Sizing Particles in Thick Ice Clouds Using Different Dual-Frequency Radar Approaches

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Dual-frequency radar parameters (for the K_a-W-band pair):

Dual-Frequency Ratio – DFR

DFR (dB) = $10 \log_{10} [Z_e(K_a)/Z_e(W)]$, Z_e in $mm^6 m^{-3}$

(*DFR-based approaches have been used in a number of studies*)

DFR= $DFR(D_0)$

Differential Doppler Velocity – DDV

DDV(ms^{-1}) = $V_D(K_a) - V_D(W)$ (for vertical pointing)

(*the air motion component cancels out*)

DDV=$DDV(D_0)$

A General form of a particle size distribution function:

$$N(D) = N_o\, D^{\mu} \exp\,[-(3.67+\mu)D/D_0]$$

Larger particle distributions usually are satisfactorily described by exponential functions:

$\mu=0 \rightarrow \quad N(D) = N_o \exp(-\Lambda D)$

where the exponential slope parameter $\Lambda \approx 3.67/D_0$

When scattering is non-Rayleigh at least at one of the frequencies:

DFR is a function of and Λ and particle shape/habit

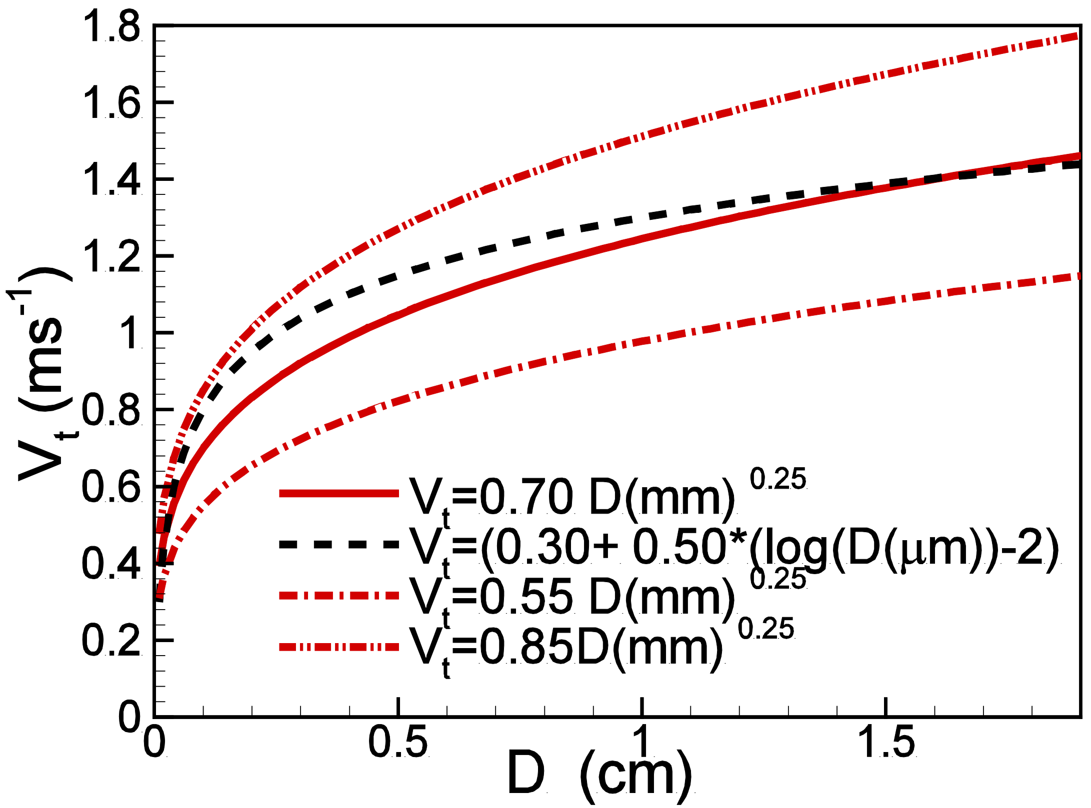
DFR depends on particle density (i.e., m-D relation and shape of the PSD only slightly)

DDV is a function of Λ, particle shape/habit , and a V-D relation

DDV depends on particle density (i.e., m-D relation and shape of the PSD only slightly)

