1. Methodology needs clarification and justification. I found myself asking many questions about the reported methods which made it difficult for me to assess the reliability and validity of the approach. The essential ingredient of the proposed method hinges on the use of equation (1) which defines mass balance for year (i) to be a product of the long-term (2000-2019) geodetic balance, mass-balance/albedo gradient (regional or global) and glacier wide summer albedo anomaly. Two things strike me. First, how does the use of the long-term geodetic balance which ends in 2019 affect this approach for albedo measurements following 2019?

To avoid ambiguity and ensure methodological consistency, we have revised the analysis to restrict all calibration, validation, and intercomparison to the period 2000–2019, corresponding to the temporal coverage of the Hugonnet et al. (2021) geodetic mass-balance dataset.

Second, what happens for a glacier where the long-term geodetic balance is zero? It would suggest that each year's mass balance (2020-2024) is zero which clearly would be unusual. I think the authors need to spend more time explaining why and how they decided on their approach and provide some additional justification for the physical reasons that such as relation might be expected to work.

From Eq. (1), the annual glacier mass balance in year i (B_i) is expressed as:

$$B_i = (\alpha_i - \bar{\alpha})\frac{db}{d\alpha} + \bar{B}$$

Where α_i is the glacier-wide summer albedo, $\bar{\alpha}$ is the mean albedo over the reference period, $\frac{db}{d\alpha}$ is the mass-balance–albedo anomaly gradient, and $\bar{B}$ is the long-term geodetic mean mass balance.

If the long-term geodetic mass balance is zero (i.e. $\bar{B} = 0$), Eq. (1) reduces to:

$$B_i = (\alpha_i - \bar{\alpha})\frac{db}{d\alpha}$$

Therefore, a zero long-term geodetic balance does not imply that annual mass balance is zero in all years. In this case, it is entirely controlled by deviations of annual albedo from its long-term mean. Years with lower-than-average albedo yield negative mass balance, while years with higher-than-average albedo yield positive mass balance, as expected physically.

I would also suggest the authors add additional details about the methodology (e.g. why did they choose mean summer albedo when many previous studies use end of summer minima, what is the rationale for a threshold of 70% for retained days and

> gap filling, what is the effect (and need?) of interpolation on the summer albedo?). I think that some of these thresholds could easily be addressed within supplementary materials which might help to justify their values.

Mean summer albedo vs. minimum end-of-summer albedo

Mean summer albedo represents the glacier-wide albedo integrated over the ablation season and averaged by the number of observation days. Similar to minimum end-of-summer albedo, the seasonal mean albedo has been widely used as a proxy for glacier mass balance (e.g., De Ruyter de Wildt et al., 2002; Greuell & Oerlemans, 2005; Greuell et al., 2007). More recently, Di Mauro & Fugazza (2022) compared average summer albedo and minimum albedo and showed that both metrics exhibit comparable skill in capturing interannual variability in glacier mass balance.

In this study, our choice of mean summer albedo is motivated primarily by the fact that, in recent years, many glaciers, particularly in the European Alps, have experienced very negative mass balance. Under such conditions, minimum albedo tends to saturate once the seasonal snow cover has completely melted, as glacier surfaces remain persistently snow-free for extended periods. In these cases, further variations in melt intensity are no longer reflected by the minimum albedo value. In contrast, glacier-wide albedo averaged over the entire ablation season remains responsive, as persistently low albedo values throughout the summer are captured by the seasonal mean. This makes mean summer albedo more suitable for representing sustained melt conditions and interannual variability under strongly negative mass-balance regimes.

Cloud cover threshold and interpolation

A 70% valid-pixel threshold was adopted to retain daily glacier-wide albedo observations, as this value represents a compromise between data availability and robustness against cloud contamination. The same threshold was also used in Daveze et al., 2018. Rather than relying on a fixed threshold, we now explicitly account for the uncertainty associated with this choice by varying the threshold between 60% and 80% within a Monte-Carlo framework. The resulting variability is propagated into the annual mass-balance uncertainty (see response to the next comment). This approach avoids over-reliance on a single threshold value and quantifies its influence on the results.

