Effect of Snow Grain Shape on Snow Albedo

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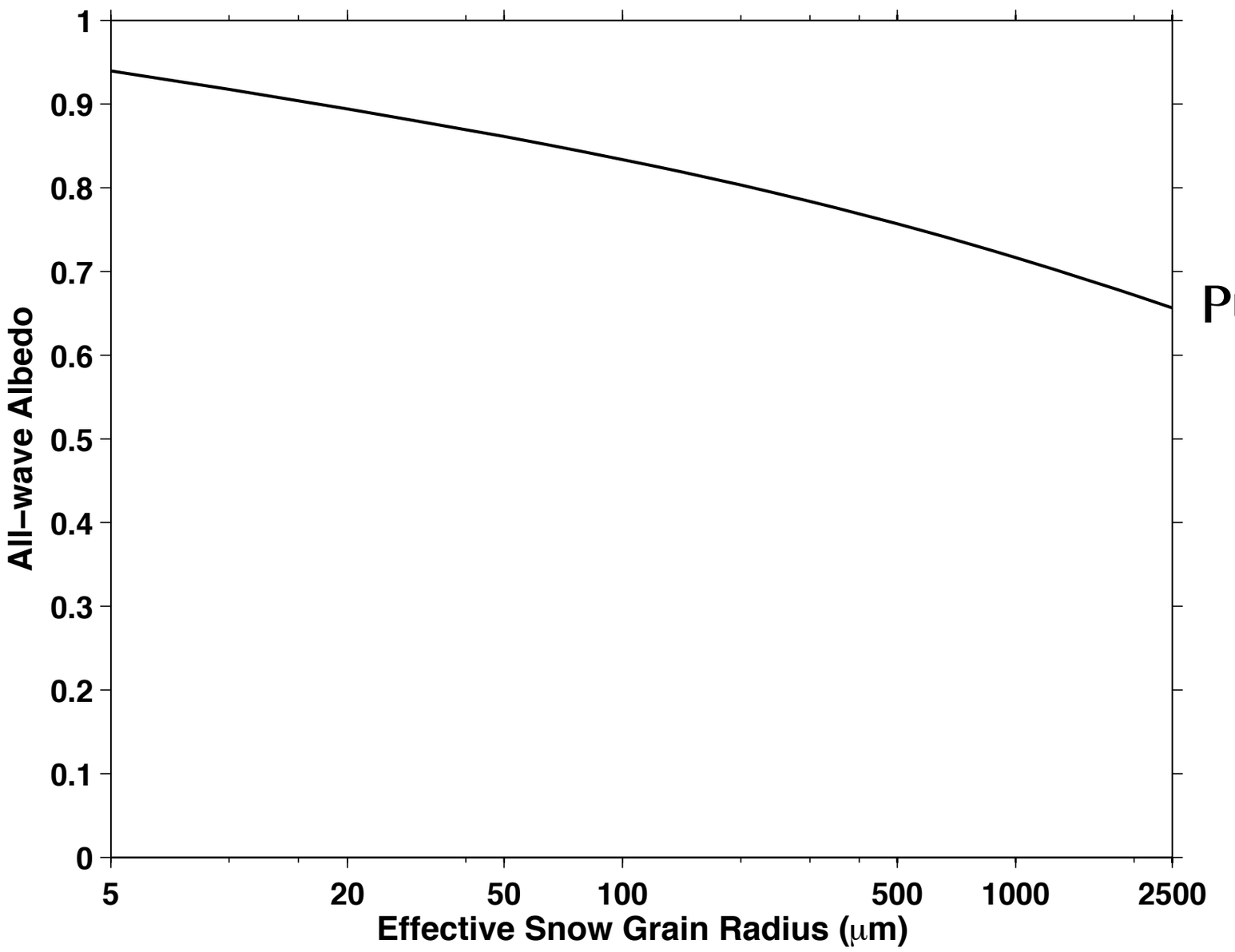
Snow Albedo

- **Snow Grain Size**



Pure Snow,Opaque

Snow Albedo

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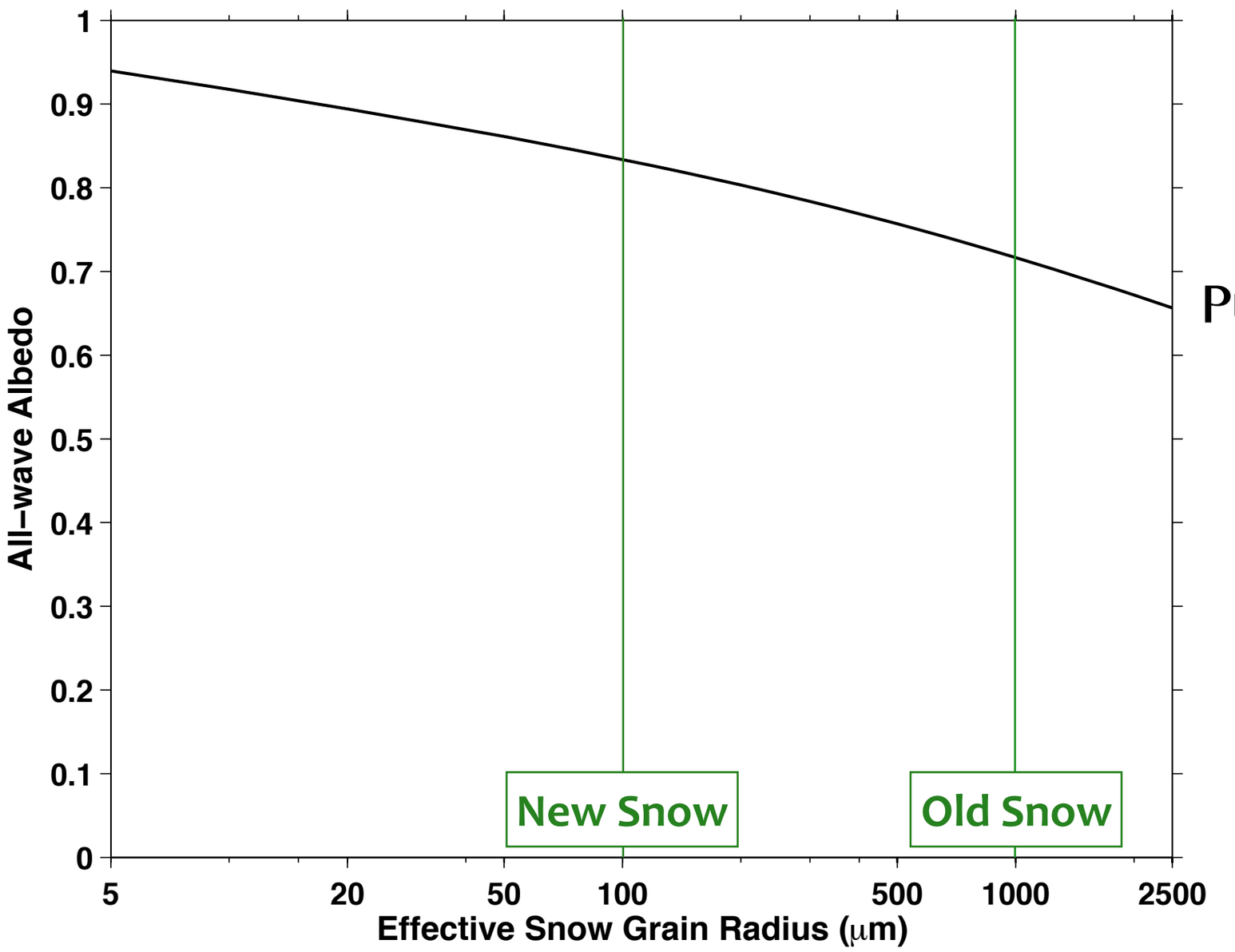
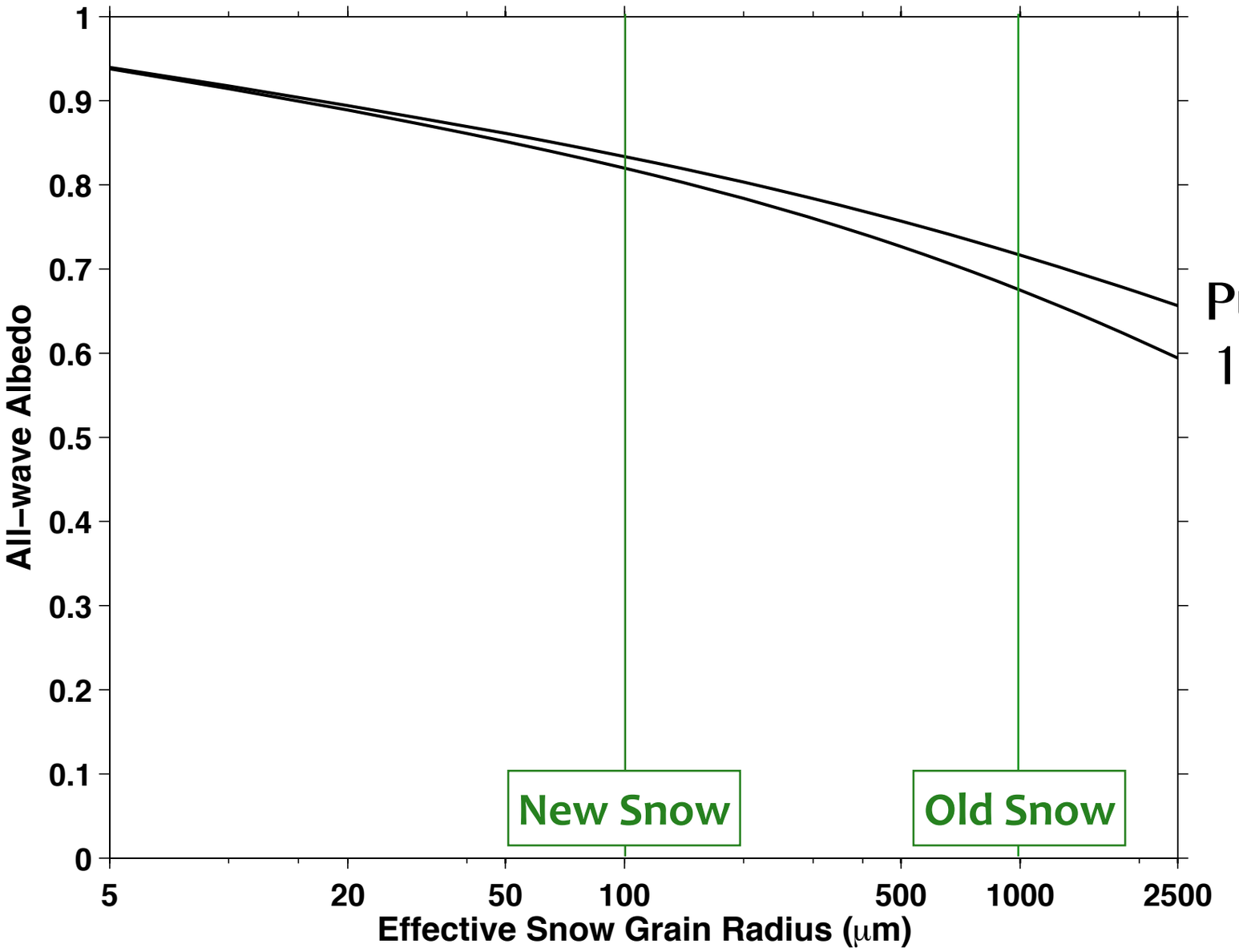