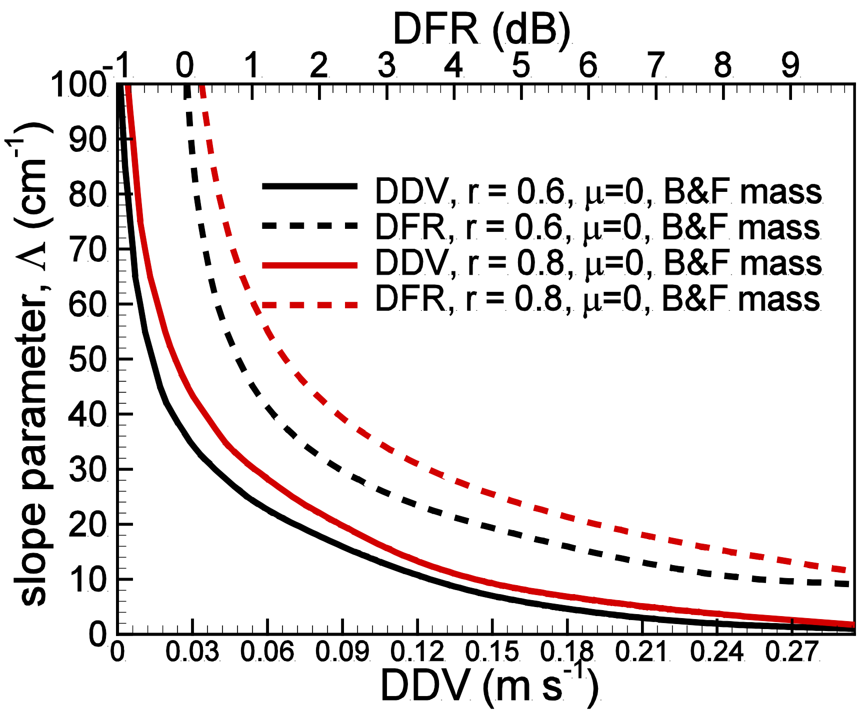
V-D relations: $V = a\,D^{b}$

for larger aggregate particles $b \approx 0.23$-0.26 (Lamb 1961, Brandes 2008), a generally varies (depending of particle type) from 0.55 to 0.85



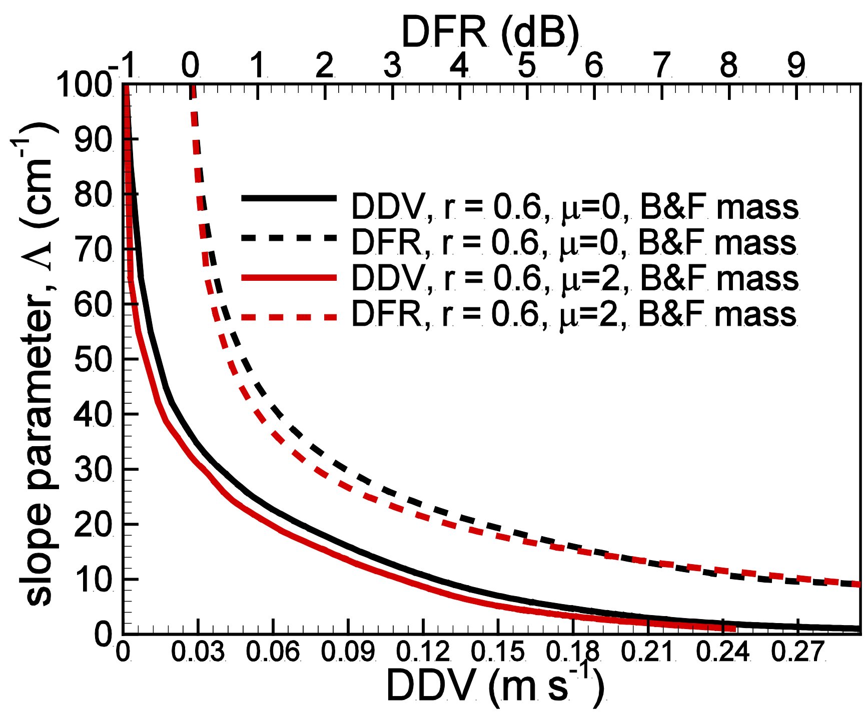
DFR-Λ and DDV-Λ relations

influence of particle shapes



r is the particle aspect ratio
which is about 0.6 – 0.8 (from in situ data)

