Microwave scattering coefficient of snow: Microstructural requirements beyond density and grain size

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MicroSnow II Workshop, Columbia, 13-17 July 2015
Lessons learned

Snow observations in the past:

General agreement about the risks:

- Smoking is bad for your health
- Traditional grain size is bad for your satellite mission
Overview: Microstructure and microwaves

Electromagnetic scattering:
- IBA
- QCA
- QCA-CP

Microstructure:
- "Grain size"
- "Specific surface area"
- "Correlation length"
- "Stickiness"
- "Bicontinuous"
Goals

Starting point: (Grenoble Workshop)

- Relevance of “grain size scaling”? Brucker et al (2010)

General difficulties:

- Different RT schemes ("MEMLS" vs "DMRT-ML")
- Different scattering formulations ("IBA" vs "QCA-CP")
- Different microstructural concepts ("Sticky hard spheres" vs "Exponential correlation length"

Goals:

- Unify different microwave modeling approaches
- Understand the relevance of microwave parameters "beyond density and SSA"
Outline

- Unifying IBA and QCA-CP
- The relevance of stickiness
- Outlook for discussions
Outline

Unifying IBA and QCA-CP

The relevance of stickiness

Outlook for discussions
Relating pair and two-point correlations

**Key relation**, valid for arbitrary sphere packings: (Stell & Torquato, 1982)

\[ C(r) = n v_{\text{int}}(r) + n^2 (v_{\text{int}} * g)(r) \]

- \( v_{\text{int}}(r) \): Intersection volume of two spheres
- \( n \): number density of spheres

**Various implications:**

1. Allows to map \( \mu \)CT images onto arbitrary hard-sphere packings
2. Allows to implement hard-sphere packings in IBA
3. Allows to compare scattering models in IBA and QCA-CP

(Löwe & Picard, 2015)
Comparison of scattering in IBA and QCA-CP

Scattering coefficient $\kappa_s$: evaluated for arbitrary hard sphere packings (in the low frequency limit!)

$$\kappa_s^{\text{IBA}} = \frac{2}{9} k_0^4 a^3 \phi_2 f^{\text{IBA}}(\varepsilon_1, \varepsilon_2, \phi_2) \tilde{C}(0)$$

$$\kappa_s^{\text{QCA-CP}} = \frac{2}{9} k_0^4 a^3 \phi_2 f^{\text{QCA-CP}}(\varepsilon_1, \varepsilon_2, \phi_2) \tilde{C}(0)$$

Microstructure parameter:

- $\tilde{C}(0)$: Zero-wavevector component of the Fourier transform of the correlation function (related to coarseness parameter)

Main messages:

- “Slight difference in dielectrics”: $f^{\text{IBA}}$ vs $f^{\text{QCA-CP}}$, ratio $r_s$:
- “No difference in the microstructure”: $\tilde{C}(0)$

![Equation (29)](image-url)
Evaluating everything for sticky hard spheres: from the “167-µCT images” data set (Löwe et al. TC, 2013)

Main message: “One stickiness fits all” fails.
Main message: SHS diameter $\neq$ optical diameter
“grain size modification” necessary but not straightforward
Results: SHS reconstruction of $\mu$CT data

Optimization landscapes for different snowtypes (examples):

New snow:

Rounded grains:

Depth hoar:

Main message: “Goodness” of SHS depends on snow type
Main message: Scattering coefficient in IBA and QCA-CP are “essentially the same” (if evaluated for exactly the same microstructure).
Outline

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Outlook for discussions
Recap: Sticky hard spheres

Model for a molecular fluid (Baxter, 1967)

- Determined by volume fraction: $\phi_2$, diameter: $d$, stickiness $\tau$

Example realizations: (identical $d, \phi_2$)

$\tau = 10.0$

$\tau = 0.11$

(MC code acknowledgements: K.H. Ding, S. Tan, L. Tsang)

Impact of stickiness $\tau$

- cluster sizes / volume fraction fluctuations / pore sizes / coordination numbers / ...
Mechanics of SHS: Discrete element simulations

Uniaxial compression and SnowMicroPen simulations:

Goals:

- Cross-property relations
- Stickiness retrieval by SMP
Mechanics of SHS: Preliminary results

Elastic modulus (uniaxial compression):

Impact of stickiness, as expected:

- via the SHS coordination number

\[ n_c = 2\phi_2 t(\phi_2, \tau) \]
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Microstructure activities

Is there an “optimal” model?

- Evaluate RMSE differences between exponential model, sticky hard spheres, bicontinuous level-cut GRF, Teubner–Strey (cf. small angle scattering methods)
Field activities

Snow cores: \( \mu \)CT sample casting technique

- Carried out for NOSREX, ASMEX (→ talk Will Maslanka)
- SnowEx? (in combination with microwave measurements)
“Microstructural origin of electromagnetic signatures in microwave remote sensing of snow”

- ESA project (→ poster Mel Sandells)