



The potential of surface-NMR to image water in permafrost and glacier ice

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Surface-NMR is a relatively new geophysical technique primarily directed at mapping water content in the shallow subsurface. For surface-based measurements, loop antennas of diameter 50-200m are typically employed. Magnetic fields arising from current pulses in these surface loops penetrate the subsurface and interact with the protons of molecules in liquid water. The resulting responses are recorded at the surface and analysed in accordance with the well established physical principles of NMR. Surface-NMR is unique among geophysical techniques in that it is directly sensitive to water molecules. Under favourable conditions it has the potential to quantitatively determine the water content distribution with depth. Recent developments in NMR modeling and inversion allow for 2-D/3-D tomographic imaging of subsurface water distributions in environments of arbitrary topography, enabling investigations of relatively complex geological structures. Furthermore, surface-NMR can be applied under conditions in which conventional geophysical techniques are limited, for example across highly resistive ground or blocky terrain.

Possible applications of surface-NMR to cryospheric studies include delineating and characterising (i) englacial water pockets, (ii) liquid water percolating through thawing permafrost, and (iii) non-mobile water in polycrystalline ice of temperate glaciers. Two field surveys in Switzerland have been undertaken to assess the capabilities of surface-NMR in permafrost settings. On the Muragl rock glacier (Engadin), our results demonstrated the absence of detectable free water within the probed volume, whereas crosshole radar and geoelectric measurements had suggested the presence of a water-saturated layer at ~ 25 m depth. Across temperate ice of the Rhone glacier (Valais), we recorded good quality surface-NMR data under low noise conditions that

yielded a water content of $1 \pm 0.5\%$ down to a depth of 50m.