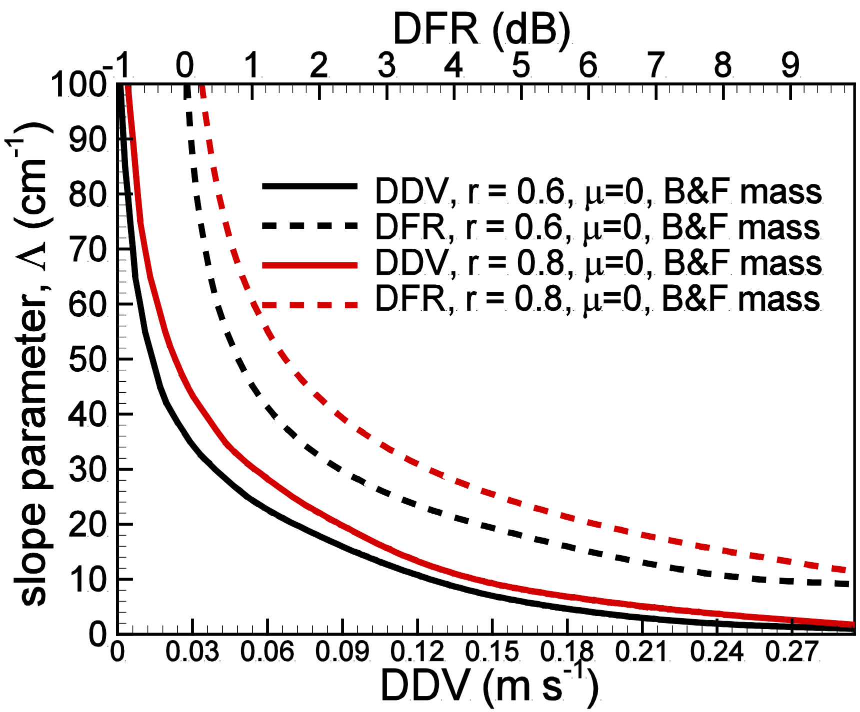
influence of PSD shape



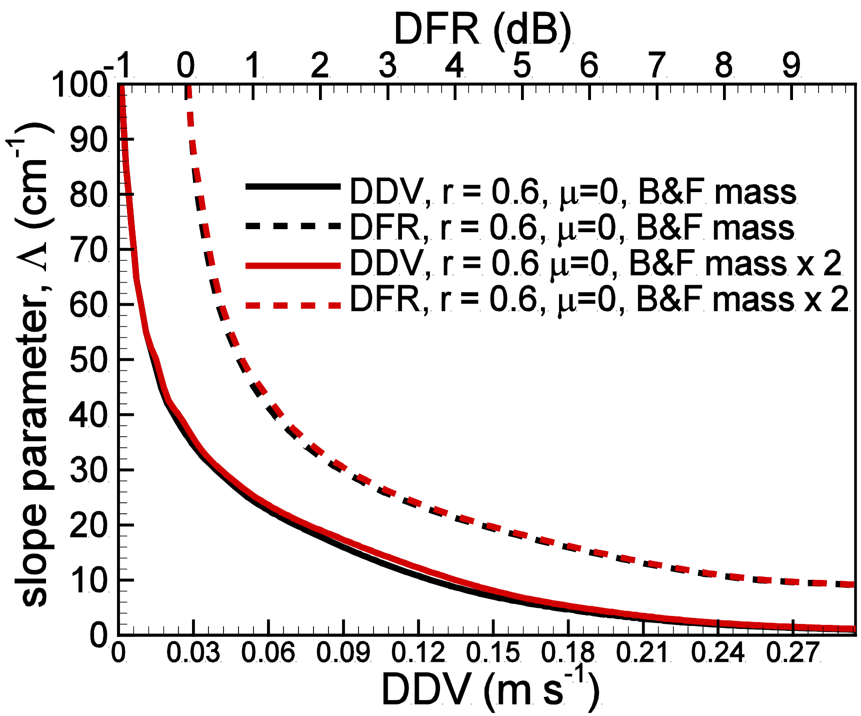
Scaled exponential slope:
$\Lambda(\mu)=3.67(3.67+\mu)^{-1}\Lambda(\mu=0)$
D_0 is the same for any μ

