Author comment – General note

We sincerely thank both reviewers for their constructive feedback and the time they invested in evaluating our manuscript. We appreciate the recognition of improvements in various sections and have carefully considered all remaining concerns.

In the previous review round, both reviewers explicitly requested a more detailed and transparent description of the technical workflow. In response, we expanded the methods section, particularly regarding the integration of the GIRAFFE tool, to ensure reproducibility. Given Melanie Elias's central role in developing this core component, and the interdisciplinary nature of the work, the shared first authorship reflects this substantial contribution. GIRAFFE has now been made openly accessible via GitHub.

We want to assure the reviewers and editors that the revision was carried out with care and deliberation. Beyond the manuscript text, significant effort was also invested in preparing the public release of the tool to ensure usability for the wider research community. However, we acknowledge that this led to a considerable increase in manuscript length. In this revised version, we have therefore substantially shortened and restructured key sections, particularly the methods, to improve readability while retaining necessary technical details.

With regard to the validation section (now 4.2.3), which raised concerns from both reviewers, we have fully rewritten the text and revised the corresponding figure (now Figure 7) and table. The revised version more clearly explains the validation process—comparing the outputs of our method to independent GNSS and total station measurements—and we have added clearer captions, annotations, and definitions to improve readability.

Finally, we respectfully note the concern raised about the manuscript's interdisciplinary character and perceived lack of clear leadership. We believe that the collaborative nature of this work—spanning geoscience, photogrammetry, and computer vision—is a key strength. The revised version strives to better integrate these domains into a coherent narrative.

We hope these revisions address the reviewers' core concerns and improve the clarity and impact of the manuscript.

Hanne Hendrickx

Melanie Elias

On behalf of all co-authors

Answer to Reviewer 1

Line 117: m d^{-1} was marked

I assume you wanted to point out that we used m a^{-1} before. In order to be consistent, m a^{-1} was used, and since the great speed, m d^{-1} was used within brackets.

Line 135: '…UAV parallel-axis, nadir image flights…' → Nadir image flights was inserted.

Table 1: Please, add also a rough estimation of the image GSD (a range of number as for the distance is fine or give the value for a particular point). I believe that this is useful for the readel and more convinent than computing it from d, f, ps.

We added the image GSD in table 1 as a range, corresponding with the range given for distance to the landform of interest.

Table 2: This table is not really intuitive at first sight, beause:

- In the caption you first talk about Wcam4 and then Wcam5, but the order of the cameras is the opposite in the table.

This has been adapted

- The structure is not repetitive (there is the summary row only for WCam05, but not for the other), and the use of bold font is somehow misleading.

This has been adapted

- There is a lot of white space (e,g., becasue of the dates column) that can be easily reduced.

This has been adapted

The table is much reduced in size and some redundant information has been removed for clarity.

Figure 6: The 3D plot is actually hard to read (the lines appear to be similar, but without a perspective view it can be measleading). May be possible to plot the 3D components in different 2D graphs? note: I saw that there is the graph of the absolute velocities in Fig 7 and it is probably enought. Nevertheless, I'm not fully conviced by this 3D plot.

Indeed, a 3D plot can be difficult to interpret without the ability to rotate it. We have therefore followed your suggestion and split the figure, presenting the 3D plot as its 2D components (i.e. the XY, the XZ and XY planes). This is now shown in Fig. 7. The absolute velocities are still available and are now presented in Fig. 8. Figure 6 has been adjusted to show only the validation principle.

Answer to Reviewer 2

General Comments.

The authors made major changes to the manuscript with the visible aim of addressing my comments from the last review. In some parts this led to significant improvements. However, it also led to an unreasonable growth of the manuscript and even worse to new obscurities in the new sections. Especially the eagerly awaited section 4.2.3on the validation with ground truth data is very confusing and incomprehensible. I can’t even say if a real comparison to the ground truth data was carried out. Obvious errors in the figures worsen the problem.

The manuscript needs significant shortening and restructuring. Hereby, especially the new content has to be better aligned in the paper story. This is a case study about the application of a combination of methods. This type of study is not appropriate to newly introduce a technical algorithm in all of its detail which only represents a part of this method chain! This has to be done in a separate publication. The Validation part has to be presented in a comprehensible clear way, explaining **precisely and unambiguously** what has been done. Also, the figures need more explanation and definition of abbreviations.

