Detailed responses to reviews

Saharan dust impacts on the surface mass balance of Argentière Glacier (French Alps)

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The authors thank the editor and the two reviewers for the time dedicated to reading the manuscript and for the constructive feedbacks, which we believe contributed to improving its quality. Answers to the two reviewers are listed in the coloured boxes and our responses in black below the boxes. The quotation marks are used when citing the manuscript in blue, and the modifications are highlighted in bold. We also provide a revised version of the manuscript, as well as a version with tracked changes.

1 Summary of the corrections

The main adjustments carried out in this revised version of the manuscript are the following:

- broader details on the ALADIN model (R1.2.)
- justifying our choice of attribution concerning the dust impact (R2.6.)
- addition of uncertainty tests regarding dust scavenging (R1.3.), and mass absorption efficiency of dust (R2.7.)
- adjustment of the mass absorption efficiency (MAE) of LAPs and its justification in a detailed analysis in section 3 of this response

2 Answers to Reviewers

2.1 Reviewer #1

R1.1. This is an interesting and rigorous study investigating the impacts of Saharan dust on a French Alpine glacier. The study nicely combines remote sensing data of albedo, in-situ measurements of glacier surface mass balance, snowpack radiative transfer modeling, and glacier surface mass balance modeling. Uncertainty is explored via numerous perturbed simulations. Overall, I find the conclusions to be compelling and robustly supported through analysis and discussion. The authors find a large impact on glacier SMB from the dust deposition in 2022, supporting previous studies, and adding context to earlier studies (e.g., Gabbi et al, 2015) that explored impacts of dust and black carbon on other glaciers in the Alps. Moreover, the manuscript is well-written and the figures are excellent. I recommend publication after relatively minor issues are addressed.

We thank reviewer #1 for his review, his positive feedback, and for his interesting and constructive comments that help improving the manuscript. We hope that our answers and modifications help to clarify our choices.

2.1.1 More important issues

R1.2. Section 2.3: Please include more detail about how the dust and black carbon emissions and deposition fluxes are simulated in ALADIN, as the deposition fluxes critically impact the results of this study. In particular, are the dust emissions simulated prognostically, or are they prescribed? Which inventory of BC emissions is used? Do the BC emissions vary between years? Does the regional domain of the model include the Sahara desert?

The ALADIN model, providing the deposition fluxes of dust and BC for this study, includes seven aerosol species, namely dust, sea salt, sulfate, black carbon, organic matter, nitrate and ammonium.

- *Does the regional domain of the model include the Sahara desert? Are the dust emissions simulated prognostically, or are they prescribed?* The domain of the model indeed includes the Saharan desert with a southern limit roughly corresponding to +15°N (see Fig. 1 of Nabat et al. (2020)). The emissions of mineral dust are "dynamically computed by the model as a function of surface wind as well as soil characteristics" (Nabat et al., 2020). Mineral dust is a prognostic variable of the model subject to atmospheric processes (emission, transport and deposition).
- *Which inventory of BC emissions is used? Do the BC emissions vary between years?* Anthropogenic and biomass burning emissions (including BC) are based on "monthly CMIP6 historical inventories provided, respectively, by Hoesly et al. (2018) and Marle van et al. (2017)" (Nabat et al., 2020).

Anthropogenic and biomass burning emissions (including BC) are based on monthly inventories commonly used in climate models. The CEDS v2021-04-21 dataset accounts for historical anthropogenic emissions (O'Rourke et al., 2021) up to 2019, extended up to 2022 following the methodology of Lamboll et al. (2021) to account for the decrease in anthropogenic activities due to lockdown periods of the year 2020. Biomass burning emissions come from the GFED4.1s dataset (Randerson et al., 2017). All these emissions vary from year to year.

To clarify the manuscript, we added the following summary in section 2.3: "Mineral dust (dust) and black carbon (BC) hourly deposition fluxes were obtained from the CNRM-ALADIN63 regional climate model driven by the ERA5 reanalysis (Nabat et al., 2020). **The prognostic aerosol scheme of ALADIN is called TACTIC (Tropospheric Aerosols for Climate In CNRM, coming from Morcrette et al. (2009) and used in Michou et al. (2015, 2020)). The domain of ALADIN included the Saharan desert with a southern limit roughly corresponding to +15°N, as shown in Fig. 1 of Nabat et al. (2020). The emissions of dust were computed by the model as a function of surface wind and soil characteristics (Nabat et al., 2020). Then, mineral dust was a prognostic variable of the model subject to atmospheric processes (transport and deposition). Anthropogenic and biomass burning emissions (including BC) were based on monthly inventories varying from year to year, namely the CEDS v2021-04-21 dataset for historical anthropogenic emissions (O'Rourke et al., 2021) up to 2019, extended up to 2022 following the study of Lamboll et al. (2021), and the GFED4.1s dataset (Randerson et al., 2017) for biomass burning emissions.** The horizontal grid resolution of the CNRM-ALADIN63 outputs is **12.5 km**. Only the nearest grid point output was used for all simulation points."

