UNCERTAINTIES IN PRODUCTS DERIVED FROM RADAR

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Uncertainty in Radar Retrievals, Model Parameterizations, Assimilated Data and In-situ Observations: Implications for the Predictability of Weather
October 31 – November 2, 2018, Norman

Layout of the talk

- Polarimetric microphysical retrievals in rain
- Polarimetric microphysocal retrievals in ice / snow
- Multifrequency polarimetric radar retrievals

Two possible ways to optimize microphysical parameterization of NWP models

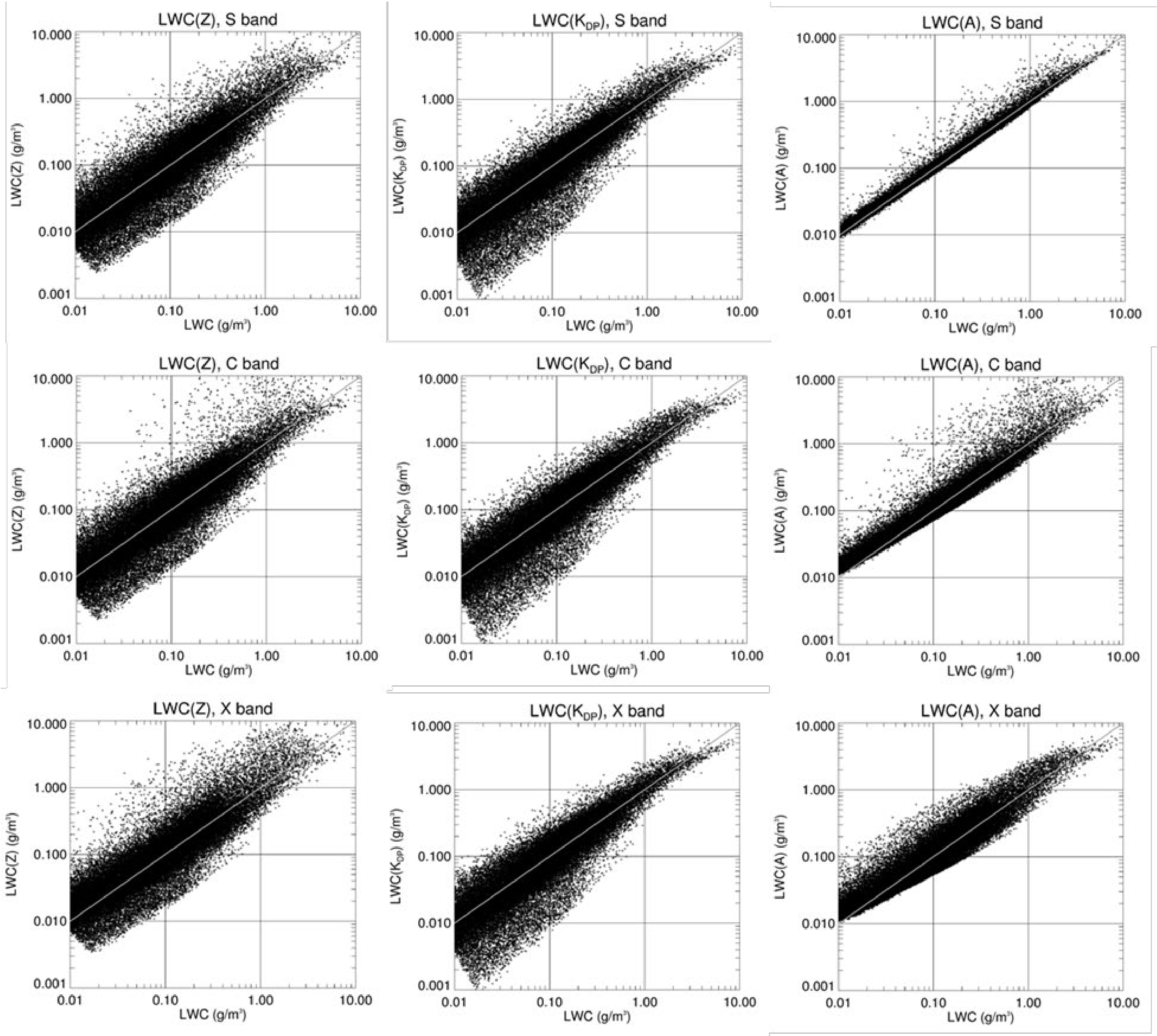
- Radar microphysical retrievals
- Forward radar operators

Two sources of errors in radar microphysical retrievals

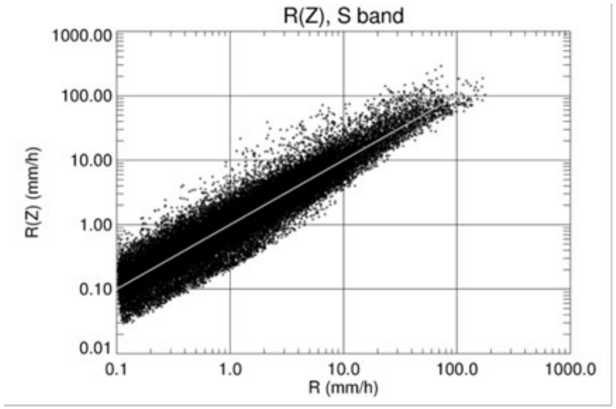
- Errors due to natural variability of microphysical properties of hydrometeors
- Radar measurement errors

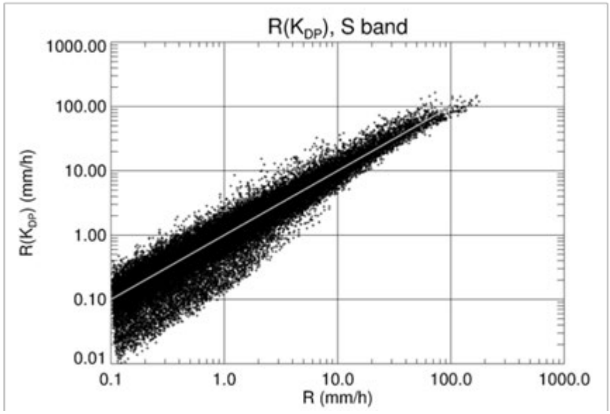
Polarimetric microphysical retrievals in rain

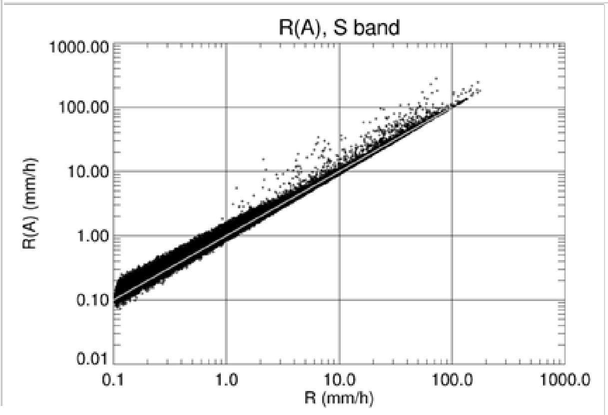
Estimation of liquid water content (LWC)



