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Interactive comment on "Comparison of soil characteristics from geophysical and geochemical techniques along a climate and ecological gradient, Chilean Coastal Cordillera (26° to 38° S)" *by* Mirjam Schaller et al.

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Response to review of manuscript soil-2020-3 by RC2

Summary of revisions made for the benefit of the Editor, and reviewer:

We thank the reviewer for the time she spent reviewing this manuscript, although the tone of many of the comments was unnecessary. This reviewer's comments are in stark contrast to the positive and constructive comments of the first reviewer. Nevertheless, we've tried our best to address this reviewer's concerns. The reviewer's comments

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revolve around: a) Not clearly understanding the differences in data and analysis presented between our previous study (Dal Bo et al., 2019) and this one. b) Suggesting many changes for this paper to have a different scope than what we state are our aims in the introduction. c) Continually emphasizing the importance of moisture data (which is not available), while many other difficult to acquire geochemical data sets are compared to extensive new GPR data with a multivariate analysis. To address these items, we have modified the text to more explicitly state the differences between our previous work and this study, and to highlight more prominently caveats associated with this study – such as no regolith moisture data availability. We note, however, that although this reviewer comments on the need for additional referencing of "gray" literature, no references (peer reviewed or otherwise) were provided in their entire review.

Finally, we honestly struggled in many places to understand what the reviewer was trying to say in her comments below and edits to the manuscript text. The edited manuscript she provided also changed text in many places to be grammatically incorrect (e.g. removal of the verb in a sentence, or incorrect preposition use, etc), and more confusing. We've tried to implement all these changes as best we could, and highlight below where we disagree with the reviewer's strong opinions for what the study should be.

Note: The reviewer's comments are in italic text, our response is in bold text.

Thank you for your time, M. Schaller on behalf of all co-authors.
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General comments This paper is a somewhat disappointing addition to work already published by the team working on the German-Chilean priority research program EarthShape (www.earthshape.net). The published work has already established that GPR could be used to map "soil" materials in the four study areas, and that interpretation can be "up scaled" from point observations to transects (Dal Bo et al. 2019). The Dal Bo et al. paper correctly identifies the importance of observations about soil mois-

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ture content and clay content to refinement of GPR data interpretation. Note, increases in both soil moisture and clay content often mark the transition from pedolith to saprolith. Unfortunately, Schaller et al. do not expand on the soil property dataset already available to Dal Bo et al., and so, unsurprisingly, do not come up with any new insights into the interpretation of their new - or the old (Dal Bo et al.) - GPR data acquired in the EarthShape Chilean study areas.

With all due respect, we disagree with the reviewer's assessment of our previous work and this manuscript. The following items were stated in the manuscript, although we've modified the text (sections 1 (introduction) and 5.2 (discussion) to make this clearer for other reviewers. More specifically, our disagreement with the reviewer stems from: - There is NO overlap in GPR or regolith property data presented in this manuscript or the Dal Bo et al., 2019 manuscript. Entirely new GPR profiles are presented here. Dal Bo et al. (2019) only use the observed transitions from B-C horizons in Bernhard et al. (2018), and the boundary between mobile and immobile layer from Oeser et al. (2019). - At the time the Dal Bo et al. (2019) manuscript was prepared in February 2018, the physical and chemical properties of the regolith used in this (current) SOIL journal manuscript were not available for use. This is in part to our honoring of Bernhard et al. (2018) and Oeser et al. (2018), having the right to publish their data first, and also due to extremely long editorial handling ($\sim$1.5 years) of the Dal Bo et al. (2019) in CATENA. - Thus, these regolith property data were not available to use in our 2019 study as the review suggests and there is no duplication of regolith property data. In fact, the scope of the Dal Bo et al. (2019) study and this manuscript are different and we are perplexed why the reviewer is criticizing a previously published study for not including additional data. This simply wasn't possible. - The focus of Dal Bo et al. (2019) is on identifying the boundary between the pedolith and saprolite. This is a very different scope than the current (Schaller et al.,) manuscript in the journal SOIL where the focus is on comparison to a large number of chemical and physical property data. - In contrast, this manuscript (Schaller et al.) tries to correlate the observed signal with physical and chemical changes provided by Bernhard et al. (2018) and Oeser et al. (2018). This

