FINNISH METEOROLOGICAL INSTITUTE

Impact of albedo measurement errors on the retrieval of snow grain size and BC concentration – some naive sensitivity tests

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Well, who am I (not)?

- **Not exactly a snow scientist**

  - although:

  Räisänen, P., Kokhanovsky, A., Guyot, G., Jourdan, O., and Nousiainen, T.: Parameterization of single-scattering properties of snow, *The Cryosphere*, **9**, 1277-1301, doi:10.5194/tc-9-1277-2015, 2015.

  +co-author for a couple of papers by R. Pirazzini

- **Not a retrieval scientist**

  - (virtually) no research on the retrieval of snow grain size or BC

- **Not an observational scientist**

- **Climate modeller since 2004**

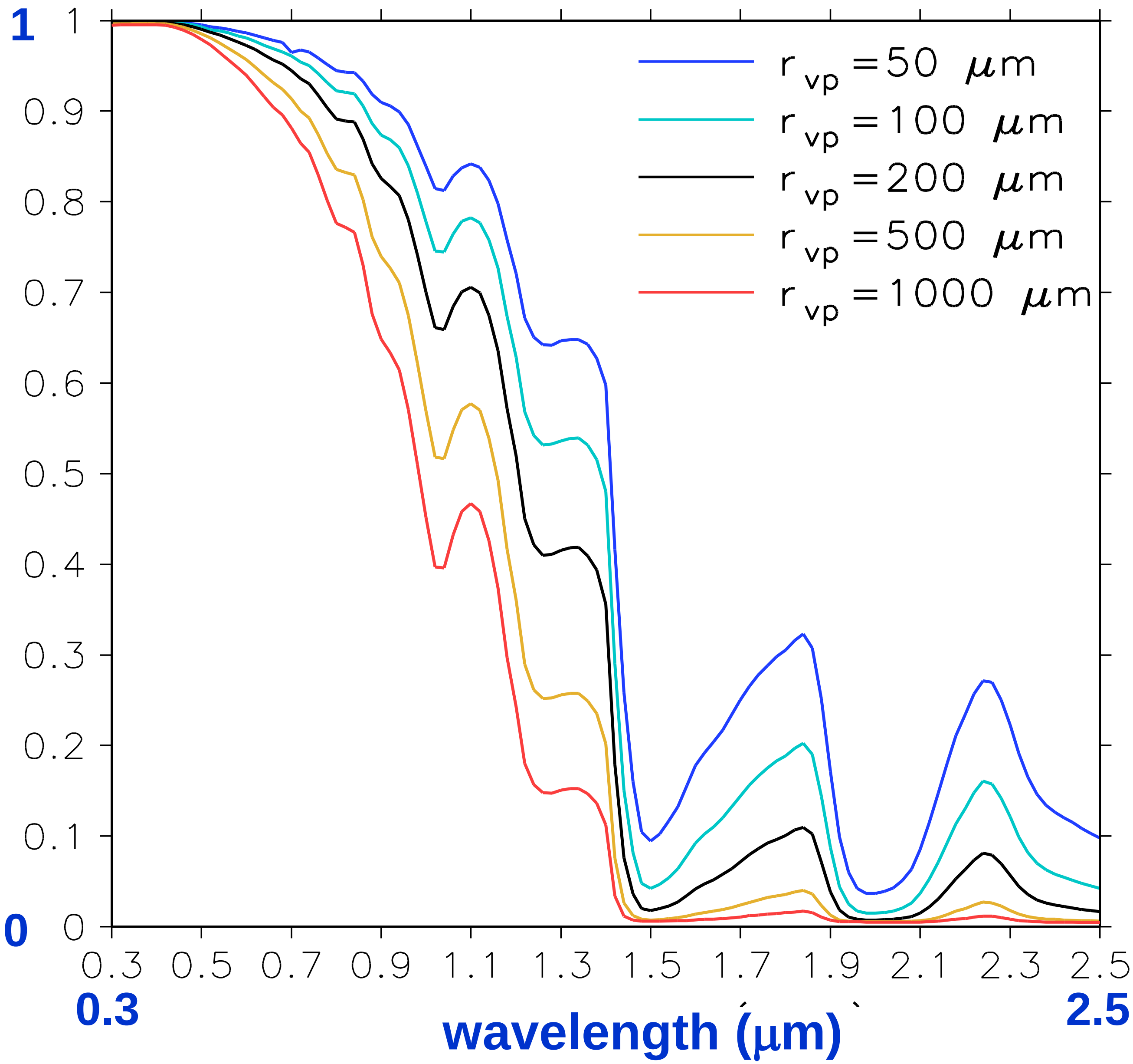
- **Some radiative transfer modelling since 1993**

Radiative transfer calculations

- DISORT, with 8 streams
- **a homogeneous, semi-infinite snow layer** (optical depth ≈ 10^6)
- no surface structure or other 3D complications
- no close-packed effects
- spherical snow grains (but see later …)
- lognormal snow grain size distribution (geom. std. dev. σ_g=1.5)
- **direct incident radiation** with zenith angle = 60°
- spectral snow albedo computed at 0.02 µm resolution
- snow grain size characterized by
  volume-to-projected area equivalent radius $r_{vp} = \frac{3}{4}\frac{V}{P}$
  (or simply radius for spheres …)

∴ Snow treated as a thick homogeneous ”cloud” of spherical ice particles laying on ground (as usual …)

Spectral albedo of pure snow (basic features)



- Very high in the UV and visible
- Substantially lower in the near-IR, and sensitive to snow grain size:
  - larger snow grains ⇔ lower albedo

Retrieval of snow grain size (pure snow)

- Invert the theoretical relationship between effective snow grain size (**r_{vp}**) and snow albedo (**α**):