Pure Snow,Opaque

Snow Albedo

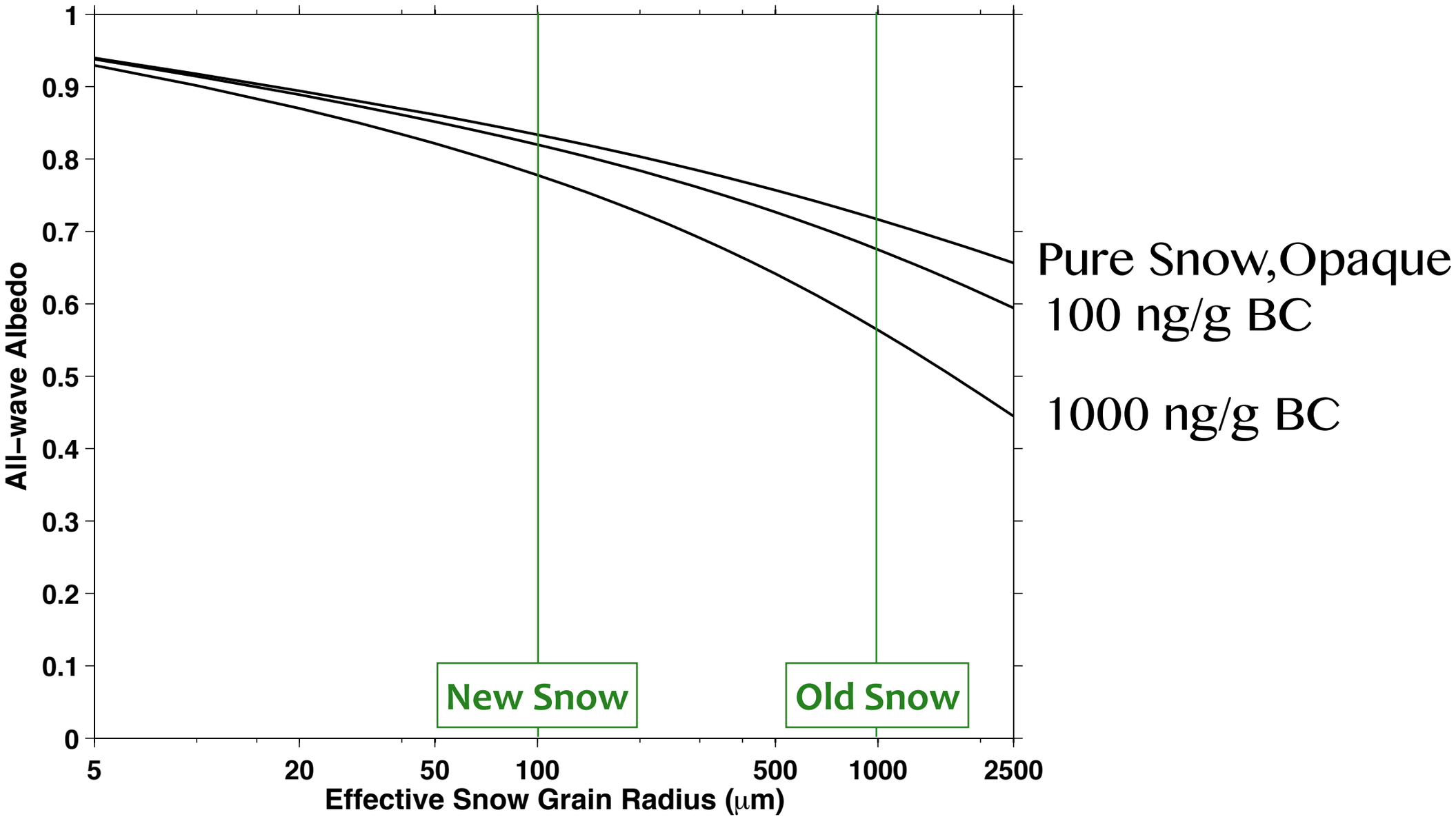
- **Snow Grain Size**
- **Light-absorbing particles**



Pure Snow,Opaque
100 ng/g BC

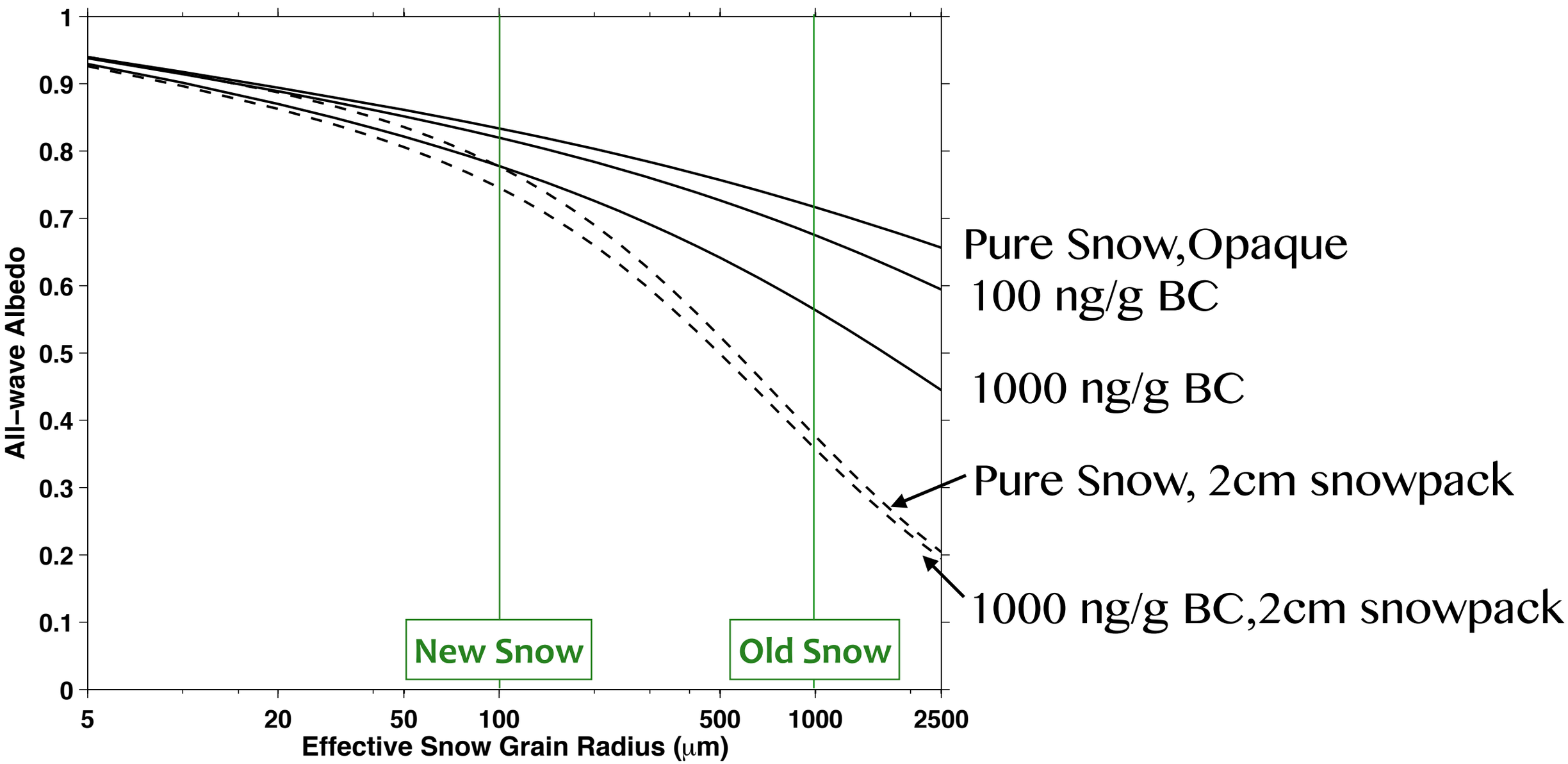
Snow Albedo

- **Snow Grain Size**
- **Light-absorbing particles**



Snow Albedo

- **Snow Grain Size**
- **Light-absorbing particles**
- **Snow Depth**



Snow Albedo Calculation

- Optical constant of ice, black carbon, and mineral dust
- Mie theory
- Radiative transfer models

  e.g: Snow, Ice, and Aerosol Radiative model (SNICAR)

  NCAR Community Atmosphere Model, Version 3

  Flanner and Zender, 2005; Flanner et al., 2006
- Spectral albedo of pure snow, and snow containing BC/dust
- Band albedo of pure snow, and snow containing BC/dust
- Parameterization

  e.g: Marshall and Warren, 1987

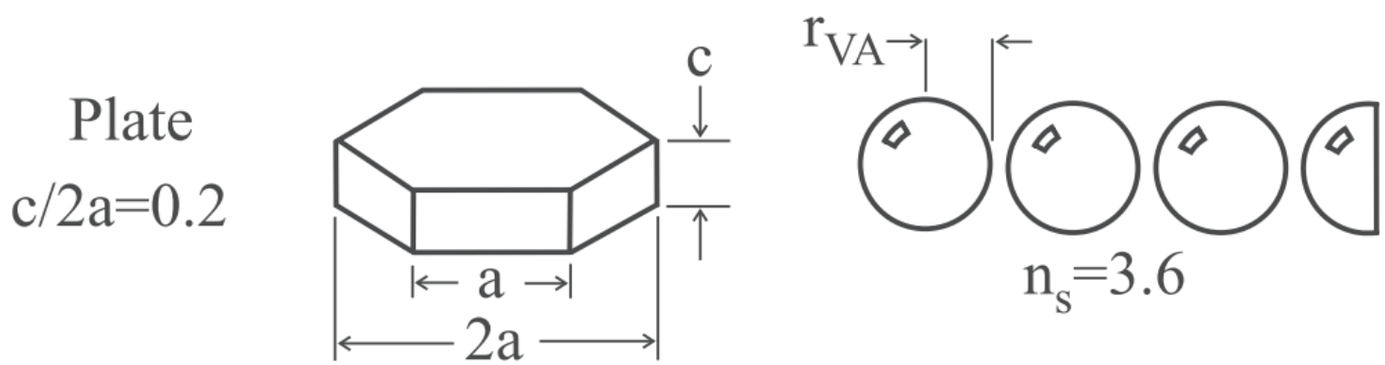
  Gardner and Sharp, 2010

  Dang, Brandt, and Warren, 2015

Snow Albedo Calculation

- Optical constant of ice, black carbon, and mineral dust
- Mie theory

Ice: a non-spherical ice crystal can be represented by a collection of spheres with the same volume-to-area ratio



- Extinction efficiency
- Single-scattering albedo
- Asymmetry factor

Neshyba S.P., Grenfell T.C., and Warren S.G., [2003]

Snow Albedo Calculation

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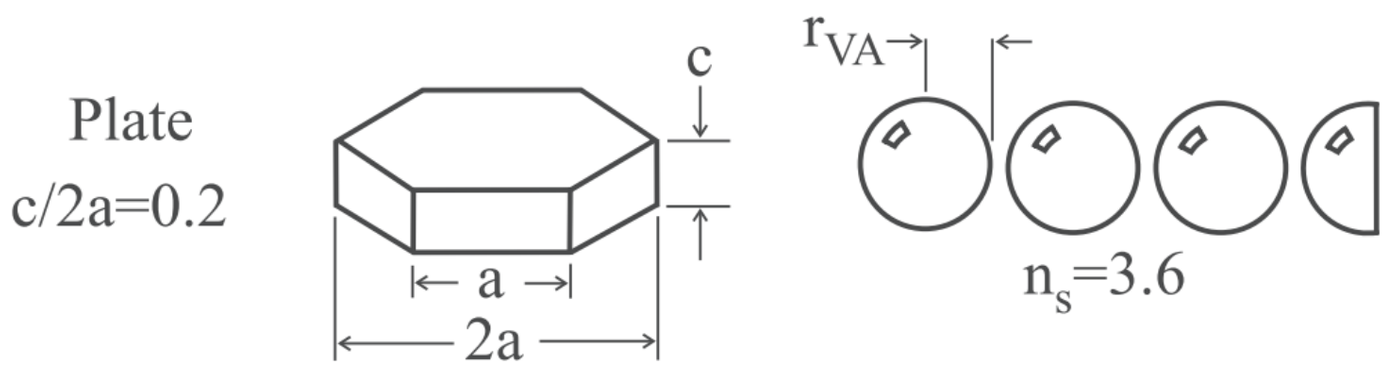
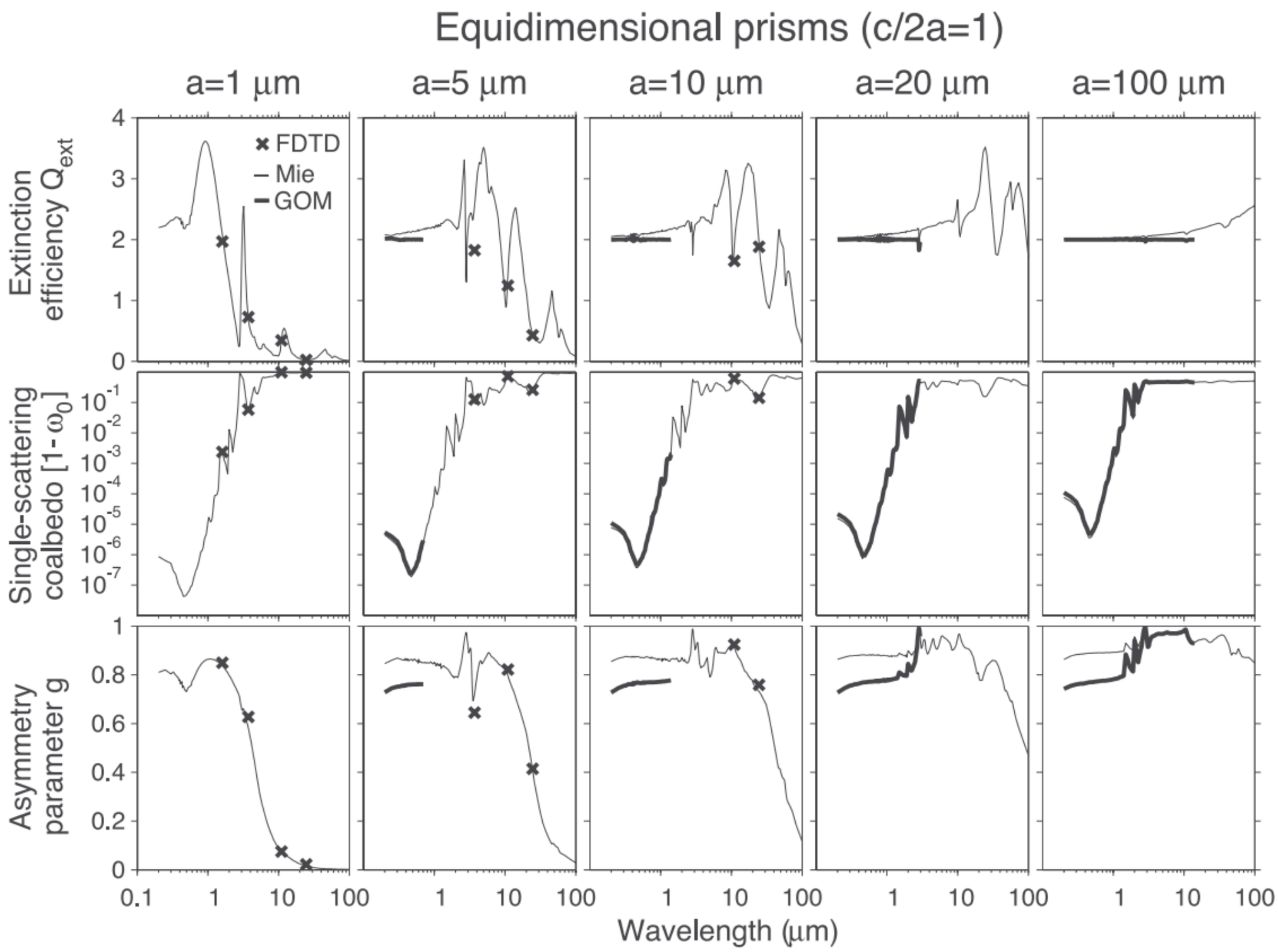


