RE: Referee # 1 comments on Light absorbing particles and snow aging feedback enhances albedo reduction on the Southwest Greenland ice sheet

Dear Raf Antwerpen and Editor,

The authors would like to thank the referee for the time and effort in reviewing and providing comments to our manuscript.

Below we include point-by-point response. For the comments the are related to technical text suggestions they will be included in the manuscript unless noted below. The reviewer comments are shown in cursive and purple highlight. Our response is in regular font.

Response to Reviewer 1

General comments

Reviewer comment: I have noted some minor comments below, the most important of which pertain to the discussion section. I would be great to see a bit more discussion of the limitations of the measurements, the methods, and the conclusions you can draw from this analysis. It would for instance be good to describe what effects other LAPs (not included in the measurements, such as algae, brown carbon, and volcanic dust) could have on the LAP-snow aging feedback and the albedo reduction in general.

Response: As suggested by the reviewer, we plan to include more discussion about the limations ofthe measurements, the methods, and the conlcusions in the revised manuscript. We may also include a section in the discussion about other LAPs and what potential effect they may have on snow aging and albedo.

Reviewer comment: Consider writing in the present tense instead of the past tense. It could make the text a bit more active

Response: As suggested, we will strive to rewrite the paper in present tense and active voice, except for the methods section which typically is better in past tense.

Specific comments

L12: add algae to the list of LAPs.
Done

L15: explain briefly what the SNICAR model is.
Done

L20: do you mean enhance albedo reduction 4 to 10 times more?
Yes

L31: elaborate a little bit more on "Greenland's summer albedo". Do you mean of the ice sheet in general ,of the snow, or of the ice?

As requested, we will better explain that we mean the ice sheet in general when we write about Greenland's summer albedo

L36: consider adding "global" before climate regulator.
Done

L39: is temperature a direct regulator of snow albedo or does it change albedo by changing the grain size/shape and water content?
We will revised this text to better explain that temperture is an indirect regulator.n

L43-44: remove "causing surface darkening". This aspect is covered in this sentence by "LAPs in snow reduce albedo"
Done

L51-L52: consider rewriting this sentence. It is not immediately clear to me what this means. Also make it clear that you are talking about CO2 and CH4 in the atmosphere, not in the ice/snow.
As requested, we will rewrite this sentence to: The total climate forcing effect of BC, including accounting for all mechanisms that include direct, cloud and cryosphere effects is +1.1 W m^{-2}. In comparison, the total climate forcing effect ofCO_2 is +1.7 W m^{-2} and CH_4 is 0.95 +W m^{-2}. The direct radiative forcing of BC in snow and ice has been estimated to be +0.13 W m^{-2} (IPCC, 2019, Bond et al., 2013).

L62: elaborate on why the 20-30 micrometer is important.
Done

L69-71: is it 16% of the average total mass loss (including dynamic losses)?
This paper is only referencing to surface mass balance. We will rephrase to make this clear.

L76: which LAPs did Lewis et al. consider?
We will rephrase to better explain that Lewis et al. considered both BC and dust.

L79-83: make sure the leap from "snow effective radius growth" to "snow aging" is clear. Right now it is not clear what "snow aging" is.
We have rephrased this text to explain snow aging and better connect the text.

L93-95: consider rewriting this sentence and elaborating a little bit on what SNICAR is and how you would use it to estimate this effect.
We have rewritten this sentence to elaborate on wht SNICAR is and how we used it.

L108: MAR is a regional climate model, not a reanalysis model.
We have corrected this error

L120: what happened at site G?
We will rewrite the text to clarify that we were not able to collected duplicate samples here.

L148-149: elaborate on what refractory BC is. Why can it be used as normal BC here?
We will elaborate and add text to explain that "Normal" BC is typically used as a catch all term for different types of carbonaceous light absorbing particles, and that it refractory BC can be used as normal BC. Depending on the methodology used, BC is named elemental BC, equivalent BC, refractory BC or other terms. Elemental BC refers to an analysis making use of the thermally stable properties (up to 4000K in an inert atmosphere) of the carbonaceous

particles. Often aerosol mass or Raman spectroscopy are used in this method. The equivalent BC is referred to that mass concentrations derived from absorption coefficient measurements using a mass absorption coefficient constant. Lastly, rBC is derived from laser induced incandescence measuring the thermal emission of the carbon particle. The methodology used in this study is widely used and the measurments can be compared to recent measurements using other methods.

L155: most of this is already mentioned before.
Removed

L157-158: what are the optimized operating parameters?
We will clarify that the optimized parameters can be found in the cited references. Since there are quite a few parameters and standard values were used, we choose not to list them but refer to the references instead.

L163: what does "adhering to outside of the detection range" mean? What are the particles adhering to?
We are rephrasing this sentence to better explain that particle can aggregate to each other becoming larger and therefore becoming out of the particle size detection range (80-2000 nm)

L180: is the 0.01mg the uncertainty?
We are rephrasing to clarify that the 0.01 mg is the uncertanty.

