Snow specific surface area retrieval from reflectance measurements: the question of snow grain shape

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See Poster for more details

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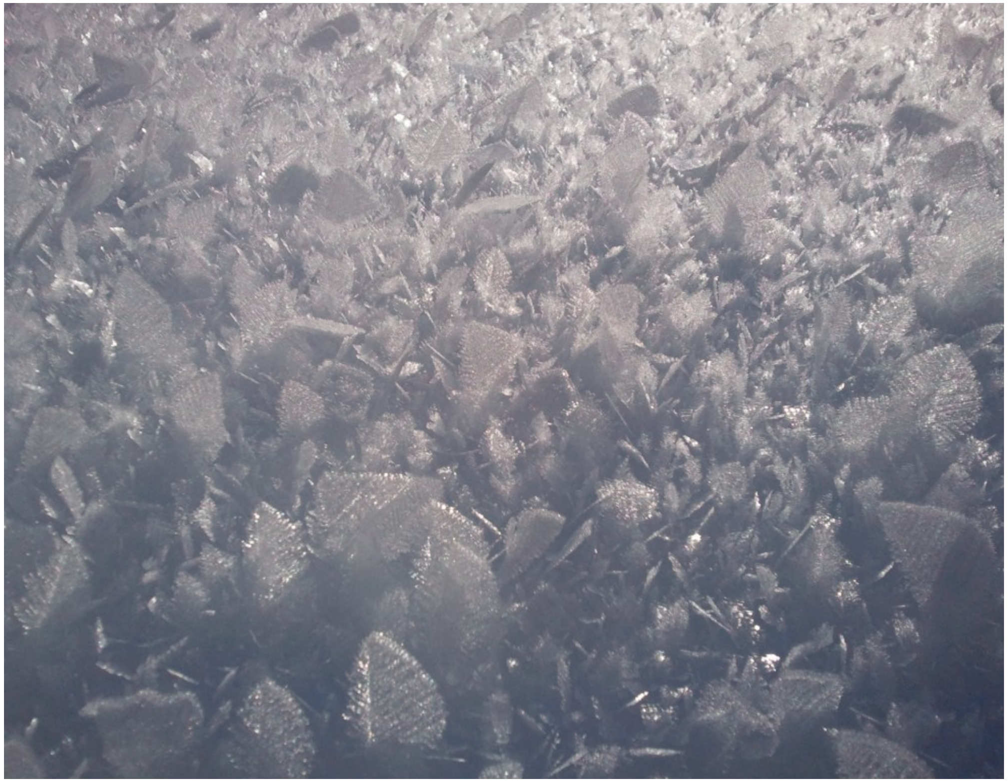
Context

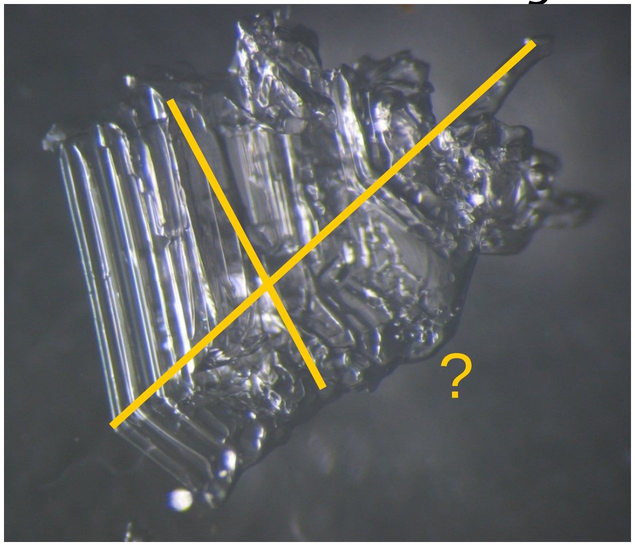
A simple naive question: Snow albedo depends on grain size (in the near infrared) but does it also depend on grain shape ?



In other terms: what is the uncertainty due to not knowing the grain shape when estimating grain size from albedo measurement ?

Context

It is naive because a metrics for "grain size" has to be chosen before addressing the question of the sensitivity to the shape.



Numerous electromagnetic or ray tracing calculations on invidual crystals have shown that the ratio **Surface/Volume** of the crystals is the « best » predictor for the albedo, at least for convex crystals

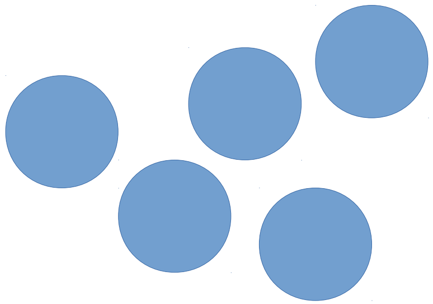
Trilogy by Grenfell et al.(1999, 2003, 2005) on ice crystals:
"Representation of a nonspherical ice particle by a collection of independent spheres for scattering and absorption of radiation"

<u>Warning:</u> "best" does not mean that S/V is a "perfect" predictor. Even with the same S/V, two crystals with different shapes have different albedo.

Context

So has been introduced the misleading **optical radius** : « the optical radius is the radius of the collection of identical spheres that have the same S/V ratio as that of snow ».

Why spheres ?



Why not to keep S/V which is defined for any bi-phasic medium, whatever it is made of grains or not ?

Florent Dominé and Martin Schneebeli have re-introduced and made popular the notion of "specific surface area" (SSA).

