Natural Hazards and Earth System Sciences Discussions

Nat. Hazards Earth Syst. Sci. Discuss., community comment CC1
https://doi.org/10.5194/nhess-2021-128-CC1, 2021

Reply on RC1

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Community comment on "Multi-method monitoring of rockfall activity along the classic route up Mont Blanc (4809 m a.s.l.) to encourage adaptation by mountaineers" by Jacques Mourey et al., Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2021-128-CC1, 2021

First of all, thank you for the two thorough reviews. They made us really think about what were the main objectives and novelties of our study.

There are on average 35 fatal accidents per year in summer mountaineering in France (Soulé et al. 2014). On average, 3.7 of those fatal accidents have occurred every summer in the Grand couloir du Goûter since 1990 (Mourey et al. 2018), hence its reputation in the media as the "couloir of death". Rockfalls directly explain at least 29% of the accidents and are partly involved in the accidents due to a fall, which account for 50% of the accidents (Mourey et al. 2018). Rockfalls are therefore one of the main factors that explain this high accident rate and contribute in making it one of the most accident-prone area in the Alps for mountaineers.

It is this particular context that motivated our study with the objective of **acquiring knowledge on rockfalls and their triggering factors in the Grand couloir du Goûter that would be of interest to mountaineers and help them adapt to the local risk of rockfalls.** This would potentially reduce the number of accidents in this sector.

Regarding this motivation, we provided one of the few continuous databases on rockfall activity in permafrost conditions with day and night and weather independent conditions thanks to the deployment of a seismic array. To our knowledge, only Guillemot et al., 2020, GJI, provided such database (which is not analyzed in terms of triggers), and other previous rockfall databases were either continuous but focusing on local unglaciated mountain areas (Helmstetter and Garambois, 2010; Dietze et al. 2017a, 2017b, 2020; Hibert et al. 2011, 2017, Durand et al. 2018; DeRoin, N., and McNutt, S. R., 2012) or at regional scales (Dussauge et al. 2003; Dammeier et al. 2011; Manconi et al. 2016; Hibert et al. 2019), or on discontinuous monitoring of rockfalls at high elevation thanks to sensors other than seismic (TLS for example). This database allowed us to investigate the daily and sub-daily scale of rockfall triggering, thanks also to the complementary monitoring of other parameters (precipitations, ground and air temperatures, frequentation, snow cover). This new data provides complementary observations to seasonal, annual, or decadal observations usually investigated (Gruber and Haeberli, 2007; Krautblatter and Moser, 2009; Ravanel and Deline, 2010; Allen and Huggel, 2013; Draebing et al. 2014). We therefore show the effect of temperature and snow melt at this time-scale, as well as anomalous peaks of rockfall activity, that correlate with high human frequentation. Although the effect of temperature at the hourly scales are well known by mountaineers, the phenomenon has never been quantified.

Also, our data on the mountaineers traffic on Mont Blanc route show that climbers are not aware of the variations in rockfall frequency and/or that they cannot/won't adapt their behavior to this hazard. Therefore, the cross-comparison of data on rockfalls and climbers traffic in the couloir provide a second novel findings regarding the behaviour of mountaineers facing rockfall danger. This justifies all the more the importance of acquiring knowledge on rockfalls and their triggering factors in the local context of the Grand couloir du Goûter and to disseminate it to the mountaineers to encourage their adaptation. This comparison also allowed us to identify the type of knowledge needed by climbers to adapt in the most efficient way. This interdisciplinary analysis between rockfall hazard and mountaineers behaviour is also quite new.

The two reviewers point out that our work is a case-study, and wonder how it can be generalized. We fully agree with this case-study comment. We however oppose to this argument the exceptional site studied here with a very high accidents rate which, to our point of view, justify by itself focusing on this specific case-study with a strong operational objective. Furthermore, in a context where several international scientific entities (IPCC, MRI, WMO) clearly identify a profound lack of knowledge on the vulnerability to climate change of socio-economic activities in mountains and a lack of medium- and long-term efficiency of adaptation strategies in glaciated mountain areas (McDowell et al. 2019), our study is a relevant example of operational research that promotes adaptation measures. We agree with the referees that this motivation was not sufficiently put forward. In a new version of the article we propose to emphasize this point by completely reformulating the introduction, discussion and conclusion (see specific comments below).

In particular, we also propose to limit the parts where our results confirm previous studies on the effects of snowmelt and permafrost degradation at the seasonal scale but to emphasize the value of our data in identifying hourly triggering factors and discussing the effects of thermal processes as triggering factors.

Finally as raised out by the two reviewers, we will clarify all the method sections, for instance by adding figures to explain the classification of the seismic data.

