

The Cryosphere Discuss., referee comment RC1
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Comment on tc-2021-206

Jigjidsurengiin Batbaatar (Referee)

Referee comment on "Towards accurate quantification of ice content in permafrost of the Central Andes – Part 1: Geophysics-based estimates from three different regions" by Christin Hilbich et al., The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-206-RC1>, 2021

Dr. Hilbich and their colleagues measured resistivity and seismic wave propagation in large number of sites in the Central Andes. Their aim was to distinguish ice from their survey data. They also drilled through some of the landforms to check the validity of their geophysical surveys. It is a very data-rich paper and I commend their efforts. The authors state that they collected their data as part of "environmental impact assessment" commissions, and I am truly happy to see that the authors got the permission to publish these privately-funded surveys. It is rare to see such data published and made available to the public. I would like this paper to be published after the following general issues are addressed and the manuscript revised accordingly:

- The main results of this paper, the ERT and RST profiles, appear to be published already in a series of reports (e.g., see my comments below for Ln 187–188). However, this fact was not explicitly stated/disclosed in the paper. The formatting of the references to the reports is incomplete and makes it hard to figure out the publisher of the reports and where to find the access to these reports. It is OK to summarize published results in addition to new results, but it would not be OK to present published data as new result. It is up to the editor how to handle this. Please consult with the editor. Please also make it clear in the text whether the data reported in this paper are new and never published before or not. It could be just my misunderstanding, but I get this notion from reading the text, so it's important to change the writing about this issue to avoid ambiguity.

- The interpretation of the tomographies and the results derived it depend on the 4-phase model (4PM) but the model was not described with enough detail. In other words, the very reason to accept the reported results as feasible is not provided properly. It may be familiar to geophysicists, but other readers don't know how 4PM distinguishes between the four "phases": rock, water, air, ice.

- Maximum and/or minimum values of the color scales used in the ERT and RST don't

match the actual colors in the tomographies. Color blind readers, for example, may not perceive the differences between the colors in the tomographies, and may use the values listed on the color scales to get the wrong impression that such values are expressed in the tomographies where it's not. Make sure every color scale actually matches the values of the tomographies.

Below are specific comments pertaining more or less to certain scientific questions/issues that needs to be addressed before publication:

Ln 128–135: Please mention "ice, water, air and rock" being the four "phases" in the model at the first instance/sentence where you introduce it. Most readers with relatively less experience with geophysical survey methods (like myself) the four phases denote something else: solid, liquid, gas, and plasma. The confusion arises especially when I read "...consistent estimates of all 4 phases..." in Ln 134. Another point in this section is that it's not clear from text how PJI model achieves similar estimates of ice, water, air, and rock content without prescribing porosity. You didn't end up using this model in your research, but you still need to explain what PJI is to your non-geophysicist readers.

Ln 142–143: Did you follow their approach to estimate the uncertainties in your data? If true, say so here, because there's no other place where you discuss the uncertainty calculations.

Ln 149: It is not clear how the ZOIs were selected for each profile. What does "assumed to be representative"? Who is making this assumption? You, the authors, or Etzelmuller et al. (2020)? This is a good example where you should use first-person narrative: "We selected ZOIs based on our assumption of this and that factors, following the previous approach by Etzelmuller et al." This is important because the characterization of ice-rich/poor units in each profile relies on the selection of ZOIs, and you've spent only three sentences to explain what ZOIs are.

Ln 157–159: I commend the authors' effort to convince the private companies to release the data and make it available for the broader scientific community. I wish more private data would become public like this.

Ln 187–188: Wait a minute--does "All profiles have been analyzed and interpreted" means the results of this paper was already published somewhere? Please clarify. The references cited after this statement all appear to be reports published in the city of Fribourg. Who is the publisher of these reports? How can the public access these reports?

Ln 362–364: The actual description of ZOI is finally provided here in the Results section, not in the Methods section.

Section 5.1: Ground truthing vs. tomographies

I appreciate the fact that the authors earnestly discuss the shortcomings of the borehole and geophysical surveys. Would it be a big ask if I suggest you to provide your opinion on how to incorporate these 'ground' data with remotely-sensed data? I'm only asking this because you've mentioned in the Introduction section that the remote sensing studies made their interpretations without consulting any 'ground' data.

Ln 533–534: The volume of ice in the colluvial slope depends on how you define its perimeter? Please explain why the extent of the colluvial slope is defined as it's shown in Figure 15. It looks rather an arbitrary ellipse. At least the satellite image in the background is so flat that the topography is not apparent.

Ln 545–546: Show the North arrows in the pictures. Provide the source of the satellite images in the background. Indicate that these are not perspective images, but flat map-view of the satellite images.