SSA = Surface / mass

SSA = Surface / (Volume * rho_ice)

Theoretical results

In the RT theory, the grain size and shape influence the scattering and absorption coefficients and the phase function.

Snow is a weakly absorbing medium in the visible/near-infrared → Asymptotic Radiative Transfer Theory (ARTT) by Kokhonavsky et al.:

$$\alpha(\lambda)=\exp\left(-\frac{12}{7}(1+2\cos\theta)\sqrt{\frac{2}{3}\gamma(\lambda)\frac{1}{\rho_{ice}SSA}\frac{B}{1-g}}\right)$$

Angle

Ice absorption
→ wavelength
dependence

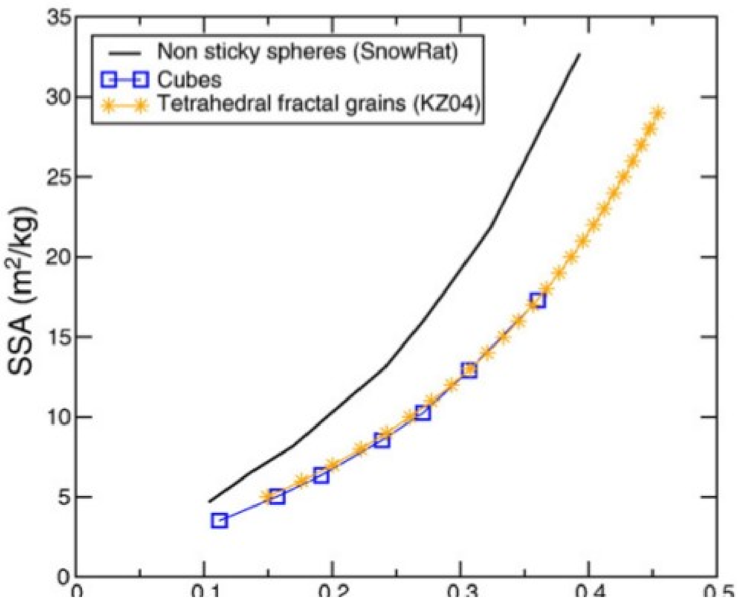
Grain size

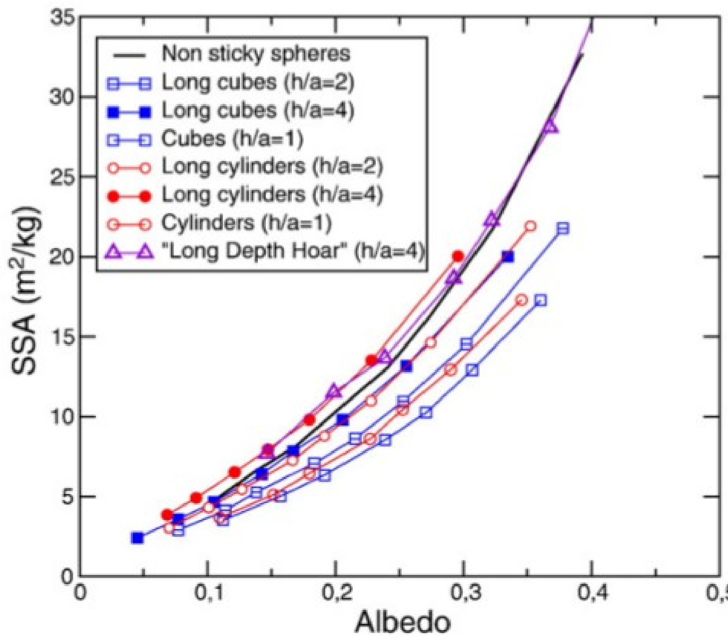
Grain shape

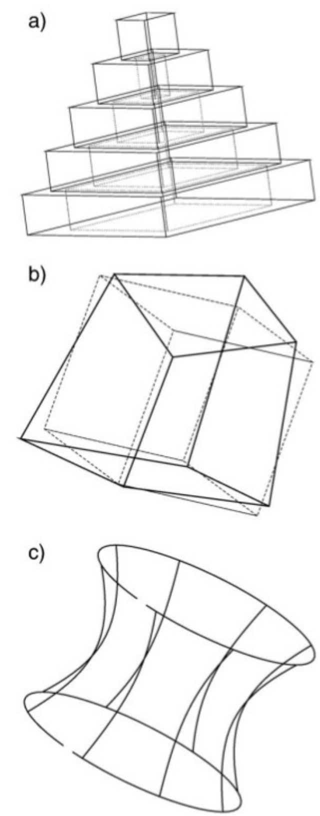
Grain shape factor is a mulpliying factor of grain size

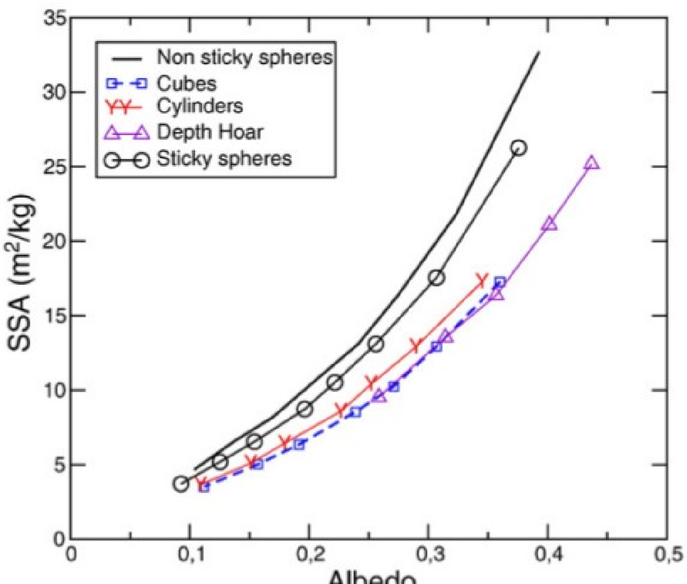
Theoretical results

Determining snow specific surface area from near-infrared reflectance measurements: Numerical study of the influence of grain shape (Picard et al. 2009)
Ray-tracing calculation on simple geometric shape









