We truly thank the anonymous Reviewer for very constructive comments and suggestions about our manuscript.

Reply point by point:

- This paper would greatly benefit from including the results and a log from the borehole observations mentioned in Line xx. The authors' repeatability refers to the validation of the geophysical methods by borehole observations yet do not include the borehole results in the study. There is no location on the base map in Figure 1 of the borehole location. The paper would be much more complete with the addition of this observation.

Reply: We fully agree with this comment and we will include in the manuscript the information about the borehole stratigraphy and the position in the map/models.

- It is commonly known that electromagnetic methods are highly non-unique. Why do the authors not constrain the FDEM inversion with the GPR depths (snow and ice) and a range of expected conductivities?

Reply: The Reviewer is right, as the result of any kind of geophysical method inversion process, we know that our FDEM models are a non-unique solution to the problem. Nevertheless, the aim of the FDEM survey on the Calderone Glacier was to verify the capability of the separated-coils FDEM device to characterize an environment with ice fraction occurring in the investigated subsurface. Consequently, it was important for us to evaluate the inversion results without using any prior structural information, as defined by the GPR profiles. In this way, we had the opportunity to understand if it is possible to use the separated-coils FDEM device in other similar environments, as rock glaciers, without the need to combine it with GPR surveys, which are challenging to perform with a coarse-blocky surface and less resolutive since the ice is highly mixed with debris (signal scattering problem). Considering the results obtained on the Calderone Glacier, we think that we achieved our goal. In the summer of 2022 we tested the separated-coils FDEM device in several rock glaciers and achieved very promising results.

- What is the uncertainty in the pseudo-2D FDEM inversion? Are there areas where the uncertainty is larger, for example in the ice, or at depth? A cross-section showing the
uncertainty range/standard deviation would be useful to enable a reliable assessment of the 2D section.

Reply: Concerning the sensitivity of the inverted models, the used code EMagPy does not provide a sensitivity 2D section. However, the software provides the percentage value of RRMSE (Relative Root Mean Squared Error) to evaluate the accuracy of the inverted models. Therefore, we will insert this information in the manuscript for both investigation lines. Nevertheless, as we highlighted in the manuscript, the sensitivity of the FDEM measurements is higher in the near subsurface and decreases with the depth till it reaches (approximately) zero at a depth of about 30 meters (see Fig.A3, which will be removed from the Appendix and insert in the main text of the manuscript), consequently, we can consider the uncertainty of the pseudo-2D FDEM models in the same way.

- I would consider changing the title. The words “prospecting for the characterization” do not work well together and FDEM should be in the title as this is the more novel technique used in this glaciated environment. I would suggest something along the lines of: “Characterisation of the Calderone Glacier, Apennines, Italy using GPR, FDEM, and borehole observations”.

Reply: We agree with the Reviewer and this useful suggestion, we will modify the title and we will include “FDEM” inside it, e.g. Combination of Ground Penetrating Radar and Frequency-Domain Electromagnetic methods for the characterization of the Calderone Glacier (Gran Sasso d’Italia, Italy).

Even if the borehole result is important to validate our geophysical results, we don’t think that “borehole” could be appropriate to insert in the title, since only the geophysical surveys were carried out to characterize the structure of the glacier, and this way define the most suitable position to drill and extract the ice core sample, which was the target of the Ice Memory Project team.

- The main text needs to be proof read thoroughly

Reply: The reviewer is right, we will do it.

- Figure A3 in the appendix should be in the main text. The depth of investigation is important in understanding the limitations of the electromagnetic inversion results.

Reply: The suggestion is correct, we can move Figure A3 in the main text, particularly in Chapter 4.2 (FDEM inversion results).

- In the inverted FDEM sections, can you explain in more detail what is going on under the ice? The values seem to be more conductive than if it was bedrock

Reply: According to values that we found in literature, and that we observed ourselves in ERT surveys in the North-Eastern Alps areas, we assigned a representative value of 2E-1 mS/m to the calcareous bedrock. In the inverted and calibrated model Line 1 (Fig.8A), the boundary with the bedrock is well defined and it is very similar to the synthetic model (Fig.7A), suggesting the presence of the bedrock as confirmed also by the GPR profile and the borehole. On the other hand, in the inverted and calibrated model of Line 2 (Fig.9A), it is true that the conductivity values at the bottom of the section are higher than expected for the bedrock, particularly in the western direction. In this area, it is plausible that the ice layer is not directly in contact with the calcareous bedrock but instead with a lateral moraine, which obviously has higher conductivity values than bedrock. We will add these considerations in the main text, in particular in the chapter of Discussion.
Specific comments:

- **L98-99:** did you get any CMP gathers to estimate the velocity of the snow and ice layers?

