# Three-dimensional investigation of ground temperatures in steep rock slopes

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A temperature-dependent reduction in rock-wall stability in alpine permafrost areas, likely induced by changes in atmospheric conditions, has recently been demonstrated both in theory and laboratory experiments (Haeberli et al. 1997, Davies et al. 2001). Most instabilities are expected from warm permafrost areas, which is supported by a study of the thermal conditions of starting zones located in permafrost (Noetzli et al. 2003). The hot summer of 2003 provided additional strong evidence for the relation of rock fall and climate change via permafrost thaw.

The delineation of the locations of sensitive zones that exhibit critical temperature changes (entering a range of ca. -1.5 to 0 °C) and are subjected to thaw requires knowledge of the temperature distribution both at the surface and in the subsurface of rock walls. The effect of complex topography in high mountain areas leads to a strong lateral component of heat fluxes (Gruber et al. 2004). Therefore, ground temperatures and permafrost degradation below variable topography such as ridges, peaks or spurs can only be investigated where 2- and 3-dimensional effects (geometry and variable surface temperatures) are accounted for. The Matterhorn rock fall on July 15, 2003 is an example of such a situation. The starting zone is located in a steep NE-ridge. The corresponding knowledge, however, still remains limited.

In order to investigate 3-dimensional thermal responses to climate change, numerical modelling experimentation is carried out in a recently started study. To better understand natural complex situations, model simulations of typical test cases are performed: In a first step and presented in this contribution cross sections of various idealised 3-dimensional geometries are explored to describe the distribution of ground temperatures under influence of high-mountain topography. The thermal regime inside ridges, peaks or spurs is modelled with varying topographical variables such as slope, aspect or elevation aiming at identifying zones of warm permafrost with critical temperature ranges as well as the position and depth of the degrading boundaries of the permafrost body.

The experimentation is conducted applying a surface energy-balance model (TEBAL, Gruber 2005) to determine surface temperatures, together

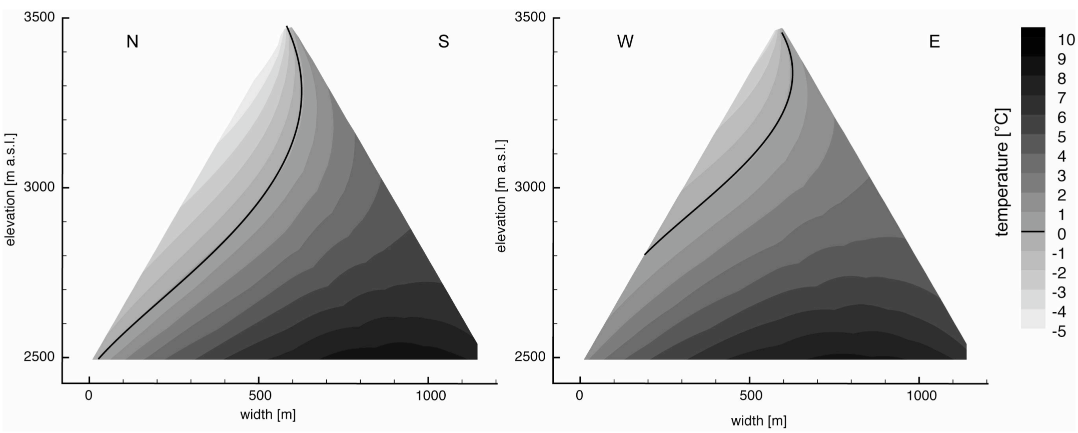


Figure 1. Modelled ground temperatures in the subsurface of an idealised east-west (left) and a north-south (right) trending ridge. The elevation ranges from 2500 to 3500 m a.s.l. and the slope is 60°. The topography influence leads to near-vertical isotherms and a strong lateral heat flux from the warmer to the colder side of the ridge.

with a 3-dimensional ground heat-conduction scheme (FRACTure, Kohl & Hopkirk 1995), both especially designed for use in complex topography. Surface temperatures are calculated based on 10years of meteorological data from Corvatsch, Upper Engadine (1990-2000). Finite-element meshes of typical topographies are then generated and forced with the TEBAL-output as surface boundary conditions.

Areas found to be especially sensitive for permafrost degradation may be identified on maps and in the future serve as a basis for hazard assessment of permafrost related slope instabilities.

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