R1.3. Figure 8 and associated discussion: The sensitivity of dust impacts to the BC melt scavenging factor is certainly an interesting result. The authors may disagree, but I suspect that uncertainty in melt scavenging efficiency of dust itself is similarly large, and if so, the simulated SMB impacts would also be sensitive to uncertainty in this parameter. One way of exploring and presenting this would be to add additional markers to Figure 8 that depict the sensitivity to dust scavenging. Regardless, I think it would be helpful to include a bit more acknowledgment and discussion of this.

We thank the reviewer for pointing out this point, and we agree with its comment. In the reference version of the simulations, we chose not to allow dust percolation, in agreement with the literature, as mentioned in section 2.4.1 of the initial version of the manuscript: "For large LAPs such as mineral dust, with a typical radius of 5 microns, Conway et al. (1996) explained that these particles stay near the snow surface, almost not percolating with liquid water, hence we set dust scavenging coefficient $k_{\text{dust}} = 0$." It applies here since the size of the dust particles of this study are likely ≥ 1 μm (*e.g.*, Fig. 2 and Fig 8 of Dumont et al. (2023)). In addition, we did a sensitivity test with $k_{\text{dust}} = 0.04$ in the initial version of the paper (Fig. 7) to account for a light scavenging of dust. We chose this value $k_{\text{dust}} = 0.04 < k_{\text{BC}} = 0.2$, because it is known that the scavenging efficiency of dust is lower than the scavenging efficiency of BC (*e.g.*, Doherty et al. (2013)).

However, although this is poorly documented in the existing literature, we also suspect that dust scavenging efficiency at the snow surface could be non-zero and higher than 0.04 (*e.g.*, during intense rain on snow events, or when liquid water flows on an inclined snow surface).

Overall, these uncertainties regarding LAP scavenging efficiencies highlights the need to better understand the motion of the different LAP inside of the snowpack at the micro-scale.

Therefore, following the advice of reviewer #1, we included an additional simulation and the corresponding marker in Fig. 8 for a dust scavenging efficiency of $k_{\text{dust}} = 0.2$. Regarding the previous remarks on the available literature, this is likely too high compared to $k_{\text{BC}} = 0.2$, so this sensitivity test has to be taken with cautious. We added the following paragraph in section 4.1: **"The dust scavenging efficiency k_{dust} that was set to 0 in the reference version, *i.e.*, no scavenging of dust (see Method Section 2.4.1). A higher $k_{\text{dust}} = 0.04$ led to a lower impact of dust (Fig. 7). Although this was poorly documented in the existing literature, we suspected that dust scavenging efficiency at the snow surface could be significantly higher than the previous sensitivity test. So we added a test of uncertainty using $k_{\text{dust}} = 0.2 = k_{\text{BC}}$ (Fig. 8), which is likely too high since BC particles scavenge more easily than large particles such as dust (*e.g.*, Conway et al. (1996); Doherty et al. (2013)). The dust impacts using those two dust scavenging efficiencies were still inside the uncertainty induced by the meteorological ensemble."**. We also modified the last paragraph of section 4.2: Overall, the uncertainties on LAP scavenging efficiencies in snow result in large uncertainties on the respective absolute impacts of dust and BC. **This highlights the need to better understand the motion of the different LAPs inside of the snowpack at the micro-scale.** Here, BC scavenging in snow, [...].

2.1.2 Minor issues

R1.4. line 30-31: "LAPs have advanced the snow melt-out date on average by 18 days in the French Alps in the past 40 years..." - As written, there is potential for ambiguity in whether this a trend towards earlier melt-out date over the last 40 years, or a mean impact over the last 40 years. Please clarify.

We agree that there is a potential confusion. This is here a mean impact over 40 years, not a trend. To insist on the mean, we propose the following formula: "For instance, **on average over the past 40 years, the presence of LAPs in snow has advanced the snow melt-out date by 18 days in the French Alps**, and even more at high elevations (more than 20 days at 3,000 m a.s.l., Réveillet et al., 2022)."

R1.5. Section 2.2.3: Please list the wavelengths of the spectral bands used for the NDSI and RGND calculations.

