Optical Properties of Small Ice Crystals with Black Carbon Inclusions

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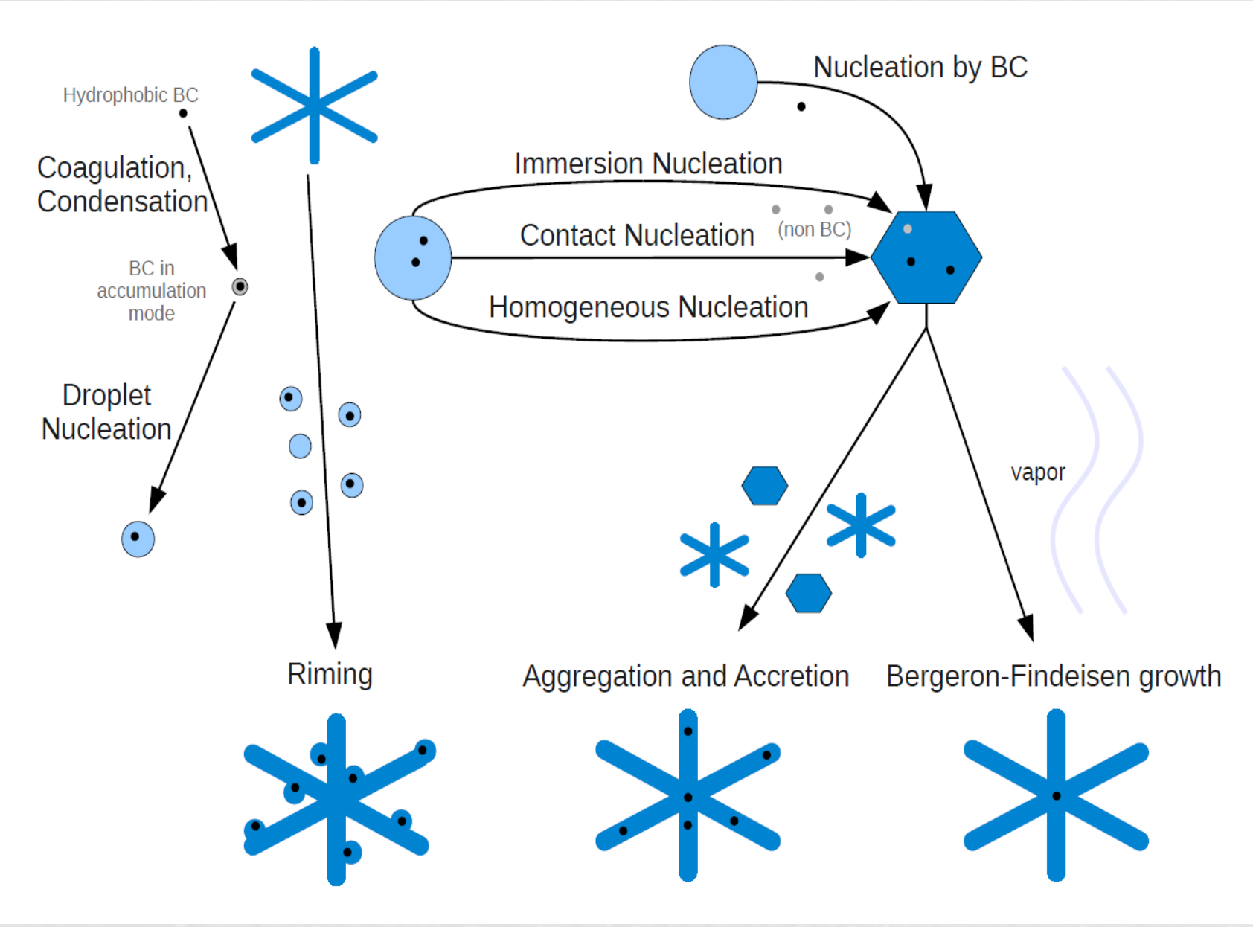
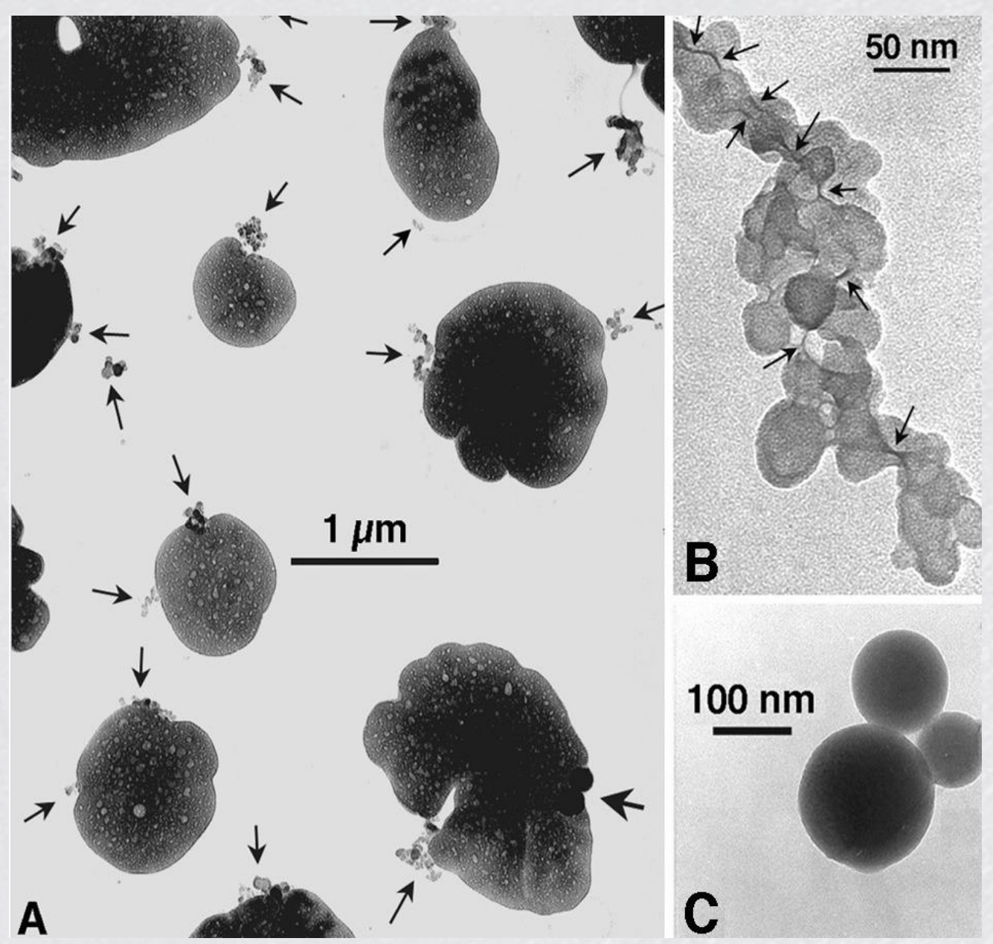
Challenge: modify the optical properties of ice crystals to model Black Carbon (BC) inclusions



