Geophysical Research Abstracts,
Vol. 11, EGU2009-5621, 2009
EGU General Assembly 2009

Quantification of ground ice loss at Schilthorn (Swiss Alps) during the hot summer 2003 by geophysical monitoring

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The application of geophysical techniques to permafrost related problems has become a standard approach in recent years and is commonly used for the detection, mapping and characterisation of mountain permafrost. Within the context of global warming not only the assessment of its present state but also the temporal evolution of permafrost is of particular interest. In addition to 1-dimensional (1D) thermal monitoring techniques (e.g. in boreholes), also 2D electrical resistivity tomography monitoring (ERTM) has been proven to be a powerful technique for the observation of possible permafrost degradation.
Since the measured resistivity is largely controlled by the electrolytic conduction of unfrozen water that is distributed across grain boundaries or contained in pores, fractures and faults, ERTM is sensitive to changes in the amount of unfrozen water in the subsurface material and can therefore provide information on changes in ice and water content with time. However, without additional information ERTM only allows a relative quantification of such changes, whereas the total amount of ice within the subsurface remains unknown.
An approach to estimate the absolute fractions of the four constituents rock, water, air, and ice of the subsurface material is provided by the so-called four-phase-model (4PM). Using coinciding data sets from tomographic electrical resistivity and refraction seismic measurements the 4PM relates the measured variables (electrical resistivity, seismic velocity) to the respective parts of the material composition, based on a) the well-known relation between the electrical resistivity of the probe, the pore-water resistivity, the porosity and the saturation known as Archie's Law, and b) a time-average equation for seismic P-wave velocities taking all four phases into account.
The presented approach combines an 8 year ERTM data set from the permafrost site at Schilthorn/Swiss Alps with the estimated total fractions of ice and water from the application of the 4PM to a ERT and seismic data set of August 2008. By this, relative resistivity changes during the past decade can be used to quantify the variations in ice content relative to 2008. With the combined approach of four-phase-modelling and ERTM it is now for the first time possible to assess the total loss of ground ice in the extraordinarily hot summer of 2003, where an immense impact was observed in both borehole temperatures and ERTM data.