Is it possible to find average snow scattering properties that can be applied globally?

A first attempt using Self-Similar Rayleigh-Gans theory and a new aggregation model

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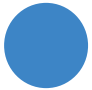
Motivation

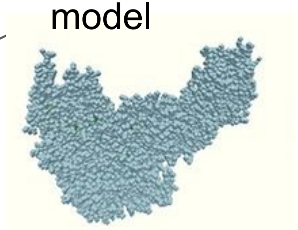
- Fast microwave radiative transfer simulations rely on approximations of hydrometeor scattering properties (soft-sphere/spheroid)
  - Computationally fast
  - easy link with mass-size relation using effective medium approximation
- These simulations are found to be incorrect for high size parameter
  - the structure of the particles become important for scattering
- Accurate Discrete Dipole Approximation (DDA) calculations are better
  - huge computational cost
  - needs to be re-done for every particle shape
- Cloud microphysics schemes are evolving towards an explicit simulation of hydrometeor properties (P3, super-droplet models)
  - Radiative transfer models need to be flexible regarding particle properties

Why should we use aggregation models?

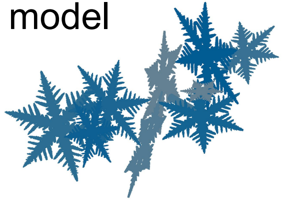
solid-sphere



Rimed aggregate model

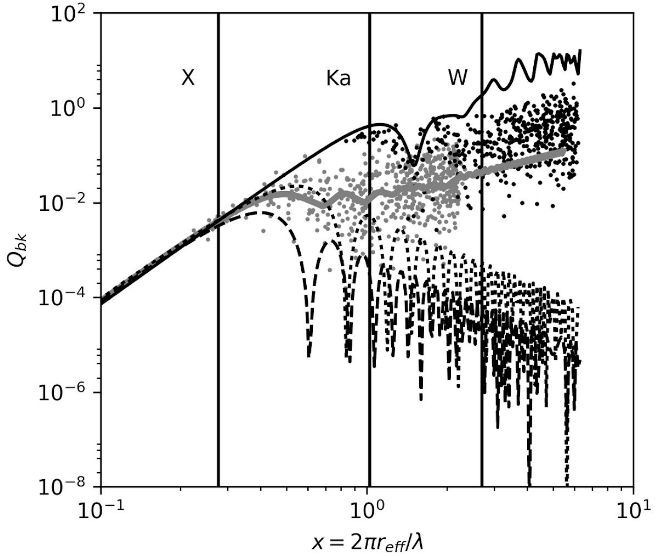


Unrimed aggregate model

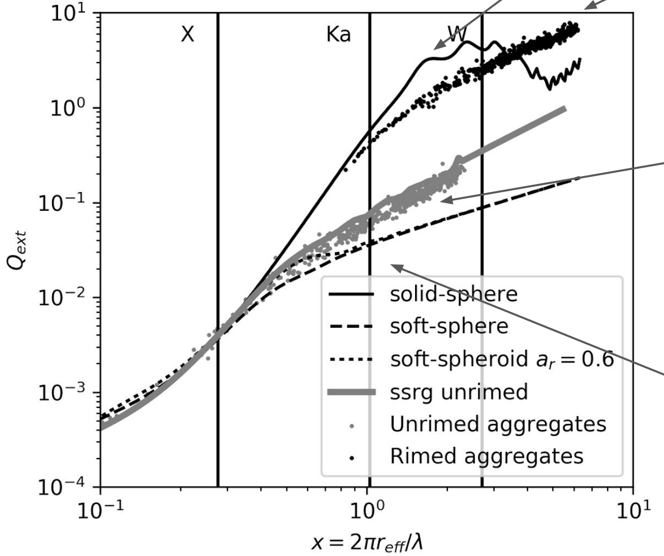


soft-spheroid

backscattering



extinction



Kneifel et al. (2020) Satellite precipitation measurement, Springer

Which particle to use?