After removing days with insufficient data coverage, interpolation of daily albedo values is required to ensure consistent temporal sampling of the ablation season across all glaciers and years. Because cloud cover and data gaps vary in time and space, interpolation allows the computation of seasonal mean albedo in a homogeneous way, avoiding biases caused by uneven temporal sampling.

2. Uncertainty estimates and degrees of freedom – An important aspect to this work, both in the way it is presented and in the presented analysis, is the nature of the spatial correlation and degrees of freedom. Most of the goodness-of-fit statistics rely on an estimate of n which, in many cases can be thought of as the degrees of freedom (number of observations). Many studies demonstrate glacier mass change (and albedo variations) strongly covary in space since they are affected by synoptic-scale meteorological conditions. This spatial covariance affects the overall significance of performance statistics by reducing the number of independent observations. There does not seem to be any attempt to correct for this known effect. At the very least, I think the authors need to acknowledge that this affect likely reduces the degrees of freedom of these tests in the methods, results and/or discussion.

We agree that glacier mass balance and glacier-wide albedo anomalies are spatially correlated, primarily because they are driven by large-scale atmospheric forcing. To account for this we assess now the performance using a 3-fold cross-validation at the glacier level, where gradients are estimated using subsets of glaciers and evaluated on separate glaciers not used in calibration. This approach reduces the impact of spatial dependence by ensuring that validation is performed on independent glacier samples.

The resulting gradients and performance metrics of the new 3-fold cross validation experiment are:

European Alps

$$\frac{db}{d\alpha} = 10.78, 10.29, 10.74 \text{ m w.e.}$$

MBE = −0.045 m w.e., MAE = 0.35 m w.e., RMSE = 0.45 m w.e., R^2 = 0.60

Scandinavia

$$\frac{db}{d\alpha} = 14.1, 12.0, 12.5 \text{ m w.e.}$$

MBE = −0.06 m w.e., MAE = 0.61 m w.e., RMSE = 0.80 m w.e., R^2 = 0.43

Svalbard

$$\frac{db}{d\alpha} = 4.3, 6.9, 5.5 \text{ m w.e.}$$

MBE = −0.18 m w.e., MAE = 0.33 m w.e., RMSE = 0.43 m w.e., R^2 = 0.31

The consistency of the gradients across folds, together with stable error metrics, supports the robustness of using regional gradients derived from independent glaciers.

> Further, the authors need to be careful evaluating their results to other studies that use similar data. While Figure 9 shows some similarity to their time series, I'm not overly surprised since both approaches uses geodetic data from the same study (even use of long term data will affect the apparent fit).

We agree with the reviewer that the similarity shown in Figure 9 should be interpreted with caution, as both datasets compared in that figure are, at least in part, constrained by the same underlying geodetic mass-balance information from Hugonnet et al. (2021). On the other hand, the method of Dussaillant et al. (2025) relies on geostatistical temporal downscaling constrained by in-situ observations, whereas our approach infers interannual variability from glacier-wide surface albedo anomalies derived exclusively from satellite data. The comparison in Figure 9 is therefore meant to indicate whether the broad temporal evolution of regional mass balance is consistent between two conceptually different downscaling strategies, rather than to provide an independent benchmark.

In the revised manuscript, we have clarified that the comparison with the dataset of Dussaillant et al. (2025) is included to assess the consistency of large-scale temporal patterns rather than to demonstrate independent agreement. As both approaches use geodetic data as a long-term reference, some level of correlation, especially at multi-annual timescales, is expected. We now explicitly state this limitation in the text to avoid overstating the significance of the observed agreement:

"To assess the reliability of large-scale temporal patterns of the estimated time series, we compared our results with the recently published dataset from Dussaillant et al. (2025). This dataset provides glacier-specific global annual mass balance estimates for the period 1976–2024, derived using geostatistical methods that integrate glaciological measurements with glacier-wide geodetic observations, including data from Hugonnet et al. (2021). The comparison was conducted using the same set of glaciers (see Table 4) to ensure consistency between the two methods. We note that both datasets are constrained by a common long-term geodetic reference, and therefore some degree of agreement is expected. Consequently, this comparison is not intended as an independent validation of the albedo-anomaly method, but rather as an assessment of the consistency of large-scale temporal patterns obtained using two conceptually different downscaling strategies. Despite these common constraints, the two datasets show good agreement, with the general trends of mass balance variation captured consistently across regions (Figure 9)."