- Extinction efficiency
- Single-scattering albedo
- Asymmetry factor

Neshyba S.P., Grenfell T.C., and Warren S.G., [2003]

Single scattering properties

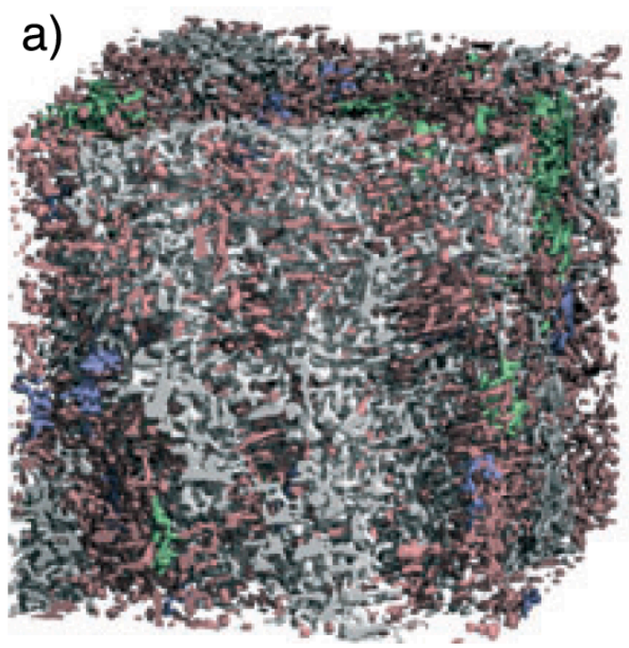


Neshyba S.P., Grenfell T.C., and Warren S.G., [2003]

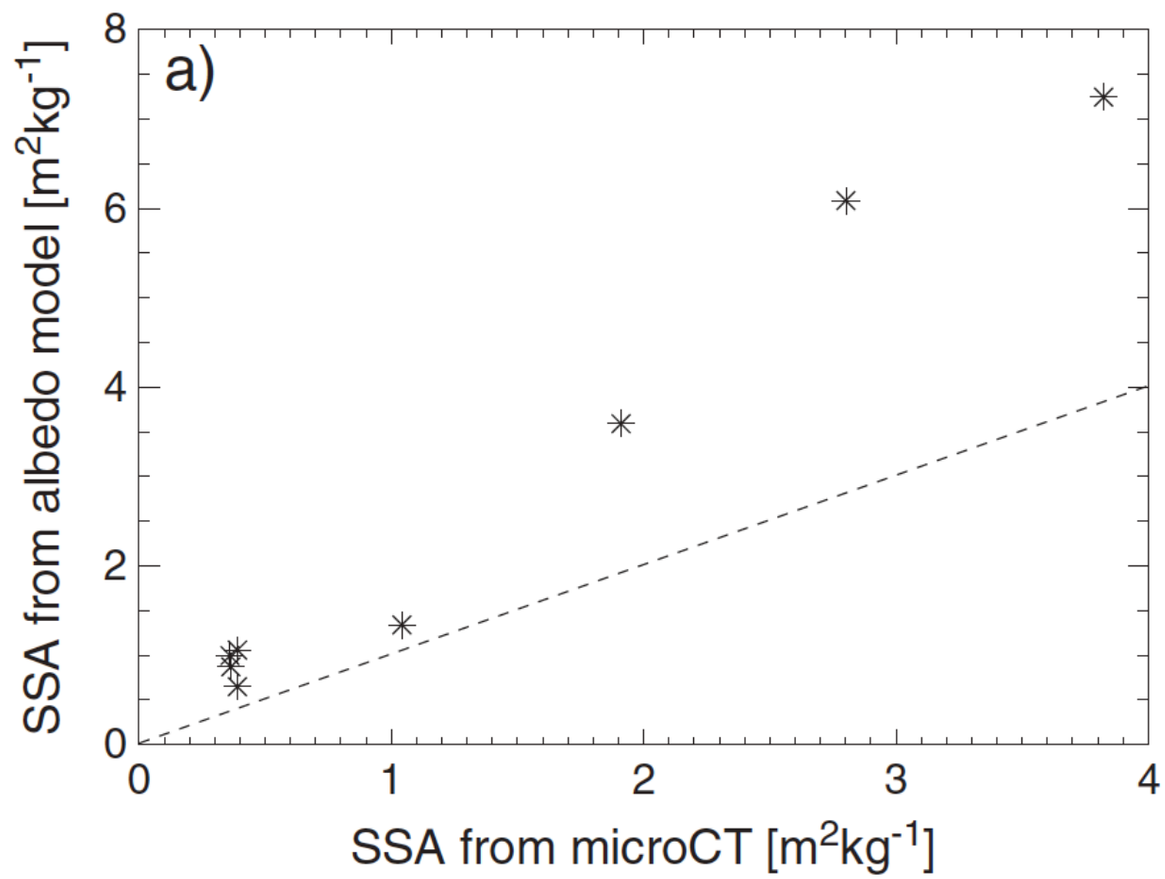
Observation - glacier ice, East Antarctica

Spectral albedo measurement: East Antarctica
Specific surface area (SSA):
ratio of the area of bubbles and cracks to the mass of ice (units m^2 kg^{-1})

FIRN, site R7, surface
SSA= 1.91 m^2/kg, ρ=820 kg/m^3



X-ray tomography



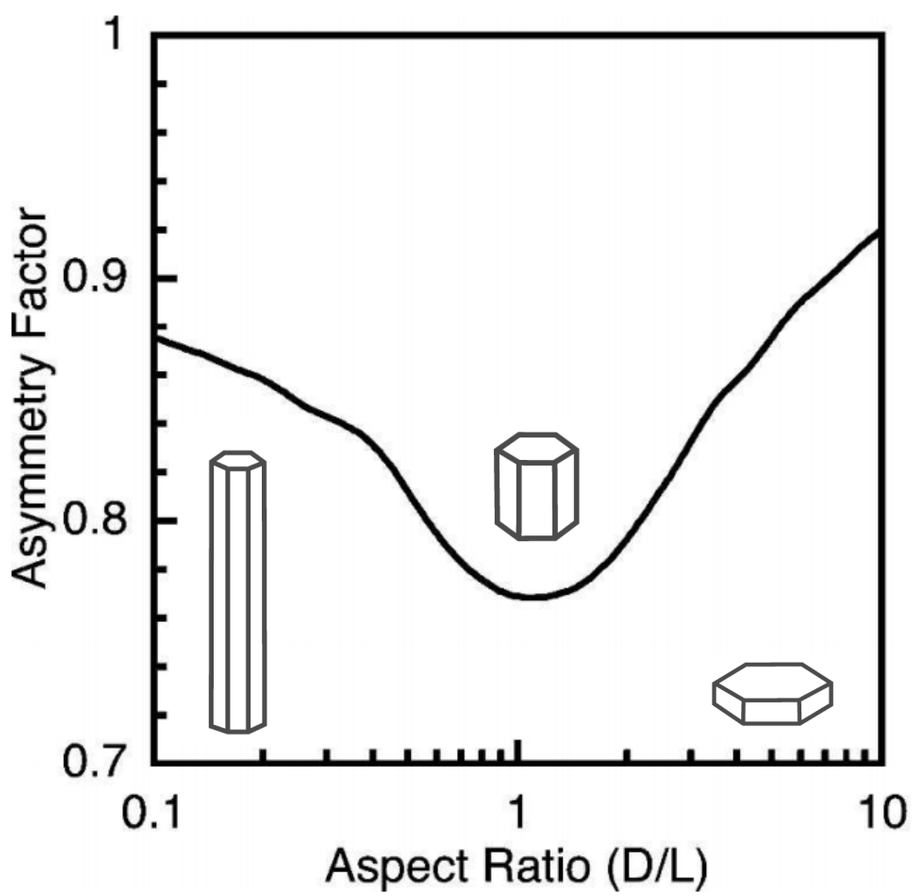
Dadic et al, [2013]

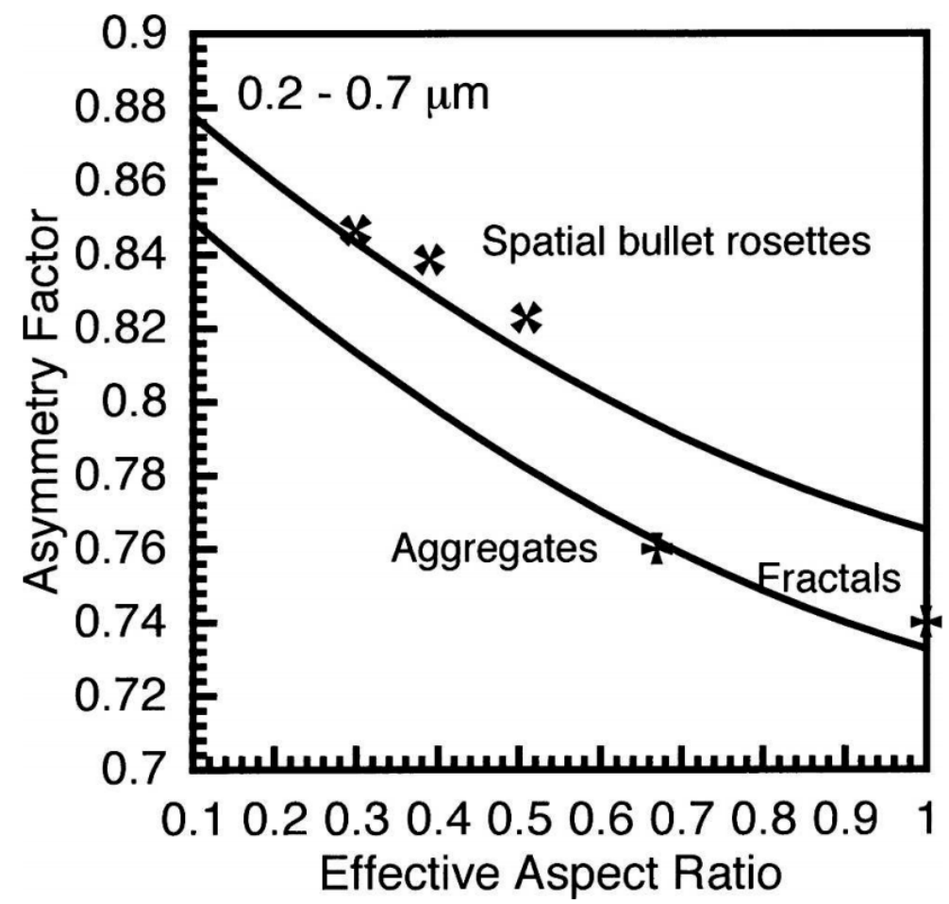
Modeled and measured SSA will agree if they reduce g from 0.86 (sphere) to 0.74.