L188-189: the first part of the sentence is already mentioned before.
As requested, we have rewritten this sentence.

L195: mention the correlation coefficient in the main text.
Done

L203: what effects (due to LAPs) do you expect to see in the near infrared spectrum? Is it reasonable to not include this in your analysis? If so, show (with a reference) why.
We have revised this sentence to clarify that we take into cconsideration NIR in the broadband albedo calculations.

L206-215: 415-575 km is a long distance and the meteorology and climatology can be very different between these locations. How do you know the situation is comparable?
We will rephrase this sentence to explain that Lewis's data is the best available to estimate optical grain size at our sites. Althougth Lewis's sites were 415-575 km away and may be influenced by other meteorological factors than our sites, they are at least from the same year as our observations.

L234: consider merging figures 4 and 5. Right now figure 5 has almost all the information embedded in figure 4, except for the elevation which you could add in the caption.
We agree with the reviewer that the figure 4 is redundant with figure 5. We have removed this figure and added the elevation information to figure 5.

L242: is it winter snow grain shape or from May 2017?
We will rewrite to clarify that althought the samples were collected in May, the snow was accumulated through the entire winter season from 2016 to 2017.

L266: does BCtot relate to the BC concentration in a vertical slice in the snow pack, given that the unit is ng cm-2? If so, consider elaborating on that. It was not immediately clear to me.

We will clarify this part to the reader to include that the total BC metric estimates BC deposition over a given area of the snowpack, independent of snow depth. Thus referring to a horizontal slice in the snowpack.

L269: does average snow density refer to the density in each layer? If so, consider rewriting this sentence to make that clearer. It now seems like you take the average density of the entire layer.
We will revised to clarify that average snow density is for the entire column.

L301: consider rewriting "that snow … albedo reductions are". It is not immediately clear to me what you mean here.
We will revise to clarify that this refer to the albedo reductions for BC, dust, and LAP considering snow metamorphism

L350: elaborate on the BC concentrations in southeast and southwest Greenland. These regions are very different and might not be easily comparable. Given what you know about the sources and transport routes of BC to Greenland, elaborate on what differences/similarities would you expect to find between BC concentrations in southeast Greenland vs what you found in southwest Greenland? Take into account the general environment, elevation and topography of the sample locations in southeast and southwest Greenland. e.g. what side of the ridge of the GrIS each location is on and what is the general wind pattern from source to deposition location. Could local sources be affecting the BC concentrations (such as for dust at Dye-2)?
As requested, we will elaborate more on the BC concentrations and the difference between SE and SW Greenland ice sheet. We will explain that larger preciptation and general wind patters could lead to more dust and BC depositions in SE Greenland. We will also better explain that local sources could be affecting dust concentrations at Dye-2.

L405: briefly repeat the results of Lewis et al. 2021 here.
As requested, we will briefly repeat Lewis et al., 2021 results here

L413-415: move this to results. Also explain how you get the value 1.18.
As requested, it has been moved to results and we will also better explain how we got the 1.18 factor. This factor was obtained from the difference in albedo reductions between SA and non SA scenarios at the maximum albedo reduction wavelength (at λ = 440 nm (Table 3).

L417-419: This statement is not immediately clear to me. If half of the measurements were under clear-sky conditions (and, thus, the other half under (partly) overcast conditions), would this not mean that your results do not solely apply to clear-sky conditions?
We will clarify this statment to clarify that while some of our sampling occurred during partly overcast conditions, the SNICAR model was run under clear-sky conditions as the SNICAR-ADv3: Online Snow Albedo Simulator only differentiates between direct or diffused incident radiation without any option for partial overcast conditions.

L421-422: what do you mean exactly with this? Are you talking about interannual variability of albedo reduction? If so, that cannot lead to greater albedo reduction over summer, it would the other way around. Greater albedo reduction in summer leads to interannual variability of albedo reduction. Or do you mean interannual variability of another variable? If so, make clear what you are referring to here.
As requested we will rewrite to clariify that greater albedo reduction in summer leads to internannual variability of albedo reduction.

L423: elaborate what you mean with snow melting processes as a factor leading to albedo variability.

As requested, we will elaborate to explain that we here efer to snow melting ability to darkern surfaces by through enlarged grain size, water pools, and conversion of snow to ice.

L425: does the 3.0 ± 0.4% refer to the difference between summer and spring albedo reduction? Consider mentioning both average albedo reductions for spring and summer to show the difference.
We will revise the text to clarify that we here mean to the difference between impurity laden snow and clean snow under the same conditions, we will also mention average albedo reductions for both here.

L429: what is the water year?
We will explain that the water year is defined as the period between October 1st to September 30th

We will also incorporate all the minor technical and editorial suggestions by the reviewer in the revised manuscript, but we will not list all of them here.