We added in Section 2.2.3 "**The central wavelengths of bands $B3$, $B4$ and $B11$ are respectively 560, 665 and 1610 nm.**"

R1.6. Section 2.2.5: Here, BC is varied within SNICAR to match the Sentinel-2 albedos. Dust also could have been varied to match the satellite albedos. Are the results at all sensitive to the choice of LAP used for this purpose?

We understand the comment and the concerns. We agree that using an more advanced method could increase the accuracy of the retrieved ice albedo.

However, (i) since only the broadband albedo was prescribed for ice albedo, and (ii) since we quantified here the impact of LAP in snow, and not in ice, we chose this simple method varying only one parameter. Varying other parameters, such as dust concentration, air bubble size or density, could indeed have slightly modified the broadband ice albedo and probably increase the accuracy. But retrieving a very accurate ice albedo is not the aim of this study. We argue that the error between our method and a more accurate method is small compared to the spatial variability of ice albedo on the glacier (that we do not represent in the model), and for which we performed the sensitivity tests of ± 20% on Figure 7.

To reflect this limitation, we added the following sentence is section 2.2.5: "**This method is rather simple since we here aimed to quantify the impact of dust in snow, not in ice. Nevertheless,** the sensitivity to this parameter was investigated in Section 3.3."

R1.7. line 138: The use of "(-)" is unfamiliar to me, but is perhaps used to indicate that albedo is a dimensionless quantity. I don't think this is needed, but if there is precedence for using such notation, it is fine.

"(-)" was indeed used for unit-less variables. We removed this notation from the text and from the figures.

R1.8. line 171: "right-hand side moraine" seems to be perspective-dependent, but perhaps there is precedence for using this terminology. Regardless, please clarify.

From an hydrological point-of-view, the right and left-hand sides are determined using the flow direction. Therefore, here the moraine AWS is on the right-hand side of the glacier considering the glacier flow direction. To clarify this point, we added this information: "Two automatic weather stations (AWS) were located at the surface and on the right-hand side moraine **with respect to the glacier flow** of Argentière Glacier **(Fig. 1d)**."

R1.9. line 203: Please clarify this sentence. It may be as simple as changing "then" to "so".

Thanks for spotting this. We switched to "**so**".

R1.10. Equation 1: Is there an upper bound of temperature to which this scaling is applied?

There is no upper bound in Equation 1. However, for example, at both the moraine or glacier AWS, located on the part of the glacier experiencing the highest air temperatures, the 2 m air temperature rarely exceeded 20 °C during the summer 2021, as shown in the example of Appendix Fig. C1. We added this information in the manuscript, section 2.3.4: "Therefore, we adjusted the SAFRAN temperature T^*, above $T_0 = 3.5$ °C **without any upper bound**, ..."

R1.11. Section 2.3.6: Although this is clarified in the appendix, please briefly communicate here whether the perturbations are random within the confines of individual variances, as in a Monte Carlo approach, or whether variables are perturbed in combination by their full variance. (Or in general, please provide a little more detail on the perturbation approach here).

We are not completely sure to understand correctly the comment. It seems that the reviewer is asking: "Are the perturbations univariate or multivariate ?". If we understood correctly the request, in this study, the approach chosen is univariate. This means that each variable was perturbed independently from other variables, *i.e.*, here each variable is perturbed uniquely using its own standard deviation σ_X. This implies that the different perturbations do not account for initial correlations between the meteorological variables, *e.g.*, an concurrent increase in air temperature and a decrease in long-shortwave radiation; are just as likely as; an concurrent increase in air temperature and a increase in long-shortwave radiation.

To account for your comment, we clarified this point in the revised manuscript, in the section 2.3.6, where you can now read: "... For a given member, the same perturbations were spatially applied to all simulation points. **Each variable was perturbed independently from other variables. For each variable, the perturbation term X_t depends on a decorrelation time τ and an amplitude σ_X^2. The exact relationship is explained in detail in Appendix C1. Given an additive variable V_t (T or LW) at time-step t, the perturbed variable V_t^* is defined as $V_t^* = V_t + X_t$, and in case the variable is multiplicative (SW or W), V_t^* is defined as $V_t^* = V_t \cdot (1 + X_t)$.** We applied the perturbations on a daily scale with a decorrelation time ..." The method is detailed in Appendix C1 that remains unchanged.

> **R1.12.** Figure 5: The month abbreviations on the x-axis appear to be in French.

Thanks. We switched to English.

> **R1.13.** line 457: "be" → "been"

We modified accordingly: "the dust impact in the ablation area would have likely **been** higher."