Ln 559: I commend all the efforts you've put into these geophysical surveys and drilling, and I agree that ground data is always better than the low-resolution remotely-sensed data. However, dismissing the remote sensing studies as "approaches without a solid data basis" is not a helpful contribution to science. The remote sensing-based studies are first-order estimates where there's no ground data exist, but they're based on reasonable assumptions about the ground conditions and their manifestation on the satellite data. Please educate us how remote sensing approaches should be improved using your data, instead of dismissing them with no consideration.

Below are somewhat nit-picky comments I made regarding the grammatical and technical corrections. The paper will greatly benefit if the authors address these issues and revise the text/figure/tables accordingly:

Ln 45: This sentence is continued from "On the one hand" in the previous paragraph. It's not a good idea to form a new paragraph by this sentence.

Ln 46: replace methodology with "methods". Methodology is the study of methods.

Ln 45–48: Maybe place the references after each of the reasons for the disputes. In other words, take the references after "...is disputed" and put after the reasons to make it clear which reference is cited for what reasons of dispute.

Ln 57–59: It's not fair to say "with only very few exceptions" when there are plenty of ground measurements, especially done by local scientists and reported in Spanish. It's not that the ground data doesn't exist, maybe it's that the existing data is not integrated enough into the new measurements of ice in periglacial landforms. For example, Trombotto et al. (2020: <https://doi.org/10.1002/ppp.2044>) show that the amount of groundwater flowing into the rock glaciers may dictate the ice content in rock glaciers. I agree with more field observations needed to better constrain the ice content. Please rephrase the sentences in Ln 53–59.

Ln 92 and everywhere else: Please replace methodology with "methods". Methodology is a study of methods. For example, the last sentence in this paragraph would read like this: "This study of methods include..." where in fact you meant to say "These geophysical methods include..."

Ln 109 and elsewhere: Please use first-person forms as much as possible. Directly say "We collected ERT data in the field using..." It's unambiguous who did what. Sometimes, especially Discussion section, such third-person narrative may cause confusion whether it's referring to data collected by the current authors or from a cited reference.

Ln 124: Which spelling is correct for REFLEXW or Reflex-W (in Ln 108). Please make them consistent.

Ln 125–127: Please be consistent in reporting the uncertainty/error. For ERT it's reported in % but it's reported in ms for RTS. Another point is that the RST is presented in velocity, m/s, but here's it's the return time I believe, in ms. Please state what the actual physical parameter/property it's referring to. Don't just say "... RMS...were below 3 ms for RST..." leaving the readers to guess what it's referring to. The RMS in the RST reported in % in Figure 8, for example. I suggest reporting all errors in the unit they were presented in figures, ohm-m and m/s, and use it consistently throughout the text.

Ln 186: The "profiles" cannot be measured. Maybe say "We measured electric resistivity along 19 profiles on..." Again, please use first-person narrative to be more specific about who did what.

Ln 186–187: I'm guessing the numbers in the parentheses are number of profiles for each landform from the fact that 16+3, but it's not clear at all. Please fix and don't leave

anything to guess for the readers.

Ln 308: What is the source of this hydrothermal condition? Is there active volcano/vent nearby? What other evidence you have that the bedrock could have been hydrothermally altered?

- Why are all tables embedded into the manuscript as images? Turning the numerical and textual data into images makes it hard to recognize via text-to-speech programs for disabled readers, and significantly reduces the data discoverability, which may lead to lower citation otherwise. I don't know if the authors actually provided their data in editable tables, but the PDF conversion turned them images. Make sure that the data tables are provided as readable numbers and text in the published version.

Ln 389: As far as I can read from Figure 10C, there's no bedrock there. Talus, rampart, rock glaciers are all depositional landforms made of sediments. Clarify what you mean by "...higher P-wave velocities (bedrock) is apparent...".

Table 1:

- Provide explanations for the other abbreviations in addition to the various landforms (ERT: Electrical Resistivity Tomography; RST: Refraction Seismic Tomography; CL: Chile; AR: Argentina)

Table 2:

- Provide unit for altitude (m asl?)

Table 3:

- Change to "Overview of" not 'over'

- I'm guessing 'y' means yes and 'n' means no. Please change the text so that it's clear that 'y' is for confirmed, and 'n' is for not confirmed. Don't leave anything to guessing.

Figure 1:

- Enlarge the font size of the lat/long in the main index panel

- Include the units and direction of the lat/long values. In other words, replace negative numbers with no units with 70°W and 30°S etc.

- Indicate the north orientation in each of the panels A–F. If north is up on all maps,

please say so in the figure caption.

Figure 2:

- Very nice. Clearly shows the variety of the landscape. This is a nit-picky stuff, but I think it looks better and grammatically correct if the second words were not capitalized. Protalus rampart in panel D is hard to read, maybe move the label to the right over the sky?

