

Comment on esurf-2022-8

Authors response to Referee #1

Dear Referee,

Please find in the following our answer to your comments.

Note that Referee comments are noted as “**RC** –“ and authors responses as “**AC** >”.

RC –The introduction is well constructed, and I only propose that the long-term rock glaciers state of the art starts first and then remote sensing studies finish the section. This sequence must be applied to the rest of the manuscript and will give a stratigraphical comprehension to the paper, according to the timescale adopted in the work.

AC > In the entire manuscript, the stratigraphic order has been applied as recommended.

RC –Besides that, a clear idea of the goals of the paper should be added at the end of the introduction.
AC > The goals of the study were clearly explained at the end of the introduction: “The goal of this study is to reconstruct the activity and the surface velocities at different timescales of the rock glacier system of the Vallon de la Route (Combeynot massif, western French Alps). [...] By discussing our estimates of rock glacier surface kinematics at different timescales, we show that it is possible to reconstruct the past activity of the rock glacier and to use rock glaciers as independent paleoclimate and paleo-geomorphological proxies revealing the evolution of alpine environments.”

RC – In the results, the relation made between the chronological evolution across the rock glacier and the geomorphological process needs to be improved with the morphological criteria, especially with boulders characteristics.

AC > Boulder characteristics have been included in section 4.1. “The surface of the boulders evolves along the rock glacier longitudinal transect. The boulders of units I and II are rounded and present Quartz phenocrystals rugged surface, millimetric weathered crust and about 80% of lichen cover (Figure 2c). On the other hand, boulder of the units IV and V are more angular, with surface presenting about 10 to 30% of lichen cover and milder surface weathering features (Figure 2d).”

RC – Here, explanations should be avoided, and I propose to describe only the paper's results.

AC > The result section has been reorganized to avoid details explanations which were moved to the discussion section.

RC – Besides that, it is necessary to state that values of rock glacier surface displacements are presented in gross values, as we don't know how debris supplied the rock glacier over the Holocene.

AC > In the section “4.2 Image correlation”, this sentence has been included to make the point mentioned by the referee “Note that those estimates integrate displacements over 58 years, here we don’t have the ability to established if the displacements have been concentrated in a specific period with the timescale analysis.”

RC – Some information must be better organized. A substantial part of the discussion should be part of the results, and there is information that was not explained in the methods.

AC > The “Methods”, “Results” and “Discussion” have been reorganized as suggested.

RC – Besides that, the three first subsections of the discussion contain only three citations and must be improved.

AC > Those subsections have been strongly improved.

RC – Finally, the discussion about the recent velocities is neglected and must be reinforced.

AC > Recent activities have been discussed regarding the literature as suggested.

We thank you for your comments and suggestions, the manuscript in its revised form has gained in quality both scientifically and clarity. Please find attached all our response to the detailed comments.

Best regards,

Benjamin Lehmann et al.,

Detailed comments:

RC – Lines 20-21: Difficult to understand, please rephrase

AC > This sentence has been rephrased as suggested.

RC – Line 21: Grammatical connector here will help the readers

AC > This sentence has been changed for "Additionally, over periods from centuries to millennia".

RC – Line 25: You have presented before the Remote Sensing analysis in first order and now the 10Be exposure ages. Please homogenize.

AC > A sentence presenting the remote sensing results has been included "The remote sensing analysis show that between 1960 and 2018, the two lower units of the rock glacier have been motionless, the transitional unit presents an integrated surface velocity of 3.4 ± 2.6 cm/a and the two upper active units above 2600 m a.s.l. show velocity between 13.9 ± 8.0 and 14.6 ± 5.1 cm/a. "

RC – Line 25: Please, present throughout the text the ages in stratigraphic order, use first the older ages and then the young ones.

AC > Changed as suggested.

RC – Line 30: Episode or phase, please homogenize.

AC > We have homogenized using only "phase".

RC – Line 31: Redundant. If they are moving they are active

AC > Changed as suggested.

RC – Line 32: When? during its formation or today?

RC – Line 32: I lost myself in this sentence. There is too much information: two/three time frames, location, geomorphological units, dynamics... I propose you rephrase and simplify.

AC > This sentence has been cut in two and modified to have be more precise: "Following a quiescent period between ca. 6.2 and 3.4 ka, the present-day active upper two units have been emplaced after 3.4 ka. Climatic conditions have favored an integrated rock glacier motion of around 0.18 m/a between 3.4 ka and present day."

RC – Lines 37 – 40: Too much information. Please divide in two sentences: 1 - morphological criteria; 2 – dynamics.

AC > Divided as suggested.

RC – Line 44: redundant

AC > Here "leeside" stands for "is sheltered from the wind". We don't understand with what word the reviewer thinks "leeside" is redundant here. It brings an additional information that was not brought by other word of the sentence.

RC – Line 46: Improve this connection

AC > Connection has been improved.

RC – Line 47: On the one....

AC > Changed as suggested.

RC – Line 48: forms; ice content increases; within

AC > Changed as suggested.