> Additionally, I think the authors could spend a bit more time thinking about the actual uncertainties of their method. For example, the long-term geodetic mass balance from Hugonnet comes with an error term, and the mass balance/albedo gradients are based on regression with error. Would it not be reasonable to produce an error term for each derived mass balance estimate?

We have now implemented a comprehensive uncertainty analysis, explicitly quantifying and propagating uncertainties associated with all terms entering Eq. (1): from Eq. (1), annual glacier mass balance is expressed as:

$$B_i = (\alpha_i - \bar{\alpha})\,\frac{db}{d\alpha} + \bar{B},$$

where each term is affected by uncertainty. We explicitly quantify and propagate the following 1-σ uncertainty components:

1) **Uncertainty associated with glacier-wide summer albedo anomaly** $(\alpha_i - \bar{\alpha})$

The uncertainty on annual glacier-wide summer albedo, accounts for measurement noise, glacier size and sensitivity to cloud-cover filtering. We estimate σ_{α_i}, i.e. the uncertainty associated with glacier wide summer albedo anomaly for year i using a Monte Carlo approach with 500 realizations. In each realization:

- the fraction of valid pixels required to retain daily albedo values is randomly varied between 60 % and 80 %, capturing uncertainty related to cloud filtering;
- for each retained daily albedo value, Gaussian noise is added to represent systematic uncertainty in MODIS albedo retrievals. The standard deviation of the gaussian noise is set to $0.05/\sqrt{n}$ where n the number of MODIS pixels covering the glacier (Daveze et al., 2018).
- the annual anomaly is then computes as $\alpha_i - \bar{\alpha} = \alpha_i - \frac{1}{N}\sum_{i=1}^{N} \alpha_i$, with $N = 20$ years (2000–2019).

The standard deviation of the resulting ensemble is taken as σ_{α_i}.

2) **Uncertainty associated with the mass-balance–albedo gradient**

The uncertainty on the gradient $\frac{db}{d\alpha}$, denoted σ_g, is estimated as the standard deviation of gradient values obtained from the 3-fold cross-validation experiment introduced in response to Comment 2. This approach captures the glacier-to-glacier variability of the albedo–mass-balance relationship within each region and avoids reliance on individual time-series fits.

3) Uncertainty associated with the geodetic mass-balance reference

The uncertainty on the long-term geodetic mass-balance reference, $\sigma_{\bar{B}}$, is taken directly from the Hugonnet et al. (2021) dataset, which provides glacier-specific uncertainty estimates.

Propagation to annual mass-balance uncertainty

Once σ_{α_i}, σ_g, and $\sigma_{\bar{B}}$ are defined, the 1-σ uncertainty on annual mass balance, σ_{B_i}, is computed by error propagation:

$$\sigma_{B_i} = \sqrt{\sigma_{\bar{B}}^2 + \left[(\alpha_i - \bar{\alpha})\frac{db}{d\alpha}\right]^2 \left(\frac{\sigma_{\alpha_i}^2}{(\alpha_i - \bar{\alpha})^2} + \frac{\sigma_g^2}{\left(\frac{db}{d\alpha}\right)^2}\right)}.$$

3. Clarity of results – I was confused by some of the results of this paper. In figure 7, for example, the authors compare WGMS mass balance data against geodetic data from Hugonnet and others (2021) and their approach (MODIS+DEMs). Are the authors plotting long-term geodetic averages against the WGMS annual data or mean data? It is not clear to me in neither the figure caption nor the text. I think the authors need to spend a bit of time ensuring that the visual presentation of their data is clearly described.

