

Response to comments by first reviewer

Dr. Jan Henrik Blöthe

We sincerely thank Dr. Jan Henrik Blöthe for the thoughtful comments and constructive suggestions, which have greatly contributed to improving the clarity and overall quality of our manuscript. Below, we provide a point-by-point response to each comment.

General comments

GC-1. In the introduction and the formulation of the aim of the study, the authors focus entirely on the rock glaciers and their surface kinematics. The justification of the study is well written and the work is a valuable contribution to the high-Andean permafrost research. That being said, the inclusion of landslides and other “gravitational slope movements” into the analysis introduces confusion and shifts the attention of the reader away from the subject of the manuscript. In my view, focusing the content and interpretation to the rock glaciers and summarizing different movements detected by the approach applied here as “other”, or “non-rock glacier” would not only increase the clarity of the work, but also make the work more in line with the aim formulated at the beginning as well as the community addressed here. The alternative would be to include a larger paragraph on landslide processes in the region in the introduction, addressing different types of landslides found and discussing their mechanisms of movement.

Response > We agree with the reviewer when he asks for the inclusion of landslides and other “gravitational slope movements” in the introduction section. However, as the entire paper is focused on rock glacier surface displacements and velocities, we believe that introducing landslides and other landforms will introduce more confusion. In fact, landslides and other landforms have not been really exploited and discussed because it was not the focus of the paper. In this sense, we added a paragraphs in the discussion section to justify our choice. Now you can read:

[...] Although the objective of our study is the monitoring of rock glaciers on a regional scale, other PMAs corresponding to mass movements such as landslides could also be identified. Our results suggest possible correlations between gravitational movements in high mountain areas (e.g. Haeberli et al., 2017; Patton et al., 2019) and permafrost degradation (i.e. freeze, thaw of permafrost) in recent deglaciated areas (Pánek et al., 2022). This study allows us to complete those existing mass movement inventories in the region (e.g. Iribarren Anaconda et al., 2015), highlighting areas for further research. While [...]

GC-2. I am very glad to see that the authors go beyond the idea of calculating mean velocities for rock glaciers. Despite the wide use of mean values for entire landforms, the very heterogeneous velocity distribution found in rock glaciers makes this very difficult. In my opinion, the authors propose a suitable metric in their analysis. However, in order to make their approach comprehensible and reproducible, a consistency of terminology is very important:

○ In L335-336, the authors propose to use the “Top 50% fastest pixels within each PMA” as this metric (“top 50%” and “fastest” are redundant here). I would recommend to either elaborate this more clearly in the text, or, preferably, include a small figure of one of the rock glaciers, illustrating what the idea behind this approach is. If I am not mistaken, the authors suggest calculating the mean of all velocity values between median and maximum, i.e. the upper 50% of the data distribution. If I am not mistaken, this metric is a “spatial mean”, as opposed to the “average velocities” computed over different temporal intervals. Especially for the text in the sections 5.3 and 6.3 it is imperative to have an unambiguous terminology throughout.

Response > This is in fact one problem we faced for computing average velocities per landform. The idea behind Top 50% average velocity is to remove the effect of the borders and keep the fastest area based on the 24-year surface velocity map. The aim of this methodology is to reduce the ambiguity behind manual selection of the most active areas. That being said, we checked the consistency of the term ‘Top% average velocity’ throughout the manuscript specially when ‘average’ and ‘mean’ velocities are computed.

Regarding the suggestion of adding a new figure, we indeed added a new figure on the supplementary material (Figure S15). This figure is attached below. The reason behind it, is because the second reviewer asks for a specific section showing more in detail the computed uncertainties. So, we prefer to add a new table as well as a new figure (now Figure 8) showing the temporal evolution of the uncertainties.