> **R1.14.** line 489: "We could not directly compare the MAC of dust..." - Despite this, please include the MAC values of dust that were assumed in your study.

As explained and justified in section 3 of this review, the MAE (mass absorption efficiency) of dust and BC were modified in this revised version. We added the revised MAE of dust and BC in the revised manuscript: "To compute the albedo of snow, the refractive indices of ice were set as Réveillet et al. (2022). **The mass absorption efficiency (MAE) of dust $\mathrm{MAE_{dust}}(\lambda)$ used for this study was the MAE of a PM10 Lybian dust from Caponi et al. (2017), *i.e.*, $\mathrm{MAE_{dust}}(\lambda) = \mathrm{MAE_{dust}}(\lambda_0) \times (\frac{\lambda}{\lambda_0})^{-\mathrm{AAE_{dust}}}$ where $\lambda_0 = 400$ nm, $\mathrm{MAE_{dust}}(\lambda_0) = 71 \times 10^{-3}$ m^2 g^{-1}, and the Ångström absorption exponent $\mathrm{AAE_{dust}} = 3.2$. The MAE of BC $\mathrm{MAE_{BC}}$ at 550 nm used for this study was 7.5 m^2 g^{-1} (Bond, Bergstrom, 2006).** To quantify the impact... To harmonize we also switched the occurrences of "MAC" (mass absorption cross-section) to **"MAE"** (mass absorption efficiency) in the whole manuscript.

3 Authors additional corrections

During the review process, we identified some inaccuracies that have been corrected, and some perspectives of evolution that have been investigated in this revised version. They are listed and detailed below, together with the corresponding modifications implemented in the revised version of the manuscript. While these corrections (especially the point 1) slightly change some of the numbers related to the quantification of dust impact, they do not alter the conclusions of the paper.

1. In the initial version of the paper, we did not redistribute the ALADIN wet and dry deposition fluxes with respect to the SAFRAN precipitations, hence deposited LAP were lost (*e.g.*, when ALADIN wet depositions without SAFRAN precipitations). We added this redistribution in this revised version following the method of Réveillet et al. (2022). Such a modification increased the simulated concentration of dust and BC at the snow surface, hence lowering albedo and advancing snow melt-out date compared to the initial version. So we adjusted and lowered (i) the mass absorption efficiency (MAE) of LAP of dust to [$\mathrm{MAE_{dust}}(400\ \mathrm{nm}) = 71 \cdot 10^{-3}$ m^2/g; $\mathrm{AAE_{dust}} = 3.2$] and the MAE of BC at 550 nm to 7.5 m^2/g, (ii) the roughness length of snow $z_{0,\mathrm{snow}}$ from $5 \cdot 10^{-4}$ m to 10^{-4} m, now better reproducing the ratio $z_{0,\mathrm{snow}}/z_{0,\mathrm{ice}}$ of 10 in Réveillet et al. (2018), and of ≈ 7 in Gerbaux et al. (2005).

To assess the accuracy of this revised parametrization, we tested different values of MAE (presented in Fig. 2), and we evaluated them using the following evaluation metrics:

- comparison to the summer melt measured at the stakes *(in the initial version)*
- comparison to the surface type evaluated from S2 *(in the initial version)*

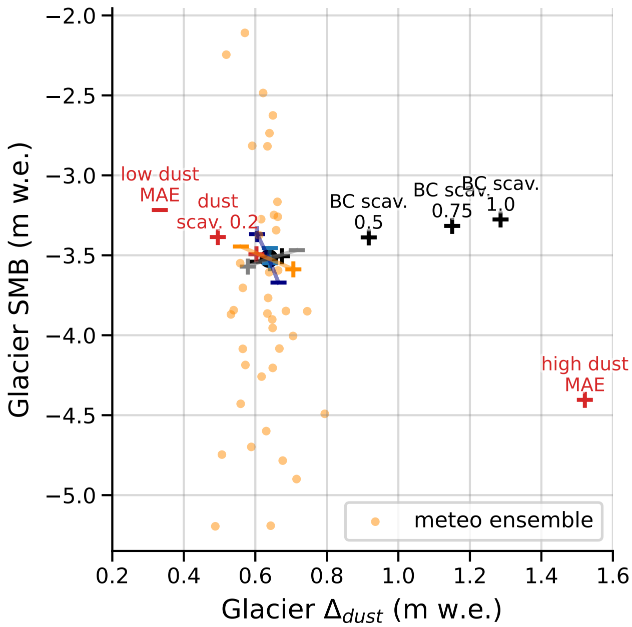

Figure 1: Figure 8: Impact of uncertainties relative to LAP scavenging efficiencies and deposition fluxes on the glacier-wide annual SMB (y-axis) and dust impact Δ_{dust} (x-axis) for hydrological year 2022. Reference simulation is represented by the central black dot. The 40 members of the ensemble are represented with the orange dots.

