

## ***Interactive comment on “Ice content and interannual water storage changes of an active rock glacier in the dry Andes of Argentina” by Christian Halla et al.***

### **Anonymous Referee #1**

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Paper overview: This paper determines the volumetric ice and water content of an active rock glacier in the dry Andes of Argentina. Changes in volume and displacements are also calculated and the rock glacier hydrology investigated. The paper provides a very important contribution in an area where rock glaciers are a potentially important water resource and yet there is a paucity of published data with regards to rock glacier water storage volumes, changes in ice volume, movement, and hydrology. The investigation of Dos Lenguas rock glacier is very comprehensive including two distinct geophysical methods, drone-derived digital photographs used to calculate volume change and displacement, and ample field observations to support conclusions. These data are nicely synthesized in the discussion and well-designed, clear and professional

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figures support the paper nicely. Some minor clarifications are required (mostly the methodology section). The only large modification required is to the text itself. In particular, the grammar, sentence structure, and writing style in a concise format need to be improved. In general the edits required are numerous but minor. However, the introduction could use some additional work.

General comments:

Introduction: Most of the information in the introduction is relevant and important to include. However, the introduction could be significantly improved if all the information presented contributed directly towards 1) highlighting the importance of studying rock glaciers in the dry Andes or 2) discussing the knowledge gaps in the current literature that will be filled by completing the study objectives. If structured in this way, all of the information in the introduction builds towards the objectives and a strong argument is created for carrying out the study. The first two paragraphs are good. The third paragraph (climate change and impacts on the cryosphere) could be modified to highlight the importance of calculating changes in rock glacier volume over time and mention the lack of studies available. Information that does not directly build toward this end could be removed (e.g. sentence starting on L47, L54). The third paragraph could also be used to highlight the importance of understanding rock glacier hydrology and lack of studies available, or information related to hydrology could be moved to the fifth paragraph. The fourth paragraph (velocities) could highlight the knowledge gaps related to surface velocities of rock glaciers in the dry Andes since surface velocity fields are one of the results for this paper. This paragraph could be made more concise and some information removed. It is not clear from reading the fifth paragraph (hydrology) how your third objective (hydrological structure of the rock glacier) will provide a new contribution to the literature. Please modify this paragraph so that it provides the reader with a clear understanding of the importance of this objective.

I have reviewed the introduction in detail for sentence structure, grammar and to make the text more concise. Please complete the same exercise for the rest of the publication

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before re-submitting (a native English speaker should do this). I have suggested some changes, but have not thoroughly reviewed the document in this context. A copy of the paper is attached in which I have highlighted text that I noticed should be reviewed and likely modified while reading through the text.

L87-103 These two paragraphs describe the objectives of the study and place these objectives in the context of previous studies in the area and knowledge gaps. The information presented is good, but there is repetition of information in the two paragraphs so I would like to suggest merging these two paragraphs, removing any repetitive information, and making the text more concise.

Minor grammatical comments:

Note: If a point pertains to a particular sentence, I have referenced the line number the sentence begins on.

L11 Change “contents” to “content” here and throughout the paper L20 Suggest removing “rates” since it is the precipitation that is stored, not the precipitation rate. L21 Suggest explicitly stating that these results are derived from the geophysical data and modify the sentence so it is a bit more intuitive to read as follows (or something similar): “Geophysical results show heterogeneous ice and water content with ice-rich permafrost and supra-, intra- and sub-permafrost aquifers in the subsurface.” L24 In this sentence the author is trying to stress the importance of the water reserve stored in Dos Lenguas rock glacier. However, the statement is not very strong because a volume estimate is compared to a % area covered so it is not possible to evaluate the importance of the reservoir with the information in the sentence. Is there data available to report an approximate value for the ice volume (.e.g in kg) in the mountain catchment? L27 Suggest removal of “that are”. It is unnecessary. L33 Suggest removing “Besides storing large amounts of sediment” since this takes up space and does not add to the discussion here. L37 This sentence seems out of place and disrupts the flow of the introduction. It would make more sense to incorporate this

