

Reply to Referee1, Mihai Cimpoiasu

This is my second review of this manuscript, now entitled: "Geophysical measurements of the Southernmost microglacier in Europe suggest permafrost occurrence in Bulgaria".

I acknowledge the clear improvements done to the article. I can safely say it is a valuable piece of science and it will be a good contribution to the literature. However, still needs a bit more work before it can be published. At the moment, I cannot recommend it for publication.

First of all, the language issue still persists especially in the paragraphs where new text was added. There are still quite a lot of mistakes and several sentences difficult to understand. I have tried to help the authors with some suggestions as much as I could, but the whole text needs to be thoroughly examined and its language more rigorously improved.

**Thank you for the effort to correct the language. The final correction of the manuscript is made by an English teacher. We hope the text is better readable now.**

There is a serious lack of detail about how ERT measurements were collected. You don't even mention the device used.

**The device used for ERT measurements is ABEM SAS 1000. It is mentioned in the text on line 173.**

How many measurements per profile?

**24 electrodes allow 121 measurements per profile. We added this information to the text.**

*... The multi-electrode resistivity technique consists in using a multi-core cable with 24 conductors, as electrodes plugged into the ground at a fixed spacing. The number of 24 electrodes allowed 121 measurements per profile...*

Did you acquire any reciprocal data?

Measurements were conducted in forward and reciprocal directions and the final values are the average of the resistivity at each point, measured in both directions. This is the usual way of collecting data from ERT in Bulgaria and we have not mentioned it in the text.

Any data filtering applied pre-inversion?

**Yes, the filtering was performed before the inversion. A small paragraph is added to the text describing the workflow.**

*Obtained ERT data was processed with RES2DINV (Loke 2001, 2010). Data preprocessing include extermination of bad data points and applying of vertical/horizontal filter weight. An option for effect reduction of side blocks and obtaining smooth anomalies is also used. First a trial inversion is made and after it a RMS (Root Mean Square) error statistics is performed. Then the data points with extreme values are removed and the inversion is made again.*

Any error models applied to the data?

**Error model was made and the data was corrected based on it.**

Any temperature corrections?

**We didn't apply temperature corrections because the anomalies caused by the ice lenses and ice rich permafrost have a big difference in the resistivity values (more than 60 000  $\Omega m$ ) than the accommodating medium. According to the Hauck (2001), there is an exponential change in the resistivity with the decrease of the temperature below 0.**

*Hauck (2001) Geophysical methods for detecting permafrost in high mountains, Versuchsanstalt fur Wasserbau Hydrologie und Glaziologie der Eidgenossischen Technischen Hochschule Zurich, 2001(p.73-76)*

It looks like you used Res2DInv as an inversion software, but you are not referencing it. Why is that?

**Thank you for this remark, we added the name of the software and the reference in the text.**

Finally, it would be useful to discuss the wider implications of your work. Why are your results relevant to the wider scientific community? Examples of a few discussion topics you might want to touch upon:

Does the discovery of permafrost make you rethink the pedo/geomorphology of the Pirin mountains?

Does it imply that we need to rethink the importance of permafrost formation factors?

Can permafrost be more common in Bulgaria than we previously thought? If that is the case, could it be that we are underestimating the permafrost distribution worldwide?

Thank you for this suggestion. The questions you ask are very interesting. We have discussed shortly the presence of permafrost in Pirin Mountain but pedogenesis is a topic, which is a bit far from ours. The following paragraphs are added at the end of Sections 3 and 4:

*Bulgaria and the Balkan Peninsula are situated in lower latitudes where no continuous permafrost exists. Only isolated patches of permafrost are present in high mountains (Brown et al.(2001)). However, its distribution is much less investigated (Oliva et al.(2018)). Permafrost probably exists above ~ 2350 m on Rila Mountains (Oliva et al.(2018)) and above ~ 2400 m in the Pirin Mountains. In the Golyam Kazan cirque is can be sporadic and presented in the area south of the glacieret, where snow patches are observed in some summers. To prove this more studies including geophysical measurements are needed. The area was described above as well shaded by the Dzhamdzhiev ridge. Most of the places in the high mountains of Bulgaria, where probably permafrost is present, are steep and this makes it difficult for geophysical measurements to be carried out. Nevertheless, more investigation into permafrost distribution and its monitoring in time should be made. It is important because changing climatic conditions can lead to the disappearing of isolated permafrost patches especially in areas with relatively warm climate like the Balkan Peninsula. Disappearing of permafrost patches can cause rapid degradation processes and rock avalanches. In Bulgaria there are no many infrastructures in the high mountains that can be damaged, unlike in the Alps or other inhabited mountains. However, many hike trails are crossing slopes that can be unstable and dangerous when permafrost melts.*