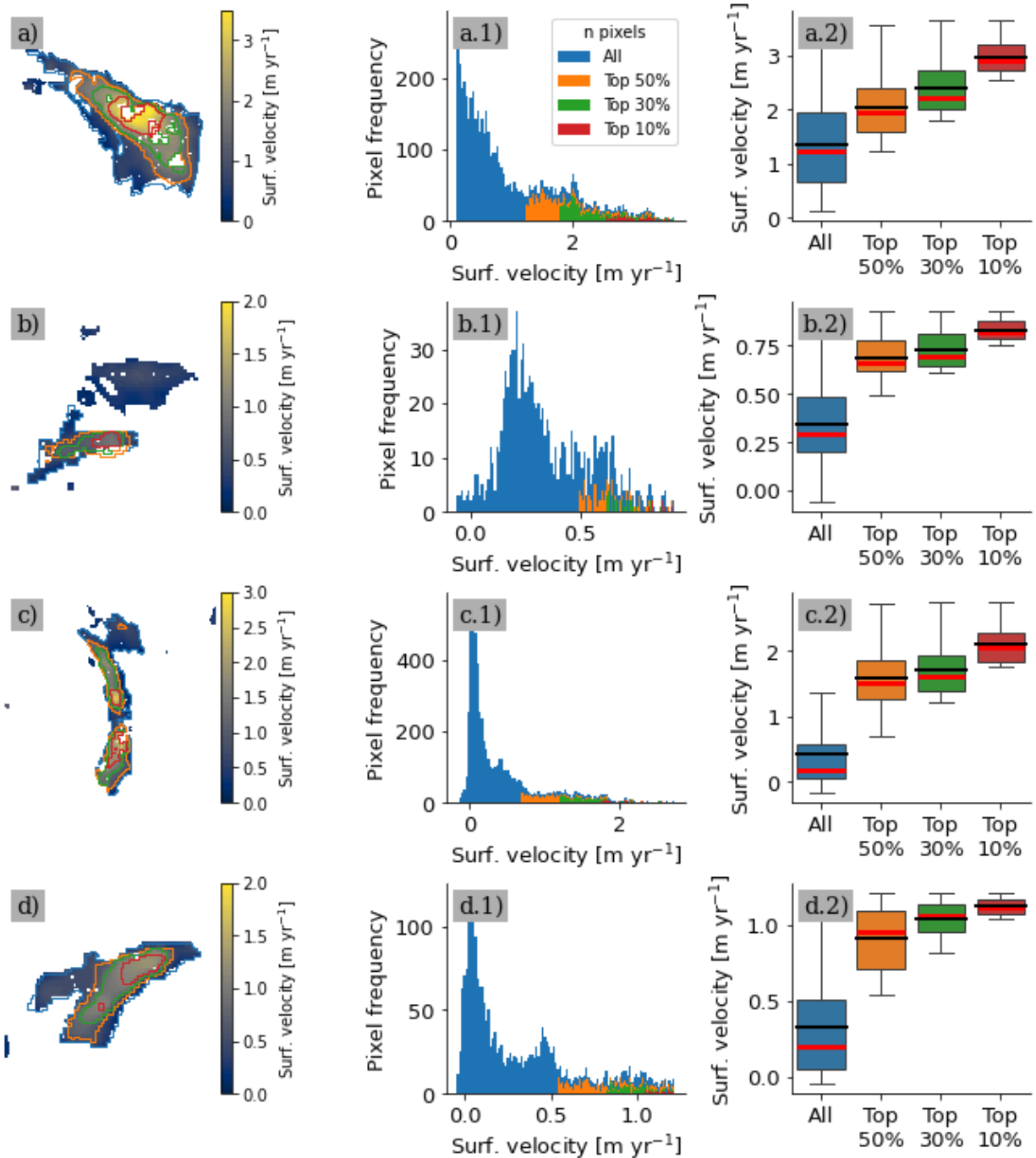


Figure S15. Representativity of spatial average statistics for four landforms: (a) Olivares debris ice complex, (b) Tapado complex, (c) Largo rock glacier, and (d) Dos Lenguas rock glacier. Subplots labeled with a suffix *.1 illustrate the pixel distribution for each metric used in this study: All (blue), Top 50% (orange), Top 30% (green), and Top 10% (red) average velocity. Subplots with a suffix *.2 display boxplots representing surface velocity for each landform, showing the variability and representativity of the computed metrics. Red and black lines in the boxplot represent the median and mean values respectively.

GC-3. To allow the interested reader to follow the processing steps, and ultimately to allow the community to make use of the workflow, the processing chain outlined mainly in sections 4.1 and 4.2 should be explained in a bit more detail (also see specific comments on that sections below).

Response > We agree with the reviewer's observation. However, as the methodologies for time series inversion (Bontemps et al., 2018) and automatic PMA extraction (Stumpf et al., 2017) are already thoroughly detailed in dedicated papers, we have opted to retain only the essential aspects relevant to this study. Since the focus of this paper lies primarily on the methodological advancements applied to rock glaciers, we prioritize discussing key elements such as the comparison with very high-resolution datasets and the associated uncertainties, which are crucial for the interpretation and validation of our results.

Specific comments

SC-1. L14-15: This statement is a bit vague, as neither "long-term" nor "high-resolution" are clearly defined. Can you be more specific here?

Response > We modified the sentence to be more specific. Now you can read:

*[...] However, representing **decadal regional spatio-temporal velocity patterns** remains challenging due to **the limited number of high-resolution (< 5m) remote sensing data**. [...]*

SC-2. L18-19: From a geomorphic perspective, gravitational slope movement would not entail rock glaciers that are bound to the presence of permafrost.

Response > From a geomorphic perspective, we agree that gravitational slope movements encompass a wide range of processes. However, rock glaciers are distinct geomorphic features specifically associated with permafrost and frozen ground dynamics. Their morphology, internal structure, and movement patterns are directly influenced by the presence of ice within the subsurface, which differentiates them from other gravitational processes not tied to permafrost. Now you can read:

*[...] This methodology enables the detection and quantification of surface kinematics of 382 gravitational slope **mass** movements (153 corresponding to rock glaciers) [...]*

SC-3. L74: It could be stated a bit more clearly here, what "the current warming context" refers to. Also for the specific study area, rising air temperatures have been documented, as the authors describe later.

Response > We modify the sentence to be more clear. Now you can read:

*[...] Given the **observed current warming context of mountain permafrost (Noetzli et al., 2019)** [...]*

SC-4. L81-82: And for short observation periods, or high temporal resolution of SAR imagery.

SC-5. L83-84: As the Landsat 7/8 data used in the present study spans the same time interval, I don't think this statement adds to the justification here. As you are making this argument later on, why not focus this statement on freely available SAR imagery?

Response > Here we answer both previous comments. We modify the sentence to be more clear. Now you can read:

*[...] However, even if this technique is well suited for rock glacier mapping (Barboux et al., 2014) satellite radar interferometry is **most suitable** for relatively slow rock glacier speeds of **approximately** $1\text{--}1.5\text{ m a}^{-1}$ **observed over short periods (6, 12 days)**. Beyond this threshold, InSAR signals become geometrically decorrelated and thus uninterpretable (Villarroel et al., 2018). In addition, **freely** SAR data with high temporal **resolution has only been** available since the early 21st-century (Strozzi et al., 2020). [...]*

SC-6. L95: As the authors are citing our work (Blöthe et al. 2021) later anyway, it deserves to be mentioned here as well, given its spatial focus.

