Geophysical Research Abstracts
Vol. 14, EGU2012-13109, 2012
EGU General Assembly 2012

Characteristics of the thermal regime in steep bedrock permafrost in the European Alps described by borehole temperatures and heat conduction modeling

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Permafrost in the Alps occurs within three main landforms – rock glaciers, debris slopes and steep bedrock. In contrast to rock glaciers and debris slopes, permafrost in steep bedrock reacts directly, fast and sensitively to changes in atmospheric conditions and these areas are therefore important for monitoring purposes. In addition, the observation of the state and changes of permafrost in steep bedrock is relevant for the stability and maintenance of infrastructure as well as the assessment and possible change of slope stability in high mountain areas. Mainly due to the difficulties of access, however, mountain permafrost monitoring activities in the Alps have concentrated on rock glaciers and debris slopes in their beginning more than 20 years ago and only started to focus on bedrock permafrost in the past decade. During the past about 5 years a number of new boreholes with depths ranging from 10 to 60 m have been installed in the scope of different research and monitoring projects at high Alpine sites in Switzerland (e.g., Schilthorn, Matterhorn, Gemsstock), Germany (e.g., Zugspitze), and France (e.g., Aiguille du Midi). Several of the boreholes have been drilled across a crest or perpendicular to the surface.

In this contribution, we compare the data and discuss the main results gained from the different borehole sites in steep bedrock. Because of the limited observation period, the extreme spatial variability in these areas, and the invisibility of the phenomenon, we combine the point measurements with numerical heat conduction modeling for extrapolation in time and space to allow a more comprehensive interpretation.

In addition to the basic characteristics that the temperature regime in bedrock is mainly controlled by conduction and no thick surface cover (such as snow, debris, blocks) or latent heat effects (low ice contents) mask the changes in atmospheric conditions, a number of specifics of permafrost temperatures in steep bedrock can be observed: a) the influence of different climatic conditions on the thermal regime, b) the influence of the surface geometry (steep topography) on the three-dimensional temperature field, b) the accelerating effect of steep topography on the pace at which changes at the surface are propagated into the subsurface (multi-lateral warming), c) the cooling effect of a thin snow cover, which is often present in such terrain, and d) the cooling effect of ventilation in clefts.