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into the final two paragraphs of the introduction or delete it. If it is retained, I would suggest rewriting the latter part of the sentence as “whose material source is derived from periglacial talus slopes.” The term slope already implies that the material is coming from a valley slope, so there is no need to specify this. L41 It is not clear what the author means by “higher” and it does not seem necessary to include this. I would suggest rewriting the latter part of the sentence as follows “..predicted to increase at a faster rate compared to lowland areas.” L42. Concomitant is not a commonly used word. I would suggest changing it to a synonym such as “associated.” L46 Change “discharges” to “discharge”. L59 Change “sings” to “signs” L59 Change “manifested in” to “manifested as” L60 Change “showed” to “shows” L63 Change “indicating increased” to “which increase” L64 Suggest changing this sentence to “Thus, rock glacier movement is impacted by hydrology and ground temperatures.” L65 I think this sentence would read better if it was divided into two and written in a more concise way. For example “Interannual vertical variations of the surface topography are mostly related to the mass balance of rock glaciers (Kääb et al., 1998; Konrad et al., 1999). Annual mass balance and discharge are significantly lower for rock glaciers compared to glaciers (Krainer and Mostler, 2002). L72 Suggest removing “on the temporal scale” as it is unnecessary. L76 Suggest removing “add significant amounts of” to make the sentence more concise. L77 This sentence does not make sense and should be reworded. I would suggest “Active layer and permafrost (e.g. rock glaciers) regulate shallow ground water drainage and throughputs functioning as an aquifer, aquitard, and/or aquiclude (Jones et al., 2019)..” L80 Here it is not clear what depends on the water input and different hydraulic properties. Do you mean to say the buffering capacity depends on water input and different hydraulic properties? Please specify. L84 Please add “have” to the sentence. “. . .studies have investigated” L92 Please change “an” to “a” L102 Change “contents” to “content”. L109 Suggest removing “few” and “different” as these are unnecessary. L12 Suggest changing to “. . .discontinuous permafrost extends to ~4000 m a.s.l. potentially covering large areas within the basin and includes active rock glaciers..” L125 Please indicate

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the subject matter of these previous studies briefly L188 In order to obtain a volume estimate it would have been necessary to multiply each raster value by the cell size, then sum all the raster pixels overlapping the rock glacier. Please specify this here so that it is clear. L189-191 This sentence could be improved and made more concise. For example “ First order estimates of interannual water storage changes are derived, assuming the volumetric changes are mainly caused by melting or gaining of ground ice at the active layer / ice-rich permafrost boundary.” Note that “changes that do not equal zero” is implied and does not need to be explicitly stated. L201 How was the standard deviation of the error of each DEM calculated? Did you use the 34 GCPs to calculate the standard deviation? Please specify here. L203 Here it makes sense to say that you have masked out values less than the LoD ( $< \text{LoD}$ ). However, I am not sure what masking out values  $> -\text{LoD}$  refers to. Could you be more explicit here? L207 It is not clear what these references refer to. Do you mean to say that you used the methodology of Hauck and Kneisel (2008) and Kneisel (2008)? If so, you could write (following Hauck and Kneisel, 2008. ...). L208-210 I think that this comment would fit better in the discussion section when you compare your results to other studies. Here, it distracts the flow of the methodology section and would be more useful in the discussion. L216 Please indicate somewhere in the methods how the y-axis depth scale was obtained for both the ERT and SRT along with any uncertainties. L217 Perhaps change “while” to “then”. I am assuming that the injection of current and measurement of potential difference does not occur exactly at the same time. The injection is first, then the measurement. L223-225 Please indicate the spacing between electrodes. This is indirectly mentioned in the seismic section, but it would be good to explicitly mention it here. L231 Please indicate the maximum depth range obtained after the inversion process (e.g. 20-30 m). Also, were the ERT data topographically corrected? If not please justify why this was not done in response to this comment. If yes, please specify how the GPS data were collected (type of GPS). This comment also applies to the seismic refraction section. L227 Change “have been” to “were” L255 Consider changing “according to” to “in alignment with” L282

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How is the rock fraction (fr) determined? Please specify. L338 Please be more explicit here and define what is meant by “paired positive and negative annual volumetric changes.” Are the pairs made up of a furrow and a ridge? L340 change “in” to “to” L354 How do you know that the changes in the water storage occurred in the active layer? I would assume that you could have changes below the active layer and this would still be expressed as a change in elevation at the surface. Consider modifying this sentence. L355 In this sentence are you saying that a change in the active layer depth, without a change in water storage, could result in a change in volume? That seems to be what is implied. Please clarify and explain why this would result in a change in volume. L358 Suggest changing “regarding the” to “with a.” L365 Change “was” to “were” L369-374 Please modify these sentences to make the more concise and avoid repetition of information. L382 I think this final sentence is more appropriate for the discussion section, than the results section. L394 Suggestion to change “to be invoked by variable active layer and permafrost conditions” to “as follows” L397 The sentence starting on this line is useful information to include, but disrupts the flow in this paragraph and is a very general statement related to the interpretation of resistivity values in permafrost. Consider moving this to the methodology section or removing it. Also, it would be good to simplify this sentence. For example, “Resistivity values are impacted by substrate characteristics (lithology. . .” L399 Suggestion to make this sentence more concise. For example “Thus, we interpret the active layer to be mainly characterized by very dry . . .” L403 Consider modifying to “Horizontal and vertical contrasts and anomalies of resistivity permitted a clear delineation of the permafrost body within the rock glacier.” L404 This sentence repeats a lot of information already mentioned in the sentence that starts on L399. Please combine it with the sentence on L399 in a concise format. L409 From the photographs it looks like there may be a fair amount of finer sediment (e.g. sand sized). If this is true do you think that air voids in the subsurface would be filled by these sediments? Perhaps your field observations could help the interpretation here. L419 After reading this paragraph it seems that there are three layers: 1) < 1500 (sandy material), 2) 1500-2000 (transition

