Dear Editor,

we would like to thank the two Reviewers for their careful reviews and for the suggestions that will help us improving considerably the manuscript.

In the following, we answer to the comments made by the reviewers, which have been numbered for improving clarity. The author responses are reported in blue colour right below the reviewers' comments. Line and page numbers are referred to the submitted paper.

REVIEWER 2

RC2: 'Comment on egusphere-2023-2689', Cristian Daniel Villarroel, 28 Jun 2024 reply

Dear Authors,

2.1) I have read in detail the work entitled ¨Spring-water temperature suggests widespread occurrence of Alpine permafrost in pseudo-relict rock glaciers ¨. Personally, I consider that it is a work of very good quality and according to the readers of this journal. The research topic is of particular interest in the Alps, and also in other mountainous regions. The use of spring-water temperature is a method that can provide valuable information on the presence and distribution of mountain permafrost, which is an issue where there are current uncertainties, mainly in the relict/pseudo-relict category. One of the advantages of this method is that it is relatively easy (the measurement device is light) to perform on the ground, regardless of the climatic and topographic difficulties of all mountainous regions. In addition, registered values, which are not conclusive by themselves, can help in the decision of other methods to apply and in the selection of the sites to be measured. This method can be applied in other mountainous regions, but I consider that in arid/semi-arid regions the presence of springs is scarce to cover spatial variability.

This is an important point raised by the Reviewer, we will add this latest consideration in the manuscript (Discussion Section)

2.2) On the other hand, I consider that the spring-water temperature analysis is a complementary method in studying the presence and distribution of mountain permafrost. The application only of this method would generate ambiguous results. Warm temperatures (such as some registered in this work) are not enough to rule out the presence of permafrost. For their part, cold temperatures, they would not be enough to confirm the presence of permafrost. In this last point it is important to highlight that the ground ice stored seasonally in active layer can have influence on the temperature of the springs. Therefore, it is highly recommended to carry out other methods. EC and TDS measurement and hydrochemical and isotopic analysis could provide valuable information.

We agree with the reviewer about the importance of integrating different methods to verify the role of permafrost on the hydrology of springs in mountain areas. However, based on our data collected in a sub-catchment of Val di Sole, only spring-water temperature proved to be effective in discriminating between permafrost affected and non-permafrost affected springs, whereas EC and isotopes where not useful (Carturan et al., 2016).

We agree with the reviewer that warm temperatures and cold temperatures alone are not sufficient to infer respectively the absence and presence of permafrost. Warm temperatures are already discussed this in

Section 5. Regarding cold temperatures due to possible seasonal ice in the ground, please see the reply to the following comment 2.6.

2.3) ERT profiles made in this work contribute to determining the presence or not of ground ice in the two rock glaciers studied. However, in one of them (Preghena) the resistive anomaly that would indicate the presence of ground ice is located at the 2D profile edges. In these sectors the reliability of the results decreases considerably. In addition, in this same rock glacier, a 20% error is considerably high.

We agree with the comment of the reviewer that the bottom and the edges of the tomogram are the least sensitive zones, nevertheless we acquired a large number of measurements with the dipole-dipole multi-skip scheme (about 5200 quadrupoles) and, even after the applied filtering, the pseudo-section was homogeneously covered by apparent resistivities, including the edges and the bottom. We are confident we are not assessing artifacts, because the high resistive area is highlighted by both the ERT lines in the overlapping position (x<70 m in Line 1 and x>100 m in Line2). We must specify better that the data error of 20% applied in the inversion process was defined using the reciprocal analysis, which minimize possible inversion artifacts (Binley, 2015), and not the more common stacking error. Obviously, the expected data error can be estimated also with the stacking error (we acquired the measurements with a stacking range between 3-6, and a standard deviation threshold of 5%), nevertheless this approach usually overestimates the quality of the dataset and is less reliable (Binley, 2015).

We will add these considerations in Section 5.4.

2.4) In general, the work is well structured, the reading is pleasant, the data is relevant, and the figures are of good quality and enriching.

Specific comments are made below.

Line 13: This work is not focused on the water contribution of the talus slopes. Nor are there many background to mention the importance or not of the talus slopes in the water supply to the rivers. Where does this statement arise?

Here we will remove the mention to talus slopes and rephrase slightly this sentence.

2.5) Line 68-71: InSAR or DInSAR would not be useful techniques for this case since the relict or pseudo relict rock glaciers have no movement or the movement can be very slow and be in the same range as the uncertainty of the method. For this reason, since it is not a method applicable to this study, this sentence should be removed.

We will add these consideration in the Introduction, where we write about InSAR. We would prefer keeping this sentence because some reader may wonder if we have considered this methodology.

2.6) Line 73-75: The measurement could be at the end of summer or principles of autumn. The temperature trend in every summer should be considered, because with colder summers the thermal wave takes longer to enter the subsoil and completely defrost the active layer. This research methodology assumes that the water in which the temperature is being measured is influenced by ground ice. But, so that the temperature value registered in the springs is a real evidence of permafrost existence, it should not exist seasonal ice in the active layer.