DFR-Λ and DDV-Λ relations

influence of particle shapes



influence of m-D relation

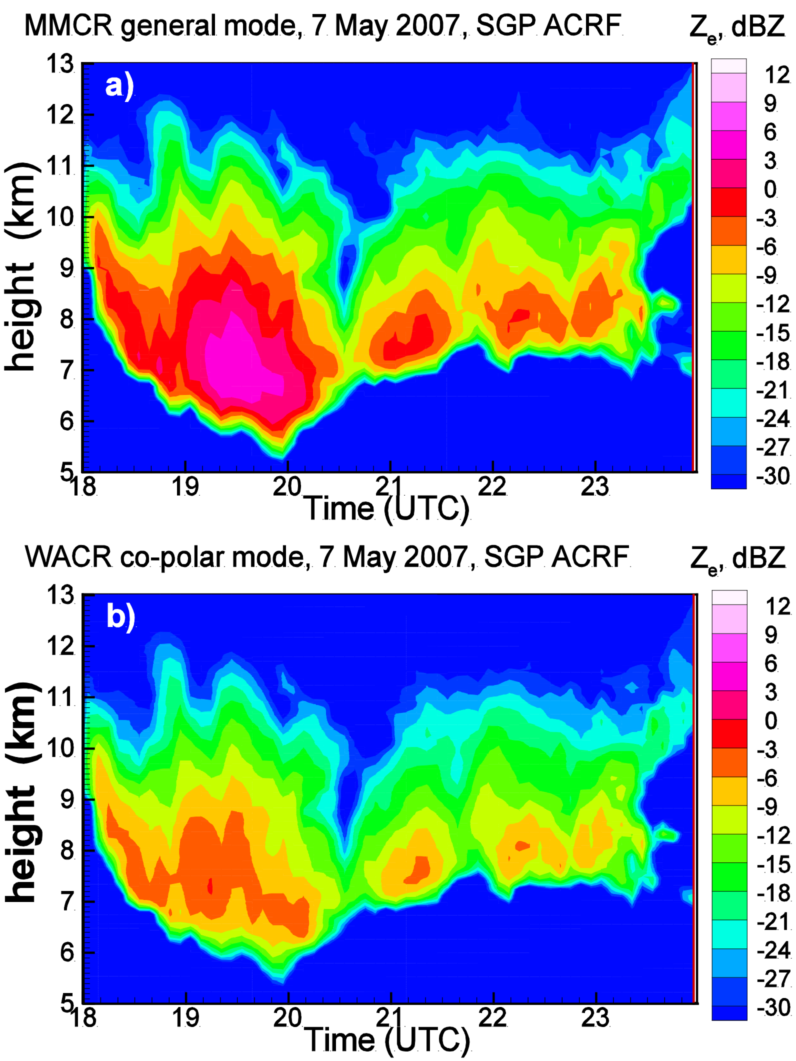


r is the particle aspect ratio,
which is about 0.6 – 0.8 (from in situ data)

