On using the relation between Doppler velocity and radar reflectivity to distinguish microphysical regimes in ice clouds

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Motivation

Ground-based profiling Doppler cloud radar are excellent tools to observe vertical (ice) cloud structure (Kollias et al., 2007). To improve the parameterization of ice clouds in numerical models, it is important to understand the link between radar observables and microphysical properties of ice clouds (Szyrmer et al., 2012). Here, the possibility of using profiles of the Doppler velocity (V_d)- radar reflectivity (Z) - power-law relation to distinguish microphysical regimes in midlatitudinal ice clouds is explored.

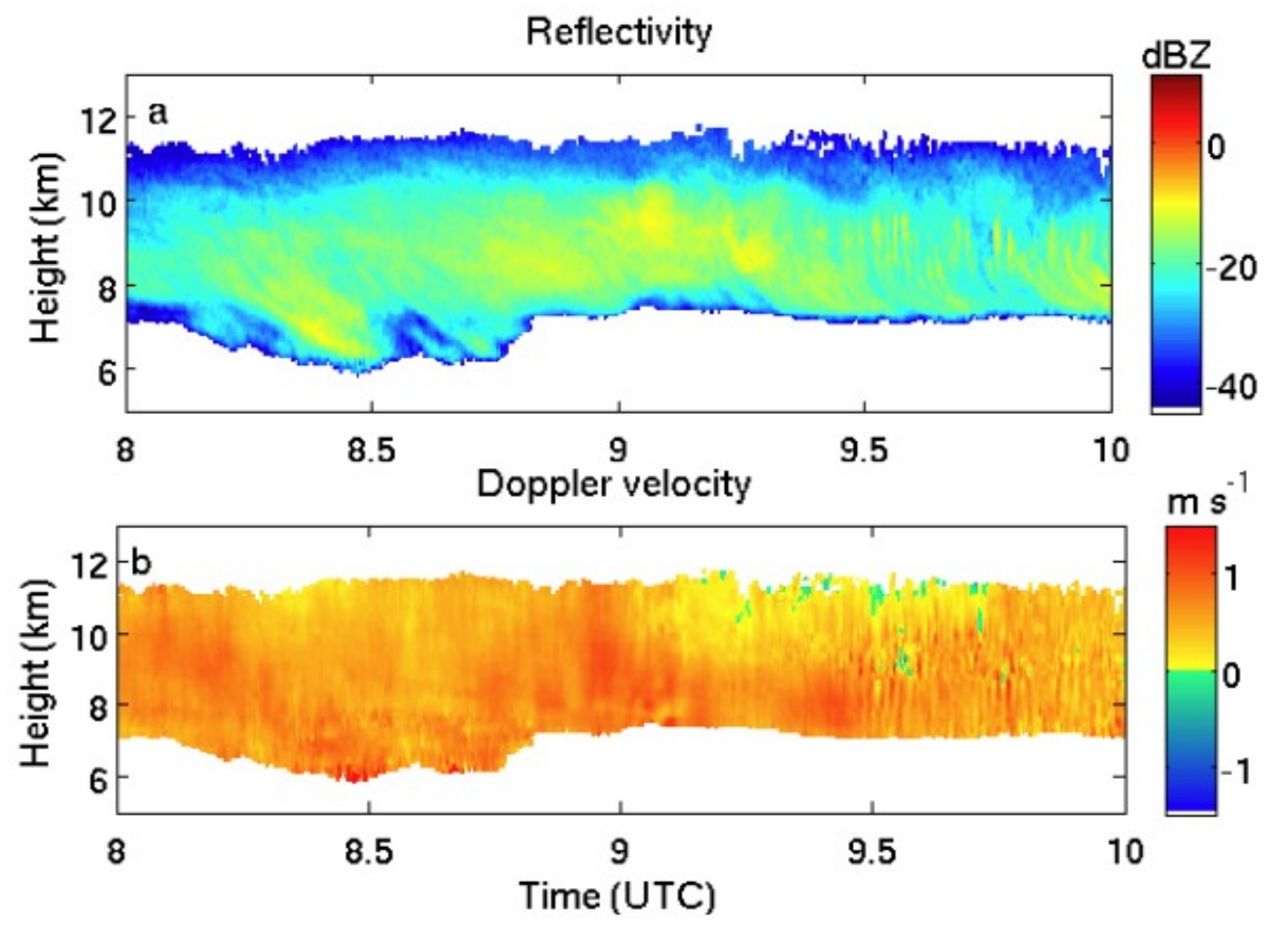
Methodology

Power-law: $\boxed{V_d = aZ^b}$ with V_d (m s^{-1}), Z (mm^6 m^{-3}) (1)

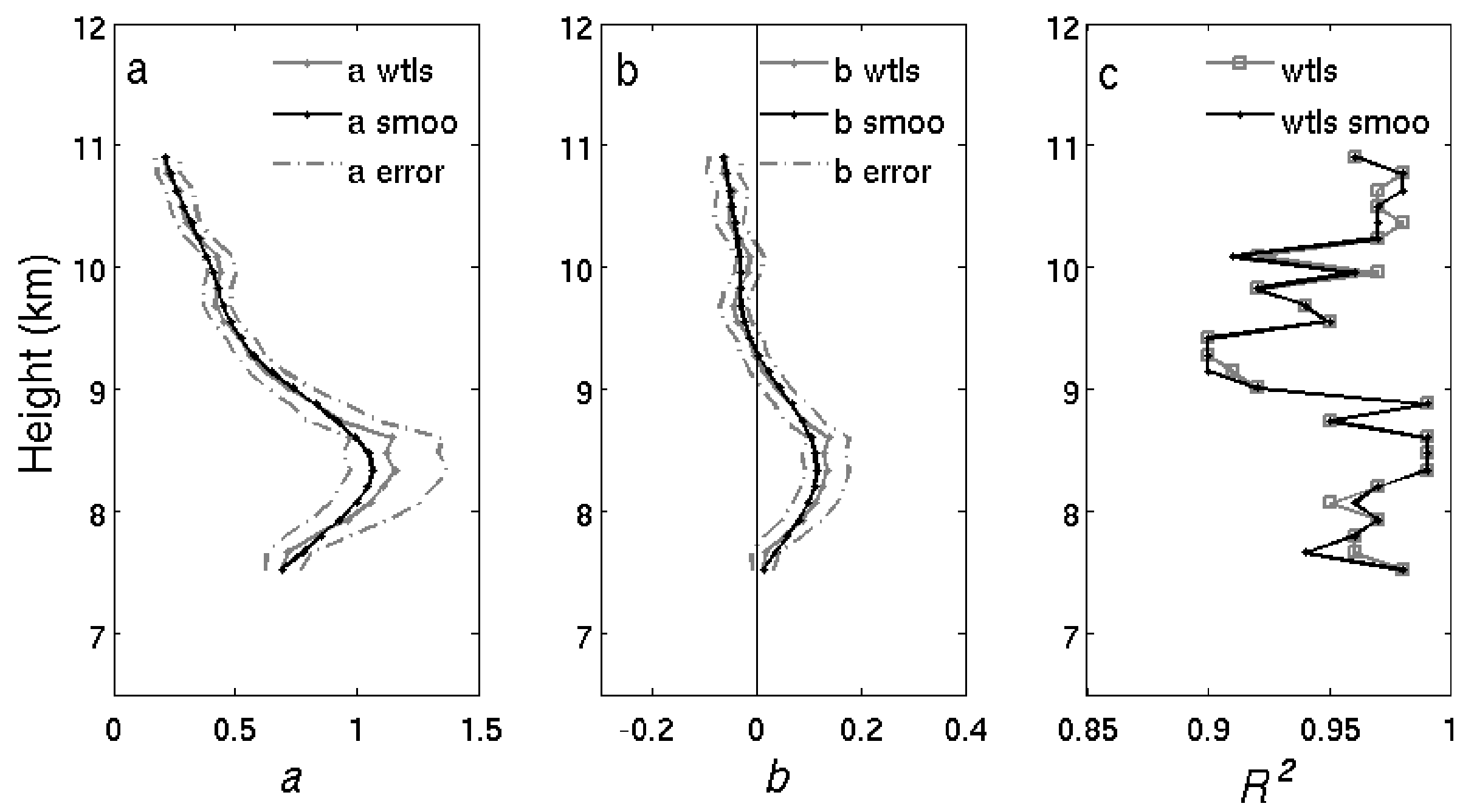
The V_d - Z – power-law relation is determined for finite time intervals (30-120min) using MMCR data. The methodology is explained in detail in Kalesse and Kollias, 2013. There, the focus is on decomposition of V_d into vertical air motion (w) and reflectivity-weighted particle terminal fall velocity(V_t), here it is on deriving smooth vertical profiles of the power-law relation. A weighted total least-squares (wtls) linear regression (Krystek and Anton, 2007) taking into account the uncertainties of the data in both coordinates is used. The uncertainties are represented by the standard errors of the means in each reflectivity bin of 2 dBZ. The V_d-Z-relationship is determined as function of height H with a very high vertical resolution (135m). Changes of this relationship with distance from cloud top reflect different microphysical regimes and ice particle growth processes which lead to changes in ice particle size, number, and density.