Figure 3:

- Include the name of the parameter (resistivity) next to the color scale.
- Please make the second words small-cap (i.e., Rock glaciers I; Protalus ramparts etc).
- I don't understand the purpose of the label "COARSE-BLOCKY SITES". If the intention was to indicate that these profiles are select few from only sites with large bouldery covers, it's better to say so in the figure caption. Because of the placement of this label, it gives an impression that that the profiles A01, A03, A09 and A07 are coarse-blocky sites and the the rest are rock glaciers I.
- Is there a really good reason for why Y-axes are elevation in some profiles, and depth in others? It is visually wrong and makes hard for the readers to compare the profiles. Please make them all in depths. I understand it's important to indicate the elevation here, where landscape can change rapidly depending on elevation, so maybe indicate the elevation of the top surface in each profile?
- The values of depth in profile A15 is positive, where every other depth values are negative as it should be. Does this mean the profile A15 should be flipped? Please fix.

Figure 5:

- Include the name of the parameters (resistivity and velocity) next to the color scales (vertically) in the top two panels.
- Spell out ERT and RST, even if it's repeated many times in the text. If you think the labeling of the parameters next to color scale is enough, you may even not need to say ERT and RST.
- Nit-picky stuff: Don't capitalize "Ice content". It's not an abbreviation like in ERT and RST. Move the "Ice content" next to the color scale (vertically.)
- The minimum of the color scale for ohm-m in panel A goes down to very dark red corresponding to 10^2 , but I don't see such dark red on the profile. Please confirm the min and max values shown in the profile and make sure that the color scale is extended between the actual values shown in the profile. Otherwise, the color scale might give a false impression that the ERT goes all the way down to 10^2 , because this rainbow color scale can be hard to separate the colors especially for color-blind readers.
- There's plenty of white space--don't abbreviate "absolute" in panel A and "average" in panel C.

- The labels inside the panels appear small (e.g., much smaller than the numbers on the axes). Please consult the journal's guide on figures and make sure these labels are big enough when they're shrunk and fitted into the publication format.

Figure 6:

- Include a label on the figure indicating which of these three pieces is top and which is bottom. Otherwise, the photo looks like three different cores, not three pieces of a single core. Caption says the upper part is ice, but it leaves the reader to guess that the upper salmon-colored piece is the one with massive ice. Most of the readers of The Cryosphere distinguish ice with crystalline texture from sediment with granular texture, but there are readers who can't tell. Don't leave anything to their guess. The transition between the ice and sediment-rich segment is really nice in the photo! The gradient of the green hue in the middle of the core can even be used to estimate the abundance of the sediment in the ice. Really nice!

Figure 7:

- Include the name of the parameter (resistivity) next to the color scale.
- I don't see any intense dark red colors in the profiles. Adjust the color scale to correctly show the actual minimum and maximum values represented in the profiles.
- Replace the elevation in panel for E16 to depth, the same as the other two profiles. Otherwise, explain in the caption why E16 is shown in elevation and the other two in depth.
- What is the purpose of including zones not related to a talus slope? Particularly in E16 almost 80% of the profiles is marked with diagonal lines. I am OK with the profile A25 where most of it actually shows the talus slope. I understand that you wanted to keep the expensive data acquired in the field and publish it, but you need to explain in the caption what kind of landform it represents and what is the (approximate) composition and texture (gravel? sand? till? fan?).

Figure 8: Similar comments I've made before

- Add labels to the color scales (resistivity, velocity, ice content) and remove the in-panel labels (ERT, RST, ICE CONTENT.) Please treat the color scales if you would with axes of any other plots.
- Adjust the color scale in panel A (dark red for 10^2) to reflect the actual values in the profile. I don't see intense dark red in the profile. Wrong color scale can mislead color-blind readers.
- In panel B, I don't see intense yellow color in the profiles as indicated in the color scale. The max value in the color scale goes all the way to 5000 m/s, but in the RST no pixel reaches that value. Please adjust the color scale to reflect the actual values presented in the profile.
- Don't capitalize "Ice content"

- don't abbreviate absolute (in panel A) and average (in C).
- the font size of the in-panel labels could be too small.
- there's a "leftover" small cross-lines near the 160 m mark in panel C. Fix it.

Figure 9:

- Add labels to the color scales (resistivity, velocity, ice content) and remove the in-panel labels (ERT, RST, ICE CONTENT.)
- Now it's the other way around--the dark blue in the color scale for the maximum value is not present in the actual ERT profile. It seems like you've plotted all the profiles using the same color scale, which is inherently correct thing to do and it works when you show different profiles in the same figure, such as in Figure 3. However, when you show the profiles one at a time like in this figure and borrow the universal color scale, it may give an impression that the maximum ERT reaches 10^5 which is not true and misleading. I'm NOT suggesting to re-plot the profiles or use a different color scale. Instead, I'm suggesting just to cut off the unnecessary part of the color scale to reflect the actual values in the profiles.

