

Geosci. Instrum. Method. Data Syst. Discuss., author comment AC2  
<https://doi.org/10.5194/gi-2021-5-AC2>, 2021  
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## Reply on RC2

Ondřej Racek et al.

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Author comment on "Observation of the rock slope thermal regime, coupled with crackmeter stability monitoring: initial results from three different sites in Czechia (central Europe)" by Ondřej Racek et al., Geosci. Instrum. Method. Data Syst. Discuss., <https://doi.org/10.5194/gi-2021-5-AC2>, 2021

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In following text, authors react on comments and suggestions.

Thank you, for all your comments and suggestions, that will lead to significant improvements in our paper.

The paper entitled « Observation of the rock slope thermal regime, coupled with crack meter stability monitoring » presents a monitoring system of the thermal and rheological behaviour at the surface and near-surface of three rock wall sites in Czech Republic.

The paper is overall well-written and easy to follow, the monitoring approach is interesting but significant improvements are required before publication.

My main concern is that the authors claims that the monitoring system is original and innovative because of its completeness and affordability. While this is true that the system is affordable, it is, in my opinion, not unique and not so innovative : many sites are equipped with both ground temperature measurements in shallow boreholes and crackmeters (e.g. Weber et al., 2019, Ewald et al., 2019, Hasler et al., 2012, Gischig et al., 2011, in addition of those already referred). More explanations would be needed to really understand how novel is the system: how (precisely) the data will contribute to improve the understanding of rock fall preparation and triggering that the other system do not allow ? Will it provide data for thermo-mechanical models ? How such improvements can be made ? Which parameters, which process in the models ? (See more detailed comments).

Answer:

Thank you for your detailed comment. It is true that system itself does not use really innovative approach. However, innovation in case of our system comes from the use of affordable instrumentation on multiple sites, which ensures partial data comparability. Other sites using similar instrumentation that you are mentioning are typically focused on permafrost degradation/thawing monitoring and are located in mountainous Alpine regions. Our system, on the other hand, is placed within mid-latitude region, where thermally-forced rock mass destabilization is not linked with permafrost thawing. With similar instrumentation on different sites, we can observe differences between thermomechanical behavior of different rock types, structural setting or aspect according

to general azimuth directions. Data from the crack meters and in-depth temperature observations together with physical and mechanical properties of the rock will be later used to construction and validation of thermo-mechanical models. Ongoing innovation of our system will include in-situ strain gauge monitoring.

Moreover, many data are presented without being discussed nor used for research perspectives: e.g. Table 2, 3, Figure 3, ... This makes the paper quite long without improving its impact. I suggest to rework the paper top make sure that the data that are presented are clearly used for the results, discussion or explanation of research strategy.

Other major comments:

- Manuscript content and objectives: they are very vague, specific research questions and a clear research strategy should be clearly explained and detailed.

Answer: Thank you for your comment. Hopefully the second version of the manuscript is more detailed in this part and provides more information about research strategy and partial results.

- Title: the title should report at least the study area (Czech Republic, 3 sites) and environmental settings

Answer: Title was revised. Now it is clear that the monitoring takes place in Czechia.

- The abstract needs to be rewritten. It is vague and general. It should be more precise: how many sites instrumented, which environmental settings (elevation range, rock type, etc.), where are these sites, when did the record start, how long are the type series, what type of differences are measured...
  - Answer: Abstract was rewritten. New version should include all of the above listed missing parts.
- Introduction: It is generally quite long, lines 47-74 are a long list of some of the existing instrumentation to monitor and detect rock slope deformation and failure. It is too long and too detailed and I didn't get the purpose of such a long list which is somehow summarized line 73-74 but is not convincing. I am not convinced that approach presented in this paper is so different than many other sites, except maybe that instrumentation is relatively affordable. In the introduction, the hydrological processes are not considered at all while they represent a major external forcing in rock falls (see for example Krautblatter and Moser, 2009). I suggest largely rewriting the introduction to make it more concise and better introduce the approach presented in the paper in order that the reader understand why it is so different than the others. In my opinion, the question related to the choice of the fractures and blocks to instrument with crackmeters is still open, and many other studies combined such point-scale geotechnical observation with geodesy data to apprehend rock deformation at a larger scale as well, which is after all, a more complete approach than only the geotechnical approach.
  - Answer: Hopefully newly rewritten introduction is clearer and answers to the above mentioned problems. Mentioned list of methods and approaches was shortened and short paragraph mentioning hydrological influence to rock slope stability was added. Of course, point geotechnical data does not represent the dynamics of the rock slope in its full extent, however other methods that allows that (camera monitoring, TLS, GbSAR) are expensive and cannot be placed within multiple sites at low cost. Point data about spatial behavior of single crack does not represent whole rock slope but if unstable block is instrumented in this way, the influence of exogeneous factors on its stability can be observed. More complex data about whole rock slope can be gained using TLS, SfM photogrammetry or IR camera campaigns. We are planning to perform these campaigns at least once per year for each locality, to find annual