  Reply: GSSI Sir4000 is a monostatic digital GPR antenna, therefore it was not possible to acquire CMP gathers.

- **L130:** “dozens” should be changed to “tens”

  Reply: The Reviewer is right, it will be changed.

- **L134-136:** the last sentence in this paragraph doesn’t make sense: “Despite this, FDEM methods proved to be efficiently applicable in high resistive environments, considering in a relative way the inverted conductibility profile (e.g. Boaga et al. 2020; Pavoni et al. 2021).”

  Reply: As the FDEM devices produced by GF Instruments (and other manufacturers) have not the capability to detect conductivity variations lower than 0.1 mS/m (instrumental limit resolution), we cannot pretend to measure the real conductivity values of the ice layers, which have conductivities << 0.1 mS/m. Consequently, in these low conductive environments, FDEM models should not be interpreted on the basis of the inverted conductivity values, but a calibration based on the forward modeling is needed to define a value representative for the frozen layers (e.g. Pavoni et al. 2021 evaluated values < 1 mS/m for the frozen layer in dolomitic rock glaciers, which was confirmed by the comparison with ERT results). We will re-phrase the sentence explaining better this concept in the manuscript.

- **L194-196:** Need to explain this sentence in more detail. What are the instrumental resolution limits?

  Reply: The FDEM devices produced by GF Instruments have not the capability to detect conductivity variations lower than 0.1 mS/m, which is therefore the instrumental limit resolution.

- **L201-202:** where did you measure the several meters of snow cover during the data acquisition? I would mark these locations on the base map in Figure 1. Was this by a snow pit?

  Reply: The Reviewer is absolutely right, we have to show in the map and in the models the point where the snow cover thickness has been measured. Yes, it was a snow pit. For the measurement, we used an extendable rod and the measured point is approximately at x~40 m in Line 1. We will specify this in the text.

- **L221-222** This sentence doesn’t make sense: “Calibration intends to explore if exist a constant correction factor to be applied to the inversion results of the field datasets, in order to have the same conductivity scale of the synthetic model.”

  Reply: We compared the inverted models obtained from the field datasets (Fig.5 - from now on field dataset inverted models) and the ones obtained from the synthetic datasets (Fig.7 - from now on synthetic models), searching for a correction factor that can be applied to the inversion results of the field datasets and allows to have a model with the same conductivity range as found in the inverted synthetic models (from 0 to 1 mS/m – see Fig.7). The defined correction factor of 1E-2 mS/m has been applied to the inversion
results of field datasets (Line 1 and Line 2). In this way, as you can see in Fig.8 and Fig.9 (FDEM inverted and calibrated sections), the range of conductivity in the field dataset models span from 0 to 1 mS/m, and the ice layer boundaries can be defined with the same values found in the synthetic models (0-0.1 for the ice-rich layer and 0.1-0.2 for the ice-debris mixture, see chapter 4.3). We will modify chapter 4.4 and explain better the calibration of the FDEM results.

- L226: “exciting”? Do you mean “existing”?
  
  Reply: Yes, sorry for the typo. We will correct it.

- L237-8: The ice ends at “x=30m”, where did it end before and what is this value relative to. The retreat of the glacier should be discussed in terms of “The ice mass has retreated xx m since 2015”.
  
  Reply: Along the longitudinal Line 1, the ice-rich layer was easily detectable along the entire GPR profile measured in 2015 by Monaco & Scozzafava, but today seems to end at x≈30m. Therefore, in the last 7 years, between x = 0 and x = 30 meters of Line 1, we had (presumably) a loss of massive ice and an increase in the amount of ice-debris mixture.

- L247-8: this borehole observation should be added to this paper.
  
  Reply: Yes, we will do it.

- L255: where is this measurement, show on Figure 1.
  
  Reply: Yes, we will do it.

- L263-267: This last paragraph is important for the FDEM inversion. I would have this in the main text before the inversion results, including figure A3.
  
