

The manuscript “High-resolution Digital Outcrop Dataset of a Fossil Hyperextended Rifted Margin, Swiss Alps” presents a comprehensive and spatially extensive dataset of digital outcrop models. The breadth of potential applications of the data is great to see presented (structural geology, geomorphology) and will be useful to many researchers in related fields. The raw imagery and ancillary documentation is well-organised, thorough, and FAIR-aligned – a critical part of science and something that digital outcrop data is well positioned to provide. So it is great to see significant strides being taken in this. The geometry quality assessment is well handled and the accompanying figures are supportive.

Though the data is good, the presentation of it could use clarification to make it easier to validate and useful for practitioners along with the language use to make it more direct and ingestible.

General Comments

1. Reduce first-person voice with more direct third person phrasing.

The text has been modified accordingly. We have carefully edited the text, changing the first person to the third person throughout.

2. Consider using more consistent terminology. For example, GSD defined once could be used throughout the manuscript instead of phrases like “ground resolution” or “cm/pix”.

The text has been modified accordingly. We reviewed consistently the terminology throughout the text in order to simply and clarify the manuscript.

3. I think the manuscript would benefit from referring to models by name instead of number. Using model names would be more useful to readers who are not familiar with the convention and may want to use associated data that they may have.

Thank you for this suggestion. The naming of the models was discussed extensively among the co-authors. In an earlier version of the manuscript, we referred to the models by name; however, this made several passages rather cumbersome and resulted in unnecessarily long sentences. In addition, many of the model names refer to local peaks or geographic locations that may not be particularly informative to a broader readership. Furthermore, given the size of the models, multiple named geographic locations are captured by a single model. For these reasons, we felt that referring to the models consistently by number throughout the manuscript provides a clearer and more concise presentation. In addition, the relation between the model name/area and model number is provided in Table 1.

4. Brief clarifications of some technical terms would help readers and practitioners to grasp what information is presented and then use it more readily. E.g. “confidence” or “internal error analysis”.

We added in the text: “Point confidence is a measure of the reliability of the reconstructed 3D position of a point, reflecting the number and consistency of image observations from which the point was derived”.

We have clarified the meaning of “internal error analysis” and “manual inspection” in the revised manuscript.

By “(internal) error analysis,” we refer to the assessment of the error associated within each specific model (i.e., internal analysis) and between the model and the reference data. This analysis was performed using analytical calculations to quantify the error at the individual control-point level, as well as model-wide comparisons to the reference. It complements the aggregate error metrics derived from processing reported above and provides a more detailed assessment of the quality of the results.

By “manual inspection,” we refer to an additional qualitative check of the data and results.

We manually reviewed the outputs to verify that the values were plausible, internally consistent, and consistent with the expected characteristics of the data. This inspection was

used to identify potential anomalous or inconsistent results that might not be fully captured by the quantitative error metrics. It also allowed for inspection of anomalous regions where models would deviate from the reference (e.g. due to snow packs, rock fall) and for the comparison of areas covered by multiple models (e.g., to compare a potential difference in height, texture, color)

We have revised the corresponding sentence in the manuscript to make this distinction explicit: “Quality was ensured through internal error analysis (analytical calculations to quantify the error) and manual inspection (additional qualitative check of the data and results: we manually reviewed the outputs to verify that the values were plausible, internally consistent, and consistent with the expected characteristics of the data).”

5. I suggest the authors reconsider the deglaciation monitoring section. I feel it may sit outside of the scope of the main purpose of the paper, and it is a substantial area of research in its own right. Though I think the DOMs and associated DEM data is great for this use case, it may be better suited in a separate manuscript.

The sub section aims to provide a direct example of the models applied to the glacier. It was important for us to demonstrate the diversity of applications that can be achieved with these models in this paper, both in structural geology and geomorphology.

This manuscript is part of a larger project with a focus on the 3D geometry and evolution of low-angle normal faults and their associated allochthonous blocks.

The deglaciation example highlights the potential of the models for monitoring landscape evolution through time and therefore complements the structural applications presented elsewhere in the manuscript. For this reason, we would prefer to retain this subsection, while keeping its scope deliberately limited to demonstrating the potential of the dataset rather than developing a full glaciological analysis.

In addition, following your comments, we have added several references to previous studies that used UAV-based approaches to investigate Alpine glaciers.

Detailed Comments

L1: “Fossil” - Is Fossil the right word here? I think simply removing 'Fossil' would make the title more impactful.