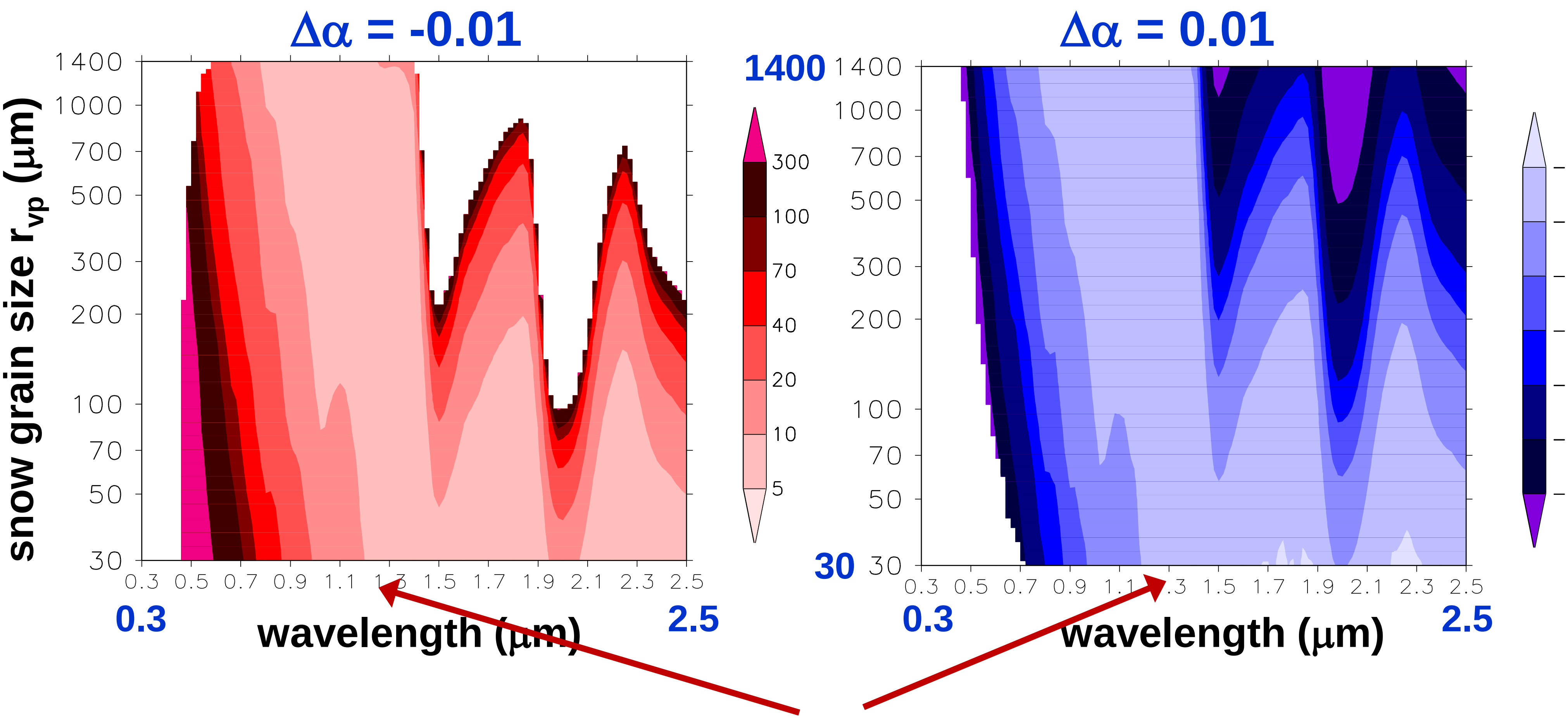
$$\alpha = \mathrm{f}\left(r_{vp}\right) \Leftrightarrow r_{vp} = f^{-1}(\alpha)$$

- However, if there are errors in the albedo measurement ($\Delta\alpha$), the retrieved snow grain size will differ from the real one:

$$r_{vp,\mathrm{retrieved}} = f^{-1}(\alpha + \Delta\alpha) \neq r_{vp}$$

- Also if some of the assumptions in the calculations are not valid (but let's keep this simple and ignore this ...)

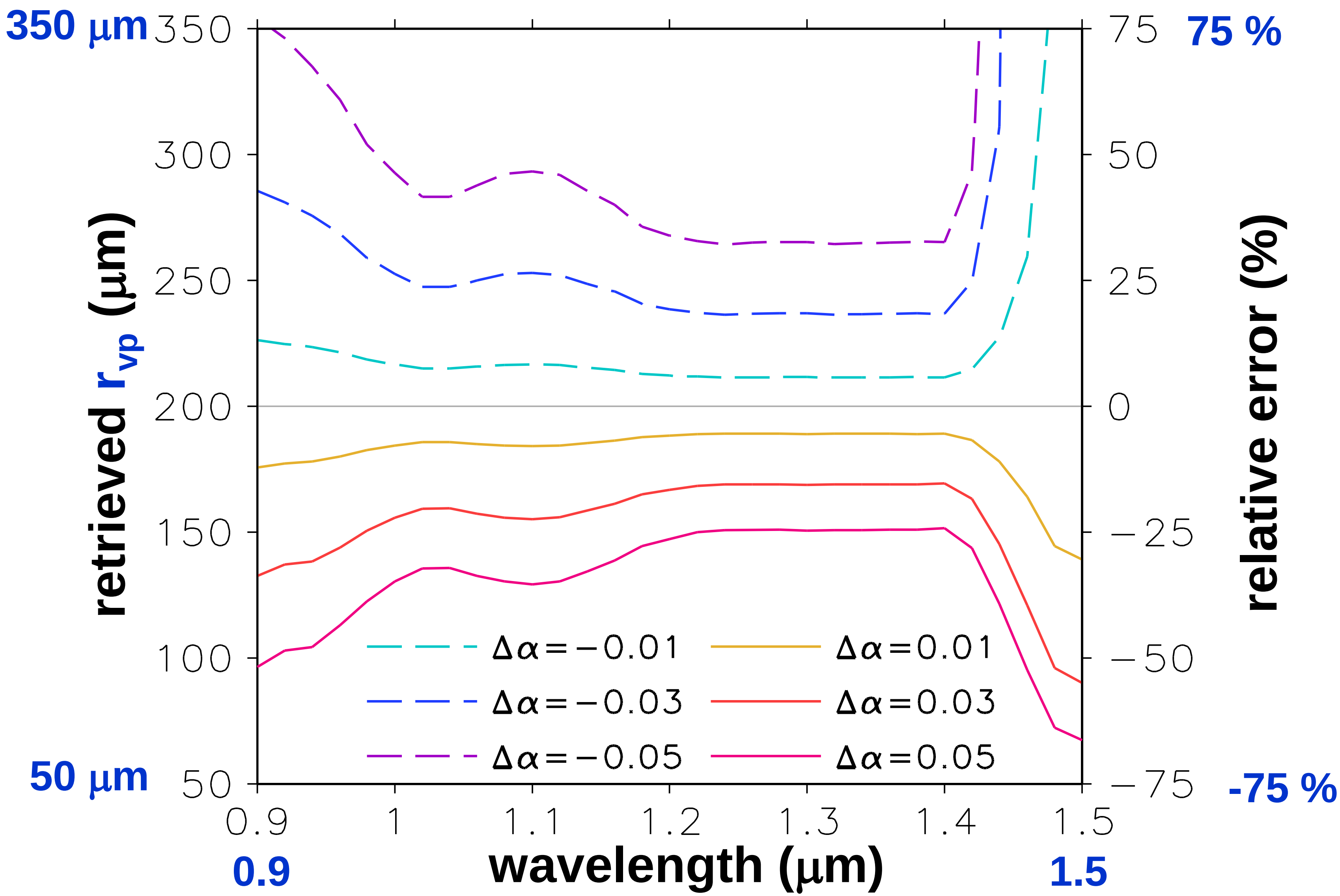
Relative errors (%) in retrieved snow grain size due to an albedo measurement error Δα=±0.01