is the logical next step for a study where there are co-located and potentially complementary data sets. - Finally, it is true that envelopes of the GPR signal are already presented in Dal Bo et al. (2019) although these envelopes come from a different data set, and slightly different geographic positions such that a robust comparison to pedons was not possible. In contrast, this manuscript by Schaller et al. correlates the envelope intensity with physical and chemical changes. This in turn allowed a more quantitative determination of the pedolith depth over a hillslope transect. - Concerning clay and water content variations in our study area – we address this comment below. In short, clay content variations are accounted for in our PCA analysis, whereas water content variations have not been measured and are not available for study. In summary, while we strongly disagree with the reviewer's statements concerning our previous work, we take their comment to highlight that the manuscript could provide a clearer distinction to our previous work. Given this, we have expanded the introduction to more explicitly state the differences with previous work.

I would suggest that the authors, and the EarthShape team, take a closer look at some of the work that is being done on using GPR to map regolith materials and processes elsewhere in the southern hemisphere, especially in Australia. Some of this work is published in "grey" literature, but it is still relatively easy to find on the internet. There is also a lot of work being done in Australia, some in collaboration with European geophysicists, on the use of electromagnetic surveys to map regolith materials and processes. The inversion of this data has become quite sophisticated and AEM surveys, designed in part to map regolith thickness, are now taking place on a continental scale.

The EGU SOIL journal guide for authors states (https://www.soil-journal.net/submission.html#references) states that "Grey" literature should not be cited, specifically: "Informal or so-called "grey" literature may only be referred to if there is no alternative from the formal literature. Works cited in a manuscript should be accepted for publication or published already". In our manuscript, we cite related

published literature so citation of 'Grey' literature is not needed. Furthermore, the reviewer's request to cite other 'southern hemisphere, especially in Australia' studies was not accompanied with specific references to consider. We've conducted literature searches to see what other relevant literature could be cited, but without specific recommendations from the reviewer we cannot accommodate this statement, nor will we cite grey literature as this is not commonly accepted for high-quality peer review journals (such as this one).

Further, Schaller et al. perpetuate some of the confusion in soil and regolith terminology that is apparent in earlier work by this team. In particular, the confusion relates to the use of the term "soil" variously as a descriptor for the entire regolith profile (pedolith and saprolith), and as a descriptor solely for the pedolith. This confusion is exacerbated by reference to soil materials that are mobile (pedolith) and immobile (saprolith). Note, the saprolith includes saprolite and saprock.

Reviewer 1 had a similar comment. There is a difference in terminology between the surface processes and soils communities, and we had provided a reference for the terminology we were following. However, given that this journal is a soil sciences community journal, we have adjusted the terminology as requested. The terminology of soil used in this manuscript has been adjusted to "World Reference Base for Soil Resources" as suggested by reviewer 1.

The distinction between these units can be important for the interpretation of geophysical data, although the EarthShape Chilean study does not appear to have properly investigated beyond the pedolith. A visit to some of Chile's open cut mines might be a salutary experience in this regard.

We thank the reviewer for this suggestion, but in practicality, we are not sure how this would be useful at this time. In particular, - The investigation of the pedolith is the main topic of this manuscript and much of the EarthShape Phase 1 research. Several months ago other EarthShape projects completed drill cores within about 10 km of

each study area to study soprolite, saprock, and bedrock. What we learned is that the bedrock is hard to reach and is reached at ∼30 to ∼80 m depth. These drill cores and data from them are still 1-2 years away from publication (at the earliest) and are not available for this study. - We are not sure what insights the proper investigation beyond the pedolith in an open cut mine would change the interpretations made in this study, particularly because they would be located far off site from the actual study area where physical and chemical measurements were made and lateral extrapolations from regolith formed in different host lithologies where we have no chemical or physical measurements would not provide a robust comparison.

