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Climate warming enhances rockfall activity from permafrost environments - but rockfall risk increases primarily due to larger exposure and vulnerability

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Rockfall in high mountains is perceived to change more than other mass-wasting processes, presumably as a result of ongoing climate warming and the related, increasing degradation of permafrost. However, the systematic lack of longer-term observational records of rockfall largely hampers any in-depth assessment of how process activity may have been altered by a warming climate and its variability since pre-industrial times. Here, we present evidence that the ongoing climate warming in the Swiss Alps indeed controls rockfall activity from degrading permafrost, and that changes in rockfall frequency correlate significantly with warming air temperature since the 1880s. Using this dataset, we then look into rockfall risk by combining changes in process activity with socio-economic developments at the study site. We illustrate how rockfall risk has changed over the past 140 years and how it might change over the course of the 21st century. While more rockfall and larger volumes occur nowadays as compared to the early 20th century, rockfall risk has increased mostly due to changes in exposure and vulnerability and only partly due to changes in process activity itself.