We have added a clarifying paragraph at the beginning of Section 4.2, explicitly describing the datasets used in the comparison and the purpose of the comparison. The added paragraph now reads:

“Glacier mass-balance estimates from the Hugonnet et al., 2021 dataset are known to be affected by substantial noise at yearly resolution, as the magnitude of annual elevation change is often comparable to the uncertainty of the measurements. As a consequence, this geodetic mass-balance dataset is typically interpreted at multi-annual to decadal timescales, where temporal averaging suppresses errors and yields robust estimates of long-term mass change.

Here, we assess whether glacier-wide MODIS summer albedo anomalies can provide additional information to interannual variability and thereby improve annual mass-balance estimates derived from geodetic data alone. To this end we compare two sets of annual mass balance estimates against the WGMS observations: (i) annual estimates derived directly from the geodetic dataset of Hugonnet et al. (2021) (hereafter "DEMs"; Fig. 7, Table 3) and (ii) annual estimates obtained by combining the geodetic mean mass balance with MODIS albedo anomalies using Eq. (1) (hereafter "DEMs+MODIS"; Fig. 7, Table 3)."

> I looked at Figure 10 for some time and trying to understand how differencing the mean from the observations to yield anomalies can collapse the variance as profoundly as Fig 10b shows. What happened, for example, to the positive outliers of MOD10A1 which appear on 10b and disappear altogether on 10a? Deriving anomalies should simply be a scale translation, no?

Indeed, when anomalies are computed as deviations from a mean, this operation represents a scale translation for each individual time series. However, the anomaly computation is performed separately for each glacier, using its own glacier-specific mean albedo over the reference period. As a result, each glacier undergoes a different translation, not a common shift applied to all data points. When anomalies are computed (Figure 10b), what remains is the interannual variability around each glacier's own mean, which is much more consistent between the two products.

Minor comments

Abstract: remove subjective words such as 'accurate' , 'reliable' since the RMSE values don't really support these strong qualifiers.

"accurate" and "reliable" removed from the abstract

Lines 38-40: This section largely avoids other methods (laser and radar altimetry) which have been shown to be useful for estimates of volume change of mountain glaciers. Several studies have used cryostat, icesat-2, GEDI for example.

Laser and radar altimetry technologies have been included in the introduction.

Lines 105-149: As specified above, I would recommend the authors redraft this section of their paper, detail important assumptions they are making, explain the physical reasons/processes (perhaps right before the paper's objectives) which helped them to formulate their study.

Following this recommendation, we added to section 3 an explanation of the key assumptions of the proposed approach and clarified the underlying physical processes that motivated its formulation:

"To estimate annual glacier mass balance, we combined satellite-derived glacier-wide summer albedo with long-term geodetic mass balance data. The approach is based on the assumption that glacier-wide summer albedo anomalies act as an integrated proxy for key accumulation and ablation processes. Interannual variations in albedo primarily reflect changes in the persistence of seasonal snow cover during the melt season. Reduced snow persistence is often associated with lower winter accumulation, leading to earlier exposure of bare ice. This early snow depletion, in turn, enhances melt by lowering surface albedo and increases the absorption of short-wave radiation, thereby amplifying ablation."