Estimation of rain rate (R)
S band

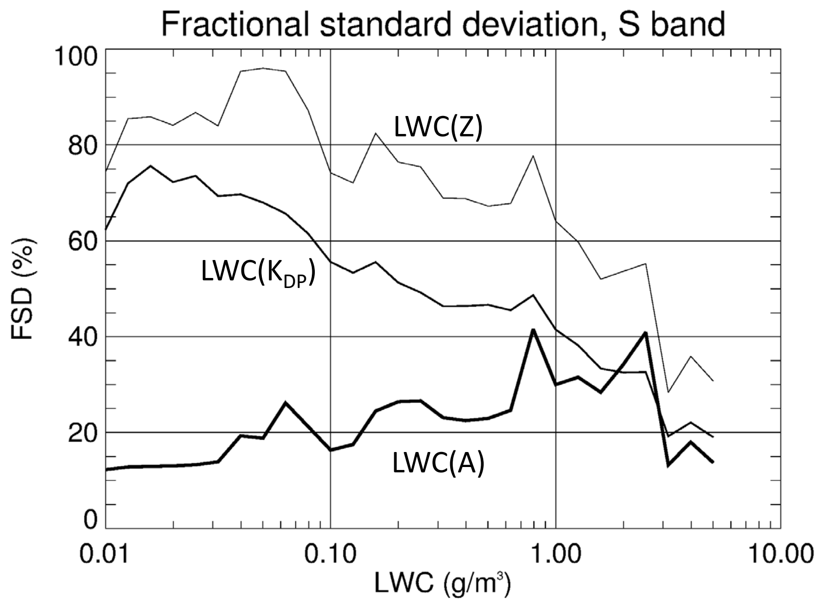






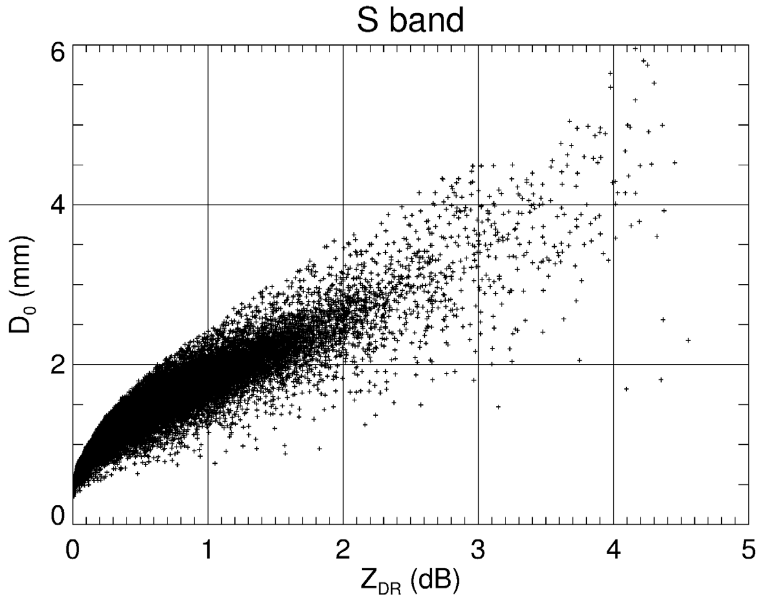
- The estimates of LWC and R from specific attenuation A are much less affected by the DSD variability than the Z- or K_{DP}-based estimates
- The A-based estimates are immune to radar miscalibration, attenuation, partial bream blockage, and impact of wet radome
- Cloud modeling community should utilize specific attenuation for estimation of LWC and R following its successful use for the WSR-88D QPE. R(A) and LWC(A) can be made a routine products on the WSR-88D network

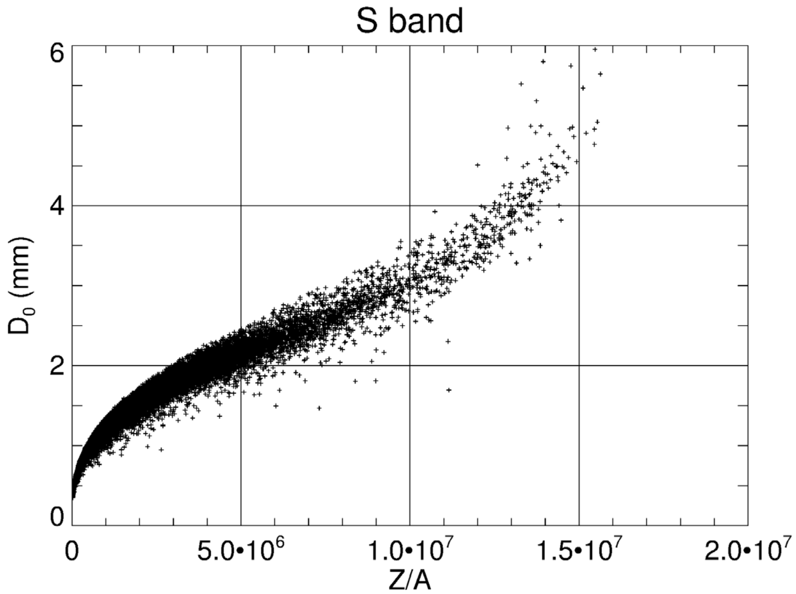
Fractional standard deviation of the LWC estimate



- The accuracy of the LWC estimate is a function of LWC varying between 15 and 25% for lower LWC and not exceeding 40% for larger LWC
- The accuracy of the LWC(A) estimator is 4 – 5 times better than the one for the R(Z) estimator for lower LWC

Estimation of the median diameter of raindrops D_0





- Differential reflectivity Z_{DR} is commonly used for estimation of D_0
- FSD of the estimate related to the DSD variability is 10 – 12 %
- Measurement errors of Z_{DR} (as low as 0.1 – 0.2 dB) may produce much larger impact on the accuracy of the D_0 estimate than the DSD variability, especially for lower values of D_0
- Combined use Z and A may offer a very attractive alternative to the Z_{DR} – based estimator. This requires further exploration

Polarimetric microphysical retrievals in ice / snow

Ice microphysical retrievals

- **All existing ice microphysical retrievals are based on the use of radar reflectivity Z measured at a single or multiple radar frequencies**

- **The IWC(Z) relations are notoriously inaccurate because they are strongly parameterized by (a) mass-weighted diameter D_m , (b) total concentration N_t , and (c) density (or degree of riming)**

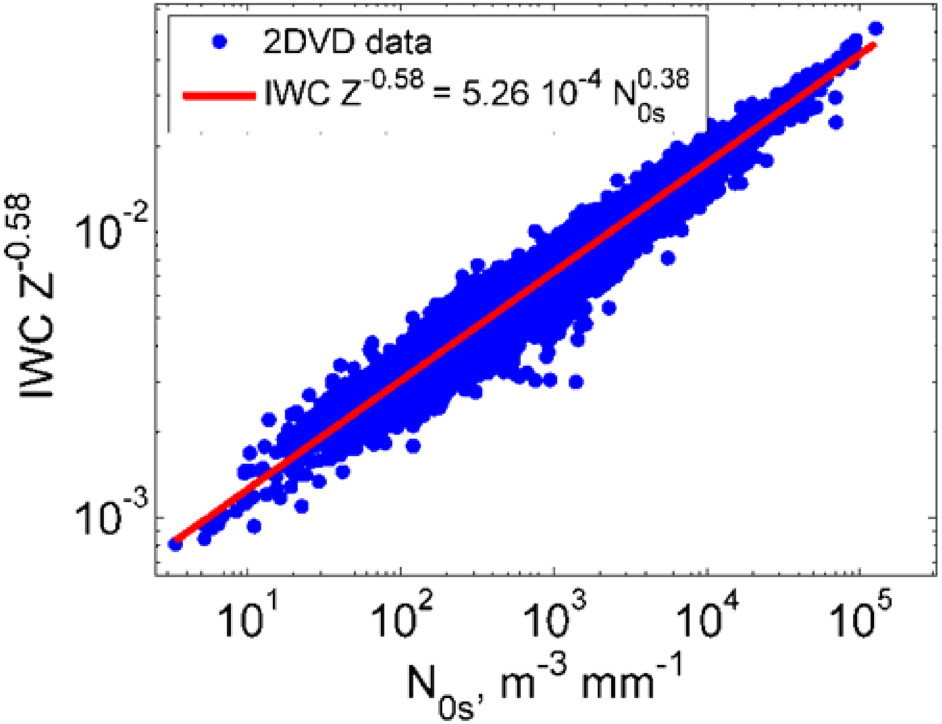
$$N(D) = N_{0s} \exp(-\Lambda_s D) \qquad \rho(D) = \alpha D^{-1} \qquad \Lambda_s = 4 / D_m$$

$$IWC = 3.81\,10^{-4} \alpha^{-0.2} N_{0s}^{0.4} Z^{0.6} \qquad IWC = 3.09\,10^{-3} \frac{Z}{\alpha D_m^2}$$

- D_m varies 2 orders of magnitude
- N_t varies 4 orders of magnitude
- α changes at least by a factor of 4

Variability of the intercept in the IWC(Z) power-law relation as a function of N_{0s} (Bukovcic et al. 2018)

Disdrometer snow measurements in Oklahoma



Basic formulas for polarimetric ice retrievals

$$Z = \frac{|K_\mathrm{i}|^2}{|K_\mathrm{w}|^2} \frac{1}{\rho_\mathrm{i}^2} \int \rho_\mathrm{s}^2(D) D^6 N(D) dD$$