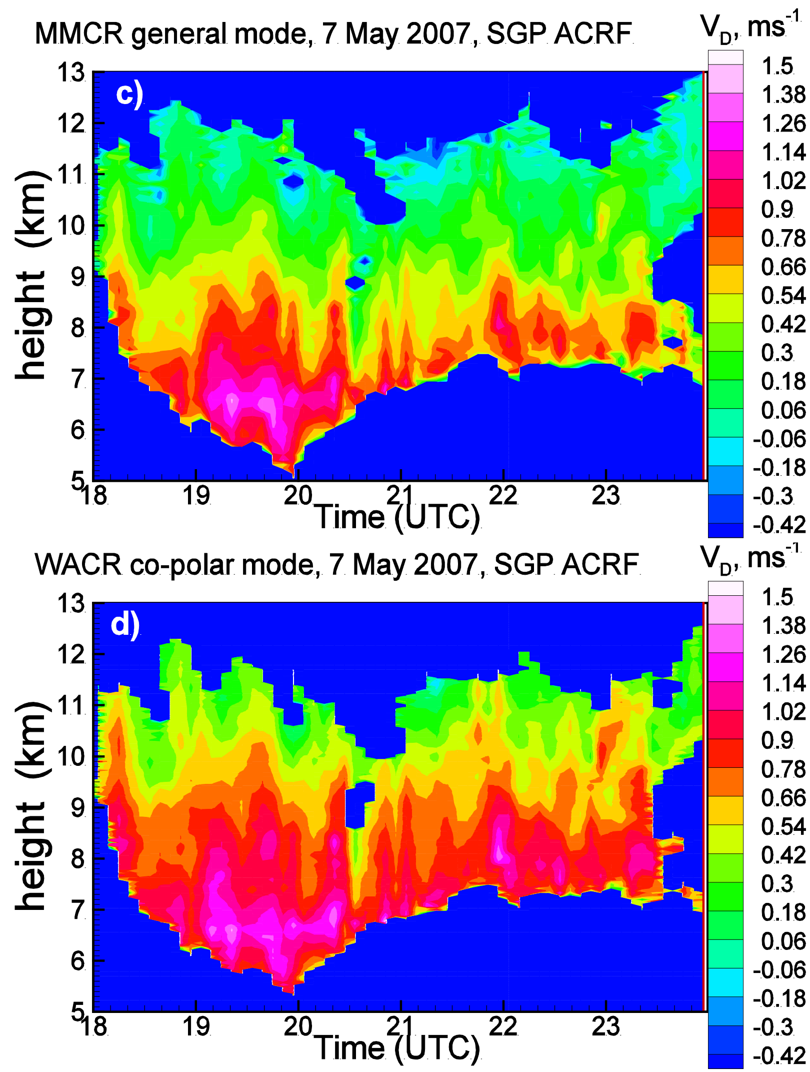
negligible influence of density

An experimental example of dual-frequency observations

reflectivity



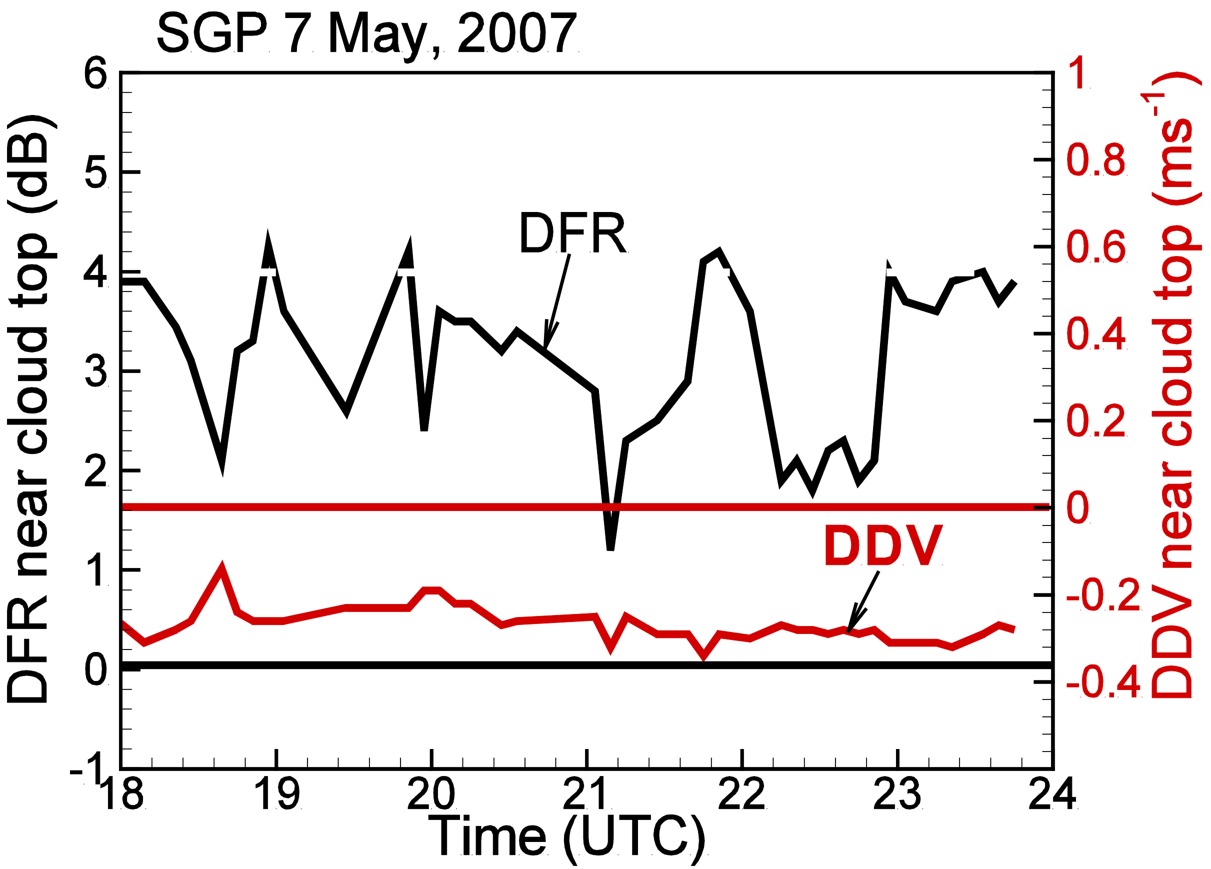
Doppler velocity



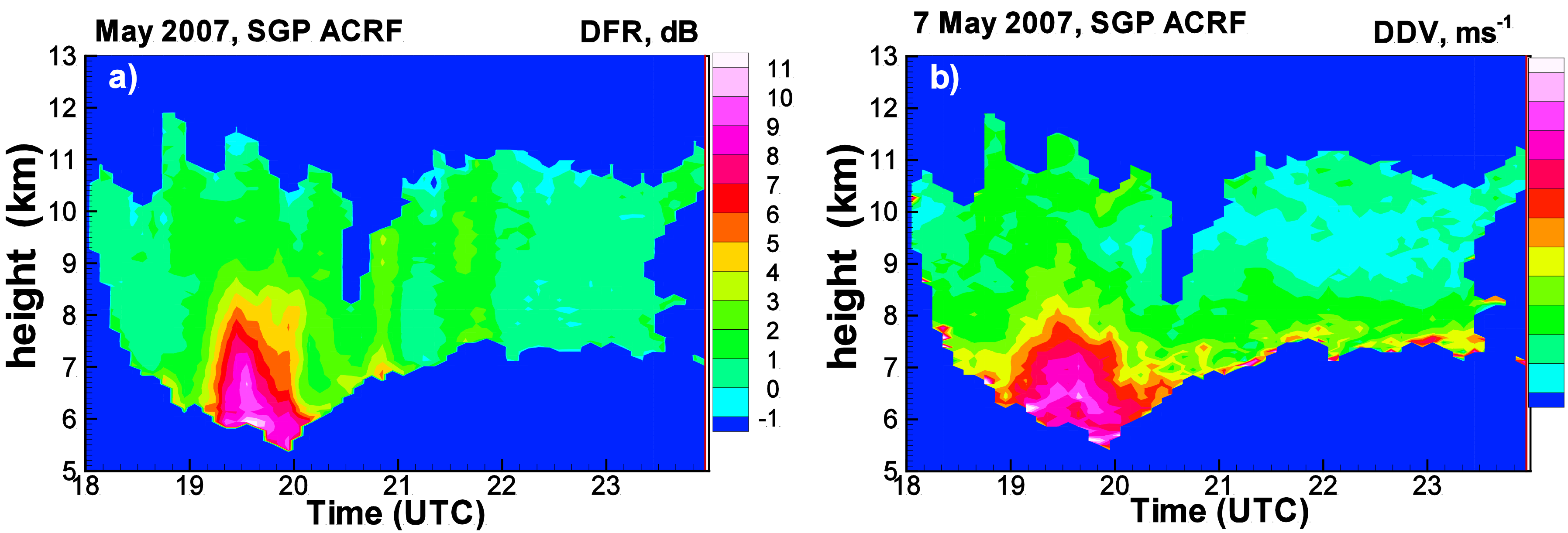