The algorithm is applied to MMCR observations of single-layer ice clouds at the ARM Southern Great Plains (SGP) during 1997 – 2010.

Case study: 20041208

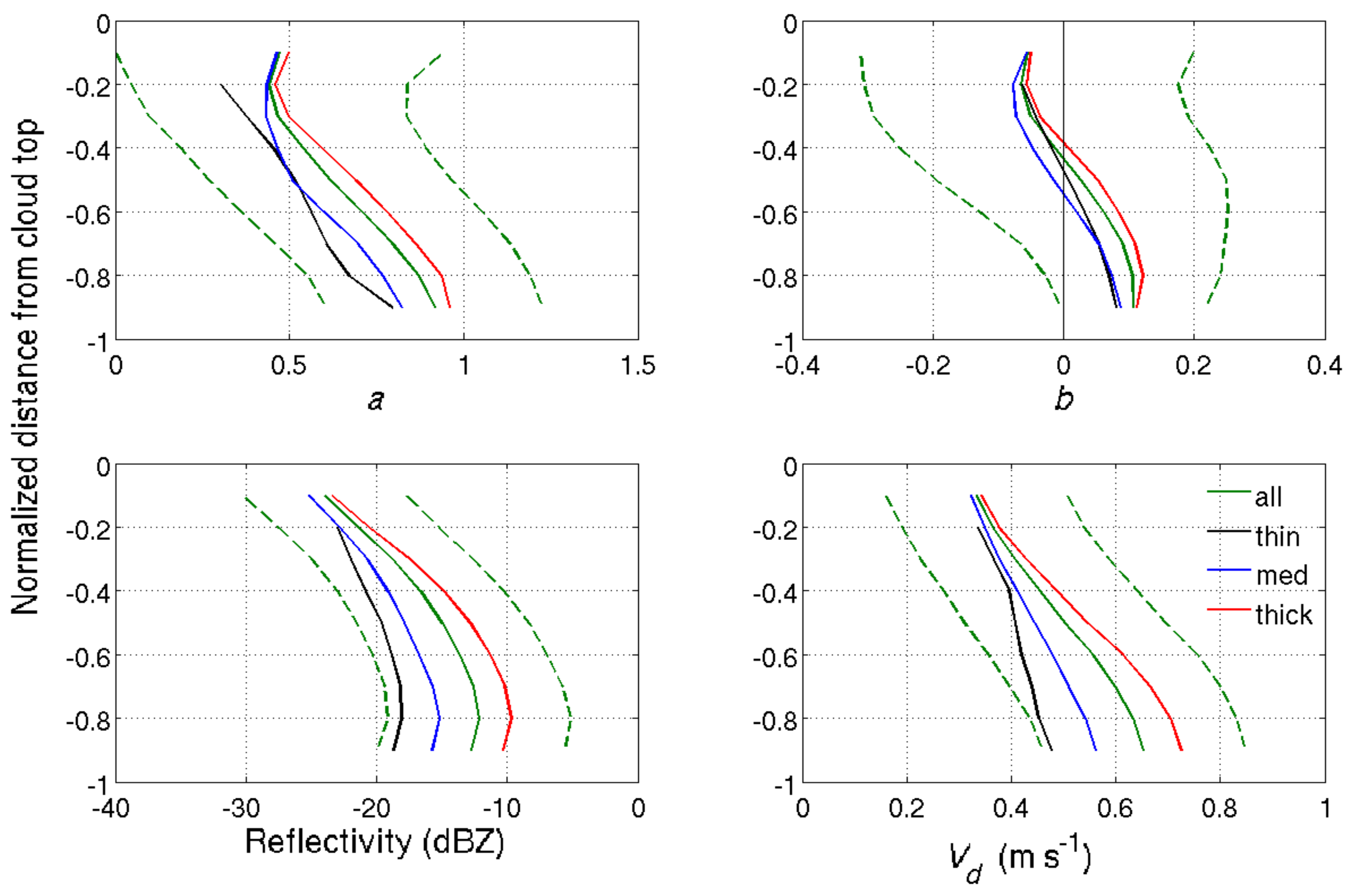


MMCR radar reflectivity Z and Doppler velocity V_d for ice cloud observed at SGP on 8 Dec, 2004.



Profiles of derived wtls-fit coefficients a and b as well as their smoothed profiles.

