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Parameterization of single-s

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1. Introduction

Snow grains are non-spherical and often irregular in shape. Still, in many radiative transfer applications,the single-scattering properties (SSPs) of snow have been based on the assumption of spherical snow grains. Here, we introduce **an analytical SSP parameterization for the solar spectral range** (wavelengths λ=0.199-2.7 μm) **based on non-spherical snow grains**.

2. Reference phase function P_{11}^{ref}

As an observational constraint for the parameterization, we use a reference phase function derived from angular scattering measurements made for blowing snow in the CLimate Impacts of Short-Lived pollutants in the Polar region (CLIMSLIP) campaign at Ny Ålesund, Svalbard (Fig. 1).

- polar nephelometer measurements at λ=0.8 μm, for scattering angles θ_s=15°-162°
- an average over two cases (23 and 31 March 2012)

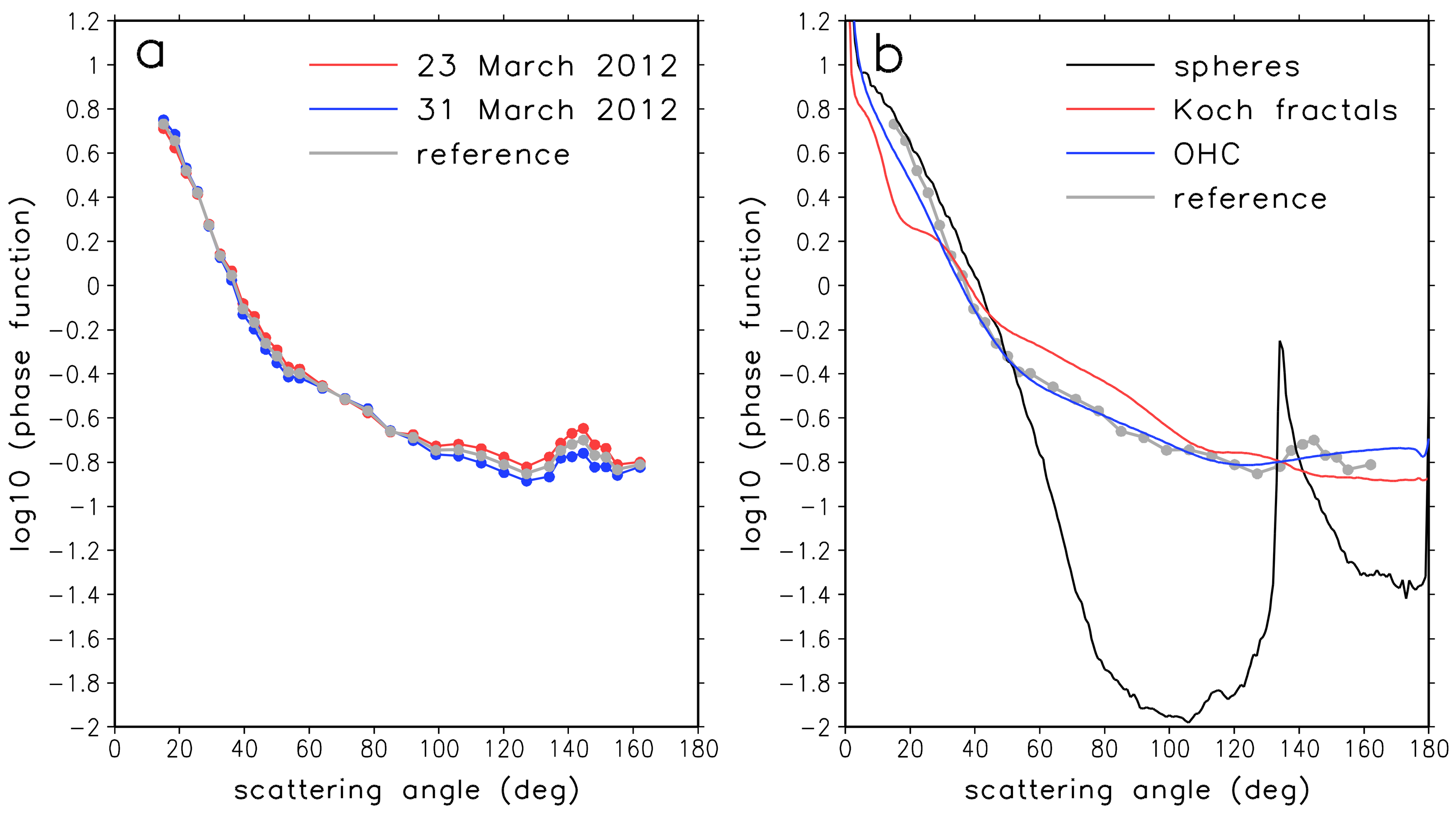


Fig. 1. (a) Phase functions for blowing snow at λ=0.8 μm measured on 23 and 31 March 2012, along with the reference phase function P_{11}^{ref} defined as their average. (b) Comparison of P_{11}^{ref} with phase functions for spheres, distorted Koch fractals and the OHC.