*The knowledge of permafrost on the Balkan Peninsula and particularly in Bulgaria is very general and studies of permafrost, including geophysical measurements, are still rare. Even though the presented study is focused on a small area of Pirin mountain (Bulgaria), it gives important information on the presence, extent, and the state of a permafrost area, surviving due to local conditions in the warming climate.*

Specific comments

Abstract

You use the spelling "glaciarret". One of the other reviewers used the spelling "glaciaret". In Ganchev, (2011) I found it spelled as "glacieret". What is the correct spelling? Please determine which one is appropriate and use it throughout the manuscript.

**Thank you for the comment, we unified the spelling as "glacieret according to Ganchev, (2011).**

1. Introduction Line 36: "also" / in addition of what? Please remove "also".

**Done**

Line 37: how is it visible? This is a rather vague sentence.

**We decided to remove the sentence.**

Line 51-53: references required

**References are added.**

Line 54: "The ERT technique is one of the basic methods for permafrost evidence and studies". I don't know if basic is the best term here. A commonly used geophysical method maybe? Also, please add references.

**The proposed change is made and a reference is added.**

Line 81: Electrical Resistivity Tomography (ERT) method

**Done**

Line 81: is sensitive to the changes ...

**Done**

Line 85: significant how? Please be specific e.g. "increases by 'x' orders of magnitude", include a reference.

**The change is exponential. It is added to the text together with a reference.**

Line 86: Please delete this sentence. Either include this mention earlier in the paragraph or merge it with another sentence. On its own at the end of the paragraph doesn't fit well with how the text flows.

**The sentence is merged with the first one from the paragraph. Thank you for the suggestion.**

Line 93: Did you want to say: "even though"? I think what you say before "there are some limitations" is redundant.

**The sentence is changed as suggested.**

Line 95: please rephrase as "the complicated logistics of transporting ... and the aspects regarding a safe system of work"

**Done**

Line 98-99: Not clear. Please rephrase.

**Done**

Line 101: "To minimize the inaccuracies the relief can be estimated using unmanned aerial vehicle (UAV) for example." Include a reference please.

**References are added.**

Line 103: ERT has limitations when applied

**Done**

Line 104: Use "firstly". Consequence of what? Ground not "rock"

**The sentence is corrected as suggested.**

Line 93-108: I can see that the point of this paragraph is to justify the complementary use of GPR, ERT and UAV measurements. However, you didn't say how exactly they benefit from each other. Please be a bit more specific. For example, ERT resulting subsurface images suffer inherently from non-uniqueness. GPR, as an independent method of subsurface investigation, can supply more accurate information about where the boundaries between layers are located. This in turn can be used to give some geological context to the ERT tomograms or even constrain the ERT inversion results.

**To add such a paragraph, describing limitations of the methods, was suggested by the Referee2. We have used the text you propose to extend the paragraph a little bit.**

Line 109: "a very short" What is a surface capture? Maybe I am not familiar with the term. Is it a series of photographs of the ground surface? "An UAV"

**Yes, we mean under "surface capture" a series of photographs, made by the drone. They are aligned and processed after that to produce a model of the surface.**

Line 112-113: rephrase as "there is not much information about the ice thickness" Please delete "and one point of our work was to solve this". You already said this above.

**Done**

Line 115: Please delete what is in parenthesis.

**Done**

Line 116: Move this sentence at the beginning of the paragraph where you state what you will be showing us in this manuscript, such as: "the aim was to investigate the thickness...the glacial bed). In addition, we investigated where the meltwater from Snezhnika disappears beneath the microglaciers' bed.

**The suggested change is made.**

Line 117: Last sentence is redundant.

**The sentence is removed.**

2. Methods

2.1. Study site description

Line 134: Rephrase "In the Golyam Kazan Cirque we find low coverage alpine and subalpine vegetation."

**Done**

Line 135: "There is no evidence of surface water"

**Done**

Line 136: This sentence is not well integrated in the text: "Pirin Mountain is on cross-roads of Mediterranean and Continental climate". As it stands, it sounds redundant.