Response > We added the citation corresponding to Blöthe et al., 2021 as well as more recent studies from Kääb and Røste, (2024). Now you can read:

*[...] some isolated regions in the Andes i.e. Tapado rock glacier (Vivero et al., 2021; **Blöthe et al., 2021**), in northern Tien Shan (Kääb et al., 2021) **and more recently in the United States (Kääb and Røste, 2024)**. [...]*

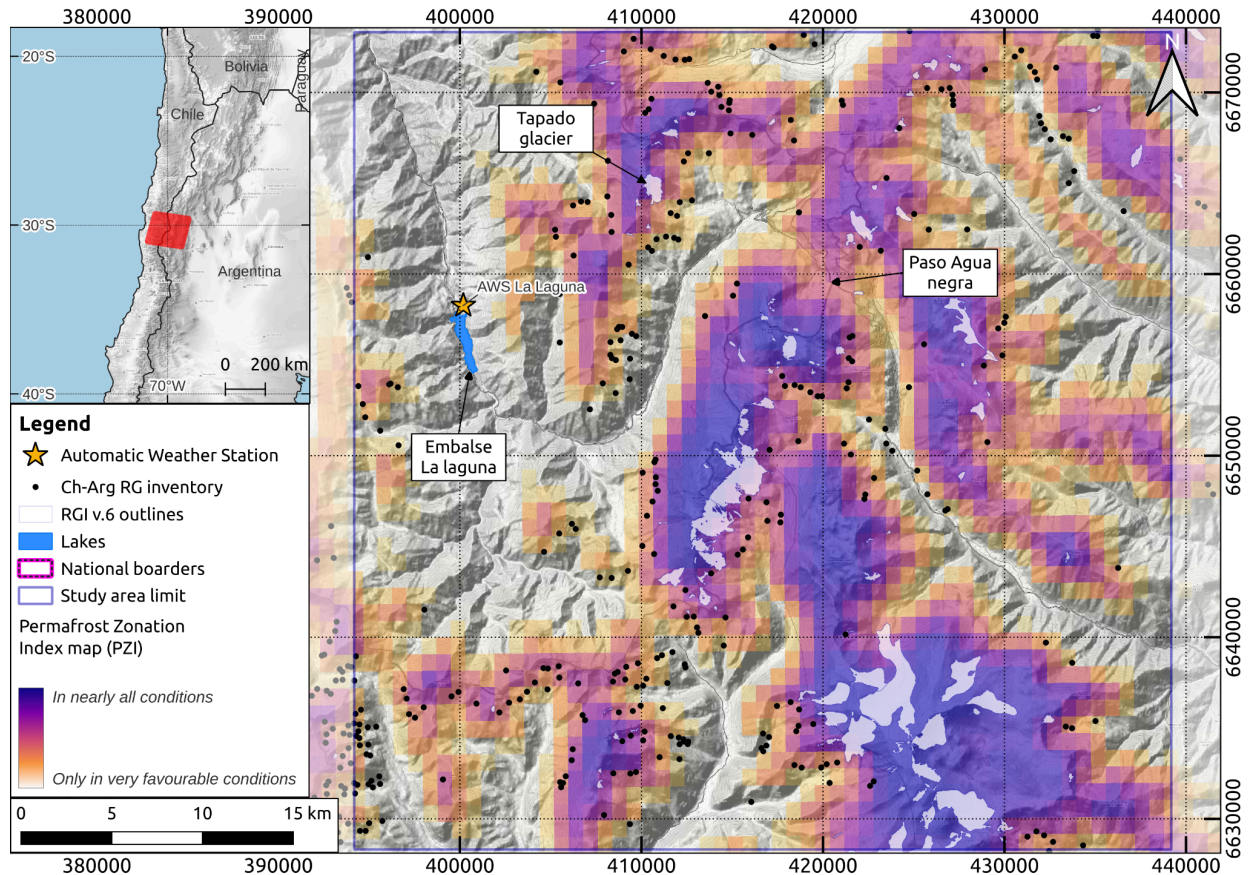
SC-7. L102-104: If it is really the aim of the study to investigate rock glacier velocities “for the late 20th century”, imagery from 2000 to 2024 maybe wasn't the best choice :-)

Response > We clarified the text. Now you can read:

*[...] rock glacier displacements and velocity for the **early 21th** century in a region [...]*

SC-8. L122: Are these weather stations located in the study area? If so, please include their locations in Figure 1.

Response > We included the Automatic Weather Station (AWS) used in this study in Figure 1. Now the figure look as follow:



SC-9. L139-141: I am being a bit picky here, but our study investigates velocities between 2010 and 2017/18.

Response > Thanks for pointing that out. We corrected the text accordingly.

SC-10. Figure 1 / L148-152: As the map shows the Gruber 2012 model of permafrost distribution, I suggest the authors also use the terminology of Gruber in the legend presented here or explain how this was adopted.

Response > We changed the legend and adopted the original from Gruber, 2012. Figure 1 has been updated accordingly. Please refer to the response of the specific comment SC-8 to look at the updated figure.

SC-11. L159-162: It is somewhat confusing at this point... maybe first mention that for all analysis you were relying on the panchromatic band, before describing the ETM+ data gap.

Response > We modified the paragraph to be more clear. Now you can read:

[...] We used only the L7/8 panchromatic band (B8) with the highest spatial resolution (15 m). However, due to the Scan Line Corrector failure on the Landsat-7 satellite between 2004 and 2013 (Markham et al., 2004), we excluded Landsat-7 scenes within this period to avoid data gaps. [...]

SC-12. L191-192: The “landslide” and “other” classes as not necessarily periglacial processes.

Response > We modified the paragraph to be more clear. Now you can read:

*[...] Due to the limited spatial extent of the VHR dataset, **we used raw Sentinel-1 wrapped interferograms for validate L7/8 surface displacement products (cf. Section 4.1) as well as for classifying the inventory of gravitational mass movements including rock glaciers and landslides (cf. Section 4.3).*** [...]

SC-13. L222-223: Please elaborate this processing step in a bit more detail. At this point, it remains unclear why and how exactly the DEM was used to identify the PMAs.

Response > All the details are described in “Section 4.2”. We made the link with the corresponding section. Additionally, we add some clarifications in Section 4.2 to be more clear how we use the DEM to extract PMAs. Now you can read:

*[...] Then, a medium-resolution DEM was used to identify **Persistent Moving Areas (PMAs) along the slope direction** within the study region (Section 4.2).* [...]