The manuscript has been revised in a rush. The necessary major changes haven't been addressed and incorporated with the required carefulness. My feeling is that the newly shared first-authorship led the manuscript without a clear leadership. All that unnecessarily complicates and prolongs the review process. I do not want to review the manuscript again, but before the next round, the above mentioned issues must be seriously addressed. Show the manuscript to some colleagues before you submit it again.

We thank the reviewer for taking the time to re-evaluate our manuscript and acknowledge the points raised in their latest review. We appreciate the recognition of improvements made in several parts of the manuscript and are grateful for the critical assessment. Nevertheless, we would like to respectfully clarify and respond to some of the concerns expressed.

In the previous review round, both reviewers explicitly emphasized the need for a more detailed description of the technical workflow used in our method. In response, we elaborated on this part of the manuscript, aiming to provide the required transparency and reproducibility. The shared first authorship reflects the interdisciplinary nature of the work and recognizes the substantial contribution of Melanie Elias, who developed the tool forming a central part of the method. This contribution, both intellectual and technical, justified a more prominent integration of the algorithm, particularly since it is now made openly available via GitHub.

We can assure the reviewer that the revision was not carried out in haste. On the contrary, considerable care was taken not only in revising the text, but also in preparing the public release of the tool, ensuring accessibility and usability for the broader research community. Nevertheless, we agree that the manuscript had grown in size and that parts of it may have become overly detailed. In the revised version, we have therefore significantly shortened and restructured the relevant sections. We worked to strike a careful balance—retaining the technical clarity needed for reproducibility, without overwhelming the narrative of the case study.

With regard to the validation section (4.2.3), we acknowledge the reviewer's concern and have thoroughly revised both the text and accompanying figures and table to improve clarity. The validation was indeed carried out through a direct comparison between the tracked points from our method and independent ground truth data (GNSS and Total Station measurements). This is now explained more clearly and transparently, and figure legends have been expanded with clearer annotation and definitions of abbreviations.

We respectfully disagree with the reviewer's statement about a "lack of clear leadership" in the manuscript. The interdisciplinary and collaborative nature of this work is intentional and reflects the merging of geoscientific, photogrammetric, and computational perspectives. While this naturally results in a multifaceted manuscript, we view this diversity as a strength rather than a flaw. We remain confident that the revised version demonstrates a coherent integration of the involved domains.

Finally, while we regret the reviewer's decision not to engage in a further review, we also respectfully note that such strong criticism—particularly regarding the structure and leadership of the manuscript—deserves careful and well-substantiated argumentation. We hope the revised version addresses the core concerns and will satisfy the editorial board and other reviewers.

Some Detailed Comments

Line 35/36: Still quite vague. It is unclear to which type of landside you are referring to. Creep is a process which preferentially occurs in fine grained soils (in alpine terrain e.g. solifluction) or ice oversaturated debris (= Rock glaciers). Below a descriptive definition (There are much stricter physical definitions!) Does this apply to the landslide you present in your paper? Give a reference for your statement!

Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. There are generally three types of creep: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure as other types of mass movements. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges.

We appreciate the reviewer's comment and agree that the original phrasing was too vague. Our intention was to refer specifically to permafrost warming as a process influencing both rock glaciers and certain types of rock slope failures, but we recognize that the sentence lacked the necessary specificity and could be misleading.

To clarify, we use the definitions established by the RGIK (Rock Glacier Inventory and Kinematics) action group, which was partly founded to standardize terminology in this field. Specifically, we refer to permafrost creep rather than creep in the narrower, classical geotechnical sense. The RGIK (2023) guidelines define this as follows:

"Rock glaciers are debris landforms generated by a former or current creep of frozen ground (permafrost)*, detectable in the landscape with the following morphologies: front, lateral margins and optionally ridge-and-furrow surface topography.

- Rock glacier (or permafrost) creep has to be understood here as a generic term referring to the variable combination of both internal deformation within the crystalline structure of the frozen ground (creep stricto sensu) and shearing in one or several discrete layers at depth."

