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 1

1.1) Your manuscript presents the results from spring-water temperature of several rock glaciers, investigating in conjunction with topographic and geomorphological factors, spread in an area of 795 $km^2$. The underlying method is based on measuring spring-water temperature to distinguish between intact and relict rock glaciers. Only two specific cases are investigated with electrical resistivity tomography (ERT) to investigate the permafrost presence in the ground. Although the area investigated is commendable, the study presents methodological, conceptual, and formatting failures that make this work unsuitable for publication in its current shape.

Based on the suggestions by Reviewer 1 we will revise the manuscript and hope it will be suitable for publication in the new shape.

1.2) There is a lack of context with the previous work by Seppi et al. (2012), who pioneered the rock glaciers classification in the area investigated in this research work. In general, a detailed discussion between Seppi et al. (2012) and your contribution would allow placing your findings in the context of current research.

In the Discussion section 5.2 we will add considerations regarding the Seppi et al. (2012) work and the need for a new (re)classification of rock glaciers based on the new data collected in our work. We thank the reviewer for pointing out this aspect, which was not included in the first version of the manuscript.

1.3) Finally, there are very relevant limitations in this work in the points chosen for the spring-water temperature measurements which make some data used in the analyses not exactly reliable.

Please refer to our replies to the 'Limitation' comments (points 1.9 to 1.11)

Methodology:

1.4) The ERT surveys are performed only in two rock glaciers. Considering the aim of this work, this is not enough.

Our paper is focused on spring-water temperature variability and uses geophysics as a mean for complementing spring-water temperature results at local scale for two rock glaciers. Geophysics is by no mean intended to characterise permafrost distribution in the study area, which would have been well beyond the objectives of this work. As reported in the Introduction, the general aim of the work is the analysis of the spatial variability of spring-water temperature in the study area to better understand permafrost distribution, under the hypothesis that a significant portion of rock glaciers classified as relict have spring-water temperature comparable to those of intact rock glaciers, as possible evidence of their pseudo-relict nature. The specific aim of geophysics is to investigate the presence of permafrost in two rock glaciers selected for their different spring-water temperature and surface characteristics, to constrain spring-water temperature results at local scale.

1.5) There is too assumption about the spring-water temperature and the location of some of the measuring points which need to be verified not only on two rock glaciers. This is not enough to explain the difference in temperature in your dataset and cannot be used to discriminate intact rock glaciers from relict ones.

We did not assume anything regarding spring-water temperature and the location of some of the measuring points. We measured spring-water temperature and analysed its spatial variability and the relationship with physical and morphometric variables. The measurement points were selected (where available and accessible) as representative of the rock glacier population in the study area (Section 3). We simply collected data and analysed them to check the hypothesis (not assumption) that part of rock glaciers classified as relict may have spring-water temperature comparable to intact rock glaciers.

Please refer to the reply to point 1.4 for considerations regarding geophysics. We do not understand how geophysics would allow verifying assumptions (if any) about spring-water temperature and the location of some measuring points. The relationship between spring-water temperature and permafrost is well known and has been long reported in the literature mentioned in this work.

1.6) There is a missing information about the runoff estimation. Did the runoff estimation do by visual inspection (as said in the line 171) or did you measure it properly?

The runoff was estimated visually and not measured. There was no need for accurate runoff measurements, because the aim of runoff estimation was only to discard springs with too low runoff. This approach is similar to that proposed e.g. by Strobl et al., (2020) for crowdsourced visual estimation of stream level class. We will add this in the text at the end of section 3.2.

Strobl, B., Etter, S., van Meerveld, I., & Seibert, J. (2020). Accuracy of crowdsourced streamflow and stream level class estimates. Hydrological Sciences Journal, 65(5), 823-841.

Results:

1.7) The subchapter “Ice storage in the rock glaciers and glaciers of Val di Sole” is placed in the wrong position. If the authors explain the methodology to estimate the ice volume and consequently the hydrological response, you should put these details in a proper subchapter in the methodology and add this notion in the introduction as well.

We will edit the manuscript so that this part will be placed in the proper sections (Introduction, Methods, Results and Discussion).

