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Interactive comment on "Active and inactive Andean rock glacier geophysical signatures by comparing 2D joint inversion routines of electrical resistivity and refraction seismic tomography" *by* Giulia de Pasquale et al.

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Dear editor, With respect to the comments from Referee #2, we have addressed the major concerns and specific comments indicated by the reviewer in this document. The figures modified accordingly to the comments of Referee#2 are included in the answer to Referee #1.

1) General comments Target audience: I feel that the two objectives (both of which are really interesting) present a challenge, because the latter (comparison of structurally

and petrophysically-coupled joint inversion approaches) requires a lot of prior knowledge on the two inversion approaches (and regularized inversion in general) considering that TC targets a broad (and not necessarily geophysical) audience. In contrast, a reader with an expertise in geophysical (joint) inversion would probably be interested in a more detailed comparison of the two approaches, i.e., a comparison which allows to see under which circumstances one approach outperforms the other for instance. Such a comparison should also come with a discussion on the motivation of two approaches. For example: Are structurally coupled joint inversions (and the underlying assumption of structural similarity) appropriate in a permafrost context, where a transition from ice to air can result in an order of magnitude change in velocity, while electrolytic conduction stays negligibly low?

Indeed, we agree with this review and we decided to change the title and focus of the manuscript to the geophysical signature difference between stagnant and inactive rock glaciers. The new proposed title is now "Geophysical signature of an intact and stagnant Andean rock glacier". In the new manuscript, we focus on the individual inversion results and present the petrophysical joint inversion to aid the interpretation of the differences in the geophysical signature of the two rock glaciers and completely delete the structural joint inversion approach.

Scope and objectives: Somewhat related to the previous point, I question if the 3 inversion approaches and their comparison are actually necessary for the conclusions drawn in this paper. In the key figure 9 for example, which the authors use for drawing several conclusions and recommend as a diagnostic tool for future studies,only 2 of the 3 inversion approaches appear and the corresponding inverted velocity and resistivity distributions and thus also the scattered points look very similar. This makes me wonder, if this case study could be presented with individual inversions only, while a follow-up study could then focus on a detailed comparison of joint inversion approaches in a permafrost context.

Accordingly to this and the previous comments, we re-structured and re-focused the manuscript as briefly presented above. Figure 9 has now been changed with a resistivity-velocity density plot to address the lack of correlation pointed out by reviewers 1 and 3). The new figure is still useful as a diagnostic plot and we have rewritten section 5.4 accordingly:

5.4 Towards a diagnostic model representation for the ice presence in rock glaciers.

The results from the petrophysical joint inversion help quantify the volume content of air, water, ice and rock and identify El Jote as relict and El Ternero as intact rock glaciers. However, in many cases such an interpretation is limited by the lack of proper petrophysical models (or parameters). When petrophysical model coupling is not possible, the comparison of velocity and resistivity model inversion results can still deliver plenty of information about the rock-glacier's internal structure. In Fig.8 we show resistivity-velocity density plots for each rock glacier, built from the individual model inversion results of figures 4(c),(d) and 6(c),(d). The differences between the two rock glaciers are clearly noticeable, with relatively low resistivity and low velocity clusters for the relict rock glacier, while the intact one is associated with higher velocities and resistivities. The relatively low resistivities and low velocities (Fig. 8a) are in agreement with air filled unconsolidated sediments inferred through the petrophysical joint inversion results (Figs. 5e,f). The lowest resistivities may be associated with liquid water and/or a proglacial aquifer (Fig. 5c; section 5.2). The gradual increase in resistivity and velocity (Fig. 8b) are evidence of material consolidation such as bedrock or ice-rich layers. Given the very high resistivities (over 10ˆ5 Ohm m) our interpretation is that these are ice rich layers (Table 1, resistivity values), which agrees with the petrophysical joint inversion results (Fig. 7d). The rather different appearance of the two density plots (Fig. 8a and b) can be used as an indicator of the distinct nature of the two rock glaciers: overall, the stagnant rock glacier is characterized by lower resistivities and velocities while the intact rock glacier is indicated by higher resistivity and velocity values, reflecting the ice rich layer. The schematic plot (Fig. 8c) summarizes the findings for our two end-member rock glaciers and could be useful for identifying ice-rich landforms using

seismic and electrical resistivity methods.