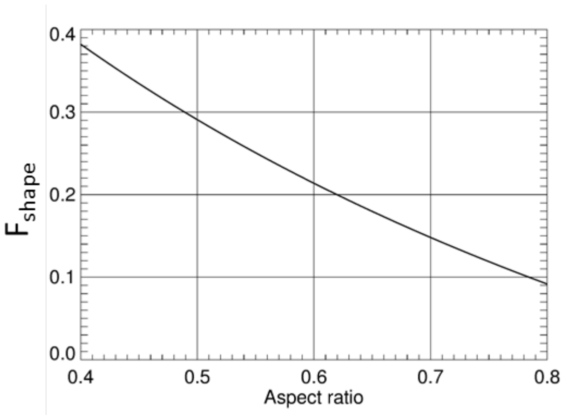
$$K_\mathrm{DP} = \frac{0.27\pi}{\lambda \rho_i^2} \left(\frac{\varepsilon_\mathrm{i} - 1}{\varepsilon_\mathrm{i} + 2} \right)^2 \int F_{shape} F_{orient} \rho_\mathrm{s}^2(D) D^3 N(D) dD$$

Z is proportional to the 4th moment of snow SD whereas K_{DP} is proportional to its 1st moment

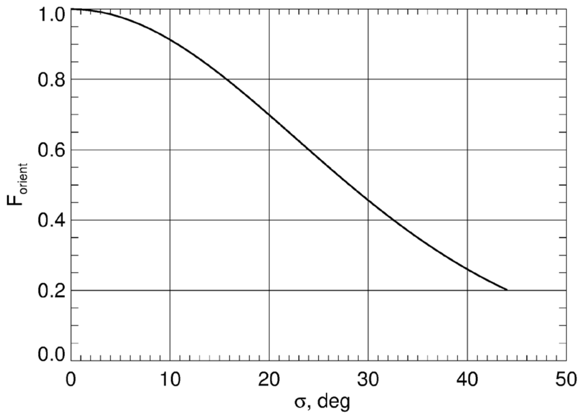
Exponential size distribution

$$Z = 5.30\,10^{-3} \alpha^2 N_\mathrm{0s} D_\mathrm{m}^5$$

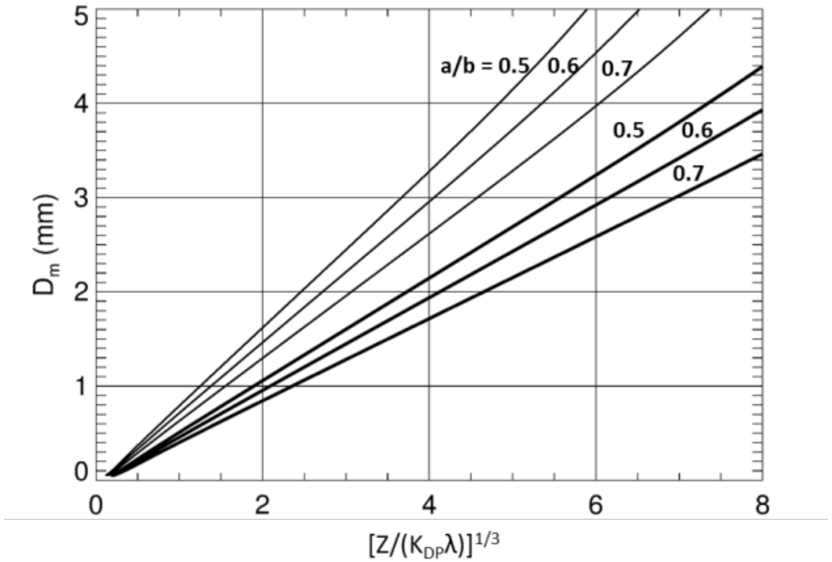
$$K_\mathrm{DP} = 1.02\,10^{-2} F_{shape} F_{orient} \frac{\alpha^2 N_\mathrm{0s}}{\lambda} D_\mathrm{m}^2$$

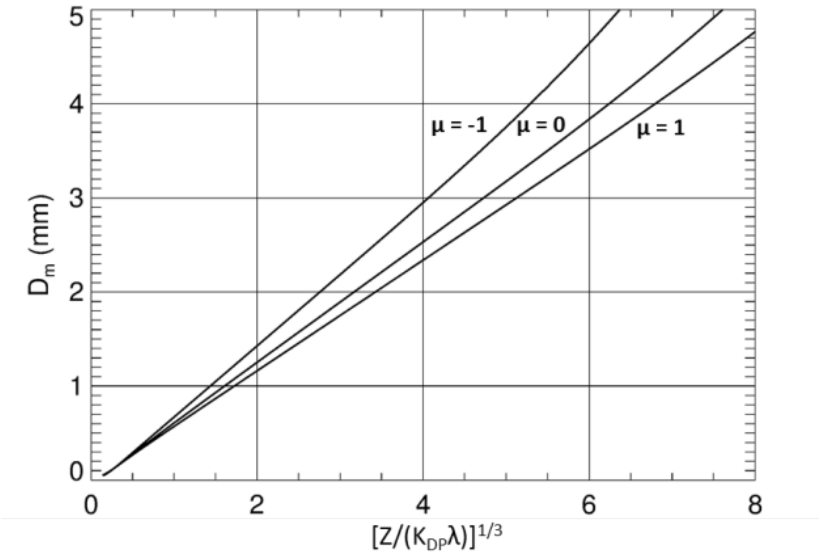


$$\frac{Z}{K_\mathrm{DP} \lambda} = 0.520 \frac{D_\mathrm{m}^3}{F_{shape} F_{orient}}$$



Median volume diameter as a function of $[Z/(K_{DP}\lambda)]^{1/3}$





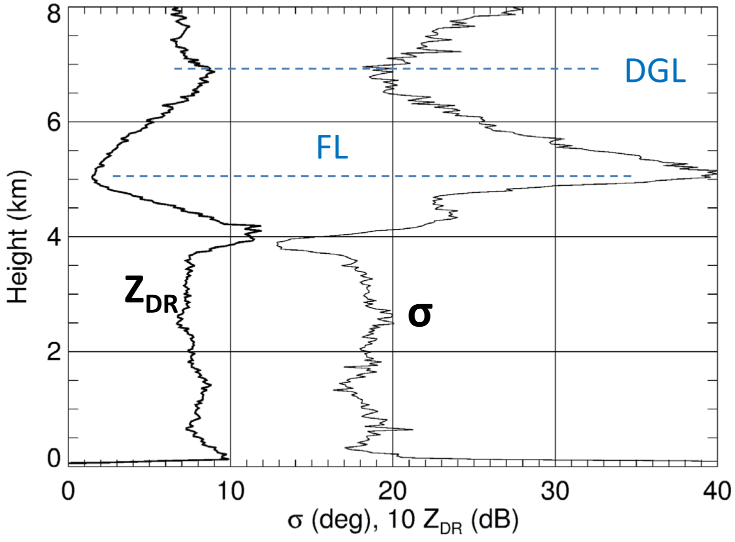
Thin lines – σ = 10°

Thick lines – σ = 40°

$$\sigma = \frac{180}{\pi} \frac{L_{dr}^{1/2}}{(1 + Z_{dr}^{-1} - 2\rho_{hv} Z_{dr}^{-1/2})^{1/2}}$$

The width of the canting angle distribution σ in ice typically varies between 10 and 40°. This is a serious source of uncertainty

Radar-retrieved vertical profile of σ

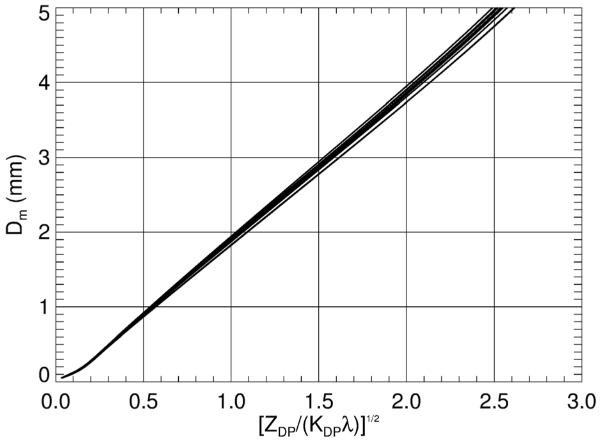


Utilization of the Z_{DP}/K_{DP} ratio for estimation of D_m

$$Z_{DP} = Z_h - Z_v$$

$$h = cL^d$$

Crystal habit	c	d
1. Dendrites	0.038	0.377
1. Solid thick plate	0.230	0.778
1. Hexagonal plates	0.047	0.474
1. Solid columns (L/h < 2)	0.637	0.958
1. Solid columns (L/h > 2)	0.308	0.927
1. Hollow columns (L/h < 2)	0.541	0.892
1. Hollow columns (L/h > 2)	0.309	0.930
1. Long solid columns	0.128	0.437
1. Solid bullets (L < 0.3 mm)	0.250	0.786
1. Hollow bullets (L > 0.3 mm)	0.185	0.532
1. Elementary needles	0.073	0.611