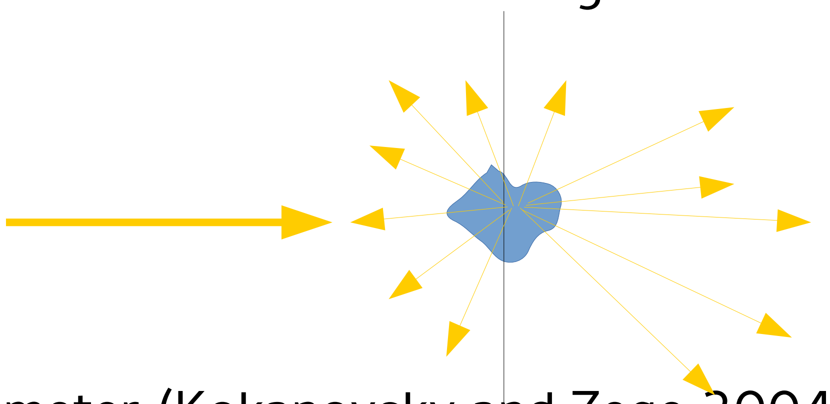
For a wide range of geometric shape, the grain shape factor varies by a factor 2 !

For a given SSA, albedo can vary by up to 1.4 due to shape

Theoretical results

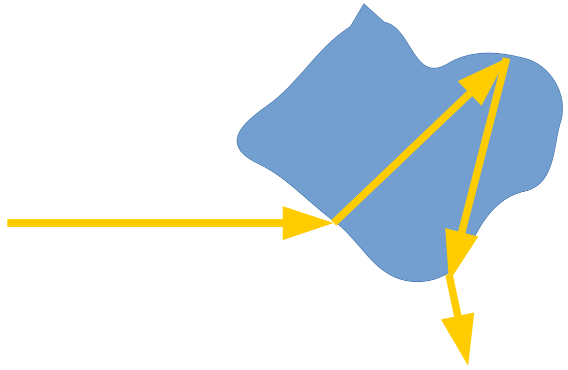
$$\alpha(\lambda)=\exp\left(-\frac{12}{7}(1+2\cos\theta)\sqrt{\frac{2}{3}\gamma(\lambda)\frac{1}{\rho_{ice}SSA}\frac{B}{1-g}}\right)$$

- g is the asymetry factor (or the 1st moment of the phase function in Legendre serie): meaure the degree of forward versus backward scattering



- B is the absorption enhancement parameter (Kokanovsky and Zege 2004)

Measure the lengthing of the path in the grain



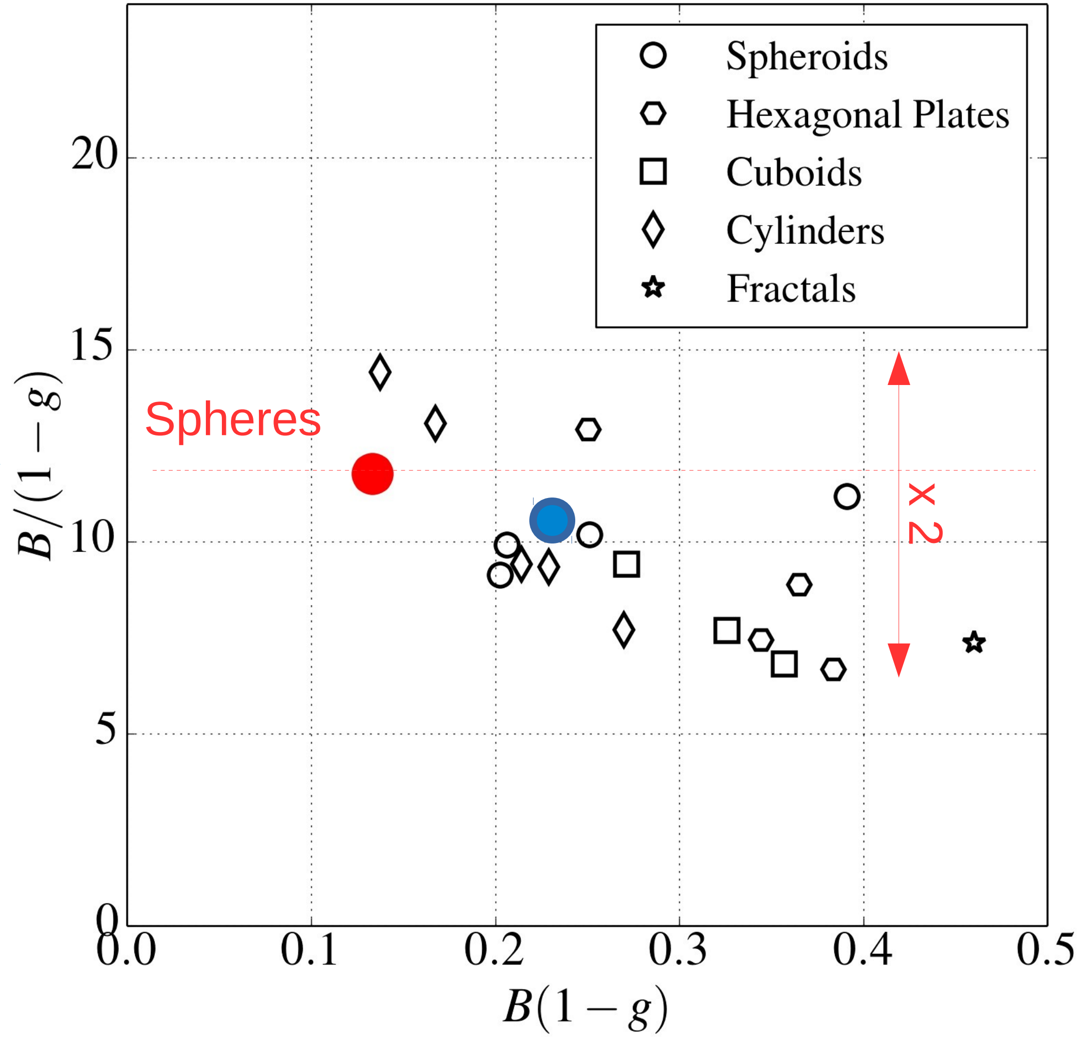
Important: they depend on shape <u>and</u> refractive index and are computed from electromagnetic principle (not purely geometrical as SSA is)