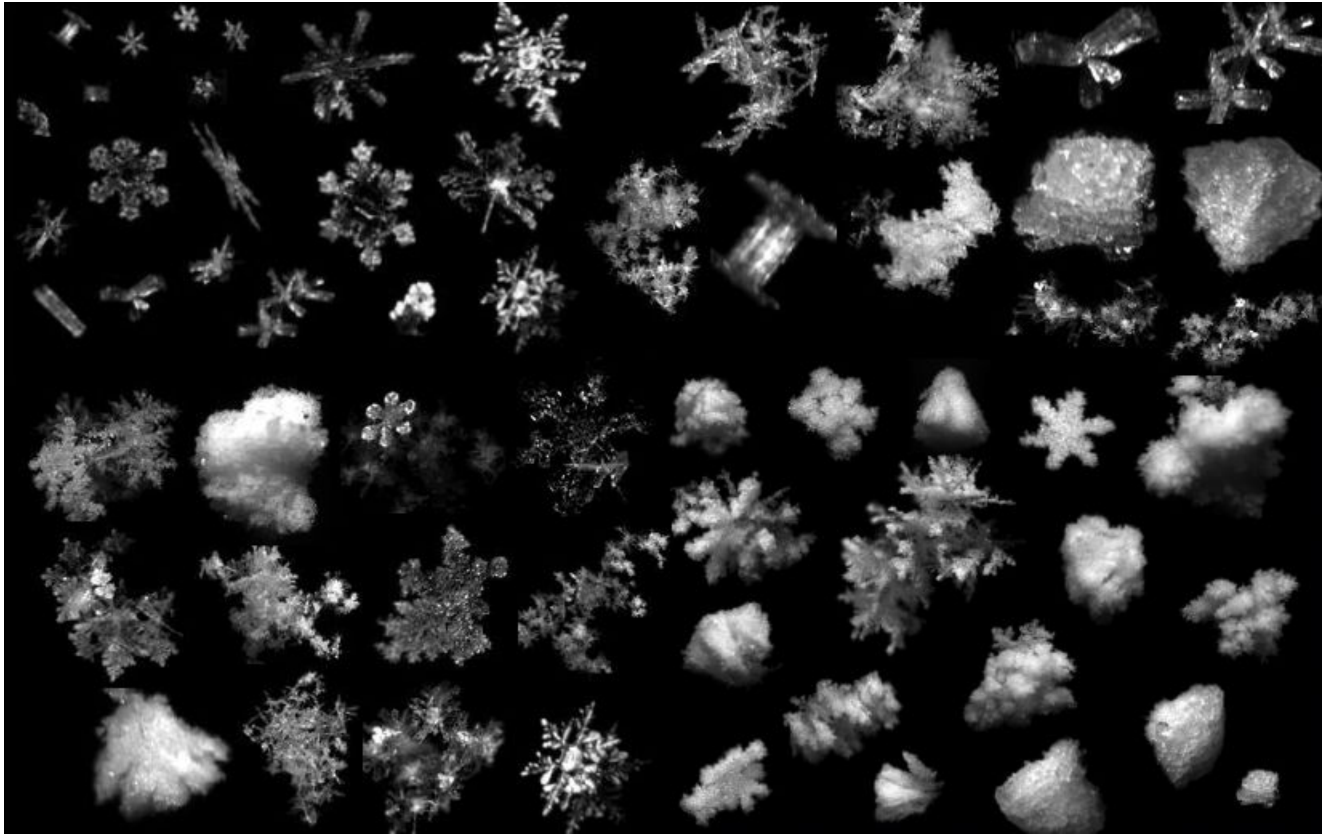
No unique shape

Vast range of properties

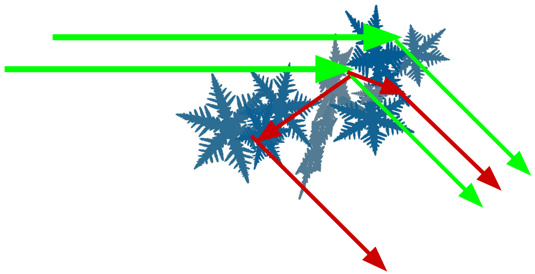
Scattering DB can only **sample** this variability

1) Can we just average all of them?

2) Can we identify the properties of the ensemble?



Rayleigh-Gans Approximation



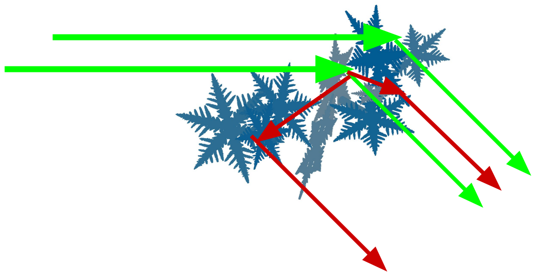
Consider every point as Rayleigh scatterer

Neglect coupling of internal parts

Rayleigh part; form factor

$$\sigma(\theta) = \underbrace{\frac{9}{4\pi}k^4|K|^2V^2\frac{1+\cos^2(\theta)}{2}}_{\text{Rayleigh part}}\underbrace{\phi(x\sin(\theta/2))}_{\text{form factor}}$$

Rayleigh-Gans Approximation



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Rayleigh part

form factor

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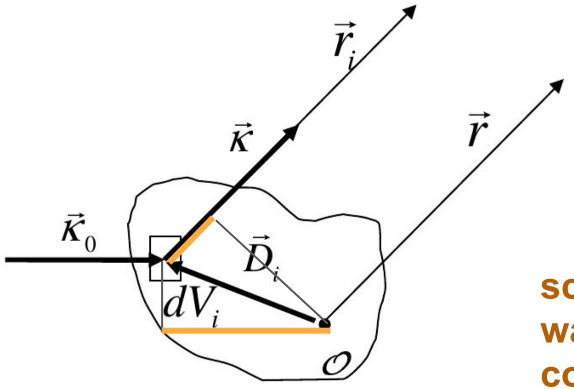
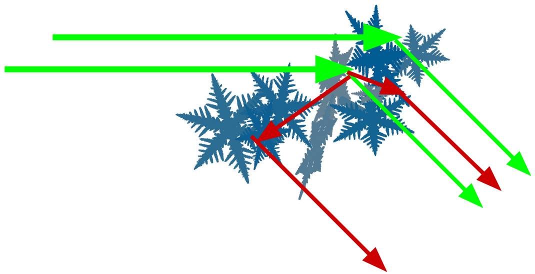
The **form factor** takes into account the **phase delay** among the scattered waves