RC – Line 56: From here is difficult to follow the sentence. Please, simplify

AC > Simplified as suggested.

RC – Line 57: Changed as suggested.

AC > Changed as suggested.

RC – Line 58: ice extent?

AC > Changed to “to non-dominant areas”.

RC – Line 64: unnecessary

AC > Removed as suggested.

RC – Line 70: based on

AC > Changed as suggested.

RC – Line 76: unnecessary

AC > Removed as suggested.

RC – Line 85: Is it to date or to estimate the exposure age?

AC > Changed for "to estimate the surface exposure age of boulders"

RC – Line 85: Pyrenees

AC > Added as suggested.

RC – Line 94: - Santos-González, J., González-Gutiérrez, R. B., Redondo-Vega, J. M., Gómez-Villar, A., Jomelli, V., Fernández-Fernández, J. M., Andrés, N., García-Ruiz, J. M., Peña-Pérez, S. A., Melón-Nava, A., Oliva, M., Álvarez-Martínez, J., Charton, J., & Palacios, D. (2022). The origin and collapse of rock glaciers during the Bølling-Allerød interstadial: A new study case from the Cantabrian Mountains (Spain). *Geomorphology*, 108112. <https://doi.org/10.1016/j.geomorph.2022.108112>

-García-Ruiz, J.M., Palacios, D., Fernández-Fernández, J.M., Andrés, N., Arnáez, J., Gómez-Villar, A., Santos-González, J., Álvarez-Martínez, J., Lana-Renault, N., Léanni, L., 2020. Glacial stages in the Peña Negra valley, Iberian Range, northern Iberian Peninsula: assessing the importance of the glacial record in small cirques in a marginal mountain area. *Geomorphology* 362, 107195. <https://doi.org/10.1016/j.geomorph.2020.107195>

AC > References included as suggested.

RC – Line 96: More than permafrost thaw, CRE ages indicate the absence of flow. Rock glacier as permafrost features can have ice within and being stable/receiving cosmic rays at the same time. I would take a contained position and be cautious here

AC > This is right, sentence part was changed for "and to identify activity phases of rock glacier".

RC – Line 104: reference is needed

RC – Line 105: reference is needed

RC – Line 106: Please, divide the reference according to the periods of rock glacier development

AC > Divided as suggested.

RC – Line 108: Please, instead showing what have you done, tell the reader what goals do you intend to achieve. It can even be with bullet points

AC > Changed as suggested.

RC – Line 126: Please confirm if references on unpublished data are accepted by the journal

AC > The mention to unpublished data has been removed.

RC – Line 141: influenced by the

AC > Changed as suggested.

RC – Line 142: ...and..

AC > Sorry we did not understand the point of the reviewer here, so have left as initial wording.

RC – Line 142: Atlantic climates

AC > Changed as suggested.

RC – Line 145: Is this data from climatic models? Please, present the data from meteorological stations

AC > This entire section has been replaced with better data reconstructions.

RC – Line 147: And the precipitation? Please correct accordingly

AC > This entire section has been replaced with better data reconstructions.

RC – Line 148: unnecessary

AC > We prefer to keep this part for clarity.

RC – Line 149: please simplify, write the values in ha por in km²

AC > Converted into km² as suggested.

RC – Line 149: same

AC > Converted into km².

RC – Line 150: please, follow the altitudinal order

AC > Changed as suggested.

RC – Line 160: Methodology. Section with no information. Write a sentence with the overall structure of your methodology

AC > Information has been included as suggested.

RC – Line 161: Section with no information. Please introduce what are you going to describe in the following subsection

AC > Here we consider that the title is informative enough.

RC – Lines 166-167: This is not field observation. You can probably change the name of the section to geomorphological mapping/identification

RC – Line 170: same

AC > This section has been changed to "geomorphological mapping/identification" as suggested.

RC – Lines 176-177: What is the spatial resolution? It might be useful to sum this characteristics (year of collection, spatial resolution, type of collection,...) in a table.

AC > We kept only the pair 1960 and 2018 as we did not used the other acquisitions. Details of the two acquisitions have been included in the text as suggested.

RC – Line 189: same code of the chapter

AC > Thanks for identifying this mistake, this was corrected.

RC – Line 190: The

AC > Included as suggested.

RC – Line 204: See the comment above

AC > Converted in km²

RC – Line 208: Section with no information. Please introduce what are you going to describe in the following subsection

AC > Information was included as suggested.

RC – Line 210: This is already results. You can just say: "the samples were collected with..."

AC > Changed as suggested.

RC – Line 214: Stratigraphic order. 1° older and last – younger

AC > Changed as suggested.

RC – Line 215: I think that topographical shielding and snow cover are errors that can be considered and need to be contable. However, from the field point of view, it is difficult to select the sample that is less affected by those factors within the same crest. Therefore, I advice to rephrase.

As you say in the end of the sentence, it is to avoid being covered or reworked.

What can you probably say is that you have calculated the topographical shielding following a specific method in the field?