$$D_{\mathrm{m}} = -0.1 + 2.0\eta \qquad \eta = \left(\frac{Z_{\mathrm{DP}}}{K_{\mathrm{DP}}\lambda}\right)^{1/2}$$

$$\gamma = \alpha D_m^2 \approx 0.78\eta^2 = 0.78\frac{Z_{DP}}{K_{DP}\lambda}$$

$$\log(N_{\mathrm{t}}) = 0.1Z(\mathrm{dBZ}) - 2\log(\gamma) - 1.33$$

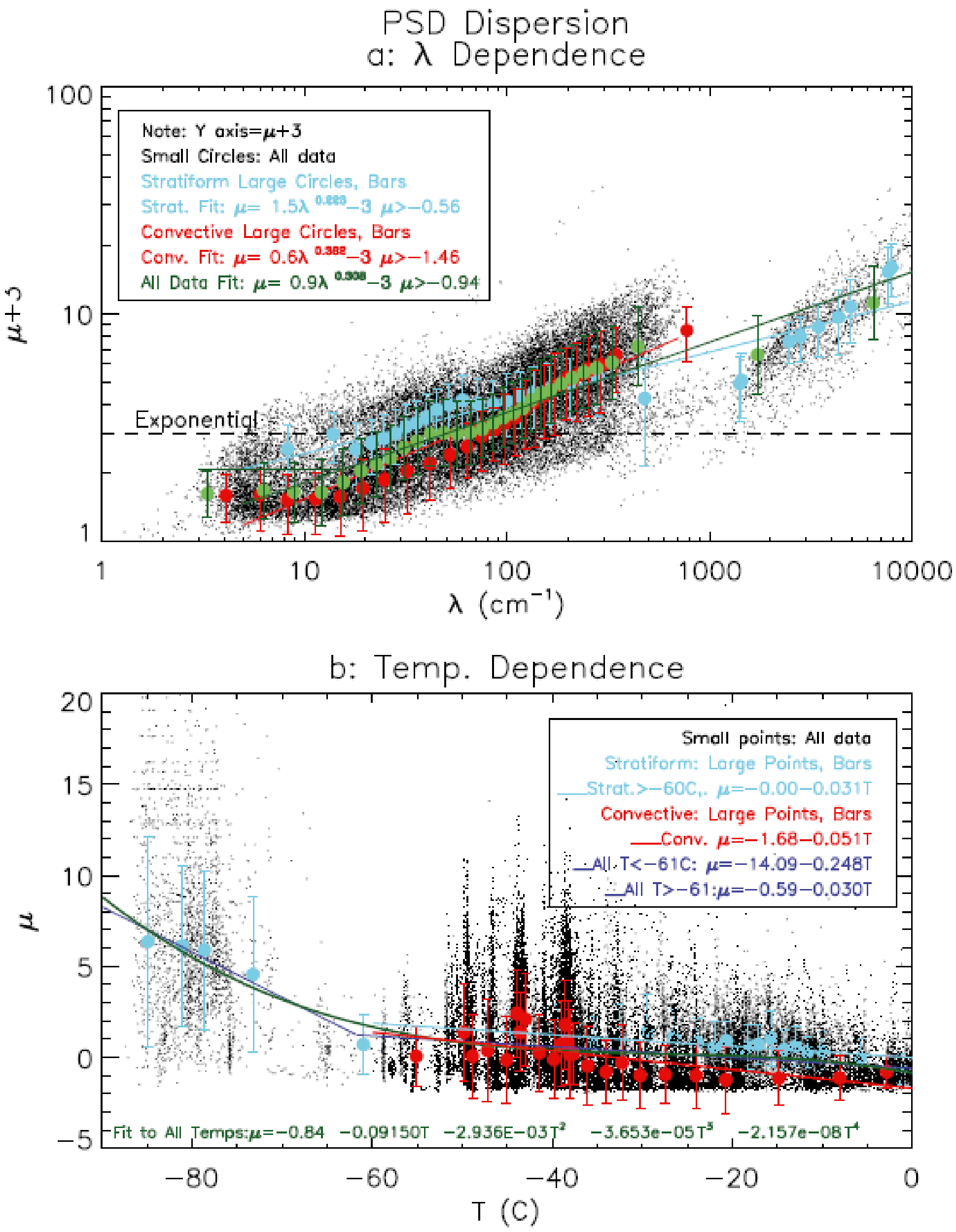
$$IWC \approx 4.010^{-2}\frac{K_{DP}\lambda}{1 - Z_{dr}^{-1}}$$

The Z_{DP}/K_{DP} ratio provides estimate of D_m which is immune to the particles shape and orientation

Sensitivity to the microphysical variability of ice hydrometeors

- The suggested estimates of IWC and D_m are not sensitive to the variability of number concentration
- The suggested relations have been optimized for exponential size distribution of ice, hence they may need to be adjusted for gamma SD (particularly for negative shape factor μ).
- The FSD of the IWC and D_m estimates is within 20 % if $-1 < \mu < 1$
- IWC tends to be overestimated and D_m - underestimated for $\mu < -1$
- The $D_m(K_{DP},Z)$ estimate is immune to the variations of ice density (or m – D relations) but is sensitive to the shape and orientations of ice particles
- The $D_m(K_{DP},Z_{DP})$ relation is immune to the variability of shapes and orientations but is sensitive to ice density (or degree of riming).

General dependencies of the shape factor μ



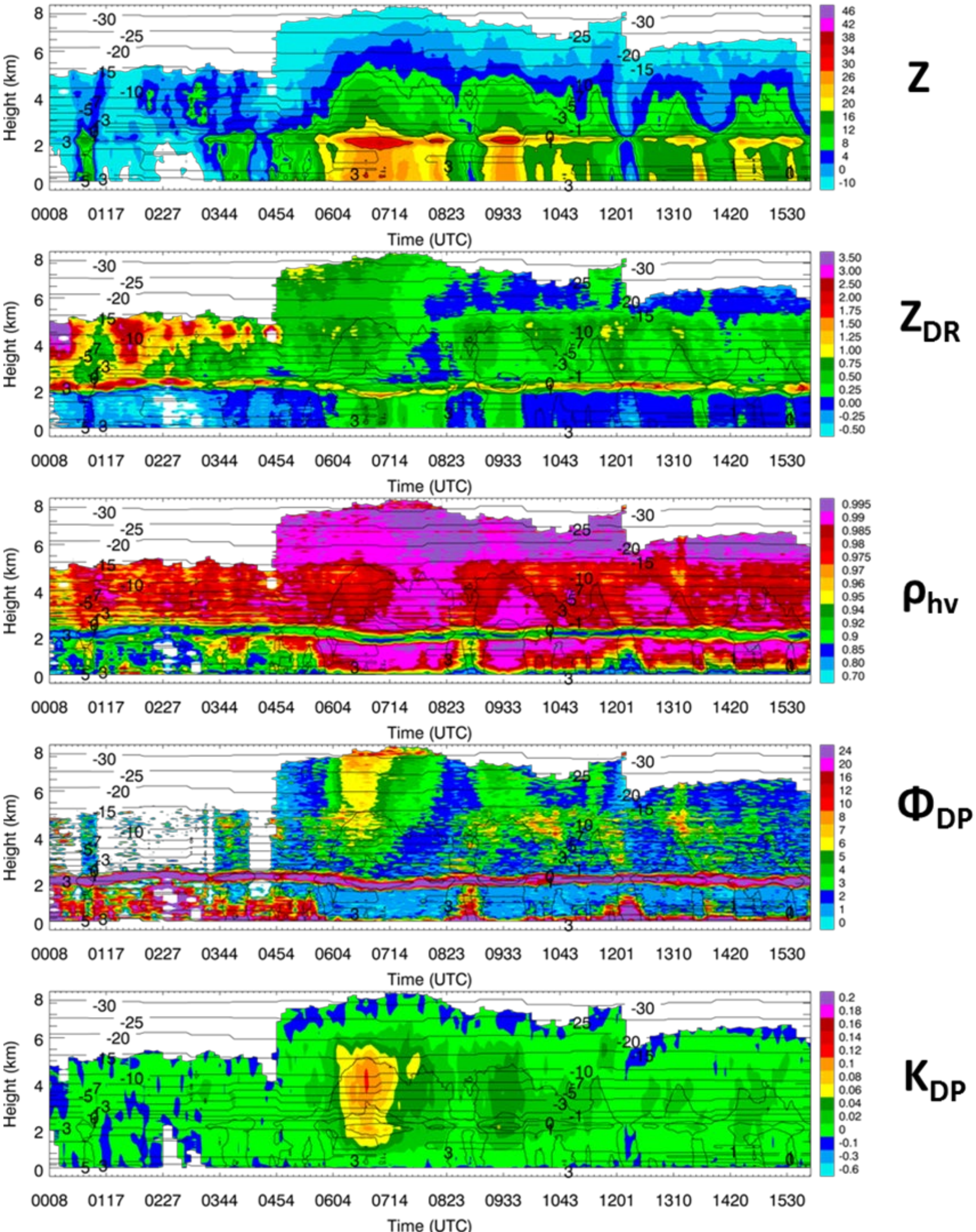
Heymsfield et al. 2013

- Factor μ tends to be negative as a result of aggregation
- Average factor μ is close to 0 (exponential SD) within the DGL