scattered waves add coherently

Rayleigh-Gans Approximation



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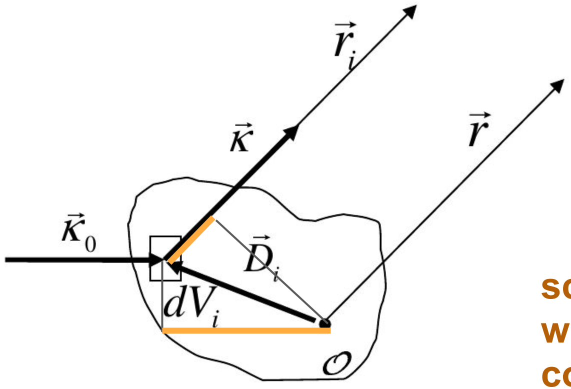
The **form factor** takes into account the **phase delay** among the scattered waves

$$\phi(y) = \frac{1}{V} \int \exp(\iota\delta(\mathbf{R}))\mathrm{d}\mathbf{R}$$

$$\delta(\mathbf{R}) = \mathbf{R}(\mathbf{k_{inc}} - \mathbf{k_{sca}})$$

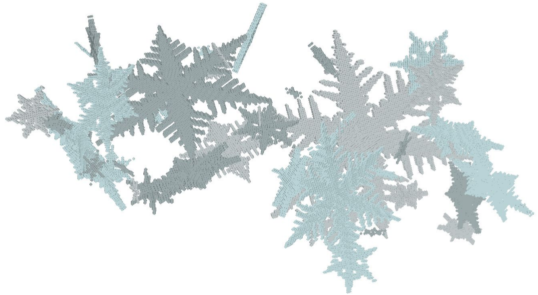


scattered waves add coherently

What matters is the distribution of masses within the particles

Westbrook (2004) “Universality of Snowflake formation” GRL
Hogan and Westbrook (2014) “Self-Similar Rayleigh Gans” JAS

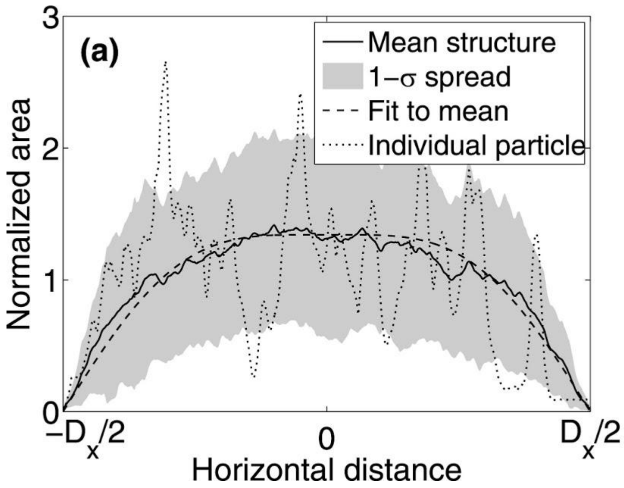
Snow aggregates are Self-Similar

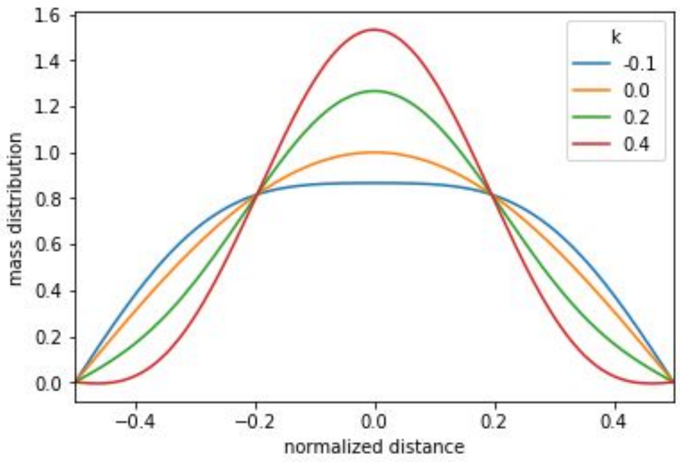


We always observe an ensemble of particles
=> the ensemble properties define the scattering

- Model the mean distribution of masses

$$A(x, k) = (1 + \frac{\kappa}{3}) \cos(\pi x) + \kappa \cos(3\pi x)$$





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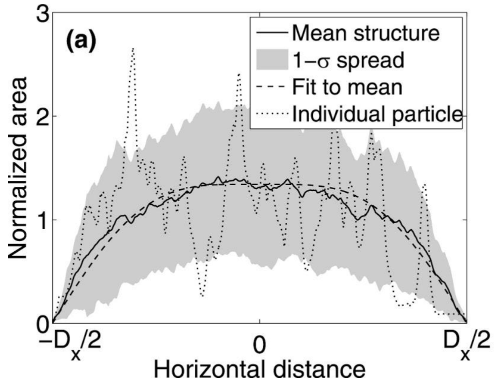
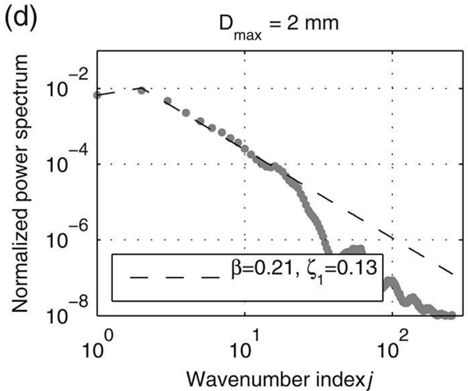




