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Interactive comment on "Inferring the destabilization susceptibility of mountain permafrost in the French Alps using an inventory of destabilized rock glaciers" *by* Marco Marcer et al.

Anonymous Referee #2

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General comments:

Good paper on an subject gaining in importance in the understanding of the behavior (stability) of mountain debris slopes underlain by permafrost : the so-called destabilization of rock glaciers. On the basis of an extended original dataset the authors spatially model the susceptibility of a location to be affected by a destabilization process in the French Alps. The preparatory work of inventorying the destabilization indices on rock glaciers in the entire French Alps is impressive and constitutes for me the most attractive part of the paper. The statistical modelling approach appears to be good, but can

only provides results which are very difficult to validate in my point of view. It is so partly less convincing. Some of the terminology used in the paper (permafrost destabilization, rock glacier destabilization, stable/unstable rock glacier, hazardous rock glacier) is somewhat unclear and even questionable. It has to be checked carefully all the paper along. I also have some questions about the interpretation/use of some the destabilization indices. Maybe some of the results may change in accordance. After having been revised the paper will be definitely very worth of being published in TC.

I hope my comments/suggestions can be useful for the authors.

Specific comments:

Title is not good. "Inferring the destabilization susceptibility of mountain permafrost. . ." has no real sense, permafrost being a thermal phenomenon. This is not the scope of the paper, which is conversely dealing with the mechanical "destabilization" of rock glaciers. There is however a much better alternative proposed by the authors on P3 L15, which can give a title like "Evaluating the destabilization susceptibility of active rock glaciers in the French Alps".

Abstract : may have to be adapted after revision of the paper

P1 L17 Express what is meant precisely by (widespread) permafrost degradation. This is not clear at all, but a very important concept for this paper. Check then in the whole paper if the concept is used always exactly with the same sense. Prefer "Permafrost has shown signs of w. degradation for the past decades in the European Alps".

P1 L18 : The connection between air temperature and ground temperature is tricky (snow buffering effect) and I do not really understand the meaning of "extreme warm air temperature" in the sentence. I would suggest to simplify it as "Warmer climatic conditions are expected to cause. . ." (eventually is a redundancy and can be omitted). Is there not more recent and more adapted references ? Finally, I do not see the link with the previous sentence.

P1 L20 : The “thermal inertia” is in particular highly related to the ice content, which can be relatively high in a rock glacier. This should be mentioned. Ground instead of soil. P1 L21 : I do not understand the meaning of this part of the sentence in the context of the present study. Why currently ? Is really the reference adequate ? Would not be for instance Scherler et al. 2013 (https://doi.org/10.1002/jgrf.20069, see in particular fig. 5, where the modelled impact of climate warming on two sites with very contrasted ice content is illustrated) more appropriate ?

P2 L1 : What kind of “other processes” ?

P2 L3 : Rock glacier destabilization can be caused by other factors than only climate-induced permafrost warming (e.g. cited Roer et al. 2008, Delaloye et al. 2013). The sentence must be adapted in consequence. This is a very important point, because the susceptibility model appears to be based on the assumption of a climate impact only.

P2 L4 : Delaloye et al. 2013 (and not 2008). To be changed also further in the paper.

P2 L4-5 : These events are far from all “representing a serious threat for alpine communities”. Sentence to be adapted.

P2 L5 (and many times in the paper): Permafrost destabilization. What is this ? The authors are rather talking about the destabilization of frozen ground inducing almost significant mass movements (>100’000m3 ?). Permafrost destabilization appears to be an inadequate terminology that must be replaced by rock glacier or debris slope destabilization and adapted all the paper along.

P2 L7, L9-13: Permafrost degradation. Again, what are we talking about ? About a complete ice melt = permafrost has disappeared, the temperature is now above freezing point ? Or about an increased liquid water content (partial ice melt) by warmer permafrost temperature (without any permafrost thaw) ? Is a permafrost warming from -1 to -0.5°C consecutively increasing the liquid water content a permafrost degrada-

tion ? In my point of view yes, making that almost all permafrost in the Alps (and in many places elsewhere) is currently degrading ! L13 : It looks that permafrost degradation is here considered as where permafrost is still occurring where it should not be (that is, despite current ground surface thermal conditions that could no more permit its occurrence) ?