Note, these general comments are supplemented with detailed comments and suggested amendments as per the attached pdf. The comments and suggested amendments have been added to the pdf using Adobe Acrobat.

Detailed comments and changes are addressed below in supplemental comments.

Supplement comments Please also note the supplement to this comment: https://soil.copernicus.org/preprints/soil-2020-33/soil-2020-33-RC2-supplement.pdf

Line 48-52: "Pedolith" may be a better term than "soil" with reference to a regolith profile "Saprolith " may be a better term than "saprolite" with reference to a regolith profile esp as saprolith includes both saprolite and saprock “Meaningless sentence in this context, as the saprolith is, by definition, immobile. It is only after it’s weathering products engage with biological and hydrological processes that they "enrich" the pedolith”

The use of soil for the mobile layer is replaced by the term pedolith. The entire manuscript has been checked for consistent use. Also, the remaining regolith terminology has been adjusted to “World Reference Base for Soil Resources” as suggested by Reviewer 1. The sentence reads now the following: ”Most biota is found in the mobile pedolith, which overlies the immobile saprolith. The pedolith is replenished with nutrients from the saprolith through chemical weathering and erosion that drives nutrient uplift towards the surface (e.g., Porder et al., 2007).

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Line 52-54: This list of factors does not follow a logical sequence and as such is confusing. In my view the list should progress from the local to the regional. Aspect, which is highlighted in proceeding published work, has been omitted altogether. Regolith thickness or "soil" thickness?? Having started with regolith I think it is best to stick with regolith.

The sequence of the list has been adjusted as suggested by referee 2. Aspect is added as a factor. The term “soil” is not used anymore. The investigated depth sequence is named “regolith” and the so far named “soil” is relabeled “pedolith”. The sentence reads now as follows: “The thickness and production of regolith is influenced by aspect, topography, composition (mineral content), biota, climate, tectonically driven rock uplift, and time (e.g., Hilgard, 1914; Jenny, 1994).

Line 55-56: Regolith thickness or "soil" thickness?? Having started with regolith I think it is best to stick with regolith.

The sentence reads now as follows: “However, sub-surface variations in pedolith thickness at the scale of hillslopes are difficult to quantify because of lack of exposure.”

Line 56-59: See previous comment and ditto for all references to "soil" in this section

The use of regolith terminology has been adjusted as suggested by the referee in the entire manuscript. The sentence reads now as follows: “Thus, subsurface imaging by geophysical techniques, when calibrated to regolith excavations (pedons), offers potential to characterize spatial variability in pedolith thickness and regolith properties (e.g., Mellett, 1995; Doolittle and Collins, 1995; Miller et al., 2004).

Line 83-85: However, on a theoretical basis, the importance of certain properties has been identified eg soil moisture content and clay content cf proceeding work by this team published in Dal Bo et al 2019. Not sure we understand what change the reviewer is asking for. The sentence reads now: “Interpreting the interplay of GPR signals with physical and chemical regolith properties is challenging (e.g., Saarenketo, 1999; Sucre

et al., 2011; Tosti et al., 2013; Sarkar et al., 2019)."

Line 89-92: Biotic processes are "critical zone" or more properly "regolith" processes

The term 'critical zone" is replaced by "regolith". "The region is home to four study areas of the German-Chilean EarthShape priority program (www.earthshape.net), where investigations of biotic interactions with regolith are conducted (e.g., Bernhard et al., 2018; Oeser et al., 2018)."

Line 141:

Soil has been replaced by pedolith: "To compare the effect of climate and vegetation on pedolith thickness and GPR observations, differences in lithologies need to be minimal.