The term “fossil” is used here because we are studying remnants of rifted margins that are now incorporated and imbricated within an orogenic belt. In the literature, the term “fossil rifted margin” is commonly used to distinguish tectonically reworked remnants of rifted margins from present-day rifted margins, such as those along the Atlantic Ocean. We therefore prefer to retain the term “fossil”, as it provides important geological context and avoids any ambiguity with modern rifted-margin analogues.

L22-24: “Beyond tectonic implications, the high resolution ... the monitoring of deglaciation.” - This part of the abstract is not needed and is outwith the scope of this manuscript. See related comments at associated section.

We have removed this sentence from the abstract.

L33: “2024;” - Replace with “2022 ?”.

The text has been modified accordingly.

L40: “Their characterization is” - Insert “accurate”.

The text has been modified accordingly.

L44: “fossil” - Delete.

Please see our comment above at L1.

L48: “exceeding 2 500 m.” - Insert “,”.

The text has been modified accordingly.

L49: “of these sites. As a result,” - Burnham et al., (2022) discuss this. Consider adding a citation here.

The text has been modified accordingly. We added Burnham et al. (2022).

L49: “the” - Delete.

The text has been modified accordingly.

L54: "fossil" - Delete.

Please see our comment above at L1.

L55: "Fossil" - Perhaps "Ancient" is a better word?

Please see our comment above at L1.

L57: "findable, accessible, interoperable, and reusable" - This should be placed before the FAIR acronym so that it is properly defined.

The text has been modified accordingly.

L62: "unique fossil example of" - Delete.

Please see our comment above at L1.

L85: "acquisition" - I understand what you mean, but to be more precise, which is important in a paper like this, to state that the UAVs enabled imagery acquisition which facilitated photogrammetric model construction and generation of DEMs...

The text has been modified accordingly : "Extensive Unmanned Aerial Vehicle (UAV) based field surveys enabled the acquisition of high-quality images, , which subsequently facilitated the construction photogrammetric models suitable for the generation of DEMs, orthomosaics, and DOMs with centimeter- to decimeter-scale resolution."

L90: "We conducted four UAV" - The authors should consider not using 1st or 2nd person voice and write a bit more directly. perhaps something like "Four UAV flights were conducted..."

The text has been modified accordingly: Four UAV summer data acquisition campaigns were conducted during 2022-2025.

L93: "as" - Delete.

The text has been modified accordingly.

L94: "various" - Delete.

The text has been modified accordingly.

L95-96: "while manually re-focusing was done in between." - Replace with "Manual camera lens focusing was completed between each image".

The text has been modified accordingly.

L97: "while avoiding" - Replace with "to minimize".

The text has been modified accordingly.

L119: "Textures" - Describing the texture resolution and resultant number of textures for each model would be useful to readers and users.

The text has been modified accordingly. We added that ten textures (8192x8192 pixels each) were generated per model.

L122-127: "Figure 1 uses the style Caption. The abbreviation ... the colour schemes accordingly." - Please remove the author guidelines text from the manuscript.

We have deleted this paragraph.

L138: "the model 11 integrated from Betlem et al., (2023a)" - The authors should consider describing this model (and all others throughout the manuscript), at least by name, would be more beneficial to readers.

See the response in the General Comments. Locally, location names have been added to aid the context in the Results part.

L143: "the total" - Delete.

The text has been modified accordingly.

L159-160: "5 to 15.4 cm/pixel" - The sentence structure makes it sounds like you determined the DOM pixel resolution the same as orthomosaic resolution - but I do not see that in Table 4. I can understand the orthomosaic and DEMs having a resolution as you describe, but DOM resolution, as the authors know, is difficult to quantify because they can vary depending on triangle number and coverage. Correct the sentence structure if this is a typo, or if the authors did determine DOM pixel size, a description of how this was achieved would be useful.

The text has been modified accordingly: "Processing of the dense cloud enabled the generation of DOMs, of which the derived orthomosaics had a ground resolution ranging from 5 to 15.4 cm/pixel and DEMs a resolution ranging from 10 to 30.9 cm/pix (Table 4)."

L169: "Figure 3:" - I really like the colourmap choice on this plot. Linear and perceptually uniform colourmaps are a more accurate representation of the data and it is color vision deficiency safe!

Thank you very much for your comment. Good to see this explicit choice noticed!

L173: "elevation values ranging from 2 680 m to 3 250 m," - The authors should consider adding the contour interval value to clarify what the difference between successive contour lines are.

