

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.