3. "Optimized habit combination" (OHC)

Several shape models (habits) were considered: spheres, Koch fractals, Gaussian spheres, and nine habits in the Yang et al. (2013) database. Phase functions for the individual shapes and combinations of two or three shapes were compared with the reference phase function. The agreement was quantified in terms of a **cost function**:

$$\mathrm{cost} = \sqrt{\frac{\int_{15^\circ}^{162^\circ} (\ln P_{11}^{\mathrm{model}} - \ln P_{11}^{\mathrm{ref}})^2 \sin\theta_s d\theta_s}{\int_{15^\circ}^{162^\circ} \sin\theta_s d\theta_s}}$$

The lowest cost functions occur consistently for three-habit combinations with asymmetry parameter g≈0.775-0.780 (see Fig. 2). The following **"optimized habit combination" (OHC)** was selected for representing the SSPs of snow:

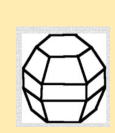
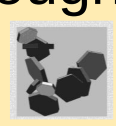
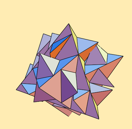
OHC = 36% area fraction of severely rough (SR) droxtals 
+ 26% aggregates of SR plates 
+ 38% strongly distorted 2nd generation Koch fractals 

Fig.1b compares phase functions for the OHC with P_{11}^{ref} and two shape models previously used for snow: spheres and distorted Koch fractals (e.g., Kokhanovsky et al. 2011).