SC-14. L237-240: Can you explain in a sentence how the “per-alignment strategy” applied here works? Also, it is not clear to me what “for the small ones” refers to.

Response > We added a sentence regarding the pre-alignment strategy. We removed the words “for the small ones” as they were not useful for the text. Now you can read:

*[...] pre-alignment strategy (i.e. **automatic identification of image features matched in a pair of images used then as tie-points**) before the feature tracking stage. Both softwares presents an adaptive windows matching strategy corresponding to 3x3 for MicMac and 7x7 for ASP as **the smallest window size.*** [...]

SC-15. L245-246: I am not sure if I understand this processing step. What exactly does “median surface displacement” refer to? Are the authors subtracting the residual mismatches from the total displacement here, or does this refer to the results of the pre-alignment strategy?

Response > Even if pre-alignment strategy was used to minimize georeferencing errors, when computing surface displacements over a whole region, the expected value of displacements on stable areas is often not zero (mainly due to the subpixel correlation and changes on the illumination). So, in order to correct this systematic bias, we center EW and NS displacement maps by compute median value over the entire correlation scene, and subtracting to all pixels. Now you can read:

*[...] displacement maps for all dates. **Median value was computed over the entire EW and NS products computing each one for their specific dates.*** [...]

SC-16. L247-248: In a nutshell, what processing step was done here?

Response > We added a brief explanation about how to minimize the striping effect. Now you can read:

*[...] For the L7/8 dataset, striping effects **from sensor inter-band misalignments (Ayoub et al., 2008; Leprince et al., 2008) were mitigated by subtracting the median value of the stacked profile in the along-stripe direction, considering only stable areas (cf. Section 4.3).***

SC-17. L255-256: I would suggest filling the bracket with the relevant processes here that might operate in your study area. A shifting river reach would also pass the “constant direction” test applied here but is not driven by gravity.

Response > We clarify the sentence by removing the three points within the brackets and by adding the example of shifting rivers. Now you can read:

[...] for motions driven by gravity (rock glaciers, landslides) or other erosive processes (i.e. shifting rivers, river banks erosion) [...]

SC-18. L264: Please explain in a bit more detail how the definition of “moving areas” (I assume this refers to PMA here?) is done. I reckon this is done for the entire time span and based on the cumulative surface displacement? How was a lower threshold applied in this to discern moving and non-moving areas?

Response > Indeed, we refer to PMA rather than moving areas. We added a sentence in the same section to clarify this purpose. Regarding the threshold of surface displacement, no threshold was used. Now you can read:

[...] The time series of cumulative surface displacements from L7/8 images are then used to automatically extract PMAs. The PMA are a group of connected pixels having a coherent movement in time and following the downslope direction, as this is expected [...]

SC-19. L273: Maybe quickly explain what processes are subsumed under “landslides” and “other”. Based on high resolution imagery presented in GoogleEarth, it would be interesting for the reader to know which processes were identified.

Response > We added a clarification about the expected geomorphological sign for each class. Now you can read:

[...] For instance, landslide class was assigned when cracks and scarps were present at the surface and rock glacier class, when typical morphology i.e. front and lateral margins with ridge-and-furrow surface topography was observed. When no clear interpretation about the movement and the geomorphology interpretation could be assessed on either InSAR or Google-Earth basemaps, [...]

SC-20. Table 1 / L295-296: It would be very good to extend this table and add columns that list the number of features that remain after the additional processing steps (i.e. the surface threshold). In the current form, the data presented in L298-320 is a bit confusing, as the numbers mentioned there are not appearing in the Table 1. Furthermore, column one does not extend to the last row, suggesting that “other” is not representing valid data?

Response > We expanded the table by adding simple PMA statistics, above the surface threshold (2250 m² - 10 pixels) for each binary class as well as each geomorphological class. In addition, we clarify the paragraph after the table regarding the manual and automatic characterisation. Now you can read:

TOTAL POLYGONS	Manual characterization		Above automatic surface threshold (2250 m ² - 10 pixels)	
	n	%	n	%

Corroborated class	Geomorph class	1710	100	975	100
NOT CONFIRMED by InSAR	Sub total	1209	71	593	61
	Other	747	62	382	64
	valley bottom	159	13	77	13
	ridges	155	13	79	13
	landslide	17	1	14	2
	rock glacier	15	1	5	1
	glaciers	116	10	77	13
CONFIRMED by InSAR	Sub total	501	29	382	39
	rock glacier	211	42	153	40
	Landslide	160	32	105	27
	Other	130	26	124	32

[...] During the manual characterization process, we have noticed the presence of an important number of small and isolated polygons within the ‘not confirmed’ class (Fig. 4), often located close to the mountain ridges and at the valley bottom (Fig. S3). As these tiny polygons cannot be correctly interpreted, we set up a surface threshold of 2250 m² (i.e. 10 pixels), to remove them automatically. [...]

SC-21. L304-306: These numbers for example are not contained in Table 1. Also, the class “deglaciated” is not mentioned there.

SC-22. L307-308: I recommend rephrasing this sentence to increase the clarity of what the “automatic surface threshold” is and how this translates into the PMA statistics? It refers to the 10 pixel threshold, right? But how is this automatic? And what does “the most smaller” refer to?

Response > Here we answer specific comments 21 and 22. We change the glaciated or deglaciated class by ‘glacier’ to avoid confusion. We check the consistency through the manuscript. In addition, we modify the paragraph to clarify the use of the automatic filter. Now you can read:

[...] The selected surface threshold seems to be a good compromise to remove noisy (smaller) PMA and keep coherent (larger) PMAs, by only compromising 15% of confirmed PMA (Fig. 4). After the surface threshold is applied and PMA corresponding to glacier class were removed, the remaining filtered dataset [...]

SC-23. Figure 4 / L322-325: Maybe show removed PMAs in light colours? In the caption, mention the threshold specifically, instead of “at left of”.

