Exploring Variability of Radar Backscattering Cross Sections of Dendrites at Millimeter Wavelengths

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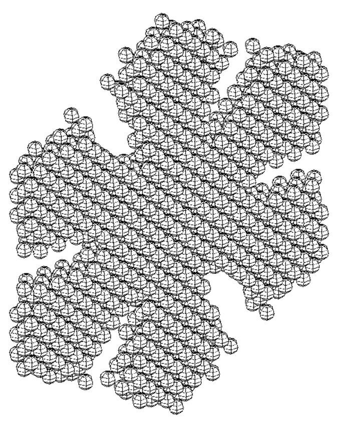
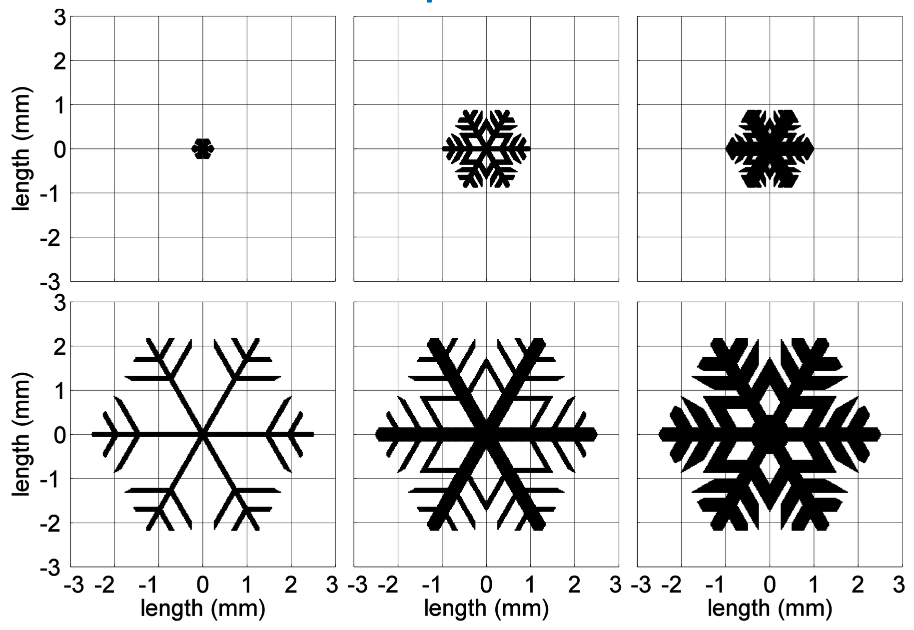
1. Introduction

Botta et al. [1] created about 600 different dendrites using closely packed tiny spheres. These dendrites have different masses, maximum dimensions, widths, numbers of branches, branch locations, etc.



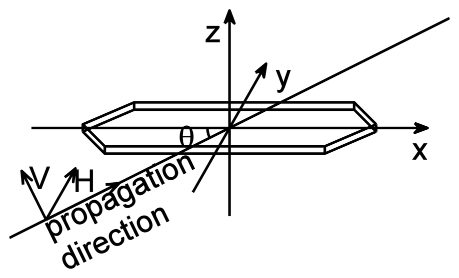
2. Dendrite Examples



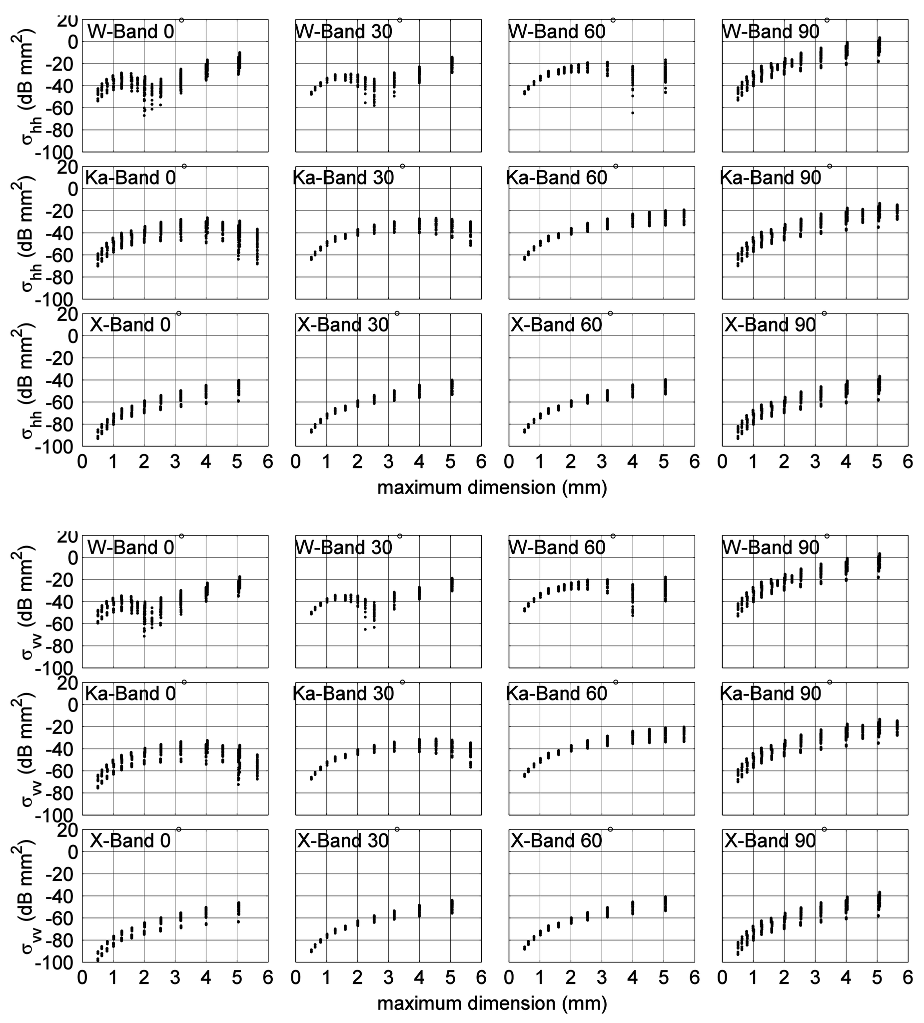
3. Calculation of Dendrite Backscattering Cross Sections