- comparison to the broadband albedo derived from S2 (Fig. 3 b) recommended by reviewer #2 *(new in this review)*
- comparison to the broadband albedo measured at the AWS (Fig. 4) *(new in this review)*

Table 3 summarizes the evaluation results. The new parametrization used in this revised version showed accurate results for all the evaluation metrics. The summer melts of the initial parametrization of MAE were too large compared to the stake measurements, and the simulated albedo are lower than the albedo retrieved from S2. Using low values of dust MAE (low parametrization), melt metrics were the best, however the comparison against S2 albedo and the AWS SMOD showed worse results than for the new parametrization. So, the new parametrization appeared as the best trade-off. The new MAE values were therefore used as reference in this revised version.

The MAE values of this revised version were lower than that of the initial version (Fig. 2). However, the initial MAE values (from Tuzet et al. (2020); Réveillet et al. (2022)) were used in in the framework of a seasonal snowpack at intermediate elevations (1'500 to 3'000 m a.s.l.). On glaciers, the LAP surface concentration may reach higher values due to longer melt seasons. This could likely lead to more aggregation of LAPs in the snowpack, which decrease their MAE (*e.g.*, Bond, Bergstrom (2006); Schwarz et al. (2013)). Therefore, it is reasonable to find lower optimal MAE on glaciers.

As a result, those revised MAE values did not affect the conclusions of this article.

We propose the following modifications. For the method section 2.3.1: "**ALADIN wet and dry deposition were redistributed with respect to the the SAFRAN precipitation as in Réveillet et al. (2022), *i.e.*, wet depositions when SAFRAN precipitations are positive, dry depositions otherwise.**" The revised values of the dust MAE have been integrated in the manuscript as indicated under comment R1.14., and the values of low and high dust MAE were also integrated in the manuscript as indicated under comment R2.7. We removed words from section 2.4.1: To compute the albedo of snow, the refractive indices of ice~~, mineral dust and BC were~~ was set as **in** Réveillet et al. (2022)~~, which quantified the impact of LAPs in the same region as in this study (the European Alps)~~. Particularly, the mass absorption efficiency of dust [...]" and to discuss the choice of

MAE, we added the following discussion in section 4.1: **"The MAE of dust used in this study was slightly lower than initial values used in previous studies in the framework of a seasonal alpine snowpack at intermediate elevations (Tuzet et al., 2020; Réveillet et al., 2022). The reliability of this parametrization was assessed by the evaluations of section 3.1 and the evaluation of the modelled snow albedo in Appendix Fig. 5. Such lower MAE implicitly accounts for the probable aggregation of LAP (likely due their high concentrations during long melt seasons) that lowers the MAE (*e.g.*, Bond, Bergstrom (2006); Schwarz et al. (2013))."**

The numeric values, concerning the results, of Sections 2.3.5, 3.1, 3.2, 3.3, 4, 4.1, 4.2, 4.3 have been modified (highlighted in the track change version attached to this response). Figures 3, 4, 5, 6, 7, 8 and Appendix Fig. D1, E1, E2, E3 have also been modified accordingly. In section 4.2, the word "almost" was removed. In section 4.3, CPU costs were adjusted to account for the addition of the sensitivity tests.

2. We modified the unit of the third row of Figure E1, from "m w.e." to "%".

3. The total melt was computed as the difference between the minimum and the maximum of SWE during the year, it is now computed accordingly to the formulation stated in section 2.5 of the manuscript, *i.e.*, as the sum of every snow or ice melt of the year.

4. We cited a recent article in the introduction (Menounos et al., 2025) dealing with glacier and LAP: "By lowering the albedo, LAPs contribute to significantly accelerate snow and glacier melt around the world, *e.g.*, [...] **Menounos et al. (2025)**."

5. All k_{BC} were adjusted to $k_{\mathbf{BC}}$.

6. In the Conclusion section, **"This year,"** was added to link to the previous sentence.

7. In the Acknowledgements section, **"Ghislain Picard"** was added.

8. Code and data availability have been revised, now providing access to the code repository, and forcing files in a Zenodo repository.