Response > We think that the black line fits well within the graph. However, we precise the caption with reviewer arguments. Now you can read:

[...] i.e. 2250 m² (10 pixels) used as a filter to remove smaller PMAs. All polygons below the surface threshold were removed. [...]

SC-24.L333-334: This is not only related to the technical approach, but also has a morphological cause (i.e. increased friction and low/no ice content in lateral margins) that deserves to be mentioned here.

Response > We agree with the reviewer. As the way of how average surface velocities were computed is more a methodological approach, we changed the positions of this paragraph on the new “**Section 4.4 Average spatial velocity and relative changes**”. Within the new section, we added the suggested text:

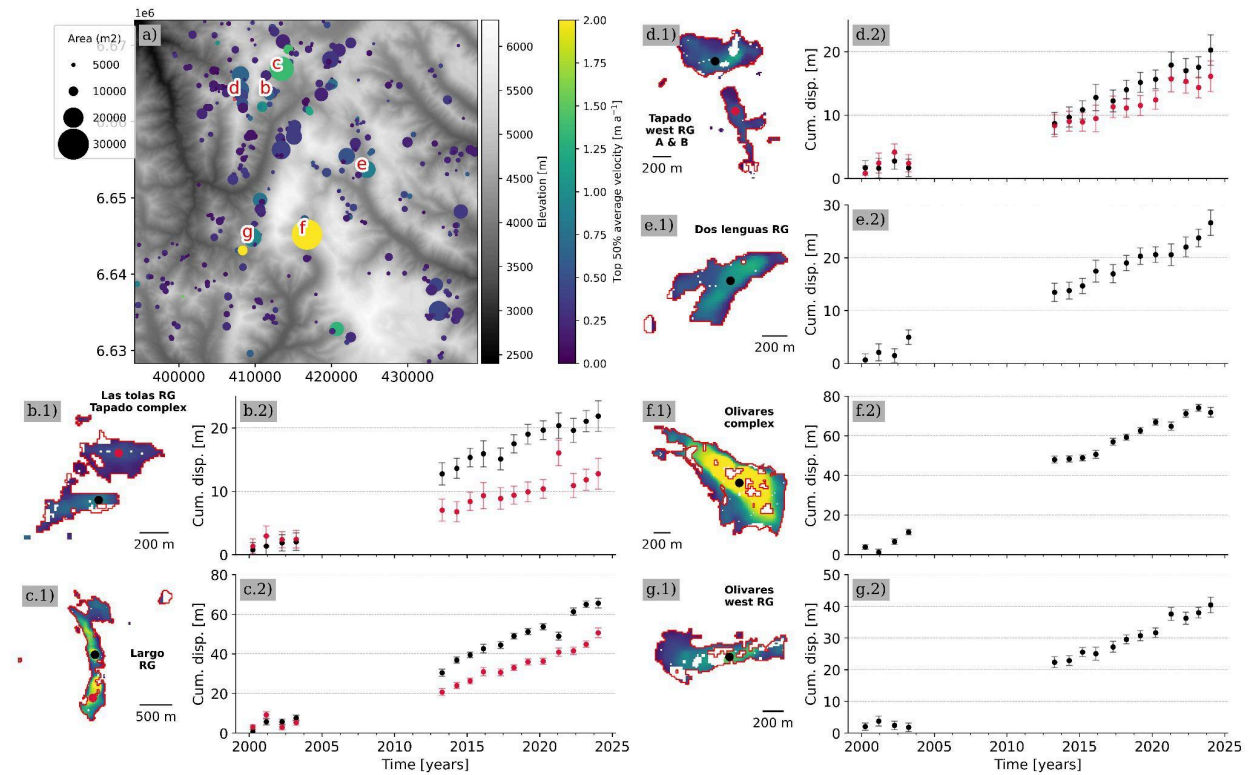
[...] As shown in Fig. 3a to d, the pixels located in the borders often have values close to 0 m a⁻¹, due mainly to natural geomorphological causes (i.e. increased friction and low/no ice content in lateral margins) as well as to window sizes of feature-tracking algorithms. [...]

SC-25.L335: This relates to one of my general comments above. I suggest you define this more clearly and use a clear and recognisable terminology throughout the manuscript. E.g. in the next sentences, (L342) does “average velocity” refer to the “Top 50% average velocity”?

Response > We removed the fattest pixels and kept only “Top 50% average velocity”. and check the consistency throughout the manuscript.

SC-26. Figure 5 / L357-365: If I understand the figure correctly, the viridis colour bar is also valid for the small rock glaciers, but the label “Top 50% mean velocity” is not. In the plots showing the cumulative displacement, error bars would help placing the data into the broader context.

