

**RC1: 'Comment on egusphere-2024-3262', Anonymous Referee #1, 27 Jun 2025**

**Author comments (AC) in blue**

I appreciate the additional explanations provided by the authors. The contents of the manuscript are now easier to follow and the discussion and interpretations are more focused and clear. The figures are much improved, although I still have some quibbles (see below). My remaining comments are minor and mostly about technicalities related to the figures, with a few additional questions. I believe this work is a valuable overview of regional rock glacier state and will make a nice contribution to ESurf.

Thank you very much for your encouraging and constructive comments. We appreciate your feedback and have carefully considered and addressed all your suggestions in the revised manuscript. We sincerely hope that our responses to each of your points are satisfactory and that the revised version meets the standards for publication.

L59 increased rock glacier velocities has been linked to warmer climate

—> have been

Thank you. The typographical error has been fixed in the revised version.

L66 consider adding a sentence to explain how destabilization differs from “normal” permafrost creep to indicate why such high velocities are reached.

We added the following phrase: “Destabilization typically involves a sudden, pronounced acceleration of a section of the rock glacier, with displacement rates increasing by up to two orders of magnitude and surface manifestations such as cracks, scarps, and crevasses reflecting enhanced internal strain between stable and unstable areas (Marcer et al., 2021; Hartl et al., 2023).”

L88 The sentence on changing temperatures might fit better in the following section where you discuss the climatology of the study region. Suggestion: Move this sentence to line 103 in Section Study Area.

We moved this phrase to Study Area.

L 90, 94: I suggest using “kinematics” instead of “dynamics” here and throughout the manuscript.

Dynamics typically refers to underlying processes and causes (why is it moving), while kinematics describes the effect (how is it moving). You mostly describe the latter.

It has been corrected in the revised manuscript!

Fig. 1: Thank you for adjusting this figure. I still have a few comments/suggestions:

In panels a and c the text size in the legend is still really small. Can this be made larger? In Panel b, the dark blue color of the permafrost extent does not seem to match the color in the legend - it would be easier to understand if the same color is used. The hashed circles for GST and GNSS measurements are difficult to visually differentiate at site 8. More contrasting colours might help. What is the difference between the thicker and thinner black outlines? Consider adding an explanation to the caption or legend.

In panel c you have added “extended” and “restricted” outlines - it is not clear to me where these come from and what the difference is. Is this explained somewhere? Consider explaining the meaning of “rock glacier units”. I believe that site 7 was presented as one landform in the previous version whereas it consists of 2 units in the revised manuscript.

We adjusted Figure 1 as follows:

In panel (a) we deleted one item (Southern Carpathians contour) from the legend and made the rest bigger and easier to read

In panel (b) we corrected the colour, for modelled permafrost extent, in the legend to match the colour in the map; We deleted the four symbols for the ground-based measurements that were performed on different rock glaciers (this information can be found on a new table added to the text).

In panel (c) we zoomed in even more and also, we made the text in the legend bigger and easier to read

We adjusted the caption accordingly.

We added to the caption the explanation for the thicker lines in the inventory.

We introduced the “extended” and “restricted” outlines at the recommendation of Reviewer2 in order to comply with the recommendation from the RGIK (rock glaciers inventory and kinematics) action group. The extended outline is the former outline, while the restricted outline follows the top of the front and margins of the rock glacier. The rock glacier unit was introduced, again, to follow the recommendations of RGIK.

We made small updates to the rock glacier inventory to comply with the recommendations from the RGIK. This include mapping rock glacier units and multi-unit rock glaciers (this being the reason why we also introduced the term “rock glacier unit”. We have split the Galeşu rock glacier (no 7 on fig. 1) into two units based on kinematics and morphology.

L136 check formatting of citation

We revised all the citations and made corrections were needed.

Fig. 3: The colours and overall legibility of the figure are much improved, thank you. The text in the legends and grid are still relatively small but legible when the pdf is displayed at full size.

For Figure 3 we changed the layout from landscape to portrait, with (a) above (b) instead of side by side. This way we had space to increase the size of the legend, including text, and of the scale bar text

L217: The next step was to assign velocity classes to moving areas considering the standardised velocity classes

Suggestion to rephrase: —> The next step was to assign standardised velocity classes to moving areas

Thank you for the suggestion. It has been corrected in the revised manuscript!

L219 -222: check font and text size

Thank you for pointing out this oversight. This mistake has been corrected in the revised manuscript!