The reviewer is right that cold temperatures can be due to the presence of seasonal ground ice. For this reason, we have stuck with the standard procedure of performing measurements at the end of the summer/beginning of autumn in order to exclude seasonal ground-ice influence on temperature measurements, or at least minimise its effect within the limit of our approach. It is true that seasonal ground ice formation could have a stronger influence on spring temperature after cool/short summer seasons, but

this was not the case in the years we have analysed, characterised by warm/long summers. We will add these considerations in the Discussion section (paragraph 5.3).

2.7) Line 94-96: It should be specified that lithology is composed of each rock glacier. Considering that ERT has been applied, which are of the relict or pseudo-relict type, and that the amount of ice present can be small, the changes or gradients in the values of the electrical resistivity could be influenced by lithology. This information could also be added in section 3.4.

The inspected rock glaciers are characterised by uniform lithology. Information regarding lithology will be added in the text.

2.8) Line 156 (Data collection): Has a monitoring of temperature variation in springs during the day been performed? If there is a variation of temperature during the day this will influence the results depending on the measurement time.

Hourly spring water records collected during summer and early autumn using dataloggers show negligible variation of spring-water temperature during the day (Seppi, 2006). We will add these considerations in Section 5.3.

Seppi, R.: I rock glaciers delle Alpi Centrali come indicatori ambientali (Gruppo Adamello-Presanella e settore orientale del Gruppo Ortles-Cevedale) - Rock glaciers of the Central Alps as environmental indicators (Adamello-Presanella Group and eastern sector of the Ortles-Cevedale Group). Phd Thesis, 199 pp., doi: 10.13140/RG.2.1.1186.5682, 2006.

2.9) Line 161-162: It is not completely clear to me. In the previous paragraph it is mentioned that 133 springs located downslope of rock glaciers were measured. This paragraph says that 67 (17 + 50) springs in rock glaciers were measured. What is the amount of spings in rock glaciers that have been measured?

Here we report how many rock glaciers we sampled, not how many springs downslope of rock glaciers. Before, we mention 133 springs downslope of rock glaciers because there were rock glaciers with multiple springs measured. We will add this at the beginning of Section 3.2, to improve clarity. Afterwards, in Section 3.3, we clarify that we retained only one spring for each rock glacier sampled.

2.10) Line 175: How were those streamflows measured? With what criteria was that threshold (0.11 l/s) established?

We have a long experience of runoff measurements using the salt dilution method on mountain creeks and torrents. Based on this experience we were able to estimate by eye the runoff of springs, and to assess that a 0.1 l/s threshold was adequate for discriminating between semi-stagnant and well-fed springs, and thus to discard springs affected by large temperature fluctuations during the day. The estimated runoff was not used in the analyses of spring-water temperature. This will be added in the text at the beginning of Section 3.3. Please see also the reply to comment 1.6.

2.11) Line 251-252: In these cases of high contact resistance it is advisable to add under the sponge an aluminum foil of approximately 20 cm side and cover it if possible with fine material. If contact resistances remain high, after incorporating abundant salt water and aluminum foil, it is advisable to move the profile position to a more favorable sector. Personally, I do not recommend measuring with such high contact resistances.

We agree with the Reviewer that these were unfavourable conditions, even applying the traditional approach of stainless-steel spike coupled with sponges soaked in salt water (Hauck and Kneisel, 2008), which usually guarantee optimal contact resistances (<100 kΩ). Nevertheless, in the specific case of the Preghena rock glacier, the surface was particularly dry due to drought conditions. In our experience, good quality ERT datasets can be collected on Alpine rock glaciers even with contact resistances larger than 100 kΩ, adopting large quadrupoles number acquisitions that considerably helps redundancy and data reliability, as we did.

The surface of the rock glacier is almost entirely covered by blocks. For this reason, it was not possible to find a more favourable position.

2.12) Figure 8: The scale of values should be expressed in Ωm or kΩm, as in the text. In addition, it is convenient to add the RMS in each profile.

We will make uniform the units of measurement between the text and the figure. We will also add the RMS in each profile, as suggested.

2.13) Line 464 (section 5.3): One of the main uncertainties is that it is not known if there is ground ice from the previous winter that has been stored in an active layer and that is influencing the temperature of the springs. In a way, the monitoring of the springs over the years would allow to eliminate this situation to a certain degree.

Please see the reply to the previous comment 2.6. We will add these relevant considerations in Section 5.3.

2.14) Another uncertainty factor is that water inside a rock glacier can follow different paths (Villarroel et al., 2022). In pseudo-relict rock glaciers, with the presence of ground ice in the form of islands, the water could follow paths without contact with the ice. I consider that this situations must be discussed.

We agree with the Reviewer that this situation must be included in the discussion, and we will do that in the revised version of our manuscript.