AC > "Topographic shielding" was changed for "local shielding".

RC – Line 215: Totally agree

AC > We thank the reviewer.

RC – Line 216: covered by

AC > Changed as suggested.

RC – Line 234: Here it is necessary to explain what ages did you adopt across the paper: non-corrected ages or corrected ages with snow cover

AC > Precision has been included.

RC – Line 248: Have you used to the older ages? Difficult to follow. Rephrase

AC > The second part of the sentence was removed.

RC – Line 250: Section with no information. Please introduce the results by saying how many units did you divide the rock glacier and that your methods allowed you to reconstruct the chronology of the rock glacier displacement since the onset of the Holocene

AC > Information was included as suggested.

RC – Line 252: Please organize the results following the stratigraphic order. 1° older unit/landforms at lower elevations and then younger units at higher elevation

AC > Those changes have been done.

RC – Line 254: which is?

AC > “(steeper than the angle of repose)” has been removed.

RC – Line 258: The

AC > Changed as suggested.

RC – Line 266: Unnecessary

AC > This sentence is here to better connect the different part of the manuscript; we decided to keep it.

RC – Line 268: Please explain why did you just use 1960 to 2018. Was it because of many shadows? clouds? unified spatial resolution? problems with the ratification of the imagery...

AC > We decided to remove the mention of the other orthomosaics because only 1960 and 2018 are used in the present study.

RC – Line 275: Please, homogenize the format of the text

AC > Homogenizing has been done as suggested.

RC – Line 281: Please verify if it is the median or the average

AC > Verification has been done; it is the median.

RC – Line 281: Please, it is important that you state here that is a gross value. You don't know if this displacement was concentrated in a specific period within your timescale analysis.

AC > This sentence was added "Note that those estimates integrate displacements over 58 years, here we don't have the ability to established if the displacements have been concentrated in a specific period with the timescale analysis. "

RC – Line 282: same

AC > “Median” is correct.

RC – Line 293: Please, see the comment about the chronological order

AC > Changed as suggested.

RC – Line 304: This is the section of the results. Please, describe only the results. Any casualties, explanations or hypothesis must be explained in the discussion.

AC > Re-organization has been done as suggested.

RC – Lines 304-305: That is true and expected however why was not transported at the surface of a debris-free glacier or debris-covered and then turned into a rock glacier? Please, reinforce the morphological facts across the landforms to sustain your work

AC > Precision has been included in the discussion, section 5.3: “The Vallon de la Route cirque is occupied by a rock glacier system with well-defined rock glacier geomorphological attributes such as steep fronts, margins, ridges and furrows topography (Figure 1b and 2) and no evidence of former occupation of the cirque by a clean ice or debris covered glacier are visible (moraines, polished bedrock surfaces). Consequently, we interpret the correlations presented in section 4.3 between the ^{10}Be surface-exposure age and distance to the headwall to support the hypothesis that rock boulders originate from the headwall and are then transported downward on the surface of the rock glacier: the further from the headwall (and the lower the elevation) the boulder is, the older its ^{10}Be surface-exposure age.”

RC – Line 305: This causality (chronology vs process) needs to be better justified. Such chronological relation could happen in glacial cirque with only moraines. This is important because you are excluding the possible role of a glacier to transport material into the rock glacier. Again, reinforce the morphological facts across the landforms to sustain your work

AC > Morphological facts have been mentioned as suggested: "The Vallon de la Route cirque is occupied by a rock glacier system with well-defined rock glacier geomorphological attributes such as steep fronts, margins, ridges and furrows topography (Figure 1b and 2) and no evidence of former occupation of the cirque by a clean ice or debris covered glacier are visible (moraines, polished bedrock surfaces). Consequently, we interpret the correlations presented in section 4.3 between the ^{10}Be surface-exposure age and distance to the headwall to support the hypothesis that rock boulders originate from the headwall and are then transported downward on the surface of the rock glacier: the further from the headwall (and the lower the elevation) the boulder is, the older its ^{10}Be surface-exposure age."

RC – Line 308: Based on what statistical method? What variables did you used?

AC > The sentence was changed for "Visual inspection of the ^{10}Be -age dataset allows the identification of two clusters."

RC – Line 313: I completely support this organization: stratigraphic order

AC > The stratigraphic order has been implemented as suggested.

RC – Line 315: This is the discussion of your results. I see no discussion of your results in the paragraph. Please, explain how are the results affected or not. e.g. is there any sample excluded by inheritance?

AC > The discussion has been reorganized as suggested.

RC – Line 318: delete

AC > Deleted as suggested.

RC – Line 321: Is the first time that I see linear regression across the paper. It must be included in the methods and in the results

AC > This has been introduced in the method section as suggested.

RC – Lines 335-336: Please confirm if you have explained the quantification of potential inheritance in the methods

AC > Explained in the method section as suggested.

RC – Line 336-337: This is a result. Just now I see the relation between the chronology and the process. I propose a better organization of this idea in the results and discussion

AC > The manuscript has been reorganized as suggested.