changes of the rock faces.

- Section 2.3: the same concern arises. Words such as « complex monitoring », « innovative » are used but I still do not understand why the approach is so innovative. Many other studies also combine shallow borehole temperature measurements with crackmeters.
  - Answer: It is true, that the instrumentation and approach itself is not really innovative. Therefore, we have changed description of the system in this chapter. Main advantage of here presented system is the affordability and modularity, so it can be placed within all kinds of rock slopes at low price.
- It would be interesting for the reader to know if any instrument was calibrated or not.
  - Answer: All parts of system were calibrated by the manufacturer of the components. Moreover the borehole thermometer probe was calibrated during assembly.
- Another concern : the instrumentation do provide any data about the temperature and the mechanical behaviour of the failure plane, which, in my opinion, strongly limits the interest to understand failure mechanisms.
  - Answer: Temperature within failure plane, or discontinuity that defines monitored blocks can be monitored with datalogger placed inside discontinuity. Regime of destabilization of partial blocks was described during field investigation and crackmeters were placed to best capture the possible destabilization trends.
- The paper is long with lot of tables and figures that are not necessarily relevant for understanding the approach. I suggest to create supplementary material or to barely remove information that are not a direct relevance to understand the strategy behind the instrumentation (see detailed comments).
  - Answer: To address this comment. Irrelevant pictures, tables etc. were removed in new manuscript version.

Detailed comments :

- Line 33: permafrost doesn't melt, it thaws. Answer: it was corrected using the right term.
- Line 38: see also the PERMOS reports from the Swiss permafrost monitoring system.
  - Answer: information about PERMOS system was added in introduction.
- Line 43: « Unfortunately... » : such formulation is not appropriate in a scientific paper
  - Answer: sentence was rewritten to meet the appropriate formulation.
- Line 55-56: there is something wrong with this sentence, rephrase.
  - Answer: sentence was rewritten.
- Line 83: what is a « 2D environment »?
  - Answer: This sentence meant that the temperature is measured both on the surface and in rock mass depth. It was misleading formulation and whole paragraph was rewritten.
- Line 95: is the monitoring system the same for each site?
  - Answer: Used sensors are same for all monitoring sites. Of course, monitored blocks differ in terms of dimensions and regime of destabilization. Moreover, different number of crack meters are used within the sites.
- Table 1: why some items have no price?
  - Answer: Prices are listed for set. It means one price is for pair of crack meters and datalogger, or for whole weather station (control unit, thermometer, rain gauge etc.).
- Figure 2: remove « so far » from the caption, it is not appropriate
  - Answer: Sentence was rewritten.
- Table 5: over which period are the radiation measurements available?
  - Answer: Table was suppressed. Pyranometer data are available since 1/2020 (Branická skála), 2/2020 (Pastýřská skála) and 12/2020 (Tašovice).
- Line 268: number of the figure is missing