- Model the mean distribution of masses

$$A(x,k) = (1+\frac{\kappa}{3})\cos(\pi x) + \kappa\cos(3\pi x)$$

- Model the power spectrum of the deviations

$$P(j) = \beta j^{-\gamma}$$

- Solve for the form factor

$$\phi(x) = \cos(x)\left[(1+\frac{\kappa}{3})\left(\frac{1}{2x+\pi} - \frac{1}{2x-\pi}\right) - \kappa\left(\frac{1}{2x+3\pi} - \frac{1}{2x-3\pi}\right)\right]$$
$$+\beta\sin^2(x)\sum_j \zeta_j (2j)^{-\gamma}\left[\frac{1}{(2x+\pi j)^2} + \frac{1}{(2x-\pi j)^2}\right]$$

Much faster than complex models (DDA)

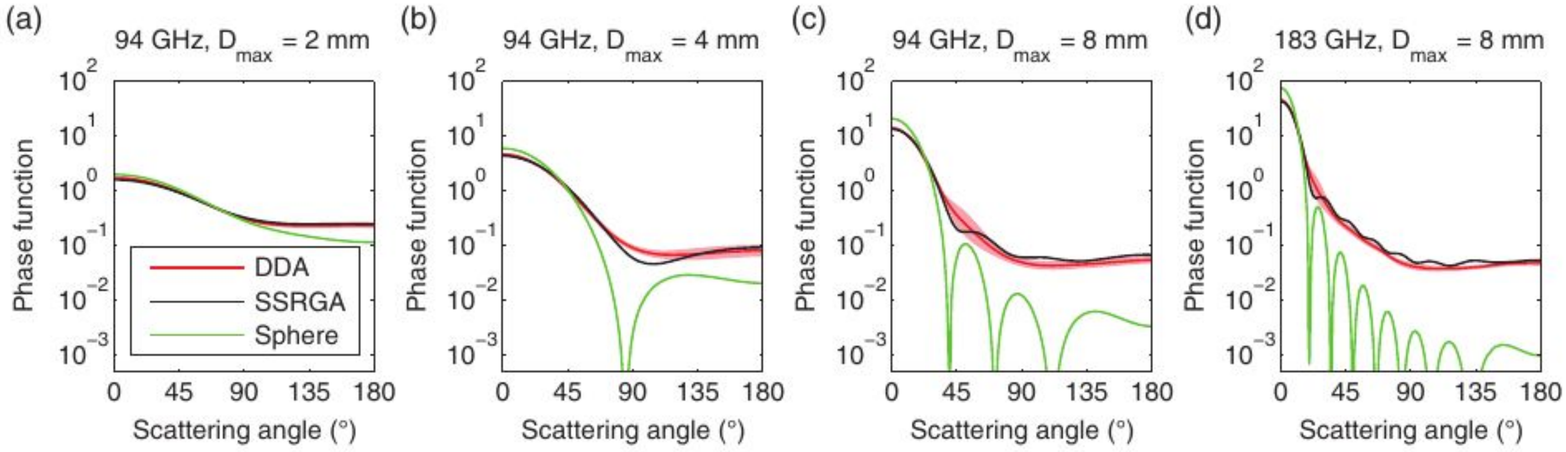
How does SSRGA perform?

The results of SSRGA are comparable with those of more complex DDA calculations

Needs testing for frequency > 183 GHz

Reasonably good even for rimed particles (Leinonen et al. 2018)

