Review of "Comparison of optical-equivalent snow grain size estimates under Arctic low Sun conditions during PAMARCMiP 2018"

The manuscript introduces quite interesting observations about an important problem—the processes controlling snow and ice albedo—at large solar zenith angle where radiative transfer calculations about the surface and atmosphere have difficulties. Unfortunately, the analyses are confusing enough that the essential messages and uncertainties are obscured. All the retrievals of grain size and shape are based on some sort of radiative transfer calculation, but the algorithms are different for IceCube, SMART, MODIS, and SLSTR. There were apparently no physical observations recorded for the grains, so retrievals about shapes are difficult to interpret. Moreover, if grain shape is important, would not the grains' orientation also be important? Whereas ice crystals in cirrus clouds have a preferred orientation, observations in snow on the ground seem less conclusive. Once snow has begun to sinter, the original shapes of the flakes during snowfall are mostly obscured.

Especially at these solar illumination conditions, macroscale roughness affects the angular distribution of the reflectance, even when the roughness elements are only a few centimeters tall. Thus the exquisite detail of the calculations, which assume a smooth surface, do not account for the roughness. I appreciate the measurements in the images that show such variability, but the main message is that the details of the retrievals might be irrelevant, especially about shape.

The retrievals from satellite imagery gloss over some important variability. The pixels sizes for MODIS on Terra and Aqua and for SLSTR on Sentinel-3 are large. To what extent does variability *within* the large MODIS or SLSTR pixel affect the results? Moreover, the MODIS and SLSTR measurements on different days have varying view angles. Whereas the different view angles measure different samples of the BRDF and thereby cause variability (Diner et al., 2005), a bigger effect likely arises from the varying pixel size, a factor as large as 10x between nadir and the edge of the scan for a nadir scan angle of 55° combined with Earth curvature (Dozier et al., 2008).

Figures 6 through 8 are truly interesting, but hard to interpret. From the discussion in the text, it would be useful to indicate the coastline in Figure 6 and thus the boundary between snow on land and snow on sea ice.

Therefore, I agree with the other referee's assessment and comments. This manuscript needs substantial reanalysis and revision before it should be published as a peer-reviewed contribution.

Detailed comments on specific text:

Page 2, Lines 28-31. The statement is incorrect: "Microscopic differences in water vapour pressure at saturation due to variable curvatures for a single snow grain cause water vapour diffusion from convex to concave parts of the snow grain. The corresponding deposition (at concave surfaces) and sublimation (at convex surfaces) changes the particle shape to more rounded particles, which have a larger grain size than initially (Colbeck, 1982; Cabanes et al., 2002)."
Calculation of this effect using the Kelvin equation shows that concavity or convexity is significant only for minute radii of curvature (<1µm). The process that causes the change in the grain shape in near equilibrium conditions (low temperature gradiant) is grain-boundary diffusion. The dihedral shape of the boundaries between sintered grains is inconsistent with the vapour-diffusion explanation, as Colbeck (1998) clarifies. The Flanner-Zender (2006) model might give reasonable results, but perhaps for the wrong reason.

Page 3, Line 17. The statement is incorrect: “All common retrieval methods rely on the same asymptotic radiative transfer (ART) approach (Kokhanovsky and Zege, 2004) …” Approaches that retrieve grain size along with fractional snow-covered area from multispectral sensors MODIS and Landsat (Bair et al., 2020; Painter et al., 2009), and the new USGS product (Landsat Fractional Snow Covered Area (usgs.gov)), use Mie scattering and the radiative transfer equation, with different assumptions about grain shape. I am not sure the distinction matters, because the different approaches give similar results, but one should be careful about any sentence that has the word “all.”

Page 8, Line 15. Rather than Stamnes et al. (1988), it is probably better to cite the original delta-Eddington paper (Joseph et al., 1976), which Wiscombe and Warren (1980) applied to model snow’s spectral albedo.

Page 8, Lines 28-30. For a smooth surface, we would expect that snow albedo would increase with SZA. For a rough surface, would greater shadowing at larger SZA compensate in the opposite direction?