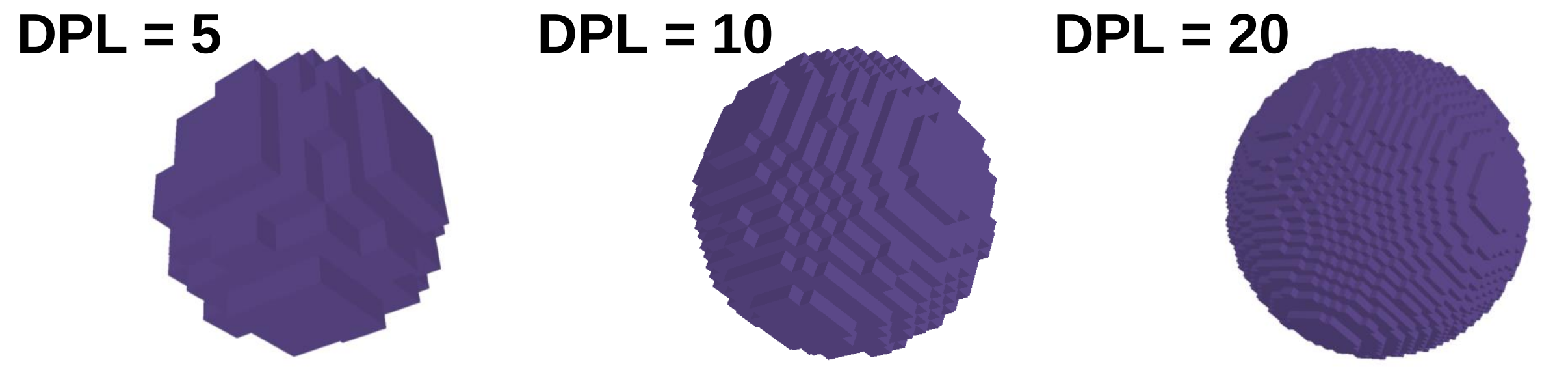
Schematic of mechanisms by which black carbon can enter into precipitating ice hydrometeors.
(Flanner et al. *Atmos. Chem. & Phys.* 2012)