Application to ice cloud climatology

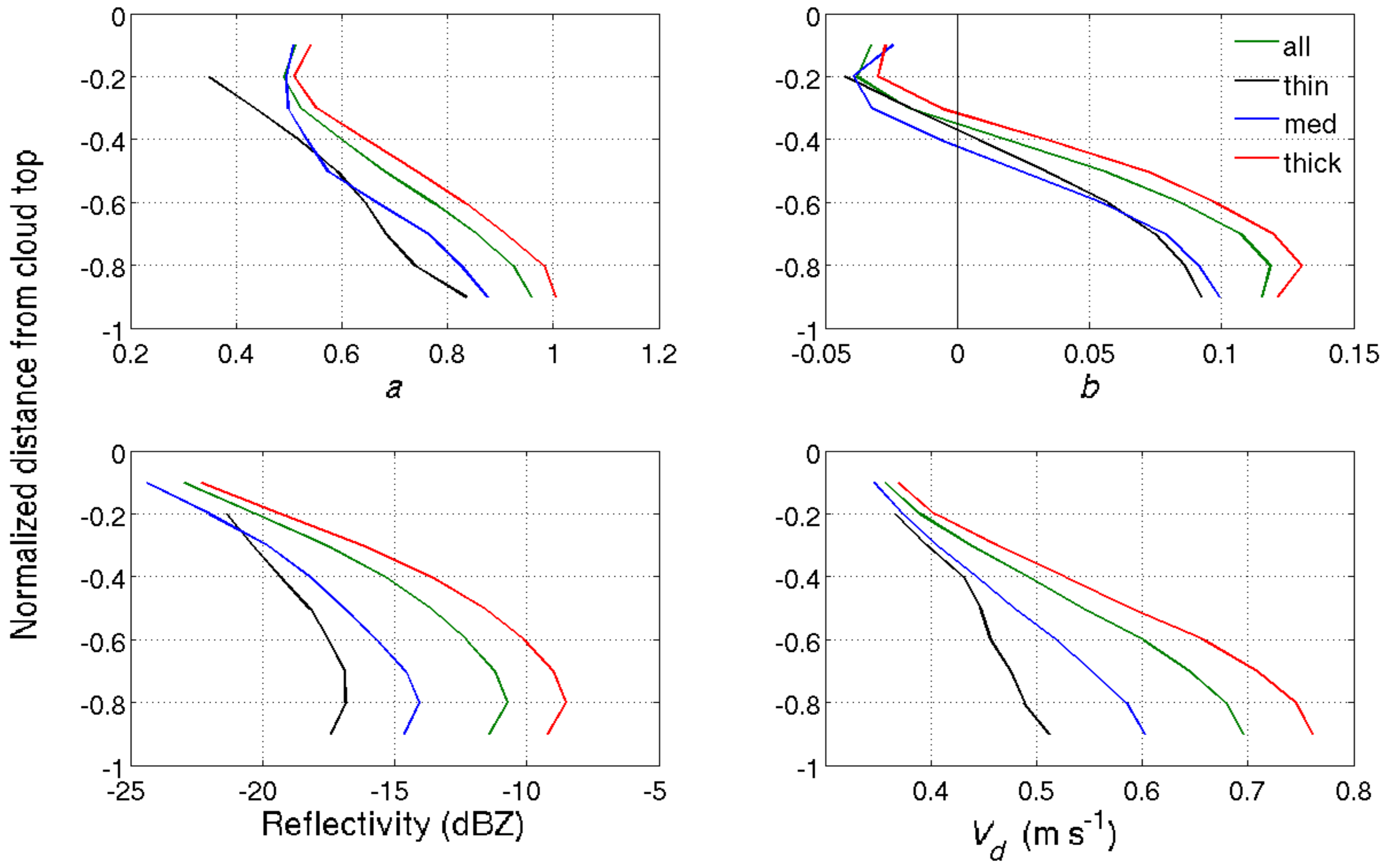


- Mean profiles derived for SGP single-layer ice cloud observations 1997-2010
- Subdivision in cloud depth categories (thin:<1.5km, med: 1.5-3km, thick:>3km)
- Large standard deviation considering all ice clouds (dashed line)
- Which modes explain most of the observed variance?

→ Find out via principal component analysis (PCA, e.g., Zivcovic, 1995)

Principal Component Analysis (PCA)

- First PC mode which explains 89% of observed variance:



Comparison with other studies

Data set	Power-law coefficient *a*	Power-law coefficient *b*
Heymsfield, 1977 (midlat)	0.59 - 0.67	0.06 - 0.095
Orr and Kropfli, 1999 (midlat)	0.20 - 0.52	0.05 - 0.44
Protat, 2003 (midlat)	0.29 - 0.7	0.05 - 0.18
Protat, 2011 (Tropics)	0.35 - 0.8	0.01 - 0.26
Here*, all ice clouds (midlat)	0.65 ± 0.42	0.03 ± 0.19
Here*, thin clouds	0.53 ± 0.41	0.01 ± 0.19
Here*, medium thick clouds	0.64 ± 0.42	0.03 ± 0.19
Here*, thick clouds	0.72 ± 0.4	0.06 ± 0.2

* mean and standard deviation over profiles

A look at the microphysics

Assuming that in a cloud layer the a and b from (1) vary only slowly with height h, (1) leads to:

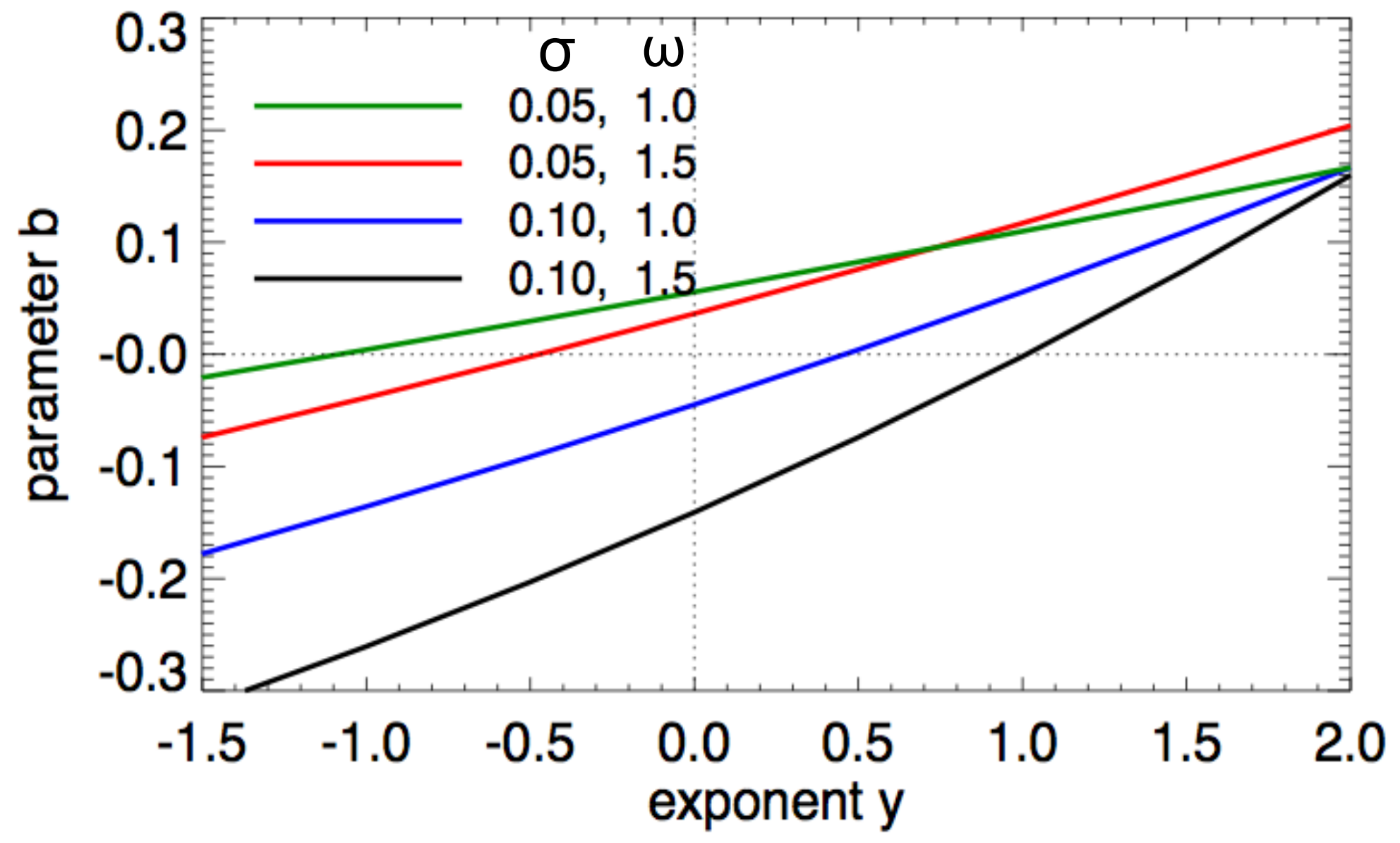
$$b = \frac{\Delta(\ln V_d)/\Delta h}{\Delta(\ln Z)/\Delta h} \tag{2}$$

The rate of change of the melted diameter D_w *via* a given microphysical process *PRC* such as deposition or riming can be written as :

$$\left.\frac{dD_w}{dt}\right|_{PRC} \approx xD_w^y \tag{3}$$

Using (3) within a two-moment (M_3,M_6) normalization scheme with a selected Particle Size Distribution (PSD) shape and assuming single particle terminal velocity is expressed as $u(D_w) = \kappa D_w^{\omega}$, (4)

the b calculated from (2) is only a function of y, ω and the PSD shape parameter σ. Results shown are calculated assuming lognormal PSD shape.

