The Cryosphere Discussions

The Cryosphere Discuss., author comment AC3
https://doi.org/10.5194/tc-2021-272-AC3, 2022

Reply on RC2

Chloe A. Whicker et al.

Author comment on "SNICAR-ADv4: a physically based radiative transfer model to represent the spectral albedo of glacier ice" by Chloe A. Whicker et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-272-AC3, 2022

Dr. Dadic, thank you for your review of our paper and your insightful comments. All comments are addressed below, with the original comment first and the response in italics.

Review #2 (Ruzica Dadic):

Summary and recommendations

This paper uses extends the current multi-layer two-stream delta-Eddington radiative transfer model to be applicable in a wide range of snow and ice environments. The work is relevant because of the role that cryospheric albedo plays in Earth's climate in the context of climate change. Especially the inclusion of LACs is of relevance and I appreciate that the authors include different types of impurities, so the model really is applicable in a wide range of regions. The paper is well written with and the methods are well explained. I only have a few minor comments, that I summarize below.

1) There are inconsistencies on the definition of "snow" and "ice" in the model. In the abstract, the cutoff is 650 kg/m^3. In Figure 2, density of 600 is defined as ice. And later you say that snow is below 500 and ice is above 600? How is the firn modeled, as firn or as ice? This just needs to be made consistent. I think it's just adjustments in the text, the results appear to be ok.

Thank you for pointing out this inconsistency. We originally used 600 kg/m3 to show a potential range of ice albedo. This has been addressed by changing the density threshold to be 650 rather than 600 for figures 2, 3, 6 and 7. Firn can be represented as either high density snow with a large snow grain size or low density ice with a small air bubble radii. This is discussed in the manuscript:

L316: "Firn has an intermediate density and can be treated as snow or ice, allowing for the techniques to be compared for media with equivalent SSAs. From a modeling perspective, it would be useful to specify a density threshold for representing a layer as snow or ice, as the model is sensitive to the ice density, and density is more easily measured in the field than other physical properties. Because ice is represented as air bubbles within snow it could be valid to treat all firn with a density greater than half that of pure ice (458.5 kg m^{-3}) as an ice layer. However, it is unlikely that ice that porous necessitates a refractive boundary. The transition between firn to ice is where pores *between ice grains close and form air bubbles within a solid ice media. The closing-off of air bubbles occurs at an ice density around ~830 kg m^{-3} or when ~10% of the ice volume is composed of air bubbles (Bender et al., 1997; Dadic et al., 2013). Because SNICAR-ADv4 incorporates numerous parameters, such as the density, grain size, layer depth, and the inclusion of an SSL, similar spectral albedos can be achieved using different model parameters (further described in Section 3.3.2). We see greater agreement between model and measurement for layers represented as ice with densities between 650-700 kg m^{-3} (Fig. 10b) and recommend that users treat media with densities over 650 kg m^{-3} as ice layers."*

In figure 10b, when comparing SNICAR-ADv4 to the Dadic et al. (2013) firn measurements, we found that using an ice layer rather than a snow layer achieved slightly better agreement, especially at λ > 1.2 µm.

2) Usually the term SSL (surface scattering layer) is used just for sea ice and shows a particular structure because of the anisotropic structure of brine channels in sea ice. To avoid confusion, you might considering calling it a different name, because the "crusty layer" on glacier ice is not associated with brine channels and is more sotropic that the same layer on sea ice.

Thank you for pointing out the specificity of the term SSL as applied in the sea ice community. To avoid confusion with this context of SSL, we have decided to instead refer to this layer as a "rough scattering layer". The main purposes of the layer are to 1) add surface roughness that reduces or eliminates specular reflection by the Fresnel Layer and 2) introduce small scale surface roughness typical of snow and ice surfaces. A glacial crustal surface, which is a very coarse and porous ice surface, can be roughly represented using very low density snow and large aspherical snow grains. SNICAR-ADv4 also includes the ability to simulate scattering layers that are optically dissimilar from glacial crustal surfaces, therefore, we avoid calling it a "crustal layer" and use "rough scattering layer" as a more general term.

3) You say that snow layers are represented as "ice crystals", but it's rather "spheres". I would correct this throughout the manuscript, unless you are really representing the crystal shape instead of a collection of independent spheres.

The text has been changed from "crystals" to "grains" because this study utilizes hexagonal plate shaped ice grains. The model allows for spheroids, hexagonal plates, or Koch snowflake shaped grains. We've included a more thorough description of the use of hexagonal plates in the manuscript in response to R1 comment 4.3.

4) L 153: what is the "merged" ice refractive index?

The merged ice refractive index is described in Flanner et al., (2021). It utilizes the imaginary index of refraction from 0.2 – 0.6µm as reported in Picard et al. (2016) and the real and imaginary index of refraction reported by Warren and Brandt (2008) elsewhere in the spectrum. For more clarity, the word "merged" has been removed, Flanner et al. (2021) is referenced in the description, and a brief explanation is included.

5) Figures 8-11 are hard to read, because the x-axis is so stretched. Maybe redo them with a better readable x-y-ratio. Also it may be worth plotting the difference (in %) between model and measurements at different wavelengths, rather than actual values. Or add the differences as a righthand y-axis. It may be worth to give the %-ages of albedo variations in the manuscript, rather than absolute values (e.g. L24, L288, L291)

(Same response to R1 – last comment) Thank you for pointing this out. The figures have been reformatted so they have a closer 1-1 x-y ratio. We have also added the difference

between the measurements and model albedo to each comparison plot. The difference is the modeled albedo value minus the measurement value interpolated to the higher resolution model λ scale. Negative values indicate the model is underestimating the albedo and positive values indicate the model is overestimating the albedo. Figure 2 in the supplement is an example of the model - measurement comparison reformatted with the difference plot included.

We chose to show the absolute difference to avoid inflating the difference at longer wavelengths where the albedo is generally lower due to higher absorption and limited insolation.

Please see the Figure 2 in the supplement for R1 comment's for the new measurement and model comparison plots.

Citations:

Dadic, R., Mullen, P. C., Schneebeli, M., Brandt, R. E., and Warren, S. G.: Effects of bubbles, cracks, and volcanic tephra on the spectral albedo of bare ice near the Transantarctic Mountains: Implications for sea glaciers on Snowball Earth, JGR, 118, 1658–1676, https://doi.org/10.1002/jgrf.20098, 2013.

Flanner, M. G., Arnheim, J., Cook, J. M., Dang, C., He, C., Huang, X., Singh, D., Skiles, S. M., Whicker, C. A., and Zender, C. S.: SNICAR-AD v3: A Community Tool for Modeling Spectral Snow Albedo, GMD, 1–49, https://doi.org/10.5194/gmd-2021-182, 2021.

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Warren, S. G. and Brandt, R. E.: Optical constants of ice from the ultraviolet to the microwave: A revised compilation, JGR, 113, https://doi.org/10.1029/2007JD009744, 2008.