Constraining DFR and DDV measurements near the cloud top

DFR= 0 dB (mean offset is 3.1 dB, standard deviation is 0.9 dB)

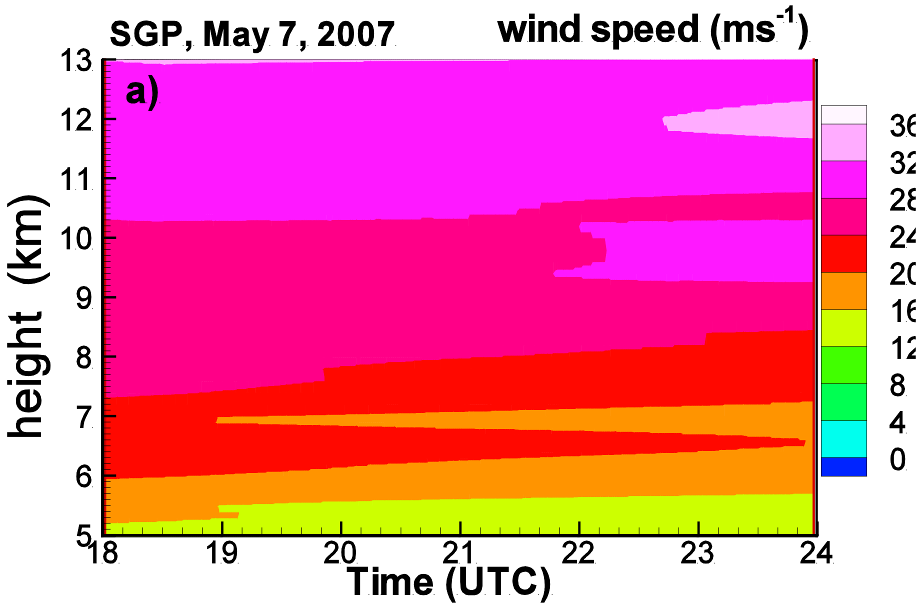
DDV= 0 m/s (mean offset is -0.27 m/s, standard deviation is 0.03 m/s)