RC – Line 340: I don't understand the last part, seems incomplete. Rephrase, please.

AC > Rephrased as suggested.

RC – Lines 353-355: This information is part of your results.

AC > This paragraph has been moved to the results section as suggested.

RC – Line 358: improve the English

AC > Improved as suggested.

RC – Lines 366-368: This is results, as you said

AC > This sentence has been modified. We acknowledge that that information are part of the results, but also argue that they fit perfectly in the flow of the manuscript in their current place. We prefer to keep their presentation in this section.

RC – Line 368: see comment about the the term median

AC > The term median is correctly used.

RC – Lines 379-384: This information is part of the methodology

AC > This paragraph has been moved to the method section as suggested.

RC – Lines 385-387: This information is part of the results of your work

AC > This information has been moved to the results section.

RC – Lines 394-395: this is results

AC > This has been moved to the result section.

RC – Lines 398-402: This paragraph is the only one where there are some discussion. Please reinforce the discussion and tell the reader what is the meaning of such velocities. Compare with other work; is there any motion analogue with the recent velocities.

AC > This paragraph has been reinforced as suggested.

RC – Lines 414-415: And snow avalanches? did you consider that it was always stable throughout the Holocene? Please, clarify

AC > This sentence was added to the text "During, this phase of inactivity, we consider that neither snow nor rock avalanches are active."

RC – Line 441: Is it the first time this model is presented? Please state it, otherwise, references are needed

AC > The adjective "innovative" was added in the presentation of the model: "In this innovative and conceptual model, we assume that the first phase of activity transports the boulders further downstream than the second phase of activity."

RC – Line 453: text format

AC > Corrected as suggested.

RC – Line 453: Your oldest age of the dataset is 13.1 ka. Please confirm if you what to say mean age of the unit V

AC > We included a mention that this is the median value for unit I.

RC – Line 454: Exposure ages from rock glaciers tend to constrain the moment of the stabilization or absence of flow which mean that is was active before. Please, clarefy this idea

AC > This sentence was included in the manuscript: "Note that here we consider ^{10}Be surface exposure ages represent the sum of the residence time of the boulder in the cliff (inheritance), the transport time at the rock glacier surface and time since inactivation."

RC – Line 457: When is the first period of rock glacier activity ending?

AC > The end of the activity was mentioned.

RC – Line 457: Some paper have been demonstrating the relation of rock glacier development and the onset of warm periods (GI-1 or the Holocene). Please, do not exclude the possibility of climate influence and add a sentence about the Younger Dryas-Holocene transition

AC > Climate influence was mentioned in the text as well as Younger Dryas-Holocene transition.

RC – Lines 470-471: Those are important principles closely related to the rock glacier dynamics and besides that you have extimated less inheritance in the lower units (IV and V) than the upper units, so why would they preserve nuclides? I ask you to reinforce this position with facts from the field (were the boulders showing intact and sharp surfaces? were they embedded in the rock glacier crest or lying on the crest from a rock fall (Figure 2d looks they are embedded?)) If not, please references are needed to justify this statement.

RC – Line 473: see the comment above

AC > We addressed this comment in the text with: “In the present study, we interpret the ^{10}Be surface-exposure ages as being the sum of its residence time on the headwall cliff, the time spent traveling on the surface of the rock glacier, and the time since deactivation of the relict portion of the rock glacier for the relict units. Indeed, we considered that rock boulders remain at the surface of rock glacier while being transported downward. This affirmation is supported by the little variability of ^{10}Be surface exposure results obtained from the ridge replicate far from the headwall, interpreted as a little occurrence of tilting and burial events (c.f. Section 5.1). This is also supported by the rock boulder weathering evolution through the rock glacier, more weathered surface far from the headwall (c.f. Section 4.1).”

RC – Line 474: what happened during this phase? Is there any insight that can come from the end of the holocene thermal maximum at 6 ka?

e.g. Liu, Z., Zhu, J., Rosenthal, Y., Zhang, X., Otto-Bliesner, B. L., Timmermann, A., Smith, R. S., Lohmann, G., Zheng, W., & Timm, O. E. (2014). The Holocene temperature conundrum. *Proceedings of the National Academy of Sciences of the United States of America*, 111(34).
<https://doi.org/10.1073/pnas.1407229111>

AC > As no strong paleoclimatic argument allows to correlate the end of activity of phase 1 at 6.2ka, we prefer to keep our current conservative discussion.

RC – Line 474: ok! please tell the climate oscillations during this phase

AC > This comment has been addressed in the manuscript.

RC – Line 478: Here is the subsection where you discussed more the rock glacier motion and I miss the discussion of the recent rock glacier displacements in units I and II. This could be a good opportunity to compare different rates across the Holocene

AC > Discussion about modern estimate of surface displacement of the two active units has been done in section: “5.2. Surface velocity comparison and reconstruction”.

RC – Line 503: chronological order please

AC > Changed as suggested.

