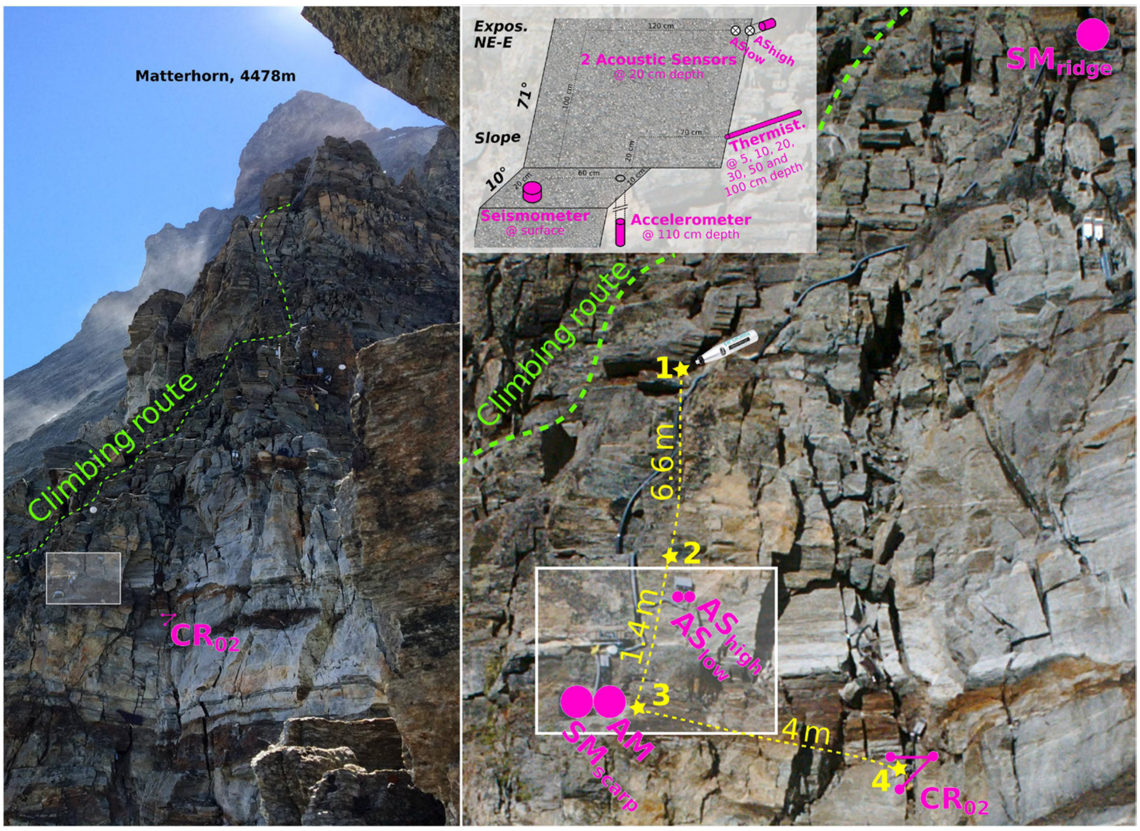

Figure 1. Detailed view on the Hörnligrat field site on the North-East ridge of the Matterhorn in the Swiss Alps with an average slope >60°C. Instrumentation setup for measuring acoustic (AS = acoustic sensor), micro-seismic (SM = seismometer; AM = accelerometer) and fracture kinematics (CR = crackmeter with displacement directions) are indicated in pink. A schematic zoom-in of the AE/MS instrumentation in the scarp is shown in the top white box. The yellow stars show the locations of the artificial events generated by the rebound hammer method.