Calculation

- Optical constant of ice (*Warren and Brandt 2008*), black carbon
- Mie theory: single-scattering albedo, absorption efficiency

Replacing the asymmetry factor of spherical crystal with that of non-spherical crystal
Parameterization of asymmetry factor [*Qiang Fu 2007*]

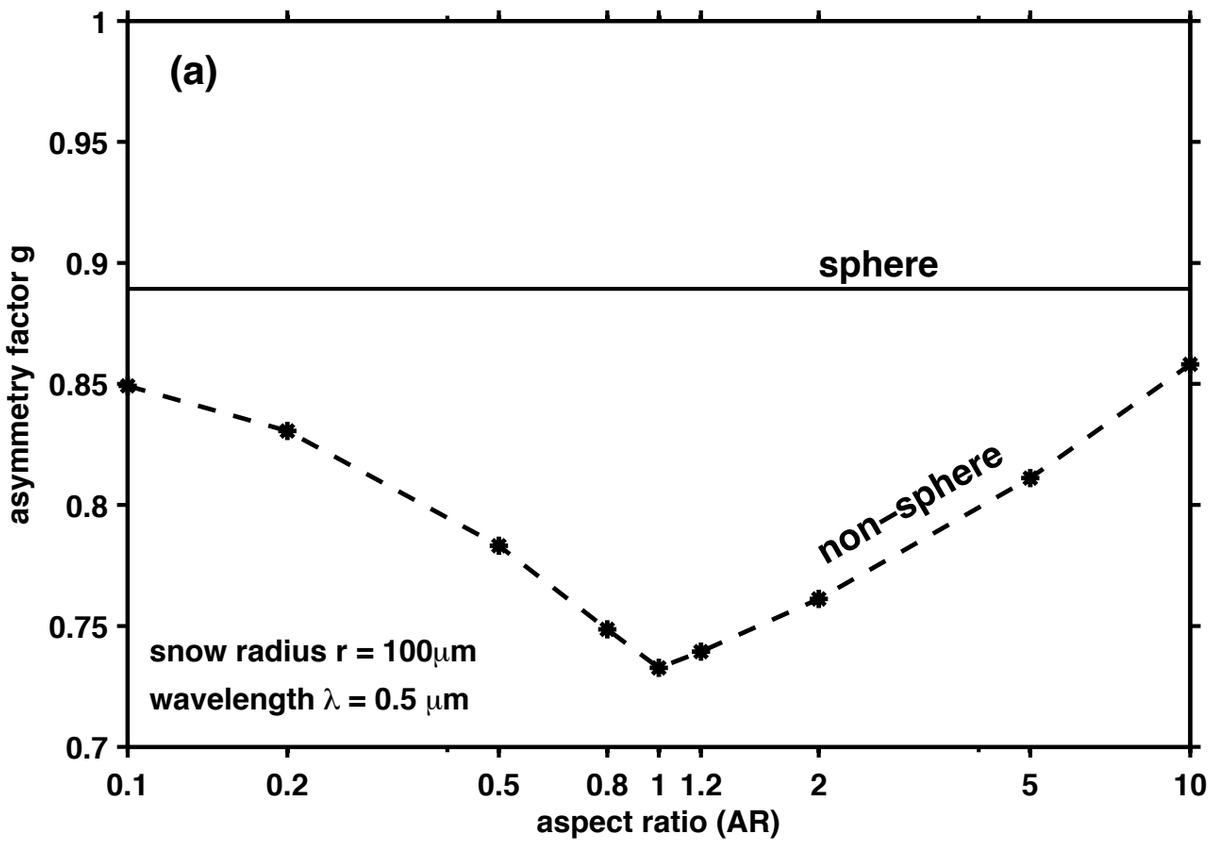




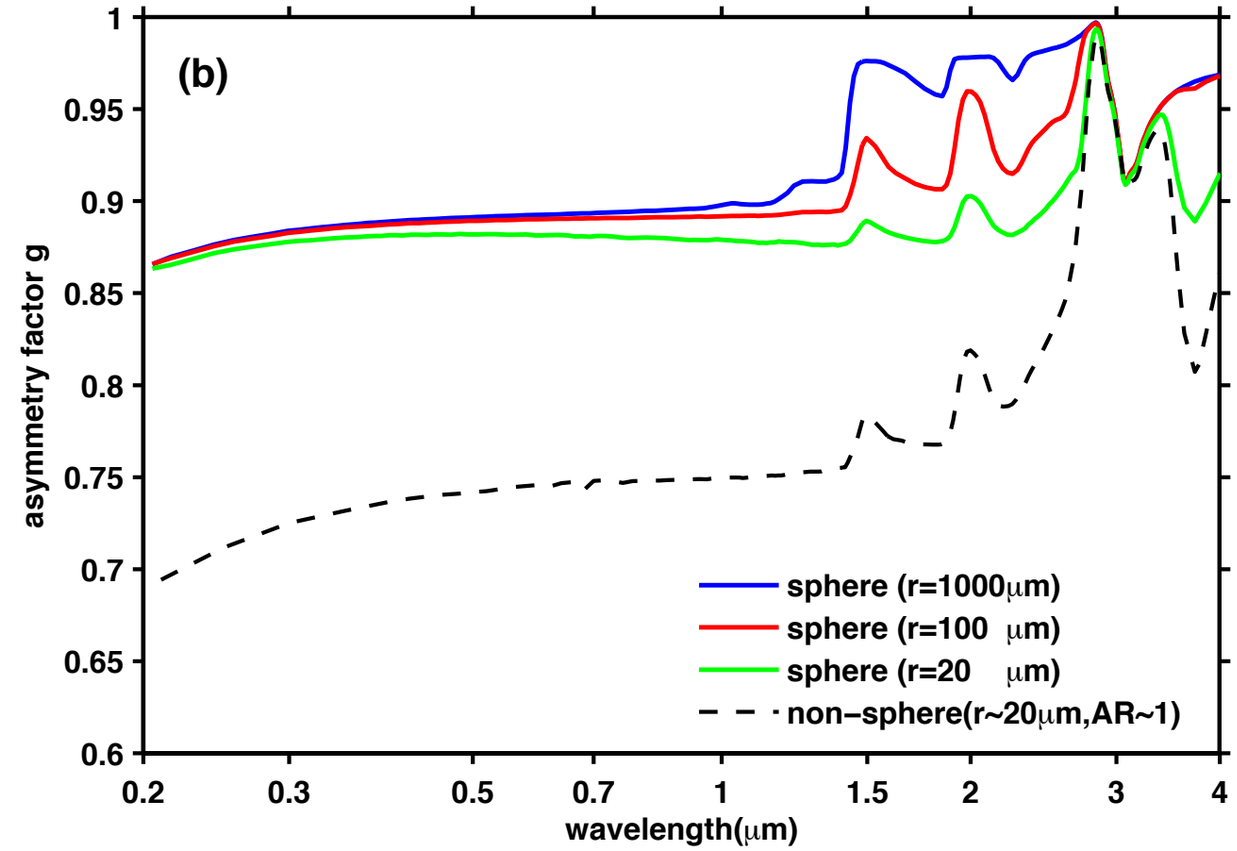
[*Qiang Fu 2007*]

Asymmetry Factor

Asymmetry factor (λ= 0.5 μm)



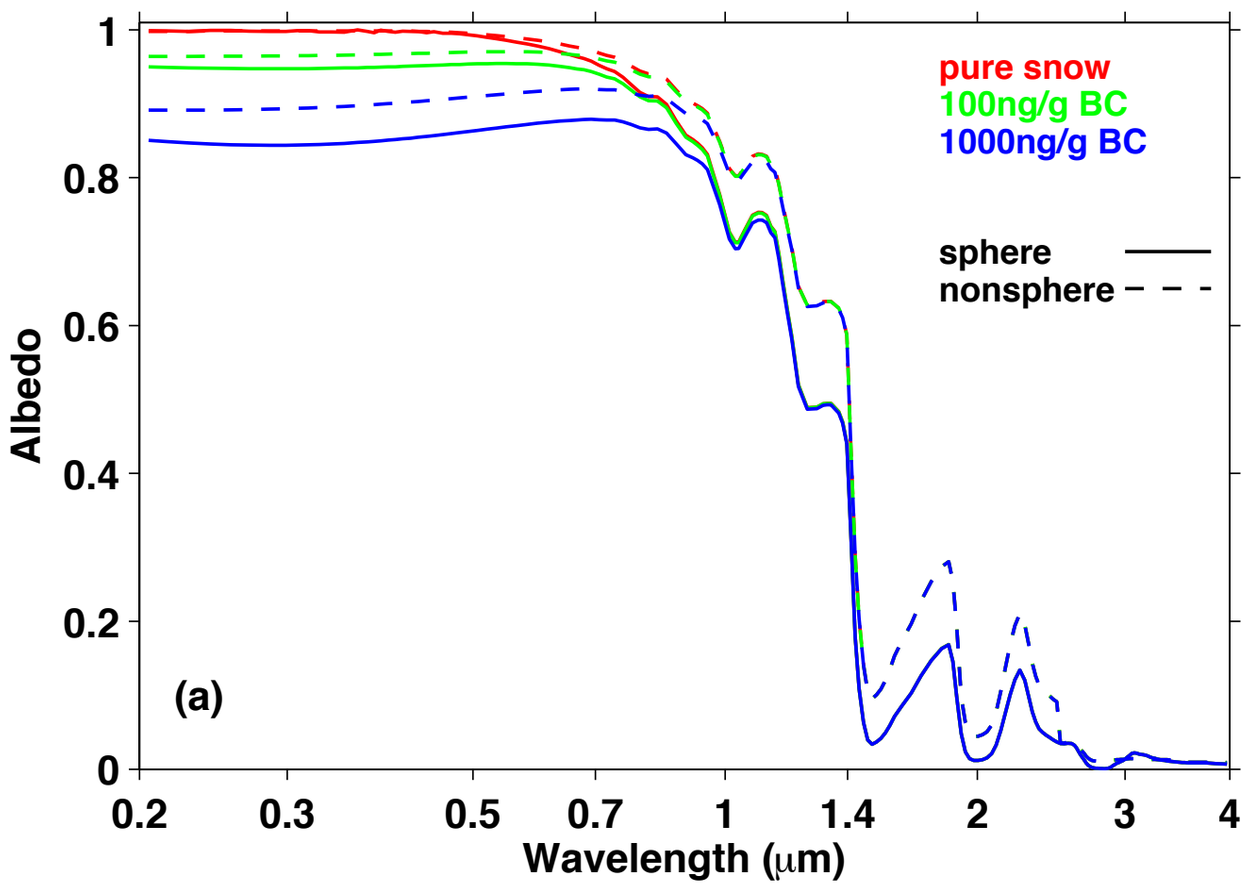
Asymmetry factor



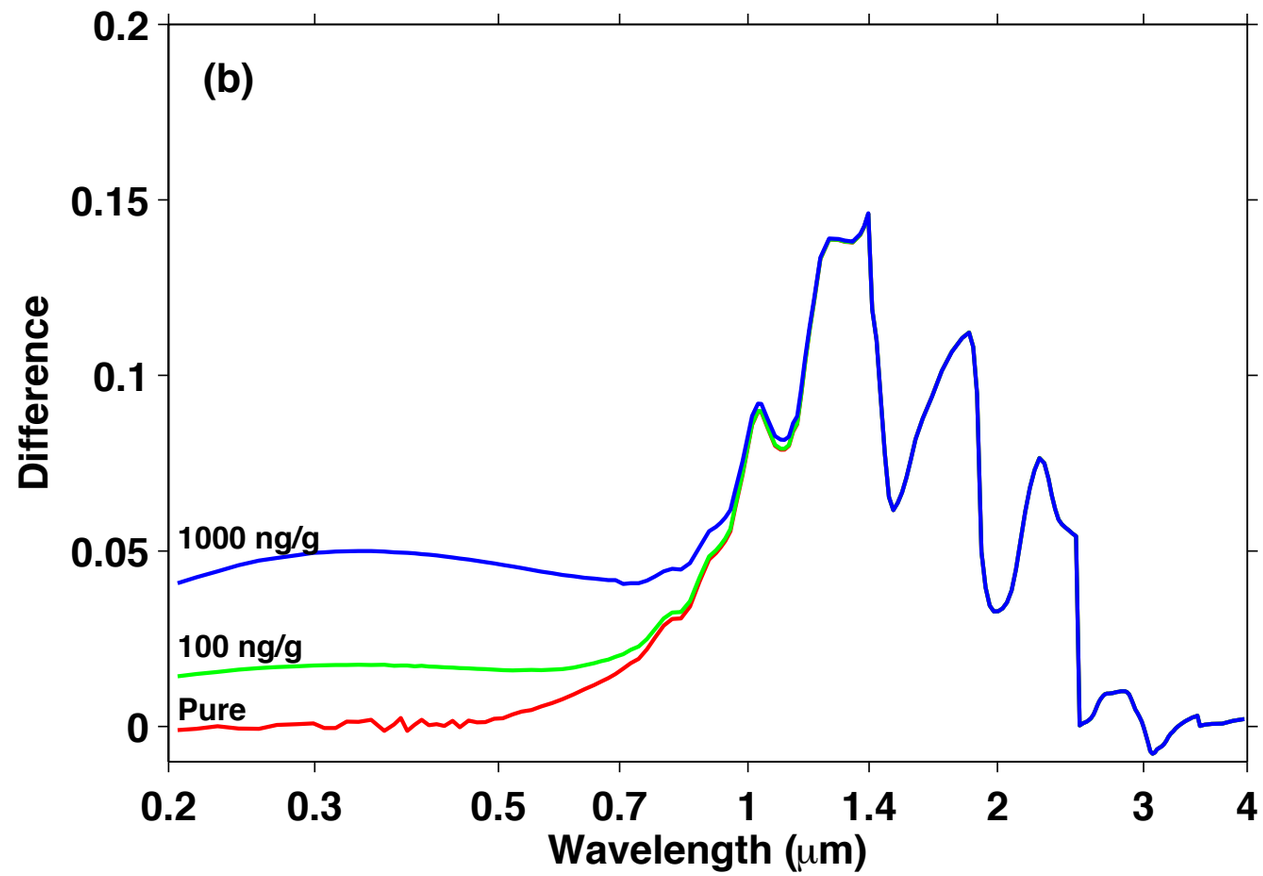
- Non-sphere: Minimum g ~ 0.74 when AR = 1
- Visible: the asymmetry factor is mainly influenced by the shape of ice crystals
- λ>1.4 μm: the asymmetry factor depends on both particle shape and size
- λ=3 μm: strong absorption band, little side scattering by ice particles of any shape, so neither shape nor size of snow grains influence g too much