Theoretical results

In Libois et al. 2013: Calculations from Kokhanovsky and Macke, 1997; Picard et al., 2009 → B and g for geometrical shapes.

+ random mixture by Malinka et al. 2014

$$\alpha(\lambda)=\exp\left(-\frac{12}{7}(1+2\cos\theta)\sqrt{\frac{2}{3}\gamma(\lambda)\frac{1}{\rho_{ice}SSA}\frac{B}{1-g}}\right)$$



Spheres have a **medium** B/(1-g)

Theoretical results

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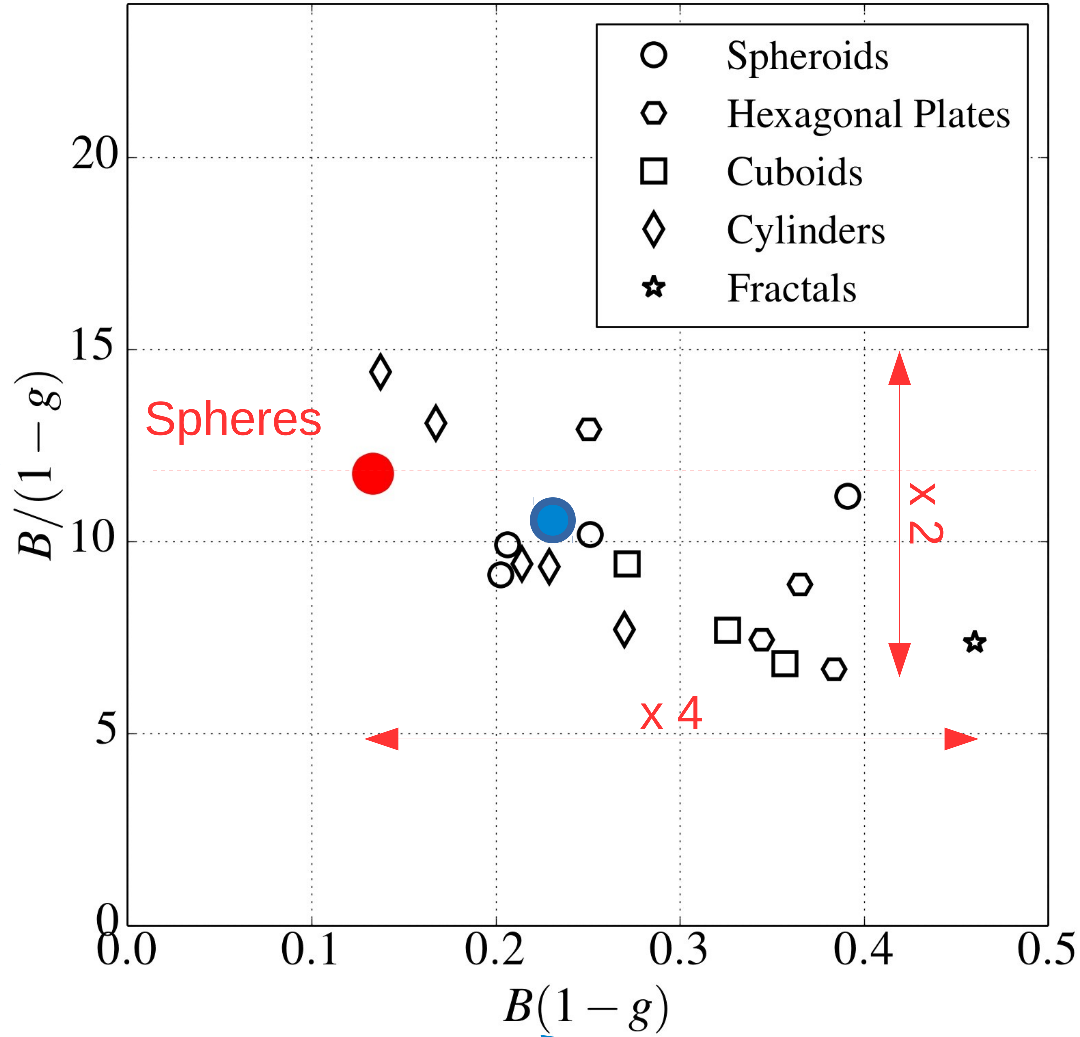