Best accuracy (~6-10%) achievable in the near-IR at λ~1.2-1.3 μm

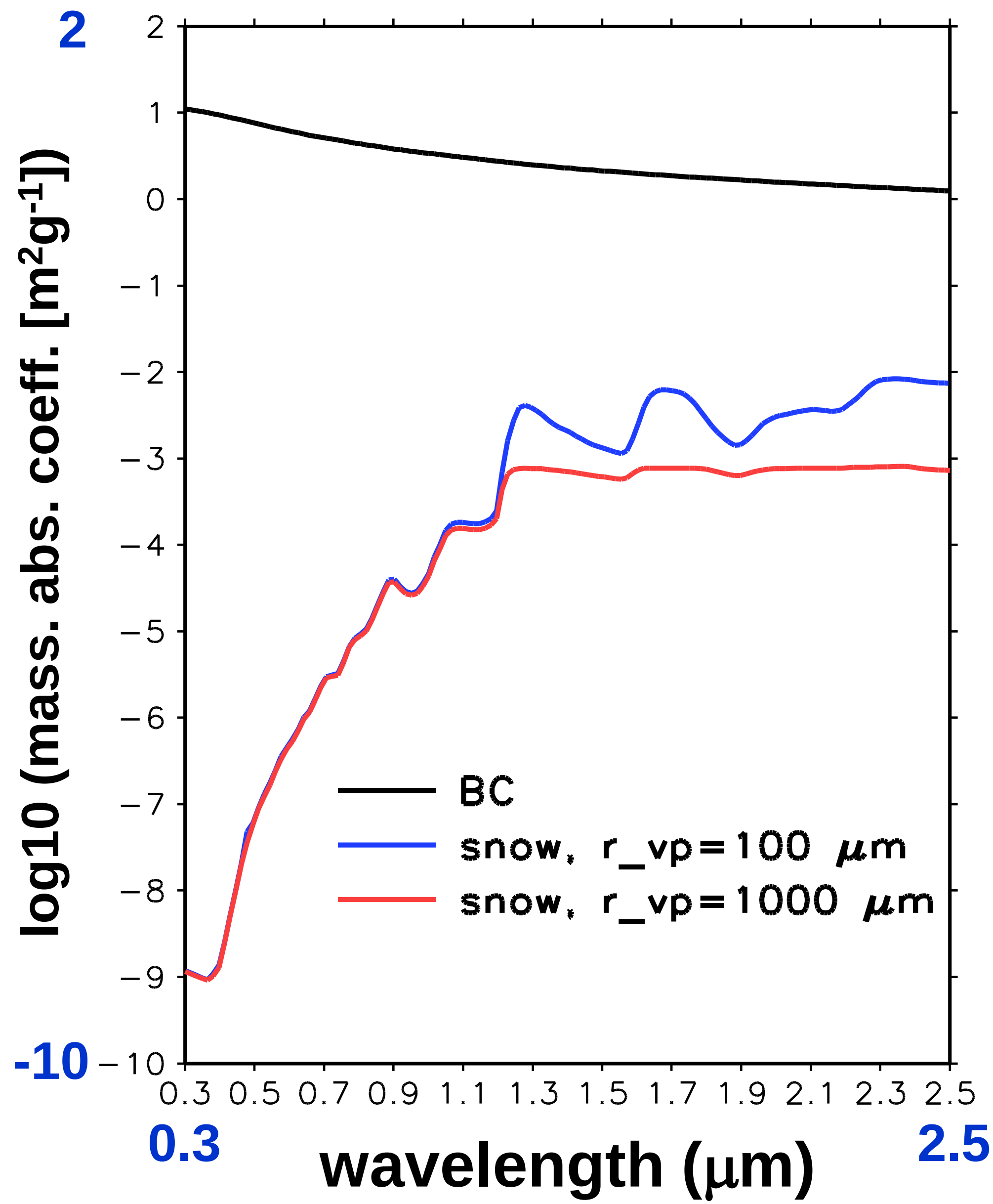
Albedo measurement errors $\Delta\alpha=\pm0.01, \pm0.03, \pm0.05$