1. Spectral Albedo - grain size 100 μm

Albedo



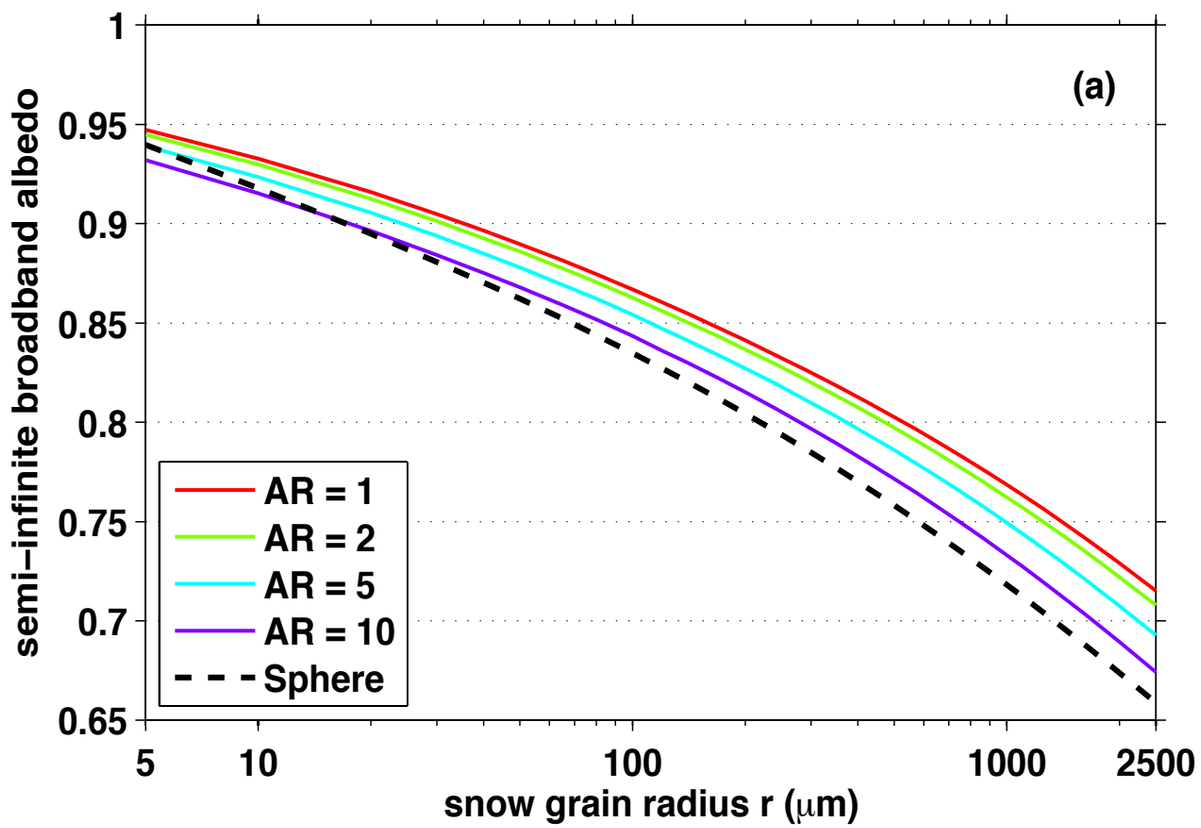
Difference in albedo



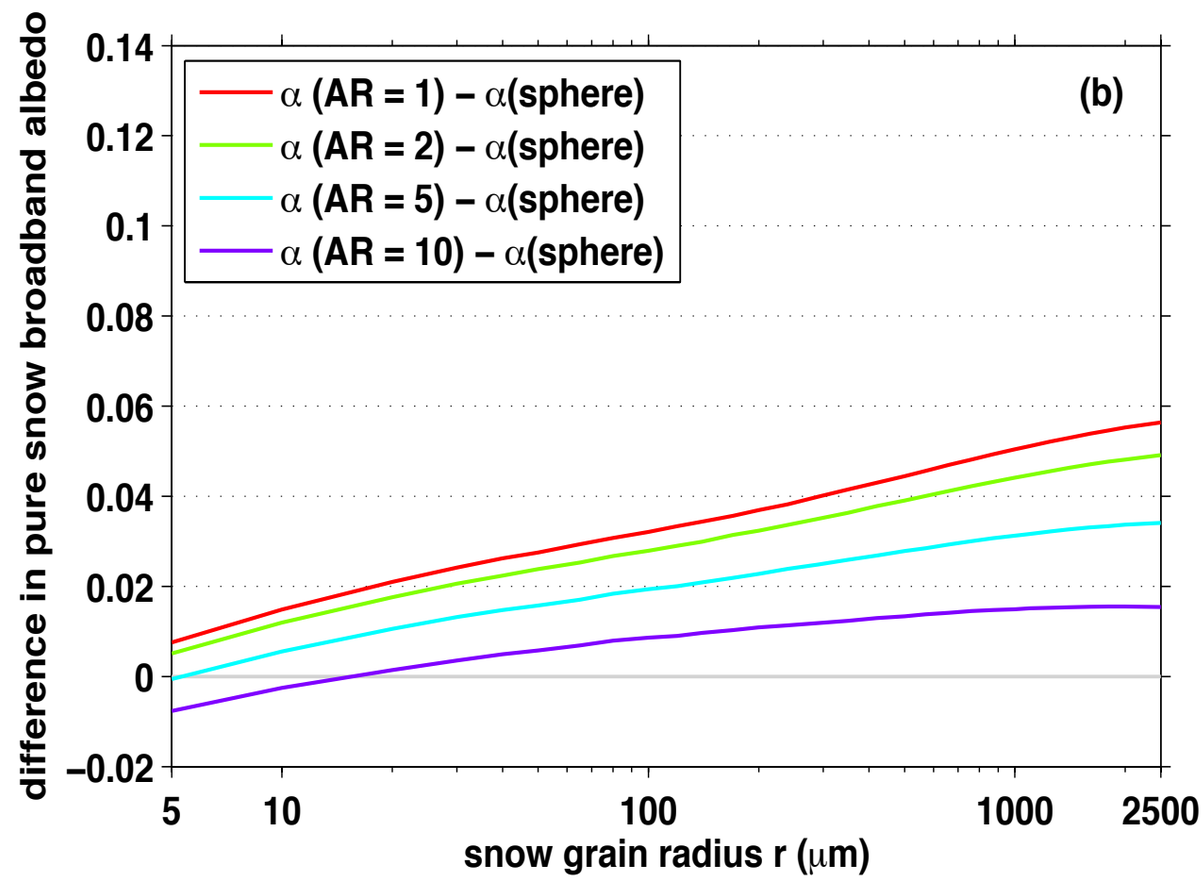
- Weak light absorption (Pure snow @ visible) : similar albedo regardless of snow grain shape
- More light absorption (Sooty snow @ visible band, Any snowpack @Near-IR): non-spherical snow grain has higher albedo
- The change of albedo caused by BC:
  @Visible wavelengths: more black carbon —> higher albedo increase due to non-sphericity
  @NIR wavelengths: less/no impact due to non-sphericity

2. Broadband Albedo of Pure Snow

Albedo



Difference in albedo



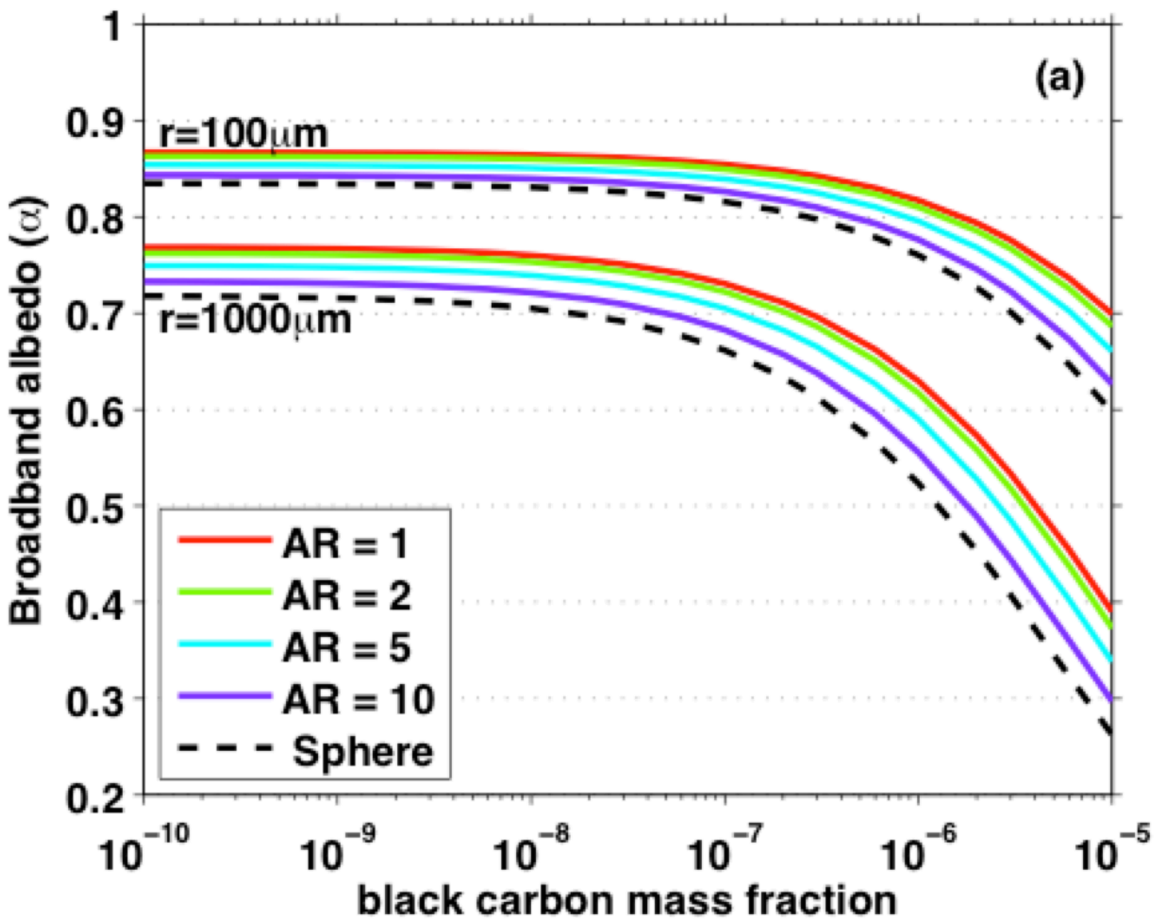
- Non-spherical snow grains has higher albedo than spherical snow grains
- The difference increases as grain size increases, also depends on the aspect ratio.
- Maximum difference (AR = 1)