Line 158-161: a saprolith (which includes saprolite and saprock and thus includes the "C horizon"

The sentence has been changed to: "In this study, we refer to depth profiles as regolith profiles that are composed of a mobile pedolith that includes the A and B horizons, and an immobile saprolith including the C horizon."

Line 162-163: Alternatively "has been described as" WRB ref needed

The sentence has been corrected as suggested by referee 1 and reads like:' In Pan de Azúcar, the regolith, a regosol (IUSS Working Group WRB, 2015), consists of A and B horizons with a combined thickness of 20 to 25 cm and an underlying saprolith (the C horizon), which is coarse-grained and jointed (Oeser et al., 2018). The requested reference has been added.

Line 165-166: The entire regolith profile ie pedolith and saprolith or just the pedolith??

The sentence has been corrected to: "The average bulk density of the A and B horizons is 1.3 g cm-3.".

Line 166-168:

"The cambisol in Santa Gracia consists of 30 to 55 cm thick layers of soil with A and B horizons overlying the saprolite (Bernhard et al., 2018)." The sentence has been changed to: "In Santa Gracia, the 30 to 55 cm thick pedolith overlying the saprolith is a cambisol (Bernhard et al., 2018)."

Line 234: As previously noted, both the physics of GPR data acquisition and work carried out elsewhere suggests the importance of soil moisture content. Why wasn't data on this property acquired?

We agree with the reviewer that regolith moisture content is important and would be nice to know. Unfortunately, this data is not available. The pedons that we compare our GPR data to were excavated in March 2016, and promptly filled in by July 2016 because they were located in national parts. Regolith moisture measurements were not made on samples collected in 2016, and no pedons were available for sampling at the time the GPR data for this manuscript was collected in 2017. Furthermore, as the reviewer likely knows, regolith moisture varies both seasonally and annually, such that comparison to regolith water content measurements from a previous year would be difficult to assess the robustness of.

To address this reviewer's comment – we have modified the text (Section 3.1 methods/data compilation) to also state more clearly that regolith moisture is important (amongst other factors) for GPR data interpretation, but that this data is not available. We had already mentioned this in the text, but we make it clearer now to hopefully reach a happy middle ground with this reviewer. We also address this topic in the new concluding discussion section 5.4.

Furthermore, we addressed this topic, and other limitations / caveats of the study, in a new concluding discussion section "5.4 Comparison to previous work and study caveats". Hopefully this reaches a happy middle ground with the reviewers concern.

Finally, clay content is also important for GPR data interpretation (as the reviewer mentioned earlier). We note that clay content was measured and reported by Bernhard et

al. (2018), and we have included this in our PCA analysis.

Line 344-346: pedolith/saprolith

“Mobile/immobile” has been changed in the entire manuscript “mobile and immobile” as suggested by referee 1. The terminology “pedolith/saprolith” is not used because Oeser et al. (2018) used the terms “mobile/immobile” for the boundary they observed. The sentence reads as follows: “In Pan de Azúcar (Fig.1, 2A), a gradual transition from the B to the C horizon was visually observed in the pedons at 20 to 40 cm (shaded gray areas after Bernhard et al., (2018); Fig. 4, Fig. S1 to S3), whereas the mobile and immobile boundary is considered to be at 20 to 25 cm (black lines after Oeser et al., (2018);); Fig. 4, Fig. S1 to S3).

Line 390: pedolith/saprolith

See response above for line 344-346.

Line 385-387: pedolith/saprolith

See response above for line 344-346.

Line 387-390: ?pedolith ? pedolith or total regolith

Sentence reads now as: “Bulk density and grain size change gradually with depth and no clear pedolith thickness could be determined.”.

Line 409: pedolith/saprolith

See response above for line 344-346.

Line 416: pedolith/saprolith

See response above for line 344-346.

5.1 Synthesis of GPR data with physical and chemical properties from point locations Suggest that theory and the findings of previous studies throughout the world should be the starting point ie properties such as soil moisture content, salinity and clay content,

should be the starting point for this discussion. Some of the measured properties could be considered proxies for these properties of known importance, and the discussion should be explicit in that regard.