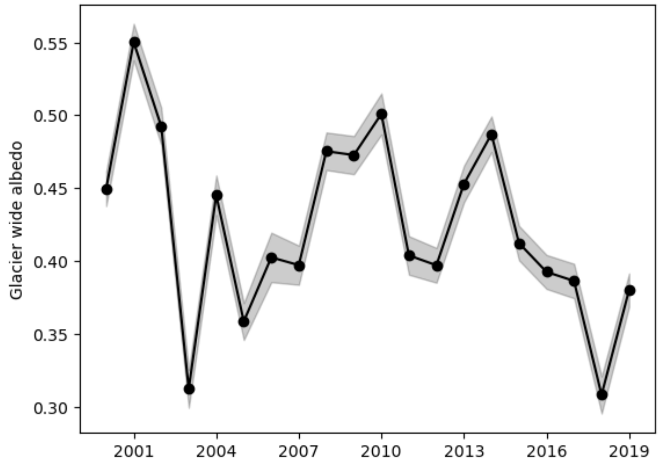
Figure 2: Since you include the dates for the albedo anomalies and average geodetic balance, ensure your rightmost box (annual balance estimates) include the range. Right now several of your results seem to report mass balance estimates beyond 2019. Figure 4, for example. How does this affect your results? Would the results improve if you only calculated mass balance up to 2019? How does one use your approach if you only use albedo up to 2019?

To avoid ambiguity and ensure methodological coherence, we have revised the analysis to restrict all calibration, validation, and intercomparison strictly to the period 2000–2019, matching the temporal coverage of the Hugonnet et al. (2021) geodetic mass-balance dataset.

We now clarify explicitly that application after 2019 requires an updated geodetic mass-balance reference spanning the period of interest: a new multi-annual geodetic dataset (e.g. from updated DEM products) can replace the Hugonnet et al. (2021) dataset to anchor albedo-derived annual anomalies in subsequent years.

Figure 4: It would be good once uncertainties are calculated from equation one to add these to the figure. As commented on in the major points, you'll need to convey to the reader why average summertime albedo is better than minimum (the latter is a closer proxy to transient snow line at end of ablation period – and closely related to net balance for many glaciers).

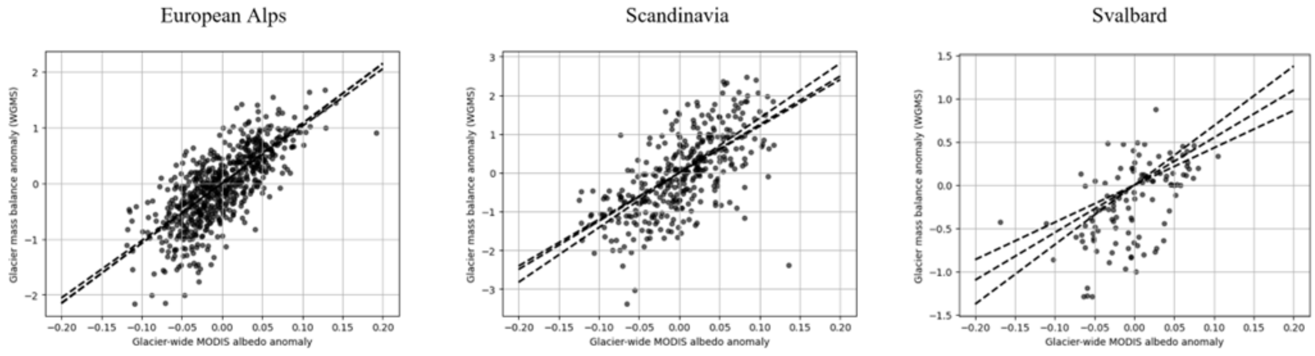
Uncertainty estimates for the glacier wide albedo time series, computed as described in the response to comment 2 are now included in Figure 4:



Clarifications on the use of mean summer albedo rather than minimum end-of-summer albedo have been provided in response to comment 1.

Figure 5: The degree of scatter here is fairly large. As specified earlier, I think your results would be more robust if you propagate your errors by using the uncertainty of the gradient in equation 1.

We now present Figure 5 as three separate subfigures, one for each study region (European Alps, Scandinavia, and Svalbard), and derive the mass-balance–albedo anomaly gradient $\frac{db}{d\alpha}$ using a 3-fold cross-validation strategy. For each region, gradients are estimated iteratively using two-thirds of the glaciers and evaluated on the remaining subset. The resulting three regression lines are shown as dashed lines in each panel:



(a) (b) (c)

Figure 5: Glacier-wide summer albedo annual anomalies versus annual glacier mass-balance anomalies from WGMS observations for glaciers in the European Alps (a), Scandinavia (b), and Svalbard (c). Dashed lines show the linear db/dαrelationships obtained from the 3-fold cross-validation, where the mass-balance–albedo

anomaly gradients ($\frac{db}{d\alpha}$) are estimated iteratively using two-thirds of the glaciers in each region. The spread between dashed lines reflects the variability of the gradient across the three cross-validation folds.