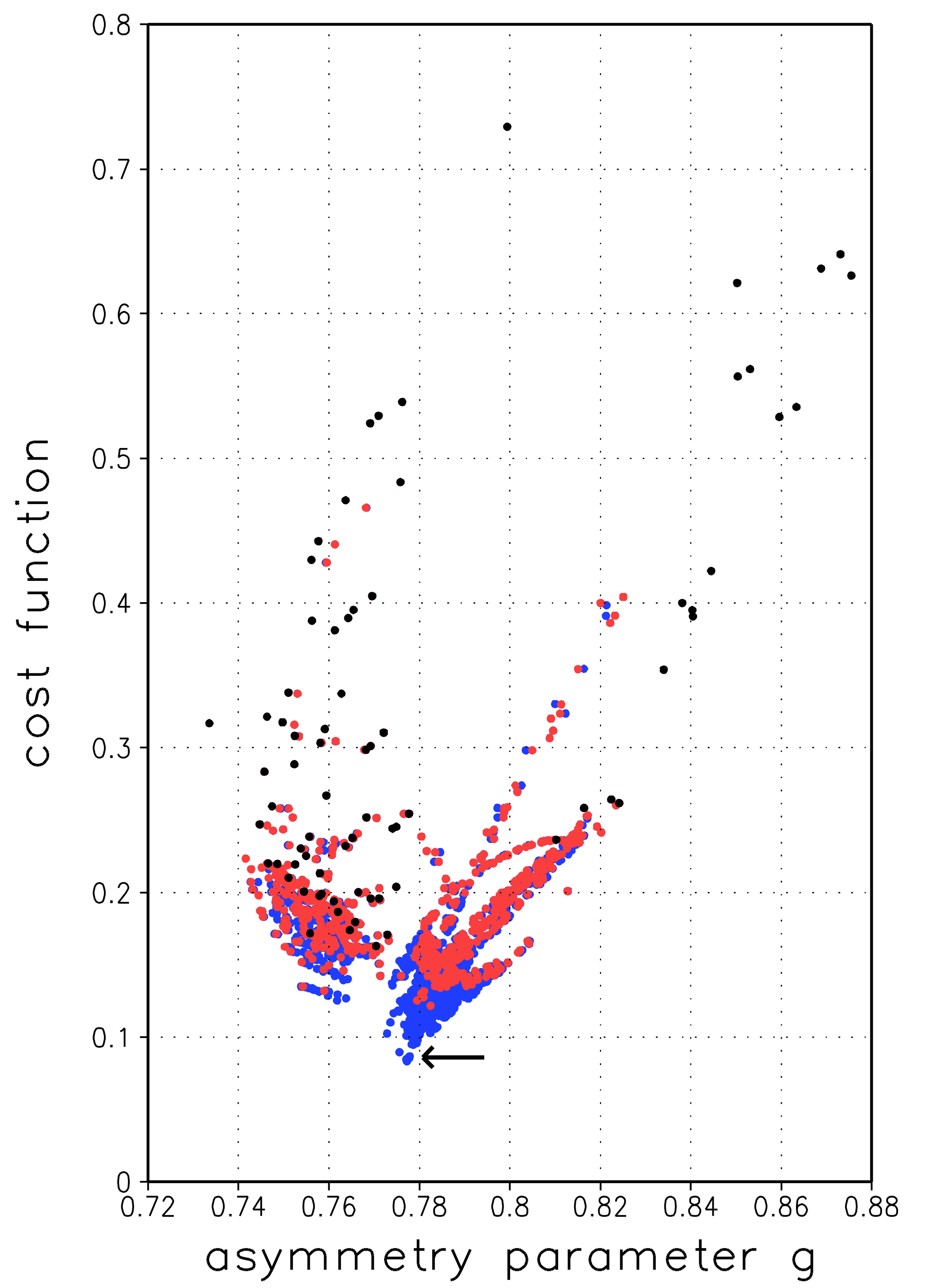


Fig. 2. Scatter plot of cost function vs. asymmetry parameter for single-habit (black), two-habit (red) and three-habit (blue) cases. The OHC is marked with an arrow.

cattering properties of snow

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4. Snow SSPs as a function of wavelength and snow grain size

Figure 3 compares the asymmetry parameter g and a dimensionless absorption parameter ξ (basically, co-albedo β normalized by the grain size and the imaginary part of ice refractive index) for the OHC with spheres and distorted Koch fractals. Especially in the visible region, *g* for the OHC (0.77-0.78) is much lower than that for spheres (≈0.89), though slightly higher than that for Koch fractals (≈0.74). Also, for a fixed volume-to-projected area equivalent radius r_{vp}, ξ and β are generally larger (i.e., absorption is stronger) for the non-spherical particles than spheres.

