Impact of ice aggregate parameters on microwave and sub-millimetre scattering properties

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Abstract

Improved observations of ice hydrometeors can lead to better weather predictions and understanding of the hydrological cycle. Global coverage is best achieved by satellites, using active and passive microwave remote sensing due to the inherent penetration capability and sensitivity to the snow and ice cloud particles which scatter and absorb the radiation. Snow and cirrus cloud particles are to a large degree composed of aggregates. While it is known that the shape of these aggregates influence microwave measurements to various degrees, it is currently not fully clear to what extent certain particle features are of importance. For example, of what importance is the shape of individual crystals in the aggregates? This work is an attempt at improving our knowledge on the impact of ice aggregate microphysics on microwave and sub-millimetre scattering properties from a modelling point of view. A large amount of aggregates (roughly 4000) where modelled through several semi-physical stochastic simulations. The aggregates are composed of hexagonal ice crystals of varying axis ratio, ranging from 1/15 (plates) to 15 (columns), and assumed to be oriented in the horizontal plane. Single scattering properties of over 1000 aggregates were then assessed for zenith/nadir observations, using the discrete dipole approximation (DDA) at three typical radar bands (13.4, 35.6, 94.1 GHz) and three passive microwave frequencies (183.3, 325.15 and 664 GHz). An analysis on the sensitivity of these scattering data to various aggregate parameters is presented. In general, extinction was found to be less sensitive to shape than back-scattering at investigated at frequencies. Extinction at 664 GHz in particular was found to be shape insensitive; promising for the sake of the Ice Cloud Imager (ICI) on the upcoming Metop-SG satellite. In contrast, evaluation of triple frequency signatures showed relatively high shape sensitivity; of relevance to future multi-frequency radars.

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Introduction

Understanding electromagnetic scattering by ice particles is important for microwave radiative transfer and remote sensing. Ice aggregates have complex shapes, but are generally simplified in models. Improving the representation of aggregates could lead to better weather prediction through data assimilation, for instance.

This study investigates the impact of aggregate characteristics on single and bulk scattering properties. The total modelling system consists of two parts. 1) Generating particle model data, and 2) Calculating the scattering properties of generated particles.

This poster is based on the study presented in [1].

Particle model data

Aggregate particles were generated in a stochastic fashion, explicitly simulating the aggregation of hexagonal crystals.

Several simulation runs were performed, assuming different crystal axis ratio r_{cryst}, ranging from 1/15 to 15. r_{cryst} is here defined as $r_{\mathrm{cryst}} = h/(2a)$, where h is the height and a the side base length of the crystal.

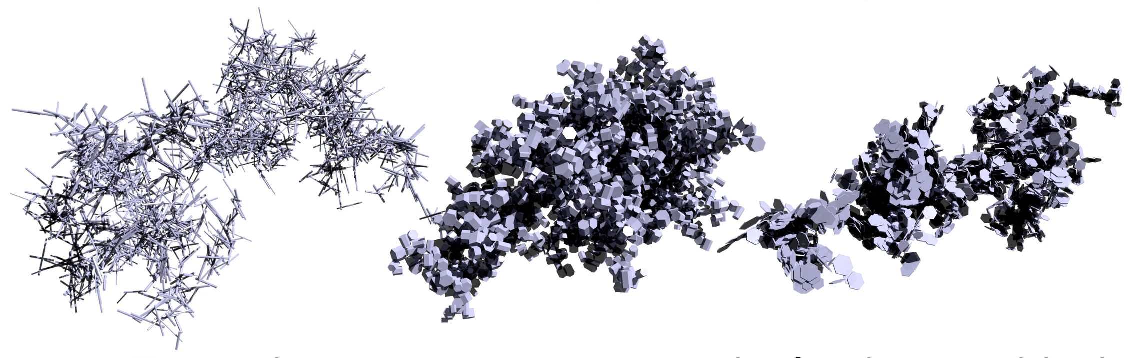

Fig. 1: Example aggregates composed of columns, blocks and plates ($r_{\mathrm{cryst}} = 15$, 1 and 1/15, respectively.)

The particles are here mainly characterized using the aerodynamic area ratio A_{r}:

$$A_{\mathrm{r}} = \frac{4A_{\mathrm{aer}}}{\pi D_{veq}^2},$$

where A_{aer} is the aerodynamic area and D_{veq} is the volume-equivalent diameter of the particle.