They calculated the backscattering cross sections of these dendrites using the Generalized Multi-particle Mie Method (GMM) [2] for

- Both H and V polarization
- Multiple incidence angles θ
- Three frequencies:
  - W-Band (3.19 mm)
  - Ka-Band (8.40 mm)
  - X-Band (31.86 mm)



The backscattering cross sections show large variability.



4. Questions

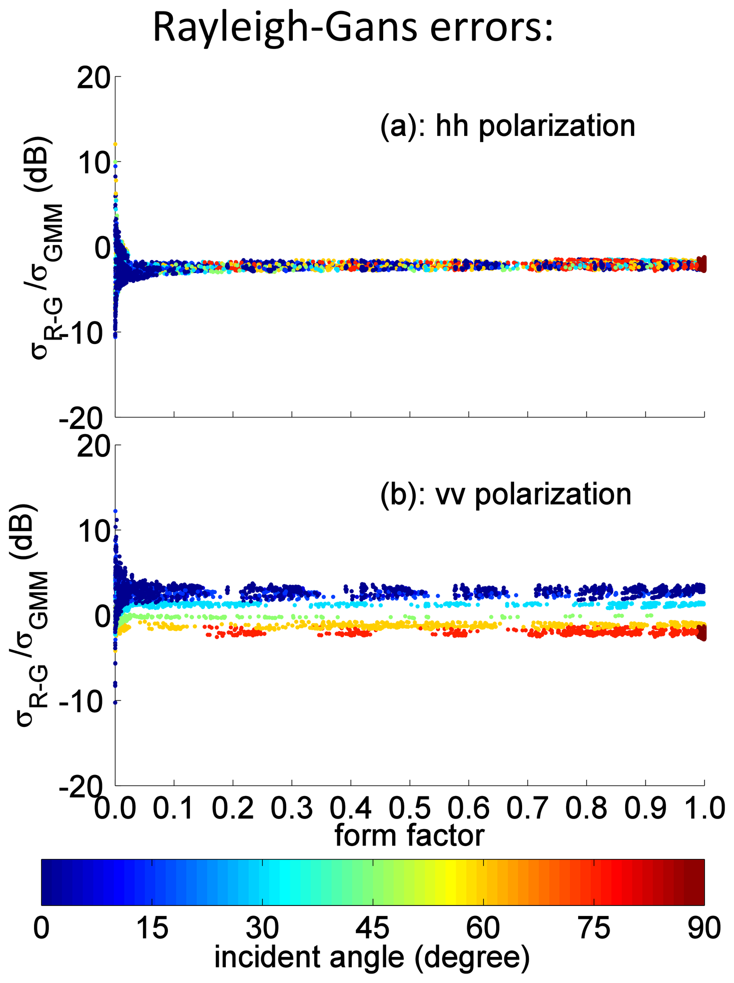
What leads to the variability?

How to model the variability?

5. Rayleigh-Gans theory: Interference effects

- Divide particle into small volumes
- Ignore the interaction between these small volumes
- The way mass is distributed along propagation direction is critical.
- Captures the interference effects between the small volumes
- f: form factor
- σ_r: Rayleigh backscattering cross section
- $\sigma_{R\text{-}G}$: Backscattering cross section calculated using the Rayleigh-Gans theory
- For HH polarization, most errors are about −2 dB.
- For VV polarization, most errors range from −2 dB to 5 dB.