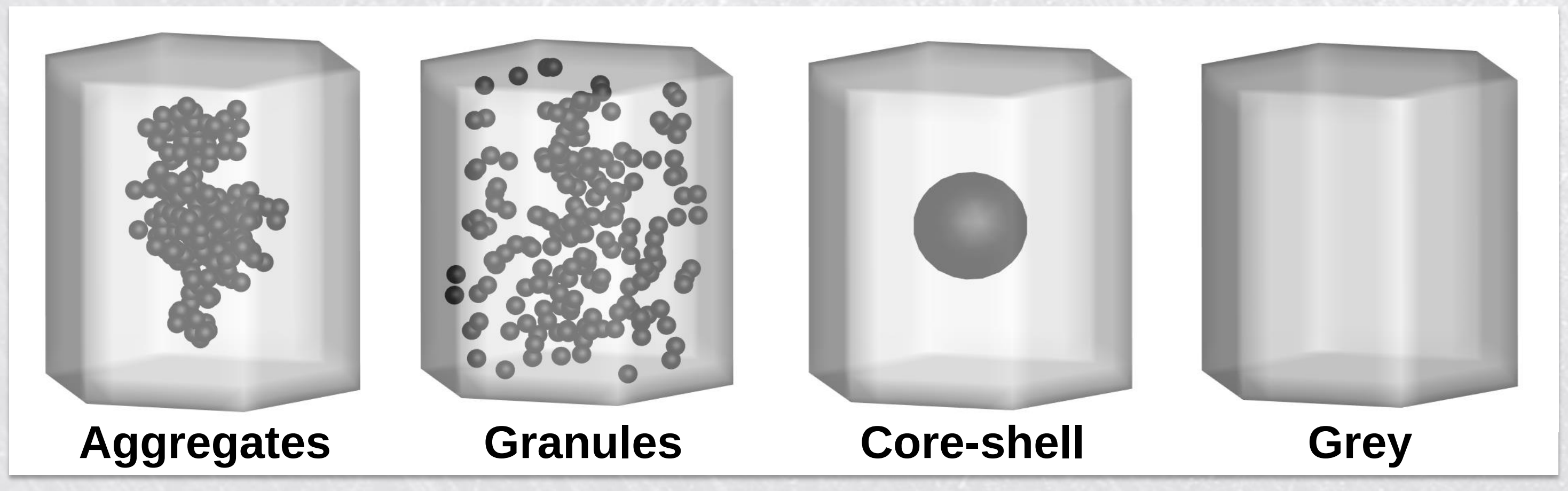
A: Black carbon mixed with sulphate particles.
B: Typical chain-like black carbon aggregate
C: Fly-ash black carbon particles spheres
(Pósfai et al., *J Geophys Res.* 1999)

Method: DDA models

Discrete Dipole Approximation computes scattering of radiation by particles of arbitrary shape (Yurkin & Hoekstra, *J. Quant. Spectrosc. Radiat*., 2011)