RC – Line 813: - The frame map should contain a visible identifier of the study area. An arrow or polygon would help. The lines look like parallels and meridians instead of the cross to identify the study area. - No need of seconds in the coordinates of the figure 1a. - Please, identify the talus slope in the figure 1b. It will help the geomorphological interpretation.

AC > All modifications were applied as suggested, thanks for those useful reviews.

RC – Line 844: Where is it?

AC > A black dotted line was present in the previous version of this figure, thanks for spotting the mistake in the legend. this sentence was removed.

RC – Line 863: Samples of what? and which purpose?

AC > Precision has been included as suggested.

RC – Line 875: delete space

AC > Space has deleted as suggested.

RC – Line 880: Do you mean, average/mean? median has another statistical mening

AC > The term median was employed and used correctly in all the study.

RC – Table 4: Why median now?

AC > The median was used for the ^{10}Be surface exposure dating values to avoid giving too much weight to extreme values.

RC – Line 890: mean/average

AC > Here it is the median.

Comment on esurf-2022-8

Authors response to Anonymous Referee #2

Dear Referee,

Please find in the following our answer to your comments.

Note that Referee comments are noted as “**RC** –“ and authors responses as “**AC** >”.

RC –The presentation of the recent rock glacier velocities based on image correlation needs revisions.

AC > The presentation of the recent rock glacier velocities based on image correlation has been revised.

RC – The description of the orthomosaic production needs revision. Without presenting the quality of the relevant parameters during orthorectification (e.g. GCPs accuracies, RMSE or SD, bundle block adjustments), the photogrammetric results are not comprehensible and meaningful.

AC > Then quality of the orthorectification and coregistration has been evaluated using 11 manual control point providing a mismatch of topographic feature on both orthomosaics. The IMCORR results haven also filtered using IMCORR parameters (xerr and yerr). Finally, 6 control areas have been defined to assess the quality of the feature tracking analysis.

RC –I suggest discussing and expanding the relevant literature in more detail (see the attached annotations). Furthermore, a table (or two) indicating all relevant parameters for each dataset (resolution, scale, number of GCPs, Tie-points per image, mean RMSE, among other parameters) should be provided

AC > The relevant literature has been discussed and expanded in more detail as suggested. Remote sensing analysis has been improved. First the ground control points (GCPs) accuracies, distribution has been provided and discussed (Figure A1 and Table A1).

We thank you for your comments and suggestions, the manuscript in its revised form has gained in quality both scientifically and clarity. Please find attached all our response to the detailed comments.

Best regards,

Benjamin Lehmann et al.

Detailed comment and answer:

RC - Line 12: Please, specify that you are talking about active - or intact - rock glaciers

AC > We specified that we are talking about active rock glacier.

RC - Line 13: This is somehow vague. What do you really mean with strongly influence (hydrological, geomorphological)?

AC > We specified the hydrological and geomorphological influence of rock glacier.

RC - Line 14: This is questionable. The quantification of the ground ice melt from rock glaciers and their role in the mountain runoff are rarely considered.

AC > In this sentence we are speaking about the "reserve" character as water storage of rock glacier and not the "resource"

RC -Lines 20-21: please consider: " Remotely sensed images and correlation techniques are used to document"

AC > This sentence has been updated following your recommendation, thanks.

RC -Line 21: Please, review this $10^1 = 10$

AC > This sentence has been changed for: "over timescales ranging from year to decades."

RC -Line 29: I do not see the need of using "rock-glacier" (with the hyphen). Please review this use thoroughly.

AC > All hyphens were removed according to suggestion

RC -Line 31: Please, remove Ka

AC > Removed as suggested.

RC -Line 38: What about the fall sorting, kinetic sieving and down-washing of fine sediments? Please, develop these ideas.

AC > To not to dive in complexity straight for the first sentence of introduction "Poorly-sorted" was removed.

RC -Line 41: What about rock glacier acceleration and destabilisation associated with rising air temperatures. This has been observed in many places (e.g. Marcer et al 2021)? Can we consider rock glaciers as resilient cryospheric bodies?

Marcer, M., Cicoira, A., Cusicanqui, D., Bodin, X., Echelard, T., Obregon, R. & Schoeneich, P. 2021. Rock glaciers throughout the French Alps accelerated and destabilised since 1990 as air temperatures increased. *Communications Earth & Environment* 2 : 81. DOI: 10.1038/s43247-021-00150-6

AC > This sentence was added to address the acceleration and destabilization you mentioned: “However, in-situ measurements since the last decades have shown rock glacier acceleration and destabilization associated with increasing air temperature in the European alps (e.g., Marcer et al. 2021).”

RC -Line 42: mountain glaciers

AC > Changed as suggested.

RC -Line 42: It is not easy to assess the importance of rock glaciers as water supplies from this Article. I recommend removing this reference.

AC > This reference has been removed as suggested.

RC -Line 43: Are rock glaciers eroding the headwalls? Please explain this.

