The Cryosphere Discuss.,
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The Cryosphere
Discussions

Interactive comment on "Quantifying bioalbedo: A new physically-based model and critique of empirical methods for characterizing biological influence on ice and snow albedo" *by* Joseph M Cook et al.

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Dear Reviewer,

thank you very much for your comments. I have been through them in detail and made amends as requested. The revised manuscript with the changes will be made available after the other reviewers have commented. For now, I can provide a line-by-line response detailing the changes made to the manuscript and present new versions of the figures I have enhanced according to your suggestions. I have included the full

figure captions at the bottom of this page, beneath my responses.

Responses:

Main Comment:

This crystal clear, relevant, and very complete paper provides a physically-based framework for quantifying the effect of biological activity on the albedo of snow and ice. For a radiative transfer expert, this paper dwells quite long on RT theory and observational techniques. But I guess that the authors have a much broader audience in mind for this paper (but this is nowhere stated explicitly!), including biologists that have not worked much with RT before. In that sense, this manuscript is a great on-estop reference for everyone working on bioalbedo. I have only one major request: For figures 2, 3, and 4, could an additional panel be added showing the dependence of the broadband albedo on the variable of interest? Otherwise, I only have some minor suggestions for improvement. Note to the editor: my background is in radiative transfer modelling, so separate advice on the biological aspect of this paper should be sought by another reviewer.

Response to main comment:

Thank you! We have added a note in the abstract to indicate the intended audience. We have updated our figures 2, 3 and 4 to include inset panels with broadband albedo against variable of interest. We thank the reviewer for this suggestion and agree that the result is a more informative plot.

Specific Comments:

P1L28-31 : I would cast some of the 10 challenges differently, such that it is clear what the challenge exactly is. E.g. "Ambiguity in terminology: -> "Reconciling ambiguous terminology"; "Surface anisotropy" -> "Accounting for surface anisotropy"; "Measurement and instrument configurations" -> "Standardizing measurement and instrument configurations" or similar.

Amended throughout

P1L37: ... on THE ice surface ... P4L19: You use both BioSNICAR and Bio-SNICAR (with and without hyphen). Please standardize.

Amended throughout.

P4L21: Please turn this list into a table, with an additional column showing the mathematical symbol used in this paper. Instead of the somewhat cumbersome lines 42-45. P4L21: I guess that these library files are wavelength-dependent? At least, the items 2,3 and 4 in the list? Could you indicate which information is wavelength-dependent?

These two comments have been addressed together by creating a new table (Table 1) and referring to it in the main text.

P5L39: This is a good example of a section that I would recommend to shorten significantly, if the audience of this paper were strictly limited to RT specialists. No new insights are presented here, and a paper like Schaepman-Strub et al. covers this entire section.

I agree, but the audience is broader than RS specialists,. It is specifically intended for glaciologists and biologists who might benefit from an overview of the key literature. This has now been made explicit in the abstract and introduction.

P7L15: strictly speaking, the rightmost part of the equation is a definition of r_eff. You could add a second equation here, defining r_eff as r_eff = 3 / (rho_ice * SSA)

Amended

P10L11: Ambiguous. Please reformulate: "... unless dust can be accounted for accurately. Otherwise, there is a high risk of biomarker false positive"

Amended

P10L12: on the other hand, rough surfaces create photon cavities that increase scat-

tering and absorption, and lower albedo (e.g., Cathles et al., 2011, Ann. Glac. 52(59))

Amended and citation added to text and reference list.

P13L14: straightforward

Amended

Figure 2: It would be very illustrative to add a panel here that shows broadband albedo as a function of pigmentation level. I understand that this requires an additional setting, namely the prescription of an atmospheric vertical profile determining the spectral composition of the radiation arriving at the surface. Nonetheless, I believe that this would be very instructive. How much does the presence of biomass really mean for broadband albedo? And what aspects of the biomass matter most for albedo?

We have added broadband subplots of broadband albedo against biomass for each pigment scenario to Figure 2. We have also added a new figure to Appendix 2 showing broadband albedo against pigmentation. The plot shows that secondary carotenoid production is important for determining biological albedo reduction, but that above a threshold increasing carotenoid mass fraction has diminishing effect on the light absorbing properties of the cells. As biomass concentration increases, changing pigmentation has a greater effect on albedo.

Figure 3: idem, but with a panel showing broadband albedo as a function of biomass concentration, for 3 cell radii.