L 222: PSInSAR-based surface displacement of  $\leq 0.3$  cm yr<sup>-1</sup> were assigned to the “no movement” category, ...

This reads like a contradiction to the sentence two lines up that lists the categories. Are “undefined” and “no movement” the same categories or do you differentiate this somehow? Maybe add “no movement” to the list of categories.

Thank you for the suggestion. The 'Undefined' category was assigned exclusively to moving areas (MAs) exhibiting inhomogeneous velocity patterns, as explicitly stated in the Methodology section (two sentences further). In contrast, the 'No movement' category refers to areas without detectable displacement and therefore cannot be considered a type of moving area.

Fig 10: text size could be increased. The annotations in 10b would be easier to see with a backdrop as in 10a. The small text in the “fringe cycle” inset in 10b is very hard to read.

We increased the font size for the legend for fig. 10 (a). We modified the graphics for the “fringe cycle” and we increased the font size for all the text in the legend for fig. 10 (b). We added a white background to the text in the main window of fig. 10 (b) to increase its visibility.

Fig 11: as above, I am wondering what the difference between the “extended” and “restricted” outlines is.

We introduced the “extended” and “restricted” outlines at the recommendation of Reviewer2 in order to comply with the recommendation from the RGIK guidelines. The extended outline is the former outline, while the restricted outline follows the top of the front and margins of the rock glacier.

L390 while only three falls within —> fall within

Thank you. The typographical error has been fixed in the revised version!

Fig 12: label size for panel a and d is small, scale bar text is small

We increased the font size for labels (a) and (d). We also added a white background for labels (a), (b), (c) and (d) for better visibility. We increased the font size for the scale bar text on panels (a), (b), (c) and (d).

L521 and following: statements such as “very cold” and “considerably warmer” could be quantified by giving corresponding measured values.

Thank you for the suggestion. We added corresponding measured values.

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**Author comments (AC) in blue**

I have very much appreciated the thorough consideration of the reviewers' comments and the efforts made the authors for improving their manuscript. To me, the paper has well gained in both consistency and quality. It is now in a very good shape.

I have very few final comments on the text and would still suggest further improvement of some figures (see below).

Otherwise, all is fine. Very good job !

Thank you for your valuable and constructive comments. We have carefully considered all your remarks and addressed each of them in the revised version of the manuscript. We hope that our responses are satisfactory and that the revised submission will meet your approval for publication.

I.32 – « At this site, the recorded surface displacements are more likely the result of ice-melt-induced subsidence....” If this is an ice-poor site, ice-melt-induced subsidence cannot really occur. In fact, what is actually causing the motion observed at the surface is unknown. I agree to assume that is not related to permafrost creep. So, the rock glacier cannot be classified as transitional, but only as relict or relict uncertain.

Thank you. This phrase has been corrected in the revised manuscript.

I. 33 – “..., solifluction, or the tilting and sliding of blocks within the active layer”. I would suggest to simplify and just write that you presume, because of the heterogeneity of the observed surface displacement, that the motion is primarily occurring by deformation at shallow depth, namely in the active layer.

This part of the phrase has been deleted.

I.34 – at two other rock glaciers (add “other”)

This phrase has been corrected.

I.54 – Ice-melt subsidence cannot occur in the active layer, but only at the permafrost table if the active layer is gaining in thickness.

This phrase has been corrected.

I.62-63 – “According to Necsoiu et al. (2016), slow-moving rock glaciers in the Southern Carpathians exhibited increased velocities between 2007 and 2014, attributed to rising permafrost temperatures”. Interesting and important but not placed at the right location. This is here a paragraph about rock glacier creep in general. The sentence should come 2-3 paragraphs later or in Section 2, when describing the regional settings. Provide also numbers.... e.g. Slow-moving RGs in the S. Carp. displace up to x cm/year. They exhibited a velocity rise of x % between 2007 and 2014...

This phrase has been moved to the Study area as you suggested.

l.77-78 - No movement means a kinematically relict rock glacier according to RGIK, not a transitional one.

Thank you for the suggestion. It has been corrected in the revised manuscript!

l.88-89 – “Above 2000 m in the Southern Carpathians, the 1991-2020 climatological period was 0.8 °C warmer than the 1961-1990 baseline (Berzescu et al., 2025).” Should be placed in section 2.

It has been moved in section 2.

l.91 – « more broadly » or more precisely ?