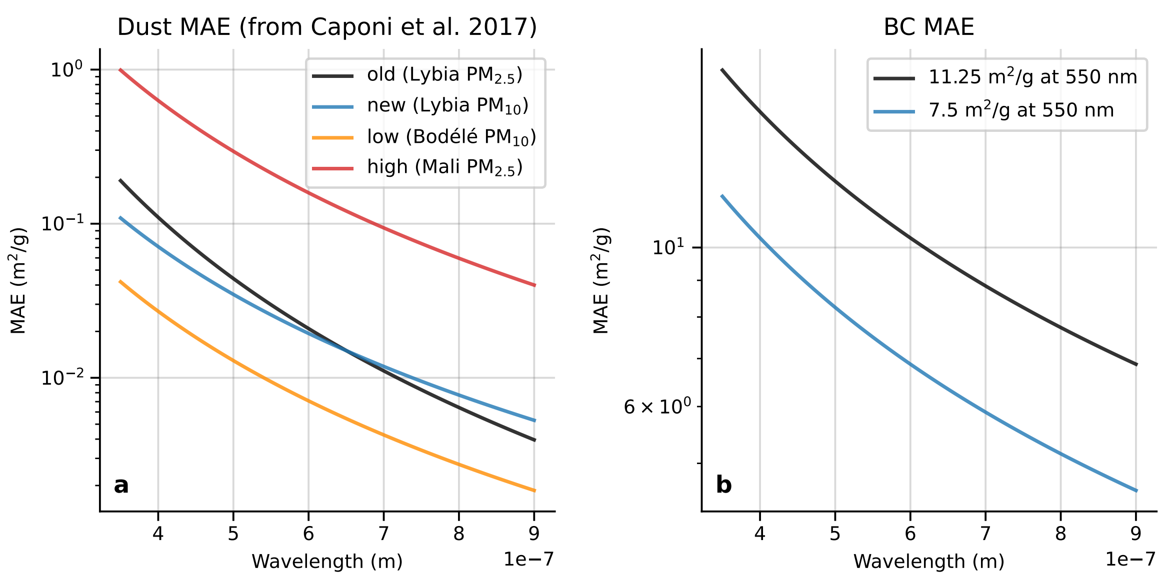

Figure 2: Numerical values used for mass absorption efficiencies (MAE) for both dust and BC. New and old values are respectively the ones of the revised and the initial version. The MAE of dust are from Caponi et al. (2017) with couples [$MAE_{dust}(\lambda_0)$; AAE_{dust}] being respectively equal to [$110 \cdot 10^{-3}$ m^2/g; 4.1], [$71 \cdot 10^{-3}$ m^2/g; 3.2], [$27 \cdot 10^{-3}$ m^2/g; 3.3] and [$630 \cdot 10^{-3}$ m^2/g; 3.4] for old, new, low and high parametrization. The old BC MAE was an enhanced MAE of 11.25 m^2/g at 550 nm previously used in Tuzet et al. (2020) to "implicitly account for the potential absorption enhancement due to internal particle mixing or particle coating". The new BC MAE of 7.5 m^2/g at 550 nm for BC is a non-enhanced MAE close to the external-mixing of BC used in SNICAR (Flanner et al., 2021).