Hogan et al. 2016 QJRMS



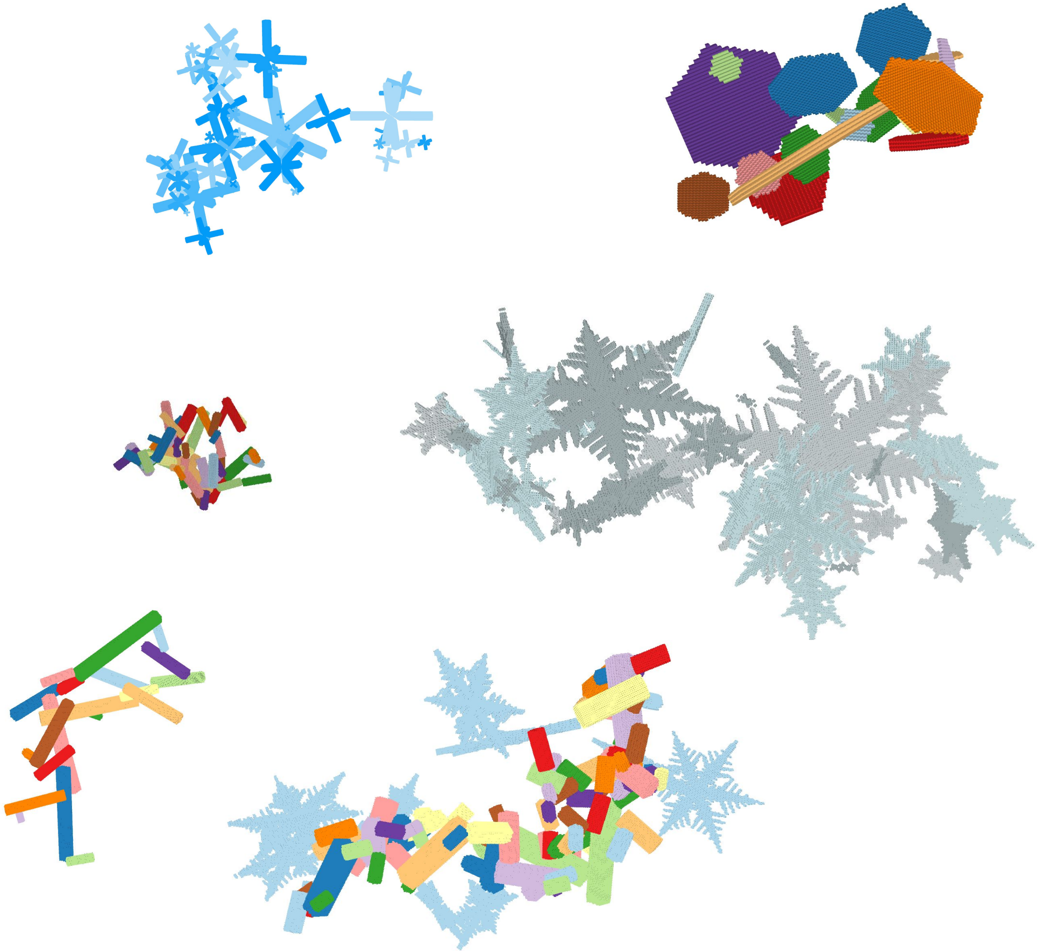
Snowflake models

SSRGA connects scattering with microphysics

Currently over 100k aggregates modeled

Various monomer habits:

- plates
- columns
- dendrites
- rosettes
- needles
- <u>mixtures</u>

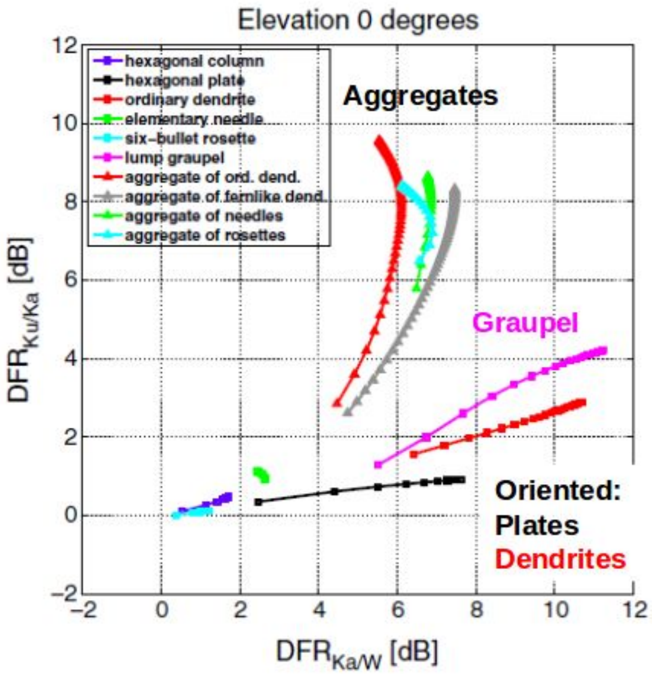


Tyynela and Chandrasekar 2014 JGR

Multifrequency radar approach

Combine **multiple frequencies** to constrain snow precipitation properties

$$DWR_{XK_a}[dB] = Z_X[dBZ] - Z_{K_a}[dBZ]$$



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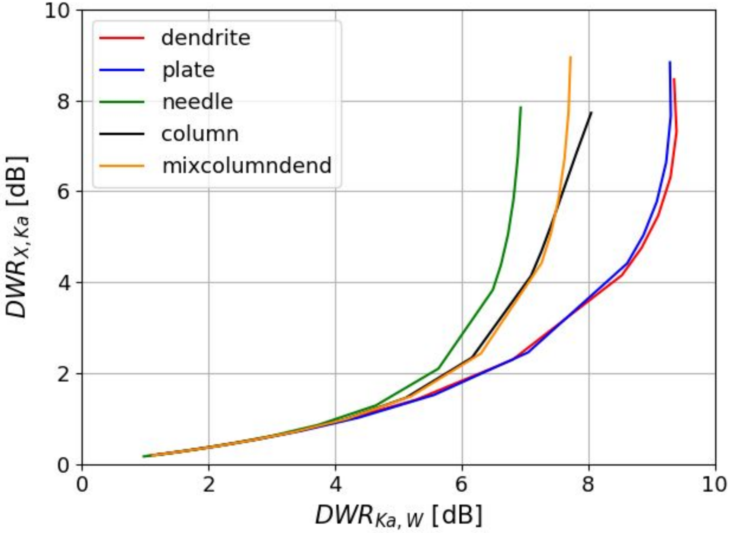
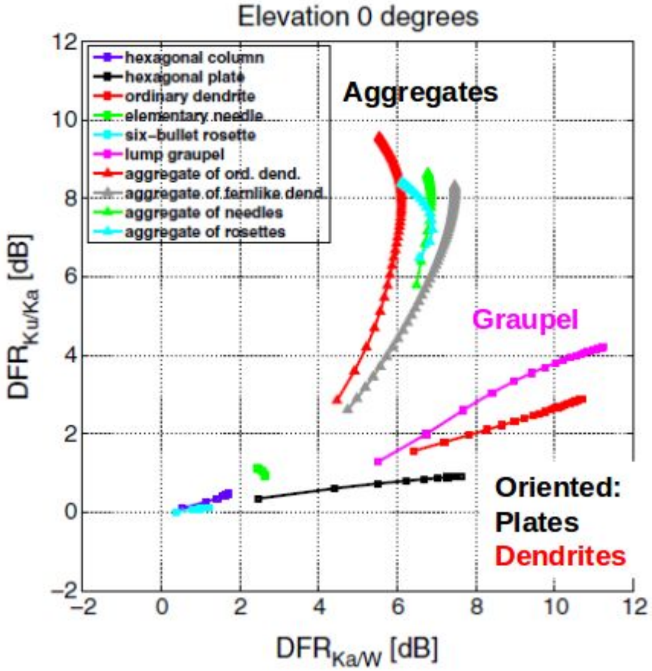


von Terzi et al. (under preparation)



TRIPEx observation campaign

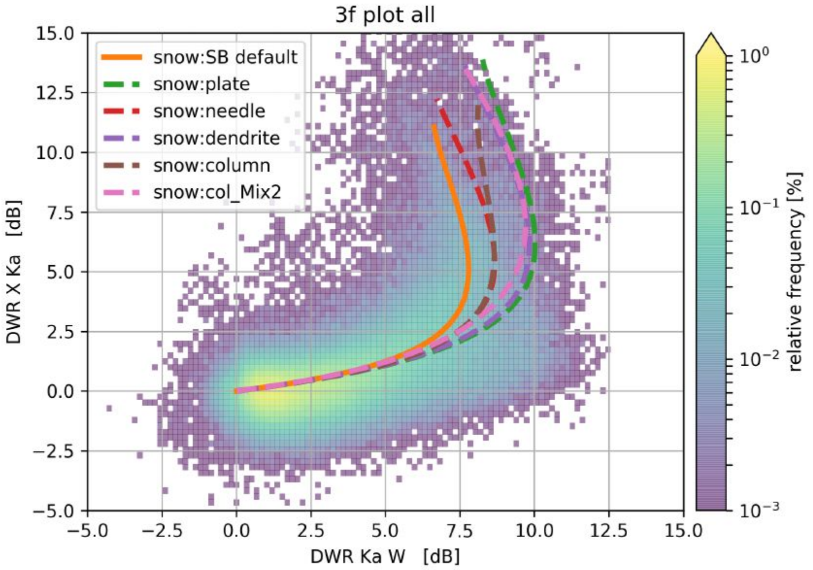
3 co-located vertically pointing radars
(X, Ka and W band) - polarimetric and Doppler

Processed dataset publicly available (Dias Neto et al. 2019)

Test the scattering properties:

Aggregates of needles represent well the portion of the dataset with the largest snowflakes

Instrument simulator PAMTRA (Mech et al. submitted to GMD)



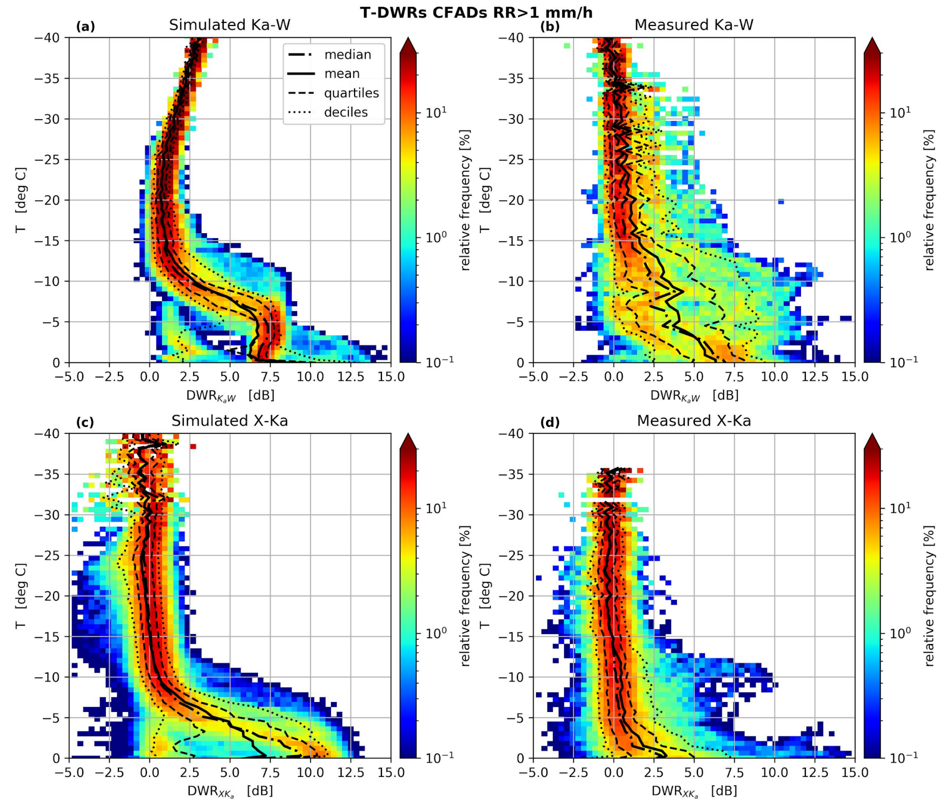
Application: ICON-LEM microphysics evaluation