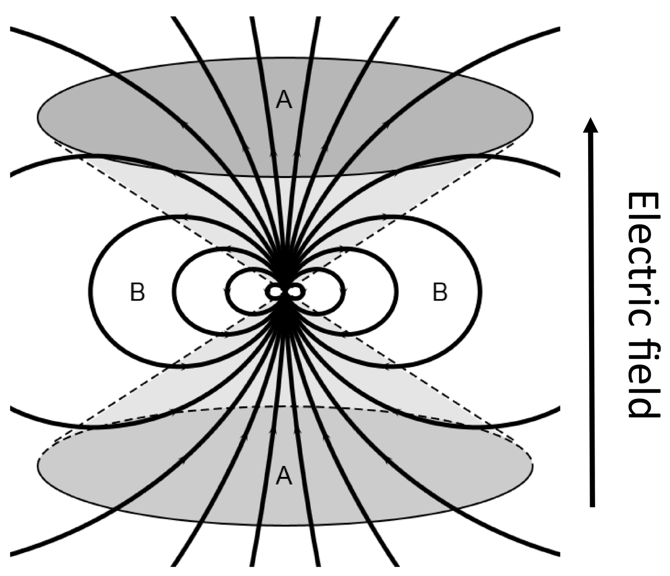
Rayleigh-Gans errors:

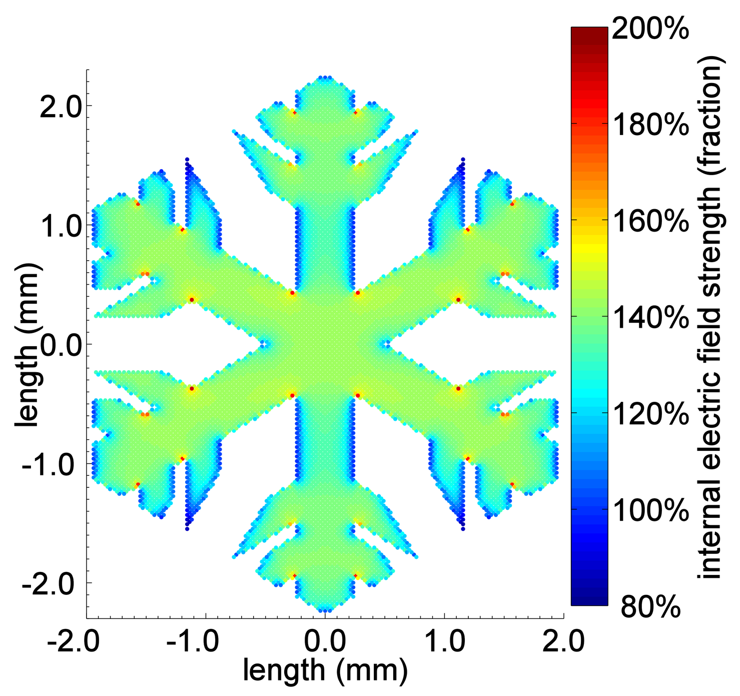


$$\sigma = \sigma_r \cdot f, \quad \sigma_r = \frac{9k^4}{4\pi}\left|\frac{\varepsilon - 1}{\varepsilon + 2}\right|^2 V^2, \quad f = \left|\frac{1}{V}\sum_m \left(V_m \exp\left(i2kz_m\right)\right)\right|^2,$$

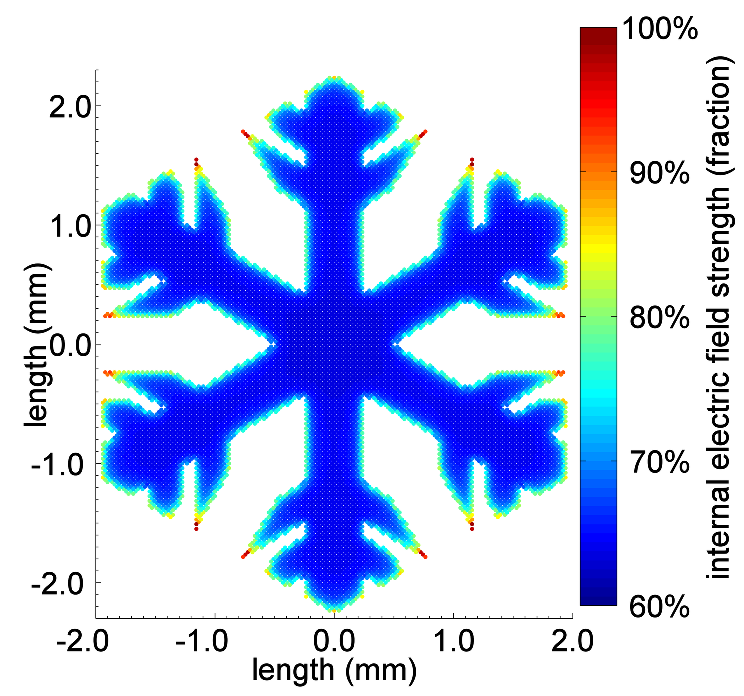
6. Internal Field Strength: Interaction Between the Small Volumes

