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Interactive comment on "Permafrost distribution in steep slopes in Norway: measurements, statistical modelling and geomorphological implication" *by* Florence Magnin et al.

Anonymous Referee #1

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The paper "Permafrost distribution in steep slopes in Norway: measurements, statistical modelling and geomorphological implications" by Magnin et al. presents a new rock permafrost model for mainland Norway and draws conclusions of permafrost distribution in rockwalls on current rock instability and landform development. The authors installed more than 25 rock temperature loggers in 8 key regions and used a sophisticated model approach to upscale their findings on the rockwall thermal regime into a regional rock permafrost model. Rock permafrost in Norway is responsible for a large number of rock instabilities that currently threaten infrastructure and inhabitants. In the past, these instabilities caused hundreds of deaths and the knowledge of rock permafrost distribution as provided by this paper is required to mitigate ongoing and future landslide hazards and risks. Therefore, the importance of this work is very high. Unfortunately, the link of permafrost distribution to rock instabilities is poorly addressed, the use of chosen parameters of the model are incompletely explained, results are insufficiently presented and compared to non-connected landforms (moraine-derived rockglaciers) instead of existing instabilities. In addition, the reader needs knowledge on Norwegian locations to understand the research set up. In current state, the paper focuses on permafrost and lacks on geomorphology and would be better suited for a journal focusing on periglacial phenomena than Earth Surface Dynamics. However, a revision which address the shortcomings would improve the manuscript and the suitability.

1) Link between permafrost and rock stabilities. Permafrost affects rock stability, however, this effect can be both positive and negative, thus, permafrost affects driving and resisting factors as previously discussed Krautblatter et al. (2013) and Draebing et al. (2014). Permafrost aggradation for example following the LIA causes cryostatic pressures (Wegmann et al., 1998), however, this does not provoke ice segregation and large rock slope failures as suggested by the authors. Ice segregation can be amplified by permafrost when active-layer thaw increase rock moisture that can migrate towards the freezing front at the top of the permafrost as identified by Murton et al. (2006). However, this effect is limited to the upper 20 m of rock depth (Krautblatter et al., 2013), thus, the normal load of the overlying bedrock would counter the effects of ice pressure. Therefore, ice segregation cannot cause rock slope failure with shear planes below 20m depth. The authors are not addressing further effects of permafost on instability. The instability of permafrost rockwalls is also affected by active-layer thaw that can cause small-scale rockfall as conceptually discussed by Draebing et al. (2014) and derived from rockfall inventories by Ravanel et al. (2010; 2017). Permafrost warming and degradation increase instability as mechanically described by Krautblatter et al. (2013) and can result in an increase of rockfall activity (Ravanel and Deline, 2010). Due to these findings, several authors discusses a connection between rock slope failures and quaternary climate fluctuations in Norway (Hilger et al., 2018; Matthews

et al., 2018). The authors should include these findings in their introduction and in the discussion of their results. Beneath these permafrost effects, rock slope stability is controlled by paraglacial effects which are non-glaciated processes conditioned by former glaciation as the authors mentioned. McColl (2012) and McColl and Draebing (2019) recently reviewed paraglacial effects on rockwall stability and connection to permafrost dynamics. Oversteepening of rockwalls results in stress redistributions and can prone rockwalls towards instability. Thus, areas affected by permafrost are very often also affected by current or former glaciation, paraglacial and periglacial effects are hard to decipher. This can become even more complicated as paraglacial adjustment can work over more than one glacial cycle (Grämiger et al., 2017). The author introduce vaguely paraglacial effects without including any up-to-date literature or discussing a potential influence. The problem of deciphering periglacial and paraglacial processes should be addressed in the discussion.

2) The modelling approach The authors a priori chose a slope angle threshold of 40° to identify steep rock slopes. There is no geomorphic argument why this threshold is chosen. Previous models by Hipp et al. (2014) and Steiger et al. (2016) chose a threshold of 50° and 60° for steep rock slopes in Norway. Before extrapolating the results to entire Norway, the authors should try to evaluate their threshold. They can map rockwalls from orthophotos for small areas or data subsets and compare them to rockwalls derived by their threshold approach to test the sensitivity of their model. Also they could compare their derived rockwalls with the location of instabilities mapped by Oppikofer et al. (2015). The rock temperature loggers are installed following the approach by Gruber et al. (2004) which choose the steepest part of the rockwall to limit effects of snow accumulation. Therefore, the setup excludes snow cover, which can be present even in rockwalls with a slope angle up to 75° (Haberkorn et al., 2015a; Haberkorn et al., 2015b; Haberkorn et al., 2017; Phillips et al., 2017). Figure 5 shows that large rockwall areas are covered by snow cover. A coarse DEM with a resolution of 10 m will smooth out ledges that enable snow accumulation (Draebing et al., 2017; Haberkorn et al., 2015a), therefore, the chosen resolution will limit the effects of snow cover. Snow