P2 L14 : What are stable and unstable rock glaciers ? In addition, I cannot agree with the sentence, which seems to be based on the assumptions that all rock glacier destabilizations are induced by climate warming (permafrost warming) and that all rock glaciers with “degrading” permafrost conditions have to destabilize.

P2 L20: “Observing rock glacier dynamics and morphology can be rather useful” for what ?

P2 L21: Permafrost degradation (complete ice melt ?) in ice-rich landforms does not directly cause the mobilization of significant amount of materials. It makes the material easily erodible, but does not put it in motion. It does not trigger debris flow, but only precondition it. Moreover, this is the (increased) motion of the rock glacier, which is making (more) materials available for later debris flow events (e.g. Kummert)

P2 L23 : An increase of the liquid water content is assumed to cause the so-called destabilization (and not can).

P2 L24-29: About the occurrence of destabilization of active rock glaciers, see also Lambiel et al. 2008. Proceedings of the Ninth International Conference on Permafrost, Fairbanks, Alaska, 1 pp. 1019-1025, in particular Table 2 and related text.

P2 L26 : ... exceptionally (instead of eventually ?) lead to the collapse of the rock glacier (or a significant part of it)

P2 L29: Lambiel and Reynard (2001) has nothing to do with destabilization

P3 L13: Is DEFROST the most appropriate name for the model, because it helps to evaluate the destabilization susceptibility of active rock glaciers only, and not per-

mafrost (or all permafrost slopes) ?

P3 L19 : Sorry but 15'000 km2 fits with the total area of the French Alps (50-75 x 250 km) and consequently not with the area above 1500 m. And why to mention this latter area ?

P3 L22: Climate is changing fast. Indicate the reference time period for the elevation values of the annual 0° isotherm.

P3 L23: What is the Great Alpine Region ?

P3 L25: Permafrost is suspected to warm at a rate of 0.04°C per decade at which depth ? Since when ? Does is not depend also on the ground ice content and the temperature of the permafrost (the closer is the temperature to the melting point, the larger is the latent heat consumption and the smaller is the warming rate) ?

P3 L26: Increased rock glacier velocities since the 1990s : provide a reference (Laurichard ?)

P3 L26: The increase of rock glacier velocity and some destabilization phenomena (and not their destabilization). . .

P3 L27: Was really the Berard a rock glacier and not "simply" a landslide (of frozen shale and coarser debris) ?

P3 L28: Did not start the destabilization of Pierre Brune rock glacier much earlier than 1990 (see Figure 2), what is not in accordance with the sentence L26.

P3 L29: It cannot be spoken about the detachment of the active layer of the. . . Lou rock glacier, causing a debris flow. So far I know, there was a thunderstorm, which caused the debris flow mobilizing the active layer of the. . . Lou rock glacier. The permafrost table probably limited the torrential regressive erosion and consecutively the total volume of mobilized sediments.

P4 L4-6: What is the accuracy (limit of detection) of the multi-temporal orthoimagery ?

Was for instance a rock glacier moving 10 cm/y detectable as active ? How many of the 2100 rock glaciers not classified as active. . . could be active, to say moving more than a (few) cm/y ? This may also have an importance for the model.

P4 L13: A debris flow gully is not a rock glacier surface disturbance. It cannot be used as an indicator for rock glacier destabilization. . . but only for rock glacier motion (and the availability of water) in very specific topographical settings. Rock glaciers classified as destabilized on the single basis of the occurrence of a debris flow gully at their front are not and must be disregarded when building up the model.

P4 L20-21: 2 m x 2 m is quite coarse. What is accuracy (limit of detection) in a decade (2000-04 to 2012-13) ?

P5 L3 : . . . to a possible shift. . .

P5 L15: . . . Grosse Grabe and Gänder. . .

P7 L12-14: Rock glacier destabilization was observed to occur . . . at the lower limit of the permafrost zone. Is it really so ? Or what do the authors precisely mean ? Lambiel and Reynard 2001 is not here an adequate reference.

P7 L24-25: It could be worth to explain in a few words (if possible) how the PFI index is determined. Values between >0 and <1 represent the uncertainty domain of the PFI model ? Is this correct ?

P7 L30ff : The new PFI map is a shift of about 300 m of the permafrost lower limit (?), making that all PFI values within this shifting range are now set to 0, whereas in the 300 m above some are reduced to values between >0 and <1 ? Is it right ? Highest PTP values are found close to the upper boundary of the 300 m shifting range or slightly above it, no ?