AC > This sentence has been edited as such: “Over geological timescales, rock glaciers participate actively in the development of asymmetrical mountain crests by conveying rock from leeward headwalls (where rockfall is the primary source of debris) to lower elevations in the valley”.

RC -Line 44: The list of references needs some revision. The references Gilbert, 1904 and Johnson et al., 1980 are missing.

AC > Reference list has been updated.

RC -Line 50: the remnant of glacial deposits

AC > Changed as suggested.

RC - Lines 50-51: Please, consider including one documented case of this process by:

Monnier, S. & Kinnard, C. 2015. Reconsidering the glacier to rock glacier transformation problem: New insights from the central Andes of Chile. *Geomorphology* 238 : 47–55. DOI: 10.1016/j.geomorph.2015.02.025

AC > Reference included as suggested.

RC - Line 52: According to your second holistic view, this process will be likely quite short (few decades)

AC > Modified as suggested.

RC - Lines 54-55: Please, consider including:

Ikeda, A. & Matsuoka, N. 2006. Pebbly versus bouldery rock glaciers: Morphology, structure and processes. *Geomorphology* 73 : 279–296. DOI: 10.1016/j.geomorph.2005.07.015

AC > The reference was included as suggested.

RC - Line 60: This reference does not fit what has been declared in this sentence. Please, remove or adapt the sentence accordingly. Also, please specify that you are talking about European rock glaciers.

AC > The reference has been removed and specification of European rock glaciers included as suggested.

RC - Line 64: Please, review the use of Hyphens

AC > Hyphens were removed as suggested.

RC - Lines 67-69: This sentence is hard to read. Please, consider splitting it into two

AC > The sentence has been split in 3.

RC - Line 70: Please consider: "remote sensing tools for monitoring changes on high mountain landforms"

AC > Changed as suggested.

RC - Line 71: The work of Robson et al., 2020 does not really fit this sentence. However, the more recent work of Robson better fit this monitoring concept.

Robson, B.A., MacDonell, S., Ayala, Á., Bolch, T., Nielsen, P.R. & Vivero, S. 2022. Glacier and rock glacier changes since the 1950s in the La Laguna catchment, Chile. *The Cryosphere* 16 : 647–665. DOI: 10.5194/tc-16-647-2022

AC > Changed as suggested.

RC - Lines 74-77: It feels that this sentence is a little bit overstated. As Cusicanqui et al., 2021 only used orthorectified images derived from historical aerial photographs and recent UAV surveys, declaring satellite images seems inadequate and not right. Also, surface velocities are normally reconstructed using co-

registered orthorectified images and not DEMs. I suggest reviewing the following references for additional insights into rock glacier surface velocities using image correlation techniques:

Kääb, A., Strozzi, T., Bolch, T., Caduff, R., Trefall, H., Stoffel, M. & Kokarev, A. 2021. Inventory and changes of rock glacier creep speeds in Ile Alatau and Kungöy Ala-Too, northern Tien Shan, since the 1950s. *The Cryosphere* 15 : 927–949. DOI: 10.5194/tc-15-927-2021

Vivero, S., Bodin, X., Farías-Barahona, D., MacDonell, S., Schaffer, N., Robson, B.A. & Lambiel, C. 2021. Combination of Aerial, Satellite, and UAV Photogrammetry for Quantifying Rock Glacier Kinematics in the Dry Andes of Chile (30°S) Since the 1950s. *Frontiers in Remote Sensing* 2 : 1–17. DOI: 10.3389/frsen.2021.784015

Fleischer, F., Haas, F., Piermattei, L., Pfeiffer, M., Heckmann, T., Altmann, M., Rom, J., Stark, M., Wimmer, M.H., Pfeifer, N. & Becht, M. 2021. Multi-decadal (1953–2017) rock glacier kinematics analysed by high-resolution topographic data in the upper Kaunertal, Austria. *The Cryosphere* 15 : 5345–5369. DOI: 10.5194/tc-15-5345-2021

AC > We thanked the reviewer for pointing out these problems, and for providing the references. Changes have been done as suggested.

RC - Line 78: Please, consider the work by:

Frauenfelder, R. & Kääb, A. 2000. Towards a paleoclimatic model of rock-glacier formation in the Swiss Alps. *Annals of Glaciology* 31 : 281–286. DOI: 10.3189/172756400781820264

AC > Reference included as suggested.

RC - Line 84: Please consider: in old permafrost cores from a rock glacier

AC > Changed as suggested.

RC - Lines 109-110: photogrammetry is a subset of remote sensing.

AC > The sentence was changed for "Remote-sensing approach such as image correlation over photogrammetric products allow us to reconstruct the surface displacements field of the rock glacier over the last six decades."

RC - Line 112: Please clarify: It is unclear whether the sampling was done right on the headwall or below it.

AC > We did not sample the headwall. This was changed to "its highest part".

RC - Line 115: Consider "proxies"

AC > Changed as suggested.

RC - Line 118: Barre des Écrins is the only 4000 m on this massif. Please, clarify this

AC > The sentence was completed with the following "with its highest summit being the only one above 4000 m a.s.l. (Barre des Ecrins, 4101 m a.s.l.)".