- assumed real snow grain size: $r_{vp} = 200\ \mu m$

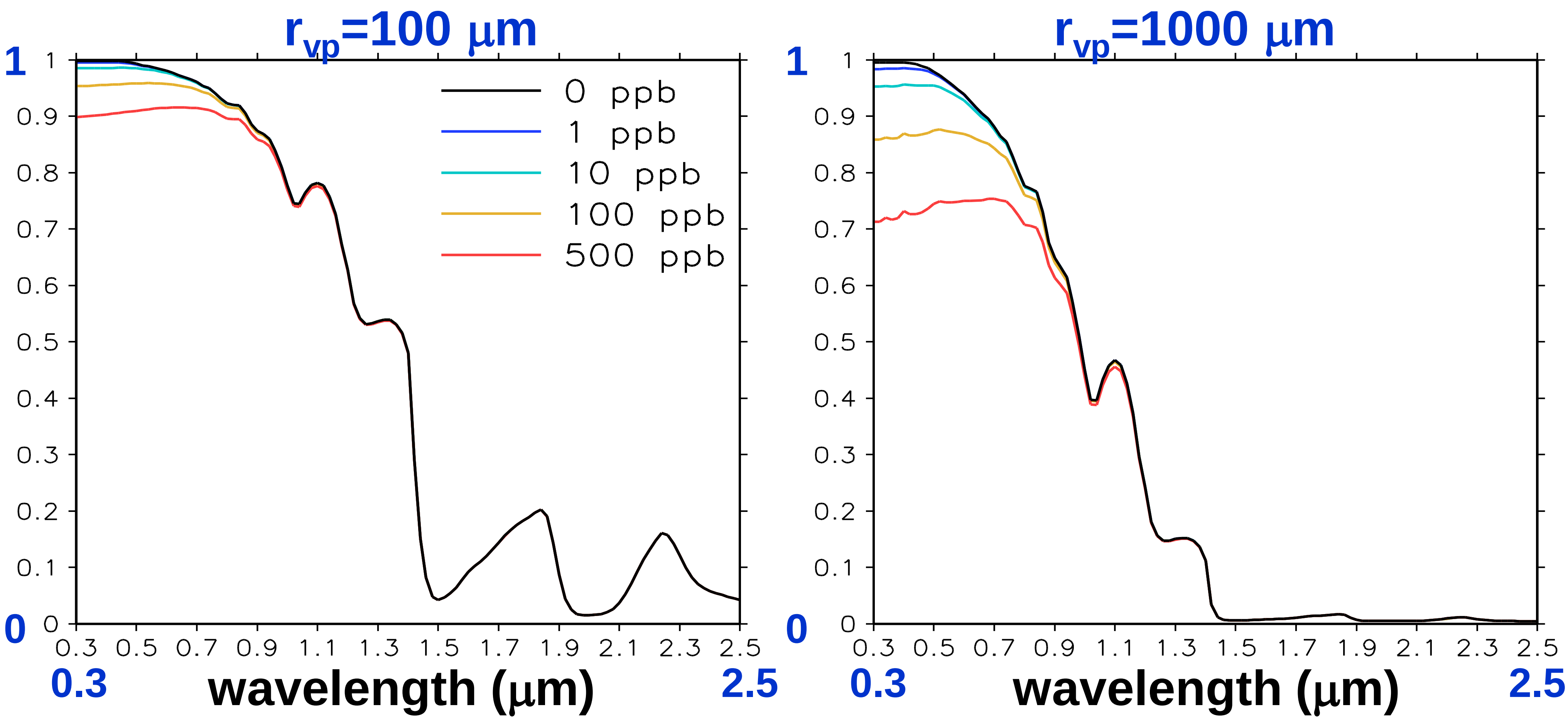


Effect of snow impurities: black carbon (BC)

- Assume an external mixture of BC particles and snow grains
- BC properties mimicking the SNICAR model, with a mass absorption coefficient of $\sigma_a \approx 7.5\ m^2 g^{-1}$ at λ=550 nm

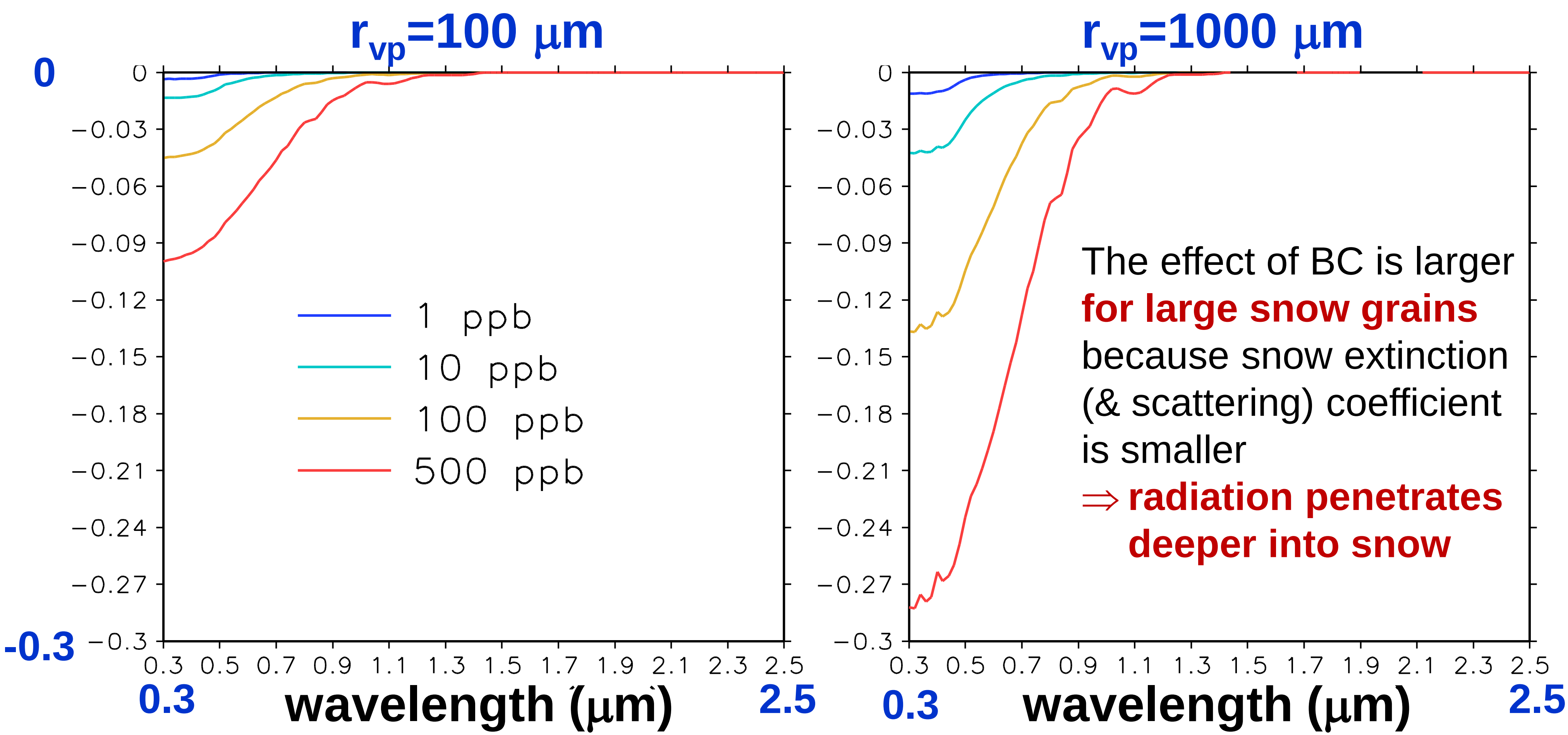


Impact of BC on snow albedo (for 2 different snow grain sizes)



- Substantial effects in the UV+VIS region for high BC concentrations
- Larger effects when snow grains are large

Albedo differences to pure snow



- Substantial effects in the UV+VIS region for high BC concentrations
- Larger effects when snow grains are large

Retrieval of BC concentration

- Assume that the effective snow grain size r_{vp} is known precisely. Obviously, this is generally not true, but let's keep this simple …

- In this case, we can invert the relationship between effective snow grain size (r_{vp}), BC concentration (**BC**) and albedo (α)