Spheres (x = 12) discretized with different dipole per wavelength (dpl)



"Granules" Crystal model: assume BC is included as randomly distributed granules and each BC monomer is discretized using multiple dipoles

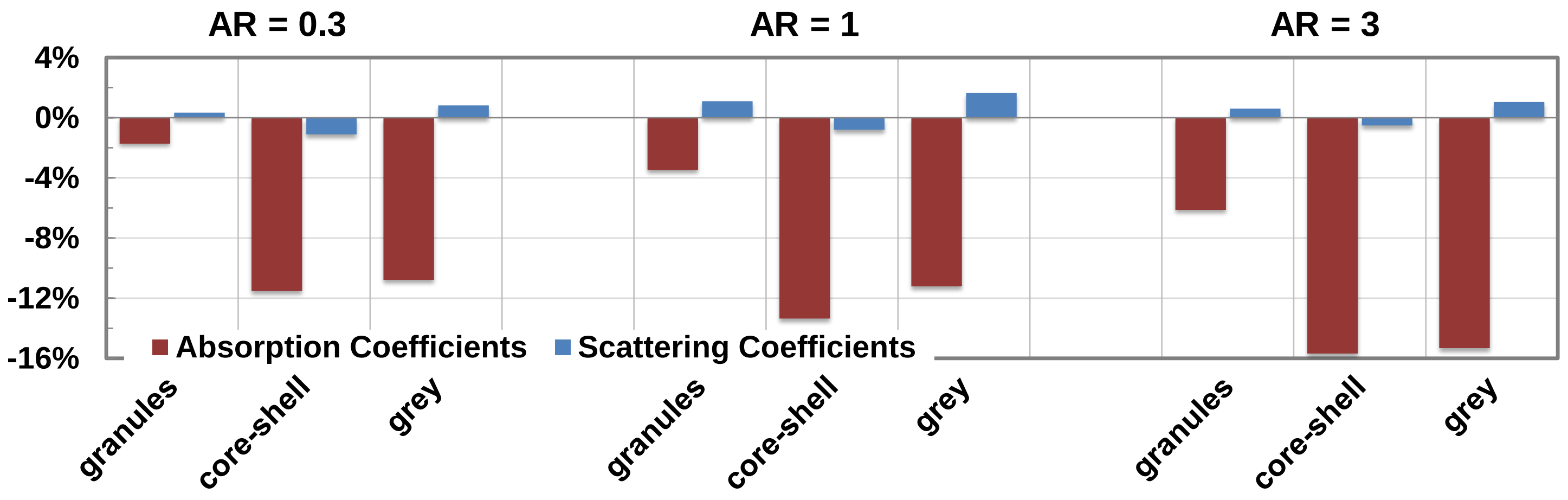
"Grey" Crystal model: assume BC is completely mixed internally with ice following the *Maxwell Garnett Mixing Rule*:

$$\varepsilon_{eff} = \varepsilon_m \frac{2(1-\delta_i)\varepsilon_m + (1+2\delta_i)\varepsilon_i}{(2+\delta_i)\varepsilon_m + (1-\delta_i)\varepsilon_i}$$

ε_{eff}, ε_i and ε_m are the refractive indices of the effective medium, BC inclusion and ice at 532 nm.; δ_i is the volume fraction of the inclusions.