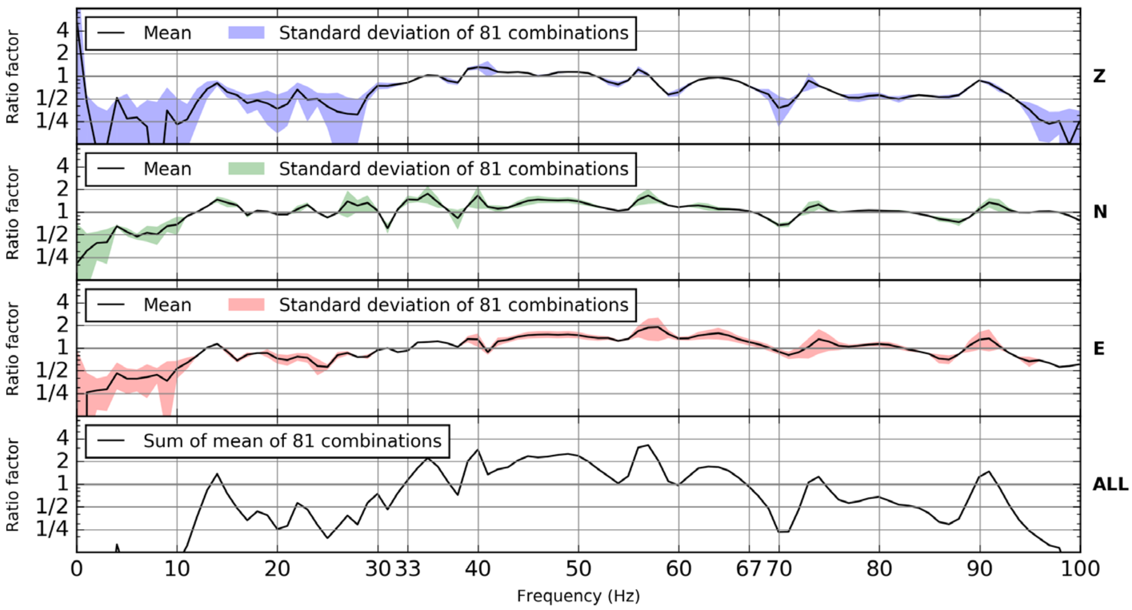

Figure 2. Filter spectrum between Location 3 and Location 4 indicating mean and standard deviation of 81 combinations. Amplification in the middle part of the frequency range (33-67 Hz).

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Influence of slope angle on the convective heat transfer in porous permafrost substrate

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Permafrost is a widespread phenomenon in the Swiss Alps. Its occurrence is not only influenced by meteorological and topographical parameters of the site, also landform and soil substrate have a significant impact on the ground thermal regime. Many studies showed that especially coarse blocky material with a high porosity influences the ground temperature (Kneisel et al., 2000; Delaloye & Lambiel, 2005; Gudong et al., 2007; Wicky & Hauck, 2017). The high porosity allows air (in addition to water) to circulate within the ground and thus convective heat transfer takes place. Convective heat transfer can lead to a cooling of the ground, which has the largest effect on low elevation permafrost sites, which would otherwise be unfrozen. On steep slopes, the gradient between the temperature of the air in the atmosphere and the ground temperature leads to a seasonally alternating circulation which is generally referred as the “chimney-effect”. On flatter terrain, the lateral extension of the circulation is smaller and vertical convection cells are forming. This is referred to the “Rayleigh-Bénard-Circulation” (Gudong et al., 2007).

In this study, we will present results from numerical experiments on the changing slope angle of an idealised talus slope to show the transition from vertical convection cells to a more lateral dominated convection (advection) and its influence on the ground thermal regime in the context of permafrost. The model setup consists of three domains (bedrock, porous talus and air as a simplified atmosphere; for material properties and other details refer to Wicky & Hauck 2017), where the governing equations for heat transfer, pressure and air flow are solved with the finite element method in GeoStudio2016©.

The results show that the slope angle has a major influence on the air circulation pattern and thus also on the temperature distribution in the ground. Flat terrain and low slope angles (<10°) result in a vertically dominated circulation. This is characterized by (i) the air velocity amplitude being higher in the vertical direction (ii) the air flow direction often close to +-90° and (iii) lower summer temperatures than winter temperatures compared to the mean over all slope angles due to the absence of air circulation in summer. Advection can also be observed on low inclines but has a minor influence. Steeper slopes (>20°) lead to a bi-directional chimney-type circulation characterized by (i) a seasonal reversal of 180° in main air flow direction parallel to the surface and (ii) temperatures being high/low in summer/winter compared to the mean over all slope angles due to the pronounced aspiration of warm/cold air. Slope angles in between show both vertical convection cells and advection over the whole domain depending on the boundary condition. A higher temperature gradient between air and talus temperatures generally leads to a convection dominated by one horizontal cell, whereas lower gradients lead to a vertical convection regime. The transition period in spring and autumn with air temperatures around the freezing point are often characterized by a phase of vertical convection.

The different circulations regimes are also reflected in the temperature distribution. Steeper slopes lead to a more pronounced chimney-type circulation and thus to a higher temperature difference between the lower and the upper part of the talus. This results in a strong cooling at the foot of the slope and can be favourable for azonal permafrost as observed in many field cases (e.g. Kneisel et al., 2000). Still, also at high Alpine sites, these circulations can lead to colder ground temperatures and in some cases explain the inhomogeneous distribution of permafrost in an Alpine setting (Delaloye & Lambiel, 2005).

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