- Each tiny sphere is modeled as a dipole driven by a plane wave.
- Each tiny sphere increases (decreases) the electric field at the location of its neighbors inside (outside) the shaded cones.
- Internal electric field at the location of each sphere is estimated using an iterative based method.
- Internal electric field through a dendrite for two polarization directions are shown below





polarization direction



polarization direction

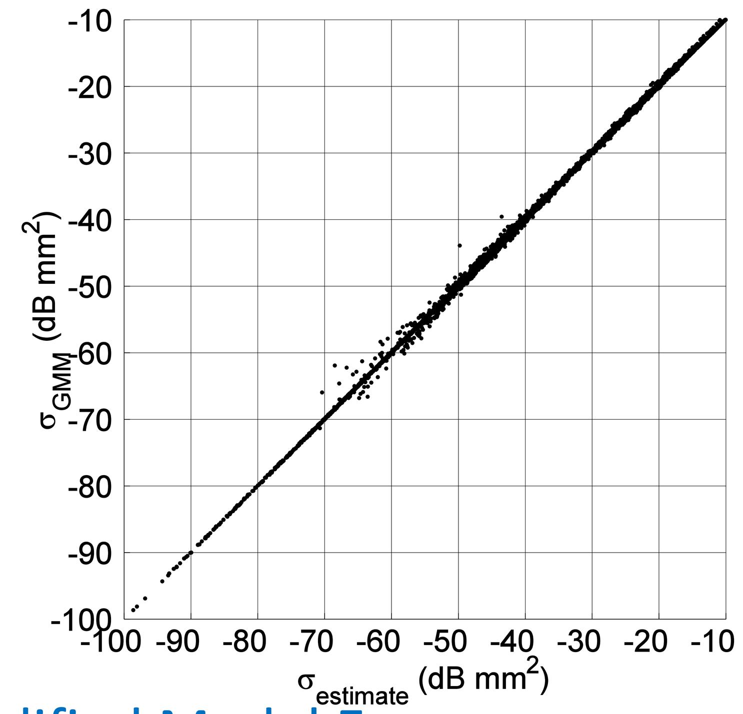
7. Modified Form Factor

- Combining interference effects and internal interactions, we modify the form factor:

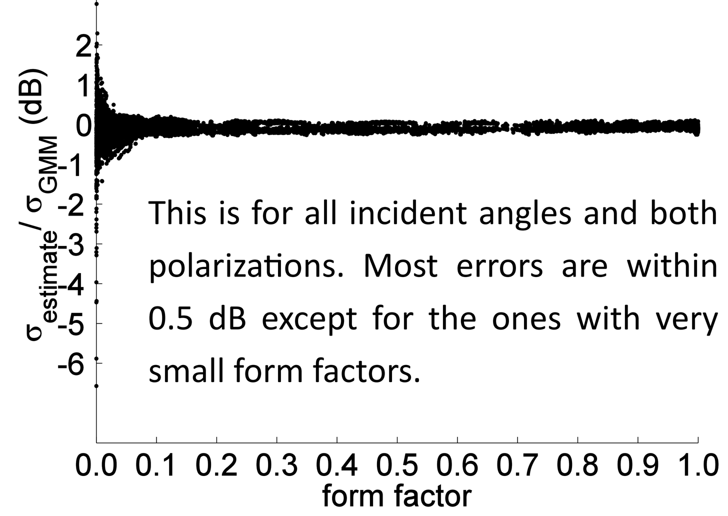
$$\sigma = \sigma_r \cdot f_{mod}, \quad f_{mod} = \left|\frac{1}{V}\sum_m \left(A_m V_m \exp\left(i2kz_m\right)\right)\right|^2,$$

where A_m is the normalized internal electric field strength for the m^{th} tiny sphere.

8. Model Fit to GMM Calculations



9. Modified Model Errors



10. Conclusions:

- The detailed crystal shape must be provided to estimate the backscattering cross section.
- The modified form factor is promising as a predictor variable for backscattering cross sections.

References:

[1]G. Botta, K. Aydin, J. Verlinde, Database for dendrite scattering properties, J. Quant. Spectrosc. Radiat. Transf. In progress

[2]Y.-l. Xu, Electromagnetic scattering by an aggregate of spheres, Appl. Opt. 34 (21) (1995) 4573–88, doi:10.1364/AO.34.004573

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