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area from unfrozen to permafrost), and 3)  $> 2000$  (permafrost). I think the paragraph would be easier to follow, would flow better, and would be more concise if rewritten as follows (or something similar) starting at L419 “The upper low velocity layer ( $<1500$  m  $s^{-1}$ ) was interpreted to represent unfrozen areas, followed by a transition area ( $\sim 1500$ - $2000$  m  $s^{-1}$ ; corresponding isolines shown on Fig. 6), then the highest velocity area ( $> 200$  m  $s^{-1}$ ) interpreted as permafrost. The transition layer between unfrozen debris and permafrost observed on previous seismic surveys of rock glaciers in the study area during summer (Croce and Milana, 2002; Schrott, 1994), could either indicate the presence of water ( $v_w = 1500$  m  $s^{-1}$ ) and lower ice content and/or be related to the vertical resolution of the smoothly inverted p-wave velocities.” L420 Do velocities of 1500-2000 definitively indicate permafrost? If another interpretation is possible, consider changing “indicates” to “is interpreted as ” L429 Please remove “and” directly before “volcanic rocks” as it is unnecessary. L433 Upon comparing the ERT and SRT most of the anomalies (ice-rich areas) roughly correspond, except on L1 at  $\sim 50$  and  $\sim 210$  m where there are large areas that are highly resistive. These two areas are not apparent on the SRT figure. It would be good to address this difference in the text somewhere. L434 Please remove “yet” as it is unnecessary. L445 add “porosity” after 70% e.g. “. . .50%, and 70% porosity, respectively.” L496 Suggest removing “however.” Including “however” implies that your results are not that useful and undervalues your work. I think the results are very useful and would therefore suggest removing “however.” L498 This sentence is redundant as much of the information is provided at the end of the next paragraph. It also makes it sounds like your results are very uncertain which contradicts the strong statement in the second paragraph that balances derived from volumetric surface changes reliably estimate interannual storage changes. I would suggest removing the sentence starting on L498 or incorporating the info here into the final sentence in the last paragraph. L520 Change “reasonable” to “reasonably” L534 Please change “have lower confidences” to “are of lower confidence” L536 Please add “the” so the sentence reads “. . .in the deepest model areas.” L538 rewrite sentence as “. . .7.4% with only 7.7% filtered. . .”

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L547 rewrite sentence as "...in turn ice content might ...". Also consider providing a very brief explanation for the underestimation in ice content. L567 change "contents" to "content" L653 Are the depths (e.g. 20-25 m) the distance from the surface to the shear horizon, or the thickness of the stiff basal layer? Please specify. L692 Here, do you mean to say that the total discharge at the spring is equal to 14-30% of the Dos Lenguas liquid water content in late summer? Please modify the sentence to be more explicit. L693 Does the "total liquid water content" refer to the liquid water content calculated for the Dos Lenguas rock glacier? I would assume so, but it would be good to specify this in the text. L716 suggestion to summarize your results in this section. The conclusions are a qualitative discussion at present, and I think the section would be much stronger if you summarized your main results quantitatively and main points from the discussion briefly. Fig. 4 The units for vertical change are in "m yr<sup>1</sup>", but likely should be changed to "m yr<sup>-1</sup>". Fig. 4 In general the figure is easy to understand and nicely displays the data. However, it is not clear if the bar graphs refer to data at one point location or a ridge and furrow set. I am assuming a ridge and furrow set as explained in the text, in which case it would be good to add a line or box on the glacier image to identify the data source (e.g. ridge and furrow pair). Fig. 7 It would be helpful to briefly describe the legend at the top of the figure in the caption. Table 1 Change "of" to "for" in the caption. Table 2 Please modify the caption to describe what is contained in the table in more detail. Table 4 The text at the very bottom of this table is very hard to read. Please increase the font size. Table 5 Remove "]" for 2016-2017 period header

Please also note the supplement to this comment:

<https://www.the-cryosphere-discuss.net/tc-2020-29/tc-2020-29-RC1-supplement.pdf>

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