Reversible and irreversible movements in steep fractured bedrock permafrost

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Steep fractured rock slopes are common in alpine regions and the behavior of frozen zones is of fundamental importance in controlling slope stability as permafrost warms or thaws. Rising temperatures translate into slope destabilization in mountain permafrost areas globally, yielding increased hazard potential. A likely reason behind such phenomena is the presence of highly fractured zones containing ice (bedrock permafrost), acting as preferential failure planes as temperature increases. But identifying gravity-driven failure in rock is a complex task, mainly because the abrupt rupture is a highly nonlinear process sensitive to unknown heterogeneities present at all scales in rock. Thus, improved knowledge of processes and factors affecting slope stability is essential for detecting, monitoring and eventually assessing stability of potentially hazardous slopes.

Rock-slope creep may be a pre-failure deformation of rock fall or, at least, has similar controlling mechanisms. We have collected over seven years of fracture dilatation data at 3500 m a.s.l on Hörnligrat, Matterhorn, in steep fractured permafrost bedrock. The surface displacements measured using crackmeters include reversible and irreversible movement components resulting from a balance between driving and resistive forces in strongly fractured bedrock. As rupture is irreversible, we apply a linear regression model with rock temperature as input to remove the reversible movement component caused by thermal expansion and contraction of the rock (see Fig 1). The resulting movement pattern is strongly dominated by enhanced fracture dynamics during summer caused by a thawing related reduction in strength. The start of this summer creep correlates with the initiation of snow melt in early summer. The percolating water, mostly melted snow and ice, changes properties along friction zones in fractures. The inter annual variability and summer offsets show, in our seven years of data, no clear trend. Such surface displacement measurements strongly depend on the choice of the measurement location with obvious limitations in spatial coverage, temporal resolution and accuracy of the instruments used. As a complement to the initial external measurements, analysis and interpretation using a linear regression model, additional data describing the internal evolution of the bedrock is required.

The occurrence of rupture (macroscopic failure) proceeds in bursts of smaller internal failures prior rupture and does not appear instantaneously. These mechanical failures inside the rock mass, such as the evolution of the crack network through progressive damage accumulation or the frictional deformation of pre-fractured rock, release elastic energy that can be detected by the micro-seismic/acoustic emission (MS/AE) approach. Therefore, four different MS/AE sensors have been installed on Hörnligrat, profiling MS/AE activity across the whole frequency spectrum from 1 Hz to 80 kHz and measuring continuously from summer 2015. The initial data analysis and model development is currently ongoing. It is expected that in combination, surface displacement and MS/AE activity will allow to investigate the irreversible movement component in more detail. Here, the material's heterogeneity (anisotropic fractured bedrock) actually is seen as an advantage, because bursts of smaller cracks are expected to occur before major failures.

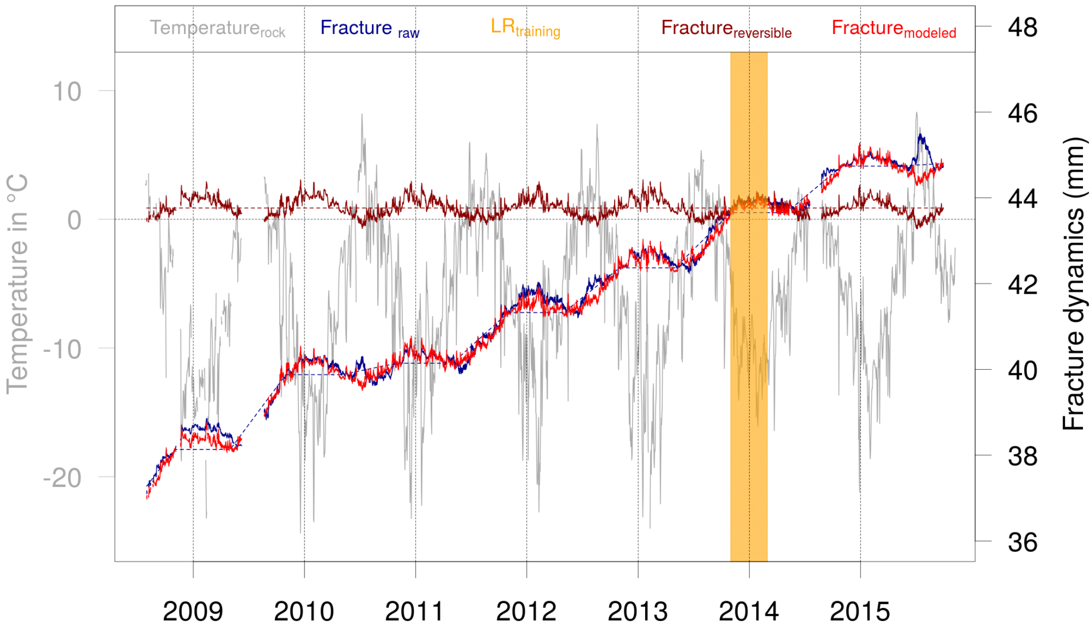

Figure 1: Result of raw dilatation measurements in tension (blue). The reversible component due to thermal expansion can get modeled by a linear regression model (LRM) with temperature as input data (darkgrey) and dilatation measurements during a several months training period (bright blue). Assuming there is a summer creep (blue dotted) that can be described by a one fracture dilatation measurement in winter and a defined winter period. The combination of the LRM and the summer creep results in modeled fracture dilatation (red).