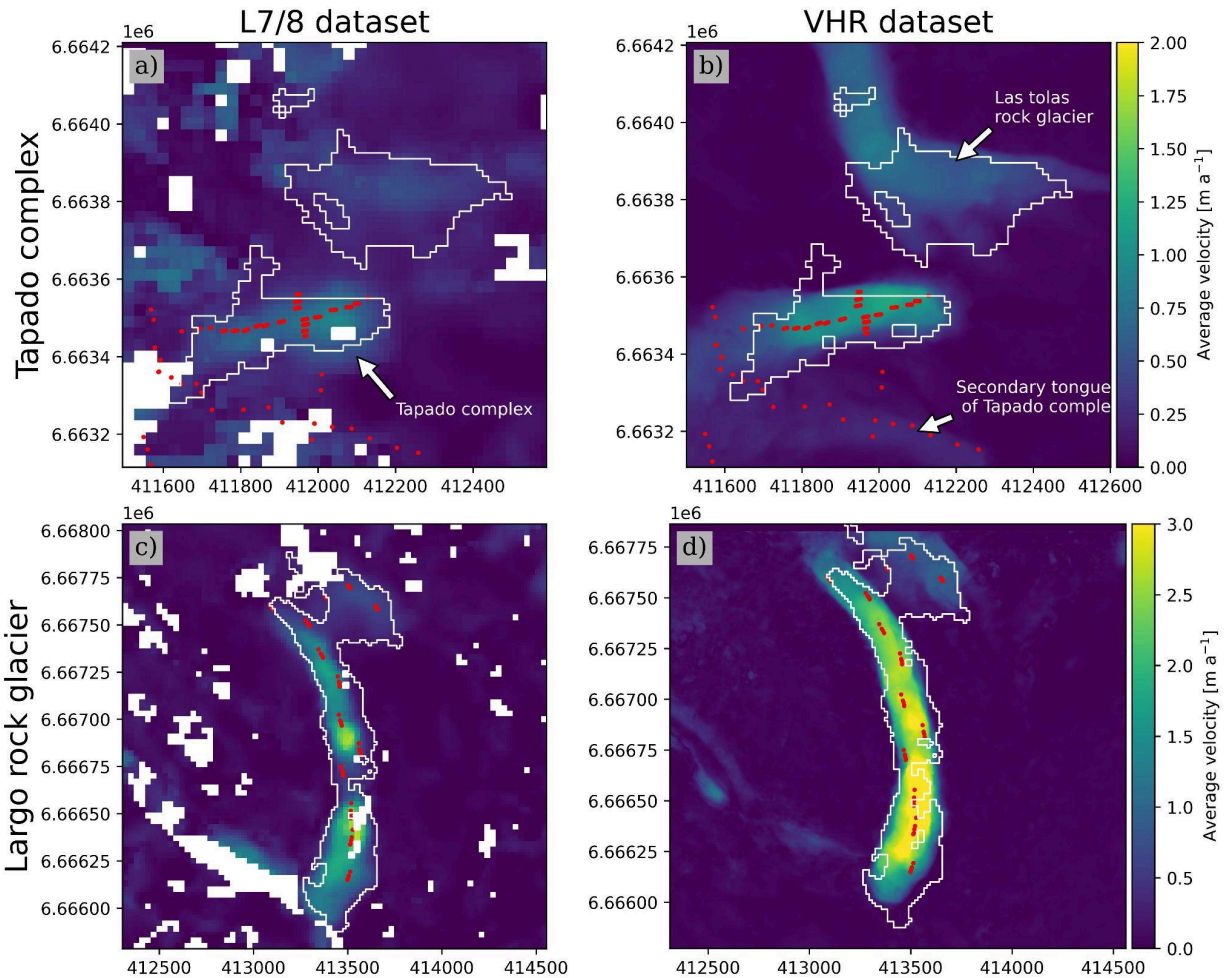
Response > You are right about the velocity. We updated the figure legend to clarify the use of the colorbar as well as some clarification about the subplots. In addition, we added the cumulative error bars as well as the names for each study site in bold. Now you can read:



[...] Figure 5: Surface kinematic characterisation for all PMAs in the central Andes region. a) Illustrates the spatial distribution of all confirmed PMAs (rock glaciers = 146; landslides = 115; others = 103) coloured by the 'Top 50% average velocity' (viridis colorbar) within the PMA surface. The size of the circle is proportional to the rescaled PMA surface in $m^2/1,000$ for better visualisation. The red letters correspond to the study cases presented in the following subplots. The remaining subplots b) to g) (with a suffix of *.1) illustrate mean annual velocity field over the 24 years (2000-2024) for a specific landform (name is displayed in bold) where the magnitude of velocity is coloured using viridis colorbar from panel a). Subplots with a suffix of *.2 represents the cumulative surface displacement time series in metres, extracted on the black (and red) point within the landform. Cumulative error bars were computed NMAD on stable areas for each date respectively (Section 5.4).[...]

SC-27. Figure 6 / L404-407: In the panels a) and b), a label indicating which rock glacier is the Tapado and which is the Las Tolos would help the reader following the specific results and discussion sections. Alternatively, this could also be indicated in Figure 5. Furthermore, please elaborate what a "pseudo-GCP" is and how it was constructed – it is not mentioned anywhere else in the manuscript.

Response > We updated Figure 6 and added the names for each rock glacier to avoid confusion.



Regarding the pseudo-GCP, this was already mentioned in Section 3.4 GNSS data. We clarify the sentence by adding the number of pseudo-GCPs used in this study and how they were built. Now you can read:

[...] Additionally, as no GCPs exist for Largo rock glacier, we manually tracked 13 pseudo-GCPs control points on representative features clearly identified on the VHR dataset to compare with L7/8 dataset (cf. Section 5.3). [...]

SC-28. Figure 7 / L419-420: Please elaborate more precisely what is shown in the figure, especially regarding the time span of the averaged data that is plotted here. What exactly does the point to pixel comparison contain? Are these velocities averaged over the temporal range of the entire analysis? In section 3.4 it is mentioned that DGNSS records started in 2009, but what time frame is the comparison with L7/8 and VHR data based on here?

Response > The comparison shows average velocity field for GNSS, pseudo-GCPs measurements and average surface velocity fields from remote sensing data. We computed surface velocities using the commission time span from 2009 until 2020. We modify the caption of Figure 7 by adding all these elements. Now you can read:

[...] Figure 7: Comparison between GNSS, pseudo-GCPs points average velocity and average surface velocity fields from inversion time series for both L7/8 and VHR datasets in

the subregions of Tapado complex and Largo rock glacier. The average surface velocities from GNSS measurements, L7/8 and VHR datasets, were calculated according to the common time period, spanning from 2009 to 2020. [...]

SC-29.L433-435: Again, I don't think this statement is valid here, as the Landsat 7/8 data exploited here also roughly covers the same time span.

Response > We agree with the reviewer. However, what we tried to say is that with Landsat imagery you can go back to the mid-1980's. So, remote sensing observations using medium resolution satellite i.e. Landsat covers almost 40 years. We added this statement as well as their respective references to clarify the sentence. Now you can read:

[...] but these datasets are relatively recent, covering only the past 20 years (Toth & Józskó, 2016). In contrast, Landsat imagery (e.g. L4-5-7 or L8) extends back to the mid-1980s (Kooistra et al., 2024; Ustin and Middleton, 2021). However, VHR and freely available SAR datasets are often limited [...]

