

***Interactive comment on* “The impact of Saharan dust and black carbon on albedo and long-term glacier mass balance” by J. Gabbi et al.**

Anonymous Referee #1

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Overall, I found this to be a thorough and informative analysis of the potential impacts of black carbon and dust on glacier mass balance in the Swiss Alps. I recommend publication in The Cryosphere after numerous minor issues are addressed.

General issues:

More detail should be included on the sensitivity studies described in Section 5. It was not clear exactly how each of the parameter changes should influence the simulated mass balance, and interpretation of this part of the study could be improved with more discussion on these parameter changes. It would be helpful to include a table listing the ranges of parameter values that were applied in the sensitivity studies. Specific questions related to these studies are: In the runs with altered concentrations of BC and dust within precipitation, was the total aerosol deposition conserved and the ratio

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of wet to dry deposition altered, or was the total aerosol deposition altered? (The latter case would presumably produce disagreement with the ice core data). Secondly, how does variability in the ratio of haematite to goethite impact the simulations? In section 3.1.1 it is mentioned that these minerals have different absorption characteristics, but it seems that a single absorption coefficient is applied to all iron oxides. Is it merely through differences in the molecular weight of the two minerals that different haematite/goethite ratios impact the simulations?

One of the stated motivations for conducting this analysis at Claridenfirn is that there are 100 years of mass balance measurements at this location. It would therefore be helpful to include a comparison of the simulated and measured glacier mass balances, e.g., added to Figure 7. Was this excluded because the parameterization was heavily tuned to match the observations, and therefore the simulated and observed mass balances are essentially identical? If so, this should be stated more clearly. It is a bit unsettling that the parameters of the mass balance model were adjusted for each year of simulation (as indicated in section 3.5), though at least the ratio of weights applied to temperature and insolation was held constant throughout the simulation. Does the simulation that includes both black carbon and dust produce the best agreement with measured mass balance?

The black carbon mass absorption coefficient assumed in this study (7.5 m²/g) is inconsistent with that assumed by Gardner and Sharp (2010) in their parameterization of albedo. They state that the maximum mass absorption coefficient of BC is 6.8 m²/g at a wavelength of 0.4μm. This is relevant for the determination of a BC-equivalent dust concentration, which is based on the ratio of mass absorption coefficients of BC and iron oxides. This determination should be made consistently with the assumed absorptivity of BC in the Gardner and Sharp (2010) albedo model. This issue may not have a large impact on the results, but should be fixed or at least addressed.

The methodological description for calculating radiative forcing needs more detail. This calculation appears to be based on melt production and is therefore different from other

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commonly used (e.g., IPCC AR5) definitions of radiative forcing. If the radiative forcing is derived in terms of the amount of energy used to melt snow, it may underestimate the true radiative forcing, which also operates during the pre-melt season. Implications of such differences in methodology for comparisons with other studies should also be mentioned.

I suggest modifying the title to indicate that the study focuses on Swiss or Alpine glaciers, or even specifically to the Claridenfirn. The current title implies a general study of glacier impacts associated with BC and dust, but the analysis is really quite specific to the Swiss Alps.

Minor comments:

1134,10: "employed to assess dust/BC-albedo feedback" - To many, "albedo feedback" implies feedback between the atmosphere and land surface, which is not assessed here. The meaning of "feedback" in this context should be clarified.

1134,16: "dust-enriched layers" - Should this be "dust and BC-enriched layers"?

1135,26: "Since mid-20th century BC concentrations started to decrease and have stabilised over the last few decades (Bond et al, 2007)" - Although European emissions have declined during the past few decades, Figure 6 of Bond et al (2007) indicates that global BC emissions have continued to rise. It wasn't clear if this passage was meant to refer to global or European emissions.

1136,16: "we examined the dust/BC-melt feedback" - Again, please clearly define this feedback. Here, I believe it refers to enhanced melt induced by BC/dust, which in turn increases the surface layer concentration of BC/dust and thereby further increases melt.

1138,17: "... an annual cycle of BC concentrations in the atmosphere" - This seems like a useful way of deriving seasonal variations in BC deposition from annually-resolved ice core data, but I wonder if the seasonal cycle of BC deposition could have been

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different 100 years ago, e.g., due to more generation of BC for winter heating purposes. It would be interesting to include a sensitivity study that varies the seasonal cycle of BC deposition. I would not consider this critical for the paper, though, so I leave it up to the authors.

1139,11: "... the ratio of haematite to haematite plus goethite" - Is this the mass ratio of minerals, or the mass ratio of Fe within the minerals?

Section 3.3: Does the albedo model provide diffuse or direct-beam albedo? If the latter, how was solar zenith angle incorporated into the model? Please include more detail on this.

1143, Equation 6: Is Delta R_{opt} a rate (e.g., mm/day)? Please include units for this term.

1144,1: I think C1 should be 10⁻³ rather than 10³.

Section 4.1: Very interesting discussion!

Section 4.2: Please clarify whether the calculated albedo reductions are relative to pure snow, or relative to snow only without BC (in the case of dust estimates) or without dust (in the case of BC estimates)

1152,6-9: Please clarify this sentence.

Figure 6: If this shows an absorption optical depth, as indicated in the caption, over what thickness of snow/ice is it derived from? Optical depth is usually calculated over the entire column. The quantity shown in this figure needs to be defined more clearly.

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