In our study area, both the rock glacier and the observed landslide are driven by permafrost creep in this broader sense. However, the landslide is not classified as a rock glacier due to the absence of rock glacier-specific surface morphologies, as outlined in the RGIK definition.

We also acknowledge that the sentence, "The same is true for certain types of landslides, where the primary driver of motion is permafrost creep", remained too generic. We have therefore revised this section to provide greater specificity regarding the type of landslide process we refer to:

"They efficiently transport sediment (Delaloye et al., 2010; Kummert and Delaloye, 2018), and this becomes more pronounced as rock glacier creep rates increase in a warming climate (Delaloye et al., 2013; Pellet et al., 2023). **Similarly, large volumes of sediment can be mobilised by permafrost-affected rock slope failures, such as deep-seated slides, topples, or deformations that involve in situ bedrock (McColl and Draebing, 2019)."**

We hope this revision better reflects the nature of the process, avoids terminological confusion around "creep", and sufficiently addresses the reviewer's request for clarity and specificity regarding landslide type and driving mechanisms.

Line 104: Consider splitting site and dataset description into two individual sections or even shift the dataset part into methods. Especially the UAV part includes a lot of method description.

We followed your suggestion to split the site and dataset descriptions into two separate sections. The UAV part was substantially shortened but retained under the dataset description, as we do not find it appropriate to include it under Methods, where we aim to focus specifically on the workflow for deriving velocity data from time-lapse imagery.

Line 111/112: Refers to the first comment: I would suggest deleting these lines. Obviously, you do not have clear evidence for the type of movement and concluding from increased surface velocities on the process type is not a valid approach. There can be plenty of reasons for higher displacement velocities. The most common reason is a higher permeability and water infiltrations. Moreover, creep of 1.5m per year is hardly compatible with your previous statement that the landside consists of fractured in-situ bedrock. In the end, this is no ta deciding information for your paper.

We agree with your comment and have removed the respective lines from the manuscript. This information was originally included following a request in the first round of reviews; however, as the site is still under active investigation and many aspects of the movement remain uncertain, we now recognize that it is premature to speculate on the driving mechanisms. We fully agree that such interpretations are better suited to a dedicated geomorphic analysis once more comprehensive data are available.

L167:"Our workflow requires minimal input data." Phrase! Please delete. In total there is a lot of data involved, you just described in in the section above (e.g. pointclouds).

Agreed that this is subjective and this has been deleted.

L206: This entire section (GIRAFFE)is VERY long, often hard to follow and contains a lot of detailed descriptions with little relevance for the actual study. Please shorten it! Give references instead of explaining every small detail. I guess GIRAFFE is published somewhere else already? Anyway, such a case study is not the place to introduce such an algorithm in that overwhelming detail. If still necessary consider to split it into subparagraphs

We thank you for this feedback and understand the concern regarding the level of technical detail. In the revised manuscript, we have shortened the GIRAFFE section and structured it into subparagraphs to improve readability. While GIRAFFE in its current form is not yet formally published, it has been described in previous works (Elias et al., 2019; Elias & Maas, 2022; Elias et al., 2023).

The more detailed explanation of the 2D-to-3D geometry registration was included in response to specific requests from both reviewers during the previous revision round. We recognize the challenge of balancing transparency with conciseness and acknowledge that this section may have become too dense as a result. We have now aimed to strike a better balance by focusing on the most relevant components of the workflow for this case study, and referring readers to the GitHub repository for further technical details.

We hope the revised section is now more appropriate in scope and presentation for this type of study.

L323-327: As you conclude by yourself: This is not the scope of you study, so delete it.

We did not delete it but decided to rewrite it: 'Our developed method provides a framework for such future research, enabling the analysis needed to address these open questions.' This section has also been moved from 'Results' to 'Discussion'.

L376*4.2.3 Validation with ground truth data:* I was very curious to see the results here but unfortunately I did not understood what you have done! I showed this section to some of my colleagues, but they did not understand it either. It is obviously very unclear what you did here! You fitted lines through trajectories. Only the figure reveals, through the trajectories of which dataset this was done. Then you compared points to the lines!? Which points? To which lines? And how in the end did you compared the GNSS to the feature tracking results? Have you even done that or do you compare the datapoints of one method to their own linear fit? (What would be really odd)I couldn't figure out what kind of values table 2 is actually showing. SD=standard deviation?? DIFFXYZ of what? This must all be completely rewritten. In the end we need a comparison of displacement rates and direction of both methods for a given time period.