Page 9, Line 30 and other places. The text is unclear about the model based on age and temperature to estimate change in grain size. Do you use Essery et al. (2001) or Flander & Zender (2006)? Or are the models combined? Moreover, the Essery et al. (2001) reference has no information about availability in the bibliography, like a DOI.

Page 10, Lines 21-22. Perhaps change this sentence to, “Snow grain size and snow particle shape are then obtained by minimizing the differences between theoretical simulations and SLSTR observations of surface directional reflectances at two wavelengths (0.55 µm and 1.6 µm).” (The other referee also suggests a revision of this sentence.)

Figure 3. The caption and the figure seem inconsistent. There is no “thick solid red line” in the figure itself, and the lines for “α_{3000m}” and “60 µm (reference)” appear identical.

Pages 10-13, generally. For surface values, grain size is retrieved by a delta-Eddington approximation of the radiative transfer equation. But for the remotely sensed retrievals, the XBAER approach, which incorporates and atmospheric adjustment also, is used for the SLSTR data; the Zege et al. (2011) method is used for the MODIS data; and Carlsen et al. (2017) is used for the airborne data. The different methods treat the diffuse fraction of the irradiance differently, along with different methods of solving the radiative transfer equation. To what extent are the retrievals of grain size/shape and light-absorbing impurities affected simply by the different approaches? Figure 2 seems to address this question, but indirectly. Moreover, none of these models of snow reflectance incorporate macroscale surface roughness.

Page 20, Line 29. The word “data” is the plural of “datum” so “data was” should instead be “data were”.

Page 21, Line 5. A retrieved grain size of 12 µm is exceptionally tiny, or does the 12 µm refer to some difference? The sentence is unclear.

The other referee had more comments on the later pages. I agree with them.

References cited in the review

Bair, E. H., Stillinger, T., and Dozier, J.: Snow Property Inversion from Remote Sensing (SPIReS): A generalized multispectral unmixing approach with examples from MODIS and Landsat 8 OLI, IEEE Transactions on Geoscience and Remote Sensing, https://doi.org/10.1109/TGRS.2020.3040328, 2020.

Colbeck, S. C.: Sintering in a dry snow cover, Journal of Applied Physics, 84, 4585-4589, https://doi.org/10.1063/1.368684, 1998.

Diner, D. J., Braswell, B. H., Davies, R., Gobron, N., Hu, J., Jin, Y., Kahn, R. A., Knyazikhin, Y., Loeb, N., Muller, J.-P., Nolin, A. W., Pinty, B., Schaaf, C. B., Seiz, G., and Stroeve, J.: The value of multiangle measurements for retrieving structurally and radiatively consistent properties of clouds, aerosols, and surfaces, Remote Sensing of Environment, 97, 495-518, https://doi.org/10.1016/j.rse.2005.06.006, 2005.

Dozier, J., Painter, T. H., Rittger, K., and Frew, J. E.: Time-space continuity of daily maps of fractional snow cover and albedo from MODIS, Advances in Water Resources, 31, 1515-1526, https://doi.org/10.1016/j.advwatres.2008.08.011, 2008.

Joseph, J. H., Wiscombe, W. J., and Weinman, J. A.: The delta-Eddington approximation for radiative flux transfer, Journal of the Atmospheric Sciences, 33, 2452-2459, https://doi.org/10.1175/1520-0469(1976)033<2452:TDEAFR>2.0.CO;2, 1976.

Painter, T. H., Rittger, K., McKenzie, C., Slaughter, P., Davis, R. E., and Dozier, J.: Retrieval of subpixel snow-covered area, grain size, and albedo from MODIS, Remote Sensing of Environment, 113, 868-879, https://doi.org/10.1016/j.rse.2009.01.001, 2009.

Wiscombe, W. J., and Warren, S. G.: A model for the spectral albedo of snow, I, Pure snow, Journal of the Atmospheric Sciences, 37, 2712-2733, https://doi.org/10.1175/1520-0469(1980)037<2712:AMFTSA>2.0.CO;2, 1980.