Scattering calculations

Electromagnetic scattering by the aggregates was calculated using the Discrete Dipole Approximation (DDA) method, which treats arbitrarily shaped particles. The Amsterdam DDA implementation was used.

Incident radiation travels along the nadir or zenith direction, and particles are aligned with their maximum moment of inertia axes normal to the horizontal plane.

Results: single scattering

Single scattering properties are shown in terms of extinction efficiency Q_{e} at common passive microwave frequencies 183.31, 325.15 and 664.00 GHz, and back-scattering efficiency Q_b at radar frequencies 13.4, 35.6 and 94.1 GHz.

Only particles with $D_{\mathrm{veq}} \approx 2\,\mathrm{mm}$ are shown here.

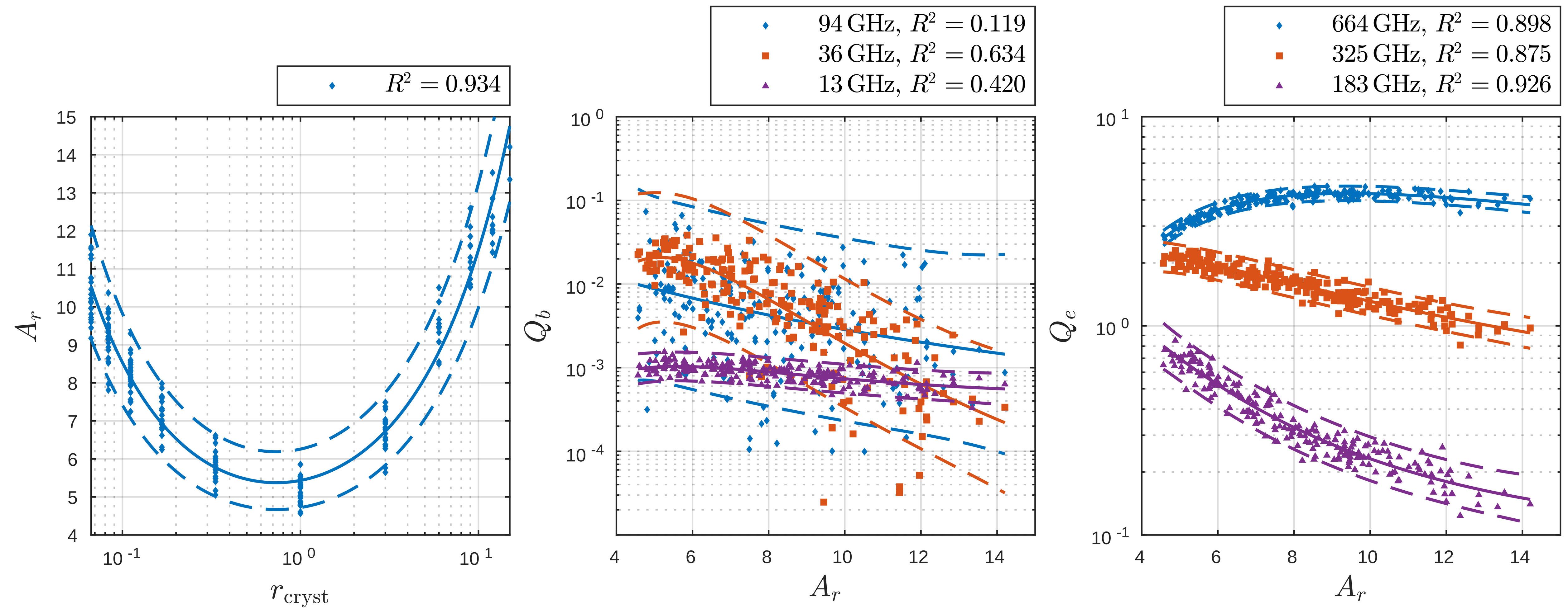

Fig. 2: Left: A_{r} as a function of r_{cryst}. Middle: Back-scattering as a function of A_{r}. Right: Extinction as a function of A_{r}. Points represent individual particles, while the full lines are 3-degree polynomial fits and dashed lines are the associated prediction bounds. R-squared values (R^2) are reported for each fit in the legends.