Thank you for the suggestion. `More broadly` has been replaced with `more precisely`!

l. 115 – Fig. 1 - The color do not fit with the map for the modelled permafrost extent. Those in the dots are impossible to read and distinguish. Maybe add a table instead of using this color code.

We have to zoom a lot to make the text in maps (a) and (c) readable.

We adjusted fig.1 as follows:

In panel (a) we deleted one item (Southern Carpathians contour) from the legend and made the rest bigger and easier to read

In panel (b) we corrected the colour, for modelled permafrost extent, in the legend to match the colour in the map; We deleted the four symbols for the ground-based measurements that were performed on different rock glaciers (this information can be found on a new table added to the text).

In panel (c) we zoomed in even more and also, we made the text in the legend bigger and easier to read

We adjusted the caption accordingly.

l. 119 – “The rock glaciers that are discussed in the present paper are numbered (1 - Stânișoara, 2 - Bucura, 3 - Pietrele, 4 - Pietricelele, 5 - Valea Rea, 6 - Păpușa, 7 - Galeșu, 8 - Judele, 9 - Berbecilor), and the ground based measurements that have been performed on

each of them are represented by a composite symbol near the number”. Not necessary if an adjacent table is used.

We removed the symbols from fig.1b and we introduced Table 1, which provides information on the investigated rock glaciers, their activity status and the type of measurements conducted on them.

I. 131 – Fig. 2 - Nice views, but an outline should be provided for the rock glaciers (don't leave the reader to interpret the landscape by him/-herself only).

Which rock glaciers are relict ? transitional ?

Thank you for the suggestion. We have added which rock glaciers are relict / transitional.

I. 132 – It might be useful to use the same numbering as in Fig. 1, e.g. 3 - Pietrele..

Thank you for the suggestion. Similar numbering has been added.

I. 156-157 - Remove the URL and add the reference in the bibliography.

We revised all the citations, including these one, and made corrections where needed.

I. 188-191 – “In general, there are technical differences in the computation of data across EGMS products, primarily due to the involvement of multiple groups in the project. Terrasigna’s algorithms are more closely aligned with those used for the EGMS in southern Europe, which appear to offer better extraction of non-linear motion”. Could be removed or placed one paragraph earlier.

This phrase has been removed.

I. 192 – 181 images in both modes (ascending and descending) ?

In the fourth paragraph in the 3.2 section, we state that the EGMS product (fig.3 a) uses both ascending and descending orbits while the TerrasignaPSInSAR (fig. 3b) uses only Path 80 descending of S1.

I. 200-202 – “Due to significant atmospheric noise in steep terrain or in areas with large elevation differences, a reference point at a similar elevation to the rock glaciers was chosen on the mountain summit. This approach minimizes atmospheric phase differences, improving

coherence and reliability of the PSInSAR measurements”. Already written a few paragraphs before.

This phrase has been removed.

I. 203 – “underestimation of actual displacements” : underestimation of the along-slope displacement, but not in case of subsidence, and without any option to distinguish them.

Thank you for the suggestion. It has been corrected in the revised manuscript!

I. 205 – Fig. 3. – All is very small (text, legends), as well as the PSInSAR dots. Maybe zoom to a smaller area and make the dots larger.

For Figure 3 we changed the layout from landscape to portrait, with (a) above (b) instead of side by side. This way we had space to increase the size of the legend, including text, and of the scale bar text.

b) This is just in descending mode, right ?

The TerrasignaPSInSAR is only presented for descending mode. We stated this in the 3.2 section, paragraph 4 (also, see comment above).

I. 216 – about delination, just note that the RGIK guidelines for MAs recommend that, when MAs with various velocity classes co-exist, faster MAs are always embedded into slower MAs. This recommendation has not been applied here.

Thank you for your suggestion. We highly value the RGIK guidelines and fully acknowledge their importance in reducing discrepancies across rock glacier inventories worldwide. These standards are essential for fostering consistency, particularly in regions with well-developed and active permafrost dynamics. However, as the guidelines themselves acknowledge, applying uniform criteria in marginal periglacial environments—where displacements are minimal and often near the detection threshold—presents significant challenges. In such contexts, methodological flexibility becomes necessary. As is often the case in science, it is inherently more complex to study phenomena at the edge of their environmental or process-driven limits. This also explains the relatively limited number of studies addressing the behavior of rock glaciers in these transitional zones.

As mentioned in our previous response, even within RGIK, ambiguities remain—such as in the definition of transitional rock glaciers, which includes those with “little to no downslope movement over most of their surface.” The guidelines themselves acknowledge this



complexity by stating that “subjectivity must be acknowledged as part of the rock glaciers mapping process.” We consider this recognition fundamental in the context of our study.