Added

Figure 4: idem, but with a panel showing broadband albedo as a function of layer thickness, for different mass concentrations

Added

New Figure Captions:

Figure 2: Spectral albedo of snow (grain radius 1500 μm) with equal biomass loading of algal cells with varying pigmentation. In all four simulations, chlorophyll a = 1.5% total cell dry weight. In A) Primary and Secondary carotenoids = 10% dry weight each. In B) primary and second carotenoids = 5% dry weight each. In C) primary and secondary carotenoids = 1% dry weight each. In D) no carotenoids are present, the cell contains chlorophyll only. In all simulations the solar zenith was 60°. The legend applies to all four subplots. Inset plots show broadband albedo against biomass concentration for each pigment mixture.

Figure 3: Simulations of 1500 μm radius ice grains with no interstitial water or inorganic impurities and biomass concentrations 0.01, 0.1, 0.5, 1 and 2 mgalg/gsnow confined to a thin (3 mm) surface layer. The mass fraction (% dry weight) of pigments in the cells was 1.5% for chlorophyll a and 5% for each of primary and secondary carotenoids. In A) the cell radius was 5 μm, in B) the cell radius was 15 μm and in C) the cell radius was 25 μm. In all plots the solar zenith was 60°. Legend applies to all three subplots. Insets show broadband albedo against biomass concentration for each cell size.

Figure 4: A constant biomass (0.5 mgalgae/ gice, pigment mass fractions (% total cell dry mass) = 1.5% chlorophyll a, 5% primary and secondary carotenoids, 15μm cell radius) distributed vertically in layers of ice (1500 μm grain radius) of varying thickness (1, 2, 3, 4, 5, 10 mm). B) Varying concentrations of mineral dust in a 3 mm surface layer (0.1, 0.5, 1, 1.5, 2 mgdust/ gice) on otherwise clean ice (grain radius 1500 μm). The dust used was SNICAR's 'dust 4' which has grain radii 2.5 – 5 μm; C) Equal mass concentrations (0.01, 0.1, 0.5, 1, 2 mgimpurity/ gice) of algal cells (pigment mass fractions (% total cell dry mass) = 1.5% chlorophyll a, 5% primary and secondary carotenoids, 15 μm cell radius) and mineral dust (SNICAR's 'dust 4' which has grain radii 2.5 - 5 μm) in a 3 mm surface layer in otherwise clean ice (1500 μm grain radius); D) Albedo of a dry snowpack (grain radii = 1000 μm) and snowpacks with liquid water as a coating around the ice grains. The legend indicates the thickness of water layer around a 1000 μm ice grain. Insets show broadband albedo plotted against the relevant model

variable.

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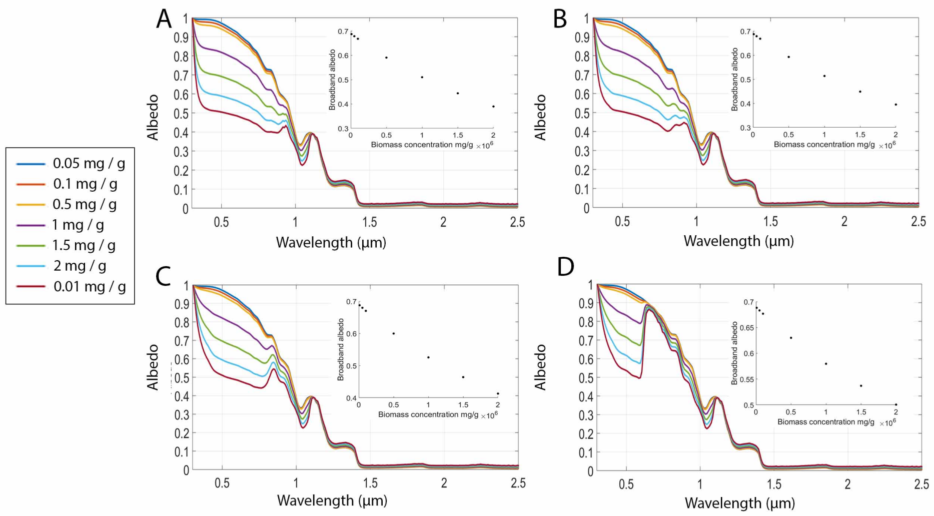