We appreciate your detailed feedback on this section and understand the confusion regarding the validation procedure. Based on your comments, we have now completely rewritten Section 4.2.3 to clarify the steps taken and improve the flow of information. We have also revised the associated figures and captioning to better guide the reader through the comparison process.

To clarify:

- We first observed that the trajectories derived from ground truth data (GNSS or total station) show a clear linear trend over time, as illustrated in the updated Figure 7 (previously Figure 6).
- For each corresponding point tracked using the PIPs++/GIRAFFE workflow, we expect the trajectory to also follow a linear path, assuming consistent motion and limited deformation.
- However, the reconstructed trajectories show some deviation ('jumps') between time steps (clearly visible in Figure 7). We interpret these deviations as error introduced by our image-based workflow.
- To assess whether this error is random or systematic, we fitted a linear trajectory to the PIPs++/GIRAFFE point data and compared the residuals to that linear fit. This step was

indeed comparing the data to their own fitted line—not as a final validation, but to assess the nature of the internal noise. This clarified that the scatter is mostly random.

- For the actual validation, we compared the linear fits of the GIRAFFE-derived trajectories against those from the ground truth data. We did this by analyzing vector distances (i.e., displacement and direction) between the two line fits over the same time interval. These differences were mostly within a few decimeters and are presented in Table 2.
- In summary, while individual measurements can be noisy, the average direction (Figure 7 and Table 2) and magnitude of displacement (Figure 8) over several time steps aligns closely with the ground truth. We now also clarify that "SD" in Table 2 refers to standard deviation, and "DIFFXYZ" describes the Euclidean distance between the two linear trajectory vectors in 3D space.

We hope that this rewritten section, along with the improved figure annotations and terminology clarification, now conveys the validation steps in a more transparent and comprehensible way.

Figure 7: Also here it is very unclear what you are showing in the charts. The Figure caption does not match the figure: "*Validation points, marked in red…" There are no red points in the chart!? Why is there two times a validation curve?*

Thank you for pointing out the inconsistencies between the figure and its caption. We have revised both the figure and the caption to ensure they are clearer and fully coherent with the rest of the manuscript, particularly with Figure 7 (before Figure 6).

The revised caption now begins with a concise description of what is shown: *"Figure 8: Graphs showing weekly velocities and cumulative distances of tracked points measured using the PIPs++/GIRAFFE workflow, including validation against ground truth data."*

To clarify the visual elements:

- **Ground truth data** (GNSS for Webcam 4 and a total station point for Webcam 5) are displayed as **solid blue lines**, consistent with Figure 7.
- The **same points**, tracked using the PIPs++/GIRAFFE workflow, are displayed as **solid orange lines**.
- **Orange dots** represent the average of all tracked points (not just the validation point), derived from the PIPs++/GIRAFFE workflow.
- **Grey dots** represent the cumulative distance averaged over all tracked points from the PIPs++/GIRAFFE workflow.

We retained the broader set of tracked points (not just the validation ones) to highlight spatial heterogeneity in landform motion. For example, the fixed GNSS point shows a distinct velocity peak not reflected in the landform average. This difference underscores how single-point ground truth measurements may not capture complex or localized dynamics, as discussed in the revised Discussion section:

"Spatial heterogeneity of landform movement is evident, including instances where larger boulders move faster, seemingly 'surfing' on the main landslide body. This phenomenon, illustrated in Figure 8, is supported by in-situ GNSS data, which indicates faster movement compared to the overall

landform. [...] The movement seems restricted to large boulders, possibly pointing to a gravitational origin due to the steep terrain."

We hope this revised figure and explanation now clearly communicate the rationale and layout of the validation plot.

I stop the detailed commenting here, since there are too much general problems with the manuscript.

We regret that you have chosen to pause your detailed review at this point. Without more specific feedback on the "general problems" you mention, it is difficult for us to address any concerns you might still have. We hope the revised version addresses the core concerns and will satisfy the editorial board and other reviewers.