This representation allows the reader to visually assess the uncertainty associated with the estimation of $\frac{db}{d\alpha}$, as the spread between the dashed lines reflects variability in the gradient across the cross-validation folds. In addition, the corresponding gradient uncertainty is now formally propagated into the annual mass-balance uncertainty through the error-propagation framework described in the response to comment 2.

Table 2: Explained variance exceeds 50% for the European alps whereas the other two regions have much lower explained variance. I think the authors need to consider how reliable their method is in terms of estimating surface mass balance in light of these numbers. As mentioned previously, I think the number of independent (validation samples) needs to be consider at least in the discussion in terms of spatial covariance.

To mitigate the influence of spatial covariance, we implement a 3-fold cross validation strategy: for each region, the glaciers were randomly divided into three subsets. In each iteration, gradients were estimated using two-thirds of the glaciers and evaluated on the remaining subset, ensuring that validation is performed on glaciers not used to estimate the gradient. The results are specified in the answer to comment 2.

Higher R^2 values obtained for the European Alps primarily reflect more favorable conditions for an albedo-based approach, including (i) predominantly temperate glaciers with mass balance largely controlled by summer melt, (ii) a strong and consistent link between snow persistence, surface albedo, and annual mass balance, and (iii) a relatively dense and long-term network of WGMS observations that allows a more robust estimation of the albedo–mass-balance gradient. In contrast, the lower explained variance observed in Scandinavia and Svalbard reflects known limitations of albedo-based proxies in these environments. In maritime Scandinavia, frequent years with near-zero or positive mass balance reduce the sensitivity of annual mass balance to summer albedo anomalies, while in Svalbard, colder and polythermal glacier regimes result in reduced interannual albedo variability. These factors diminish the strength of the albedo–mass-balance relationship and therefore the explained variance.

Despite these regional differences, we emphasize that glacier-wide albedo anomalies provide a clear added value (also for glaciers in Scandinavia and Svalbard) when combined with geodetic mass-balance estimates, as demonstrated by the substantial reduction in RMSE and increase in explained variance relative to DEM-only annual estimates (Fig. 7).

Furthermore, the comparison with the independent reconstruction of Dussaillant et al. (2025) shows that the albedo-based approach achieves regional-scale downscaling performance comparable to methods relying on spatialization of in-situ observations.

Figure 7: As specified in the major comments, I don't understand how this graphs on the left column (WGMS vs DEMs) were constructed. Are these mean values for both?

The left-column panels of Figure 7 compare annual values, not mean or multi-annual averages.

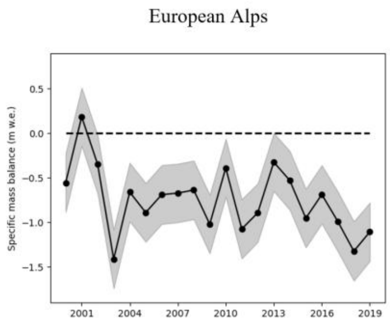
Specifically, the "DEMs" estimates plotted against WGMS observations correspond to annual glacier mass-balance estimates directly derived from the Hugonnet et al. (2021) dataset at annual resolution, using the glacier-specific annual elevation-change time series provided in that dataset. These annual geodetic estimates are shown purely for comparison purposes, despite their known limitations at yearly resolution.

The WGMS data shown in the same panels represent the corresponding annual glaciological mass-balance measurements for the same glaciers and years. No temporal averaging or aggregation is applied to either dataset in the left-column panels.