  New snow (r = 100 μm): +0.035

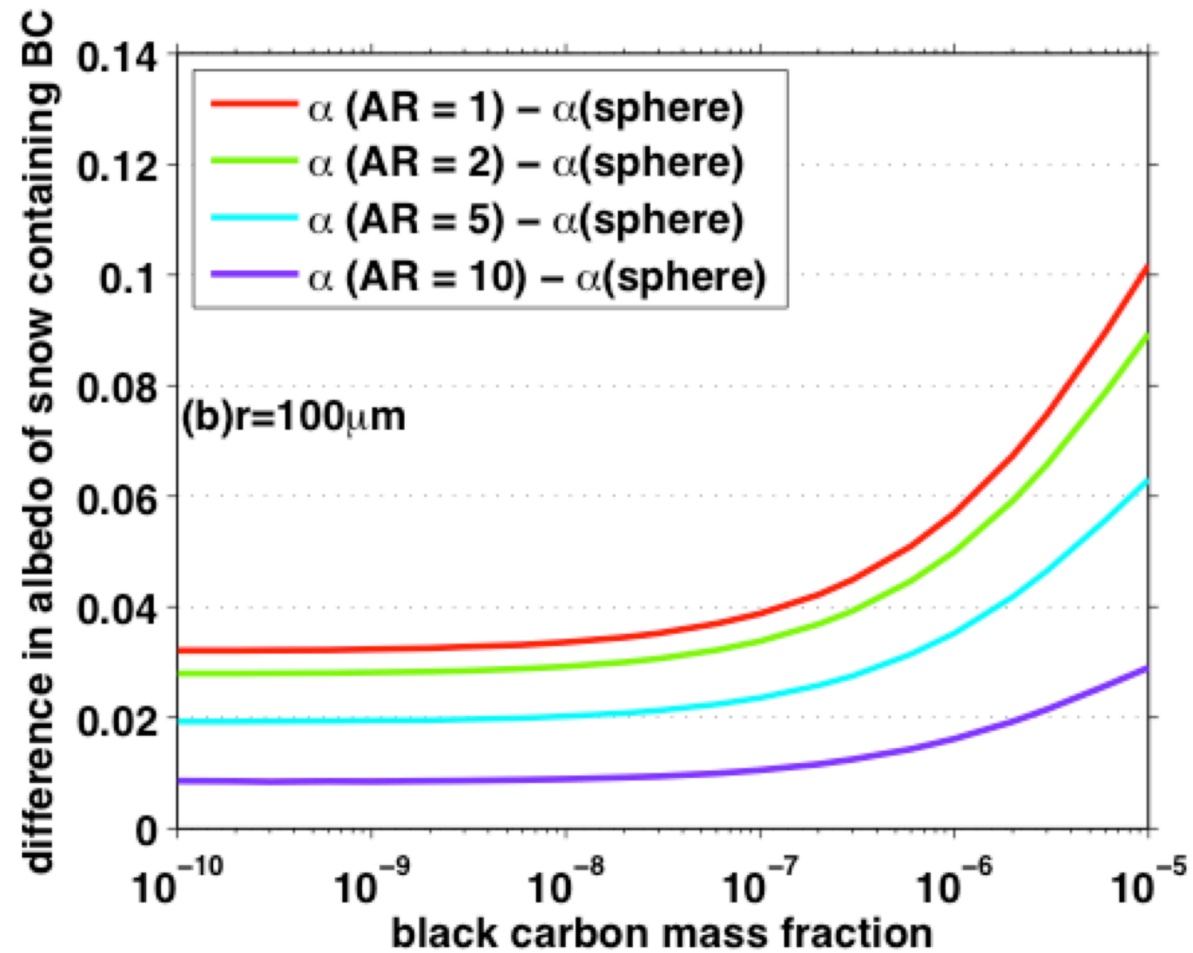
  Old snow (r = 1000 μm): +0.058

3. Broadband Albedo of Snow containing BC

Albedo



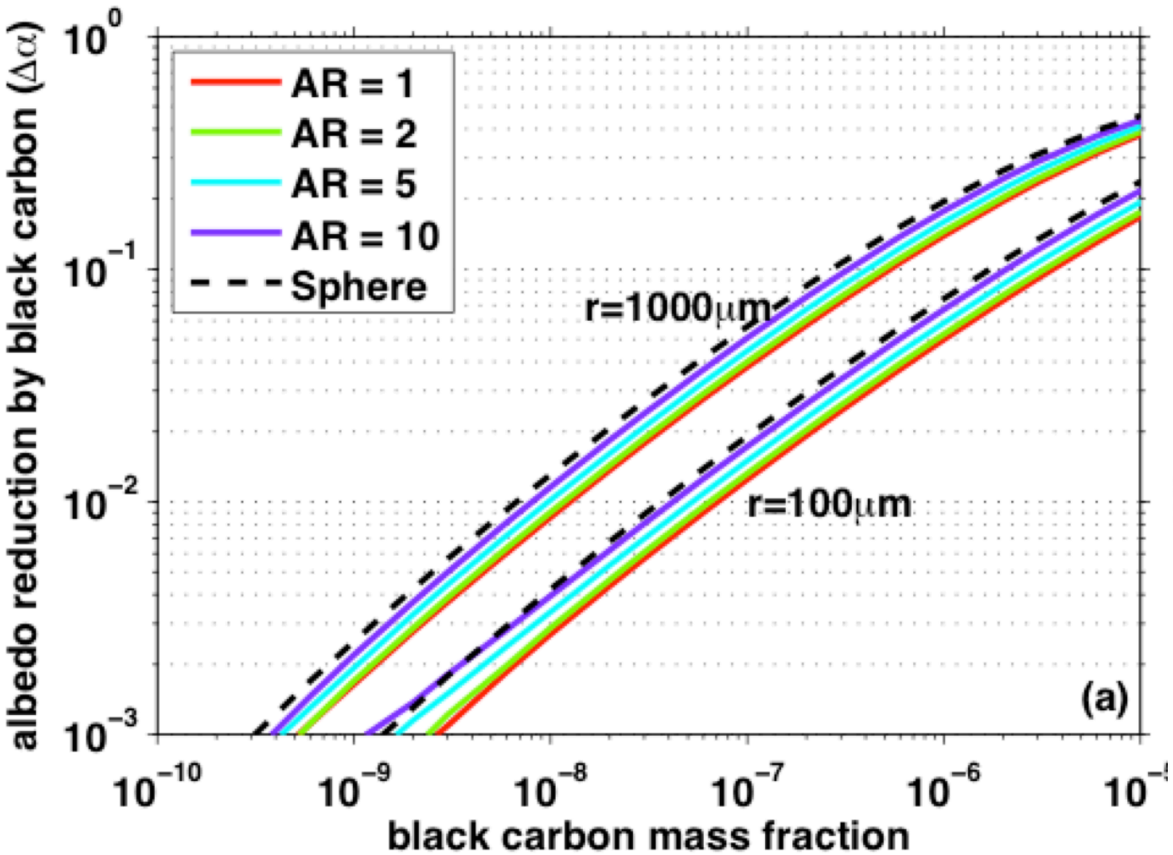
Difference in albedo



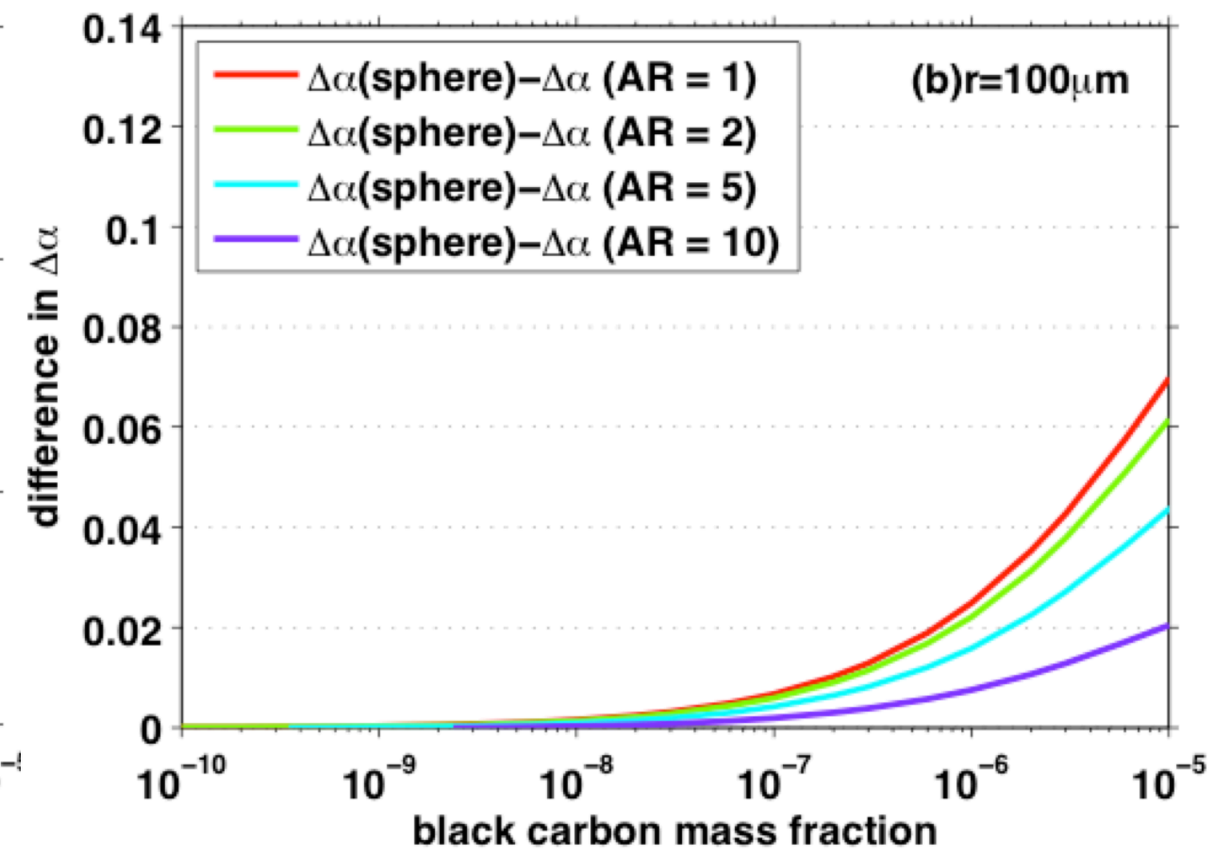
- Non-spherical snow grains has higher albedo than spherical snow grains
- The difference increases as BC concentration increases.

4. Broadband Albedo Reduction induced by BC

Albedo Reduction

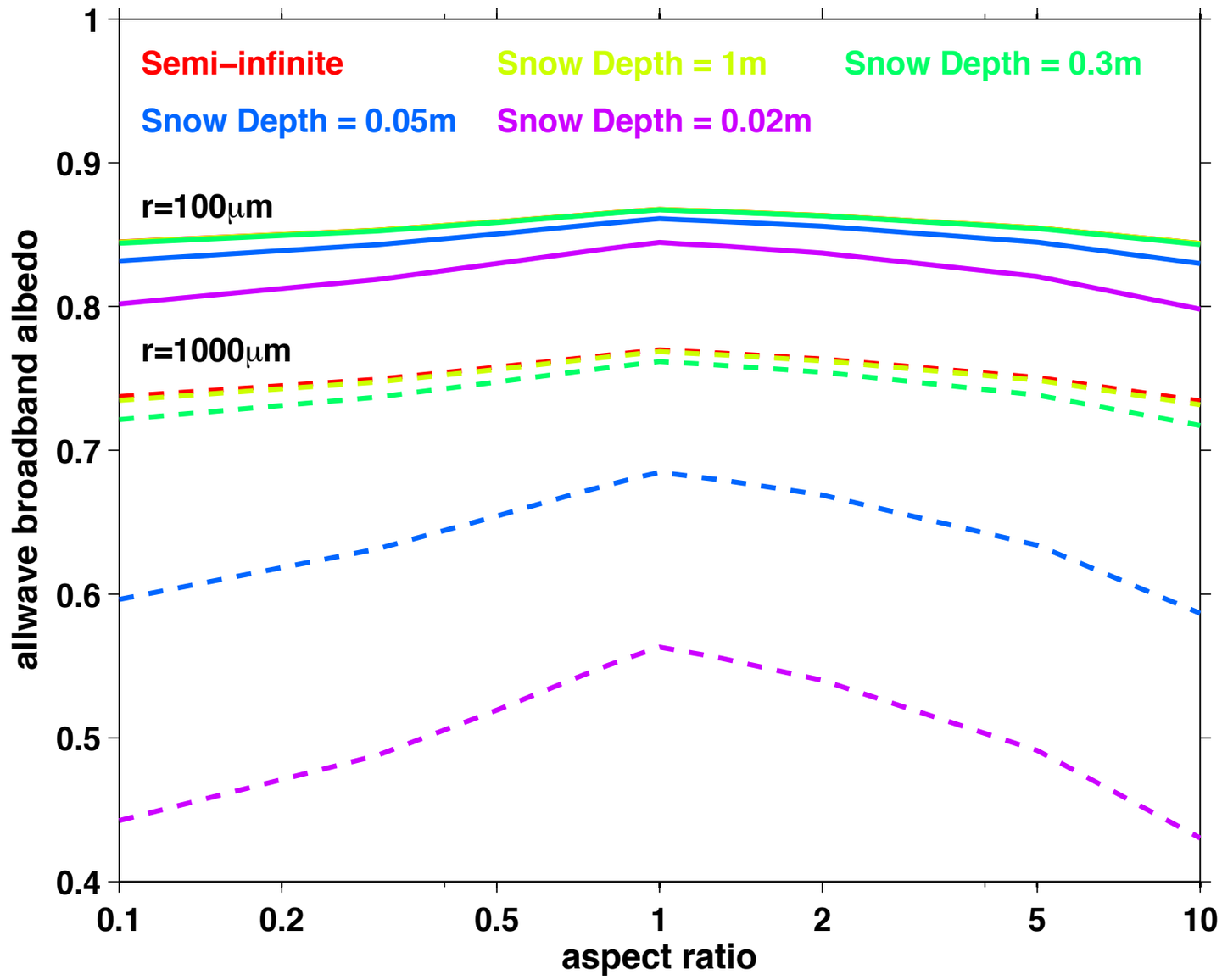


Difference in albedo reduction



- Given the same amount of BC, using spherical ice crystals increases the albedo reduction caused by BC.
- Such overestimate increases as BC concentration increases.
- Maximum overestimate (AR=1):
  BC = 10^{-5} (10^{4} ng/g): 0.07

