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The Cryosphere
Discussions

Interactive comment on "Soot on snow experiment: bidirectional reflectance factor measurements of contaminated snow" *by* J. I. Peltoniemi et al.

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Response to reviewer comments on the manuscript "Soot on snow experiment: bidirectional reflectance factor measurements of contaminated snow". We thank the reviewers for the positive and constructive review. Reviewer 1. Anonymous Referee #1

"Received and published: 1 July 2015 This study reports measurements of the directional reflectance of snow that has been artificially contaminated with different impurities. The measurements are novel and some of the results are quite interesting, particularly that the impurities generally cause much more darkening from a nadir-looking perspective than at oblique viewing angles. This has important implications for the in-

terpretation of satellite observations, which usually occur at near-nadir viewing angles. It is also an interesting observation that snow melt commences within minutes of application of the impurities, suggesting effi- cient energy transfer from the particles to the ice grains. I recommend publication of the manuscript after the following minor issues are addressed: Major comments: The technique used to remove the diffuse contribution to the bidirectional reflectance factor (BRF) is unclear and needs to be described more precisely. To accurately ac- count for the contribution of diffuse incident light, the full BRF of the snow, with respect to all incident light angles, must be known. What is the term "M_D" in equation 3, which is currently described only as the "estimate for the diffuse part"? Please include more precise definitions and descriptions of the terms used in equation 3, including subscripts for incident/viewing angles, if necessary."

Answer: We added the required things in Eq 3. The procedure for the diffuse correction is explained in detail in several earlier articles cited in the text. e.g. Peltoniemi et al 2014, Peltoniemi etal 2010b, Peltoniemi etal 2009. We measure the diffuse part separately, by shadowing the direct sunlight (M_D). We will add this explanation to manuscript.

"The uncertainty in BRF associated with the diffuse correction is reported as 1-5%. Please describe how this estimate was arrived at."

Answer: Typically, the diffuse part is less than 10% of the total illumination, except the UV end, where it usually reaches 30-50%. Errors in the measurement may be 5-10%, due to the shadow screen blocking also some diffuse radiation, and some sunlight penetrating to target area under the snow surface. Assuming the diffuse part to be Lambertian may cause additional 5-10% error. Thus, total error 1-5%, for snow probably in the lower side. Typically, the difference between raw and corrected reflectance is less than 10%. Bigger, when very unsiotropic scattering, less, when more isotropic. No more quantified analysis of this has been made, because of other more significant contributors to the uncertainties.

“The impurity loads applied in this study are necessarily very high, relative to natural snow, so that the signal can be clearly discerned. An implication of studying snow with such high impurity loads, however, is that some of the conclusions drawn from this study may not apply to natural snow surfaces, or at least not apply to the same extent. In particular, the downward diffusion of impurities, which is critical for explaining the directional reflectance signal, may not occur as often or as markedly in natural snow, especially when the impurities do not actually cause snow melt to occur. Please acknowledge more clearly the potential limitations of studying snow with extreme impurity loads, perhaps even in the abstract.”

Answer: Indeed we cannot say very much, how smaller impurities behave, and how this behavior would change under different weather conditions, particle size etc. Is the local heating around the particle alone sufficient to cause the sinking, or is the collective effect increasing or decreasing the heating of single grains? How fast is the heat transfered out from the heated particle?

We have added some clarifying sentences on that in our ‘Conclusions’ section along with the lines proposed by the reviewer.

“The authors note, that impurity loads applied in this pioneer study are high, relative to natural snow, so that the signal can be clearly discerned. Therefore some of the conclusions drawn from this study may not apply to the same extent to natural snow surfaces with lower impurity loads and may also change, for example, under different weather conditions. In particular, the downward diffusion of impurities, which is critical for explaining the observed directional reflectance signal, may not occur as often or as markedly in natural snow, especially when the impurities do not actually cause snow melt to occur.

If any quantitative details about the impurity optical properties can be provided, e.g., from previous studies, it would be helpful to provide them. This would potentially enable modelers to attempt to reproduce the general features of the measured impacts of the

impurities.”

Answer: We agree, it helps. We are working on these, and will provide more data in forthcoming publications.

“Minor comments: How was instrument shadowing accounted for, if at all? How important, or unimportant, is this issue likely to have been? Please address this issue in the text, even if briefly. Perhaps there is no shadowing at the incident zenith angles explored, and the issue only matters for the diffuse contribution of incident light.”

Answer: The instrument shadow is much less than 1% of the sky, and should not be a significant issue. The main body is on the side, and the moving arm has very low profile. Only near the backscattering the head of the measurement arm goes between the sun and the target, and these angles cannot be measured. More problematic can be unexpected reflections around and people coming too close, which tried to be avoided in the course of the measurements.

“3077,17 (Abstract): "albedo should be lower..." - I think the authors instead mean the "albedo perturbation should be lower" (?) “

Answer: thanks, corrected.

“3078,23-25: Many of these studies were actually conducted on "natural snow" rather than "pure snow", and were contaminated to some (unknown) degree by impurities. I suggest changing "pure snow" to "natural snow", to the extent that this change applies to all of the listed studies.”

Answer: Changed.

“3079,2: The reference to Flanner and Zender (2006) would be more appropriately changes to Flanner et al (2007), as the former did not study impurities but the latter did.”

Asnwer: Changed.

“3080,1-3: Please use consistent symbols for the terms listed in Equation 1, shown in Figure 1, and described in the text. The in-text symbols seem consistent with the figure but inconsistent with the equation.”

Answer: We use cosines in equations (\mu=\cos\epsilon), and they are defined in the text following the formula 1 and in the capture to figure 1 as well.

“3080,20-21: Please add units of "nm" to the FWHM values of 3 and 10.”

Answer: added.

“3081, bullet 3: What is the reflectance of the "white" Spectralon standard that was used? In practice it is likely less than 100%.”

Answer: About 99%. We have measured it in detail with Mikes/Aalto, ref Peltoniemi et al 2014.

“3084,12: How much was the "measured amount of soot"? 3084: Although the volumes of applied impurities (usually 10 mL) are listed, it would also be helpful to know the masses that were applied. If these are known, please report them. This is requested because most impurity-in-snow studies report mass mixing ratios of impurities, rather than volume mixing ratios.”

Answer: We provide corresponding values in grams in the updated paper.

“3085,23: "bandwidht"”

Answer: corrected

“3086,4-11: Presumably the laboratory measurements of the pure impurities were conducted on optically semi-infinite samples, but please indicate this in the text. Conclusions: The text in this section could be improved a bit for clarity.”

Answer: added clarification.

“3088,19: "this kind of particles" - which kind of particle? Perhaps "dark particles", in

general, are being referred to here.”

Answer: Clarified.

“3090,4: "wide conclusions" -> "wide conclusions are drawn"”

Answer:OK

“Figures 9-12 are too small to read on a printed copy. These are probably the most important figures of the study, so I suggest enlarging them, or breaking them into multiple figures if necessary. Enlarging the axis labels would also help.”

Answer: We tried to improve the figures.

“Table 1: The meaning of "unstable data" should be explained more precisely.”

Answer: This is due to increasing cloudiness, clarified.

“Figure 7: Do "just above" and "just below" refer to the snow-air interface? Please clarify. Please also mention whether "just" implies a distance on the order of millimeters, centimeters, or something different.”

Answer: cm. Clarified.

Interactive comment on The Cryosphere Discuss., 9, 3075, 2015.