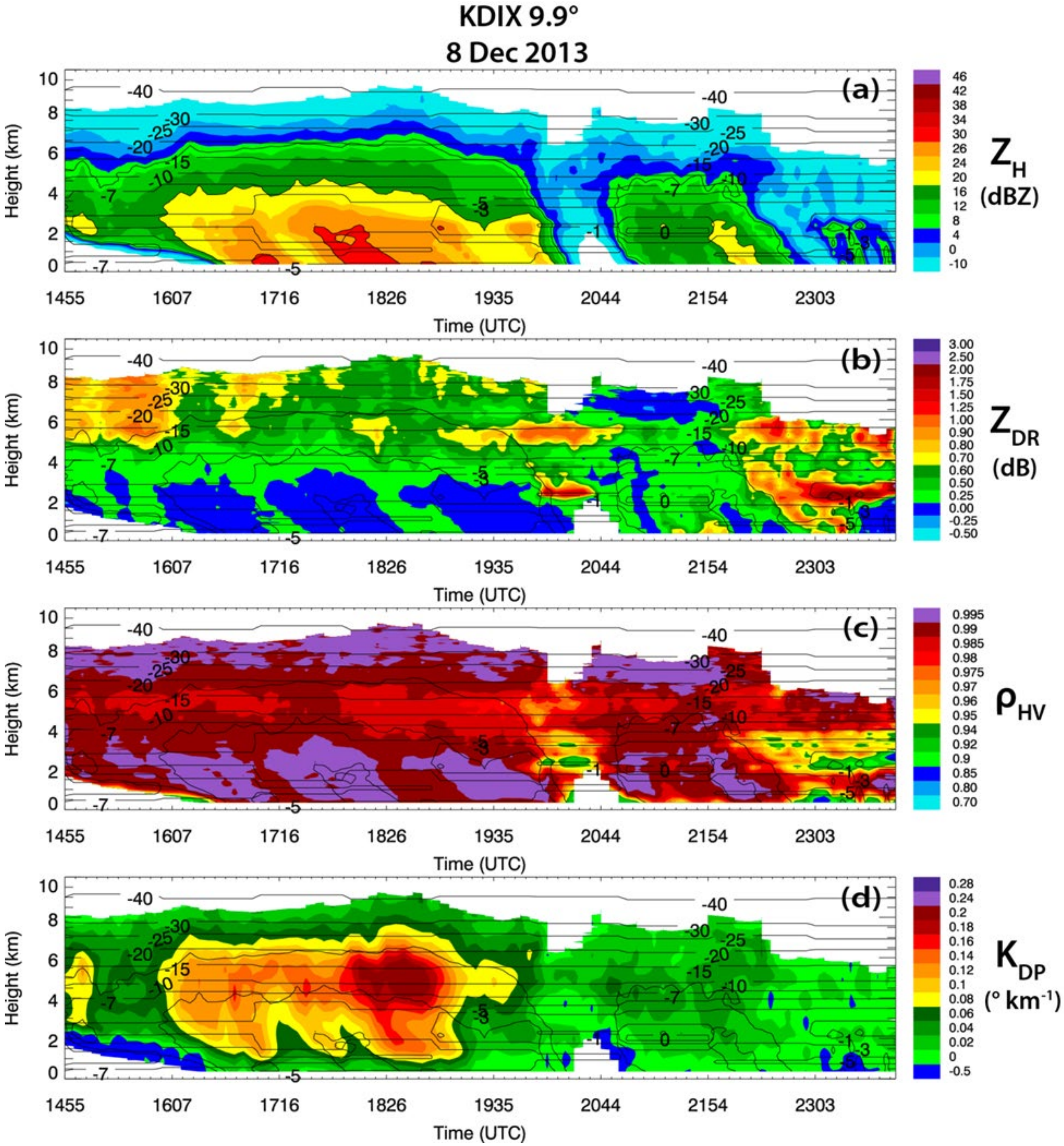
The impact of measurements errors of K_{DP} and Z_{DR} (Z_{DP})

- Statistical errors of the point measurements of K_{DP} and Z_{DR} are prohibitively large. SD(D_m) > 70% if $K_{DP} < 0.05$ deg/km; SD(D_m) > 25% if $Z_{DR} < 0.2$ dB
- Aggressive spatial averaging of K_{DP} and Z_{DR} is required to obtain their meaningful values which is inevitably results in the degradation of spatial resolution
- Various techniques for processing and presentation of polarimetric radar data have been developed recently (QVP, range-defined QVP, CVP, 4D-grid) to reveal polarimetric signatures in ice / snow, to reduce statistical errors in polarimetric radar variables, and improve their vertical resolution
- The best results are achieved in the dendritic growth layer and the worst are just above the freezing level where K_{DP} and Z_{DR} signatures almost vanish as a result of strong aggregation of dry snowflakes