We added this information in the caption: (contour lines spaced at 250 m intervals)

L175: "Processing of the datasets" - Swapping the noun and verb here would make it more succinct and remove passive voice. Perhaps something like: Dataset Processing

The text has been modified accordingly.

L178: "Models 1, 2, 3, 10, and 12" - I think providing the names of the models instead of their number would be beneficial for users who will have that model in mind and look for the associated data. This should be completed throughout the manuscript.

See the response in the General Comments.

L193-194: "owing to how the calculation is made per horizontal square meter." - I'm not sure I understand what is being stated here. A bit more description of what you mean is needed here. Presumably, the UAV pilots focused on the geological areas of interest (outcrops) and less on the periphery. Therefore, there are more images which allows the SfM and MVS algorithms to identify more common points. Surely the pts/m² is

We clarified in the text: "Often, point density is lower in the periphery and highest in areas with geological outcrops of interest, as well as in steeply inclined areas (e.g., Figure 3), where data were acquired on steep and near-vertical outcrops. The reason for this is mostly two-fold. First, increased targeting and imaging of the areas of interest increases the point density. (and confidence) Second, point density is calculated in in a two-dimensional pts/m², points and vertices along vertical and steep sections get projected into the same square meter area used for binning, therefore exhibiting "inflated" and particularly high point densities."

L196: "average confidence" - The authors should consider defining confidence a bit more thoroughly here - confidence could mean a few things in this context.

We added in the text: "Point confidence is a measure of the reliability of the reconstructed 3D position of a point, reflecting the number and consistency of image observations from which the point was derived".

L198: "Both" - Delete.

The text has been modified accordingly.

L198: "highest density and" - Delete.

The text has been modified accordingly.

L201-202: "as also evident from the reduced point density and camera overlaps" - I recommend this be discussed in the relevant section about point density (C in the charts).

See the response provided for the comment on lines 193–194.

L206: "cm/pix" - The authors should consider using the consistent naming conventions or abbreviations. Either is fine, as long as it is consistent.

We standardized the text by using "cm" and "pixel" throughout.

L206: "low" - Consider rephrasing to use 'small' instead of low'. The word 'low' could be interpreted as elevation in this context with regards to DEM and orthomosaic.

The text has been modified accordingly.

L213: "(internal)" - Could the authors clarify what an internal error analysis is? This would help others reproduce the error analysis.

See the response in the General Comments.

L230-231: "covered from a greater distance (Figure A9), as does model 4 in the southwestern part," - The authors should consider rephrasing to clarify that 'greater distance' refers to UAV distance from outcrop. At the moment, 'covered from greater distance' does not make sense in this context.

The text has been modified accordingly: "covered with a greater UAV distance from the outcrop".

L260: "quantifiable data form tool suited" - The authors should consider rephrasing the sentence, because at the moment it is unclear what the tool is and what it is suited for?

This paragraph has been rewritten as follows: "When combined with local geoscientific datasets and field observations, the resulting quantitative data provide a valuable basis for integrated and detailed geoscientific analyses across multiple spatial scales, from the kilometer scale to the centimeter scale."

L262: "fossil" - Delete.

Please see our comment above at L1.

L273-274: "avoiding control points located in areas subject to seasonal or short-term surface changes," - Excellent! This is a key point users should be aware of.

Thank you very much for this comment.

L277-278: "with ice dynamics and retreat were also avoided, as ... georeferencing accuracies." - The authors should consider rephrasing this for clarity. Perhaps something like "Additionally, glacier-covered areas present in some models were avoided because the elevation and geometric temporal variability, as a consequence of ice dynamics (e.g., glacier retreat) can affect the overall geospatial accuracy."

The text has been modified accordingly.

L280: "display reduced reliability because" - Insert "geospatial".

The text has been modified accordingly.

L282: "likely." - Replace with "common".

The text has been modified accordingly.

L282: "xyz errors" - Is this 'xyz error' an average of the three vectors? A simple clarification sentence would be a useful addition for references to this type of error in the manuscript.

The text has been modified accordingly. We added the following explanation to clarify the rationale for introducing the control points: "The aim was to correct the meter-scale georeferencing errors in the x, y, and z directions observed when generating the initial models without control points."

L298: "our" - The authors should consider refraining from using 1st or 2nd person voice. I would suggest just using "the" here

The text has been modified accordingly.