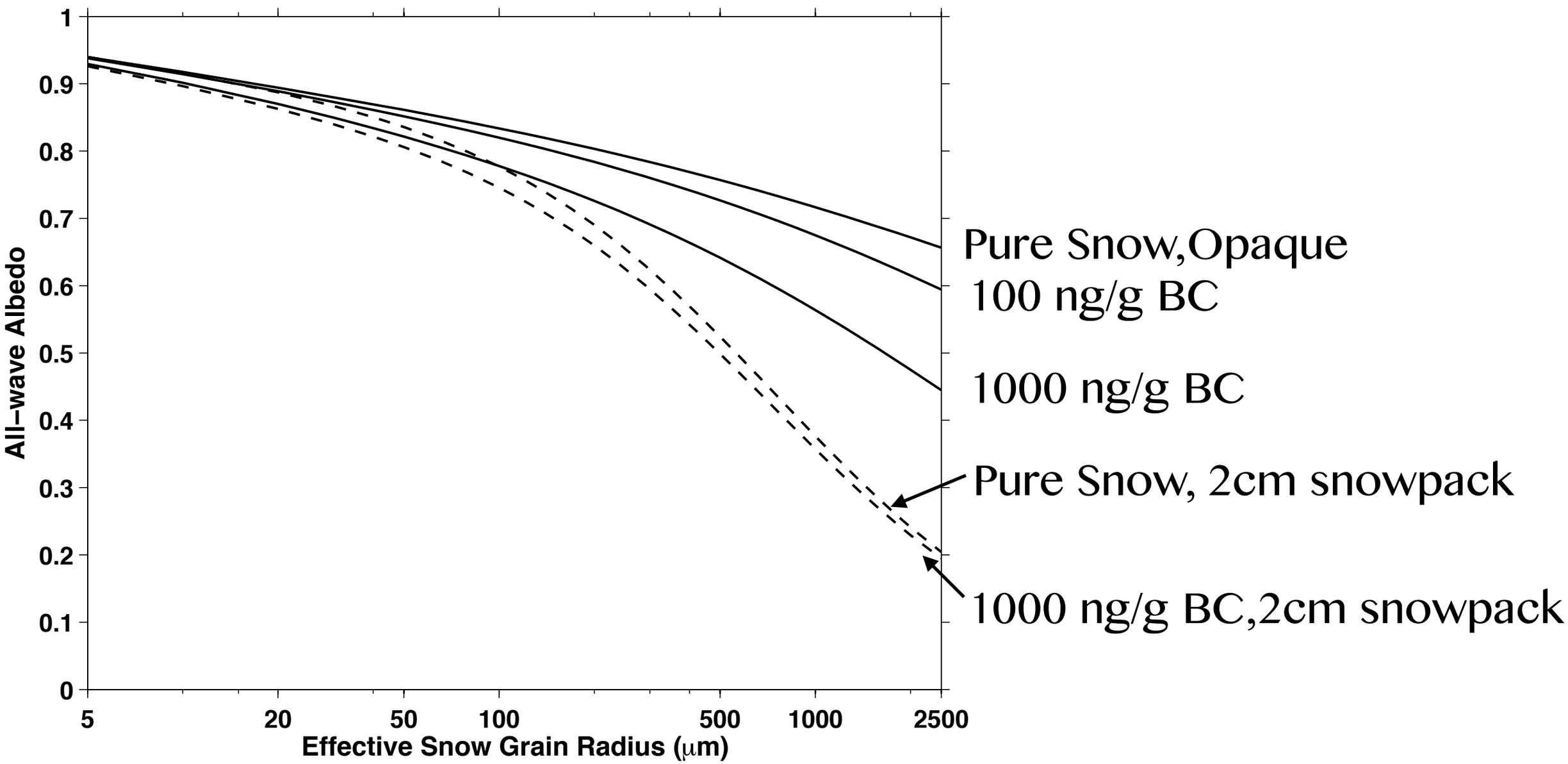
5. Broadband Albedo of Thin Snow



- Black surface: snow albedo decreases as snow depth decreases.
- For snow crystal with aspect ratio ~1 (minimum g), the impact of snow depth on snow albedo is smaller.
- Albedo of thin snow in model simulation may be higher if using non-spherical ice crystals rather than spherical ice crystals.