Spheres have a **medium** B/(1-g)

Effective extinction coefficient :

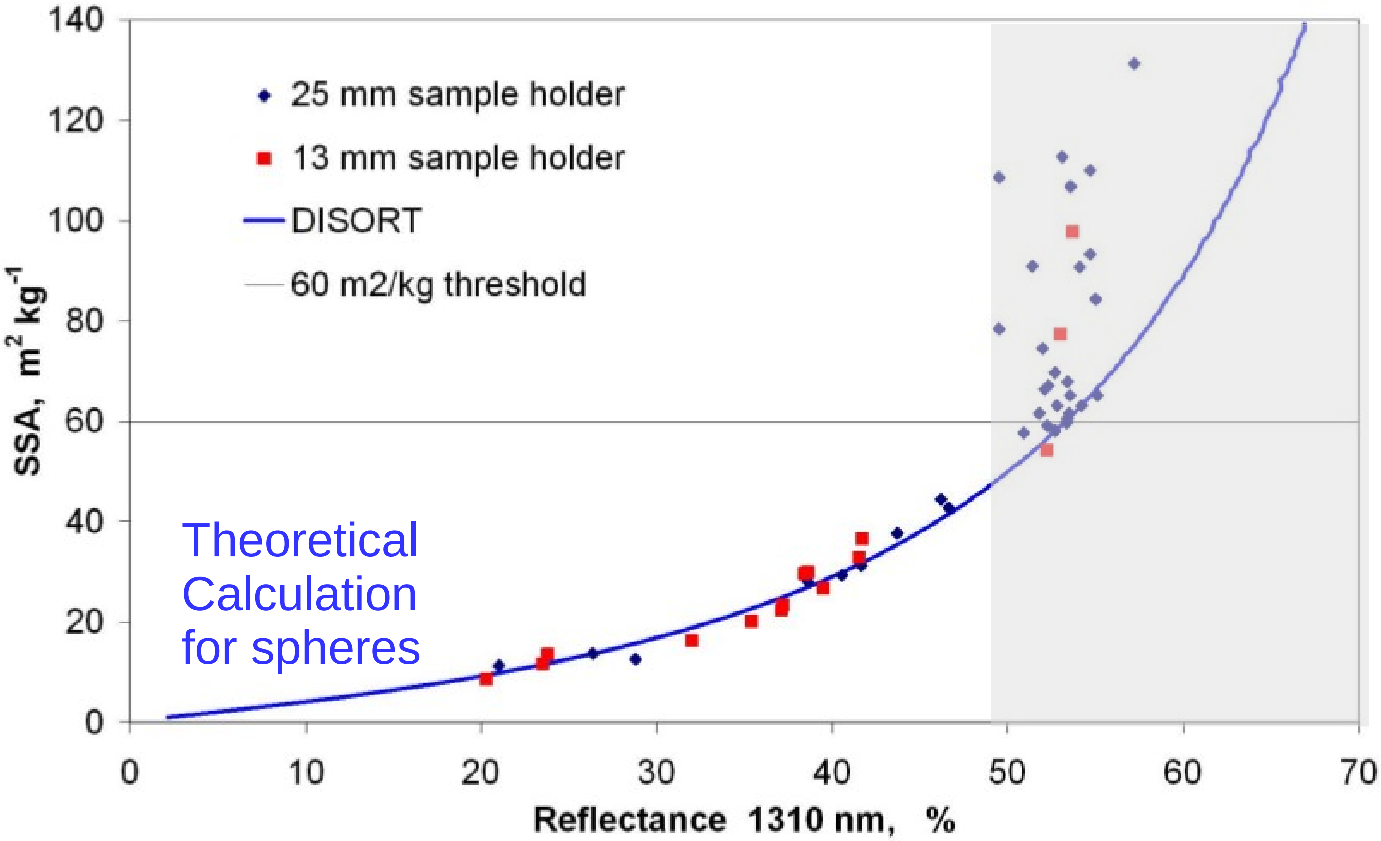
$$ke(\lambda)=\rho\sqrt{\frac{3}{2}\gamma(\lambda)\frac{SSA}{\rho_{ice}}B(1-g)}$$

Spheres have an **extreme** B(1-g)

Experimental results

What about natural snow ? Difficult because SSA needs to be measured by an independent method of the optics

- Gallet et al. 2009: SSA measured by methan adsorption



Experimental results are close to the calculation for spheres.

- Numerous of (unpublished) results acquired in 2014 (Davos intercomparison) seems to confirm this finding.