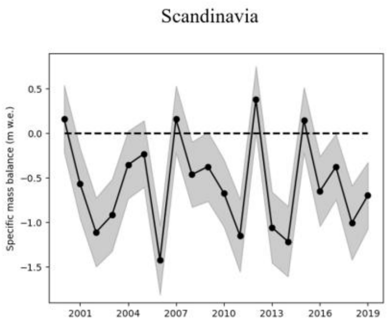
We have added a clarifying paragraph at the beginning of Section 4.2, explicitly describing the datasets used in the comparison and the purpose of the comparison (see reply to comment 3).

Figure 8: It would be more informative to have the shading represent uncertainties derived from errors in equation 1. That would allow us to know, for example, the true ability of this annually-resolved approach to detect true changes in surface mass balance.

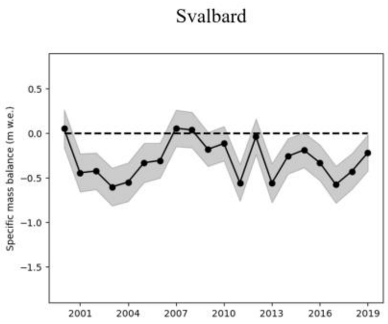
We have revised Figure 8 so that the shading now explicitly represents uncertainties derived from the error-propagation of Eq. (1), rather than inter-glacier variability:



(a)



(b)



(c)

In the revised analysis, each glacier-specific annual mass balance is associated with a 1-σ uncertainty, computed by propagating uncertainties in glacier-wide albedo anomalies, the mass-balance–albedo gradient, and the long-term geodetic mass-balance reference (see response to comment 2). These glacier-level uncertainties are then propagated to the regional mean annual mass balance shown in Figure 8.

Two limiting cases can be considered for uncertainty propagation to regional averages:

1. Independent errors, in which glacier-specific uncertainties are assumed uncorrelated. In this case, the uncertainty of the regional mean, σ_{avg}, is given by

$$\sigma_{\mathrm{avg}} = \frac{1}{N}\sqrt{\sum_{g=1}^{N} \sigma_g^2}\,,$$

   where N is the number of glaciers in the region. Under this assumption, σ_{avg} decreases with increasing N and tends toward zero for large glacier samples.

2. Fully correlated errors, in which glacier-specific uncertainties are assumed to be strongly correlated. In this case,

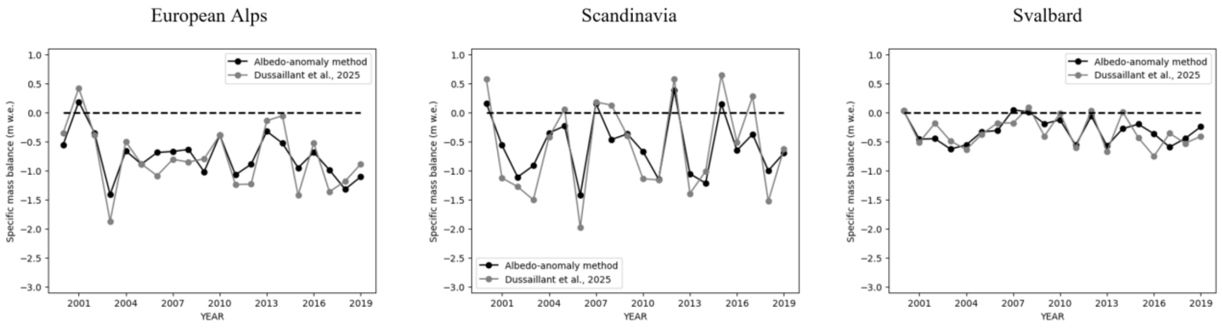
$$\sigma_{\mathrm{avg}} = \frac{1}{N}\sum_{g=1}^{N} \sigma_g\,,$$

   representing a conservative upper bound on the regional uncertainty.

Because all glaciers within a region are estimated using the same formulation (Eq. 1) and share a common regionally derived mass-balance–albedo gradient, we consider the assumption of high error correlation to be more appropriate. We therefore adopt the second, conservative formulation when visualizing uncertainty in Figure 8. This choice ensures that the shaded envelopes represent a worst-case estimate of uncertainty and avoid overstating the precision of the regional mean time series.