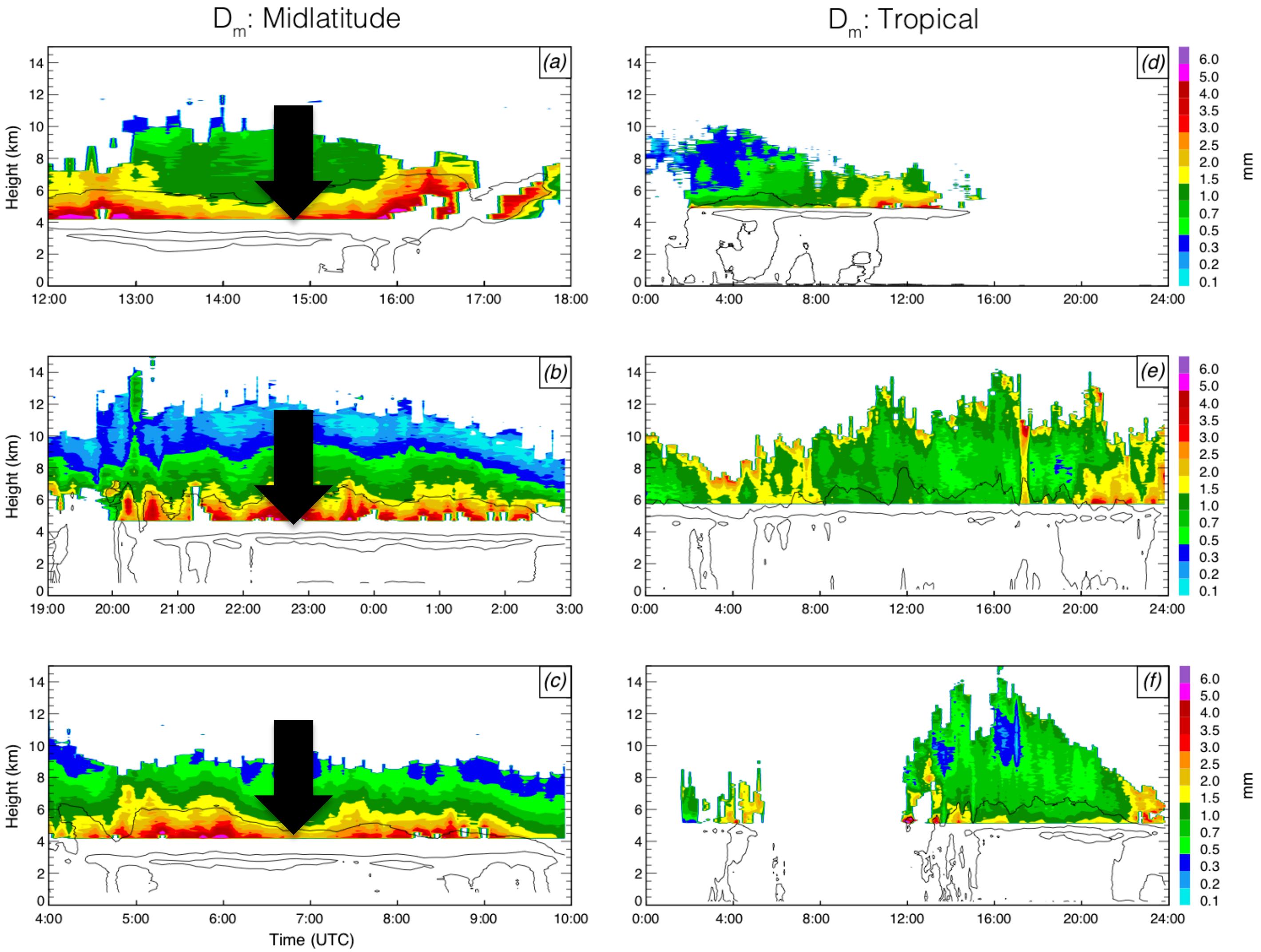
QVP example for stratiform rain



QVP example for snow



Midlatitude vs. Tropical MCSs



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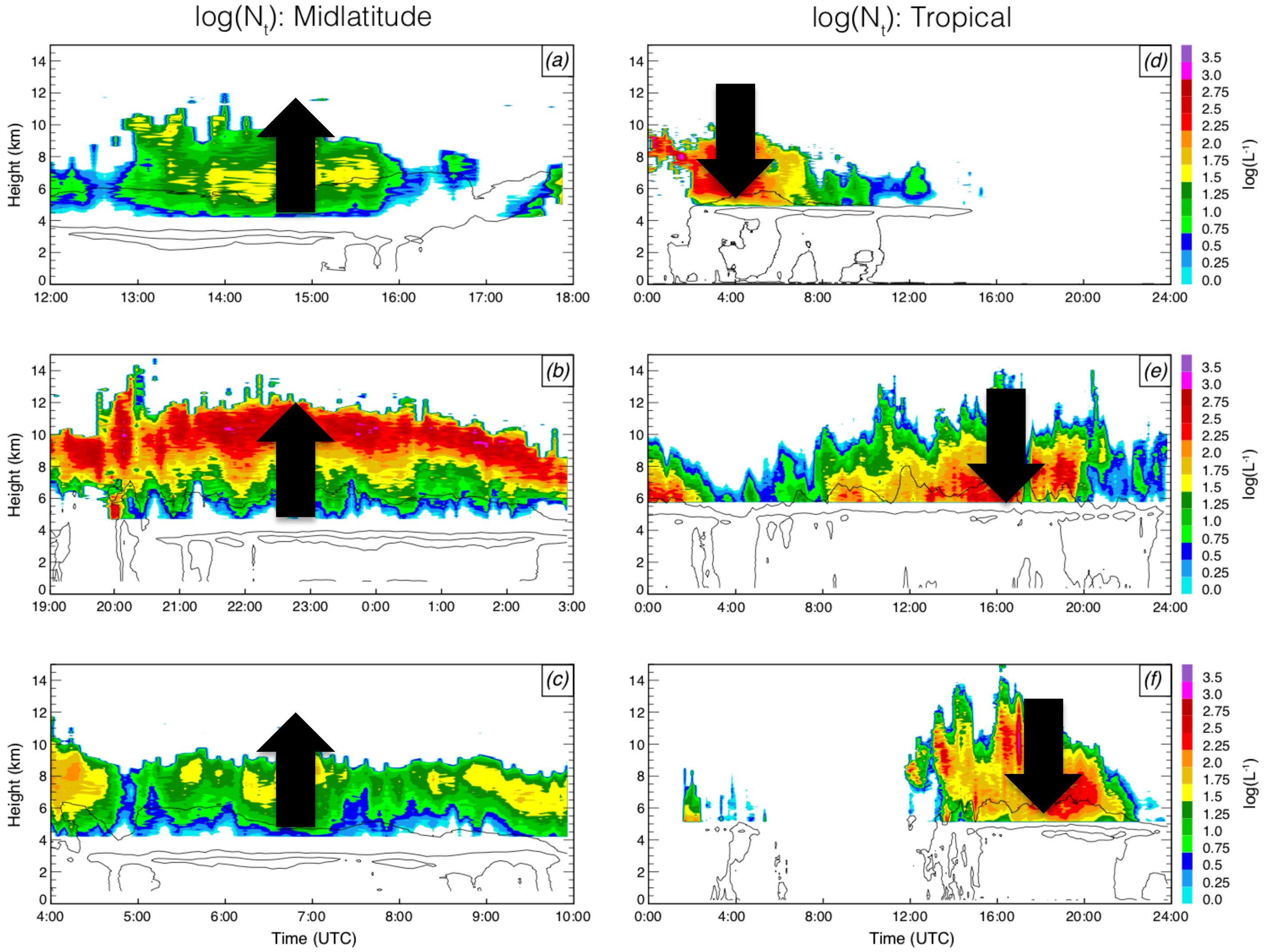

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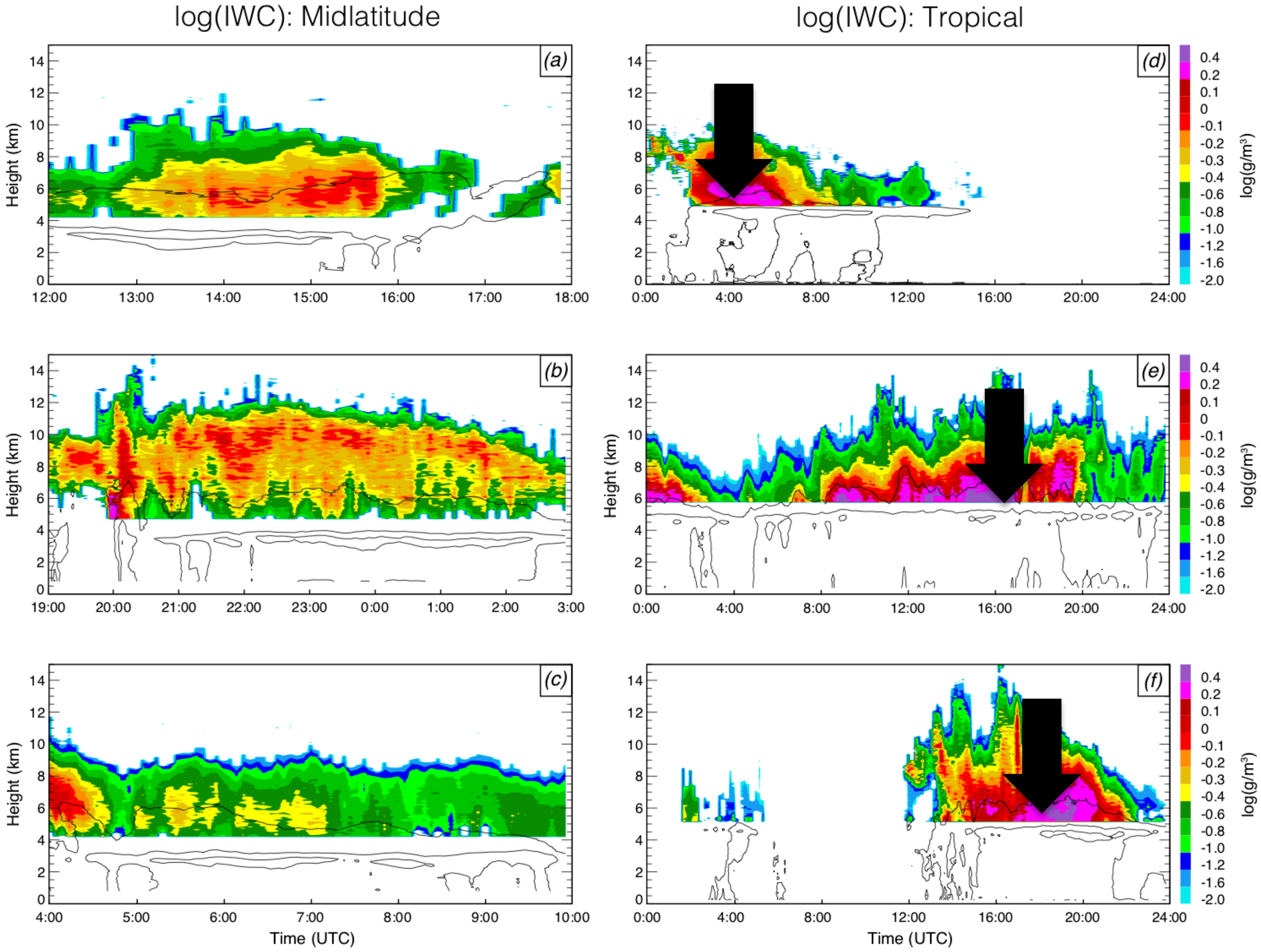