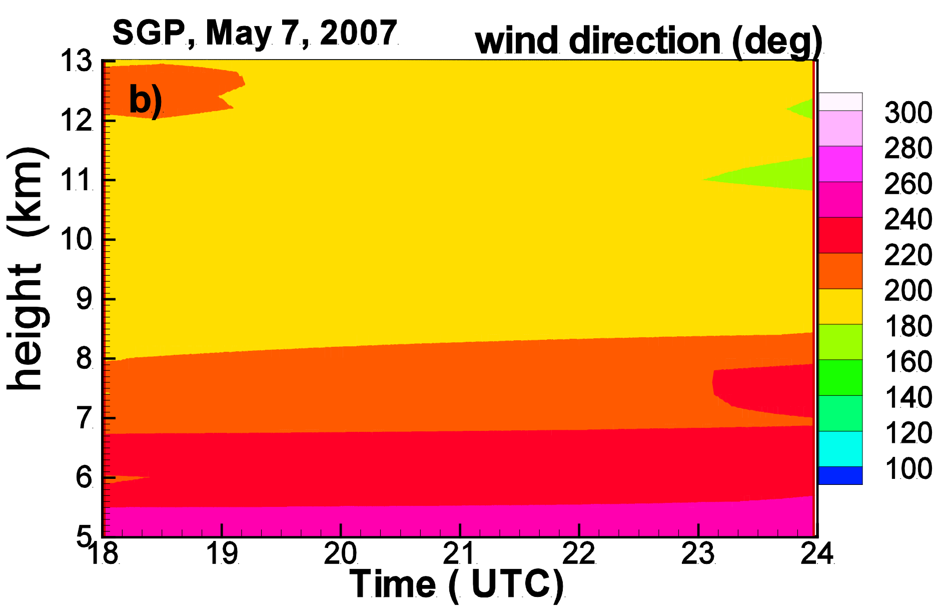


DFR and DDV measurements after introducing bias corrections



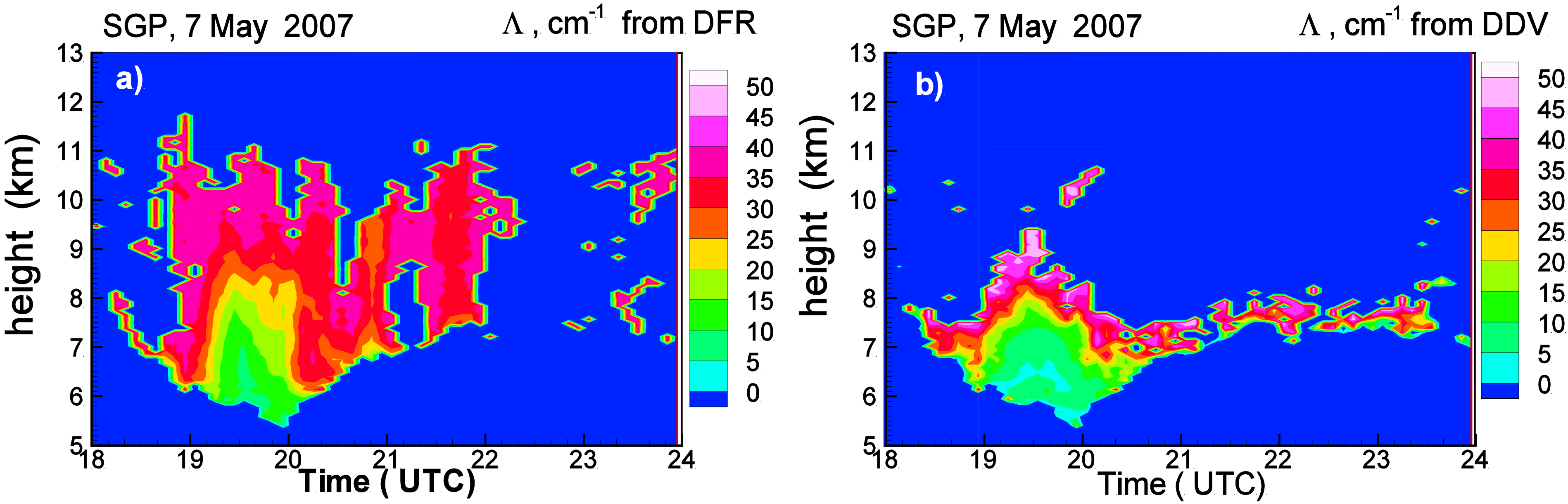
Horizontal flow was not changing drastically