BC Distribution Models

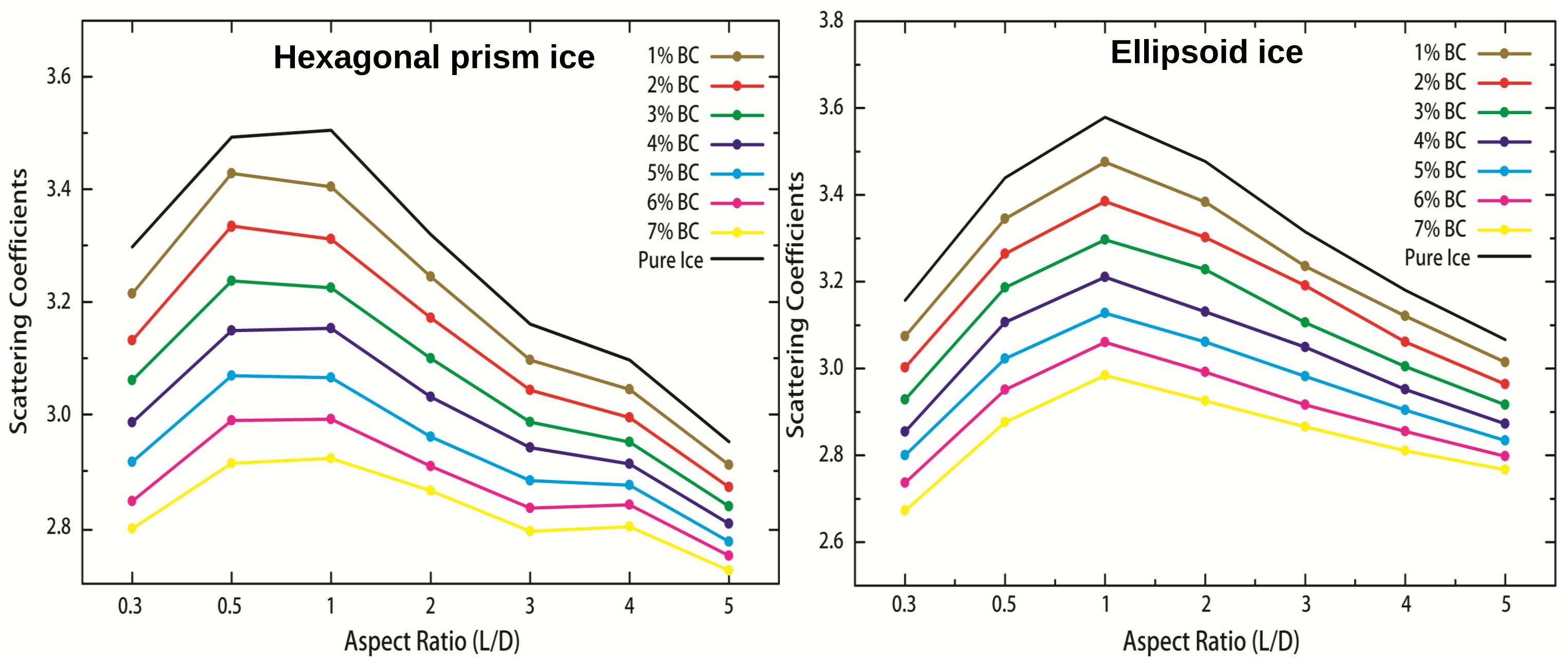
Percentage of deviation for V = 0.4 μm³ hexagonal ice crystals with 1.2% BC inclusions at 532 nm



- The absorption coefficient with respect to the reference "aggregate" scenario is under-estimated by 2% to 16%, with the largest error due to the "core-shell" model.
- The scattering coefficient is less affected by the BC distribution models.