Regarding the delimitation of moving areas (MAs), while we could not identify the specific reference you mentioned in Section 6.2.1 of the RGIK guidelines (Moving areas chapter), we acknowledge that other sections may contain broader interpretation. However, in our case, the velocity fields are highly uniform (ranging from 0.3 cm/year to 5 cm/year), which minimizes concerns regarding heterogeneity. The observation you raised becomes more relevant in studies aiming to compute velocity for entire landforms, especially when internal velocity contrasts are significant. In contrast, our study’s objective was not to assign a representative velocity to each rock glacier, but to delineate MAs and use this information to classify landforms as relict or transitional. Concerning the delineation of individual MAs, we refer to the RGIK guidelines, which state: “The minimum extent of a MA depends on the spatial resolution of the data input, but also on the size of the considered landforms. It is based on the operator’s judgment.” In line with previous studies (e.g., Bertonne et al., 2012), we argue that mapping individual MAs provides valuable insights—particularly in cases where localized destabilization occurs. For example, if a clearly defined section of a rock glacier is accelerating (e.g., moving at several meters per year), while the rest is creeping at decimetric rates, delineating this area separately is scientifically justified and important for future monitoring. Merging such a feature into a broader, slower-moving MA would obscure a significant dynamic signal.

While we fully support the use of RGIK as a guiding framework, we believe our approach remains consistent with its flexible principles and is appropriate for the specific conditions of our study area and objectives.

I. 217 – standard instead of standardized

Thank you for pointing out this oversight. This phrase has been corrected.

I. 238-239 – Simplify the sentence as follows : The velocities used in the analysis were calculated between the initial and final position over a two-year period.

Thank you for the suggestion. It has been corrected in the revised manuscript!

I. 244-246 – “For the interpretation of the interferograms, we followed the practical guidelines of the IPA Action Group Rock glacier inventories and kinematics (RGIK, 2023b) ». It might be worth of shortly describing what it means. Most readers surely don’t know.

We changed this sentence with the following text: “We masked areas affected by geometrical distortions and we used only interferograms from snow-free periods. For the interpretation

of the interferograms we only assign kinematic attributes when signals were reliable (e.g. on descending mode), we identified and delineated moving areas independently and then we linked the MA to the existing rock glacier units (RGIK, 2023b)."

I. 313-314 – "and were classified into three velocity classes: 0.3 – 1 cm yr<sup>-1</sup>, 1 – 3 cm yr<sup>-1</sup>, and 3 – 10 cm yr<sup>-1</sup>". Repetition of what already written in lines 218-219.

Thank you for the suggestion. It has been corrected in the revised manuscript!

I. 315 – remained "consistent" or constant ?

Thank you for the suggestion. It has been corrected in the revised manuscript!

I. 315 – about the "trendlines in Fig. 5". My previous answer (1st revision round) has not been answered (or I missed or misunderstood the explanation) : if we cannot trust the seasonal variations, why could we trust the winter ones (long data gaps), on which the trendlines are mostly based on ?

Thank you for the question. The trendlines in Figure 5 are based exclusively on snow-off periods, i.e., periods with valid displacement measurements. While interannual variability in rates is evident, the overall trend is derived from seven distinct snow-off periods.

I.337 – Fig. 4 – Outside of the rock glaciers, there are various noisy areas with values balancing between < 0.3 and 1-3 cm/yr. Why to consider classes < 0.3 cm/y and 0.3 to 1 cm/y as consistent or to limit them at the rock glacier drawn boundaries ?

Of course, there are moving areas outside of the rock glaciers, but for the purpose of the present study, we only present the moving areas from inside the rock glaciers. This decision was made to simplify the presented data in order to make the figures easier to read and understand.

PSI velocity : the legend must be adapted to the main text (< 0.3 cm/y , 0.3 to 1 cm/y...)

We adapted the legend on all figures to have the same MA categories as the main text.

I. 340 – Fig. 5 – Which rock glacier is represented ? Make the legend of the inserted map larger (and readable).

“PSI velocity class” (what is this ?) or MA velocity class ?

We modified fig. 5 as follows:

- We removed the geophysical profiles from the inserted map and from its legend and we increased the font size for the legend in order for it to be easier to read.
- We changed the representation of moving areas, from hushed polygons to hollow polygons, in order to make the dots for the location of the profiles more visible.
- We changed the legend title for the main graph from “PSI velocity class” to “MA velocity class”

I. 341-342 – “4 locations (identified in the location map with dots of corresponding colour” - I don’t really see them, at least the yellow and green ones, which also are difficult to read on the chart.