cover is also highly heterogeneous in space and time, which makes it very difficult to include in modelling approaches. However, the author should mention and discuss this shortcoming of the model resulting from chosen logger locations and DEM resolution. In their model, the authors simulate PISR using GIS. It is unknown which latitudinal location and the time period they chose to run the PISR algorithm provided by ArcGIS. Solar parameters show large changes between North and South of Norway and model results should reflect this. The author should therefore provide more information on the modelling approach and how they incorporate differences within their data set. The authors classify permafrost occurrence based on bedrock setting. They refer to Figure 5 where they highlight three areas and suggest different fracture properties in these areas. From the photo alone, fractures or degree of fracturing is not visible. It remains unclear where the fracture information comes from for e.g. local sites or even entire Norway. However, the authors use this information to classify permafrost into isolated, sporadic, discontinuous and continuous permafrost based on a permafrost classification scheme for the Arctic. In Alpine areas topography has strong control on permafrost distribution and the use of this scheme is limited. The same authors use a permafrost probability approach in the Mont Blanc Massif (Magnin et al., 2015; Ravanel et al., 2017), which is better suited. The authors connect this scheme somehow to slope ruggedness and fractures but it is completely unclear where they derive the information from necessary for the classification. If you apply the classification to the rockwall in Figure 5 and assume the fracture properties are correct discontinuous permafrost can be located in direct proximity to isolated or spontaneous permafrost. It would make more sense to model rockwall permafrost and compare every pixel to its neighbouring pixels to identify isolated, sporadic, discontinuous and continuous permafrost. Rockwalls are not uniformly distributed in Norway and conclusions on rock permafrost occurrence cannot be used without normalization. Differences between East and West Norway are caused by a decrease of rockwall occurrence and not permafrost occurrence. Other periglacial landforms are abundant in the east and the authors cannot conclude on permafrost distribution without normalization.

3) Comparison to rock glaciers and the use of instabilities The authors compare their permafrost distribution to other landforms such as rock glaciers and found a strong local connection to moraine-derived rock glaciers. Areas affected by rock permafrost are very often previously glaciated and inhabit other periglacial and glacial landforms. Permafrost rockwalls can produce material that can accumulate on snowfields and with time, the material can develop into a talus-derived rock glacier. The permafrost develops when debris-covered snow develops into ice via ice metamorphosis. The permafrost in the rock glacier has no causal connection to permafrost in the rock-wall. Moraine-derived rock glaciers are developed from creeping former dead ice and is more connected to previous glaciation. Due to a lack of connection, a comparison makes no sense. The author should focus on their objectives and present directly from the beginning the Norwegian rock instability inventory by Oppikofer et al. (2015). They should test if their threshold-derived rockwalls include all instabilities. Furthermore, they should compare their permafrost distribution to the location of instabilities. Can you develop a relationship based on your data? What would be interesting is to model future permafrost distribution as previously done by Hipp et al. (2014) by using temperature increase scenarios. The authors can compare future permafrost distribution to slow creeping rockslides (e.g. Jettan) and other instabilities in the inventory and can draw conclusions of permafrost degradation on potential instability sites. The map could identify hot spots of future rock slope failures, which can be used for hazard mitigation such as planning or zoning. This would be of more interest than comparing permafrost distribution to other periglacial landforms.

In summary, this paper can be a very important contribution to Earth Surface Dynamics if linkages between permafrost and instability are mproved and coherently discussed. The model set up should be better explained and sensitivity of the rock slope angle threshold evaluated. The paper should focus more on rockwall instabilities, thus, the Norwegian landslide inventory provides a unique dataset and comparison to current and future rock permafrost distribution would provide valuable information for geomorphologists but also for hazards mitigation by the managing authorities.

See also detailed comments in the attached pdf.

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Please also note the supplement to this comment:
https://www.earth-surf-dynam-discuss.net/esurf-2018-90/esurf-2018-90-RC1-supplement.pdf

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