Experimental results

Libois et al. 2014: Design an optical to estimate the shape parameters. Only B can be estimated when SSA is not available

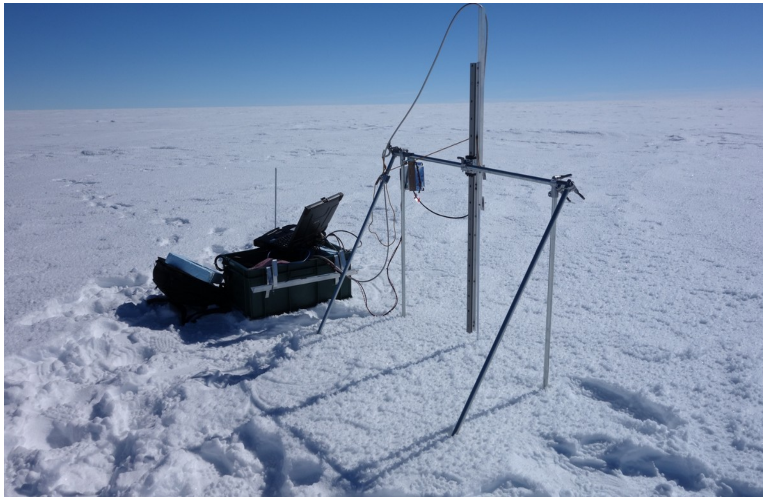
$$\alpha(\lambda)=\exp\left(-\frac{36}{7}\sqrt{\frac{2}{3}\gamma(\lambda)\frac{1}{\rho_{ice}SSA}\frac{B}{1-g}}\right)$$

$$ke(\lambda)=\rho\sqrt{\frac{3}{2}\gamma(\lambda)\frac{SSA}{\rho_{ice}}B(1-g)}$$

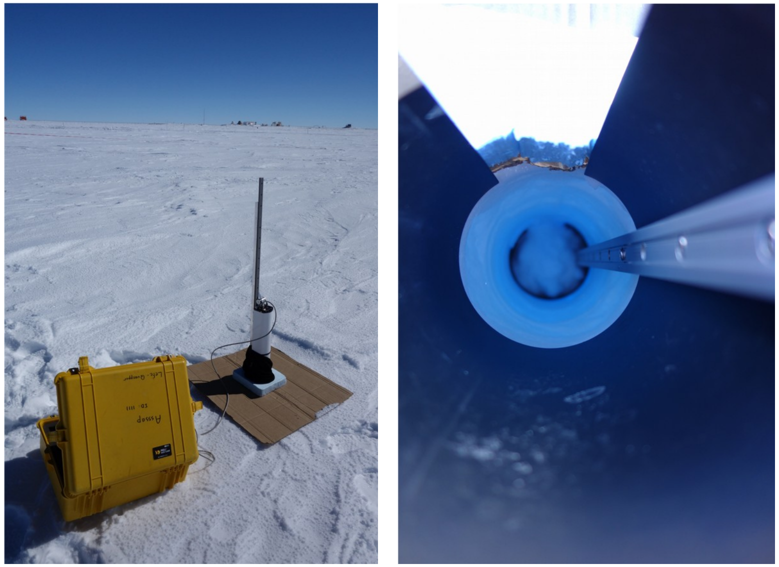
$$\rightarrow \quad B=\frac{\rho_{ice}}{4\rho\gamma(\lambda)}\ln(\alpha(\lambda))ke(\lambda)$$

Using concomittent measurements of profiles of irradiance (Solexs) and reflectance (ASSSAP) at Dome C → B

Solexs (Libois 2014 et al., Picard et al. 2016 TCD)