  Reply: We really appreciate this suggestion. Our proposal is to add at the end of Chapter 3.2.1 (FDEM forward and inverse modeling) this sentence: “to define the bottom depth of the models, sensitivity profiles of the measurements have been calculated with EMagPy. In the current work, the inverted FDEM models are limited to the depths where the normalized sensitivity of the measurements reaches approximately zero.” We can show the sensitivity profiles in Chapter 4.2 (FDEM inversion results) and add this sentence: “the sensitivity of the measurements performed along Line 2 is presented (same results were found for Line 1). It is clear that sensitivities are higher in the near subsurface and decrease to (approximately) zero at a depth of about 30 meters. Consequently, we considered the uncertainty of the pseudo-2D FDEM inverted models in the same way, and we defined the bottom of the FDEM sections at a depth of 30 meters from the surface.” Finally, we can leave the following sentences in the discussion chapter: “It should be noted that both the FDEM inverted models have lower penetration depth (~30 m) than those predicted by the instrument manufacturer (see Fig.2). This is expected since the investigation depth decreases in low electrical conductivity environments (Hauck and Kneisell, 2008).”

- L269: The paper needs to back up this concluding sentence with the borehole observations and a more detailed map in Figure 1 of where the snow depth measurements were acquired.
  
  Reply: Yes sure, we will do it.

- L274-275: do you mean time-lapse geophysical surveys?
Reply: Yes, it was the meaning of the sentence. The Reviewer is right and we can insert directly the reference to the time-lapse surveys (e.g. “A future development for the GPR measurements on the Calderone Glacier is to apply the method proposed by Santin et al. (2022), to estimate the debris content within the layer composed of ice-debris mixture. In case of periodic measurements in time-lapse configuration, this method could help to estimate the ice volume losses of the Calderone Glacier in the next future.”).

- L292: Repetition of the drilling/borehole observations with no results detailed in the paper.

  Reply: It will be insert into the manuscript.

- L294-297: this should be in the discussion.

  Reply: We respect the opinion of the Reviewer but it is our opinion that these sentences fit better in the conclusions of our work.

- Table 1: could be moved to the appendix.

  Reply: We would prefer to leave it inside the main text, but we can move it to the Appendix if required.

- Nice figure. what is the measured apparent conductivity used to create these depth ranges? Do you not have to input a conductivity to estimate the depth of each coil separation?

  Reply: Fig. 2 shows the nominal effective depth range influencing the measured apparent conductivities suggested by the manufacturer of the CMD-DUO device, GF Instruments. Instead of showing a Table with these effective depth ranges, we preferred to create a new intuitive figure expressly for this work.

- Table 2: This is just a personnel preference, however many recent papers using electromagnetic methods in a glaciological environment work in terms of resistivity, in ohm*m, the inverse of conductivity. It might be easier for your readers to follow and directly compare with other studies if you worked in terms of resistivity.

  Reply: In our experience, we prefer to use conductivity (mS/m) when we work with EMI methods. As the Reviewer correctly mentioned, this is just our personnel preference. To be consistent, in the main text of the manuscript we will remove all the references to electrical resistivity and we will refer only to conductivity.

- Figure 5: This is also another personnel preference, however most recent papers using electromagnetic methods in a glaciological environment have hot colours (like red and purple) representing high resistivity/low conductivity and cold colours (e.g. blue) representing low resistivity/high conductivity. Again, this might make it easier for your readers to follow and compare with other studies.

  Reply: As before for conductivity-resistivity, we personally prefer to use a color scale where the frozen/ice layer (with high electrical resistivities – low electrical conductivities) is presented with cold colors as blue, and the unfrozen subsoil/subsurface is defined by hot colors as red. In our opinion, as we verified in various geophysical conferences, it is more intuitive to associate the blue color with the ice, particularly for people that are not usually inside the cryosphere “world”. Again, as the Reviewer correctly mentioned, this is just our personnel preference.

- Figures 8 and 9: Consider having one figure for 8 and one for 9, merging A and B, with
the GPR transparently overlaid on the conductivity plot.

Reply: We appreciate the suggestion of the Reviewer but it is our opinion that a comparison of separated models (FDEM and GPR) is the best solution to better appreciate the similarities between them. Moreover, we will insert in this Figure the stratigraphy of the borehole. Once again, this is just our personal preference.

- Figure A3: Have this in the main text. Add a dotted line at the depth of investigation. To me, it looks like you only have sensitivity to 20 m depth as the sensitivity curves come close together after 20 m?

We will move Fig.A3 into the main text, e.g. in Chapter 4.2. (FDEM inversion results). We could add a vertical dashed line that defines the value of zero sensitivity. In this way, it would be easier to appreciate that the sensitivity of the FDEM survey reaches zero at approximately 30 meters of depth. Between 20 and 30 meters of depth, the sensitivity of the measurements is still > 0, so that part of the subsurface is still contributing to the measured apparent conductivities. For this reason, we have limited our FDEM models to 30 meters of depth from the ground level.