Results: bulk scattering

Bulk scattering quantities (i.e. scattering from a whole volume element) such as the extinction coefficient γ_{e}, are calculated for particle ensembles assuming an exponential size distribution, i.e. $N(D_{veq}) = N_0 e^{-\Lambda D_{veq}}$.

Bulk back-scattering is shown in terms of radar triple frequency signatures, defined as pairs of dual wavelength ratios (DWR), i.e. ratios of radar reflectivities (in log-space) at three selected radar frequencies.

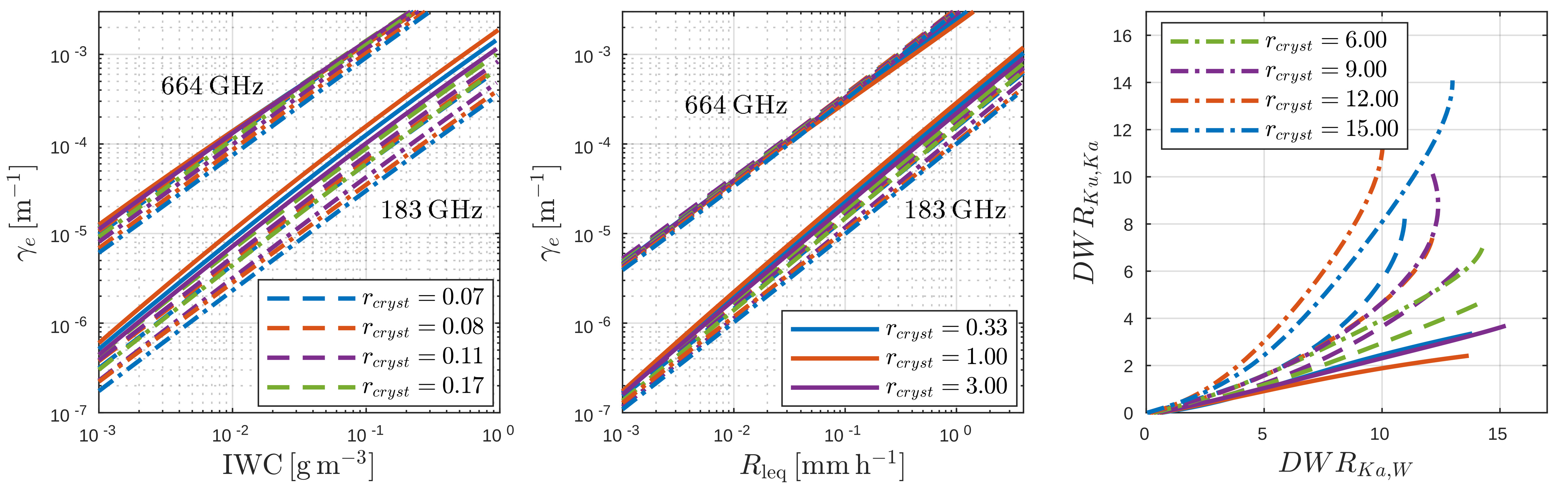

Fig. 3: Bulk scattering properties, divided into lines of r_{cryst}. Legends are common to all panels. Left: Bulk extinction as a function of ice water content (IWC) at 183.31 GHz and 664.00 GHz. Middle: As left, but with snowfall rate R_{leq} on the x-axis. Right: Triple frequency signatures, at frequencies: 13.4, 25.6 and 94.1 GHz ($\mathrm{K_u}$, $\mathrm{K_a}$ and W-band, respectively).

Conclusions

A clear impact of crystal axis ratio (r_{cryst}) on resulting simulated aggregates characteristics, e.g. aerodynamic area ratio (A_{r}), can be observed.

Moreover, A_{r} shows a clear impact on investigated single scattering properties, i.e. extinction efficiency and back-scattering.

Bulk extinction (γ_{e}) shows less sensitivity to r_{cryst} at 664 GHz than at 183 GHz. Also, retrieval of snowfall rate is potentially more accurate than for ice water content.

Outlook

Ongoing efforts focus on the impact on radiative transfer simulations.