L300: "dataset we acquired." - The authors should consider, as above, from using 1st or 2nd voice. Instead, using something like this that is a bit more direct and doesn't use passive voice "acquired dataset"

The text has been modified accordingly.

L308: "ground resolution" - In aerial surveyors and remote sensing scientists typically use Ground Sampling Distance (GSD) when referring to accuracies like this. The authors should consider using this terminology for consistency.

The text has been modified accordingly.

L308: "resolution" - Replace with "GSD".

The text has been modified accordingly.

L323: "our" - Replace with "the acquired".

L324: "our" - The authors should consider using terminology here, to reduce the use of 1st and 2nd person, to something like "FATDOM"

The text has been modified accordingly.

L336: "our" - I would encourage the authors to simply reference the DOM dataset itself in this context because it is different from the SwissALTI3D data, therefore does not require the discriminator. This also removes the 1st or 2nd person voice.

The text has been modified accordingly.

L339: "the" - Delete.

The text has been modified accordingly.

L340: "(around 0)" - The authors should consider stating what the observed error levels are.

We specified in the text : "(GCPs RMSE ranges from 0.02 to 1.47 m. The RMSE of the CPs ranges from 0.49 to 3.11 m"

L346: "variations and limitations of the datasets" - I would suggest the authors choose subsection titles with that are more direct and do not use the passive voice. Perhaps

something like "Dataset quality and limitations"

The text has been modified accordingly.

L348: "ground resolution" - Replace with "GSD".

The text has been modified accordingly.

L357-359: "In addition, the observed distortions (e.g. image ... (e.g., see model 8; Figure A8)." - The authors should consider moving information from this sentence to the sentence what discussed the Blurred areas, one sentence above.

The paragraph has been revised accordingly: "The DOMs exhibit minor gaps across the datasets as a result of a heterogeneous data coverage with typically less images near the model edges, in contrast to a higher density of images for first order geological structures (i.e., structures of interest). The observed orthomosaics blurring is related to insufficient image overlap, particularly near the edges of the model, where fewer images are available to reconstruct the same surface features (e.g., see model 5; Figure A5). Higher overlap provides more redundant observations of the same areas, thereby improving image matching and the robustness of the photogrammetric reconstruction. This may be due to manually operated UAV flights. A pre-planned mission could provide better coverage at the edges of the model if this is taken into account during the acquisition planning. However, the significant topographic variations in the study area (approximately 840 m of elevation difference within the dataset) and operational constraints prevented the acquisition of images through pre-planned autonomous missions. In addition, the observed distortions (e.g. image stretching, blurring, and erroneously textured domains), particularly observed in the periphery, correspond to extrapolated areas during the processing (e.g., see model 8; Figure A8)."

L361: "Textureless domains" - The authors should consider adding information to clarify what a textureless domain is. Presumably these are areas where insufficient texture information is available. Stating something like this is sufficient.

We have added the clarification to the text: "Textureless domains, corresponding to are areas where insufficient texture information is available, are visible along ridges and steep peaks and correspond to artefacts generated during reconstruction in Agisoft Metashape."

L365: "is small," - Insert ".".

Based on the comments provided by reviewers 1 and 2, this paragraph has changed to: "They therefore have a limited impact on the interpretation of larger-scale geological features, such as distinct lithologies (e.g. basement versus sedimentary rocks) or regional tectonic contacts (e.g. LANFs, as illustrated by model 11 in Figure 3, and Alpine thrusts, as illustrated by model 3 in Figure A3)." The correction is therefore no longer applicable.

L366: "for" - Replace with "F".

See comment above.

L369: "spatial resolution" - I assume you mean GSD here? I would suggest that the authors simply state that since it would have already been defined previously.

The text has been modified accordingly.

L385: "cliff scale" - Could a cliff not also be an outcrop? I'd suggest that the authors do not need the latter half of the sentence and simply state that the literature presents numbers DOMs were acquired in the Alps.

The text has been modified accordingly.

L389-391: "This resolution is one of several key criteria for ... and stratigraphic features." - This is true and a key point - are there references that the authors have as examples or back up the statement?

We have modified the sentence in accordance with the reference : "This resolution is one of several key criteria determining the suitability of a DOM for geological interpretation, as higher spatial resolution enables the identification and accurate measurement of small-scale geological structures such as fractures, fault planes, and stratigraphic features (Casiraghi et al., 2025)."