We changed the representation of moving areas, from hushed polygons to hollow polygons, in order to make the dots for the location of the profiles more visible. (see paragraph above)

I. 345 – same question as in line 315 about the “gap” : how is the gap solved ? Because it looks that it is especially these gaps which define the trendlines.

Same answer as above: the trendlines in Figure 5 are based exclusively on snow-off periods, i.e., periods with valid displacement measurements. While interannual variability in rates is evident, the overall trend is derived from seven distinct snow-off periods.

I. 364 – What are “areas with high variability in displacement” ? Spatial or temporal variability?

Thank you for the suggestion. Spatial has been added!

I. 365 – “more detailed mapping of the monitoring areas (MAs), allowing for the differentiation of relatively minor velocity differences”. MAs means “moving areas” and not “monitoring areas”.

Thank you for the suggestion. It has been corrected in the revised manuscript!

I. 372 – Fig. 10 – Provide both mode (Asc. / desc ?) and time of the represented interferogram. Make texts and legends larger and/or better readable.

Thank you for the suggestion. We increased the font size for the legend for fig. 10 (a). We modified the graphics for the “fringe cycle” and we increased the font size for all the text in

the legend for fig. 10 (b). We added a white background to the text in the main window of fig. 10 (b) to increase its visibility.

We stated in the main text, at Line 173-175, that we computed interferograms for both modes, ascending and descending, but we only present the descending mode, since it is the one that produced the most reliable results. Unfortunately, ascending paths proved too noisy over the Carpathians, and as stated in the Methodology section, we chose to rely exclusively on descending paths for mapping the moving areas. We also added this information in the figure caption. The time of the interferogram has been added after the first review.

I. 376 – What is a RGU ?

We modified the caption, we replaced “RGU” with “rock glacier unit”.

We added an introduction to the RGU abbreviation at Line 273-274, RGU – rock glacier unit. We introduced the term after the first review in order to align our inventory to the RGIK recommendations.

I. 377 – “0.56 cm/y” - Where does this value come from ? There is about half a fringe (light blue to pink-violet), meaning about 5-6 cm in 5 years or 1-1.2 cm/yr.

We deleted the information on velocity from the Fig. 10 caption, since the objective of the figure is to compare the distribution of the moving areas between the two methods, PSInSAR on S1 and InSAR on ALOS-PALSAR2 .

I. 378 – largest instead of “biggest”. According to my previous comment, is this PSI-based MA velocity class still in line with the present observation ?

Thank you for the suggestion. It has been corrected in the revised manuscript!

We decided to remove the information about the velocity derived from InSAR on ALOS PALSAR.

Revising the velocity from the interferogram in fig10b to between 1 to 1.2 cm/year it's still comparable with the velocity presented in fig10a, where there are 3 moving areas (0.3-1cm, 1-3cm, 3-10cm), when we consider the small velocities and the possible error rates for ALOS PALSAR (0.2 – 0.5 cm/year).

This is also another argument to only present the comparison for the spatial distribution of moving areas and to simplify by eliminating the comparison for velocity classes

l. 416 -  $+0.8^{\circ}\text{C}$  is not negative. Maybe slightly adapt the sentence.

Thank you for the suggestion. This phrase has been adapted!

l. 455 – The ice content in d) appears to be in contradiction with b) and c), as described in the main text. There is almost no ice where ice is supposed to occur. Does it still make sense to keep the "ice ?" mentions on b) and c) ?

Yes, we agree that the labels are confusing and removed them from b) and c) accordingly.

l. 512 – “Unlike other regions (e.g., Central Italian Alps, Eastern European Alps, Himalaya) where there is a considerable elevation difference between active/intact and relict rock glaciers (Kellerer-Pirklbauer et al., 2012; Scotti et al., 2013), the Retezat Mountains exhibit a significantly smaller separation”. But there is no active rock glacier at Retezat, just some transitional or relict uncertain ones on one side, and relict ones on the other. So, the sentence does not really make sense.

Thank you for the suggestion. This phrase has been deleted!

l. 533 – “...but likely suggests negligible ice content”. Maybe better to write “... but likely suggest an insufficient ice content for permafrost creep to occur”.

Thank you for the suggestion. This phrase has been corrected!