Figure 9: How are values post-2019 calculated in light of figure 2? It appear the this albedo approach always underpredicts extremes. Why? I presume this is due to the use geodetic mean and albedo mean values? What would happen if albedo minima were used? Would the results improve?

As previously mentioned, to avoid ambiguity and ensure methodological coherence, we have revised the analysis to restrict all calibration, validation, and intercomparison strictly to the period 2000–2019, matching the temporal coverage of the Hugonnet et al. (2021) geodetic mass-balance dataset. Figure 9 now includes only this period:



(a) (b) (c)

We explicitly clarify that application of the approach beyond 2019 requires an updated long-term geodetic mass-balance reference spanning the period of interest. Once such a dataset becomes available (e.g. from updated DEM products), it can integrate the Hugonnet et al. (2021) dataset to anchor albedo-derived annual anomalies in subsequent years. Without this updated reference, post-2019 estimates should be considered provisional and are therefore no longer included.

Regarding the apparent damping of extremes, we agree that the use of an anomaly-based formulation anchored to long-term mean values can reduce the amplitude of reconstructed extremes. However, as demonstrated by our results, this formulation can provide stable, regionally consistent estimates of interannual variability. Concerning the use of mean summer albedo versus minimum end-of-summer albedo we provided clarifications in response to comment 1. More in detail, as showed by Di Mauro & Fugazza, 2022 average summer albedo and minimum albedo exhibit comparable skills in capturing interannual glacier mass-balance variability. Our choice of mean summer albedo is motivated by its greater robustness during strongly negative mass balance, when minimum albedo tends to saturate once seasonal snow has fully melted. For this reason, we do not expect the use of minimum albedo to improve the representation of extremes within the anomaly-based framework adopted here.

Lines 310-330: I'm not certain I agree with some of the discussion here and some of my points here pertain to clearly laying out the physics/background on why this approach should work at all. Surface mass change of these glaciers is due to any process changing mass. End of summer minimum surface albedo is correlated to net mass balance partly because it is recording glacier-wide changes in snow cover (any remaining snow is a positive). But the albedo is also driving surface energy melt. Impurity deposition due to wildfire or dust events (e.g. Europe) can lower albedo and help ablate surface mass. Harmonized Landsat Sentinel (HLS) data yields frequent (5-day) repeats which could be used with broadband albedo methods described elsewhere. I'm not proposing that the authors complete/test these methods, but it would be good re-structure their discussion to better reference these other methods, re-iterate the physical processes which they capture in their approach.

Glacier surface mass balance is governed by multiple processes, including variability in winter accumulation, summer melt driven by surface energy balance, and additional effects such as impurity deposition. Glacier-wide summer albedo integrates several of these processes simultaneously. In particular, we clarify that:

- Albedo correlates with mass balance because it records the extent and persistence of seasonal snow cover, which is directly linked to both winter accumulation and the timing of snow depletion
- Albedo actively modulates melt through its control on short-wave radiation absorption, thereby exerting a direct influence on ablation intensity
- External forcings such as dust deposition, which lower surface albedo independently of snow cover, can further enhance melt and are implicitly captured by glacier-wide albedo anomalies.

Harmonized Landsat Sentinel (HLS)

We acknowledge that high-resolution datasets such as harmonized Landsat–Sentinel (HLS) products can provide frequent (~5-day) observations suitable for broadband albedo retrievals. While this dataset offers substantially higher spatial resolution, its applicability at multi-decadal scale is limited by data availability. In particular, prior to the launch of Sentinel-2 in 2015, Landsat missions provided a revisit time of 16 days, which strongly restricted the temporal sampling of surface conditions for many glaciers. We therefore emphasize that the proposed MODIS-based approach represents a complementary, rather than a replacement, solution to higher-resolution methods, enabling the generation of spatially consistent annual glacier mass-balance time series extending back to 2000.