**We changed the order of the sentences in the paragraph. Now it starts with the climate, then vegetation, and at the end is the sentence about the surface water.**

Line 138: Is this correct: "measured until 2005"? 2005 was 17 years ago, I am sure a lot has change in the meantime. Are these records still representative?

**Yes, you are right. The records were made 17 years ago, but are the most recent official information we have found. According to our observations during winter hikes in Pirin (not related to the research), the snow at the end of winter is 2-3m. It can be easily appreciated, since the snow completely covers the dwarf mountain pines (Pinus mugo), which in Rila and Pirin Mountains reaches about 2 m.**

## 2.2. Ground-penetrating radar

Table 1: GPR measurements settings

SURVEY |space| PARAMETERS

**Done**

Line 165: What does this mean "without additional security? ". I think you mean that you didn't have the right gear, but you don't need to justify that. Just say: "highest elevation area accessible with the gear and tools available at the time."

**Thank you for the suggestion, we changed the text.**

Line 166: Change "the second reason" to " In addition, most of..."

**Done**

## 2.3. Electrical resistivity method

Line 186: Do you mean "safe access to..."?

**Yes, "safe" is the right word. It is corrected now.**

Line 186: why was pole-dipole and dipole-dipole impossible? You have to explain if you decide to mention it.

**We decided to remove this part of the sentence. Pole-dipole and dipole-dipole measuring schemes were not possible to be used due to the rough terrain.**

Line 191-194: This bit of text still doesn't sound right. I have given you a nice example in the previous round of revision, but you chose not to correct it. What is a real geoelectrical section? I think you mean the result you get post inversion, but it's the first time I come across this terminology. Please rephrase.

**Thank you for the suggestion. We corrected the text according to your first suggestion.**

Line 198: rephrase to "harsh weather conditions did not allow us to work on the same date every year"

**Thank you for the suggestion, we have accepted it and changed the text accordingly.**

Line 201: rephrase to "This measurement window is relative, changing from one year to another, with 2017 and 2018 seeing the first snow fall in September, whereas in 2020, with a warm month of October, the first snow fall was recorded in []"

**Thank you for the suggestion, the sentence is rephrased.**

Figure 3. How did you obtain the outline of the glaciaret? Is that from UAV images/ photos? Please specify in text.

**The outlines of the microglacier were recorded with Garmin and for 2018 it was also improved with the UAV image. The information is added in the main text of the manuscript. Thank you for this remark.**

## 3. Results and discussion

This section as a whole does not have a lot of structure. I suggest the introduction of some subsections to aid the reader.

**There were subsections in the first version but we decided to remove them. Now we uncommented the rows with subsections and changed the names. Thank you for this suggestion.**

Line 210-211: I have no idea what this sentence means "and accordingly its lowest part consists of the" new" snow left from the last winter. This are profiles GPR(2018)-1, GPR(2018)-2 and partially GPR(2018)-3 (Fig. 4a,b and c)." Why is new in quotation marks? Do you mean those profiles are relevant because they are down the slope? Please rephrase and be clear.

**Thank you for the comment, we changed these sentences to be more clear.**

*...In 2018 the size of microglacier was bigger than in 2017 (Fig.2a and Fig.3) and accordingly its lowest part consists only of the snow left from the last winter. This can be observed on profiles GPR(2018)-1, GPR(2018)-2 and partially GPR(2018)-3 (Fig.4a,b and c) situated in the lowest part of the microglacier. Within the first layer, there are some less differentiated discontinuities...*

Line 246: What depth of 11m? Is that what Gruenewald found? What aerial geophysical measurements? Is UAV photography a geophysical method? Please be clear. Rephrase.

**Thank you for the comment, the text in this paragraph is changed to be more clear.**

Line 254: How is this sentence relevant here? - "Subsurface structure of microglacier bed was investigated using ERT and GPR measurements." Isn't this a generic sentence? How is it connected to the rest of the text?

**The sentence is merged with the next one.**

Line 257: aren't the years implied by the survey names?

**We removed the years in the name of the profile only here due to the repetition.**

Fig 6 is barely discussed. Please expand the discussion around it or remove it.

**You are right, after the last editing we have removed some text connected with this figure. Now we decided to remove also the figure.**

Fig 7: You call those pseudosections in the text. Results obtained post inversions are not pseudosections. Pseudosections are a plot of apparent resistivity values, measurements obtained in the field. An RMS error of 22.5 is quite high. Why is that? Don't you think this error might influence the validity of your conclusions regarding Fig 7c?