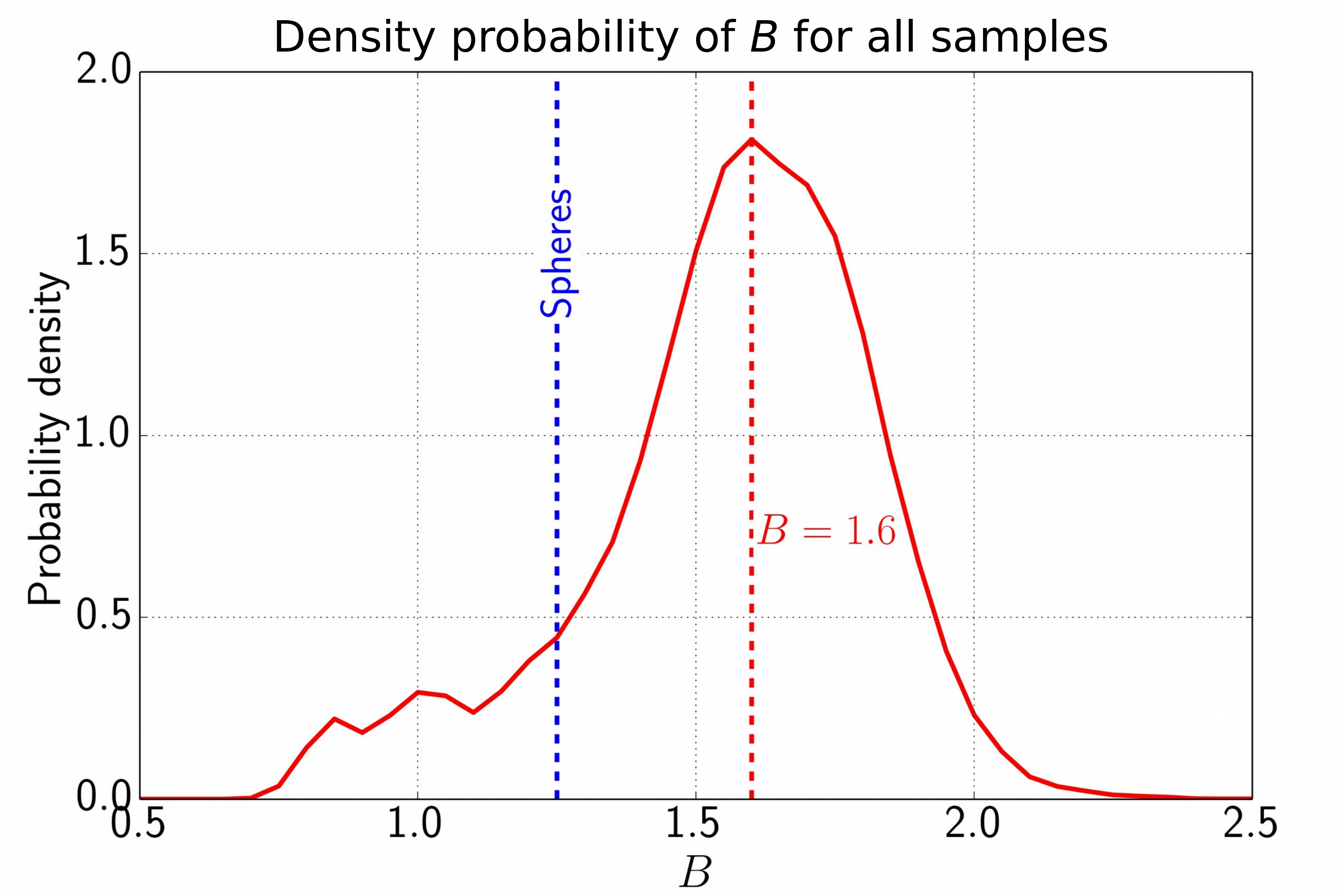


ASSSAP (Arnaud et al. 2011)



Experimental results

56 snow layers at Dome C + 36 samples in the Alps



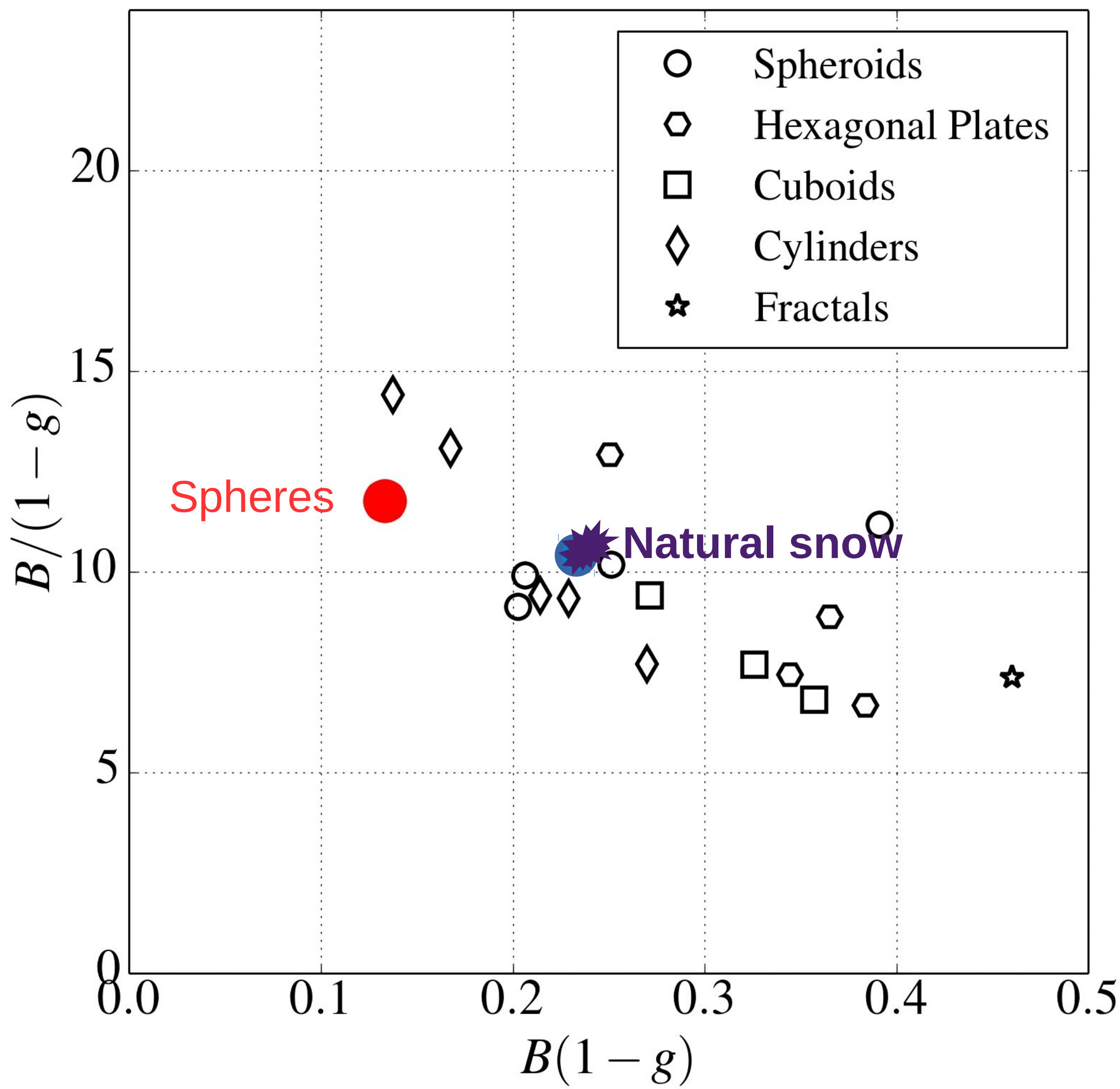
B_{snow} = 1,6± 0,2

> B_{sphere}=1,25

No clear dependence to the « visual » shape

Experimental results

Mixing B from Libois and SSA-albedo from Gallet et al. 2009



Conclusion & Perspectives

- Theory says : SSA retrieval from measured albedo largely depends on grain shape

- Experimental results on natural snow disagree on « largely ».