Discussion:

1.8) Some information (see previous comment about the subchapter 5.5) are presented for the first time in this section. It is well explained, and the analysis are done in a proper way, but the position is wrong and completely unlinked with the text. The authors never mentioned previously this analysis, so its introduction is completely not in the correct place and never explained before along the text.

Please see the reply to the previous comment 1.7

Limitations:

1.9) First limitation: as mentioned by the authors, there are several relevant limitations in this work.

Location of the points where the spring-water temperature are performed.

If the point is located not in correspondence of the rock glacier but a few meters downstream, how this measure can be considered a real temperature value of the water coming out of the rock glacier? Between the rock glacier and the measuring point, the water is subject to alteration process that can alter its property and thus may represent an unrealistic spring-water temperature data. Therefore, this value should not be

used to distinguish between intact and relict rock glaciers. By doing so, part of your dataset is based on unreliable data, if this situation arises. How many springs investigated fail in this case?

We have checked the impact of spring location downstream of the rock glacier front at three measurement sites, where the same stream emerged briefly at the rock glacier front and a few tens meters downstream. Measurements confirmed that there is negligible warming (from 0.0 to 0.1°C) of the water downstream of the rock glacier front, at least as long as the water remains below the surface (this will be added in the text in Section 5.3). Possible warming over longer distance is what happens at the Bordolona rock glacier, as discussed in section 5.3. However, given the patchy distribution of permafrost in pseudo-relict rock glaciers, there is no way to know or estimate the distance between permafrost and the measured springs, as this would require systematic and extensive geophysical surveys on all rock glaciers where spring-water temperature is measured.

1.10) Second limitation: as you said, some springs were only monitored once. It seems a bit small to me to be used within a dataset where the ultimate goal is to use the spring-water temperature information to discriminate relict rock glaciers. I appreciate the explanation for their validation, but I do not think your conclusion to include this data in the dataset is robust enough.

We thank the reviewer for her/his opinion but we prefer to quantify uncertainty by showing experimental data and numeric validation in our manuscript. Please see also the reply to comment 1.27.

1.11) Third limitation: this work seems based on outdate rock glacier classification which distinguish between intact (active and inactive), and relict rock glaciers. The update classification of rock glaciers distinguishes them between active, transitional, and relict. Could the authors explain why this latter classification is not taken into consideration?

As we explain in the text, the only available classification was that of Seppi et al. (2012), who inventoried the rock glaciers in the study area using guidelines available in 2012. We will edit the text and the figures in order to account for the updated classification proposed by RGIK (2023).

RGIK (2023). Guidelines for inventorying rock glaciers: baseline and practical concepts (version 1.0). IPA Action Group Rock glacier inventories and kinematics, 25 pp, DOI: 10.51363/unifr.srr.2023.002

DETAILS:

1.12) Line 60: check grammar

We will divide this period into two separate sentences

1.13) Line 86: ….and particularly on relict rock glaciers

We prefer adding ‘of’, instead of ‘on’, because it better clarifies the meaning of this sentence

1.14) Line 96: add reference

We will add the requested references (geological map of Italy)

1.15) Line 107: what is the time interval considered for the precipitation parameter?

The time interval goes from 1971 to 2008, added in the text

1.16) Lines 112-115: Add a short explanation of Seppi’s method to classify rock glaciers and how they pointed out the number of rock glaciers in every single category.

Ok, it will be added (end of Section 2)

1.17) Line 120: …mean annual precipitation of 1233 mm (Carturan et al., 2016)

Modified accordingly (beginning of Section 3.1)

1.18) Lines 129-130: rewrite the sentence. It is not clear.

We will simplify this sentence for clarity

1.19) Lines 130-132: These two sentences are not placed in a correct position since they provide results. Please, consider to move these lines in the appropriate section.

Actually these sentences help the reader understanding what follows, that is why we built the spring-water sampling scheme around rock glacier activity, length, mean elevation, and vegetation cover.

1.20) Line 133: What "considering accessibility" means?

Accessibility 'of springs', it will be added in the text to improve clarity

1.21) Line 159: Why some springs were collected once per year? What is the reasoning behind the authors' choice to carry out only one measurement per year (albeit repeated between 2018 and 2020) and to consequently be able to consider this value sufficiently truthful?