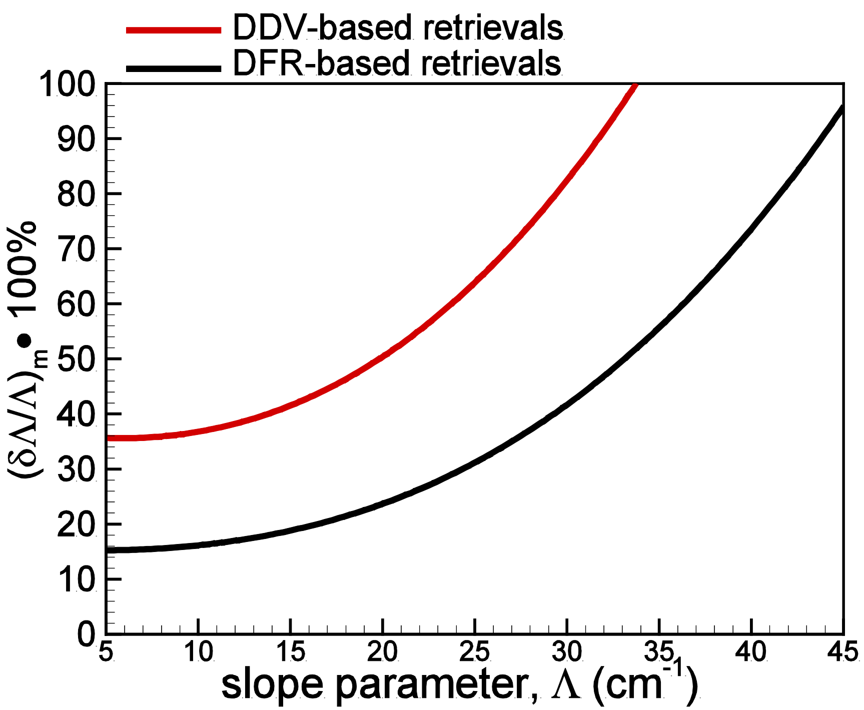
Retrievals of the slope parameter Λ from DFR and DDV measurements

In a range of 7 cm^{-1} < Λ < 35 cm^{-1}, the relative bias is 25%, relative standard deviation is 42%

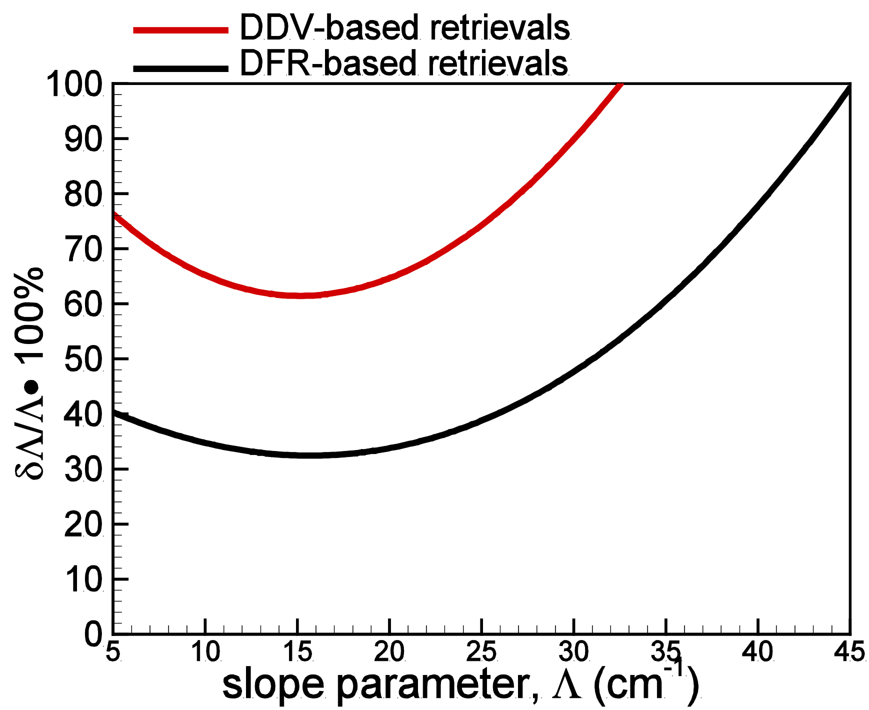


Retrieval uncertainties

Retrieval errors due to DFR / DDV measurement uncertainties (0.9 dB for DFR, 0.03 m/s for DDV)



Total retrieval errors assuming independence errors due to measurement uncertainties and model uncertainties (particle shape, PSD, fall velocity – size and mass - size relations)



Conclusions

Two dual-frequency radar methods based on independent measurements (DFR and DDV) resulted in indicated the retrievals that were consistent and within expected retrieval errors

Dual-frequency methods are insensitive to the radar mis-calibration errors and to the vertical air motions. The measurement constrains are needed at the vicinity of cloud tops in order to remove effects of differing attenuations at K_a and W-bands in lower layers.

The best retrievals accuracy is expected for distribution slope (i.e., effective ice particle size) retrievals when 10 $cm^{-1} < \Lambda < 25$ cm^{-1}.

DFR -based retrievals are generally more accurate then DDV-based retrievals.
Although in some important instances DFR-based measurements might be not applicable (e.g., retrievals in mixed-phase clouds where differential attenuation effects are appreciable, retrievals in ice parts of precipitation systems when W-band signals at cloud tops are missing).

Precise vertical pointing of radar beams is crucial for DDV measurements.