Statistics of multifrequency observation and forward modeled (PAMTRA Mech et al. submitted) synthetic measurements

Restricted to precipitating clouds RR> 1 mm/h

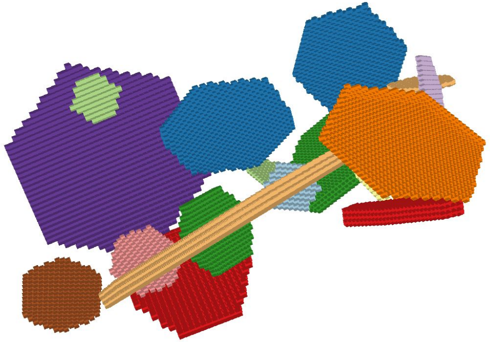
The ice particle growth in the model appears overestimated

Most probably related to parametrizations of snow aggregation



Ori et al. (to be submitted to QJRMS)

Modeling snowflakes fallspeed

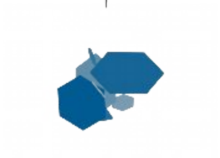


Particle terminal fallspeed also depend on the shape

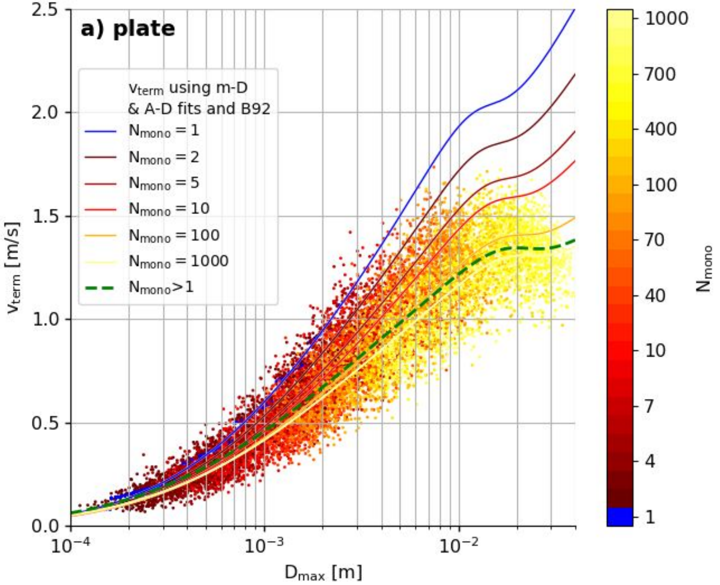
ρ_{air} air density
A projected area
C_D drag coefficient
Re Reynolds number

$F_{drag} = \rho_{air}/2 \, A \, C_D \, v^2_{term}$

$C_D = f(Re)$
$Re \sim v_{term}$



$F_{gravity} = mg$



Karrer et al. (submitted to JAMES)

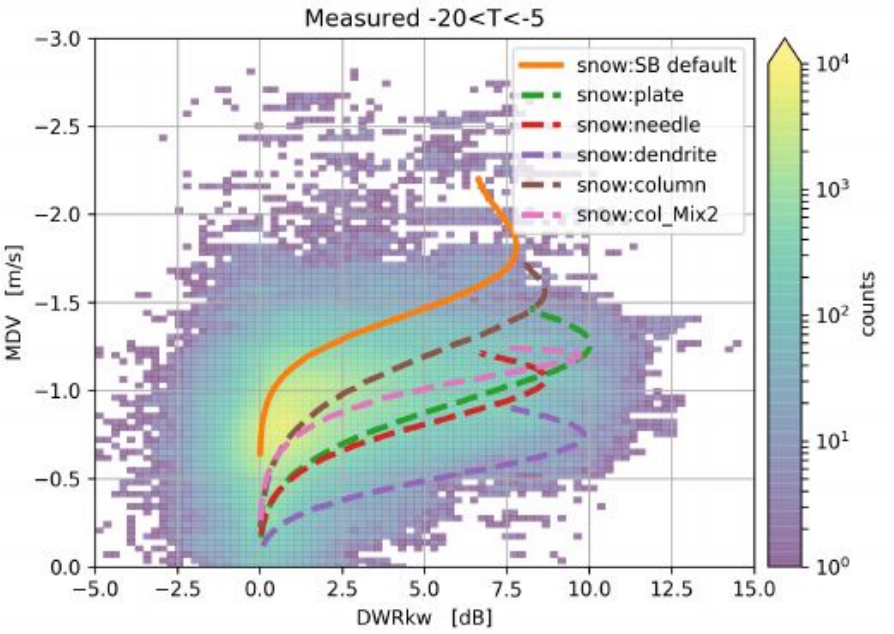
The **mass**,
fallspeed
and **scattering** properties are linked together through a consistent physical model