RC - Line 126: Please check this reference

AC > Those references of unpublished data have been removed.

RC - Line 126: glacierized terrain

AC > Changed as suggested.

RC - Line 131: from

AC > Changed as suggested.

RC - Line 131: to

AC > Changed as suggested.

RC - Line 131: Use either "rooting zones" or "root zones"

AC > Changed for "rooting zones".

RC - Line 134: since

AC > Changed as suggested.

RC - Line 149: it would be better to show such values in km².

AC > Converted in km² as suggested.

RC - Lines 153-154: This is unclear. please review this

AC > this part has been deleted for clarity.

RC - Lines 166-167: DEM and landscape image analysis are not part of your field observations. Please review this section.

AC > The name of the section was changed for "Geomorphological mapping/identification".

RC - Lines 173-174: I would suggest employing "landform" for your entire rock glacier system. Ridges and furrows should be catalogued as parts of your landform.

AC > "Landforms" was changed for "ridges" in the entire manuscript.

RC - Line 174: Please, review if you are using orthomosaics (2 or more images) or orthoimages (1 image).

AC > Here we are using "orthomosaics", thanks for the clarification.

RC - Lines 175-176: This sentence should be removed or reformulated. The image correlation protocol was originally presented by Scambos et al. (1992) and not Cusicanqui et al. (2021). Also, image correlation is not part of the orthomosaic production.

AC > This sentence was modified by "The reconstruction of the rock glacier surface displacement over decade timescales is done using image correlation protocol between different orthomosaic."

RC - Line 180: Please, include the location of these GCPs on figure 1a

AC > Details of the GCPs have been included in Figure A1 and Table A1.

RC - Line 180: coordinates

AC > Corrected, thanks for spotting this typo.

RC - Line 181: LiDAR surveys normally provide information in 3D point clouds. Please, specify if you are using the original point cloud to extract GCPs or a derived product such as a DSM. In the latter case, please also provide the interpolation method from point clouds to raster grid.

AC > Details about the DSM have been added as suggested.

RC - Line 183: Pléaides

AC > Changed as suggested.

RC - Line 185: Please, specify which DEMs and orthoimages are coregistered. Also, review the difference between DEM and DSM. From what is declared, I only see the LiDAR DSM. Are you talking about the Pléaides-derived DEM?

AC > Here only orthomosaic were coregistered. Sorry for this mistake.

RC - Line 187: orthoimages are 2D (x and y); therefore, I do not see the need of using the z coordinated during the shift.

AC > Thanks for spotting this mistake, this was corrected.

RC - Lines 196-197: where are those accurate results presented? If you want to express the displacement values in imcorr, the velocity will help to recude the error as the time interval increases.

AC > Only 1960 and 2018 were kept for the remote sensing analysis. Other orthomosaics are not mentioned anymore in the revised manuscript.

RC - Lines 197-198: Why not use the earlier grid space =4m? using the same grid size among the different combinations of orthoimages ensures that the same points are concurrent.

AC > This part has been removed as only 1960 and 2018 orthomosaics were kept in the study.

RC - Lines 199-201: What about the IMCORR error estimates for x and y directions? Why not use those statistics provided by IMCORR to filter your dataset?

AC > We re-analysed the IMCORR results and proceeded to a first phase of selection with a threshold of 100 pixels for xerr and yerr (error in x and y directions).

RC - Lines 201-202: Please, provide the % of points removed for all pairs

AC > As mentioned before, we only kept the 1960 and 2018 pair.

RC - Lines 204-205: What is the vegetation cover (green patch) impact inside this assumed “stable terrain.”?

AC > More work has been done on this part. The displacements obtained on the rock glacier system are compared to the measured displacements of 6 control areas where no displacement should be observed. Details of those control area are given in Figures 3, A1, A2 and Table A3. These control areas have been chosen to be outside of and around the rock glacier system and out of the scree field. The absence of movement (solifluction, creeping, landsliding) has been determined by visually inspecting historical aerial photographs collected from the IGN-France and the two orthomosaics.

RC - Line 210: features

AC > "Landforms" was changed for "ridges".

RC - Line 217: Maybe, you should clarify that the rock glacier displays or evidence a passive transport of the blocky material.

AC > The geomorphological evidence of activity has been already described in Section 4.1.