**Thank you for this remark. The wrong plot/not the last one was merged in this figure. We check the figures before submission but the difference is very small and we missed it. Now the correct one is merged.**

Line 259: It is definitely not just marble that can have resistivity values between 8000 and 40000 Ohm.m. Many mixtures of rock fragments, water and soil can have a resistivity response within the same resistivity range. Given the local lithology, I understand why you made such statement, but the phrase needs rephrasing. Presently, it sounds as if because it has that resistivity it must be marble, which is not true.

**The correction is made.**

Line 284-286: Are you not just repeating what you said above?

**The text is reordered and the repetition is corrected.**

Line 289: Figure number not included.

**Figure number is included.**

Line 300: Figure number not included.

**Figure number is included.**

Line 327-328: I don't understand this sentence. Please rephrase.

**Done**

At the end of section 3 (and consequently at the end of the conclusion section) I would suggest including a short discussion about the wider implications of your study. Why is this work relevant/how is it useful for the study of permafrost/ geophysical methodology or geomorphology of Bulgarian mountains? How can future research build upon your results?

**Two short paragraphs are added as suggested.**

4. Conclusions Line 332: rephrase "is a large-scale assessment of the ice-thickness"

**Done**

Line 338: "by size"? do you mean surface area?

**Yes, we mean "be the surface area". The correction is made.**

Line 342-343: "ERT measurements were repeated over three consecutive years, detecting the anomaly during every measurement campaign."

**Done**

Line 344: rephrase "an answer to the question: where does the meltwater disappear?" I would have my reservations about claiming you found the answer to that question. I feel that the evidence you present is not sufficient to claim that. You might however say that based on your observations you have formulated a new hypothesis.

**The correction is made**

References

Gachev, E. (2011). Inter-annual size variations of Snezhnika glacieret (the Pirin mountains, Bulgaria) in the last ten years. *Studia Geomorphologica Carpatho-Balcanica*, 45(October), 7–19

Reply to Anonymous Referee2

I have only several specific comments listed below: - Title: I suggest keeping 'Pirin Mountains' in the title and placing 'Bulgaria' in the bracket.

**The title is changed according to suggestions**

- You should decide if your paper deals with perennial snow patches or glaciers. Despite, you having changed the title there are still many phrases in which you are presenting the importance of snow patches etc. In addition, you make confusion when considering snow patches as remnants of glaciers.

**The term "perennial snow patches" has been removed in most of the places yet. But we decided to keep it in some sentences in the Introduction.**

- Replace 'glaciarret' with 'glacieret' (see Gachev's papers).

**Done**

- Language should be improved!

**The final correction is made by an English teacher. We hope the text is better readable now.**

Line 14: delete the definition of 'perennial snow patches' because in the title (and the entire manuscript) you present a glacieret/microglacier.

**Done**

Line 23: replace 'since the Holocene' with 'since the end of the Pleistocene'

**Replaced**

Line 25: again perennial snow patch? You should decide if you discuss about snow patches or glaciers!

**We have removed "perennial snow patches" in most places but some we decided to keep.**

Line 27: when had Vihren glacier that size? LGM or LIA?

**Thank you for the comment. The given size is of the microglacier between 1994 and now. The sentence is rewritten to be correct.**

Lines 37-45: I think this part should be improved. 'In my opinion, you should refer here to the relation between permafrost and glaciers.

**Thank you for the comment. A few sentences about the permafrost-glacier interactions are added to the text.**

*Glaciers and permafrost are well studied separately but the interaction between them is topic of less publications (Harris et al.(2005)).....Permafrost can be absent in areas where glaciers are present but the ice rich permafrost and ground ice can be formed in front of and beneath the glaciers (Harris et al.(2005))....*

Lines 63-64 and elsewhere: when citing more papers try to list them ordered by the year.

**Thank you for the comment, the references are ordered yet.**

Lines 64-65: what do you mean? Please rephrase! In the case of seismic, it is not true!

**"Geophysical methods" is replaced with "GPR and ERT". Thank you for this remark.**

Line 84: 'The perennial snow patches in high mountains are similar to mountain glaciers (as remnants of them)'. Snow is snow and ice is ice (glacier), don't mix it! You make confusion here. Please eliminate this phrase! Snow patches are not remnants of glaciers! Snow patches are the accumulation of snow. Remnants of glaciers are glacierets, ice patches, ice masses etc

**We have removed the suggested part of the sentence.**