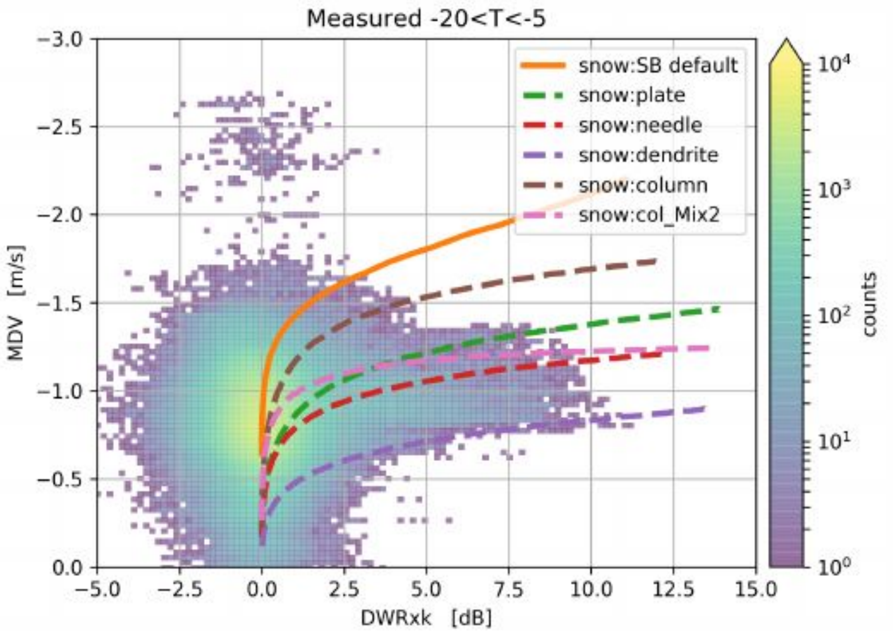
We see a continuous transition of fallspeed characteristics as a function of the aggregation stage

Connect scattering with sedimentation

Test with multifrequency ground based Doppler radars

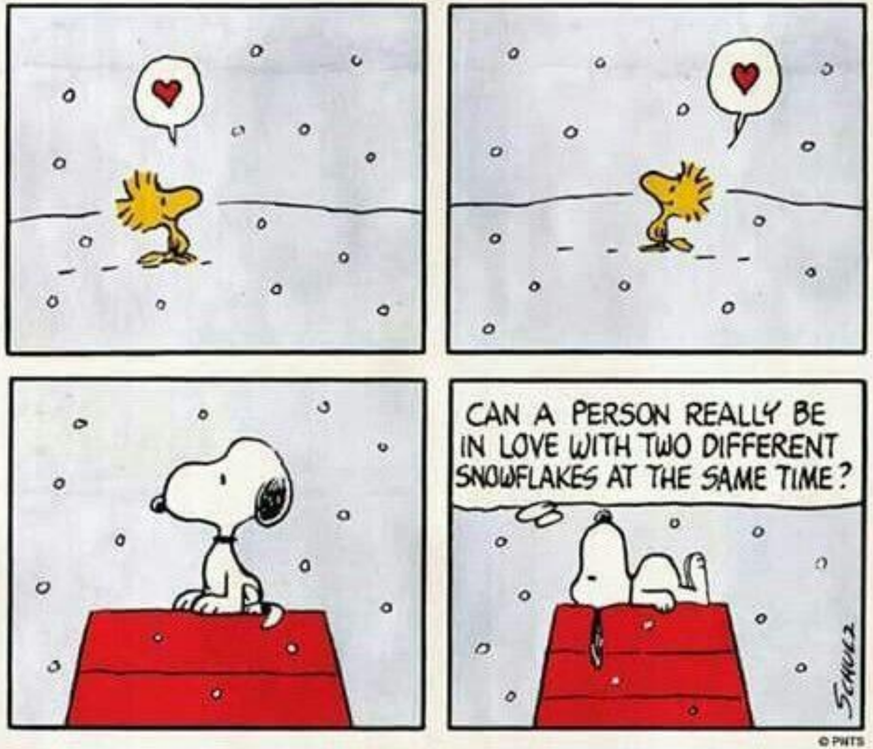
The fallspeed relation implemented in the model overestimates Doppler velocity





Summary

- Model many snow aggregates to cover the range of observed variability of properties
- Use SSRGA to model their microwave scattering properties realistically
- Use hydrodynamic theory to calculate their terminal fallspeed consistently
- PAMTRA can simulate passive and active microwave measurements using SSRGA
- The multifrequency approach helps constrain the scattering properties of snowflakes
- With our modeling approach we can relate the observed scattering properties with the underlying snow shape model
- The scattering properties are related to particle ensembles not individual properties


CAN A PERSON REALLY BE IN LOVE WITH TWO DIFFERENT SNOWFLAKES AT THE SAME TIME?
SCHULZ
© PNTS

Application: model evaluation

Not easy to find differences if non-precipitating clouds are left