- Answer: Number was added
- Line 269: the operating time is not relevant here as all sensors seem to record the greatest amplitude within this period on Fig. 5. If not, clarify.
  - Answer: You are right that all sites shows the greatest amplitude within this period. On the other hand, at Pastýřská rock site and Branická rock site, time series span over two summer periods with largest surface temperatures fluctuation. This paragraph was rewritten, to clarify, that surface temperature at Tašovice site is caused by lower albedo of dark rock surface.
- Line 271: I do not understand this statement: the temperature amplitude decrease with depth is related to the thermal diffusivity, not the albedo.
  - Answer: Statement was meant in a way, that lower albedo leads to greater surface temperature amplitude.
- Line 272: how sure is this statement ? Please refer your interpretation to facts/proper observations or do not interpret.
  - Answer: The different aspect of the rock face causes temporal shift between diurnal surface temperature peaks. Different lithology causes differences in heat transfer, which cannot be directly observed. Sentence was rewritten.
- Figure 6: explain the statistics displayed with the boxplot in the caption: median... ?
  - Answer: Legend was rewritten.
- Line 280: what is a significant opening? Does « significant » have a scientific meaning or definition in this context?
  - Answer: Opening, that is clearly not caused by thermal expansion of rock mass. Pattern of measured crackmeter opening should contain irreversible trend.
- Line 290: same question with « relatively high »
  - Answer: Again, sentence was rephrased to describe amplitude larger than 1 mm.
- Line 293-294: this is very speculative as the time series is very short. Please, base your interpretation on facts rather than speculation. The interpretation might change completely with a longer time series.
  - Answer: We agree it is speculative but in general larger amplitudes over short time shows that the monitored block is more dynamic. That should be confirmed by further monitoring. The sentence was rephrased.
- Line 295: how does a block destabilization trend is expected to look?
  - Answer: Trends should be confirmed by statistical analyses. However fast destabilization trend should be visible from graphs, when crackmeter opening/closure is not driven by thermal expansion/dilatation of rock mass.
- Line 313 ff: the present forcings are not the only factors of rock stability. Past conditions and events (climate change, former rockfall, ...) have to be accounted for as well. In addition, the hydrological processes must be considered.
  - Answer: Thank you for this comment. Forcings that you mentioned were added to the revised version of the manuscript.
- Line 323: the automatic discontinuity extraction approach needs some detailed explanation.
  - Answer: It was done using freely available DSE software. Citation is listed in manuscript.
- Line 335-340: this is part of the method, not the discussion !
  - Answer: Paragraph was rewritten and moved to methods.
- Table 7: I also wonder if this is relevant in the discussion. This would be better to explain why the monitoring system of this study is so innovative.
  - Answer: Thank you for your suggestion. This table was moved to results.
- Table 8: This is part of the results.
  - Answer: Sentence rewritten and moved to results.
- Figure 8: idem.
- Table 9. Idem, and I do not really see the relevance of giving so much details.
  - Answer: Table was suppressed.
- Line 366-367: explain this statement and appropriate references.
  - Answer: This is given by shorter period with freeze-thaw activity, lower solar

- radiation caused temperature amplitudes or lower overall precipitation.
- Line 372: explain the concept of « rock disintegration » and how temperature change act for such process.
    - . Temperature changes causes irregular heating and cooling of rock mass. These leads to irregularities in rock mass dilatation at surface and in the depth, which causes thermally induced stress/strain. This eventually leads to discontinuity evolution and breakage of rock mass surface layers. Thermally driven disintegration also acts at grain-scale, where grains of different minerals expand differently and induce stresses into the rock mass (Hall and André, 2001,2003).
  - Line 376-377: to determine the place of the potential rock failure, quantitative understanding of the mechanical properties of the failure plan would be required. Similarly, the measured temperature in compact rock is not representative of the temperature in fractures. See Hasler et al., 2011 for example.
    - Answer: Numerical modeling will be combined with field data gained by IR camera and radiation data. By our approach places where thermally induced stress is concentrated, will be compared with field data about unstable parts of the rock slopes.
  - L 390: the sentence is difficult to understand. Please rephrase.
    - Answer: Sentence was rephrased.
  - Line 412: this statement is ehre again very speculative in the absence of proper comparison of climate data.
    - Answer: Sentence was rephrased, to clarify, that is only applicable to our data.
  - L 440: these perspectives should be cleraly detailed in the discussion. The reader needs to understand the research strategy and how the data will be used for the implementation of the perspective.
    - Answer: Discussion was rewritten with additional research strategy explained.

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