SC-30.L449-451: What is the detection threshold mentioned here and how was this determined?

Response > The detection threshold mentioned here is the same identified in Section 5.1 (i.e. 2250 m² - 10 pixels). The explanation about how it was defined is explained in Section 5.1 where we mentioned that only a group of contiguous pixels greater than 10 pixels can be interpreted correctly. We added the explanation to clarify the paragraph. Now you can read:

[...] This suitability largely depends on rock glacier size, and pixel coverage within the landform (Section 5.1). Here, a minimum surface threshold of 2250 m² (10 pixels) proves effective for the Andes, but perhaps less so for other regions with smaller rock glaciers as the European Alps, [...]

SC-31.L512-515: While I agree that landslides in general might show a higher motion variability, I am not sure that comparing the different processes here helps the line of argument of the manuscript. The term landslides encompasses a range of different gravitational processes and with that a range of movement mechanisms that operate on very different timescales, often rather instantaneous. Also see my general comment on this.

Response > Sorry for the misunderstanding. WE agree that landslides encompass a range of different processes. However, we are not comparing processes in the paragraph. The goal of the paragraph is to show that rock glaciers have been better detected than landslides due to their nature (constant viscous flow with lower motion variability compared to landslides. Now you can read:

[...] Rock glaciers are slightly better detected than other features like landslides, likely due to the lower motion variability over time. Indeed, rock glaciers are viscous flows (Haeblerli et al., 2006) that face changes of activity over long periods of time (Kellerer-Pirklbauer et al., 2022; Lehmann et al., 2021). On the contrary, landslides can be influenced by seasonal and transient patterns (Lacroix et al., 2020b). [...]

SC-32.Figure 9 / L557-559: It should be made clear what "mean average velocity" means exactly and how this compares with the mean velocity (panel a) and average velocity (panel b). Further, use same unit m yr⁻¹ also here.

Response > We modified the X and Y axis titles of Figure 9 to state clearly which statistics has been used. We also change the unit label in the X and Y axis. Figure 9 looks as follows:

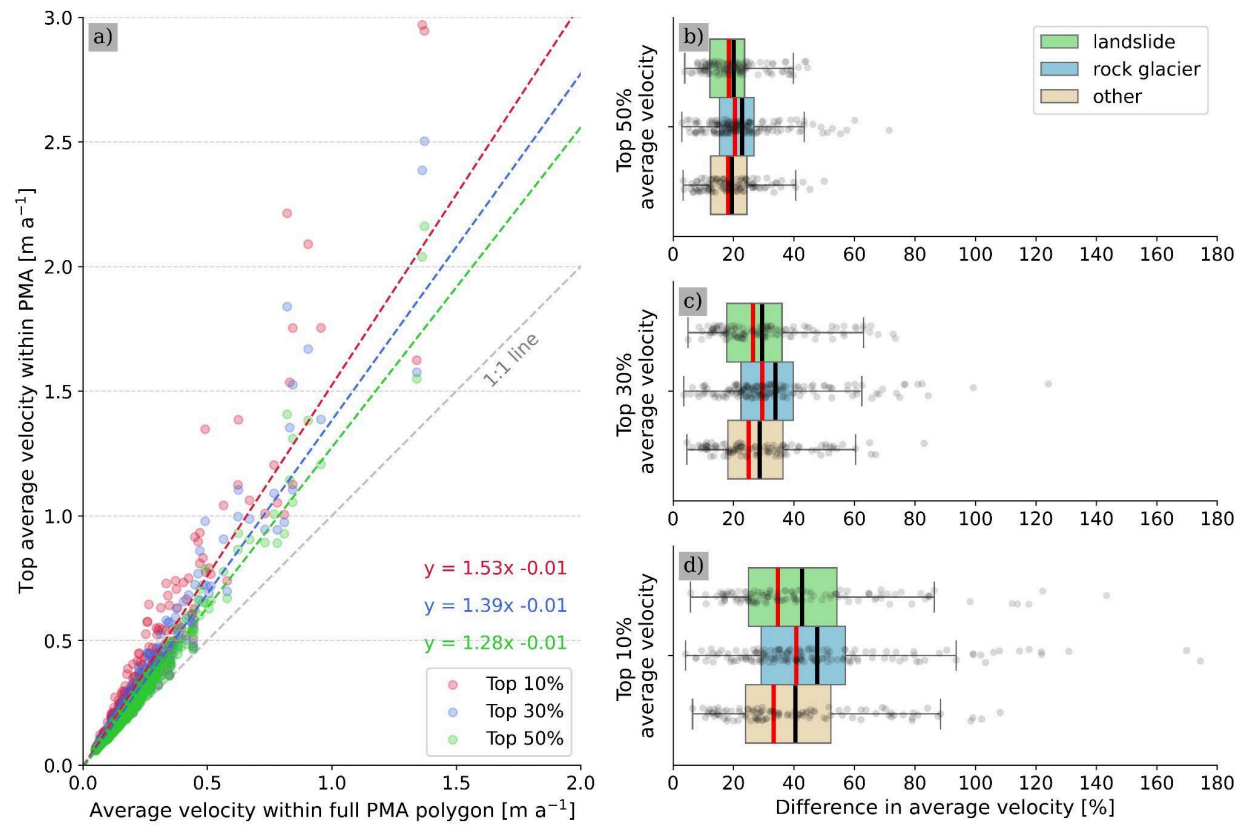


Figure 10: a) Comparison between average velocity computed using the entire PMA surface and 'Top 50%, 30% and 10% average velocity' within PMA. Subplots b), c), and d) show the difference of average velocity 'Top 50%, 30% and 10% average velocity' in respect to the **average** velocity computed over the entire PMA surface.

SC-33.L568-569: I might have missed this before, but are these different types of rock glaciers? If so, quickly explain in which respect these are different.