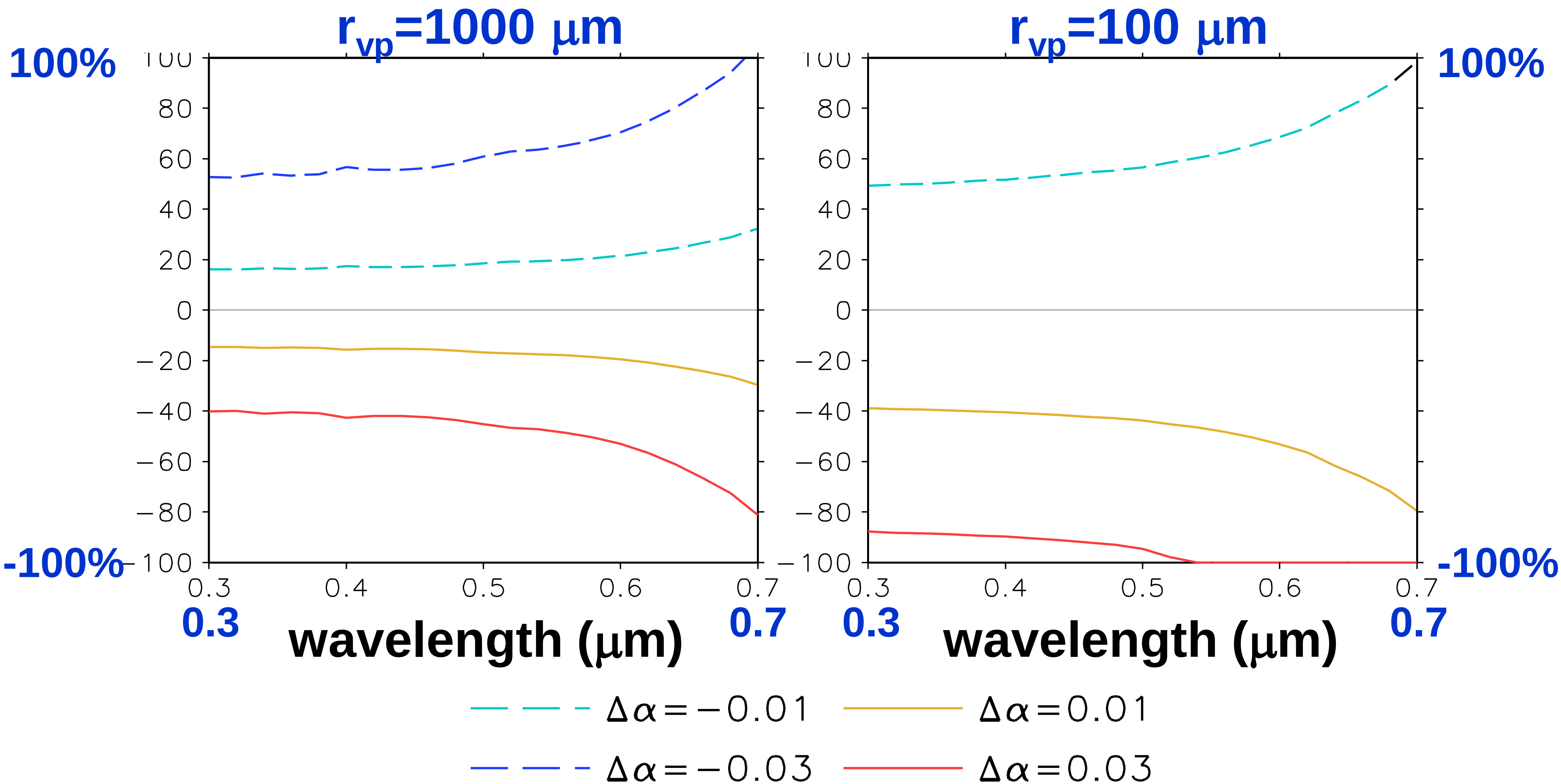
$$\alpha = g(r_{vp}; \mathrm{BC}) \Leftrightarrow \mathrm{BC} = g^{-1}(\alpha; rvp)$$

- However, if there are errors in the albedo measurement ($\Delta\alpha$), the retrieved BC concentration will differ from the real one:

$$\mathrm{BC}_{\mathrm{retrieved}} = g^{-1}(\alpha + \Delta\alpha; rv_p) \neq \mathrm{BC}$$

Relative errors in retrieved BC concentration:

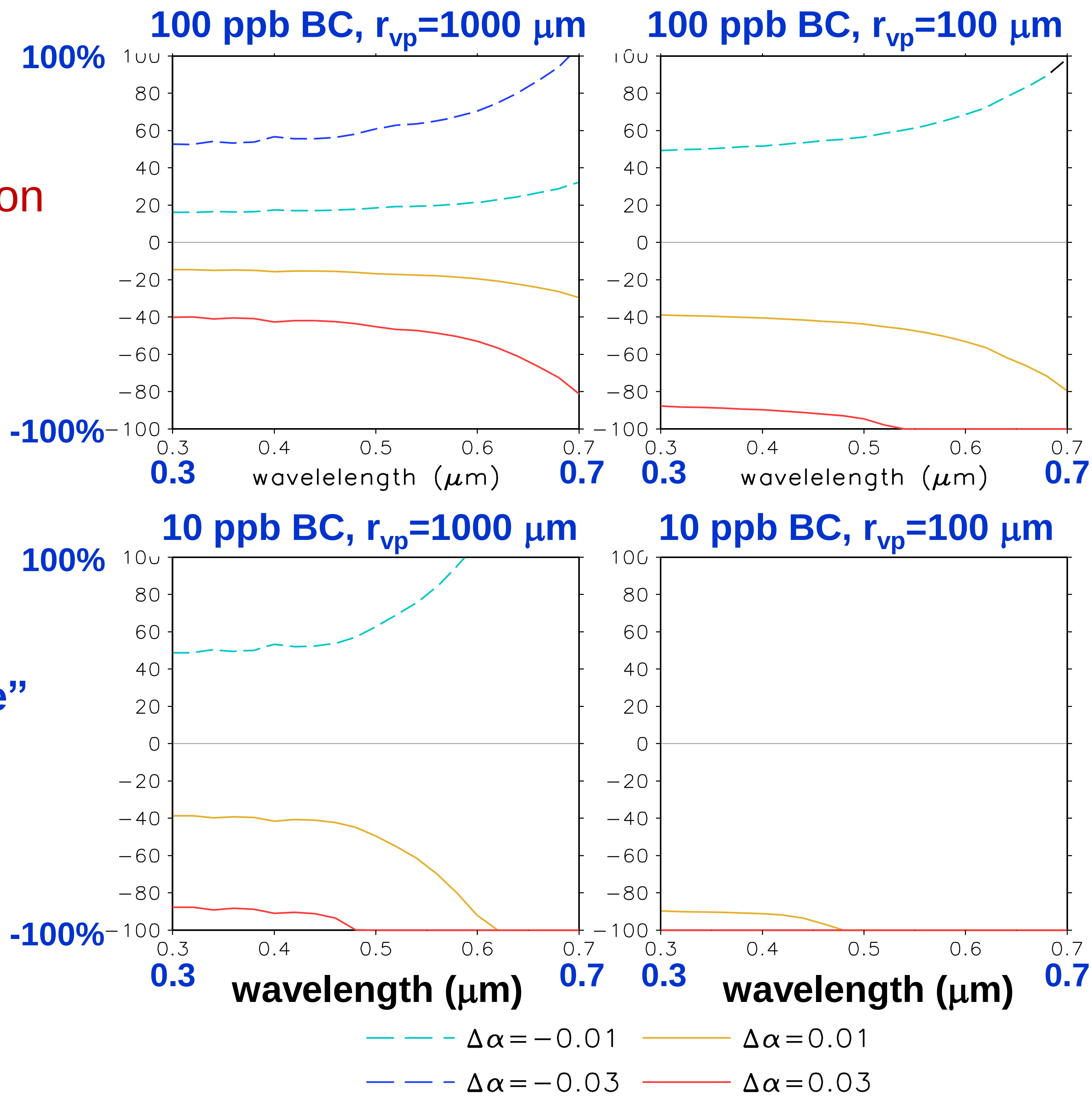
Δα=±0.01, ±0.03, real BC = 100 ppb



Relative errors in retrieved BC concentration depend on the BC concentration itself and the snow grain size

- Best accuracy for high **BC** and large r_{vp}

- Low **BC** and small r_{vp}
  ⇒ ”mission impossible”



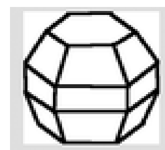
Impact of snow grain shape

- Above, spherical snow grains have been assumed. In reality, snow grains are non-spherical.

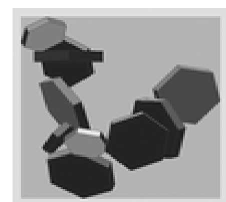
- One suggestion: an ”optimized habit combination” (OHC) fitted to phase function measurements for blowing snow (Räisänen et al., The Cryosphere, 2015)

Fraction of projected area

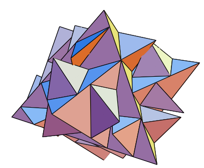
34 % severely roughened droxtals



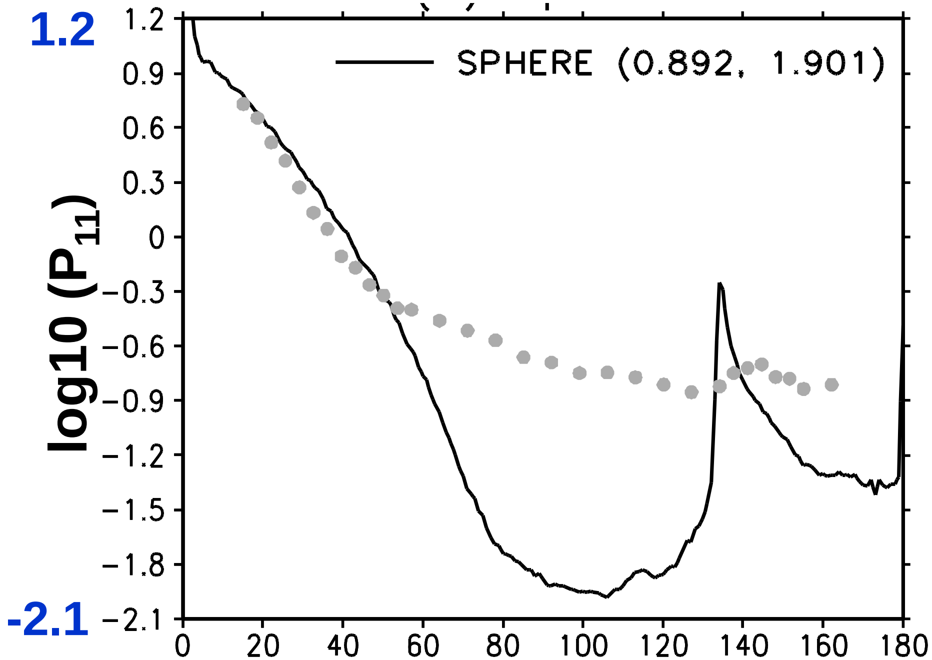
34 % severely roughened aggregates of plates



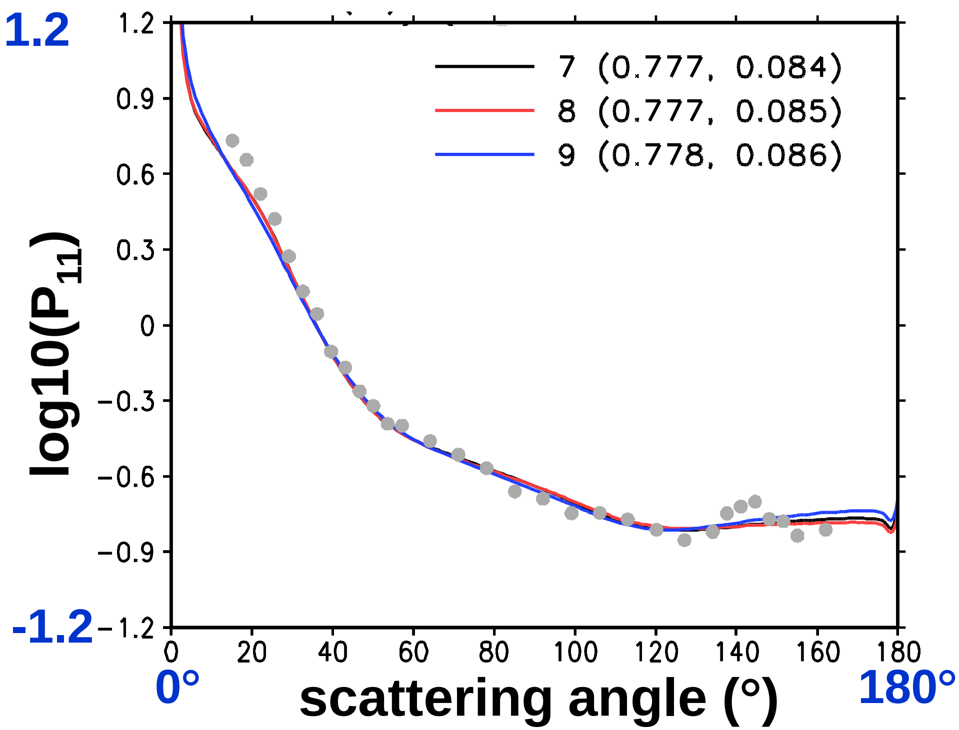
32 % strongly distorted Koch fractals



- This is meant to represent the scattering properties of snow rather than the actual distribution of snow grain shapes