We thank the reviewer for this comment. We agree that more general discussion of factors influencing GPR data could be discussed. However, we did not include this in section 5.1 because this section focuses on synthesizing our results and interpreting them. However, to accommodate the reviewers concern, we have added a new section 5.4. We hope that this addition improves the manuscript further.

Line 443: Soil moisture content is known to be important so why has this been neglected in this study?

Please see our response to this reviewer's comment for line 234 above. The data is not available! However, we'd like to emphasize that while regolith moisture content would be nice to have for inclusion into our PCA analysis, the lack of having this data does not invalidate the observations we present. The addition of this data would help constrain the interpretations better, but it's not available. We expanded text related to regolith moisture in section 3.1, and 5.4.

Line 448: Was "basal saturation" as reported by et al 2019 useful? If not, why not?

We apologize, but we do not understand what the reviewer is referring to here. We conducted a "find" on the manuscript text and do not see the word "basal saturation" used by us. The same words do not appear in the work of Dal Bo et al. (2019). Also – we are unclear why the reviewer is commenting on a previous (published) study whose data are different from this study, and not collected in the same location.

Line 449: ? pedolith/saprolith

Sentence has been changed by referee 1 and reads now as: "In addition, the determination of the boundary between the pedolith and saprolith in the field causes its own problems because observed changes are not discrete but transitional over a depth

interval of 5 to 10 cm".

Line 457-459: ? within the saprolith

Sentence has been changed:" Whereas the 500 MHz signal shows interfaces in the saprolith, the maximum in the 1000 MHz energy interval signal agrees with the pedolith thicknesses observed in the field (Fig. 4 and Figs S1 to S3)."".

Line 459-461: ? pedolith and saprolith

Sentence has been changed: "However, the boundary between pedolith and saprolith is probably too shallow to be detected with the 1000 MHz antennae.".

Line 461-462: ? pedolith and saprolith

Sentence has been changed: "An even higher frequency would be required to detect the pedolith/saprolith boundary.".

Line 473: Theory would suggest that in such shallow dry and uniformly sandy "soils" GPR might be useful in mapping changes in moisture content over time

We don't disagree with the reviewer that GPR data are also sensitive to regolith moisture, but we don't understand what the reviewer is asking for in this comment.

Line 474-478: Does this mean that the visual observations are not supported by physical and chemical measurements?

Correct. The sentence reads as: "Although the 500 MHz and 1000 MHz GPR envelopes indicate changes at depth, the physical and chemical properties observed with depth show only a few distinct changes implying that the pedolith thickness cannot easily be determined using only physical or chemical properties.".

Line 486-488: Well known, which is why forward modeling of "remote" geophysical data should be supported by the best available petrophysical data

Sentence changed to: "These observations again underscore, that for different loca-

tions with variable regolith type, vegetation, and physical and chemical properties local calibration between pedons and GPR data are required." Forward modeling of GPR data is not the stated intent of this manuscript, and is beyond the scope of this study. This manuscript focuses on comparisons between geochemical and geophysical data, not forward modeling of geophysical data.

Line 497-498: Is this a consequence of an increase moisture levels? "Chemical properties seem to have a considerable influence on GPR signals in this setting"

We are unclear as to what the reviewer is asking for here. Regolith moisture was not available for comparison. What the PCA analysis tells us is the variables that co-vary with each other. Any other variables not included in the PCA analysis (e.g. moisture levels) would be lumped into the unexplained variance in the analysis. If regolith moisture co-varies with the chemical properties measured, then it would also show up in the analysis. However, we are not aware of any published work that shows co-variation of regolith moisture with the chemical properties measured here. As such, we do not see a basis for adding speculation on this here.

Line 505: The most important of which are?

Physical properties have been listed. The sentence reads now as: "The pedolith thickness is easily identifiable based on physical properties (e.g., bulk density, grain size variation)."