Brevity: Some figures are discussed too briefly. The first paragraph in subsection 4.1 for example ends with the sentence "The model results for El Jote are given in Fig. 2(a) and (b)." (line 275). This should be directly followed by a discussion on what can be seen in Fig. 2. The reader is left alone here until the figure is briefly mentioned again in the next subsection (4.2, line 322). Furthermore, subsection 4.1 ends with a single sentence on which quantity is plotted in Fig. 5. A further discussion on this figure and the shown residuals is missing.

We address the brevity issue within the manuscript adding a proper description of each figure within the text. Also, because the focus is now on the individual inversion results as principal tool for the building of a diagnostic model, we presents the collected datasets and inversion results separately for each rock glacier in new Figure 4 (for El Jote) and Figure 6 (for El Ternero) and comment on those within the text. Moreover, we avoid presenting Figures 5 and 8 simply referring to the chi2 values as a measure of the goodness of fit.

Structure: The paper formally follows a standard structure, i.e. introduction, methods,results, discussion, conclusions and outlook. However, the current version of the manuscript deviates from this structure several times, which is confusing for the reader. For example section 3 "Methods" contains a lot of theory and could be renamed more appropriately to "Theory and methods". Furthermore, many details with regard to the processing (e.g., used correlation lengths in the geostatistical regularization, choice of regularization strengths using L-curve analysis, choice of starting model, etc.) appear in the results section (rather than in methods). The manuscript would benefit from a clearer differentiation between theory, methods and results.

We have followed the suggestion and changed the title of section 3 in Theory and Methods and summarize the processing and inversion parameter choices in a new subsection of it:

3.3 Data processing and Inversion The ERT observation were automatically filtered by the acquisition software which did not take measurements when the contact resistance was too high, while for the seismic refraction traveltime, we manually picked the first arrivals after applying a gain to the seismic traces and therefore the traces were filtered according to our ability of identify the first arrival times. The inversion algorithms we use in order to interpret the geophysical observations are part of pyGIMLI, an open-source library developed in python for geophysical inversion and modelling (Rücker et al., 2017). On each rock glacier we implement the same discretization mesh for both ERT and RST inversion routines and use a regularization weight of lambda= 10 for the inversion of all the dataset, chosen according to the L-curve analysis (Hansen, 2001). A schematic plot of the L-curve analysis for each dataset collected is given in Figure 3, in all cases we present the model solution L2-norm against the residual L2-normobtained for lambda=1, 5, 10, 15, 50 and 100. For both rock glaciers we use an homogeneous resistivity starting model, with a value equal to the median of the apparent resistivities (rho_mediana= 4561 Ohm m for El Jote and rho_mediana= 36054 Ohm m for El Ternero) and a gradient model for the seismic velocity, starting with 300m s$\hat{}(-1)$ at the top of the tomogram and gradually increasing to 5000 m s$\hat{}(-1)$ at the bottom of it. In each case, we refer to the error-weighted chi-square fit, where chi2= 1 signifies a perfect fit (Günther et al., 2006), to quantify the resulting model parameters' ability to explain the field observations. Moreover, in order to quantify the volumetric percentage of water, ice, air and rock within each of the two rock glacier, we implement the four phase petrophysical joint inversion scheme presented by Wagner et al. (2019) and tested in Mollaret et al.(2020). For this inversion scheme we kept the same discretization meshes used for the individual inversions. The methodological details regarding this inversion algorithm and its application for this case study are given in Appendix A.

Missing information / lack of clarity I had problems following the data acquisition and processing. For example: Where were the off-line shots located? I feel that an additional figure illustrating the roll-along scheme and source/receiver positions,potentially

in combination with Fig. 1, would come a long way here. With regard to the processing, not much information is given. How was the data quality? How did the authors process and filter the data sets? Please provide a plot with raw and filtered seismic and electrical data (e.g., apparent resistivities and apparent velocities) and explain the filtering steps applied.

We have addressed this point adding the new subsection 3.3 Data Processing and Inversion and clarifying in section 3.2 Acquisition strategy the location of the off-line shots on El Ternero: "The total length of 575 m was then obtained by moving the 24-channels set-up four times and adding off-line shots (Fig. 2f) to link the different acquisitions at distances of 5, 15 and 25 m from the last geophone at each end of the cable."

We have modified Figure 2, where we show aerial images of the two rock glaciers, to include the location of the geophysical survey line and its topography (from DGPS measurements) with schematics to clarify the roll along schemes and geophone-inline/offline shots positions. The filtering is addressed in section 3.3 Data processing and Inversion (above), and we show the filtered data in the new Figure 4 and 6.

2) Specific comments:

First line of abstract: "four-times"->"four times"

Modified accordingly in the manuscript.