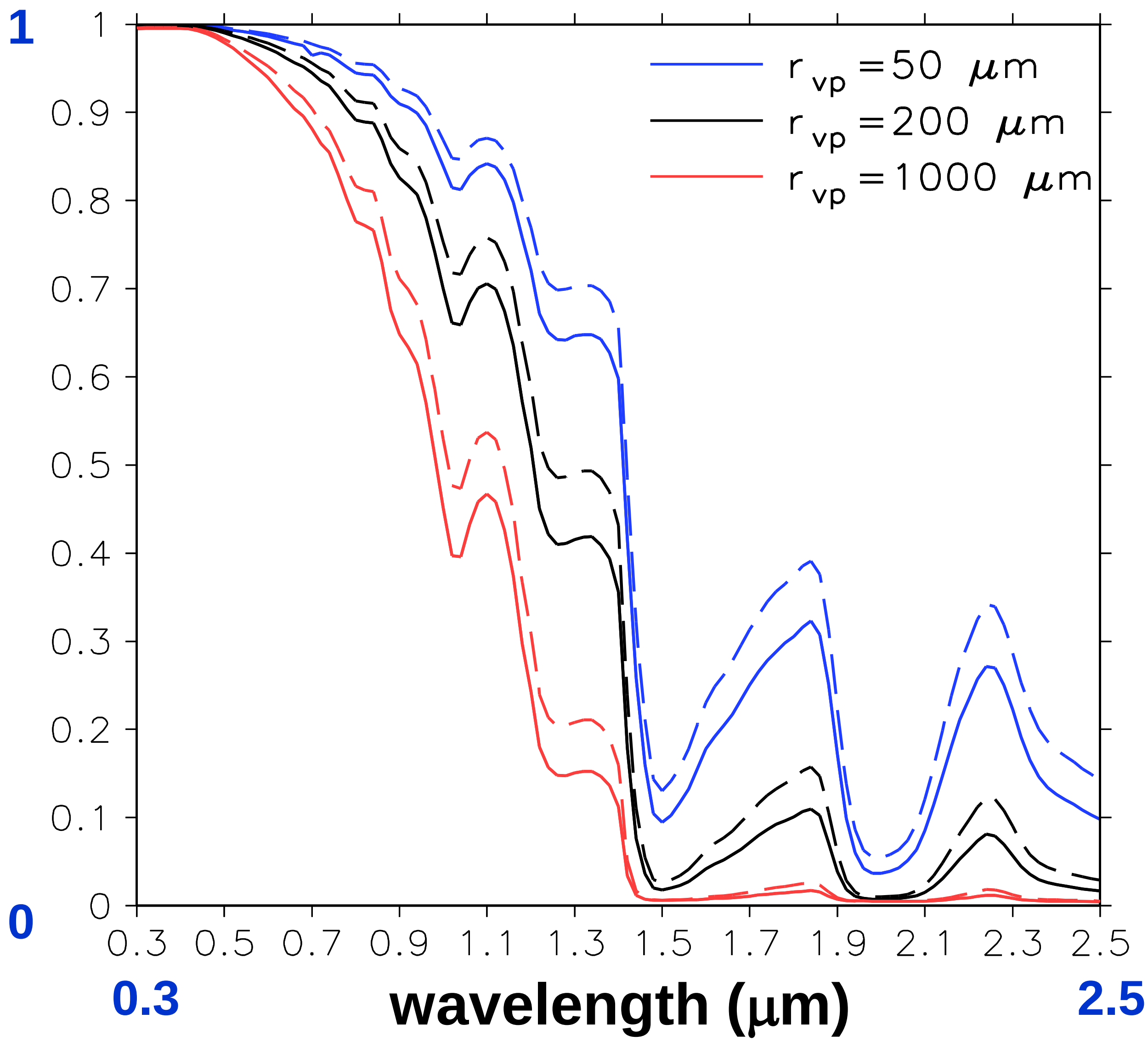
This is how spheres compare with the phase function measurements (gray dots) for blowing snow (at λ= 0.8 μm)



And this is how the optimized habit combination (in blue) (+ two other ”good” combinations) compare with the observations

∴ Key difference to spheres: more sideward scattering
⇒ lower asymmetry parameter ($g \approx 0.78$ vs. $g \approx 0.89$)

Spectral albedo of pure snow: spheres vs. OHC



Solid lines for spheres

Dashed lines for OHC

∴ For a given snow grain size, higher albedo for the OHC than for spheres

- This is due to the smaller g for the OHC
- Partly compensated by a slightly lower single-scattering albedo

Shape impacts on the retrieval of grain size

- Assume, for the sake of the argument, that the ”real” relationship between snow grain size and snow albedo follows that computed using the ”optimized habit combination”

$$\alpha = f_{\mathrm{OHC}}\left(r_{vp}\right)$$

- However, use the relationship computed for spheres to infer the effective snow grain size (**r_{vp}**) from snow albedo (**α**):