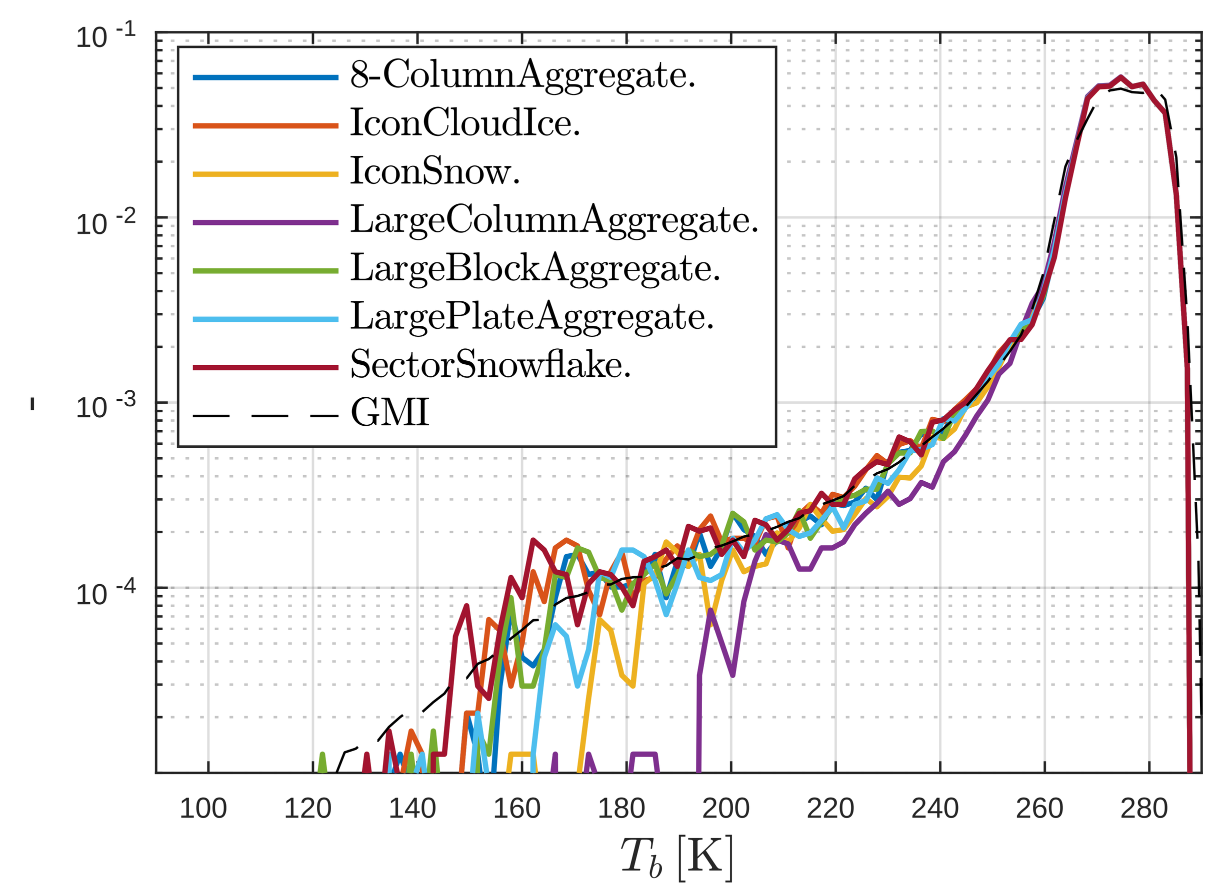

Fig. 4: Occurrence frequencies of simulated brightness temperatures, assuming different particle models taken from [2]. Simulations mimic GPM Global Imager (GMI) measurements over the tropical pacific ocean. Synthetic scenes based on the v2.1.1 DARDAR product were used as input.

Acknowledgements/References

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Rymdstyrelsen
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[1] Robin Ekelund and Patrick Eriksson. Impact of ice aggregate parameters on microwave and sub-millimetre scattering properties. *J. Quant. Spectrosc. Radiat. Transf.*, 224:233–246, feb 2019.

[2] P. Eriksson, R. Ekelund, J. Mendrok, M. Brath, O. Lemke, and S. A. Buehler. A general database of hydrometeor single scattering properties at microwave and sub-millimetre wavelengths. *Earth System Science Data*, 10(3):1301–1326, 2018.