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Ice or rock matrix? Improved quantitative imaging of Alpine permafrost evolution through time-lapse petrophysical joint inversion

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Quantitative estimation of pore fractions filled with liquid water, ice and air is one of the prerequisites in many permafrost studies and forms the basis for a process-based understanding of permafrost and the hazard potential of its degradation in the context of global warming. The volumetric ice content is however difficult to retrieve, since standard borehole temperature monitoring is unable to provide any ice content estimation. Geophysical methods offer opportunities to image distributions of permafrost constituents in a non-invasive manner. A petrophysical joint inversion was recently developed to determine volumetric water, ice, air and rock contents from seismic refraction and electrical resistivity data. This approach benefits from the complementary sensitivities of seismic and electrical data to the phase change between ice and liquid water. A remaining weak point was the unresolved petrophysical ambiguity between ice and rock matrix. Within this study, the petrophysical joint inversion approach is extended along the time axis and respective temporal constraints are introduced. If the porosity (and other time-invariant properties like pore water resistivity or Archie exponents) can be assumed invariant over the considered time period, water, ice and air contents can be estimated together with a temporally constant (but spatially variable) porosity distribution. It is hypothesized that including multiple time steps in the inverse problem increases the ratio of data and parameters and leads to a more accurate distinction between ice and rock content. Based on a synthetic example and a field data set from an Alpine permafrost site (Schilthorn, Swiss Alps) it is demonstrated that the developed time-lapse petrophysical joint inversion provides physically plausible solutions, in particular improved estimates for the volumetric fractions of ice and rock. The field application is evaluated with independent validation data including thaw depths derived from borehole temperature measurements and shows generally good agreement. As opposed to the conventional petrophysical joint inversion, its time-lapse extension succeeds in providing reasonable estimates of permafrost degradation at the Schilthorn monitoring site without *a priori* constraints on the porosity model.