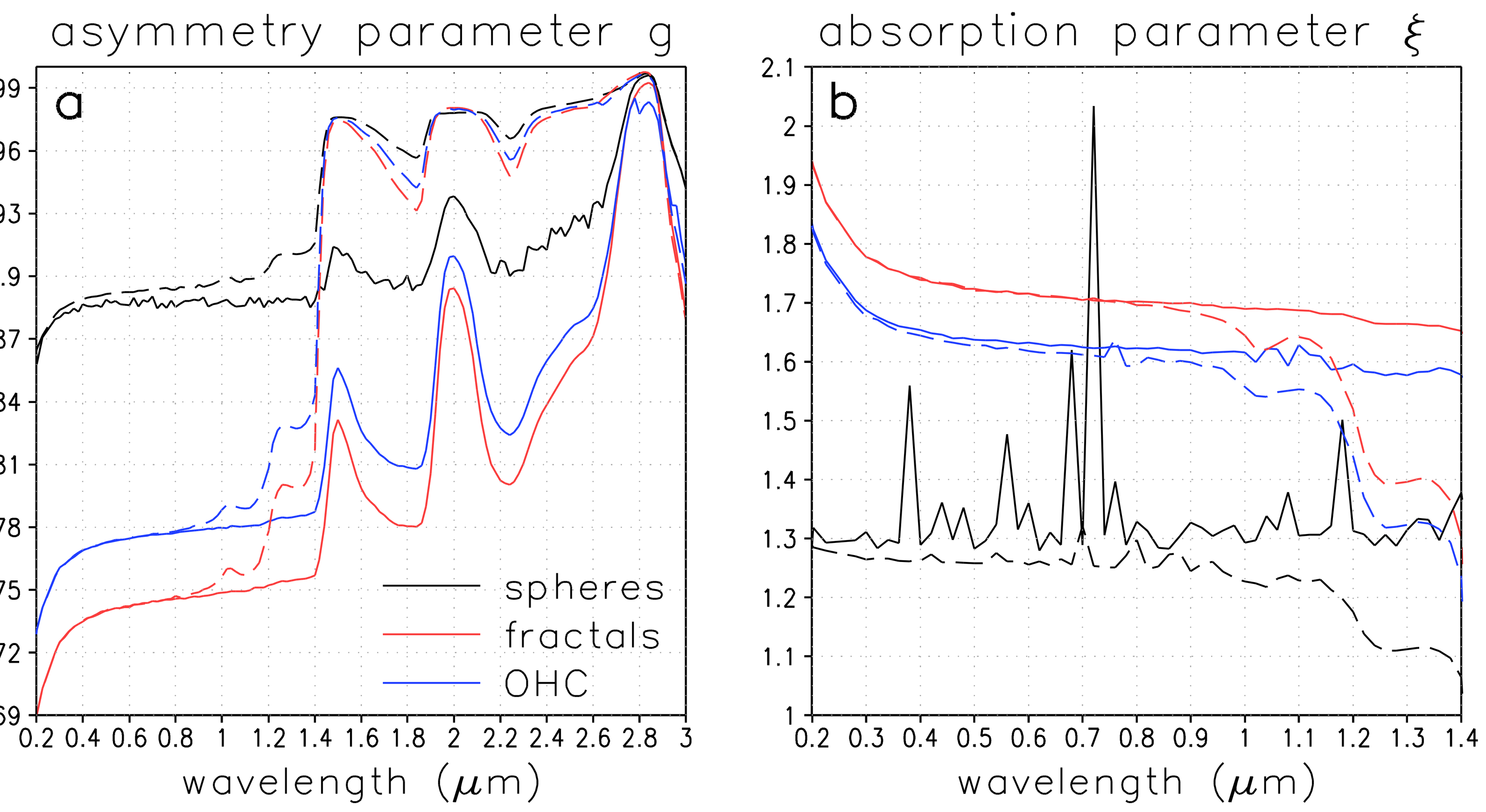

Fig. 3. Comparison of (a) asymmetry parameter *g* and (b) dimensionless absorption parameter ξ (see Kokhanovsky 2013) for spheres, Koch fractals and the OHC. The solid lines are for small snow grains (r_{vp}=50 μm) and the dashed lines for large snow grains (r_{vp}=1000 μm).

5. Parameterization equations

Extinction efficiency: $Q_{\mathrm{ext}} = 2$

Single-scattering co-albedo: $\beta = 0.470\left\{1-\exp\left[-2.69x_{\mathrm{abs}}\left(1-0.31\min(x_{\mathrm{abs}},2)^{0.67}\right)\right]\right\}$

Asymmetry parameter: $g = 1-1.146(m_r-1)^{0.8}(0.52-\beta)^{1.05}\left(1+8x_{vp}^{-1.5}\right)$

Phase function: a bit too long for the poster -- see Räisänen et al. (2015)

Notation:

Size parameter: $x_{vp} = 2\pi\dfrac{r_{vp}}{\lambda}$

Size parameter for absorption: $x_{\mathrm{abs}} = 2\pi\dfrac{r_{vp}}{\lambda}m_i m_r^2$

Volume-to-projected area equivalent radius = r_{vp}

Wavelength = λ

Real part of íce refractive index = m_r

Imaginary part of ice refractive index = m_i

These equations were fitted for the range λ=0.199-2.7 μm; r_{vp}=10-2000 μm. The numerical accuracy of the fits for *g* and β is quite high, as demonstrated in Fig. 4. The same is true for the phase function parameterization, expect for the most strongly absorbing cases (β > 0.3).