Figure 10:

- Be consistent in the Y-axis value for the resistivity in panel A. I think it's better to express it as 10^2 , 10^3 etc, instead of a bunch of zeros or $1e+06$.
- A nit-picky suggestion for the large panel in the right: spell out the landforms instead of the abbreviations (e.g., Sediment slope (SED); Talus slope (TS) etc.) I see that it's explained in the caption and the abbreviations are consistent with the panels on the left. However, you have plenty of white space to fit those words and it is always best if a figure itself can be understood clearly on its own without relying heavily on captions. Don't force the readers to hunt for what these abbreviations stand for.
- The same rule applies to ZOI. I highly recommend spelling out the zone of interest(s) instead of its abbreviation. I totally understand that it's near the end of the paper and a reader who started from the beginning memorized it already. However, imagine a reader who's skimming and just looking at the figures without the captions, to see if the paper is interesting. Your paper will attract much more people if the individual figures were clear on its own without heavily relying on text or captions.
- Spell out ER and RS in the caption to avoid repeating "tomogram". Change it to "...respective electric resistivity and refraction seismic tomograms..."
- There's no 'C' in the scatter plot. Add C in the corner of the scatter plot.

Figure 11:

- Spell out PF. You have plenty of space to fit permafrost.
- In panel B, I like the way you've used gray and black lines for the error bars to indicate

which is for max and mean values. The error bars for D009, however, look like drawn with the same gray color.

Figure 12:

- Remove the title of the figure "Max/Min ice content..." from the top of the figure and include it in the caption.
- Capitalize i in "Ice" in Y-axis
- Spell out "borehole" and "4-phase model" instead of BH and 4PM. Shorten the black and gray bar in the legend and you'll have plenty of space to fit the words.
- Add "survey sites" or "survey lines" in the X-axis. Otherwise, they're not explained in the caption and the readers need to hunt for what they are in the text. Again, make the figure stand on its own without relying on text and caption.

Figure 13:

- Add "Profile" before A02 and A16b as in "Profile A02".
- Why numbers in A02 and A16b are smaller than the letters? Fix them to have the same font size.
- I highly recommend adding a legend/explanation panel for all the lines, just like you have it in Figures 10 and 11.

It could say:

- Borehole data
- 4-phase model estimates:

40% porosity

60% porosity

80% porosity

Calibrated with borehole data

- I'm a bit worried about the fact that borehole data is represented as continuous black line from top to bottom. I think it's better to show the ice content estimates from the core with dots (or squares, diamonds etc) in their reflective depths, to truthfully reflect the method. Say in the caption what was the sampling interval in the core for measuring ice content. What was the depth interval for the 4PM model runs? Indicate that in the caption too.

Figure 14:

- Please spell out PR and RG. You have plenty of space there.
- A tiny orange polygon is visible below the black bar in E17. Must be an error in illustrator.
- Change in the caption to "...the minimum (black) and maximum (grey) thickness of..."
- I highly recommend including a legend/explanation for this figure showing what black, gray and orange bars and the black lines indicate. If somebody looked at this figure without the caption, they will not be able to what it entails at all. That means other people cannot use this figure for presentations and other visual reports straight away, diminishing the possible exposure and citation.

Appendix:

- All figures in the appendix lack caption. Provide figure captions even for the appendix figures. You need to explain the what the dashed-line boxes are etc.
- Add an appendix table that includes lat/long and elevation of all profiles. I would like to, for example, to load these locations into Google Earth and check them out. For future researchers as well, it would be easier to find and re-measure the active layer thickness, permafrost depth, and ice content etc. Your field data are the very first measurements, which is laying the ground for the repeat measurements in 100 or 200 years in the future.

Table A1:

- Maybe report the RST error in m/s, not ms? As for the ERT, it would be more useful to see the errors in ohm-m than in relative percentages. You have room in this table--why not report the errors both in the physical units and percentages?

Figure A1:

- it's the same figure as Figure 3. No need to include it in the appendix.

Figure A2:

- Please provide the parameter name and unit next to the color scale (resistivity)
- The maximum values of the color scale with intense dark blue do not appear on the actual profiles. Adjust the color scale to reflect the actual values on the profiles.
- Profile E11_D has "depth" axis but the values indicate it's actually elevation.
- Add "depth [m]" in Profile A24 after fixing the Y-axis of E11_D

Figures A3 and A4:

- Provide the name and unit (depth [m]?) of the Y-axes
- The horizontal axes also lack name and unit too (distance [m]?)
- The RMS errors are given in ms (millisecond) but I think they should be m/s. Please fix. If it's indeed ms for return times, it's not really helping because the profiles are in velocities [m/s]. How do you think the reader should convert return times to velocities and get the correct sense of RMS error?