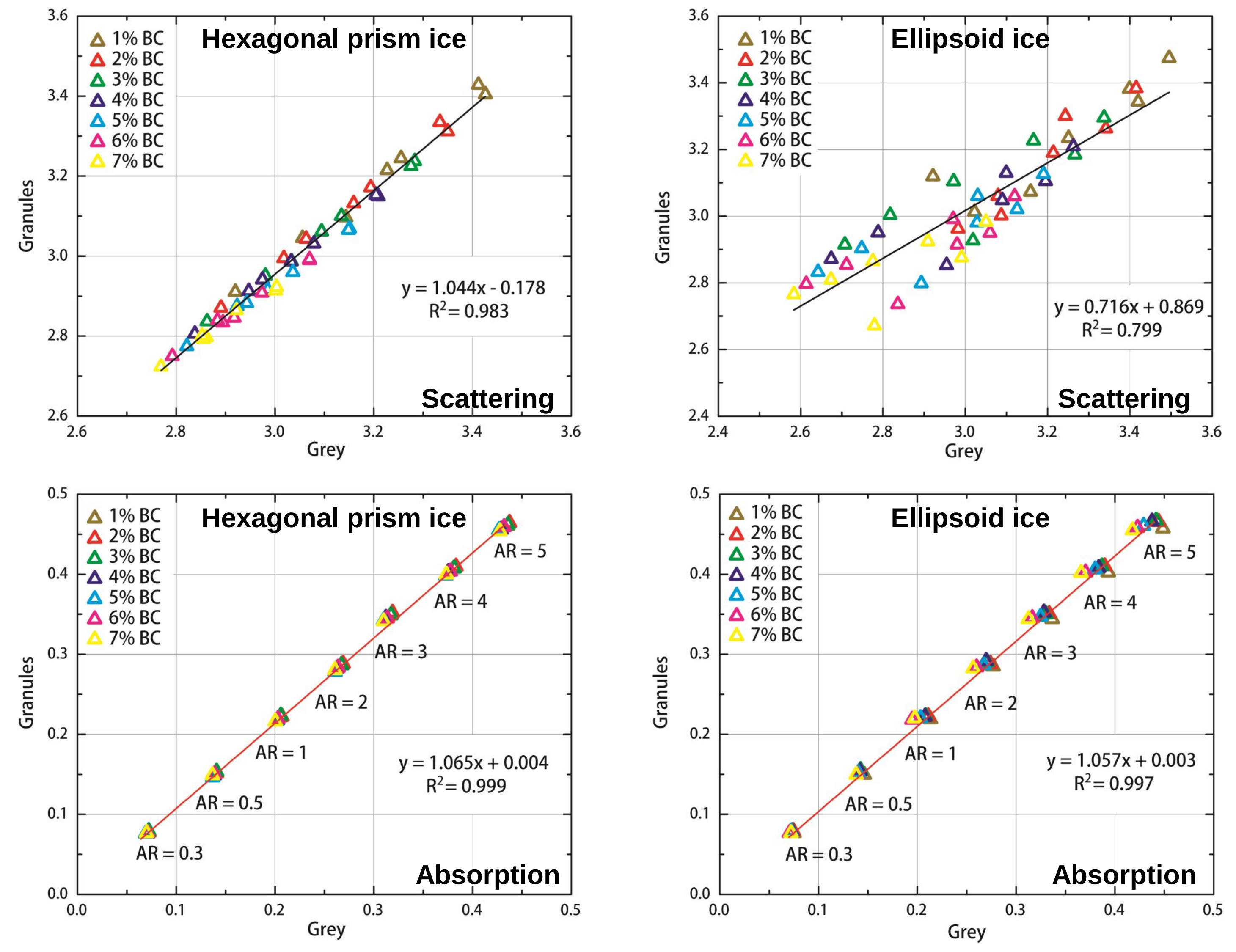
Dependence on Crystal Shape

Scattering coefficients for V = 0.4 μm³ ice crystals with aspect ratio L/D = 0.3 ~ 5 at 532 nm with BC granules



- The scattering coefficients for the same volume crystals vary across flat to "needle" shapes.
- The ***higher*** concentration of BC, the ***smaller*** the variations.
- The ***longer*** the crystal is (L/D >1), the smaller the difference of scattering across percentages of BC inclusions.

"Grey" vs. "Granules" for V = 0.4 μm³ ice crystals with aspect ratio L/D = 0.3 ~ 5 at 532 nm



- The absorption coefficient is directly related to the concentration of BC with no significant variation across shapes.

Conclusions and Future Work

1. The aspect ratio (AR) has a major effect on the particle's scattering. It may require more careful characterization in current climate models.
2. Absorption is mainly dependent on the BC concentration and its distribution. Commonly used inclusion models all underestimate absorption.
3. With increasing BC concentration, scattering is less affected by AR variations.
4. The volume of ice examined is small. We are working on scaling up the analysis using ray tracing methodology with more complex ice crystal shapes.

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