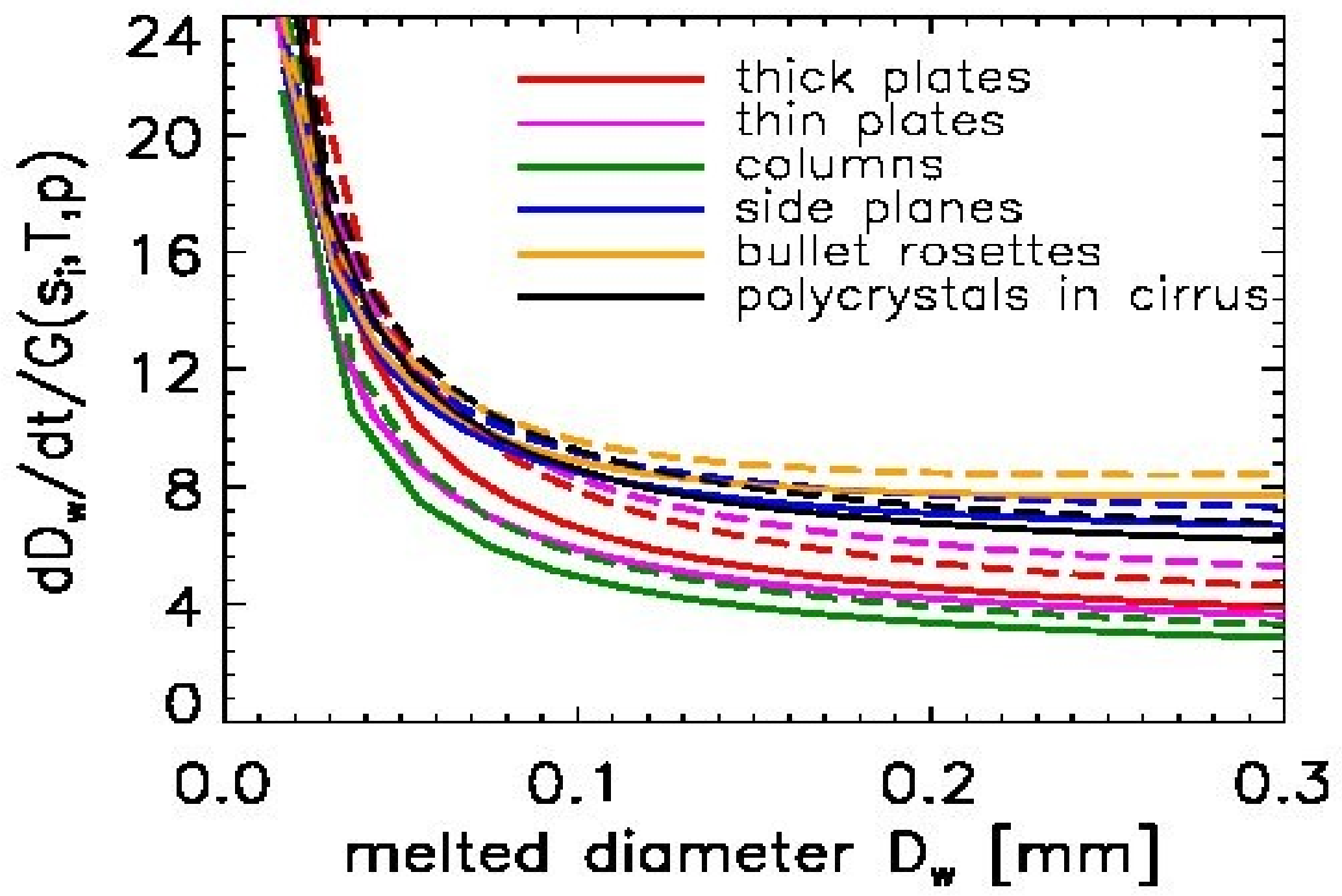


- Deposition process:

$$\frac{dm}{dt} = G(s_i,T,p)C \xrightarrow[m=\frac{\pi}{6}\rho_w D_w^3]{m=\alpha D^{\beta}} \left.\frac{dD_w}{dt}\right/ G(si,T,p)$$

C: Capacitance

α,β from Mitchell,1996



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