- The range of B and g would be narrower. No clear relationship between B, g and « visual » geometrical shape. See Quentin Libois' poster for more details.

- Increasing experimental evidences that snow optical properties differ from that of spheres.

- but using spheres has little impact on the albedo / large impact on the penetration depth.

Conclusion & Perspectives

To play with shape : TARTES radiative model (in Python), Libois et al. 2013

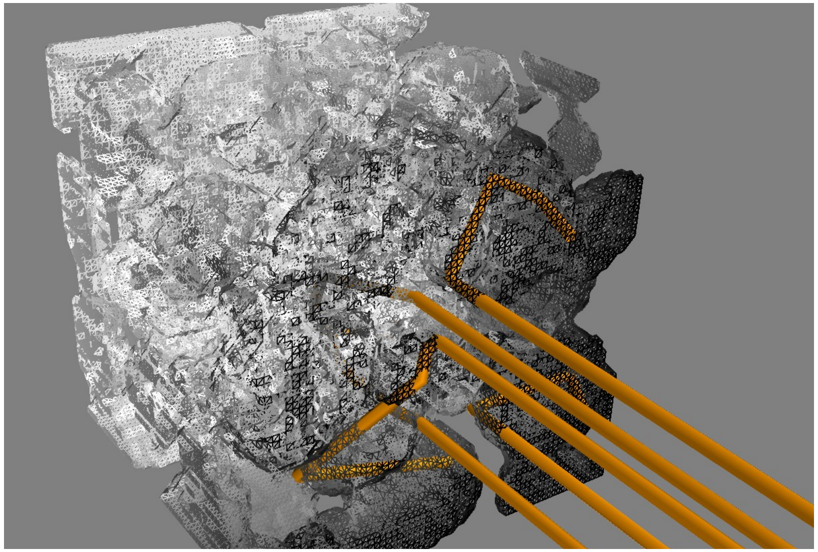
Also TARTES webapp: http://snowtartes.pythonanywhere.com

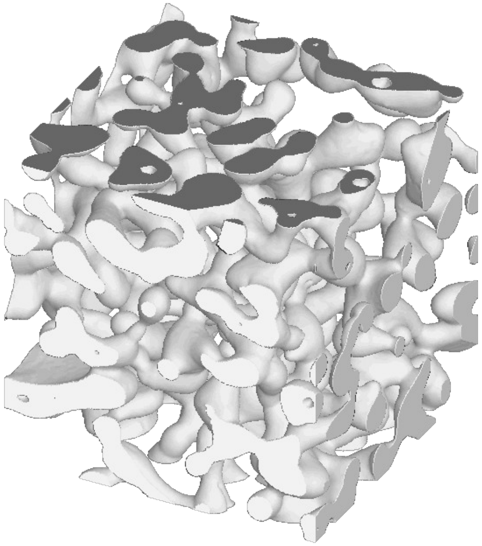
Conclusion & Perspectives

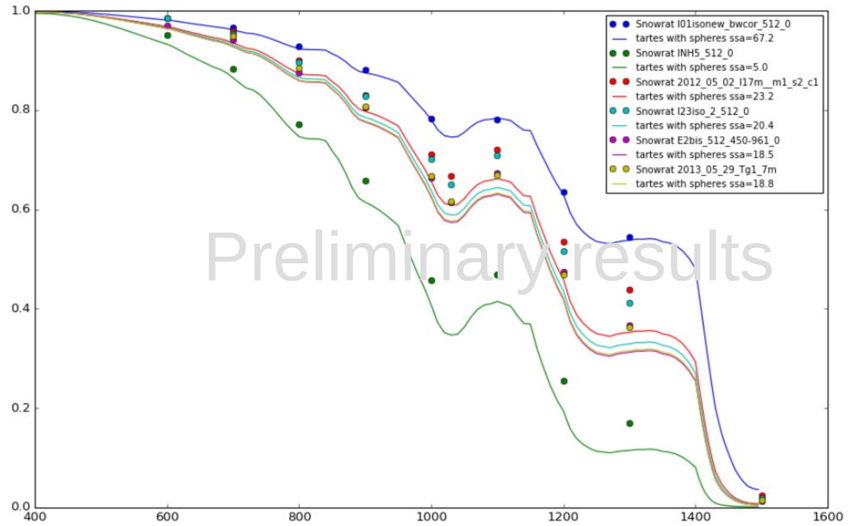
- The number of studies on the shape of natural snow is still insufficient.

On promising direction : Calculation on tomography

1- Raytracing with SnowRAT (Picard et al. 2009) improve to support tomography Tomo support Coll F. Flin, M. Dumont, CEN







2- Advanced geometrical metrics by H. Löwe, SLF

Krol and Löwe, Relating optical and microwave grain metrics of snow: The relevance of grain shape, The Cryosphere Discussion