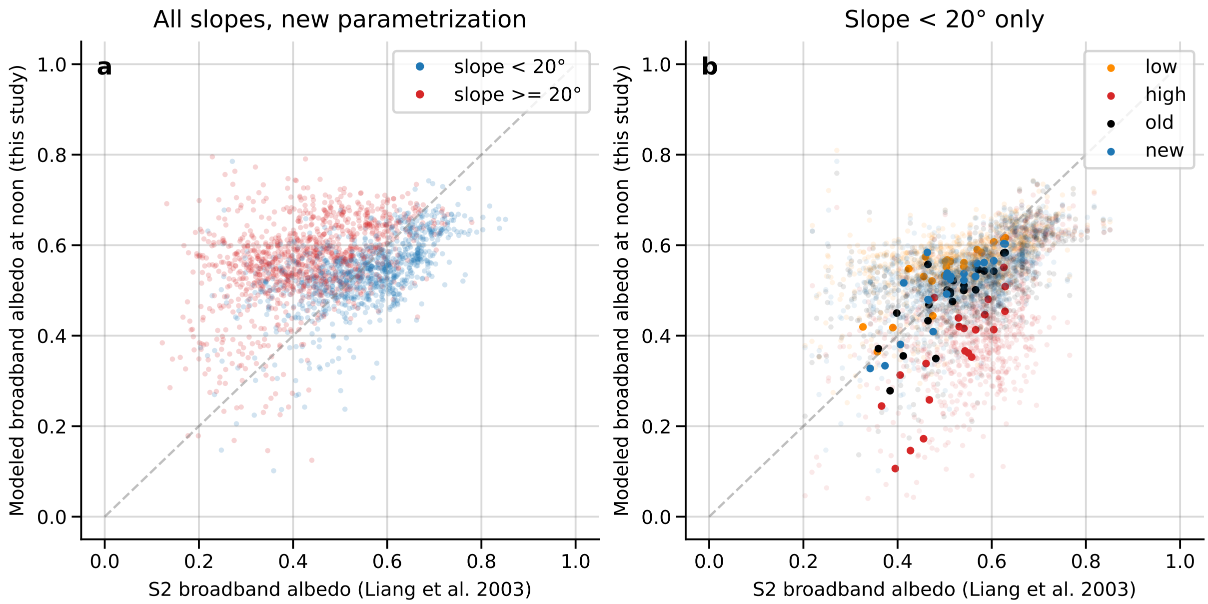

Figure 3: Comparison between modelled broadband albedo and observed broadband S2 albedo using the method of Liang et al. (2003) (S2 albedo $= 0.356 * R_2 + 0.130 * R_4 + 0.373 * R_5 + 0.085 * R_{11} + 0.072 * R_{12} - 0.018$ where R_i is the reflectance of Sentinel-2 band i). All S2 dates mentioned in Table B2 were used. Only the points where the surface type was snow for both the model and S2 were used. a) Using the new MAE parametrization of the model, blue point are for slopes $\leq 20°$, and red points for slopes $> 20°$. b) Using only slopes ≤ 20 ° for the different model MAE parametrizations found plotted in Fig. 4. Large opaque dots are the means for each date.

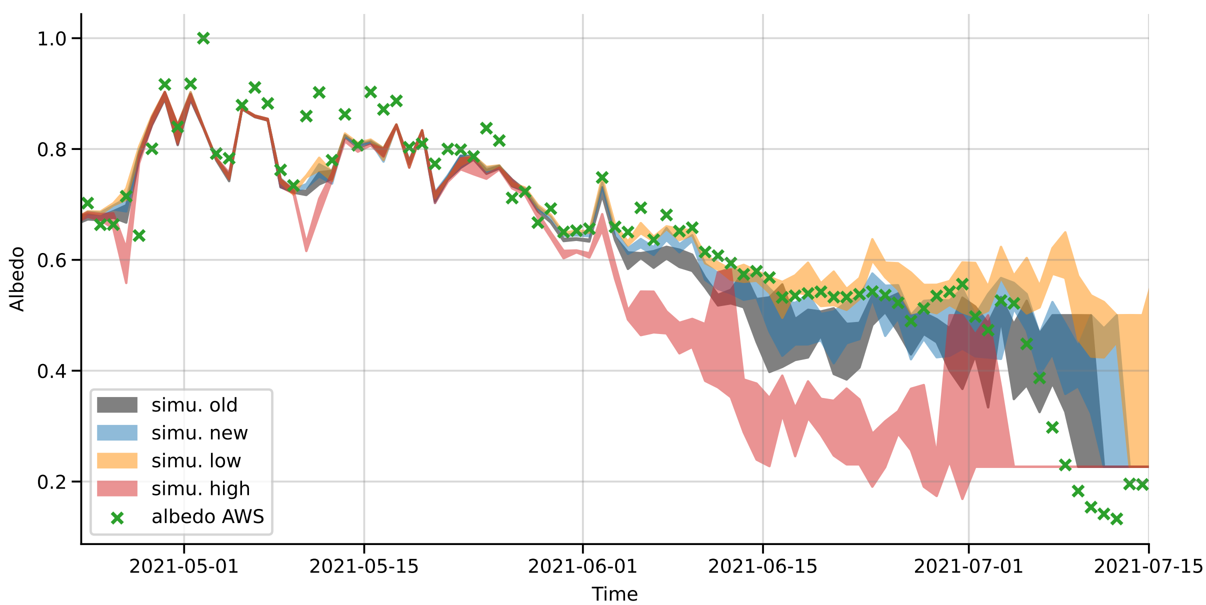

Figure 4: Albedo at the AWS glacier location. Albedo AWS (green crosses) is the measured albedo at the AWS computed as the ratio of reflected and incoming shortwave radiation between 9:00AM and 15:00PM. The simulated albedo (coloured contour envelopes) are the albedo values at noon plotted for the 4 simulation points near the AWS glacier.