Most springs were measured once per year between 2018 and 2020, only a few of them was also measured in 2021. Only one measurement per year was feasible at each spring, primarily because of the large number of springs measured over a large area, short period of time available (about one month), limited funding and, in particular, low available manpower (often only one person). We think that there is no need to write it out explicitly.

1.22) Line 161: This classification between intact and relict rock glaciers is based on the outdate classification. As the authors may know, there is an update rock glaciers classification made by RGIK2023.

Please see the reply to the comment 1-11 (Third limitation)

1.23) Line 171: How did the authors estimate runoff "visually"? It is a very subjective value and depends heavily on the operator in charge of the measurement.

Yes it is but the operator was always the same. We add that runoff estimation was only used to discard measurements at springs with too low runoff (please, see also the reply to comment 1.6).

1.24) Line 174: Do you mean outlier values?

No, we mean problems of too low runoff and selection of only one measurement for each rock glacier, where there was redundancy (as detailed in the following)

1.25) Line 175: How did you exactly estimate runoff? You previously said, "runoff was visually estimated".

There was no need for exact runoff estimation, it should be clearer with the explaining text added at the end of Section 3.2

1.26) Line 177: See comment above. At least, insert a value for this "higher".

Here 'higher' is a relative concept: higher compared to the other springs available at the same rock glacier. There is no need for inserting runoff values in our opinion.

1.27) Line 219: I consider that one measure is not enough. Can the authors explain why they consider this measurement to be sufficient? Since your work is focused on distinguishing between intact and relict rock glaciers based on spring-water temperature, I don't think one measurement is sufficient enough.

We do not write that 'one measure is enough'. Conversely, we express doubt about that and question explicitly the representativeness of springs measured only once. To prove/disprove that, we present

calculation results based on the collected data, that indicate a low impact of extreme temperatures and the suitability of using the median of all available measurements (regardless of their number) in statistical analyses. We let the numbers speak for themselves because our personal opinion is not relevant in a scientific paper.

Most of the papers regarding permafrost applications using spring-water temperature mentioned in our manuscript deal with single measurements, including our published paper based on this methodology (Carturan et al., 2016). For this reason, we consider a plus that the majority of springs analysed in Val di Sole had more than one measurement! Actually, we planned to repeat all the measurements at least three times, in three different years, but many springs had too low runoff or were even dry at the time of revisits, due to drought conditions.

1.28) Line 243: Insert the length of each survey.

Ok, it will be added in Section 3.4

1.29) Line 258: This seems more a result than a method. Consider moving in the appropriate section.

Ok, this part will be moved at the end of Section 5.4

1.30) Lines 265-270: This part does not seem a result. It should be better to move it in the method section.

Here we shortly present the descriptive statistics of our dataset reported in Table 4. For this reason, we prefer keeping this part where it is.

1.31) Line 386: Please consider indicating this information in Figure 1.

Ok, we will add the location of Careser diga in Figure 1

1.32) Lines 397-398: This is not something surprise. It has been already reported in some previously studies. Please add more recent references.

Ok, we will add these references:

Wagner, T., Pauritsch, M., Mayaud, C., Kellerer-Pirklbauer, A., Thalheim, F., & Winkler, G. (2019). Controlling factors of microclimate in blocky surface layers of two nearby relict rock glaciers (Niedere Tauern Range, Austria). Geografiska Annaler: Series A, Physical Geography, 101(4), 310–333. https://doi.org/10.1080/04353676.2019.1670950

Amschwand, D., Scherler, M., Hoelzle, M., Krummenacher, B., Haberkorn, A., Kienholz, C. and Gubler, H., 2024. Surface heat fluxes at coarse blocky Murtèl rock glacier (Engadine, eastern Swiss Alps). The Cryosphere, 18(4), pp.2103-2139.

1.33) Section 5.5: Why this part is inserted in the discussion section? The explanation about the volumes should be moved in the methodological part.

Ok, we will modify this accordingly

1.34) Figure 2: Insert north arrow and scale bar.

Ok, we will add north arrow and scale bar in Figure 2

1.35) Figure 3: Insert (a), (b), (c), and (d) and adjust the caption accordingly.

Ok, we will modify this accordingly