Line 508-510: Related properties

We are not sure what properties the reviewer is asking for here since we already mention relevant properties we can constrain. The sentence reads: "The variance is strongly explained by PC1 containing physical properties (e.g., bulk density, clay content, LOI) and less by PC2 including chemical properties (e.g., pH, ïĄť of Na and Zr).

Line 545-547: How do these results compare with those reported by Dal Bo et al 2019?

Figures 12 to 15 and figures S14 to S23 show the pedolith thickness based on visual observations in the GPR signal as well as the pedolith thickness based on amplitude signal in the GPR envelope signal. The pedolith thickness determined by the GPR signal generally agrees with the pedolith thickness based on GPR envelopes. However, pedolith thickness based on GPR signals is not always possible, GPR envelopes give continuous information where a change from pedolith to saprolith is to be expected. The sentence in questions is changed to: “However, the complications which frequency of GPR antenna to use for analysis (Dal Bo et al., 2019) in addition to what envelope interval to select (section 5.1) requires careful up-scaling of the pedolith thickness to hillslopes.”

Line 557-559: ? down

Sentence corrected as suggested: “The pedolith thickness based on the 1000 MHz GPR envelope at the top-slope position (SGPED20) decreases first downhill and then increases again, thereby demonstrating laterally variability down the hillslope.”

5.3 Changes of soil thickness with hillslope position, aspect, and latitude This topic is throughly explored in preceding publications by this group

Yes, we know we’ve written about this topic before. We address it again here because a lot of new (and different types) of data are presented and it is important point for the community to know if the previous results still stand. Furthermore, the study areas presented in here were specifically chosen to address variations due to hillslope position and latitude and we’d be remiss not to cover this.

Line 660-662: ?pedolith to saprolith Although the correlations are not consistent from one area to the next

Sentence corrected: “The visually observed transition from the mobile pedolith to immobile saprolith coincides with one or more changes in measured physical and chemical properties in each study area.”

Line 662-665: This could be because the data on "soil" properties did not include data on properties known to be an important influence on GPR responses eg soil moisture content. As a consequence, the work could be considered to be inherently flawed.

The way in which this comment is worded is unnecessarily offensive. Nevertheless, we don't disagree that regolith moisture can also be important. As stated before, regolith moisture data was not available. However, many other relevant data sets were available and a multivariate analysis was conducted to identify where signals do lie within the data. In some cases - a large amount of variance in the data set is explained by these data. In other cases not. In the cases where all the variance is not explained, yes – this could be due to other factors like regolith moisture. To address this comment, we have modified the text in section 3.1, and also in the new 'caveats' section in the discussion section (section 5.4) to more explicitly state these caveats and the other factors (such as regolith moisture) could also be important for observed GPR signals. To say the study is inherently flawed when a comparison of GPR data to difficult to acquire chemical data is frankly surprising. There are very few studies to our knowledge that conduct this detailed comparison between chemical and geophysical data over a $\sim$1300 km ecological and climate gradient in a similar lithology. We apologize if the reviewer doesn't see the merits in this. Reviewer 1 did explicitly recognize the utility of this.

Line 6742-674: Not new findings. Petrophysical data, or an understanding of the variation in the properties being investigated at a local scale, are fundamental to proper design, processing and interpretation of all geophysical surveys.

Yes – we are aware that the GPR community frequently conducts subsurface point calibrations to their data. The sentence the reviewer is referring to here is the last sentence of the conclusions and is a wrap up sentence. We've deleted the sentence for the reviewer's benefit. We've added a new concluding sentence to this section that gives more details about what frequency antennas work better in which climate/vegetation zones.

Please also note the supplement to this comment:
https://soil.copernicus.org/preprints/soil-2020-33/soil-2020-33-AC4-supplement.pdf

Interactive comment on SOIL Discuss., https://doi.org/10.5194/soil-2020-33, 2020.