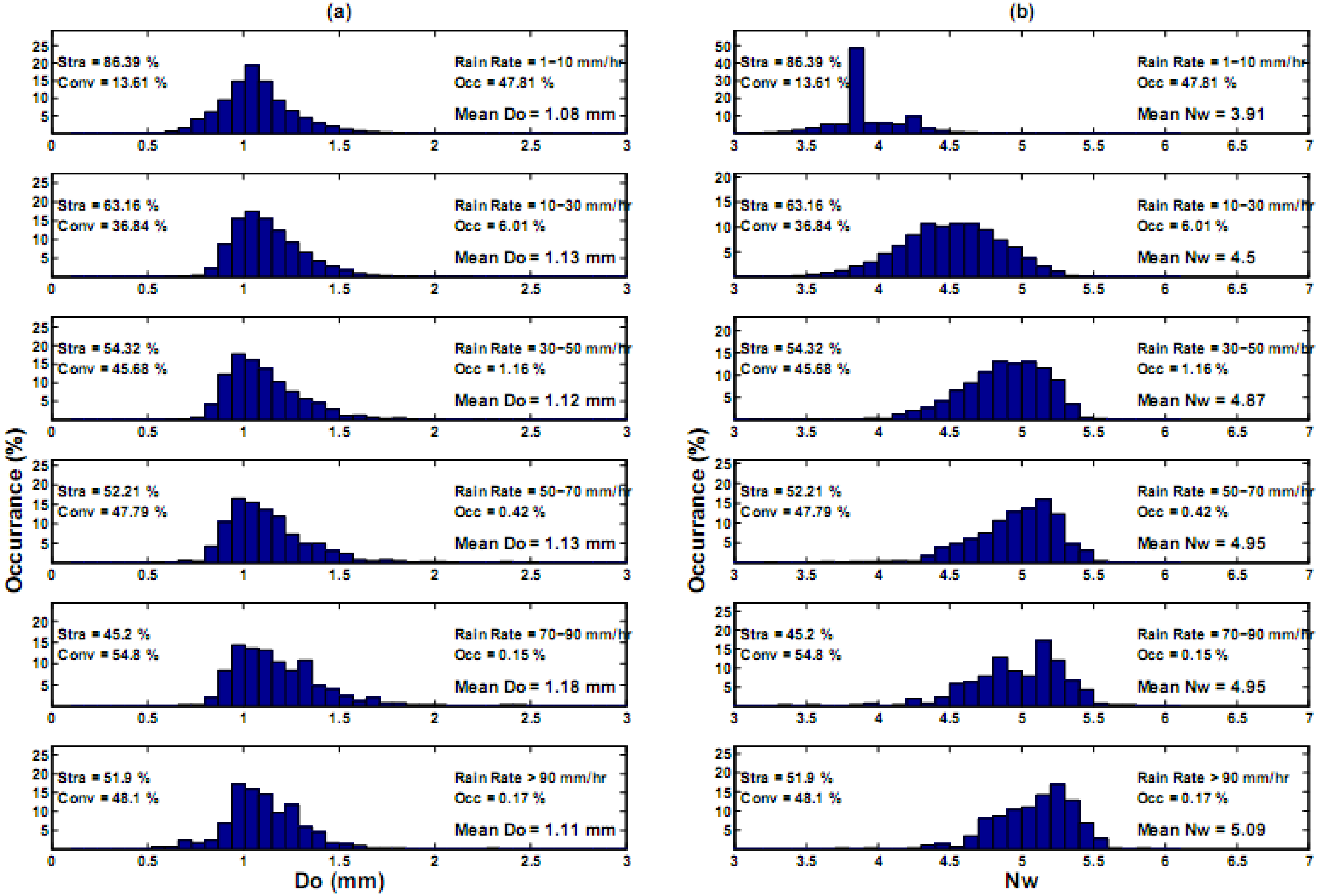
Simulation of Ka-band radar observations of tropical storm using TRMM-PR observation



Simulation of Ka-band radar observations of tropical storm using TRMM-PR observations



DSD parameters estimation of tropical storm using TRMM-PR observations



Summary

- Observations of precipitation from space are discussed.
- Theoretical computations of radar reflectivity and specific attenuation of precipitation particles at 3 different radar frequencies are described, and the model relations of the two are constructed.
- Characteristics precipitation observations from a spaceborne PR are illustrated, and characterization of the vertical profile of reflectivity are performed.
- Drop size distribution (DSD) parameters using the PR observations are estimated and statistics and global map are shown.

Summary

- Characteristics of observations of precipitation by spaceborne dual-frequency radar (DPR) and dual-frequency retrieval techniques are discussed.

- Development of microphysical models for simulation of precipitation observations based on airborne radar observations are described.

- Methodologies of simulation of precipitation observations are described and results of the simulation using TRMM-PR observations and dual-polarization ground-based radar measurements are shown.

- Simulation of tropical storms observation and DSD parameters estimations are shown.

Conclusions

- Theoretical relations between Ze and k and variability of Ze with frequency can be used to simulate radar observations of precipitation from one frequency to another.

- Simulation of Ka-band observations based on TRMM-PR observations suggests that TRMM-like retrieval algorithm can be used in Ka-band channel because of stronger PIA(Ka). However, a loss of signal may occur, when strong attenuation is present, thus preventing the use of dual-frequency algorithm.

- Phase-height transition information obtained via dual-polarization measurements can be used to improve the simulation scheme.

- The simulation of a High Plain precipitation regime (CSU-CHILL) suggests that dual-frequency can be always applicable for this precipitation regime.

- Simulation of Ka-band observations of tropical storms suggest that for most part of storm cell, dual-frequency algorithms are applicable.

Suggestion for future work

- More airborne data from a variety of precipitation regimes (maritime and continental) should be included to further generalize the microphysical model.

- A quantitative simulation of DPR observations using long-term observations of the TRMM-PR on a global scale should be performed so that statistical characterizations of a global diversity of DPR observations can be constructed.

- A quantitative testing of dual-frequency algorithms on the simulated observations of the DPR should be done so that their robustness and uncertainty can be statistically characterized.

- More simulation of DPR observations using ground-based radar dual-polarization measurement should performed. A more sophisticated microphysical models could be further implemented such as snow on the ground and hail, based on dual-polarization radar measurements.

Acknowledgements

- Dr. V. Chandrasekar (My advisor)
- Committee members: Dr. Anura. P. Jayasumana, Dr. Branislav Notaros, and Dr. Paul W. Mielke
- Dr. V. N. Bringi, Dr. M. Thurai
- Members of the Radar and Communication lab.

Thank you

Questions ?

Back up slides

Space-based radar observations of precipitation: What are their general characteristics ?

- TRMM-PR

- GPM-DPR