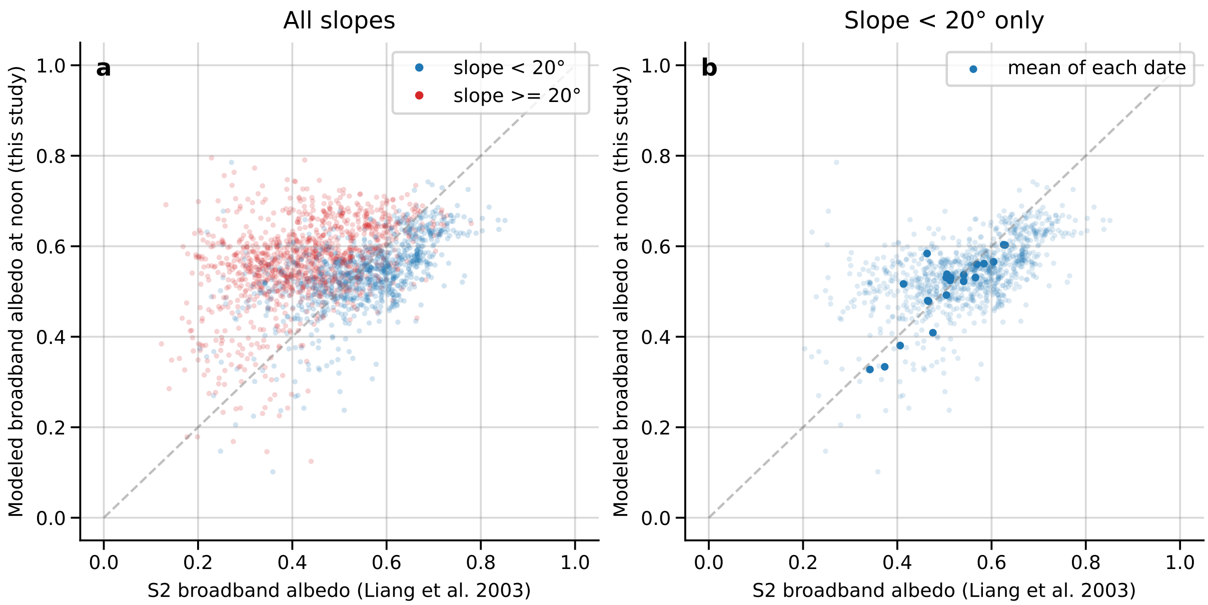

Figure 5: **Figure B3. Comparison between simulated broadband albedo and broadband albedo derived from S2. See section 2.2.6 for methods and limitations. (a) Influence of the slope. (b) Comparison for slopes < 20°. The mean of all dates, except 2, shows less than 0.1 of difference between the modelled albedo and the albedo derived from S2. This comparison of broadband albedo has to be taken with cautious. Indeed, there are several limitations. First, the broadband albedo derived from S2 (Liang et al., 2003) was not developed for snow, an anisotropic surface (*e.g.*, Dumont et al. (2010)), *i.e.*, the reflectance depends on the observation angle. Second, the uncertainties of the reflectance retrievals in complex terrain may be too high to estimate the accuracy of the simulated albedo, *e.g.*, Cluzet et al. (2020), or panel (a) of this figure where the broadband albedo derived from S2 strongly depends on the slope.**

		stakes summer mean error				stakes summer RMSE				vs. Sentinel-2		vs. AWS	
$z_{0,\mathbf{snow}}$ **(mm)**	**MAE dust, MAE BC**	2019	2020	2021	2022	2019	2020	2021	2022	snow albedo	surface type	snow albedo	SMOD
0.1	high, new	1.12	0.94	0.97	1.08	1.30	1.08	1.09	1.38	too low	too much ice	too low	5–6 d early
0.1	old, old	0.67	0.28	0.40	0.60	0.89	0.52	0.56	0.97	too low	OK	too low	2 d late
0.1	new, new	0.49	0.10	0.25	0.46	0.74	0.43	0.45	0.86	OK	more snow	OK	4 d late
0.2	new, new	0.57	0.19	0.31	0.57	0.78	0.44	0.48	0.90	OK	OK	?	?
0.05	new, new	0.33	-0.08	0.12	0.24	0.69	0.47	0.38	0.84	OK	more snow	?	?
0.1	low, new	0.33	-0.16	0.02	0.28	0.63	0.44	0.31	0.76	too high	too much snow	OK	6–9 d late

Table 1: Summary of the evaluations for different parametrizations. See Fig. 2 for the numeric MAE values. Melt evaluation against the stakes measurements (in m w.e.) and surface type evaluation against S2 are the metrics initially used in Figure 3 of the manuscript. SMOD stands for snow melt-out date. Evaluations, except evaluation with stakes, are qualitative. Question marks stand for uncalculated metrics.

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