Third line of abstract: Please rephrase or explain "human pressure"

Rephrased: human pressure on water resources.

L14: "four-times" -> "four times"

Modified accordingly in the manuscript

L45: "semiarid" was written with hyphen ("semi-arid") earlier in the abstract. Be consistent.

Modified as semi-arid.

L56: This sounds as if there were only two options, but borehole-based geophysics and a combination of approaches exist as well.

Reformulated: Rock glacier composition can be derived from direct observations (e.g., boreholes logs, outcrops, tunnels and temperature measurements), borehole and surface-based geophysical observations (Hausmann et al., 2007).

L74: "their" is unfortunate here as it could refer to both the glaciers and the inversion methodologies.

Reformulated: These methods ability. . .

L105: Space missing between number and unit (3020 m)

Modified accordingly in the manuscript.

L130: "Geophysics measurement" ->"Geophysical measurements"

Modified accordingly in the manuscript.

L136: "collects" sounds a bit too easy (data is easily collected, but the parameter estimation is a bit trickier). Maybe use "tries to infer" or "aims to estimate"instead.

Reformulated: ERT aims to estimate. . .

L152: "Following Maurer and Hauck (2007) methodology" -> "Following the methodology of Maurer and Hauck (2007)"

Modified accordingly in the manuscript.

L210: Does it really enforce structural similarity? I think "promote" would be more correct here.

The section 3.3.1 Structural joint inversion has now been removed from the manuscript.

L223: So what's the difference to the superposition of damping and smoothing then?

The section 3.3.1 Structural joint inversion has now been removed from the manuscript. Nevertheless damping in this case referred to a regularization which favors model close to a reference one while for smoothing it favors models with less parameter variability.

Eq. 5: Is Phim the same as in equation 1 here, i.e. does the petrophysical joint inversion use geostatistical regularization as well? Otherwise, I'll recommend using a different symbol. The section 3.3.1 Structural joint inversion has now been deleted and section 3.3.2 Petrophysical joint inversion is now in appendix. The regularization in case of petrophysical joint inversion is now the only one referred with the symbol ÏŢm

L243: "constrain" -> "constraints"

Modified accordingly in the manuscript.

L255: "no-physical" -> "non-physical"

Modified accordingly in the manuscript.

L259: Please provide more justification here. How and for which substrate types were the literature values determined? What assumptions are implied by using them to your study sites? Added in text: Such parameters are of value in periglacial environments and consistent with the relevant physical parameters for ERT and RST value also presented in Table 1, nevertheless geotechnical in situ measurements could improve the estimation of those and therefore the accuracy of the inversion model results.

L261: Remove comma after Wagner et al. (2019).

Modified accordingly in the manuscript.

L269: "we implemented". Was it really implemented from scratch or were codes available / provided to you? Please specify or reformulate to "we applied based on the implementations provided by Jordi et al. [...]".

This part has been removed in the new manuscript.

L271 and L319: I suggest to use rho_mediana instead of rho_aˆmedian. Otherwise, the apparent resistivity rho_aˆmedian cannot be differentiated from the resistivity times a factor a,i.e. rho_a.

Modified accordingly in the manuscript.

L276-279: These details would fit better in section 3.

This part has been removed from the new manuscript.

L293: "(Mollaret et al., 2020)" -> "Mollaret et al. (2020)"

Modified accordingly in the manuscript.

L307: Subscripts are capitalized here (but not in equation 6).

This equation has been removed from the text, agreeing with reviewer 1 we decided that such analysis was redundant and rely on chi2 for the quantification of the goodness of fit.

L309-311: This would be better suited in the section of data acquisition.

Modified accordingly in the manuscript.

L328: I appreciate that the authors use the same colorbar limits to allow visual comparison. I think this is valuable between the inversion approaches of a single profile, but there is no reason to keep it the same for the different sites as well. It is somewhat unfortunate that velocities of up to 7000 m/s appear for El Ternero,while the colorbar is limited to 4000 m/s. As a consequence, Fig. 6 is mainly yellow.

New figures presented with modified colorbar.

L369-L370: Please elaborate: What is meant by remaining ambiguity within the interpretation of observations?

This part has been removed from the manuscript.

L406: Redundant space after opening bracket

Removed in the manuscript.

L412: It looks like the colors in Fig. 9 have changed (red is joint inversion) and black vs. blue.

Figure 9 has been modified (see general comments)

L462: Missing space after period.

Modified accordingly in the manuscript.

L467: Missing space after comma.

Modified accordingly in the manuscript.

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