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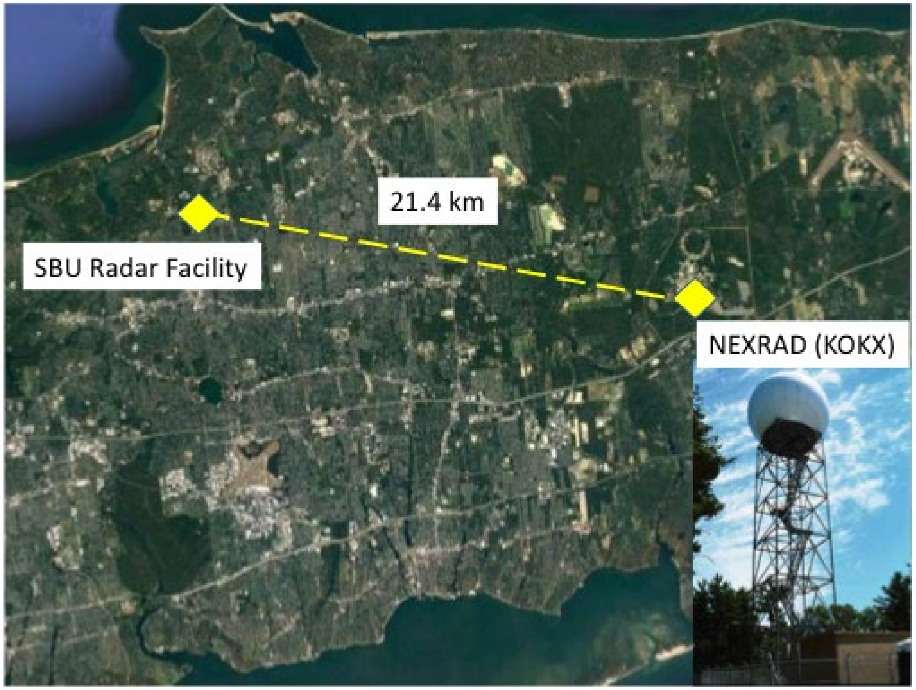
Dual-frequency polarimetric radar measurements with Ka-band and S-band radars