P9 L12: Pixels of 2x2m or 0.5x0.5m ? How to get 0.3 m/year accuracy in the first 2000-2004 to 2008-2009 time window with 2x2m pixels ?

P9 L13: Undisturbed (instead of stable ?) active rock glaciers. . .

P9 L14-18: The two sentences are somewhat contradictive.

P10 L1 : The negative correlation of PISR with the destabilization probability is somewhat surprising. Is this not due to the fact that rock glaciers are (much) less frequent on southern expositions due to mountains that are not high enough to allow the occurrence of rock glaciers in such an aspect ?

P11 L29: . . . reaching much more than 5-10 m/y in extreme cases of destabilization (at least seasonally) (e.g. Grabengufer – Delaloye et al. 2013, Ádjet – Eriksen et al. 2018 GRL DOI: 10.1029/2018GL077605), Jegi – Ghirlanda et al. 2016 https://media.gfz-potsdam.de/bib/ICOP/ICOP_2016_Book_of_Abstracts.pdf p.36-38, etc.)

P11 L32: See also Lambiel et al. 2008 9ICOP Proceedings

P11 L33: . . . because of the high rate of sediment supply in a subjacent gully (if occurring) that may be prone to debris flow events (e.g. Kummert et al. 2017 PPP)

P12 L6 (and previous): What is a hazardous rock glacier ? This is mostly a question of connectivity toward very steep slopes or torrential gullies and transfer rate of sediments (e.g. Kummert et al. 2017 PPP), but for sure not a question of destabilization. Most of the destabilized rock glaciers are far from being hazardous (for human beings and infrastructures) ! But active “stable” rock glaciers may be.

P12 L11-13: According to my comment on P7 L30ff, it would be very interesting to explore more deeply the relationships between PTP and active rock glaciers. PFI being basically based on the front position of active rock glaciers, one can assume that migrating PFI 300 m upward would makes that the highest PTP values to be found much higher on rock glaciers. . . that is more likely were cracks and crevasses are located. I am wondering to what extent is this DEFROST-PTP correlation physically significant or just fortunately caused by the common morphology of rock glaciers in the French Alps ?

P12 L15ff: The comparison to the active layer detachment in the Canadian Arctic appears not to be so adequate because we are comparing two completely different phenomena/processes : shallow infiltration of water in unfrozen ground versus a deep creeping process. Moreover, the snow melt period is occurring later on northern slopes, but it starts also later. Is it so much longer ?

P13 L2 : What is this special thermal regime of rock glaciers ?

P13 L3 : Why is active layer thickening causing rock glacier destabilization ? I do not clearly understand what is meant.

P13 L6: Debris flows need debris and water. How to use their occurrence for validating the DEFROST susceptibility is so far obscure to me.

P13 L8-12: And if we look toward the future (to say again +1.5°C), what will remain “sustainable” ?

Figure 5 : Only about 25 rock glaciers are moving faster that 2 m/y in the most recent period (5% of the active ones), and not all are considered as potentially destabilized. Is this finally much or not ? About half of the potentially destabilized rock glacier (cat. 3) are moving less than 2 m/y ? I am wondering here if the criteria to define a destabilization phenomenon are all pertinent (see also my comment on Tables 1 and 3). How many rock glaciers are considered in this figure (it looks that there is only a reduced number of cat. 0 and 1) ? This could be indicated.

Figure 6 : Destabilization rating dots are almost not visible on the map.

Figure 7: PISR : I am wondering if there is not also an effect of illumination, that may make much easier to detect crevasses and cracks on a north slope (better contrast) than on an over-illuminated southern slope (less contrast) ?

Table 1 : As already said, I do not consider a debris flow gully as a sign of rock glacier destabilization. The “rugged topography” proposed by Roer et al. (2008) was related to crevasses and scarps and is not synonym of the “crack cluster” described here.

Table 3 : I am very impressed by the high number of rock glaciers displaying cracks and crack clusters. Is it due to a specific lithology ? Is it finally really a sign of destabilization ? Are all rapidly moving rock glaciers (> 2 m/y) exposing scarps and/or crevasses ? Or not ? It may be helpful to organize the table by importance of the specific disturbances as destabilization signs : crevasse(s), scarp(s), cracks cluster, crack(s). Omit gully.

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