Response > The sentence has been removed as this is not coherent with the findings.

SC-34.L600-605: If I understand this correctly, it is not only the number of images that is different between both epochs, but also the length of the epochs differ – 14 years (with six images) versus 11 years (with 12 images).

Response > This is correct. We added the clarification within the manuscript. Now you can read:

*[...] **Observation discrepancies:** The 2000 to 2014 period includes only six years of observations due to a gap between 2003 and 2013, whereas 2013 to 2024 has 11 years of continuous observations. This may bias the average velocity for each period, conditioning related uncertainties (Fig. 5). The use of ASTER images or other medium-resolution data could help to fill this gap despite the low radiometric resolution.[...]*

SC-35. L639-641: Frankly, this seems a bit speculative, and I am not sure which data presented here supports this statement.

Response > We modified the sentence to avoid speculative statements. Now you can read:

*[...] **In contrast, landslides and other features** are predominant on North-west to East slopes (Fig. 11d). Similar **findings from Blothé et al., (2021)** in the Cordon del Plata **also emphasize slope orientation as a controlling factor.** [...]*

SC-36. L660-664: The topographic parameters are not only not covering the entire rock glacier but leave out the feeder basin that delivers material and water to the rock glacier.

Response > We added the text as suggested by the reviewer. Now you can read:

*[...] **Although the objective of our study is the monitoring of rock glaciers on a regional scale, other PMAs corresponding to mass movements such as landslides could also be identified. Our results suggest possible correlations between gravitational movements in high mountain areas (e.g. Haeberli et al., 2017; Patton et al., 2019) and permafrost degradation (i.e. freeze, thaw of permafrost) in recent deglaciated areas (Pánek et al., 2022). This study allows us to complete those existing mass movement inventories in the region (e.g. Iribarren Anaconda et al., 2015), highlighting areas for further research. While these findings suggest useful regional relationships between surface kinematics and topographic parameters at the regional scale, they must be interpreted cautiously. The morphological statistics here are derived only within PMA boundaries and may not fully represent the whole landform (Fig. S12). Additionally, PMAs exclude feeder basins, responsible for material supply and water to the rock glacier (Blöthe et al., 2021; Cusicanqui et al., 2021). Further studies should be conducted to look at the influences of feeder basins on surface kinematics of rock glaciers.** [...]*

SC-37. L676: Please explain how this topographical context was extracted from which data set.

Response > As the lines 676 does not refer to topographical context, we believe that the referee refers to the caption in Figure 10. We added an explanation to clarify how the topographical context was obtained. Now you can read:

*Figure 11: [...] geomorphological class vs **regional topographical context (computed using average pixel frequency from TanDEM-X 12 m DEM).** a) PMA mean slope; b) d [...]*

Technical corrections

SC-38. L22: “debris frozen landforms” ?

Response > Modified as suggested.

SC-39. L26: word missing or unclear: “10% of the accelerations in one decade”?

Response > Modified as suggested. Now you can read:

*[...] **Nevertheless, decadal velocity changes were observed in 3% of PMAs, where three rock glaciers showing 11% increase and six rock glaciers showing an 18% decrease in velocity over one decade.** [...]*

SC-40. L32: Please rephrase! Do you mean “snow cover variability”?

Response > Modified as suggested.

SC-41. L70: delete “and”

Response > Modified as suggested.

SC-42. L71: a lot of “thus” here

Response > Modified as suggested.

SC-43. L86: “set tracking techniques”?

Response > We change “set” by “feature” as suggested.

SC-44. L94: If I remember correctly, Eriksen et al. 2018 investigate a rock glacier in Norway...

Response > We remove the reference. Modified as suggested.

SC-45. L105: at not “ate”

Response > Modified as suggested.

SC-46. L106: explain “VHR” here

Response > Modified as suggested.

SC-47. L124: have shown a warming trend?

Response > Modified as suggested.

SC-48. Figure 2: the font of the panel labels as well as the text is not consistent throughout the figure.

Response > We modified the font of panel b as suggested.

SC-49. L203 & 216: L7/8

Response > Modified as suggested.

SC-50. L285: Please provide a more appropriate heading here

Response > Modified as suggested. Now you can read:

[...] 5.1 Characterization of PMA's extraction [...]

SC-51. L296: “is presented in” instead of “could be found”

Response > Modified as suggested.

SC-52. L311: This should be 58%, right?

Response > Modified as suggested.

SC-53. L332: “taking into account”

Response > Modified as suggested.

SC-54. L366: Although

Response > Modified as suggested.

SC-55. L387: rock glaciers and landslides instead of ‘rock glaciers’ and ‘landslides’, or alter in the remaining manuscript

Response > Modified as suggested.

SC-56. L390: delete “further”, as this is the results section

Response > Modified as suggested.

SC-57. L417: I am not sure if “were drawn” paints the correct picture here

Response > We replace “were drawn” by “are located”. Modified as suggested.

SC-58. L435: Elaborate which datasets you are referring to here.

Response > We replaced by “On the other hand, VHR and InSAR”. Modified as suggested.

SC-59. L437: “with a global reach”?

Response > We replaced by “with a global coverage” Modified as suggested.

SC-60. L446: Halla et al. 2021

Response > Modified as suggested.

SC-61. L458, 460, 475: I think the text here refers to Fig. 6, not 7?

Response > Modified as suggested.

SC-62. L523: Explain the abbreviation RoGI, also use consistently (L525, Rogi)

Response > We replace “RoGI” by “rock glacier inventory”. Modified as suggested.

SC-63. L568: underestimation

Response > Modified as suggested.

SC-64. L630,635: I think the text here refers to Fig. 10, not 11?

Response > Modified as suggested.

SC-65. L646: a lot of permafrost here

Response > Modified as suggested.

SC-66. L671: Conclusions

Response > Modified as suggested.

SC-67. L715-716: repetition

Response > Modified as suggested.