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Observing permafrost dynamics at depth at the Zugspitze (German/Austrian Alps): Complementary information gained from borehole observation and temperature-calibrated quantitative geophysics

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In August 2007, a 44 m long borehole was drilled from the south face to the north face under the Zugspitze summit on behalf of the Bavarian Environment Agency at approximately 2930 m a.s.l.. In February 2007, in a gallery at 30 meters distance from the north face at 2800 m a.s.l., a 280 m long transect was instrumented with permanent electrodes for electrical resistivity tomography (ERT) measurements and temperature loggers 600 m west of the Zugspitze summit.

Both measurements target permafrost development at depth and offer complementary information on an almost identical steep bedrock permafrost setting. 25 temperature loggers in the borehole provide point and gradient information. ERT characterises the state of frozen rock via resistivity that is susceptible to rock temperature. Temperature resistivity gradients in frozen rock are regularly one magnitude higher than in unfrozen rock. Laboratory values, of dolomised Wetterstein limestone below the equilibrium freezing point of -0.5 °C could be described by p [in kohmm] = 19 – 19.3 ($\pm$2.1) * t [in C°] with an R^2 of 0.99. Referencing error-controlled quantitative ERT transects to laboratory values yields temperature-calibrated surveys that may be applicable to frozen rock.

Borehole information provides accurate information on the propagation of thermal signals and of the state and distribution of permafrost in an intact rock mass temperature, but only provides point information. Measurements from 2007 to 2008 indicate that minimum temperatures close to -4°C occur at 10-15m depth. Active layer depth in 2008 was 1.5 meter on the north-face and 7 meters on the south-face while seasonal variations in temperature greater than $\pm$0.5 are restricted to the upper 12-13 m from the north face and approximately 10 m from the south face.

Referenced ERT provides less accurate information on the thermal state of the frozen rock, but can provide spatial 2D and 3D information even in unstable rock masses unsuitable for borehole installation. Both methods show similar permafrost distribution, thaw depths and permafrost core temperature values round –3°C. In fact, in the ER-tomographies we found the most pronounced thermal impulse along a heavily disturbed fracture zone that indicated rapid melting up to 30 m depth in response to snowmelt water percolation already in July.