Fig. 1. Figure 2: Updated

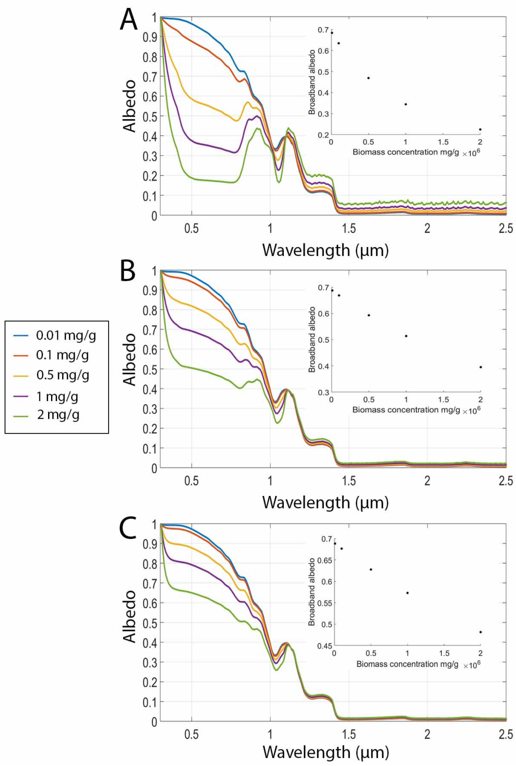

Fig. 2. Figure 3: Updated

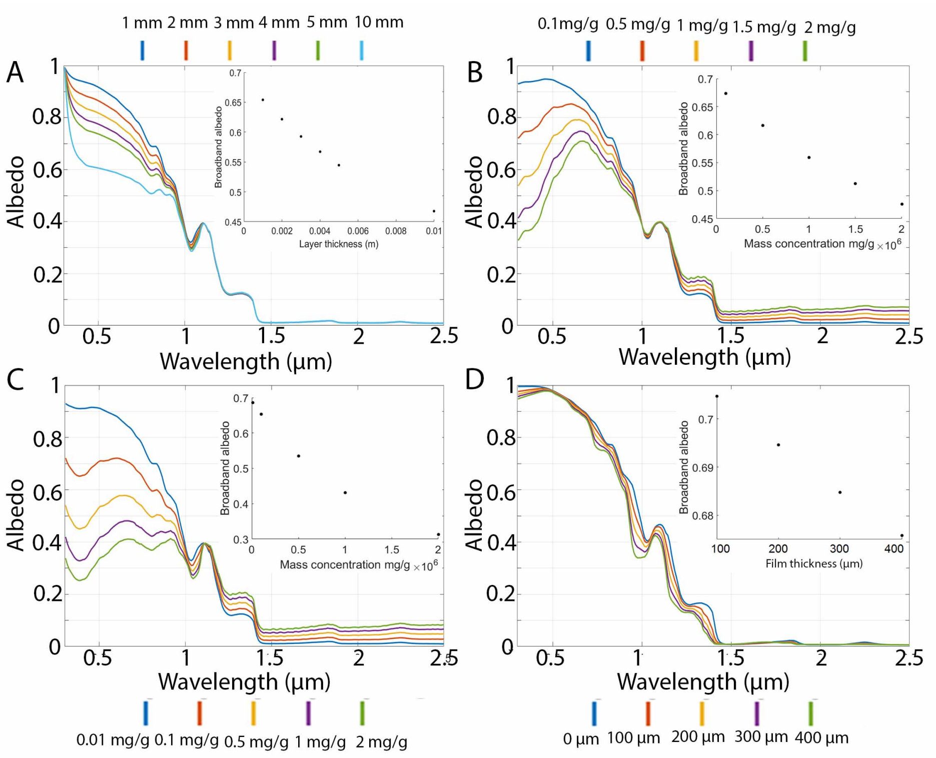

Fig. 3. Figure 4: Updated

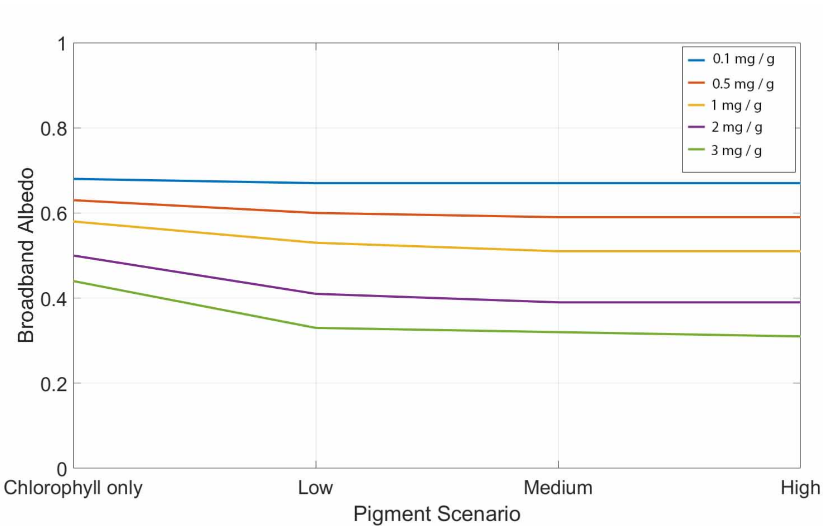

Fig. 4. Appendix 2: New Figure