Saline tracer tests visualized with 3D time-lapse electrical resistivity tomography for the detection of fractures in bedrock permafrost

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Keywords: time-lapse ERT, tracer test, bedrock permafrost, fractures

Joints and fractures, where large volumes of ground ice can accumulate, play a key role in the thermal regime of bedrock permafrost as they represent a preferential flow path for water and advective heat exchange between the atmosphere and the subsurface. Yet, it is challenging to include them in thermal modeling because their exact location and geometry are commonly unknown. In the Cime Bianche (Aosta Valley, Italy) permafrost monitoring area (highly weathered bedrock plateau) at 3100 m asl borehole temperature measurements and geophysical imaging have shown a high spatial variability in ground temperature and ice content, which suggests the presence of fractured areas affecting the ground thermal regime. We conducted saltwater tracer tests (30–100 l water per injection) at eight different locations at the Cime Bianche site coupled with time-lapse 3D electrical resistivity tomography (ERT) to track the flow of the subsurface amendment and localize flow paths associated to fractured areas. The ERT results show a large difference in flow characteristics between the injection points, even for points in close vicinity (few meters). In five of eight injection points the water infiltrated slowly into the subsurface (over 2–3 hours) resulting in slight conductivity changes over time in the 3D ERT images only close to the injection point. In the other three positions the injected water disappeared after a few seconds resulting in larger conductivity changes, not only directly below the injection point but also to a depth of >10 m, suggesting the presence of fractures. These results demonstrate that our methodology is able to reveal fractures and other preferential flow paths. To further improve the resolution of the resolved fractures more adequate inversion schemes and constraints from complementary data are required.