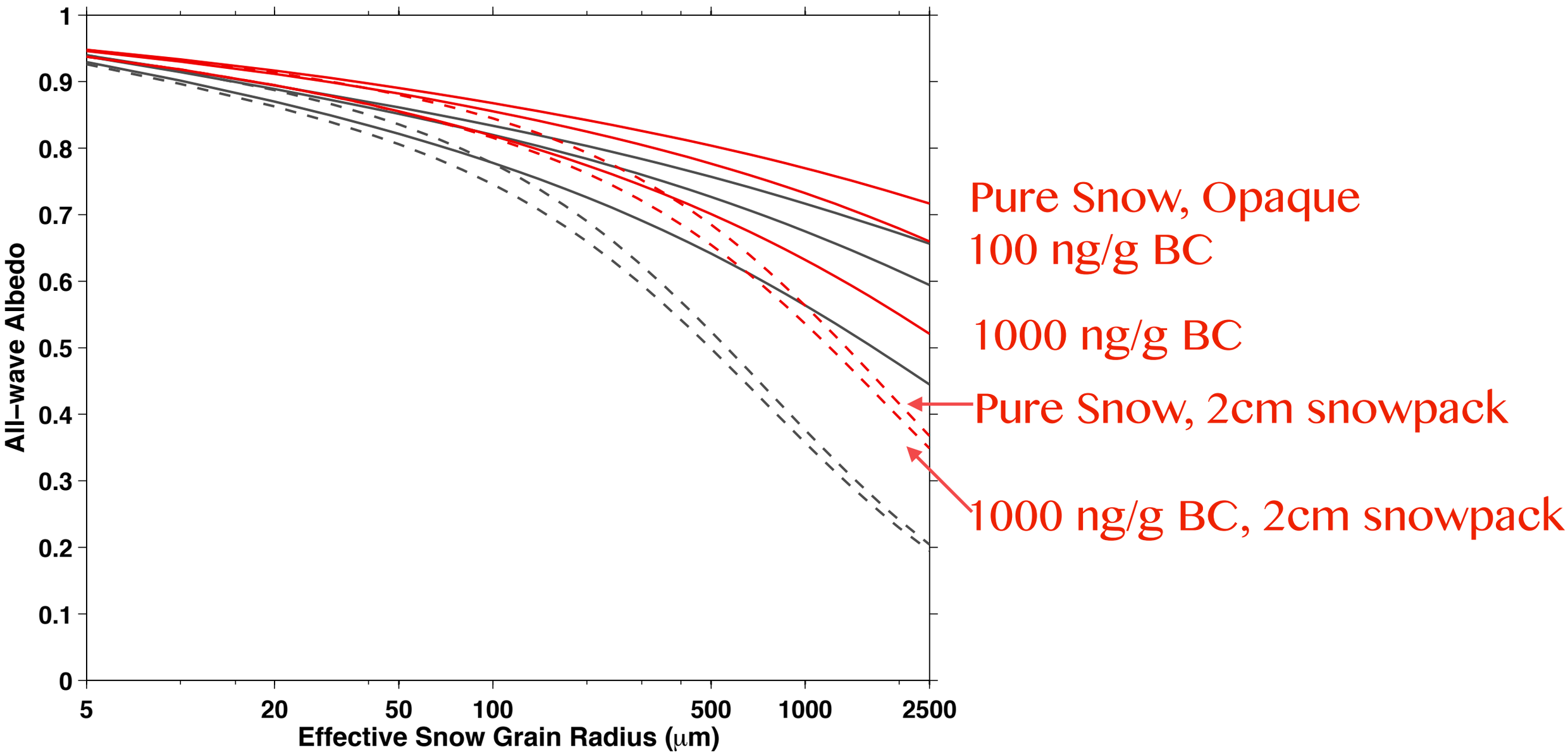
Snow Albedo

- **Snow Grain Size**
- **Light-absorbing particles**
- **Snow Depth**

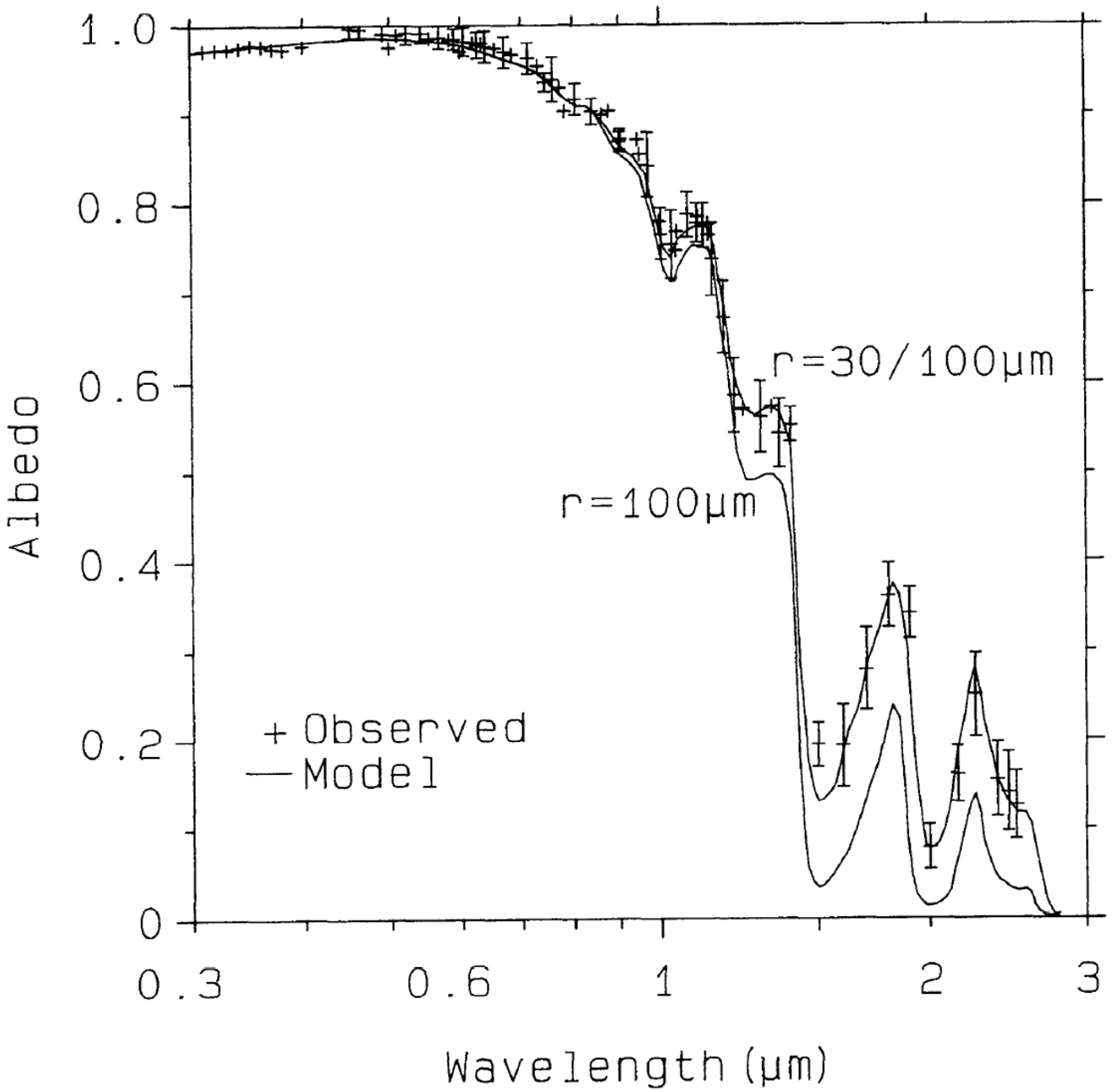


Snow Albedo

- Snow Grain Size
- Light-absorbing particles
- Snow Depth
- Snow Grain Shape



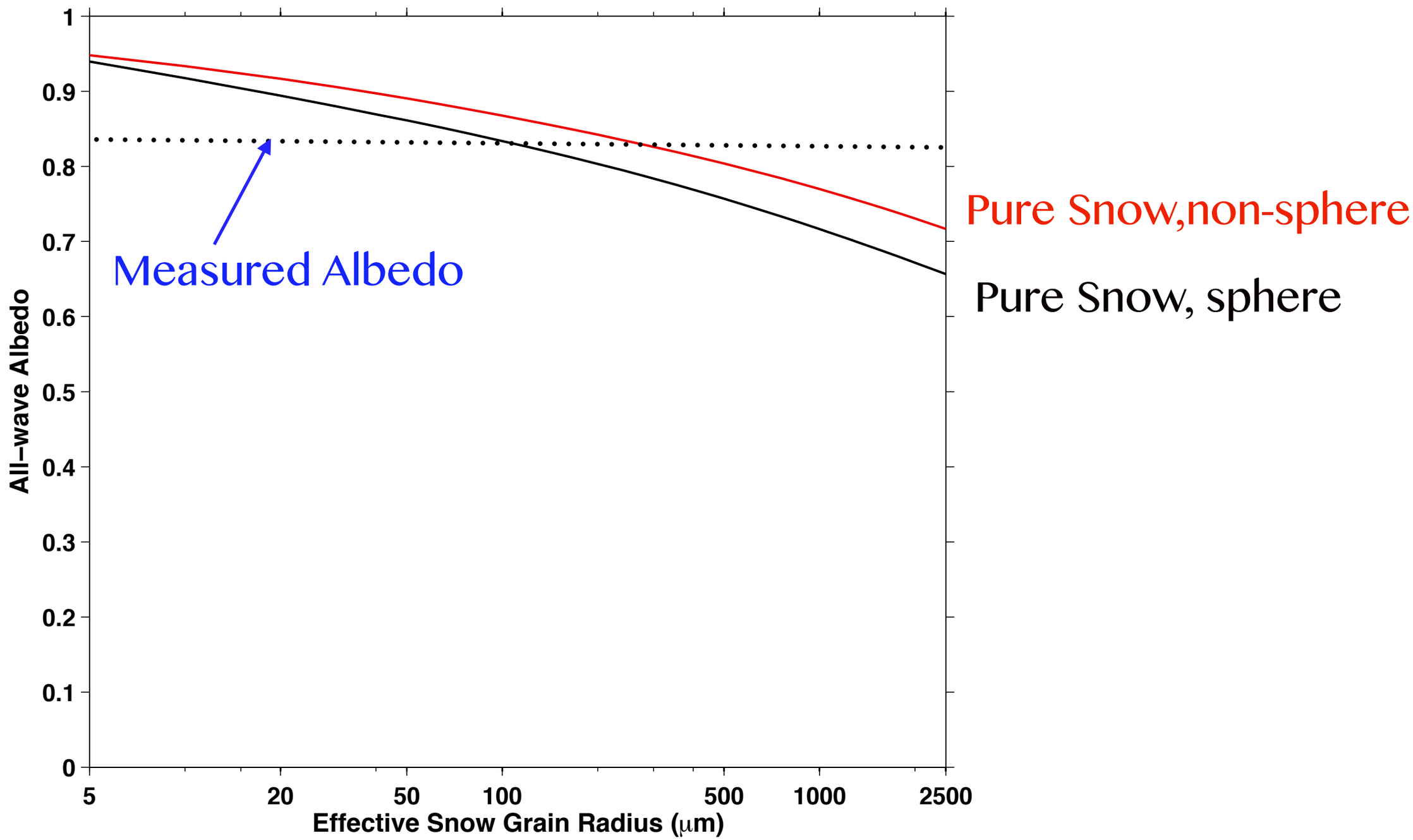
Why radiative transfer models for snowpacks of spherical snow grains were able to match field measurements of spectral albedo ?



- **Snow Grain Size is a free parameter**

Grenfell T.C.,Warren S.G., and P.C. Mullen [1994]

Implication on snow grain size



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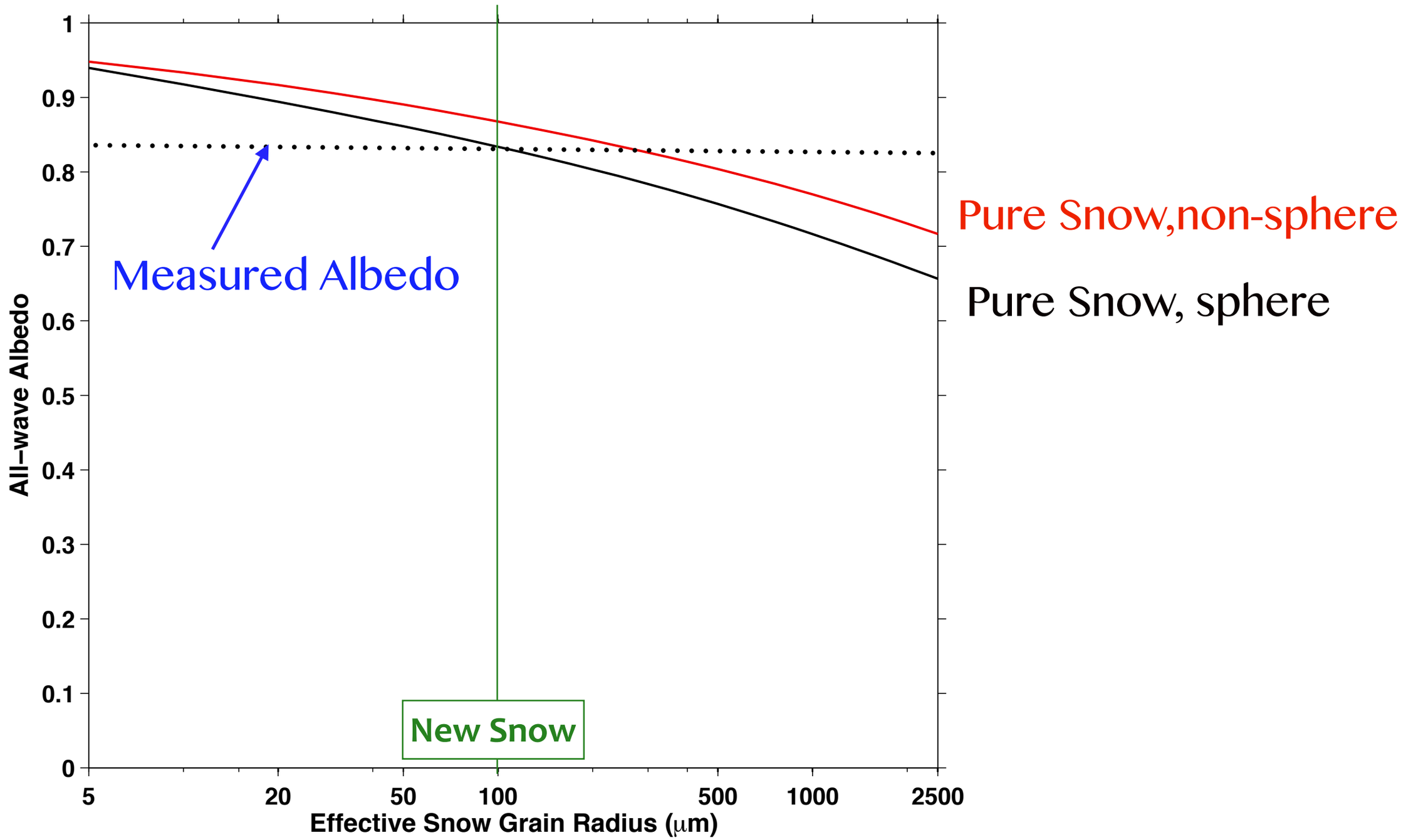

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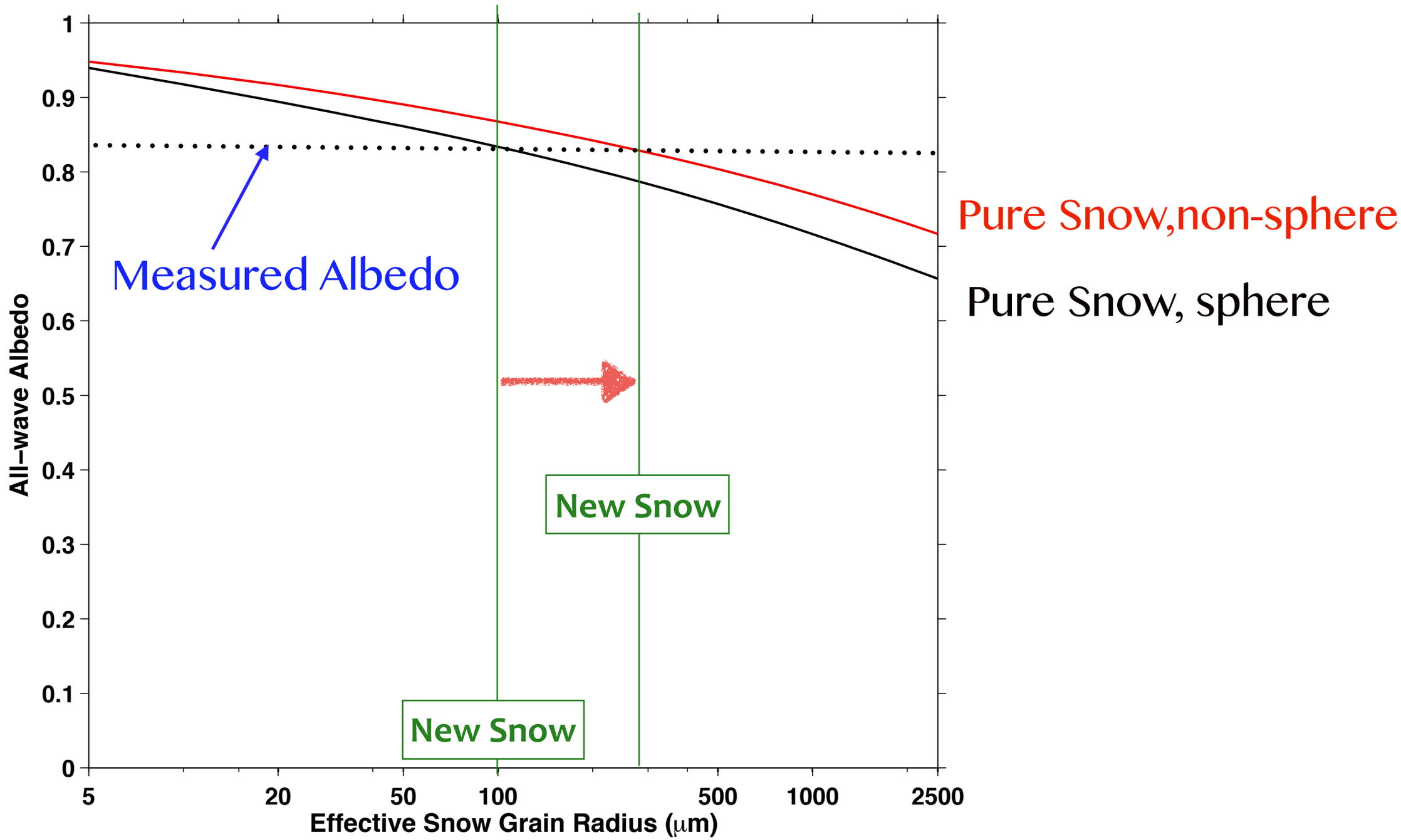

Summary

- **The effect of asymmetry factor on snow albedo has been studied. Using the asymmetry factor of non-spherical ice crystals give:**

  (1) Higher albedo of pure snow, regardless of the thickness of snowpack.

  (2) Lower albedo reduction caused by black carbon.

  (3) Higher albedo of thin snow .

- **If the asymmetry factor of non-spherical snow grains were right, the snow grains are larger than we thought**

Thanks for your attention!