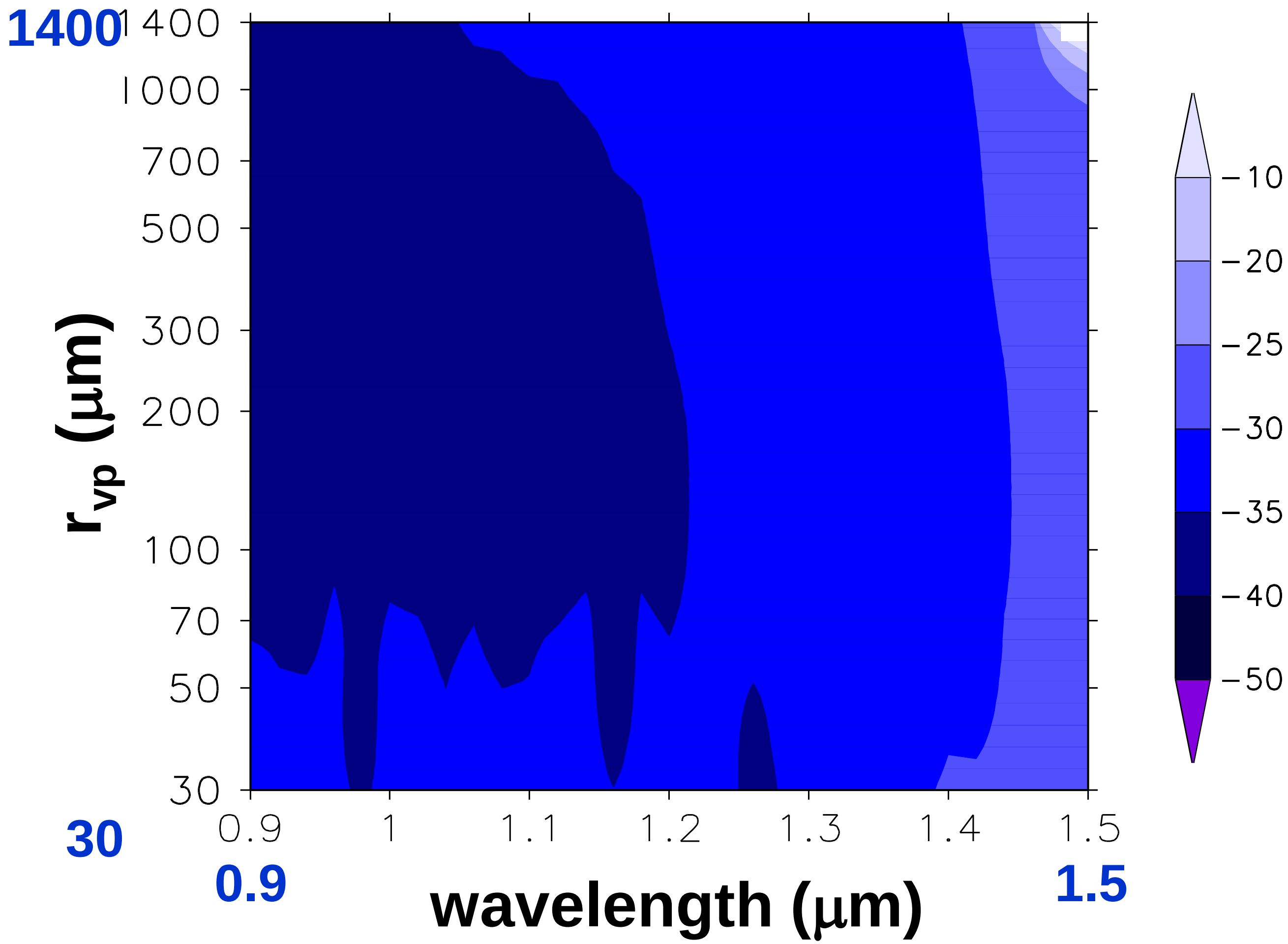
$$\alpha = f_{\mathrm{spheres}}\left(r_{vp}\right)$$

$$\Rightarrow r_{vp,\mathrm{retrieved}} = f_{\mathrm{spheres}}^{-1}\,(\alpha) = f_{\mathrm{spheres}}^{-1}\left[f_{\mathrm{OHC}}\left(r_{vp}\right)\right] \neq r_{vp}$$

- The retrieved snow grain size will differ from the real one, even if there is no error in the albedo measurement

Relative error in snow grain size (%)

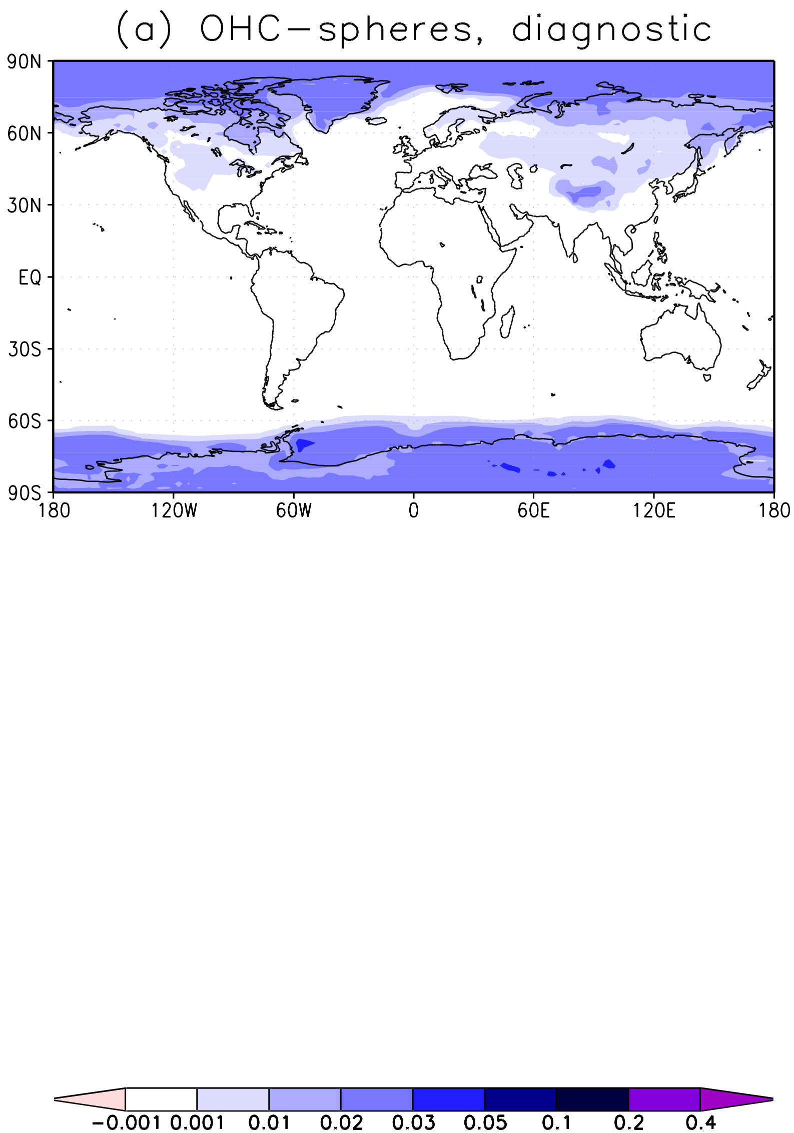
- when assuming spheres in the retrieval for
for a snowpack that has OHC scattering properties



Snow grain size underestimated by ≈ 30-35%!

Whether this applies to the real world depends on how well the OHC (with g≈0.78) represents scattering by real-world snowpacks

Impact of snow grain shape in a climate model (NorESM + mixed-layer ocean)



Impact on replacing spheres with OHC
on annual-mean surface broadband albedo
in diagnostic radiation calculations

- 0.02-0.03 in regions with permanent snow

Conclusions

- Snow grain size best retrievable at wavelengths with moderate absorption (e.g., 1.2-1.3 μm)

  - e.g.: ±0.03 error in measured albedo
    $\Rightarrow$ ~20% error in retrieved snow grain size

- Retrieved snow grain size is sensitive to the assumed grain shape

  - the use of spheres most likely underestimates the physical snow grain size, possibly by ~30%

- BC concentration best retrievable from snow albedo measurements at UV-to-blue wavelengths (say, $\lambda \approx$ 0.3-0.5 μm)

  - requires high accuracy, since the effect of BC is often quite small
  - best chances for high BC concentrations and large snow grain sizes

A cautionary remark/reminder

- All these examples included several idealized assumptions, probably giving an upper limit for the achievable retrieval accuracy
- The reality is often dirtier …