Courtesy of Pavlos Kollias and Mariko Oue

KASPR

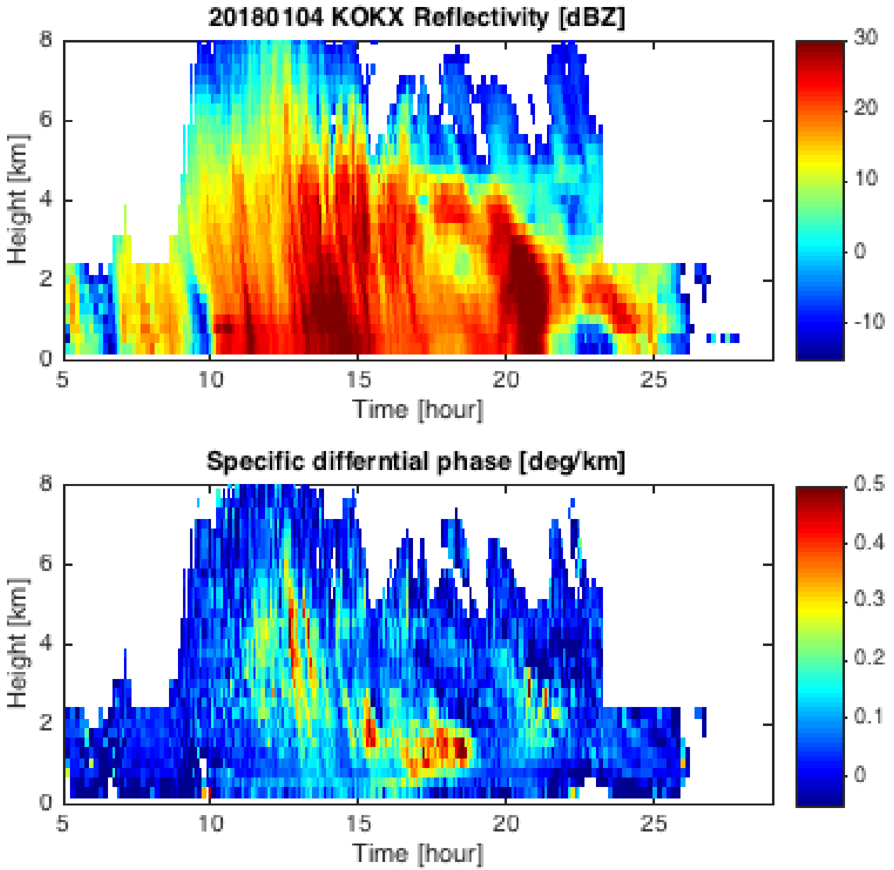
WSR-88D



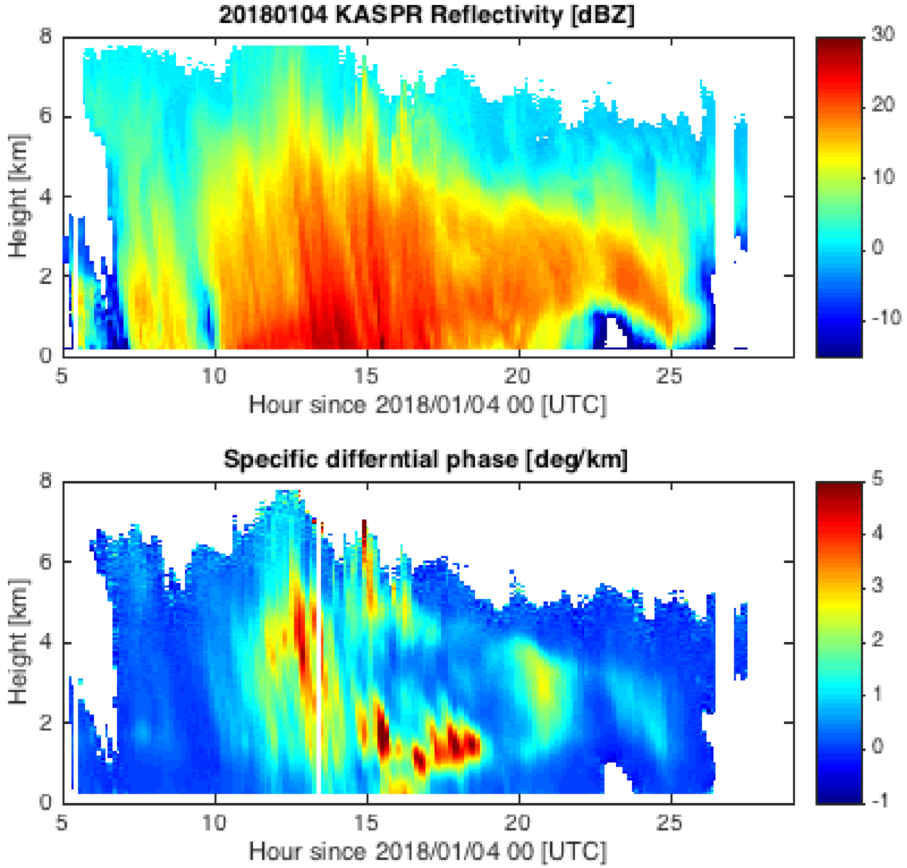
SBU – Stony Brook University

KASPR – Ka-band scanning polarimetric radar

KOKX WSR-88D

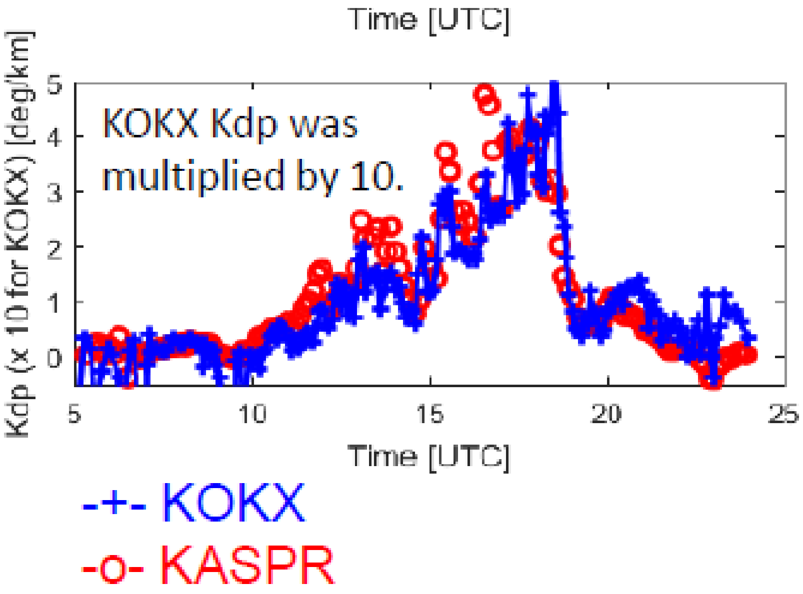


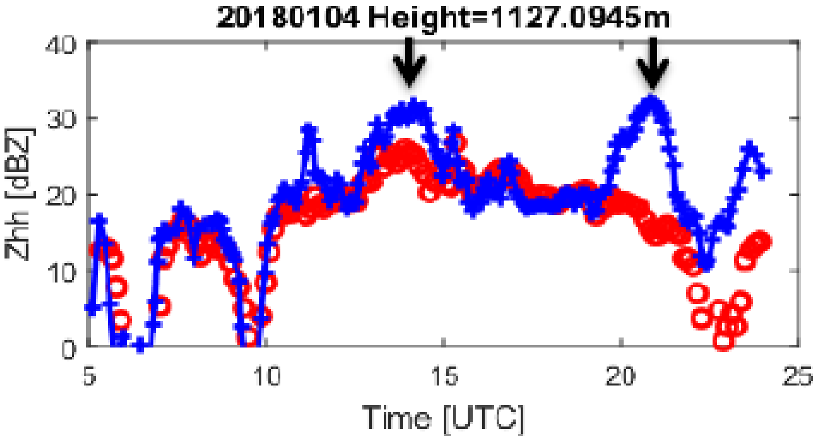
KASPR

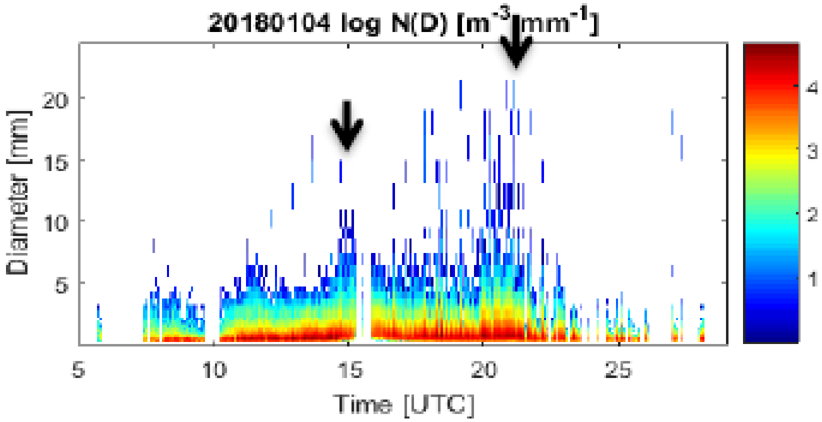


KOKX and KASPR Kdps are almost perfectly matched
The difference between Z(Ka) and Z(S) are related to (1) resonance scattering, (2) attenuation, and (3) differences in sensitivities and sampling volumes

Comparison of Z and Kdp measured by KASPR and KOKX at 1 km altitude


KOKX Kdp was multiplied by 10.



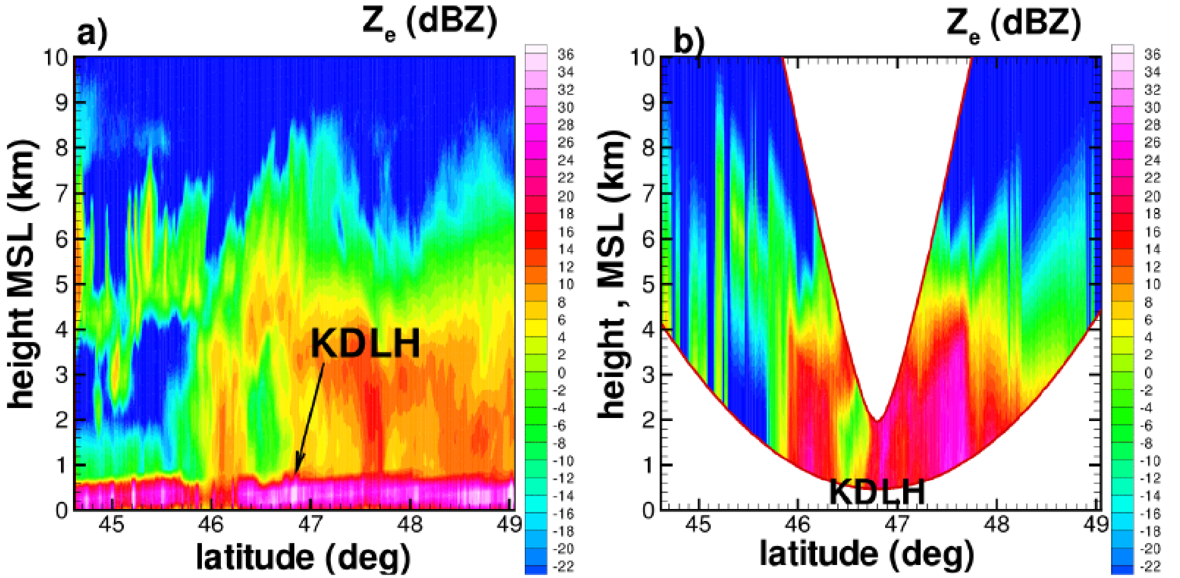


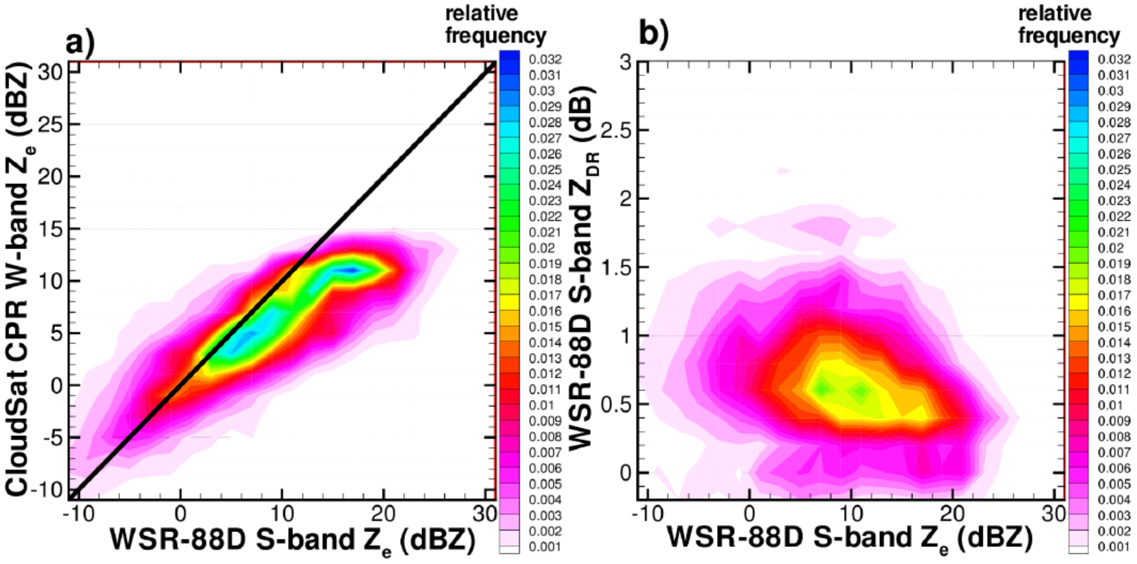
The dual-wavelength ratio is high when large snow aggregates are measured by the Parsivel disdrometer - Mie scattering

Dual-frequency polarimetric radar measurements from satellite and ground-based radars (Matrosov 2018)

CloudSat
W band

WSR-88D
S band





Conclusions

- The quality of microphysical retrievals can be significantly improved if multiparameter (particularly polarimetric) radar measurements are used instead of a sole reflectitivity factor
- It is strongly recommended to use specific attenuation A for microphysical retrievals in rain
- Novel polarimetric algorithms for microphysical retrievals in ice / snow show great promise and outperform conventional techniques based on reflectivity
- Recently developed techniques for processing and displaying polarimetric radar variables (e.g., QVP) allow to recognize “fingerprints” of individual microphysical processes and to improve the quality of radar estimates and retrievals
- The network of WSR-88D radars provides tremendous resource for cloud modelers, particularly if complemented with higher-frequency cloud radars operated on the ground or from space