Specific answer to Referee 1:

Thank you for your very thorough evaluation of our work. Your suggestions will help us improve our work. Based on the two evaluations we received, we decided to strongly modify our manuscript. We appreciated that you pointed out the rich database obtained here. Your comments allowed us to realize that the main novel aspects of our work were drawn into more classical ones. For instance the hourly and daily triggering of rockfall is very little investigated in permafrost conditions due to the absence of such a continuous rockfall database, that only seismic monitoring can get. This will lead us to rewrite the introduction and discussion, and better explain both the motivations of this work and the main novel points.

The other main novelty of this study is its operational objective: acquire knowledge on the danger of rockfalls in the specific context of the Grand couloir du Goûter, on the classic route up Mont Blanc, and the dissemination of this knowledge to the mountaineering community in order to promote the adaptation of mountaineers and try to reduce the number of accidents. Therefore, we will follow the main suggestion of referee 2 and reduce the sections on the identification of the rockfalls triggering factors (chapter 2 and discussion) and we will add two sections in the discussion on the “Interest of the acquired knowledge for mountaineers” and the “Dissemination of the acquired knowledge to the mountain community and implementation of management measures of the route”.

(1) In the current version of the manuscript we agree that we are not investigating mountaineers' vulnerability but rockfall hazard. However, in a new version of the article we plan to add two sections in the discussion in which we explain what are the interests of the acquired knowledge for mountaineers to mitigate the hazard and the dissemination of the acquired knowledge to the mountain community and the implementation of management measures of the route.

Concerning the link between rockfalls and accidents, we precise in the introduction that, according to the study of the accidents that occured in the Goûter area between 1990 and 2017 (Mourey et al., 2018), rockfalls explain directly 29% of the accidents and are partly involved in the accidents due to a fall, which account for 50% of the accidents. Rockfalls are therefore one of the main factors explaining this high accident rate. In the revised version of our manuscript, the introduction will focus more on the motivation of our study, and therefore the context should be clearer.

(2) In the revised version of our manuscript, we will give more details on the study area, how mountaineers are organising their ascent and when they have to cross the Grand couloir du Goûter in the "Study site" section. The introduction will be fully reorganised in order to better explain our objectives, justify them according to scientific literature and link them better with the methods we used and the triggering factors that were presented in section 2. According to your recommendations, section 2 will be integrated into the introduction, and lead to a clear objective of the study related both to the rockfall activity/triggering at hourly and daily scales, and to the adaptation of mountaineers to this hazard.

We will add precisions on the method used, especially the classification method of seismic signals. Although this classification is well described in previous mentioned paper (e.g. Helmstetter and Garambois, 2010), we will describe more in detail the types of signals we record on our site of study. We will particularly add a figure to show them, that will highlight the classification process. We will also add details on how to obtain the seismic energy from the signal envelope.

Concerning the monitoring of the snow cover, we will add precisions on the type of camera we used, the processing of the data, etc. Photographs taken by the camera are presented in figure 8 to illustrate the evolution of the snow cover in the couloir and temperature from temperature logger C3 is also presented in figure 8.

We will remove the CRYOGRID model. Following the restructuring of the manuscript it is not needed. We only used the CRYOGRID model to show that the active layer is the deepest at the end of the summer season, which has already been shown by other studies (Magnin et al. 2017 ; Pogliottio et al. 2015). Moreover, it limits the number of time series and clarifies the manuscript.

(3) We will be more precise in the description of preparing and preconditioning factors in the description of the site. We will, among other things, precise that the topographical and geological characteristics of the Grand Couloir du Goûter are particularly favourable to the triggering of rockfalls and due to the fracturing of the rock in the area and previous rockfalls in the couloir, many rocks/blocks are mobilizable as secondary rockfalls. We will also note that the couloir is in the altitudinal range where permafrost is degrading, which has been identified as the one where rock collapses related to permafrost degradation occur the most (Ravanel et al. 2017).

(4) We agree that we focused our results too much on the effects of freezing and permafrost degradation as triggering factors. According to the suggestions of Referee 2, we will reformulate the discussion accordingly. However we propose to insist on thermal processes as triggering factors. Our results allow us to quantify the correlation between rockfalls and different parameters (rainfall, temperature, frequentation) on a daily scale. To do so we can compute the cross□correlation function between hourly rockfall rates (R) and other parameters P at the hourly rate, defined by CR,P(t) =Sum (Pi R(ti)P(ti + t)). cf Helmstetter & Garambois, 2010). The results show that the correlation explaining the rockfall rates at the hourly scale the most is the air temperature measured at the Gouter station. The correlation is low (0.28), but significant (much higher than the peak of all the correlations; see the attached document). A time-delay of 2h is found between the temperature time-series and the hourly rockfall rates. Based on this finding we can discuss in more detail the effects of “purely thermal processes” on rockfalls triggering and compare our results with other studies such as Collins and Stock, 2016 and Draebing, 2020.

Please also note the supplement to this comment:
https://nhess.copernicus.org/preprints/nhess-2021-128/nhess-2021-128-CC1-supplement.pdf