L400: "FAIR principles" - This indeed crucial. The authors should consider a new online platform that was built around FAIR principles specifically for DOM sharing. It has the ability to link publications, published datasets, and even compose papers/internal documents/field

guides that are linked directly to outcrops published. <https://outcrop.io/>

We were not aware that it existed, thank you for pointing it out. It is good to see the increase in open online platforms for data sharing of such key geoscientific knowledge.

L400: "(findable, accessible, interoperable, and reusable)" - Delete.

The text has been modified accordingly.

L407: "area" - Replace with "areal".

The text has been modified accordingly.

L418: "Usability of the dataset" - The authors should consider rephrasing the Section title to be a bit more direct. perhaps something like: "Dataset Utility" or similar.

Following Reviewers 1 and 2 comments, this section has been moved to the Results section with a new title: 4.5 Preliminary results from the dataset (4.5.1 3D geometry of Low-Angle Normal Faults and 4.5.2 Use in geomorphology: monitoring deglaciation).

L422-423: "Finally, the FATDOM data can also be used for other ... and mapping of Alpine structures." - The authors should consider add a few references of studies that use DOMs for glacial monitoring.

We have added the following paragraph in the glacier evolution section: "Similar approaches have also been applied to study Alpine glaciers. Rossini et al. (2018) used repeated UAV surveys and SfM photogrammetry to generate high-resolution orthomosaics and digital surface models (DSMs) of the Morteratsch Glacier (Swiss Alps), allowing them to characterize seasonal changes in glacier surface topography, morphology, and ice displacement. Groos et al. (2019) also used repeated UAV surveys of the Kanderfirn Glacier (Swiss Alps) to generate high-resolution orthophotos and DSMs, which were used to quantify changes in surface elevation, roughness, and brightness throughout the ablation season."

L425: "Our" - Delete.

Deleted.

L443-444: "Thanks to the DOMs, the internal structures of ... be visualized and investigated." - The authors should consider rephrasing this to state that DOMs facilitate visualisation and investigation instead of thanking them. Perhaps something like: "DOMs facilitated visualisation and investigation of allochthonous blocks internal structures that are composed of pre-rift sediments and basement rocks."

The text has been modified accordingly.

L444: "by" - Replace with "in".

The text has been modified accordingly.

L444: "the" - Delete.

The text has been modified accordingly.

L445: "on the virtual outcrop." - This section is not needed, it is already implied by the first part of the sentence when you use VRGS. The authors should also be mindful of consistence when using digital outcrop model or virtual outcrop model.

Thank for this comment. The text has been modified accordingly. We did a careful editing of the text to be consistent in the term used.

L449: "Our" - Replace with "The".

The text has been modified accordingly.

L449: "Our DOMs provide a" - Insert "also".

The text has been modified accordingly.

L455: "Figure 5:" - Great figure! I like how the authors have visualised and illustrated the different data collected on the DOM.

Thank you very much for this comment.

L461: "The" - Replace with "DOM".

The text has been modified accordingly.

L462: "although" - Replace with "however".

The text has been modified accordingly.

L463: "fossil analogue of rifted margin" - Replace with "rifted margin analogue".

See the response in the General Comments.

L464: "new information" - Replace with "insights".

The text has been modified accordingly.

L464: "leading" - Replace with "that lead".

The text has been modified accordingly.

L465: "of such comparison" - Delete.

The text has been modified accordingly.

L465: "It illustrates" - Delete.

The text has been modified accordingly.

L474: "imaged" - Replace with "identified".

Rifted margins have been identified for decades using geophysical data. Here, we highlight that 3D seismic data now allow them to be imaged in much greater detail.

L479: "Use in geomorphology: monitoring deglaciation" - I'm not sure this section belongs in this manuscript. Glacial monitoring with DEMs (from any source) is a large area of research that is outwith the scope of this manuscript. This type of analysis, however, could merit a separate manuscript, if the authors wish to conduct further analyses. I would therefore suggest the authors consider removing this section and associated figure.

See the response in the General Comments.

L513: "Buckley et al., 2022." - Not associated with VRGS

The text has been modified accordingly.

L616-618: "Burnham, B., Bond, C., Flaig, P., Van Der Kolk, D., ... 2024." - Delete.

The text has been modified accordingly.

Figure 3. The authors should consider adding a label to the top right of each chart to quickly highlight what the chart is showing. This would allow users to quickly identify what the chart they are looking at, or looking for, is showing. I suggest this is added to similar and relevant supplementary figures. i.e., 'overlap', 'orthomosaic', 'point density', 'confidence' etc..

The figure has been modified accordingly.