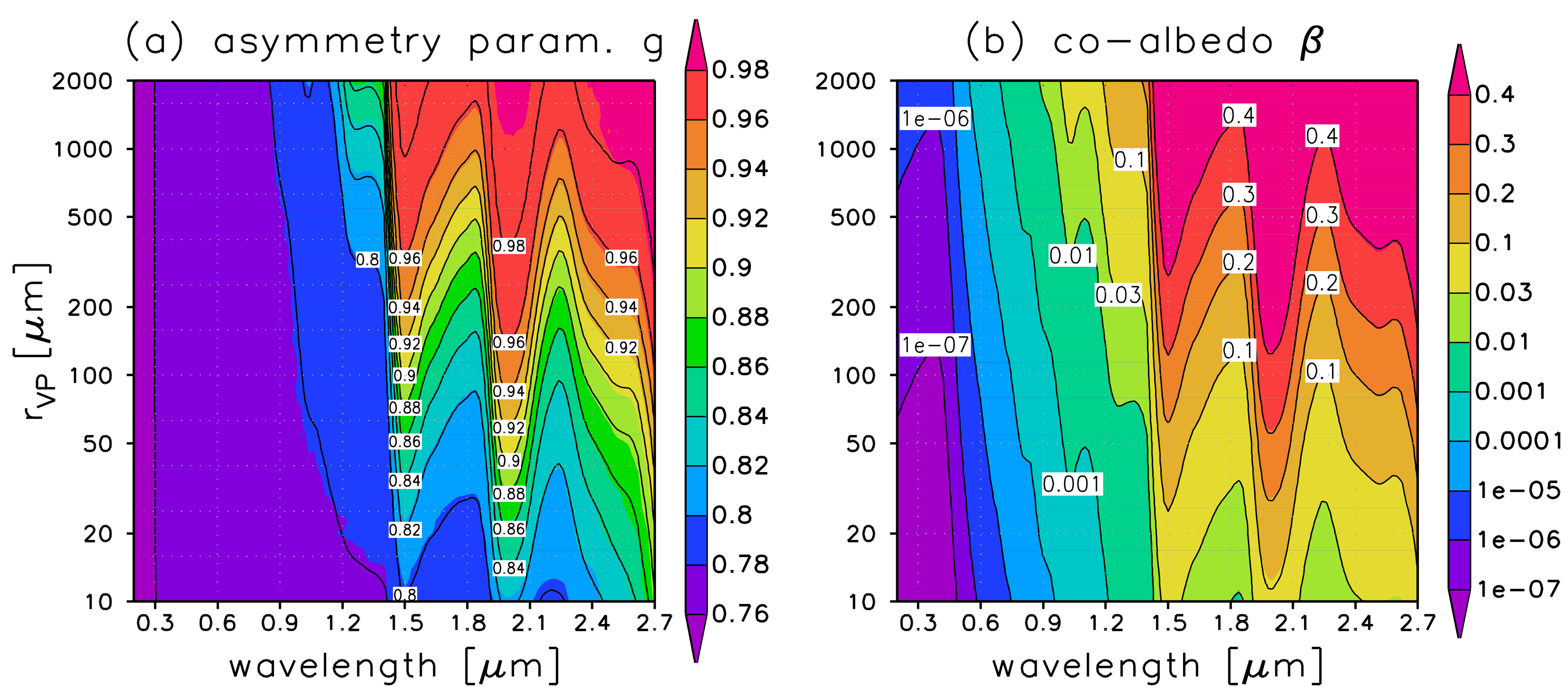

Fig. 4. Comparison of (a) parameterized asymmetry parameter *g* (contours) with the reference values computed for the OHC (shading), and (b) parameterized single-scattering co-albedo β (contours) with the reference values (shading).

6. What is it (and what not)?

The observational basis for deriving the SSP parameterization is rather limited (only one wavelength + potential differences between blowing snow vs. snow on ground) ⇒ **some caution and more validation warranted; not yet a panacea for all scattering problems related to snow**.

However, the parameterization is **simple to use in radiative transfer codes, and most likely (substantially) more accurate than the use of spheres**. It can be combined with parameterizations of effects of snow impurities (e.g., Kokhanovsky 2013).

For more information**, see Räisänen et al. (2015). A Fortran code** for the parameterization is available here**:** https://github.com/praisanen/snow_ssp.

References

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