RC - Line 275-277: The statistics of this stable terrain need revisions. The error budget should account for the different components (e.g. shifts between images, orthorectification quality and image matching uncertainties). Please, review the recent work by Kääb et al. (2021) for a better evaluation of your errors

Kääb, A., Strozzi, T., Bolch, T., Caduff, R., Trefall, H., Stoffel, M. & Kokarev, A. 2021. Inventory and changes of rock glacier creep speeds in Ile Alatau and Kungöy Ala-Too, northern Tien Shan, since the 1950s. *The Cryosphere* 15 : 927–949. DOI: 10.5194/tc-15-927-2021

AC > The analysis of the uncertainties of the remote sensing treatment has been improved as suggested. Here is the revised section: “Figures 3, 4 and 5 present the results obtained using the IMCORR feature-tracking module. The surface displacement of the control areas (dashed outlined area in Figures 3 and A1) within stable terrain shows a median displacement of 0.79 ± 0.43 m (Figures 4g, A2 and Table A3). This value represents the accumulation of error from the orthomosaic production and the image correlation procedure. The quality of the orthomosaic production can be assessed using the statistic on the GCPs showing a median absolute error of 0.57 ± 0.34 m (Table A1) and the manual control points presenting a median mismatch distance between the two orthomosaics of about 1.04 ± 0.45 m (Figure 4h and Table A2).”

RC - Lines 277-278: I am afraid I have to disagree with this statement. Failed correlation (or better false correlations) can also be above the threshold values.

AC > This part has been changed for: “This last value, being the highest of the three error estimations, is use hereafter as a threshold value to control the confidence level of our remote sensing analysis and should be considered as detection limit. Consequently, all rock glacier areas showing surface displacement lower than 1.04 m and are consequently below the detection level (dashed area in Figure 5).”

RC - Lines 278-279: Rather than considered stable, these areas are below your level of detection.

AC > Modified as suggested.

RC - Line 322: Please review this reference. Amschwand et al. 2021

AC > Reference has been reviewed as suggested.

RC - Lines 381-284: You might argue about the representativeness of your different methods (single trajectory versus area based). Image correlation provides an area-wide velocity, which might be impacted by some boundary regions (i.e slow velocities). On the other hand, the velocities from surface-exposure dating represent the travel of the boulder from different zones since the detachment from the headwalls.

AC > This part has been added to the discussion: “Those observations should be put in perspective, the remote sensing analysis for each provides an estimation on the entire area of the unit. Consequently, the median velocity of the area might be affected by the friction at the boundary conditions. On the other hand, the velocity estimated from the ^{10}Be surface-exposure dating have been calculated from samples collected at the center of the rock glacier system, where the surface velocity is supposed to be the fastest regarding a transversal cross section.”

RC - Lines 480-481: you might consider the work done by:

Humlum, O. 2000. The geomorphic significance of rock glaciers: Estimates of rock glacier debris volumes and headwall recession rates in West Greenland. *Geomorphology* 35 : 41–67. DOI: 10.1016/S0169-555X(00)00022-2

AC > This reference has been included as suggested.

RC - Lines 609-614: These entries are the same reference. Please review this.

AC > The reference list has been reviewed as suggested.

RC - Figure 3: These arrows are very difficult to read. Please, reconsider to change the arrow symbols /scale for a better visualization.

AC > The figure has been changed and revised.

Comment on esurf-2022-8

Authors response to Community comment #1

Dear Community member,

Thanks for your interest in our work and for your helpful comments.

As suggested, the Egesen stadial (alpine counterpart of the Younger Dryas) was mentioned in Section 2. We thank you for mentioning CRE ages during the Early Holocene, this sentence has been added to the manuscript: “Based on surface-exposure dating of moraine deposits, glacial advances in the Ecrins Pelvoux massif have been identified from the Lateglacial to the Early Holocene (around 11ka, Hofmann et al. 2019)”.

About the Sect. 5.4, the comments of the community member were included in manuscript. The part mentioned has been modified as such: “In a southern valley of the Ecrins Pelvoux massif, morainic deposits at Pré de la Chaumette (downvalley from Rougnoux Valley) have been dated at 12.5 ± 0.6 ka (Hofmann et al. 2019). Immediately after the onset of the Alpine glacier retreat (12.2 ± 1.5 ka in the same valley, Chenet et al., 2016), several advance episodes lasting ~ 1 ka were identified in the Ecrins massif. Dating in the south of the massif have shown glacial activity during the Lateglacial that may have lasted until the Early Holocene before final glacial retreat (around 11ka, Hofmann et al. 2019).”

Thanks a lot for your contribution!

Benjamin Lehmann et al.

Cited references:

Chenet, Marie, Daniel Brunstein, Vincent Jomelli, Erwan Roussel, Vincent Rinterknecht, Fatima Mokadem, Melody Biette, Vincent Robert, and Laëtitia Léanni. 2016. “ ^{10}Be Cosmic-Ray Exposure Dating of Moraines and Rock Avalanches in the Upper Romanche Valley (French Alps): Evidence of Two Glacial Advances during the Late Glacial/Holocene Transition.” *Quaternary Science Reviews* 148: 209–21. <https://doi.org/10.1016/j.quascirev.2016.07.025>.

Hofmann, F. M., Alexanderson, H., Schoeneich, P., Mertes, J. R., Leanni, L. & ASTER Team.: Post-Last Glacial Maximum glacier fluctuations in the southern Ecrins massif (westernmost Alps): insights from ^{10}Be cosmic ray exposure dating. *Boreas*. <https://doi.org/10.1111/bor.12405>. ISSN 0300-9483